ANNUAL STOCK ASSESSMENT AND FISHERY EVALUATION REPORT: MARIANA ARCHIPELAGO FISHERY ECOSYSTEM PLAN 2016

Western Pacific Regional Fishery Management Council
1164 Bishop St., Suite 1400
Honolulu, HI 96813

PHONE: (808) 522-8220
FAX: (808) 522-8226

www.wpcouncil.org

The ANNUAL STOCK ASSESSMENT AND FISHERY EVALUATION REPORT for the MARIANA ARCHIPELAGO FISHERY ECOSYSTEM 2016 was drafted by the Fishery Ecosystem Plan Team. This is a collaborative effort primarily between the Western Pacific Regional Fishery Management Council, NMFS-Pacific Island Fisheries Science Center, Pacific Islands Regional Office, Division of Aquatic Resources (HI) Department of Marine and Wildlife Resources (AS), Division of Aquatic and Wildlife Resources (Guam), and Division of Fish and Wildlife (CNMI).

This report attempts to summarize annual fishery performance looking at trends in catch, effort and catch rates as well as provide a source document describing various projects and activities being undertaken on a local and federal level. The report also describes several ecosystem considerations including fish biomass estimates, biological indicators, protected species, habitat, climate change and human dimensions. Information like marine spatial planning and best scientific information available for each fishery are described. This report provides a summary of annual catches relative to the Annual Catch Limits established by the Council in collaboration with the local fishery management agencies.

Edited By: Marlowe Sabater, Asuka Ishizaki, Rebecca Walker, and Sylvia Spalding, WPRFMC

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The **Western Pacific Regional Fishery Management Council** acknowledges the valuable contributions of the following Plan Team members for drafting sections of this report:

Guam Division of Aquatic and Wildlife Resources: Brent Tibbatts, Jay Gutierrez

CNMI Division of Fish and Wildlife: Michael Tenorio, Trey Dunn

NMFS Pacific Islands Fisheries Science Center: Justin Hospital, Ivor Williams, Joe O'Malley, Brett Taylor, Michael Parke, Phoebe Woodworth-Jefcoats, John Marra, Tom Oliver, Frank Parrish, T. Todd Jones, Kirsten Leong and Minling Pan.

NMFS Pacific Islands Regional Office: Melanie Brown

Pacific Islands Regional Planning Body: Sarah Pautzke

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Executive Summary

As part of its 5 year fishery ecosystem plan (FEP) review, the Council identified the annual reports as a priority for improvement. The former annual reports have been revised to meet National Standard regulatory requirements for the Stock Assessment and Fishery Evaluation (SAFE) reports. The purpose of the report is twofold: monitor the performance of the fishery and ecosystem to assess the effectiveness of the FEP in meeting its management objectives; and maintain the structure of the FEP living document. The reports are comprised of three chapters: fishery performance, ecosystem considerations, and data integration. The Council will iteratively improve the annual SAFE report as resources allow.

The fishery performance section of this report first presents a general description of the local commercial fishery within Commonwealth of Northern Mariana Islands (CNMI) and Guam including both the bottomfish and coral reef management unit species (MUS). The fishery data collection system is then explained and time series of meta-data dashboard statistics are provided. The collection system encompasses shore-based and boat-based creel surveys, commercial receipt books, and boat inventories. The fishery statistics for each MUS are organized into a summary dashboard table showcasing the values for the most recent fishing year and a comparison to short-term (10 years) and long-term (20 years) averages. Time series for catch and effort statistics are also provided. For 2015 catch in CNMI, no MUS exceeded overfishing limit (OFL), allowable biological catch (ABC), or annual catch limit (ACL). For 2016 catch in Guam, all MUS were below OFL, ABC, and ACL except for jacks. This was due to the reduction in the ACL from the previous year overage. The estimated catch for jacks in 2016 was about at a similar level as the previous 2 years. For CNMI, the 2016 catch of slipper lobsters exceeded the ACL. This is the first time in recent years that slipper lobsters appeared on the catch records. This was attributed to the implementation of the Territory Science Initiative project that aimed to improve the reporting and compliance to the commercial receipt book data collection program by the Saipan fish vendors.

For the CNMI, the main fisheries monitored are the bottomfish, crustacean, and the coral reef fisheries. The time series comparison only covers the recent 10 years. The time series does not extend far back to make a longer term trend comparison. The bottomfish catch showed a slight decline in 2016 for all species caught in the bottomfishing gear and for BMUS. The bottomfishing CPUE showed a significant increase in 2016. Fishing effort, fishery participation, and fishery bycatch have been down last year. For the coral reef fisheries, the report separates the shore-based from the boat-based fisheries. The estimated catches and fishing effort for both fisheries are lower in 2016 compared to the 10 year average. The CPUE for the boat-based trolling and the top shore-based gear are higher in 2016 relative to the 10 year average and showed to be significantly higher for hook and line and spear. The fishery participation in the boat-based coral reef fisheries exhibited no trend and showed a slight 8% decrease in 2016. The shore-based methods also showed a decrease in participation. The coral reef bycatch was also lower last year.

For Guam, the bottomfish fishery in 2016 exhibited a 20% decline in all species catch and 11% for the BMUS catch. No commercial catch trends can be reported due to data confidentiality (less than 3 vendors that reported). All the trends are similar when comparing between the short-term and long-term trends. There was an increase in fishery participation (significant) and

CPUE. Fishing effort declined in 2016. There were no trends in the total number of bycatch relative to the past 10 years but showed a decline in the past 20 years. The coral reef boat-based and shore-based fisheries, in general, showed a decline in catch and CPUE in 2016 but no apparent short-term trends. The fishing effort estimates in 2016 generally increased except for the boat-based gillnet and shore-based hook-and-gaff. The boat-based trolling, SCUBA spearfishing and shore-based cast net, gill net, and spearfishing showed significant increasing trends over the past 10 years but historically within the values over the 20 year period. Five of the 9 fishing methods monitored showed lower fishery participation and the rest showed an increase. Coral reef fishery bycatch is down slightly last year but was part of a gradual increasing trend over the past 10 years.

Ecosystem considerations were added to the annual SAFE report following the Council's review of its fishery ecosystem plans and revised management objectives. Fishery independent ecosystem survey data, human dimensions, protected species, climate and oceanographic, essential fish habitat, and marine planning information are included in the ecosystem considerations section.

Fishery independent ecosystem survey data was acquired through visual surveys conducted in CNMI, Pacific Remote Island Area, American Samoa, Guam, Main Hawaiian Islands, and Northwest Hawaiian Islands. This report illustrates the mean fish biomass for the reef areas within these locations. Additionally, the mean reef fish biomass and mean size of fishes (>10 cm) for CNMI and Guam are presented by sampling year and reef area. Finally, the reef fish population estimates for each study site within CNMI and Guam are provided for hardbottom habitat (0-30 m).

For CNMI, life history parameters including maximum age, asymptotic length, growth coefficient, hypothetical age at length zero, natural mortality, age at 50% maturity, age at sex switching, length at which 50% of a fish species are capable of spawning, and length of sex switching are provided for 10 species of reef fish and 11 species of bottomfish. The same nine life history parameters are provided for 12 species of reef fish and 11 species of bottomfish in Guam.

Summarized length derived parameters for coral reef fish and bottomfish in CNMI and Guam include: maximum fish length, mean length, sample size, sample size for L-W regression, and length-weight coefficients. Values for 25 coral reef fish species and 10 bottomfish species are presented for CNMI. Values for 22 coral reef fish species and three bottomfish species are presented for Guam.

The socioeconomics section outlines the pertinent economic, social, and community information available for assessing the successes and impacts of management measures or the achievements of the Fishery Ecosystem Plan for the Mariana Archipelago. It meets the objective "Support Fishing Communities" adopted at the 165th Council meeting; specifically, it identifies the various social and economic groups within the region's fishing communities and their interconnections. The section begins with an overview of the socioeconomic context for the region, then provides a summary of relevant studies and data for Mariana Islands, followed by summaries of relevant studies and data for each fishery within the Mariana Archipelago. Socioeconomics data will be included in later versions of this report as resources allow.

The protected species section of this report summarizes information and monitors protected species interactions in fisheries managed under the Mariana Archipelago FEP. These fisheries generally have limited impacts to protected species, and do not have federal observer coverage. Consequently, this report tracks fishing effort and other characteristics to detect potential changes to the level of impacts to protected species. Fishery performance data contained in this report indicate that there have been no notable changes in the fisheries that would affect the potential for interactions with protected species, and there is no other information to indicate that impacts to protected species have changed in recent years.

The climate change section of this report includes indicators of current and changing climate and related oceanic conditions in the geographic areas for which the Western Pacific Regional Fishery Management Council has responsibility. In developing this section, the Council relied on a number of recent reports conducted in the context of the U.S. National Climate Assessment including, most notably, the 2012 Pacific Islands Regional Climate Assessment and the Ocean and Coasts chapter of the 2014 report on a Pilot Indicator System prepared by the National Climate Assessment and Development Advisory Committee. The primary goal for selecting the indicators used in this report is to provide fisheries-related communities, resource managers and businesses with climate-related situational awareness. In this context, indicators were selected to be fisheries relevant and informative, build intuition about current conditions in light of changing climate, provide historical context and recognize patterns and trends. The atmospheric concentration of carbon dioxide (CO_2) trend is increasing exponentially with the tiem series maximum at 406.43 ppm. The oceanic pH at Station Aloha, in Hawaii has shown a significant linear decrease of -0.0386 pH units, or roughly a 9% increase in acidity ([H+]) since 1989. 2013, 2014, and 2016 showed extreme high temperature anomalies, with values surpassing 8 degree heating weeks in 2013 & 2014, and 4 degree heating weeks in 2016. The year also saw an abundance of tropical cyclones including 26 named storms and 6 major typhoons in the western Pacific.

The Mariana Archipelago FEP and National Standard 2 guidelines require that this report include a report on the review of essential fish habitat (EFH) information. The 2016 annual report includes an update of the precious corals species descriptions, effects of non-fishing and cumulative impacts on EFH. The guidelines also require a report on the condition of the habitat. In the 2016 annual report, mapping progress and benthic cover are included as indicators, pending development of habitat condition indicators for the Mariana Archipelago not otherwise represented in other sections of this report. The annual report also addresses any Council directives toward its plan team. There were no directives in 2016.

The marine planning section of this report tracks activities with multi-year planning horizons and begins to track the cumulative impact of established facilities. Development of the report in later years will focus on identifying appropriate data streams. Military activities in the Marianas continue to impact fisheries and access. With the Records of Decision on the Mariana Islands Testing and Training and Guam and CNMI Military Relocation SEIS, access to fishing grounds will be impacted at Ritidian Point on Guam and at Farallon de Medinilla in CNMI during live-fire exercises. Nearshore water quality will be impacted in Northern Guam until the Northern District Wastewater Treatment Plant is upgraded. A re-release of the draft CNMI Joint Military Training EIS is not expected until the end of 2018. CNMI and the Department of Defense will establish a coordinating council to discuss issues associated with increased military activity in the CNMI.

The 2017 Archipelagic Plan Team had the following recommendations with respect to this report.

Regarding the data integration chapter of the SAFE report, the Archipelagic Fishery Ecosystem Plan Team recommends the Council include the following variables in the exploratory data analysis being conducted by the Council’s contractor:

- Effect of subsidy program
- Market forcing
- Effects of fish import-export

Regarding the species table, the Archipelagic Fishery Ecosystem Plan Team recommends the Council direct staff, in coordination with NMFS staff, to convene a working group to finalize the species table used to generate fishery statistics

Regarding Essential Fish Habitat, the Plan Team recommends that the Council:

- Consider amending the non-fishing impacts, cumulative impacts, and conservation and enhancement recommendations in the Western Pacific FEPs based on the options provided by the Plan Team, and
- Consider amending the EFH designations and species descriptions for precious corals based on the options provided by the Plan Team.

Regarding the evaluation of 2016 catch to the 2016 ACL, the Archipelagic Fishery Ecosystem Plan Team provides the Council with the following rationale for the overages in CNMI slipper lobsters and Guam jacks:

- The CNMI slipper lobsters recent three-year average of catch amounting to 101 lbs exceeded its ACL of 60 lbs. The slipper lobster fishery is tracked through the Commercial Receipt Books. The increase in catch can be attributed to the implementation of the Territory Science Initiative designed to improve the data submitted to the commercial receipt books. In 2016, 59 invoices and 19 fishermen reporting reported sale of slipper lobsters which was zeroes in the previous years;
- The Guam jacks recent three-year average of catch amounting to 26,607 lbs exceeded its ACL of 21,201 lbs. The ACL was reduced to this level due to the overage in the previous year. This is the second year the ACL for jacks was exceeded. The Plan Team recommends the Council to revisit its accountability measure. The Plan Team further recommends considering applying the second year overage to the original ACL.

When the Council accountability measures are applied, this will result in the following ACLs for 2018:

- CNMI slipper lobsters = 19 lbs

- Guam jacks = 23,894 lbs

The Archipelagic Fishery Ecosystem Plan Team recognizes the importance of the ecosystem component amendment to address the operational issues associated with the data limited stocks managed under Annual Catch Limits.

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TABLE OF CONTENTS

Acronyms and Abbreviations xx

1 Fishery Performance 23

1.1 CNMI Fishery Descriptions 23

1.1.1 Background 23
1.1.2 Fishery Data Collection System 26
1.1.3 Meta-data Dashboard Statistics 29
1.1.4 Fishery Summary Dashboard Statistics 32
1.1.5 Catch statistics 34
1.1.6 Catch Per Unit Effort (CPUE) Statistics 41
1.1.7 Effort Statistics 43
1.1.8 Participants 44
1.1.9 Bycatch estimates 44
1.1.10 Number of federal permit holders 47
1.1.11 Status Determination Criteria 48
1.1.12 Overfishing Limit, Acceptable Biological Catch, and Annual Catch Limits 53
1.1.13 Best scientific information available 54
1.1.14 Harvest capacity and extent 56
1.1.15 Administrative and Regulatory Actions 58
1.1.16 References 58
1.2 Guam Fishery Descriptions 60

1.1.1 Bottomfish Fishery 60
1.2.1 Coral Reef Fishery 62
1.2.2 Fishery Data Collection System 63
1.2.3 Meta-data Dashboard Statistics 63
1.2.4 Fishery Summary Dashboard Statistics 67
1.2.5 Catch statistics 70
1.2.6 Catch Per Unit Effort (CPUE) Statistics 78
1.2.7 Effort Statistics 81
1.2.8 Participants 83
1.2.9 Bycatch estimates 85
1.2.10 Number of federal permit holders 89
1.2.11 Status Determination Criteria 90
1.2.12 Overfishing Limit, Acceptable Biological Catch, and Annual Catch Limits 94
1.2.13 Best scientific information available 96
1.2.14 Harvest capacity and extent 98
1.2.15 Other relevant ocean uses and fishery-related information 99
1.2.16 Administrative and Regulatory Actions 100
1.2.17 References 100
2 Ecosystem Considerations 103

2.1 Coral Reef Ecosystem Parameters 103

2.1.1 Regional Reef Fish Biomass ... 103
2.1.2 CNMI Reef Fish Biomass ... 106
2.1.3 CNMI Archipelagic Mean Fish Size ... 110
2.1.4 CNMI Reef Fish Population Estimates ... 114
2.1.5 Guam Reef Fish Biomass ... 116
2.1.6 Guam Archipelagic Mean Size ... 118
2.1.7 Guam Reef Fish Population Estimates ... 120
2.2 Life History and Length Derived Parameters ... 122

2.2.1 CNMI Coral Reef Ecosystem – Reef Fish Life History ... 122
2.2.2 CNMI Bottomfish Ecosystem – Bottomfish Life History ... 132
2.2.2.3 References ... 139
2.2.3 Guam Coral Reef Ecosystem – Reef Fish Life History ... 140
2.2.4 Guam Bottomfish Ecosystem – Bottomfish Life History ... 149
2.3 Socioeconomics ... 157

2.3.1 Response to Previous Council Recommendations ... 158
2.3.2 CNMI ... 159
2.3.3 Guam ... 164
2.3.4 Ongoing Research and Information Collection ... 171
2.3.5 Relevant PIFSC Economics and Human Dimensions Publications: 2016 ... 171
2.3.6 References ... 171
2.4 Protected Species ... 173

2.4.1 Indicators for Monitoring Protected Species Interactions in the Marianas FEP Fisheries 173
2.4.2 Status of Protected Species Interactions in the Marianas FEP Fisheries ... 175
2.4.3 Identification of Emerging Issues ... 176
2.4.4 Identification of research, data and assessment needs ... 178
2.5 Climate and Oceanic Indicators ... 179

2.5.1 Introduction ... 179
2.5.2 Conceptual Model ... 180
2.5.3 Selected Indicators ... 181
2.5.4 Observational and Research Needs ... 214
2.5.5 A Look to the Future ... 215
2.6 Essential Fish Habitat ... 216

2.6.1 Introduction ... 216
2.6.2 Habitat Use by MUS and Trends in Habitat Condition ... 217
2.6.3 Report on Review of EFH Information ... 224
2.6.4 EFH Levels ... 224
2.6.5 Research and Information Needs ... 226
2.6.6 References ... 227
2.7 Marine Planning ... 229

2.7.1 Introduction ... 229

2.7.2 Response to Previous Council Recommendations.. 229
2.7.3 Marine Managed Areas established under FEPs 230
2.7.4 Fishing Activities and Facilities 233
2.7.5 Non-Fishing Activities and Facilities 233
2.7.6 Pacific Islands Regional Planning Body Report... 235
2.7.7 References... 235
3 Data Integration 239

Appendix A: American Samoa FEP management unit species list……..……………………..…A-1
Appendix B: List of Protected Species and Designated Critical Habitat……………………..…B-1
Appendix C: Precious Corals Essential Fish Habitat Species Descriptions……………………C-1
Appendix D: Non-fishing Effects that May Adversely Affect Essential Fish Habitat
in the Pacific Islands Region…………………………………………………..............D-1

TABLE OF TABLES

Table 1. Summary of creel survey meta-data describing survey performance parameters with potential influence on the creel survey expansion 30
Table 2. Summary of commercial receipt book meta-data describing reporting performance parameters with potential influence on total commercial landing estimates (Note: Data will be reported only for years with ≥ 3 vendors reporting). 31
Table 3. Annual indicators for the coral reef and bottomfish fishery describing fishery performance comparing current estimates with the short-term (10 years) and the long-term (20 years) average. 32
Table 4. Summary catch time series of the ALL SPECIES caught using the bottomfishing gear: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system 35
Table 5. Summary of the available Bottomfish Management Unit Species (BMUS) catch time series: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system. 36
Table 6. Summary of the predefined “coral reef fishery” (catch time series (for a discrete list of species – taken from CB lbs and CS lbs from the CREMUS module) from the boat and shore-based creel surveys and the commercial purchase system. 38
Table 7. Expanded catch time series estimates using boat and shore-based creel survey data sets by gear type. 39
Table 8. Catch time series of the 12 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the boat based creel data. The CREMUS complex comprise > 92% of the total boat based landing. (ALL BF and BMUS were deemed commercial). 40
Table 9. Catch time series of the 11 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the shore-based creel data The CREMUS complex comprise > 91% of the total boat based landing 41
Table 10. Catch per unit effort time series by dominant fishing methods from the shore-based fisheries. 41
Table 11. Catch per unit effort time series by dominant fishing methods from the boat-based fisheries. 42
Table 12. Time series of effort estimates from the coral reef and bottomfish fisheries. Shore-based fisheries are expressed in gear-hours (expanded total number of hours fishing by total number of gears used). The boat-based fisheries are expressed in number of trips for bottomfish and number of gear hours for spear, troll, atulai, and castnest). Cells marked with * indicates data is confidential due to less than 3 entities surveyed or reported 43
Table 13. Number of fishermen participating in the bottomfish fishery and number of gear in the boat and shore-based coral reef fishery. Cells marked with * indicates data is confidential due to less than 3 entities surveyed or reported. 44
Table 14. Time series of bycatch estimates in the non-bottomfishing boat-based fisheries. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery. 45
Table 16. Time series bycatch estimates in the bottomfish fishery. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery........ 46

Table 17. Time series of bycatch estimates in the shore-based fishery with all gears combined. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery. 46
Table 18. Number of federal permits holders between 2007 and 2017 for the crustacean and bottomfish fisheries of the Commonwealth of the Northern Mariana Islands 48
Table 19. Overfishing threshold specifications for the bottomfish management unit species in CNMI 49
Table 20. Rebuilding control rules for the bottomfish management unit species in CNMI 50
Table 21. Status determination criteria for the coral reef management unit species using CPUE based proxies 51
Table 22. Stock assessment parameters for the CNMI BMUS complex (Yau et al 2015) 51
Table 23. Best available MSY estimates for the coral reef MUS in CNMI 52
Table 24. Mariana Archipelago – CNMI ACL table with 2016 catch (values are in pounds) 53
Table 25. Mariana Archipelago – CNMI proportion of harvest extent (values are in percentage), defined as the proportion of fishing year landing relative to the ACL or OY, and the harvest capacity, defined as the remaining portion of the ACL or OY that can potentially be harvested in a given fishing year. 57
Table 26. Summary of creel survey meta-data describing survey performance parameters with potential influence on the creel survey expansion. 64
Table 27. Summary of commercial receipt book meta-data describing reporting performance parameters with potential influence on total commercial landing estimates (Note: Data will be reported only for years with ≥ 3 vendors reporting). 66
Table 28. Annual indicators for the coral reef and bottomfish fishery describing fishery performance comparing current estimates with the short-term (10 years) and the long-term (20 years) average. 67
Table 29. Summary catch time series of the ALL SPECIES caught using the bottomfishing gear: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system 70
Table 30. Summary of the available Bottomfish Management Unit Species (BMUS) catch time series: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system 71
Table 31. Summary of the predefined “coral reef fishery” catch time series (for a discrete list of species – taken from CB lbs and CS lbs from the CREMUS module) from the boat and shore-based creel surveys and the commercial purchase system 73
Table 32. Expanded catch time series estimates using boat and shore-based creel survey data sets by gear type. 74
Table 33. Catch time series of the 11 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the boat-based creel data. The CREMUS complex comprise > 67% of the total boat based landing 76
Table 34. Catch time series of the 10 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the shore-based creel data. The CREMUS complex comprise > 91% of the total boat based landing 77
Table 35. Catch per unit effort time series by dominant fishing methods from the shore-based fisheries. CPUE estimates were derived from the top three- to five-dominant taxonomic groups that make up more than 50% of the catch. The percentage of catch is shown in parenthesis beside the method. 79

Table 36. Catch per unit effort time series by dominant fishing methods from the boat-based fisheries. CPUE estimates were derived from the top three to five dominant taxonomic groups that make up more than 50% of the catch. The percentage of catch is shown in parenthesis beside the method. 80
Table 37. Time series of effort estimates from the coral reef and bottomfish fisheries. Shore-based fisheries are expressed in gear-hours (expanded total number of hours fishing by total number of gears used). The boat-based fisheries are expressed in number of trips for bottomfish and number of gear hours for spear, SCUBA, gillnet and troll)........ 81
Table 38. Number of boats participating in the bottomfish fishery and number of gear in the boat and shore-based coral reef fishery. Cells marked with * indicates data is confidential due to less than three entities surveyed or reported........ 83
Table 39. Time series of bycatch estimates in the boat-based non-bottomfishing gear type fisheries. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery........ 85
Table 40. Time series of bycatch estimates in the bottomfish fishery. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery. 87
Table 41. Time series of bycatch estimates in the shore-based fishery (all gears combined). Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery........ 88
Table 42. Number of federal permits holders between 2007 and 2017 for the crustacean and bottomfish fisheries of Guam........ 90
Table 43. Overfishing threshold specifications for the bottomfish management unit species in Guam........ 91
Table 44. Rebuilding control rules for the bottomfish management unit species in Guam........ 91
Table 45. Status determination criteria for the coral reef management unit species using CPUE based proxies........ 92
Table 46. Stock assessment parameters for the Guam BMUS complex (Yau et al 2015) 93
Table 47. Best available MSY estimates for the coral reef MUS in Guam........ 94
Table 48. Mariana Archipelago – Guam ACL table with 2016 catch (values are in pounds)........ 95
Table 49. Mariana Archipelago – Guam proportion of harvest extent (values are in percentage), defined as the proportion of fishing year landing relative to the ACL or OY, and the harvest capacity, defined as the remaining portion of the ACL or OY that can potentially be harvested in a given fishing year........ 99
Table 50. Reef fish population estimates for CNMI........ 115
Table 51. Reef fish population estimates for Guam. Fish species are pooled by CREMUS groupings. Estimated population biomass is for 0-30 m hardbottom habitat only. (n) is number of sites surveyed per island. Each site is surveyed by means of two to four 7.5 m diameter SPCs. However, those are not considered to be independent samples, so data from those is pooled to site level before other analysis........ 121
Table 52. Available age, growth, and reproductive maturity information for coral reef species targeted for life history sampling (otoliths and gonads) in CNMI. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be

inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column. 125
Table 53. Available length-derived information for various coral reef species in CNMI. 128
Table 54. Available age, growth, and reproductive maturity information for bottomfish species targeted for life history sampling (otoliths and gonads) in CNMI. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column. 135
Table 55. Available length-derived information for various bottomfish species in CNMI. 137
Table 56. Available age, growth, and reproductive maturity information for coral reef species targeted for life history sampling (otoliths and gonads) in Guam. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column. 143
Table 57. Available length derived information for various coral reef species in Guam. 145
Table 58. Available age, growth, and reproductive maturity information for bottomfish species targeted for life history sampling (otoliths and gonads) in Guam. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column. 152
Table 59. Available length derived information for various bottomfish species in Guam. 155
Table 60. Summary of ESA consultations for Mariana Archipelago FEP Fisheries 173
Table 61. Candidate ESA species, and ESA-listed species being evaluated for critical habitat designation. 177
Table 62. Climate and Ocean Indicator Summary - Marianas. 183
Table 63. Summary of habitat mapping in the Marianas 220
Table 64. Mean percent cover of live coral from RAMP sites collected from towed-diver surveys in the Marianas 222
Table 65. Mean percent cover of macroalgae from RAMP sites collected from towed-diver surveys in the Marianas 222
Table 66. Mean percent cover of crustose coralline algae from RAMP sites collected from towed-diver surveys in the Marianas 223

Table 67. Level of EFH information available for the Western Pacific precious corals management unit species complex 224
Table 68. Level of EFH information available for Western Pacific bottomfish and seamount groundfish management unit species complex. 225
Table 69. Level of EFH information available for the Western Pacific crustacean management unit species complex. 226
Table 70. MMAs established under FEPs from 50 CFR § 665. 232

TABLE OF FIGURES

Figure 1. Mean fish biomass by Coral Reef Management Unit Species (CREMUS) grouping per US Pacific reef area. Mean fish biomass (± standard error) per CREMUS grouping per reef area pooled across survey years (2009-2015). Islands ordered within region by latitude. Continues to next page. 105
Figure 2. Mariana archipelago mean reef fish biomass. Anatahan, Guguan, and Sarigan have been grouped. Continues to next page. 108
Figure 3. Mariana Archipelago mean fish size. anatahan, Guguan, and Sarigan have been grouped. Continues to next page. 112
Figure 4. Guam reef fish biomass. 117
Figure 5. Guam mean fish size. 119
Figure 6. Average length over time of representative CNMI coral reef fish management unit species derived from the BioSampling Program. Continues to next two pages. 129
Figure 7. Average length over time of representative CNMI bottomfish management unit species derived from the BioSampling Program. 139
Figure 8. Average length over time of representative Guam coral reef fish management unit species derived from the BioSampling Program. 149
Figure 9. Average length over time of representative Guam bottomfish management unit species derived from the BioSampling Program 156
Figure 10. Settlement of the Pacific Islands, courtesy Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Polynesian_Migration.svg. 157
Figure 11. Indicators of change to archipelagic coastal and marine systems. 180
Figure 12. Regional Spatial Grids. 182
Figure 13. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data. 186
Figure 14. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii, 2013-2017. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data. 186
Figure 15. pH Trend at Station Aloha, 1989-2015. 187
Figure 16. Oceanic Nino Index, 1950-2017. 189
Figure 17. Oceanic Nino Index, 2000-2017. 189
Figure 8. 2015-2016 El Nino event infographic. 189
Figure 19. Pacific Decadal Oscillation, 1900-2017. 192
Figure 20. Pacific Decadal Oscillation, 2000-2017. 192
Figure 21. Q4 2016 Climate Impact and Outlook Infographic. 193

Figure 22. Sea surface temperature plots for the Mariana Regional Grid. 195
Figure 23. Sea surface temperature anomaly for the Mariana Regional Grid. 197
Figure 24. Degree Heating Weeks Timeseries in the Guam, 2013-2016. 200
Figure 25. Degree Heating Weeks Timeseries in the Commonwealth of the Northern Marianas, 2013-2016. 200
Figure 26. Degree Heating Weeks Maps, showing Annual DHW Maximum (Sep 15, 2013-2016) across the Pacific Ocean. 201
Figure 27. 2016 East Pacific Tropical Cyclone ACE 1970-2016. Source: NOAA’s National Hurricane Center 203
Figure 28. East Pacific tropical cyclone count 1970-2016. Source: NOAA's National Hurricane Center 203
Figure 29. 2015 Eastern Pacific Tropical Cyclone Tracks. Source: NOAA’s National Hurricane Center 204
Figure 30. Western Pacific Cyclone Tracks 2016. Source: http://weather.unisys.com/hurricane/w_pacific/2016 205
Figure 31. Comparing mean sea level anomaly for February 2016 (El Niño), and January 2017 (Neutral) 207
Figure 32. Local sea level at Apra Harbor, Guam, 1900-2016. 210
Figure 33. Monthly extreme water levels below and above MLLW and MHHW in Guam, 1900-2016. 211
Figure 34. Wave watch summary for Mariana regional grid. 213
Figure 35. Substrate EFH Limit of 700 m isobath around the islands and surrounding banks of the Mariana Archipelago. Data Source: GMRT. 219
Figure 36. Marianas Land and Seafloor Area and Primary Data Coverage from CRCP 2011. . 221
Figure 37. Regulated fishing areas of the Mariana Archipelago, including large access restrictions. 231

ACRONYMS AND ABBREVIATIONS

ABC	Acceptable Biological Catch
ACE	Accumulated Cyclone Energy
ACL	Annual Catch Limits
ACT	Annual Catch Target
AM	Accountability Measures
AVHRR	Advanced Very High Resolution Radiometer
BAC-MSY	Biomass Augmented Catch MSY
B_{FLAG}	warning reference point for biomass
BiOp	Biological Opinion
BMUS	Bottomfish Management Unit Species
BOEM	Bureau of Ocean Energy Management
BSIA	Best Scientific Information Available
CFR	Code of Federal Regulations
CMLS	Commercial Marine License System
CMS	coastal and marine spatial
CMUS	Crustacean Management Unit Species
CNMI	Commonwealth of the Northern Mariana Islands
CPUE	Catch Per Unit Effort
CRED	Coral Reef Ecosystem Division
CREMUS	Coral Reef Ecosystem Management Unit Species
DAWR	Division of Aquatic and Wildlife Resources
DLNR-DAR	Department of Land and Natural Resources-Division of Aquatic Resources
DLNR-DFW	Department of Land and Natural Resources-Division of Fish and Wildlife
DPS	Distinct Population Segment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EKE	Eddy kinetic energy
ENSO	El Niño Southern Oscillation
EO	Executive Order
ESA	Endangered Species Act
FEP	Fishery Ecosystem Plan
FMP	Fishery Management Plan
FRS	Fishing Report System
GAC	Global Area Coverage
GFS	global forecast system
HAPC	Habitat Area of Particular Concern
HDAR	Hawaii Division of Aquatic Resources
IBTrACS	International Best Track Archive for Climate Stewardship
LOF	List of Fisheries
LVPA	Large Vessel Prohibited Area
MFMT	Maximum Fishing Mortality Threshold

MHI	Main Hawaiian Island
MMA	marine managed area
MMPA	Marine Mammal Protection Act
MPA	marine protected area
MPCC	Marine Planning and Climate Change
MPCCC	Council's MPCC Committee
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
MSST	Minimum Stock Size Threshold
MSY	Maximum Sustainable Yield
MUS	management unit species
NCADAC	National Climate Assessment & Development Advisory Committee
NCDC	National Climatic Data Center
NEPA	National Environmental and Policy Act
NESDIS	National Environmental Satellite, Data, and Information Service
NMFS	National Marine Fisheries Service
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWHI	Northwestern Hawaiian Islands
OFL	Overfishing Limits
OFR	Online Fishing Report
ONI	Ocean Niño Index
OR&R	Office of Response and Restoration
OY	Optimum Yield
PacIOOS	Pacific Integrated Ocean Observing System
PCMUS	Precious Coral Management Unit Species
Pelagic FEP	Fishery Ecosystem Plan for the Pacific Pelagic Fisheries
PI	Pacific Islands
PIBHMC	Pacific Island Benthic Habitat Mapping Center
PIFSC	Pacific Island Fisheries Science Center
PIRCA	Pacific Islands Regional Climate Assessment
PIRO	NOAA NMFS Pacific Islands Regional Office
PMUS	pelagic management unit species
POES	Polar Operational Environmental Satellite
PRIA	Pacific Remote Island Areas
RAMP	Reef Assessment and Monitoring Program
RPB	Regional Planning Body
SAFE	Stock Assessment and Fishery Evaluation
SBRM	Standardized Bycatch Reporting Methodologies
SDC	Status Determination Criteria
SEEM	Social, Economic, Ecological, Management uncertainties
SPC	Stationary Point Count
SST	Sea Surface Temperature
TAC	Total Allowable Catch
USACE	United States Army Corps of Engineers

WPacFIN	Western Pacific Fishery Information Network
WPRFMC	Western Pacific Regional Fishery Management Council
WPSAR	Western Pacific Stock Assessment Review
WW3	Wave Watch 3

1 FISHERY PERFORMANCE

1.1 CNMI FISHERY DESCRIPTIONS

1.1.1 Background

The Commonwealth of the Northern Mariana Islands (CNMI) is a chain of islands in the Western Pacific Ocean. Along with the island of Guam, the chain is historically known as the Mariana Islands. The CNMI consists of 14 small islands situated in a north-south direction, stretching a distance of about 500km. The surrounding waters of the CNMI play an integral role in the everyday lives of its citizens. The ocean is a major source of food and leisure activities for residents and tourists alike. Archeological research has also revealed evidence of fishing activities in the CNMI dating back 3,000 years. Although the composition of fishing activities in the Marianas has changed significantly since then, a common view of its importance remains.

Fisheries during the German occupation

During the German occupational period (1899-1914) a majority of the economic focus in the Northern Marianas was on the copra industry. Few commercial fisheries were noted during this period of time, as the German administration focused efforts on crop production and feral cattle trade (Russell 1999). Chamorros and Carolinians utilized the protected lagoon and open waters with several fishing methods: talaya (cast net), chinchulu (surround net), gigao (fish weir), tokcha (spear), tupak (hook and line), with Carolinians additionally gleaning sea cucumbers for the Asian Markets. Most of these activities were for subsistence purposes, with the catch being distributed and bartered among relatives and acquaintances.

Fisheries during the Japanese occupation

Fisheries development prospered during the Japanese administration (1914-1945). The Japanese administration made fisheries the second largest industry. Small pelagic fishing operations were established and the Garapan port became the main area for drying fish. Large scale fishing activities occurred during the 1930's where Saipan produced 11 percent of the total tuna haul within Micronesia (Bowers 2001). However, efforts to develop the tuna fishery shifted to Palau and FSM due to the availability of bait fish in the region. Subsistence fishing still persisted within the lagoon and fringing reefs, and were mainly conducted by the natives, although a large extraction of sea cucumbers did occur. The main fishing methods used during this period were cast net, spear, gillnet, surround net, hook and line, and gleaning. During this period the topshell (*Trochus niloticus*) was also introduced into the Marianas.

Fisheries during the U.S. military occupation

The fishing industry was destroyed during WWII, but quickly rebuilt after the war with support from the U.S. military. Okinawans who operated the fishery prior to the war were hired to operate and train locals to fish commercially, targeting pelagic species. A company called Saipan Fishing Company operated after the war, which contributed to the early re-development of commercial fisheries in the CNMI (Bowers 2001). Most of the fishing activities were for *Katsuwanus pelamis* (Bonito) and other tuna species. However, other resources such as Big-Eye Scad, reef fish, and lobster were also harvested during calm weather. The Chamorros and Carolinians continued subsistence fishing within the lagoon after the war. Although limited quantities of monofilament nets were available during this period, they were used to capture fish within the lagoon and along the reef lines. The use of modern fishing gear such as masks, rubber fins, and flash lights made it much easier to harvest coral reef resources during this time.

Fisheries activities within the past two decades
The CNMI has had numerous changes in fisheries within the past twenty years. In the mid 90's, commercial fisheries activities increased significantly. Commercial SCUBA fishing became a common method not only to support local demand for reef fish, but also exports to Guam. Large-scale commercial bottom fishing activity peaked from the mid 1990's through 2002, with landings being sold locally and exported to Japan. This fishery operated almost exclusively in the Northern Islands of the CNMI. Troll fishing continued to be the dominant fishing industry during this period. An exploratory, deep-water-shrimp fishery also evolved, but didn't last due to internal company issues, and gear losses. During this time a sea cucumber fishery evolved on Rota, then migrated to Saipan. Ultimately, this fishery was found to be unstable and was subsequently halted.

Several fishing companies entered the fisheries only to close down a few years later. The CNMI also reached its highest population during this period, most of whom were migrant workers from Asia. The tourism industry was also increasing at this time which contributed to high demand for fresh fish. Subsistence fishing within the nearshore waters of Saipan, Tinian, and Rota also increased.

In the 2000's, small scale troll, bottom and reef fish fisheries persisted, with landings sold locally. Federal and state support was provided multiple times to further develop fisheries in the CNMI, with intermittent success. An exploratory longline fishery was funded in the mid 2000's and operated in the CNMI for about two years, but eventually closed down due to low productivity for high-valued, pelagic fish and issues within the business. A few larger (40-80') bottom vessels were also operational during this period, with a majority of them fishing the northern islands and offshore banks. A few of these vessels were recipients of financial assistance to improve their fishing capacities. Fisheries in the CNMI tend to be relatively small and fluid, with 16' to 20' boats fishing within 20 miles from Saipan. Many of these small vessels conduct multiple fishing activities during a trip. For example, a company which is supported mainly by troll fishing will also conduct bottom and spearfishing to supplement income. Fishing businesses will enter and exit the fishery when it is economically beneficial. Fisheries in the CNMI are also highly sensitive to changes in the economy, development, population, and regulations. Subsistence fishing continues; however, fishing methods and target species have changed along with population demographics as well as fisheries restrictions. Nearshore hook and line, cast net, and spear fishing are common activities. However, fishing methods such as gillnet, surround net, drag nets, and SCUBA-spear have been restricted or outright banned in the CNMI since 2000.

1.1.1.1 Bottomfish Fishery

The bottomfish fishery has also changed minimally from previous years. Relatively small (<25ft) fishing vessels are still being used to access bottom fishing grounds around Saipan and Tinian, while the larger (>25ft) vessels are used to access bottomfish resources in the northern islands. Only a handful of these larger bottom fishing vessels are operating in the CNMI. Most of the small bottomfishing vessels are owned by the vendors; however, there are a few subsistence bottomfishers participating in the fishery intermittently.

Two distinct types of bottomfish fisheries are identified in the CNMI: shallow-water bottom fishing, which targets fish at depths down to 150 meters, and deep-water bottom fishing, which targets fish at depths greater than 150 meters. Species targeted within the shallow-water fishery consist of the Redgill Emperor (*Lethrinus rubrioperculatus*), Black Jack (*Caranx lugubris*), Matai (*Epinephelus fasciatus*), Sas (*Lutjanus kasmira*), Lunartail Grouper (*Variola louti*) and other fish in similar depth stratums. Species targeted within the deep-water bottom fishing depths (>150m) include; Onaga (*Etelis corsucans*), Ehu (*Etelis carbunculus*), Yelllowtail Kalekale (*Pristipomiodes auricilla*), Amberjack (*Seriola dumerili*), Blueline Gindai (*Pristipomiodes argyrogrammicus),* Gindai (*Pristipomiodes zonatus*), Opakapaka (*Pristopomiodes filamentosus*), Eightbanded Grouper (*Hyporthordus octofasciatus*) and other fish found in similar depths.

Bottomfish Management Unit Species (BMUS) are not the only species being caught in the shallow-bottom fishery. Coral Reef Ecosystem Management Unit Species (CREMUS) are also caught in the shallow-bottom fishery because of the close proximity to the reef. These fish are caught with various hook and line gears such as: homemade hand lining gear, rod and reel, and electric reels. Deep-water bottomfishing requires more efficient fishing gears such as hydraulic and electric reels. Bottomfishing trips are generally during the day; however, fishing trips to the northern islands can take two to four days depending on vessel size and refrigeration capacity. These trips are most active during calm weather months. Successful fishermen targeting deep-water bottomfish tend to fish for one to four years before leaving the fishery, whereas the majority of fishermen targeting shallow-water bottomfish tend to leave the fishery after the first year.

The overall participation of fishermen in the bottomfish fishery tends to be very short term (less than four years). The slight difference between the shallow-water fishermen and the deep-water fishermen likely reflects the greater skill and investment required to participate in the deep-water, bottomfish fishery. In addition, these tend to be larger ventures that are more buffered from the impulses of an individual’s choices and are usually dependent on a skilled captain/fisherman. Overall, the long-term commitment to hard work, maintenance and repairs, and staff retention appear to be challenging, if not impossible for CNMI bottom-fishermen to sustain more than a few years. A full list of BMUS species is provided in Appendix 3.

1.1.1.2 Coral Reef Fishery

Currently, coral reef fisheries have been consistent with previous years. Small scale nearshore fisheries in the CNMI continue to be an important part of subsistence, social, cultural, recreational, and financial resources. Most fishermen are subsistence fishers with a number of them selling a portion of their catch to roadside vendors. However, some vendors employ fishermen to maintain a constant supply of reef fish. Most of the fishing for coral reef species occurs within the Saipan lagoon and fringing reefs around the islands, with targets consisting of finfish and invertebrates. All reef fish catches are sold to the local markets or used for personal consumption with a minimal percentage exported for off-island residents. Shoreline access is the most common way to access coral reef resources. Vessels are generally used during calm weather to fish areas not as accessible other times of the year. Fishing trips to other islands are made when the weather is favorable. Fishing methods have not changed significantly when compared to previous years. Hook and line, cast netting, spear fishing, and gleaning are methods still being used today. Some of the common families found in the CNMI reef fish markets are; Acanthuridae (surgeonfish), Scarinae (parrotfish), Mullidae (goatfish), Serranidae (grouper), Labridae (wrasse), Holocentridae (soldier/squirrelfish), Carangidae (Jacks), Scombridae (scad), Haemulidae (sweetlips), Gerridae (mojarra), Kyphosidae (rudderfish), and Mugilidae (mullet), as well as other non-finfish families. A full list of CREMUS species is provided in Attachment 3.

1.1.2 Fishery Data Collection System

A majority of the information collected by the CNMI Division of Fish and Wildlife (DFW) are fishery-dependent data. Since the early 1980's attempts were made to establish a data collection program for the near shore fisheries, but failed due to intergovernmental issues. Over the past 10 years, significant time and effort has been made to further develop the fishery data section. This effort has resulted in the re-establishment of the Shore-based Creel Program. DFW in collaboration with other local and federal agencies have been working on expanding on these successes.

1.1.2.1 Creel Surveys

Currently the CNMI maintains a Boat- and Shore-based Creel Program for the island of Saipan, with plans to expand it to the neighboring populated islands. The programs were established in 2000 and 2005 respectively, in order to strengthen the Division's capacity in providing sufficient information to the public regarding fishery information. Other programs such as the invoicing system and importation monitoring provide supplemental information on harvest and demand for the fishery.

Effective management of Saipan's marine fishery resources requires the collection of fishing effort, methods used and harvest. The CNMI Boat- and Shore-based Creel Surveys are some of the major data collection systems used by DFW to estimate the total annual boat-based participation, effort and harvest and to survey the near-shore fishery resources. These surveys were formerly known as the "CNMI Offshore and Inshore Creel Survey." The term "offshore/inshore" were previously used when referring to these Creel Survey Programs. However, now the proper term that should be used is "boat- or shore-based" because it covers all the fishing done from a boat or from shore regardless of where the fishing occurred, e.g., inside or outside the reef or lagoon. This is an important distinction because where the fishing activity is initiated (shore vs. boat) determines how that type of activity will be accounted for in the survey systems. For instance, very small boats launched from non-standard launching areas, e.g., from the back of a pickup truck on a beach are not included in the Boat-based survey.

The objective of the Boat-based Creel Survey Program is to quantify fishing participation, effort and catch that are done on a vessel in CNMI's waters. DFW had an early creel survey data collection program from 1988 to 1996, however since the methods were not standardized, the data collected with that early program is not currently being used. The early program was terminated due to a lack of resources. On April 2, 2000, the DFW fishery staff reinitiated the boat-based creel survey program on the island's boat-based fishery following a three year hiatus. The fishery survey collects data on the island's boating activities - including commercial and noncommercial fishermen - and interviews returning fishermen at the three most active launching ramps/docks on the island: Smiling Cove; Sugar Dock; and Fishing Base. Essential fishery information is collected and processed from both commercial and noncommercial vessels and will be vital in the management process of one of the island's valuable natural resources. Saipan's Boat-based Creel Survey Program utilizes a random scheduling protocol to survey at the three most active launching ramps/docks on the island: Smiling Cove, Sugar Dock, and

Fishing Base to collect catch and effort data and to analyze participation levels in Saipan's boat-based fishery. The two types of data collection programs utilized by Saipan's Boat-based Creel Survey Program include: Boat-based Participation Count to collect participation data, and a Boat-based Access Point Survey to collect catch and effort data (through Survey Maps, Boat Logs and Interviews) at the three major boat ramp areas listed above. The data collected are then expanded at a stratum level (expansion period [quarterly or annually], charter or non-charter day type [weekday or weekend], and gear type) to create the estimated landings by gear type for CNMI's Boat-based fishery.

DFW had an early creel survey data collection program in 1984, and 1990 to 1994, however since the methods were not standardized, the data collected with that early program is not currently being used. The early program was terminated due to a lack of resources. In May 2005 the DFW fishery staff reinitiated the shore-based creel survey program on the island's shore-based fishery following an 11-year hiatus. With the assistance of the Western Pacific Fisheries Information Network (WPacFIN) program at the Pacific Islands Fisheries Science Center (PIFSC), data processing software and a database were developed to process these survey data. In addition, expansion software was also developed to create annual expanded (estimated) landings for this fishery.

The Shore-based survey currently covers the Western Lagoon of Saipan. Some pilot surveys are being conducted on Saipan's Eastern beaches such as; Laolao Bay, Obyan Beach, and Ladder Beach. Other accessible areas are not covered at this time due to existing limited resource availability and logistical constraints. The Western Lagoon starts from the northwest (Wing Beach) and extends to the southwest (Agingan Point) of Saipan. This encompasses over twenty accessible and highly active shoreline access points.

Saipan's Shore-based Creel Survey is a stratified randomized data collection program. This program collects two types of data to estimate catch and effort information of the shore-based fishery. The two types of data collection are: Participation Count (P) and Interview (I). The Participation Count involves counting the number of people fishing on randomly selected days and their method of fishing along the shoreline. The Interview involves interviewing fishermen to determine catch, method used, length and weights of fish, species composition, catch disposition and if any fish were not kept (by-catch). The data collected from this program are used to expand and create annual estimated landings for this fishery.

1.1.2.2 Vendor Invoice

DFW has been collecting fishery statistics on the commercial fishing fleet of Saipan since the mid-1970s. With the assistance of the National Marine Fisheries Service WPacFIN program, DFW also expanded its fisheries monitoring programs to include Rota and Tinian, the other two major inhabited islands in the CNMI. DFW's principal method of collecting domestic commercial fisheries data is a dealer invoicing system, sometimes referred to as a "trip ticket" system. The DFW provides numbered two-part invoices to all purchasers of fresh fishery products (including hotels, restaurants, stores, fish markets, and roadside vendors). Dealers then complete an invoice each time they purchase fish directly from fishers; one copy goes to DFW and one copy goes to their records. Some advantages of this data collection method are that it is relatively inexpensive to implement and maintain and is fairly easy to completely cover the commercial fisheries. DFW can also provide feedback to dealers and fishers to ensure data accuracy and continued cooperation.

There are some disadvantages to the trip ticket system: (1) dependency on non-DFW personnel to identify the catch and record the data; (2) restrictions on the types of data that can be collected; (3) required education and cooperation of all fish purchasers; and (4) limited recordings of fish actually sold to dealers. Therefore, a potentially important portion of the total landings is unrecorded. Since 1982, DFW has tried to minimize these disadvantages in several ways: (1) maintain a close working relationship with dealers; (2) add new dealers to their list and educate them; and (3) implement a creel survey to help estimate total catch, including recreational and subsistence catch. The current system collects data from dealers in Saipan, where DFW estimates more than 90% of all CNMI commercial landings are made. The DFW also estimates that the proportion of total commercial landings that have been recorded in the Saipan database since 1983 is about 90%. Previous volumes of FSWP reported only recorded landings, but in recent volumes the data have been adjusted to represent 100% coverage and are referenced as “Estimated Commercial Landings” in the tables and charts.

These data elements are collected for all purchases of fishery products; however, species identification is frequently identified only to a group level, especially for reef fish.

1.1.2.3 Biosampling

The bio-sampling data base contains general and specific bio-data obtained from individual commercial spearfish catches landed on Saipan from six different vendors during 2011. The following data was captured for each fishing trip sampled: date sampled; fishing gear type; time/hours fished; location fished; number/names of fishers; lengths/weights of individual fish; number/weight of octopus and squid; number/carapace size/weight of lobster; and whether boat- or shore-based fishing trip.

Although sampling effort was intended to be spread evenly among all participating vendors, smaller vendors were inherently much more difficult to sample within the time constraints allowed by the vendors. Therefore, a regular sampling schedule was implemented for the island’s two largest vendors that included two weekdays and one weekend day each week since January/February 2011. Problems encountered in sampling the smaller vendors included: more days in any given month where no fish were purchased, the work area wasn’t conducive for sampling, and communication problems. The bio-sampling data base focuses on night time spearfishing activities. Due to vendor-imposed limitations, the other gear types that typically land their catch during normal business hours were not sampled.

1.1.2.4 Exemption netting

In 2003 the use of gill nets was prohibited in the CNMI. In 2005 the Department/Division decided to allow gill netting under special circumstances. With approval from DFW, gill netting is allowed under the strict conditions provided by DFW. All gill netting activities are to be monitored and recorded by DFW personnel.

On 2010, a law was passed allowing for the use of a gill net on the island of Rota, for the purpose of subsistence. The following year, a regulation allowing for subsistence net fishing was passed for the island of Tinian.

For a majority of the permitted gillnet activities, length and weight measurements were taken at the fishing site. Fork lengths were taken in millimeters and weights were taken in grams. If time did not permit for individual measurements, then length measurements were taken for each fish and total weight was taken for each species. Length/weight ratios were used to estimate weights of sampled fish. Information is collected for activities conducted on the island of Saipan. No official collection of information is being conducted for the other two populated islands.

1.1.2.5 Life History

The CNMI Division of Fish and Wildlife life history program began in 1996 with the redgill emperors (*L. rubrioperculatus*). Since then, sampling has been conducted on other species such as; *A. lineatus*, Myriprestinae (*M. violacea, M. kuntee, M. pralinea, M. bernti, M. murdjan), L. harak*, *N. lituratus*, *C. sordidus*, and <u>*C. undulatus*</u>. Other life history programs have also developed over the past years. DFW personnel in collaboration with NOAA NMFS collect life history information on *S. rubroviolaceus, L. atkinsoni*, *P. barbarinus*, through funding provided by NOAA-NMFS. The life history survey captures biological information such as: reproductive cycle, age at length, and age at maturity. The DFW is continually working to improve the understanding of reef fish life history in the CNMI, through this program.

1.1.2.6 Monitoring of Imported Fish

The DFW Fisheries Data Sections collect fisheries-related importation invoices from the Department of Commerce at the end of every month. The data is then entered into the ticket receipt system and reviewed prior to being sent out for compilation by the Pacific Islands Fisheries Science Center (PIFSC). A majority of the information entered in the system can only be identified to the family taxa.

1.1.3 Meta-data Dashboard Statistics

The meta-data dashboard statistics describe the amount of information used or data available to calculate the fishery-dependent information. Creel surveys are sampling based system that requires random-stratified design applied to pre-scheduled surveys. The creel surveys are comprised of: 1) participation run that captures effort and participation estimates and; 2) catch interviews that capture catch, effort, CPUE information, catch composition, size-weight information. The number of sampling days, participation runs, and catch interviews would determine if there are sufficient samples to run the expansion algorithm. The trends of these parameters over time may infer survey performance. Monitoring the survey performance is critical for explaining the reliability of the expanded information.

Commercial receipt book information depends on the amount of invoices submitted and the number of vendors participating in the program. Fluctuations in these meta-data affect the commercial landing and revenue estimates.

1.1.3.1 Creel surveys meta-data statistics

Calculations: Shore-based data

Interview Days: This is the number of actual days that Creel Survey Data were collected. It's a count of the number of unique dates found in the interview sampling data (the actual sampling date data, include opportunistic interviews).

Participation Runs: Count of the number of unique occurrences of the combination of survey date and run number in the participation detail data.

Catch Interviews: Count of the number of unique occurrences of the combination of date and run number in the participation detail data/ count of unique surveyor initials and date in PAR. This is divided into two categories, interviews conducted during scheduled survey days (Regular), and opportunistic interviews (Opp) which are collected on non-scheduled days.

Calculation: Boat-based data

Sample days: Count of the total number of unique dates found in the boatlog data sampling date data.

Catch Interviews: Count of the total number of data records found in the interview header data (number of interview headers). This is divided into two categories, interviews conducted during scheduled survey days (Regular), and opportunistic interviews (Opp) which are collected on non-scheduled days.

Table 1. Summary of creel survey meta-data describing survey performance parameters with potential influence on the creel survey expansion

Year	Shore-based				Boat-based		
	# Interview Days	# Participation Runs	# Catch Interviews		# Sample Days	# Catch Interviews	
			Regular	Opportunistic		Regular	Opportunistic
2000	NULL	NULL	NULL	NULL	44	168	9
2001	NULL	NULL	NULL	NULL	67	285	0
2002	NULL	NULL	NULL	NULL	75	200	25
2003	NULL	NULL	NULL	NULL	90	299	40
2004	NULL	NULL	NULL	NULL	77	272	16
2005	59	157	258	42	78	417	29
2006	105	337	597	248	71	342	22
2007	127	413	601	36	62	314	1
2008	157	340	911	24	55	250	1
2009	184	324	870	24	64	241	25
2010	132	294	374	29	65	161	82
2011	119	327	388	14	67	162	87

Year	Shore-based				Boat-based		
	# Interview Days	# Participation Runs	# Catch Interviews		# Sample Days	# Catch Interviews	
			Regular	Opportunistic		Regular	Opportunistic
2012	80	273	230	10	72	166	0
2013	108	277	297	2	71	191	0
2014	50	209	109	1	69	163	0
2015	44	186	84	16	57	119	2
2016	45	252	91	16	59	108	2
10 YEARS AVG	105	290	396	17	64	188	20
10 YEARS SD	46	63	290	11	6	60	33

1.1.3.2 Commercial receipt book statistics

Calculations:

# of Vendors – Count of the number of unique buyer codes found in the commercial purchase header data.

Invoices – Count of the number of unique invoice numbers found in the commercial header data.

Table 2. Summary of commercial receipt book meta-data describing reporting performance parameters with potential influence on total commercial landing estimates (Note: Data will be reported only for years with ≥ 3 vendors reporting).

Year	Number of Vendors	Total Invoices Collected
1997	54	3999
1998	52	5369
1999	49	4649
2000	47	6030
2001	39	4914
2002	32	4759
2003	24	4261
2004	25	3507
2005	23	3945
2006	21	4002
2007	18	3387
2008	13	3054
2009	6	2513
2010	5	1612
2011	3	1198
2012	19	1565

2013	17	2161
2014	15	1665
2015	10	752
2016	12	1309
10 YEARS AVG	12	1922
10 YEARS SD	5	800

1.1.4 Fishery Summary Dashboard Statistics

The Fishery Summary Dashboard Statics section consolidates all fishery dependent information comparing the most recent year with the short-term (recent 10 years) and long-term (recent 20 years). The summary dashboard shows the most current year value as the difference between the current year value with the 10 year average and the 20 year average (shown bolded in [brackets]). Trend analysis of the past 10 years will dictate the trends (increasing, decreasing, or no trend). The right-most symbol indicates whether the mean of the short-term and long-term years were above, below, or within one standard deviation of the mean of the full time series.

Legend Key:

- *increasing trend in the time series*
- *decreasing trend in the time series*
- *no trend in the time series*
- *above 1 standard deviation*
- *below 1 standard deviation*
- *within 1 standard deviation*

10,000 [**1,000**] – *point estimate of fishery statistic* [***difference from short/long term average***]

Table 3. Annual indicators for the coral reef and bottomfish fishery describing fishery performance comparing current estimates with the short-term (10 years) and the long-term (20 years) average.

Fishery	**Fishery statistics**	**Short-term (recent 10 years)**	**Long-term (20 years)**
Bottomfish	**Estimated catch (lbs)**		
All species caught in the BF gear	Boat and shore creel data estimated (expanded) total lbs (all BF trips)	**75,105[▼12%]**	**N/A**
	Estimated total lbs (all species) commercial purchase data	**23,284[▼8%]**	**23,284[▼34%]**
Bottomfish management unit species only	Boat-based creel data Estimated (expanded) total lbs (all BF trips)	**44,342[▼26%]**	**N/A**
	Estimated total lbs (all species) commercial purchase data	**10,443[▼25%]**	**10,443[▼39%]**
	Catch-per-unit effort (lbs/gear-hrs)		

Fishery	Fishery statistics	Short-term (recent 10 years)	Long-term (20 years)
	CPUE (creel data only)	0.3818[▲195%]	N/A
	Fishing effort *(only available for creel data)*		
	Estimated (expanded) total bottomfish trips	112[▼71%]	N/A
	Estimated total bottomfishing gear-hours	4,840[▼98%]	N/A
	Fishing participants		
	Estimated total # of fishers that went bottomfishing	636[▼74%]	N/A
	Bycatch		
	Total number of bycatch caught	713[▼35%]	N/A
	# bycatch released	None	N/A
	# bycatch kept	713[▼35%]	N/A
	Federal permits		
	# federal permit holders (PIRO)		N/A
Coral Reef	**Estimated catch (lbs all gears)**		
	Boat-based creel data (expanded estimate all gears, defined by a list of species?)	44,603[▼30%]	N/A
	Shore-based creel (expanded estimate all gears, defined by a list of species?)	24,241[▼52%]	N/A
	Commercial Purchase	47,907[▼42%]	47,907[▼67%]
	Catch-per-unit-effort (lbs/gear-hrs)		
	BB spear	No CPUE estimate available	N/A
	BB troll	0.0993[▲2%]	N/A
	BB atulai	No CPUE estimate available	N/A
	BB castnets	No CPUE estimate available	N/A
	SB H&L	0.1409[▲80%]	N/A
	SB spear	0.0021[▲133%]	N/A
	SB castnets	0.0526[▼42%]	N/A
	Fishing effort (# of gear-hours by gear type)		
	BB spear	No effort estimate available	N/A
	BB troll	82,175[▼55%]	N/A

Fishery	Fishery statistics	Short-term (recent 10 years)	Long-term (20 years)
	BB atulai	**No effort estimate available**	**N/A**
	BB castnets	**No effort estimate available**	**N/A**
	SB H&L	**11,832[▼97%]**	**N/A**
	SB spear	**589[▼56%]**	**N/A**
	SB castnets	**190[▼88%]**	**N/A**
	Fishing participants (# of gear)		
	BB spear	**No participation estimate available**	**N/A**
	BB troll	**635[▼8%]**	**N/A**
	BB atulai	**No participation estimate available**	**N/A**
	BB castnets	**No participation estimate available**	**N/A**
	SB H&L	**11,782[▼55%]**	**N/A**
	SB spear	**3,277[▼7%]**	**N/A**
	SB castnets	**1,551[▼38%]**	**N/A**
	Boat-based Bycatch		
	Total number of bycatch caught	**1,638[▼54%]**	**N/A**
	# bycatch released	**None**	**N/A**
	# bycatch kept	**1,638[▼54%]**	**N/A**
	Shore-based Bycatch		
	Total number of bycatch caught	**712[▼38%]**	**N/A**
	# bycatch released	**None**	**N/A**
	# bycatch kept	**712[▼38%]**	**N/A**
	Federal permits		
	# federal permit holders (PIRO)		

1.1.5 Catch statistics

This section summarizes the catch statistics for the bottomfish and coral reef fishery in CNMI. Estimates of catch are summarized from the creel survey and commercial receipt book data collection programs. Catch statistics provide estimates of annual harvest from the different fisheries. Estimates of fishery removals can provide proxies for the level of fishing mortality and a reference level relative to established quotas. This section also provides detailed level of catch for fishing methods and the top species complex harvested in the coral reef and bottomfish fishery.

1.1.5.1 Catch by data stream

This describes the estimated total catch from the shore and boat-based creel survey program and the commercial landing from the commercial receipt book system. The difference between the creel total and the commercial landing is assumed to be the non-commercial component. However, there are cases where the commercial landing may be higher than the estimated creel total of the commercial receipt book program is able to capture the fishery better than the creel survey (e.g. night time spearfishing)

Calculations: Estimated landings are based on a pre-determined list of species (Appendix 3) identified as the BF Species Complex regardless of the gear used, for each data collection (shore-based creel, boat-based creel and the commercial purchase reports).

Table 4. Summary catch time series of the ALL SPECIES caught using the bottomfishing gear: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system

Note: The creel survey estimates were not available for this report but will be included in next year's report.

	Creel Survey Estimates			
Year	**Boat-based**	**Shore-based**	**Creel Total**	**Commercial landings**
1983				16554
1984				22353
1985				19715
1986				16203
1987				19443
1988				9844
1989				8726
1990				6214
1991				3006
1992				6293
1993				12210
1994				13266
1995				25993
1996				59648
1997				61070
1998				52426
1999				50292
2000		132235	132235	33212

Year	Creel Survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
2001		44428	44428	55905
2002		44213	44213	43140
2003		26902	26902	39762
2004		50908	50908	37843
2005	26354	63140	89494	55548
2006	32484	57961	90445	26079
2007	26242	82278	108520	34617
2008	40116	49414	89530	38697
2009	28778	95893	124671	38201
2010	7039	84773	91812	22646
2011	20253	62205	82458	23653
2012	10689	159989	170678	15520
2013	22808	30667	53475	22380
2014	12522	18527	31049	25030
2015	6067	15772	21839	7833
2016	11698	63407	75105	23284
10 YEARS AVG	18621	66293	84914	25186
10 YEARS SD	10408	40823	41872	9251
20 YEARS AVG				35357
20 YEARS SD				14270

Calculations: Estimated landings are based on a pre-determined list of species (Appendix 3) identified as the BMUS Complex regardless of the gear used, for each data collection (shore-based creel, boat-based creel and the commercial purchase reports).

Table 5. Summary of the available Bottomfish Management Unit Species (BMUS) catch time series: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system

Note: The creel survey estimates were not available for this report but will be included in next year's report.

Year	Creel survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
1983				3407
1984				3463

Year	Creel survey Estimates		Creel Total	Commercial landings
	Boat-based	**Shore-based**		
1985				2087
1986				3822
1987				1889
1988				2412
1989				4022
1990				1274
1991				781
1992				607
1993				1723
1994				5476
1995				17735
1996				32446
1997				22133
1998				27277
1999				34305
2000		64413	64413	14940
2001		29375	29375	25283
2002		23825	23825	24333
2003		8642	8642	17665
2004		13094	13094	12384
2005	470	18311	18781	15376
2006	416	21702	22118	10346
2007	1296	34647	35943	15830
2008	61	9691	9752	16415
2009	246	54841	55087	18615
2010		43111	43111	12579
2011	1209	28203	29412	15495
2012	160	109894	110054	10263
2013	2663	9143	11806	16697
2014		6272	6272	18121
2015	0	12380	12380	4109
2016		44342	44342	10443
10 YEARS AVG	805	35252	35816	13857
10 YEARS SD	909	29745	29542	4281
20 YEARS AVG				17130
20 YEARS SD				6739

Calculations: Estimated landings are based on a pre-determined list of species (Appendix 3) identified as the CREMUS Complex regardless of the gear used, for each data collection (shore-based creel, boat-based creel and the commercial purchase reports). Need to finalize the CREMUS list to use for Creel and commercial landings and verify non-overlap between Bottomfish Complex and CREMUS. Also need to verify all shallow bottomfish are not included in CREMUS list.

Table 6. Summary of the predefined "coral reef fishery" (catch time series (for a discrete list of species – taken from CB lbs and CS lbs from the CREMUS module) from the boat and shore-based creel surveys and the commercial purchase system.

Year	Creel survey Estimates		Creel Total	Commercial Landings
	Shore-based	Boat-based		
1983				165854
1984				212854
1985				188292
1986				198720
1987				176787
1988				220751
1989				341704
1990				254769
1991				141554
1992				183223
1993				191632
1994				246520
1995				202791
1996				205948
1997				235331
1998				256244
1999				216037
2000		85709	85709	233969
2001		29727	29727	232500
2002		36213	36213	210855
2003		43517	43517	139249
2004		46719	46719	120466
2005	109476	54280	163756	174630
2006	114177	52190	166367	173946
2007	86335	72379	158714	145967
2008	88556	78417	166973	158572
2009	77295	83533	160828	124312
2010	48121	58682	106803	85127
2011	41027	57311	98338	90956
2012	38644	76740	115384	58018

Year	Creel survey Estimates		Creel Total	Commercial Landings
	Shore-based	Boat-based		
2013	158516	26007	184523	35567
2014	17892	18149	36041	45942
2015	36865	8830	45695	26986
2016	44603	24241	68844	47097
10 YEARS AVG	63785	50429	114214	81854
10 YEARS SD	38565	26877	50053	44846
20 YEARS AVG	43075	42632	85708	140589
20 YEARS SD	46621	27921	61926	73293

1.1.5.2 Expanded catch estimates by fishing methods

Catch information is provided for the top shore-based and boat-based fishing methods that contributes 99% and 84% of the annual catch, respectively.

Calculations: The creel catch time series will be the sum of the estimated weight by selected gear in all strata for all species except for trolling, which would exclude PMUS and any pelagic species complex.

Table 7. Expanded catch time series estimates using boat and shore-based creel survey data sets by gear type.

Year	Shore-based methods			Boat-based methods				
	H&L	Spear	Castnet	Bottomfish	Spear	Troll*	Atulai	Castnet
2005	130	259	50	3231	12	34575	520	2
2006	262	320	114	1802	91	29504	340	23
2007	203	74	110	2220	105	28464	482	0
2008	335	161	65	914	197	20080	263	48
2009	295	235	68	1974	113	13147	407	78
2010	105	102	93	1353	19	14592	74	13
2011	136	78	18	1521	6	10589	152	33
2012	93	40	36	2807	1	17921	128	0
2013	170	94	17	1324	53	19814	98	0
2014	55	0	9	299	16	16806	99	0
2015	27	123	10	470	81	15491	76	0
2016	25	83	10	1386	0	7449	0	0
10 YEARS AVG	144	99	44	1427	59	16435	178	17
10 YEARS SD	102	61	36	729	61	5493	149	26

1.1.5.3 Top species in the catch for the boat and shore-based fisheries

The time series for catch is an indicator of fishery performance. Fluctuations in the catch can be attributed to various factors and there is no single explanatory variable for the trends. The 10 species group in the boat and shore-based catch for the coral reef fishery make up 91% of the total annual catches.

Calculations: Catch by species complex is tallied directly from the boat-based expanded species composition data combining all gear types and species, for all strata.

The averages for the table this year were calculated from catch estimates from the entire time series for each of the CREMUS groupings. The average catch for each grouping is ranked from the highest to lowest catch. The dominant groups that make up more than 50% of the catch are reported.

Table 8. Catch time series of the 12 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the boat based creel data. The CREMUS complex comprise > 92% of the total boat based landing. (ALL BF and BMUS were deemed commercial).

Year	Boat-based (Estimated Pounds)											
	BF	**BMUS**	**Empr**	**Jacks**	**Atul**	**Grpr**	**Snap**	**Surg**	**Parrot**	**Mull**	**Sqrl**	**Rudr**
2000	132251	64413	49628	1929	967	1266	99	176	15628	653	3648	0
2001	44430	29377	10094	1170	4456	1453	69	0	3699	90	5569	13
2002	44602	23826	12989	253	613	2032	879	818	6555	979	3831	0
2003	26927	8641	4381	876	13579	935	2030	0	10958	2071	3924	265
2004	50909	13095	24576	1616	1008	1306	503	0	11215	407	2153	600
2005	63707	18312	22514	2776	0	776	47	0	17977	2128	1722	925
2006	58029	21702	21135	3339	2932	1792	340	0	9884	1969	4260	235
2007	82304	34648	34169	3999	7336	2778	4391	0	4280	5208	3948	985
2008	49414	9692	26918	2366	14039	4378	1104	0	6939	3499	5572	520
2009	95893	54840	31950	2762	20622	3910	635	0	2785	3556	7506	3189
2010	84774	43112	23141	1865	6195	1364	780	0	13134	3522	3934	0
2011	62208	28203	19737	803	7847	205	542	0	11567	1898	4016	3715
2012	159990	109894	43562	4088	14438	1147	1150	0	1676	770	974	88
2013	30669	9145	18143	1018	720	60	2	0	1723	640	955	175
2014	18528	6272	6789	0	330	697	233	0	5148	319	2136	0
2015	15826	12380	1450	34	111	277	345	0	1392	570	4218	127
2016	63406	44342	8848	121	0	0	70	0	9838	257	0	0
10 YEARS AVG	35253	66301	21471	1706	7164	1482	925	0	5848	2024	3326	880
10 YEARS SD	29745	40817	12575	1484	6870	1549	1214	0	4117	1690	2195	1324

Calculations: Catch by species complex is tallied directly from the boat-based expanded species composition data combining all gear types and species, for all strata.

The averages were for the table below was calculated from catch estimates from the entire time series for each of the CREMUS grouping. The average catch is ranked from the highest to lowest catch. The dominant groups that make up more than 60% of the catch are reported..

Table 9. Catch time series of the 11 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the shore-based creel data The CREMUS complex comprise > 91% of the total boat based landing

Year	Shore-based Estimated Pounds										
	Jacks	**Empr**	**Rabt**	**Surg**	**Goat**	**Atul**	**Parrot**	**Molsk**	**Mull**	**Wras**	**Rudr**
2005	15320	1181	62385	11678	6230	39110	19953	9511	8194	5247	18438
2006	30020	1317	45725	26864	7456	28557	7590	16234	13189	4532	28672
2007	31604	1483	61088	41781	8350	16192	10126	4838	10363	5210	10111
2008	45867	815	50748	57321	3878	40116	2233	6823	6412	7078	16039
2009	36928	7093	58414	47511	4419	21641	3264	9055	5608	3239	21732
2010	19068	804	32643	45172	2375	18723	938	3196	4077	1837	13846
2011	14813	4738	28792	33821	3020	24461	1456	5398	3547	1467	19700
2012	7987	251	48874	34309	2487	10448	5341	4566	11198	1375	3781
2013	30410	2935	29210	23233	1052	11730	555	39382	15120	4270	36083
2014	12011	1338	12299	2864	552	17526	620	3816	3172	452	6686
2015	12189	337	7709	726	749	3184	23	8134	8833	461	12447
2016	22685	2022	23659	1534	833	17252	1309	5473	6929	36	17277
10 YEARS AVG	23356	2182	28827	35344	2772	18127	2587	9068	7526	2543	15770
10 YEARS SD	11791	2082	19725	17704	2260	9297	2919	10254	3645	2217	8596

1.1.6 Catch Per Unit Effort (CPUE) Statistics

This section summarizes the estimates for catch-per-unit effort in the boat and shore-based fisheries. The boat-based fisheries include the bottomfishing (handline gear), spearfishing (snorkel), troll, atulai nets, and castnets that comprise 84% of the total catch. Trolling method are primarily a pelagic fishing method but also catches coral reef fishes like jacks and gray jobfish. The shore-based fisheries include the hook-and-line, spearfishing and cast nets comprise 99% of the total coral reef fish catch. CPUE is reported as pounds per gear-hours for the shore-based methods whereas in the boat-based methods its pound per trip.

Calculations: CPUE is calculated from interview data by gear type using ∑catch /∑ (hours fished*number of fishers) for boat based and ∑catch/∑ (hours fished*number of gears used) for shore based. If the value is blank (empty), then there was no interview collected for that method. Landings from interviews without fishing hours are excluded from the calculations.

Table 10. Catch per unit effort time series by dominant fishing methods from the shore-based fisheries.

Year	Gear CPUE (Lbs/Gear-hr)		
	H&L	**Spear**	**Castnet**
2005	0.0009	0.0654	0.0321
2006	0.0002	0.0434	0.0158

2007	0.0003	0.0705	0.034
2008	0.0002	0.0658	0.0074
2009	0.0002	0.0623	0.028
2010	0.0004	0.0567	0.1771
2011	0.0005	0.0556	0.0557
2012	0.0004	0.0465	0.1
2013	0.0009	0.1302	0.0833
2014	0.0024	0	0.15
2015	0.0016	0.1538	0.1042
2016	0.0021	0.1409	0.0526
10 YEARS AVG	0.0009	0.0782	0.0792
10 YEARS SD	0.0008	0.0457	0.0517

Table 11. Catch per unit effort time series by dominant fishing methods from the boat-based fisheries.

Year	**Boat_based Gear CPUE (Lbs/Fisher-hrs)**				
	Bottomfishing	**Spear**	**Troll**	**Atulai**	**Castnet**
2000	0.1102	2.3929	0.0837	0.1326	
2001	0.0301	1.4844	0.0588	0.1067	
2002	0.0485	3.9	0.0608	0.1079	
2003	0.0345	0.1009	0.0371	0.2284	1.4
2004	0.0307	0.0839	0.0568	0.048	
2005	0.0137	1	0.0372	0.0704	0.125
2006	0.0126	0.1071	0.0545	0.0437	1.15
2007	0.0289	0.3182	0.0726	0.0311	0
2008	0.0125	0.0533	0.0718	0.1927	0.6667
2009	0.0069	0.1495	0.0745	0.0755	5.5714
2010	0.0022	3.1667	0.1065	0.2284	1.4444
2011	0.0021	1	0.0855	0.6609	0.3929
2012	0.3558	0.25	0.1113	0.0914	
2013	0.1445	0.3155	0.0982	0.2917	
2014	0.1286	3.2	0.0926	0.5789	0
2015	0.2318	27	0.1594	0.7917	
2016	0.3818		0.0993		
10 YEARS AVG	0.1295	3.9392	0.0972	0.3269	1.3459
10 YEARS SD	0.1403	8.2388	0.0247	0.2638	1.9518

NOTE: consider “castnets” deleting because there is insufficient data available

1.1.7 Effort Statistics

This section summarizes the effort trends in the coral reef and bottomfish fishery. Fishing effort trends provide insights on the level of fishing pressure through time. Effort information is provided for the top shore-based and boat-based fishing methods that contributes 99% and 84% of the annual catch.

Calculations: Effort estimates (hours) are generated by summing the effort data collected from interviews by gear type. For the Shore-based estimates, da**ta collection started in 2005.**

Table 12. Time series of effort estimates from the coral reef and bottomfish fisheries. Shore-based fisheries are expressed in gear-hours (expanded total number of hours fishing by total number of gears used). The boat-based fisheries are expressed in number of trips for bottomfish and number of gear hours for spear, troll, atulai, and castnest). Cells marked with * indicates data is confidential due to less than 3 entities surveyed or reported

Year	Estimated Effort by Gear or Fishing Method							
	SB gear-hours				BB gear-hours			
	H&L	Spear	Castnet	Bottom	Spear	Troll	Atulai	Castnet
2000	1161	1119	1464	803	1577			
2001	993	898	1460	806	1095			
2002	1259	1287	730	851	1156			
2003	1374	1331	816	930	913	730		
2004	1319	1236	993	793	1313			
2005	1369	1342	1095	850	1007	730	43884	7058
2006	1130	1155	830	870	973	1825	49116	8448
2007	883	807	782	800	1186	1095	41127	6554
2008	1888	1843	848	723	1423	976	58569	5270
2009	3043	3224	821	671	1345	730	42908	4137
2010	6375	6727	730	660	876	1095	17505	3039
2011	6246	7581	730	758	913	730	24927	2049
2012	690	718	366	738	1281		17198	2751
2013	728	753	728	655	874		22960	2870
2014	666	751	365	603	1095	730	13601	2452
2015	678	782	365	641	730		8689	2873
2016	636	848		635			11782	3277
10 YEARS AVG	2403	2183	637	688	1080	893	25927	3527
10 YEARS SD	2498	2189	196	60	230	167	15463	1329

1.1.8 Participants

This section summarizes the estimated number of participants in each fishery type. The information presented here can be used in the impact analysis of potential amendments in the FEPs associated with the bottomfish and coral reef fisheries. The trend in the number of participants over time can also be used as an indicator for fishing pressure.

Calculations: Estimated number of participants is calculated by using and average number of fishers out fishing per day multiplied by the numbers of dates in the calendar year by gear type. The total is a combination of weekend and weekday stratum estimates.

Table 13. Number of fishermen participating in the bottomfish fishery and number of gear in the boat and shore-based coral reef fishery. Cells marked with * indicates data is confidential due to less than 3 entities surveyed or reported.

	Bottomfish		Coral Reef BB				Coral Reef SB Fishery		
Year	No. of fishers	No. of Gears	Spear	Troll	Atulai	Castnet	H&L	Spear	Castnet
2000	1161	1119	1464	803	1577				
2001	993	898	1460	806	1095				
2002	1259	1287	730	851	1156				
2003	1374	1331	816	930	913	730			
2004	1319	1236	993	793	1313				
2005	1369	1342	1095	850	1007	730	43884	7058	4798
2006	1130	1155	830	870	973	1825	49116	8448	5251
2007	883	807	782	800	1186	1095	41127	6554	3521
2008	1888	1843	848	723	1423	976	58569	5270	4547
2009	3043	3224	821	671	1345	730	42908	4137	2771
2010	6375	6727	730	660	876	1095	17505	3039	2145
2011	6246	7581	730	758	913	730	24927	2049	3134
2012	690	718	366	738	1281		17198	2751	2075
2013	728	753	728	655	874		22960	2870	2728
2014	666	751	365	603	1095	730	13601	2452	1656
2015	678	782	365	641	730		8689	2873	848
2016	636	848		635			11782	3277	1551
10 YEARS AVG	2403	2183	637	688	1080	893	25927	3527	2498
10 YEARS SD	2498	2189	196	60	230	167	15463	1329	1020

1.1.9 Bycatch estimates

This section focuses on MSA § 303(a)(11), which requires that all FMPs establish a standardized reporting methodology to assess the amount and type of bycatch occurring in the fishery, and include conservation and management measures that, to the extent practicable, minimize bycatch and bycatch mortality. The MSA § 303(a)(11) standardized reporting methodology is commonly referred to as a ‘‘Standardized Bycatch Reporting Methodology’’ (SBRM) and was added to the MSA by the Sustainable Fisheries Act of 1996 (SFA). The Council implemented omnibus amendments to FMPs in 2003 to address MSA bycatch provisions and established SBRMs at that time.

Calculations:
Numbers caught = Sum of the total number of fish or invertebrates found in the raw interview (catch) data, including bycatch.
Numbers kept = Sum of the total number of fish or invertebrates in the raw data that are not marked as bycatch.

Numbers released = caught - kept

% Bycatch = Sum of all bycatch divided by the total catch.

Table 14. Time series of bycatch estimates in the non-bottomfishing boat-based fisheries. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery.

Year	Bycatch from boat-based non-bottomfishing gear type			
	Numbers caught	**Kept**	**Released**	**% bycatch**
2000	3086	3089	3	0.001
2001	5731	5732	1	0.0002
2002	4885	4885	0	0
2003	8785	8785	0	0
2004	5717	5717	0	0
2005	6772	6772	0	0
2006	6759	6761	2	0.0003
2007	6683	6683	0	0
2008	4463	4463	0	0
2009	3792	3792	0	0
2010	3462	3462	0	0
2011	2515	2515	0	0
2012	3963	3963	0	0
2013	3732	3732	0	0
2014	2592	2592	0	0
2015	2693	2693	0	0
2016	1638	1638	0	0
10 YEARS AVG	3553	3553	0	0
10 YEARS SD	1315	1315	0	0

Table 15. Time series bycatch estimates in the bottomfish fishery. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery.

Year	Bycatch from boat-based bottomfishing gear type			
	Numbers caught	**Kept**	**Released**	**% bycatch**
2000	818	797	21	0.0257
2001	931	930	1	0.0011
2002	904	890	14	0.0155
2003	877	841	36	0.041
2004	1379	1359	20	0.0145
2005	3225	3221	4	0.0012
2006	1845	1842	3	0.0016
2007	2110	2110	0	0
2008	1158	1158	0	0
2009	1779	1779	0	0
2010	1474	1474	0	0
2011	1734	1734	0	0
2012	782	782	0	0
2013	857	857	0	0
2014	216	216	0	0
2015	196	196	0	0
2016	713	713	0	0
10 YEARS AVG	1102	1102	0	0
10 YEARS SD	627	627	0	0

Table 16. Time series of bycatch estimates in the shore-based fishery with all gears combined. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery.

Year	Bycatch from shore-based (all gears combined)			
	Numbers caught	**Kept**	**Released**	**% bycatch**
2005	3170	3104	66	0.0208
2006	6015	5987	28	0.0047
2007	2670	2660	10	0.0037
2008	7142	7135	7	0.001
2009	4412	4411	1	0.0002
2010	1839	1839	0	0
2011	2601	2601	0	0
2012	1466	1465	1	0.0007

2013	2007	2001	6	0.003
2014	548	548	0	0
2015	687	687	0	0
2016	712	712	0	0
10 YEARS AVG	2408	2406	3	0.0009
10 YEARS SD	1929	1927	4	0.0013

1.1.10 Number of federal permit holders

In CNMI, the following Federal permits are required for fishing in the EEZ under the Mariana FEP:

1.1.1.1 Northern Mariana Island Bottomfish Permit

This permit is required for any vessel commercially fishing for, landing, or transshipping bottomfish management unit species in the EEZ around the Commonwealth of the Northern Mariana Islands (CNMI). The permit expires one year after the date of issuance.
CNMI bottomfish fishing vessels 40 feet or longer in overall length are required to carry and operate a NMFS owned and installed vessel monitoring system (VMS) unit. Vessel operators must submit a logbook to NMFS within 72 hours after landing. Vessel owners must mark their vessels according to CNMI or Federal regulations. Medium vessels (40 feet or longer and less than 50 feet in overall length) and large vessels (50 feet or longer in overall length) are prohibited from bottomfishing in the CNMI medium and large vessel bottomfish prohibited areas. Commercial fishing is also prohibited within the boundaries of the Islands Unit of the Marianas Trench Marine National Monument.

1.1.1.2 Special Coral Reef Ecosystem Permit

The coral reef ecosystem special permit is required for anyone fishing for coral reef ecosystem management unit species in a low-use MPA, fishing for species on the list of Potentially Harvested Coral Reef Taxa, or using fishing gear not specifically allowed in the regulations. The permit expires one year after the date of issuance. Permit holder must submit a logbook to NMFS within 30 days of each landing of coral reef harvest.

A transshipment permit is required for any receiving vessel used to land or transship potentially harvested coral reef taxa, or any coral reef ecosystem management unit species caught in a low-use MPA. Exceptions to this permit requirement are made for anyone issued a permit to fish under the other western Pacific fishery management plans (pelagic, bottomfish and seamount groundfish, crustacean, or precious corals) who catch coral reef management unit species incidentally while fishing for the management unit species covered by the permit they possess. Permit holders must submit a logbook to NMFS within 7 days following the date the vessel arrived in port to land transshipped fish. Regulations governing this fishery can be found in the Code of Federal Regulations, Title 50, Part 665.

1.1.1.3 Western Pacific Precious Corals Permit

This permit is required for anyone harvesting or landing black, bamboo, pink, red, or gold corals in the EEZ in the western Pacific. The permit expires one year from the date of issuance. Permit holders must submit a logbook to NMFS within 72 hours of landing. Specific conditions are associated with various established, provisional, and exploratory areas throughout the region.

1.1.1.4 Western Pacific Crustaceans Permit (Lobster or Deepwater Shrimp)

A permit is required by the owner of a U.S. fishing vessel used to fish for lobster or deepwater shrimp in the EEZ around American Samoa, Guam, Hawaii, and the Pacific Remote Islands Areas, and in the EEZ seaward of 3 nautical miles of the shoreline of the Northern Mariana Islands. The permit expires one year after the date of issuance. Permit holders must submit a logbook to NMFS within 72 hours of landing (except when fishing in the Pacific Remote Island Areas – those reports are due within 30 days).

There is no record of special coral reef or precious coral fishery permits issued for the EEZ around Northern Mariana Islands since 2007. Table 17 provides the number of permits issued for Commonwealth of the Northern Mariana Islands fisheries between 2007 and 2017. Historical data are from the PIFSC accessed on February 9, 2017 and 2017 data are from the PIRO Sustainable Fisheries Division permits program as of February 3, 2017.

Table 17. Number of federal permits holders between 2007 and 2017 for the crustacean and bottomfish fisheries of the Commonwealth of the Northern Mariana Islands

CNMI Fisheries	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Lobster	1	6*	*4							1**	
Shrimp				2*	*1					1	
Bottomfish			2	13	10	13	5	6	7	17	20

* Permits apply to multiple areas and may include American Samoa, Guam, CNMI, and PRIA.

**Area 5 CNMI and Guam

1.1.11 Status Determination Criteria

1.1.11.1 Bottomfish Fishery

Overfishing criteria and control rules are specified and applied to individual species within the multi-species stock whenever possible. When this is not possible, they are based on an indicator species for the multi-species stock. It is important to recognize that individual species would be affected differently based on this type of control rule, and it is important that for any given species fishing, mortality does not currently exceed a level that would result in excessive depletion of that species. No indicator species are being used for the bottomfish multi-species stock complexes and the coral reef species complex. Instead, the control rules are applied to each stock complex as a whole.

The MSY control rule is used as the maximum fishing mortality threshold (MFMT). The MFMT and minimum stock size threshold (MSST) are specified based on recommendations in Restrepo et al. (1998) and both are dependent on the natural mortality rate (M). The value of M used to determine the reference point values are not specified in this document. The latest estimate, published annually in the SAFE report, is used and the value is occasionally re-estimated using the best available information. The range of M among species within a stock complex is taken into consideration when estimating and choosing the M to be used for the purpose of computing the reference point values.

In addition to the thresholds MFMT and MSST, a warning reference point, B_{FLAG}, is specified at some point above the MSST to provide a trigger for consideration of management action prior to B reaching the threshold. MFMT, MSST, and B_{FLAG} are specified as indicated in Table 18.

Table 18. Overfishing threshold specifications for the bottomfish management unit species in CNMI

MFMT	MSST	B_{FLAG}
$F(B) = \frac{F_{MSY} B}{c\, B_{MSY}}$ for $B \le c\, B_{MSY}$ $F(B) = F_{MSY}$ for $B > c\, B_{MSY}$	$c\, B_{MSY}$	B_{MSY}
where c = max (1-M, 0.5)		

Standardized values of fishing effort (E) and catch-per-unit-effort (CPUE) are used as proxies for F and B, respectively, so E_{MSY}, $CPUE_{MSY}$, and $CPUE_{FLAG}$ are used as proxies for F_{MSY}, B_{MSY}, and B_{FLAG}, respectively.

In cases where reliable estimates of $CPUE_{MSY}$ and E_{MSY} are not available, they will be estimated from catch and effort times series, standardized for all identifiable biases. $CPUE_{MSY}$ would be calculated as half of a multi-year average reference CPUE, called $CPUE_{REF}$. The multi-year reference window would be objectively positioned in time to maximize the value of $CPUE_{REF}$. E_{MSY} would be calculated using the same approach or, following Restrepo et al. (1998), by setting E_{MSY} equal to E_{AVE}, where E_{AVE} represents the long-term average effort prior to declines in CPUE. When multiple estimates are available, the more precautionary one is used.

Since the MSY control rule specified here applies to multi-species stock complexes, it is important to ensure that no particular species within the complex has a mortality rate that leads to excessive depletion. In order to accomplish this, a secondary set of reference points is specified to evaluate stock status with respect to recruitment overfishing. A secondary "recruitment overfishing" control rule is specified to control fishing mortality with respect to that status. The rule applies only to those component stocks (species) for which adequate data are available. The ratio of a current spawning stock biomass proxy ($SSBP_{Pt}$) to a given reference level ($SSBP_{PREF}$) is used to determine if individual stocks are experiencing recruitment overfishing. SSBP is CPUE scaled by percent mature fish in the catch. When the ratio $SSBP_{Pt}/SSBP_{PREF}$, or the "SSBP ratio" (SSBPR) for any species drops below a certain limit ($SSBPR_{MIN}$), that species is considered to be recruitment overfished and management measures will be implemented to reduce fishing mortality on that species. The rule applies only when the SSBP ratio drops below the $SSBPR_{MIN}$, but it will continue to apply until the ratio achieves the "SSBP ratio recovery target"

($SSBPR_{TARGET}$), which is set at a level no less than SSB_{PRMIN}. These two reference points and their associated recruitment overfishing control rule, which prescribe a target fishing mortality rate ($F_{RO-REBUILD}$) as a function of the SSBP ratio, are specified as indicated in Table 19. Again, E_{MSY} is used as a proxy for F_{MSY}.

Table 19. Rebuilding control rules for the bottomfish management unit species in CNMI

$F_{RO-REBUILD}$	$SSBPR_{MIN}$	$SSBPR_{TARGET}$
$F(SSBPR) = 0$ for $SSBPR \leq 0.10$ $F(SSBPR) = 0.2\,F_{MSY}$ for $0.10 < SSBPR \leq SSBPR_{MIN}$ $F(SSBPR) = 0.5\,F_{MSY}$ for $SSBPR_{MIN} < SSBPR \leq SSBPR_{TARGET}$	0.20	0.30

1.1.11.2 Coral Reef Fishery

Available biological and fishery data are poor for all coral reef ecosystem management unit species in the Mariana Islands. There is scant information on the life histories, ecosystem dynamics, fishery impact, community structure changes, yield potential, and management reference points for many coral reef ecosystem species. Additionally, total fishing effort cannot be adequately partitioned between the various management unit species (MUS) for any fishery or area. Biomass, maximum sustainable yield, and fishing mortality estimates are not available for any single MUS. Once these data are available, fishery managers can establish limits and reference points based on the multi-species coral reef ecosystem as a whole.

When possible, the MSY control rule should be applied to the individual species in a multi-species stock. When this is not possible, MSY may be specified for one or more species; these values can then be used as indicators for the multi-species stock's MSY.

Individual species that are part of a multi-species complex will respond differently to an OY-determined level of fishing effort (F_{OY}). Thus, for a species complex that is fished at F_{OY}, managers still must track individual species' mortality rates in order to prevent species-specific population declines that would lead to depletion.

For the coral reef fishery, the multi-species complex as a whole is used to establish limits and reference points for each area. When possible, available data for a particular species are used to evaluate the status of individual MUS stocks in order to prevent recruitment overfishing. When better data and the appropriate multi-species stock assessment methodologies become available, all stocks will be evaluated independently, without proxy.

Establishing Reference Point Values

Standardized values of catch per unit effort (CPUE) and effort (E) are used to establish limit and reference point values, which act as proxies for relative biomass and fishing mortality, respectively. Limits and reference points are calculated in terms of $CPUE_{MSY}$ and E_{MSY} included in Table 20.

Table 20. Status determination criteria for the coral reef management unit species using CPUE based proxies

Value	Proxy	Explanation
MaxFMT (F_{MSY})	E_{MSY}	0.91 $CPUE_{MSY}$
F_{OY}	0.75 E_{MSY}	suggested default scaling for target
B_{MSY}	$CPUE_{MSY}$	operational counterpart
B_{OY}	1.3 $CPUE_{MSY}$	simulation results from Mace (1994)
MinSST	0.7 $CPUE_{MSY}$	suggested default (1-M)B_{MSY} with M=0.3*
B_{FLAG}	0.91 $CPUE_{MSY}$	suggested default (1-M)B_{OY} with M=0.3*

When reliable estimates of E_{MSY} and $CPUE_{MSY}$ are not available, they are generated from time series of catch and effort values, standardized for all identifiable biases using the best available analytical tools. $CPUE_{MSY}$ is calculated as one-half a multi-year moving average reference CPUE ($CPUE_{REF}$).

1.1.11.3 Current Stock Status

1.1.11.3.1 Bottomfish

Biological and other fishery data are poor for all bottomfish species in the Mariana Archipelago. Generally, data are only available on commercial landings by species and catch-per-unit-effort (CPUE) for the multi-species complexes as a whole. At this time it is not possible to partition these effort measures among the various bottomfish MUS. The most recent stock assessment update (Yau et al. 2015) for the CNMI bottomfish management unit species complex (comprised of 17 species of shallow and deep species of snapper, grouper, jacks, and emperors) was based on estimate of total catch, an abundance index derived from the nominal CPUE generated from the creel surveys, and a fishery independent point estimate of MSY from the Our Living Oceans Report (Humphreys and Moffitt 1999, Moffitt & Humphreys 2009). The assessment utilized a state-space surplus production model with explicit process and observation error terms (Meyer and Millar 1999). Determinations of overfishing and overfished status can then be made by comparing current biomass and harvest rates to MSY level reference points. To date, the CNMI BMUS is not subject to overfishing and is not overfished (Table 21).

Table 21. Stock assessment parameters for the CNMI BMUS complex (Yau et al 2015)

Parameter	Value	Notes	Status
MSY	173.1 ± 32.19	Expressed in 1000 lbs (± std error)	
H_{2013}	0.022	Expressed in percentage	
H_{MSY}	0.261 ± 0.063	Expressed in percentage (± std error)	
H/H_{MSY}	0.088		No overfishing occurring
B_{2013}	1,262	Expressed in thousand pounds	
B_{MSY}	683.5 ± 126.7	Expressed in 1000 lbs (± std error)	
B/ B_{MSY}	1.85		Not overfished

1.1.11.3.2 Coral reef

The application of the SDCs for the management unit species in the coral reef fisheries is limited due to various challenges. First, the thousands of species included in the coral reef MUS makes the SDC and status determination impractical. Second, the CPUE derived from the creel survey is based on the fishing method and there is no species-specific CPUE information available. In order to allocate the fishing method level CPUE to individual species, the catch data (the value of catch is derived from CPUE hence there is collinearity) will have to be identified to species level and CPUE will be parsed out by species composition. The third challenge is that there is very little species level identification applied to the creel surveys. There has been no attempt to estimate MSY for the coral reef MUS until the 2007 re-authorization of MSA that requires the Council to specify ACLs for species in the FEPs.

For ACL specification purposes, MSYs in the coral reef fisheries are determined by using the Biomass-Augmented Catch-MSY approach (Sabater and Kleiber 2014). This method estimates MSY using plausible combination rates of population increase (denoted by r) and carrying capacity (denoted by k) assumed from the catch time series, resilience characteristics (from FishBase), and biomass from existing underwater census surveys done by the Pacific Island Fisheries Science Center. This method was applied to species complexes grouped by taxonomic families. The most recent MSY estimates are found in Table 22. The SSC utilized the MSYs for the coral reef MUS complexes as the OFLs.

Table 22. Best available MSY estimates for the coral reef MUS in CNMI

Coral Reef MUS Complex	MSY (lbs)
Selar crumenophthalmus – atulai or bigeye scad	122,500
Acanthuridae – surgeonfish	361,200
Carangidae – jacks	55,300
Crustaceans – crabs	9,100
Holocentridae – squirrelfish	78,500
Kyphosidae – chubs/rudderfish	29,500
Labridae – wrasses[1]	73,500
Lethrinidae – emperors	69,700
Lutjanidae – snappers	225,800
Mollusks – turbo snail; octopus; giant clams	16,700
Mugilidae – mullets	7,700
Mullidae – goatfish	31,000
Scaridae – parrotfish[2]	189,900
Serranidae – groupers	110,300
Siganidae – rabbitfish	12,000
All Other CREMUS Combined - Other CRE-finfish - Other invertebrates - Misc. bottomfish - Misc. reef fish - Misc. shallow bottomfish	14,500
Cheilinus undulatus – humphead (Napoleon) wrasse	N.A.

Coral Reef MUS Complex	MSY (lbs)
Bolbometopon muricatum – bumphead parrotfish	N.A.
Carcharhinidae – reef sharks	N.A.

1.1.12 Overfishing Limit, Acceptable Biological Catch, and Annual Catch Limits

1.1.12.1 Brief description of the ACL process

The Council developed a Tiered system of control rules to guide the specification of ACLs and Accountability Measures (AMs) (WPRFMC 2011). The process starts with the use of the best scientific information available (BSIA) in the form of, but not limited to, stock assessments, published paper, reports, or available data. These information are classified to the different Tiers in the control rule ranging from Tier 1 (most information available typically an assessment) to Tier 5 (catch-only information). The control rules are applied to the BSIA. Tiers 1 to 3 would involve conducting a Risk of Overfishing Analysis (denoted by P*) to quantify the scientific uncertainties around the assessment to specify the Acceptable Biological Catch (ABC). This would lower the ABC from the OFL (MSY-based). A Social, Ecological, Economic, and Management (SEEM) Uncertainty Analysis is performed to quantify the uncertainties from the SEEM factors. The buffer is used to lower the ACL from the ABC. For Tier 4 which are stocks with MSY estimates but no active fisheries, the control rule is 91% of MSY. For Tier 5 which has catch only information, the control rule is a third reduction in the median catch depending on the qualitative evaluation on what the stock status is based on expert opinion. ACL specification can choose from a variety of method including the above mentioned SEEM analysis or a percentage buffer (% reduction from ABC based on expert opinion) or the use of an Annual Catch Target. Specifications are done on an annual basis but the Council normally specifies a multi-year specification.

The Accountability Measure for the coral reef and bottomfish fisheries in CNMI is an overage adjustment. The ACL is downward adjusted with the amount of overage from the ACL based on a three year running average.

1.1.12.2 Current OFL, ABC, ACL, and recent catch

The most recent multiyear specification of OFL, ABC, and ACL for the coral reef fishery was completed in the 160th Council meeting on June 25 to 27, 2014. The specification covers fishing year 2015, 2016, 2017, and 2018 for the coral reef MUS complexes. A P* and SEEM analysis was performed for this multiyear specification (NMFS 2015). For the bottomfish, it was a roll over from the previous specification since an assessment update was not available for fishing year 2015.

Table 23. Mariana Archipelago – CNMI ACL table with 2016 catch (values are in pounds)

Fishery	MUS	OFL	ABC	ACL	Catch
Bottomfish	Bottomfish multi-species complex	293,000	228,000	228,000	23,753
Crustacean	Deepwater shrimp	N.A.	275,570	275,570	NAF
	Spiny lobster	9,600	7,800	7,410	2,065
	Slipper lobster	N.A.	60	60	304
	Kona crab	N.A.	6,300	6,300	NAF
Precious coral	Black coral	8,250	2,100	2,100	NAF
	Precious coral in CNMI expl. area	N.A.	2,205	2,205	NAF

Coral Reef	*Selar crumenophthalmus*	122,500	89,400	77,400	290
	Acanthuridae-surgeonfish	361,200	324,600	302,600	3,564
	Carangidae-jacks	55,300	47,400	44,900	7,686
	Crustaceans-crabs	9,100	5,300	4,400	ND
	Holocentridae-squirrelfish	78,500	69,300	66,100	335
	Kyphosidae-rudderfish	29,500	24,600	22,700	513
	Labridae-wrasse	73,500	59,900	55,100	179
	Lethrinidae-emperors	69,700	58,200	53,700	7,757
	Lutjanidae-snappers	225,800	202,700	190,400	646
	Mollusk-turbo snails; octopus; clams	16,700	11,600	9,800	ND
	Mugilidae-mullets	7,700	5,300	4,500	298
	Mullidae-goatfish	31,000	29,200	28,400	1,089
	Scaridae-parrotfish	189,900	157,300	144,000	1,673
	Serranidae-groupers	110,300	92,800	86,900	284
	Siganidae-rabbitfish	12,000	10,400	10,200	1,858
	All other CREMUS combined	14,500	8,500	7,300	898
	Cheilinus undulatus	N.A.	2,009	2,009	69
	Bolbometopon muricatum	N.A.	797	797*	ND
	Carcharhinidae-reef sharks	N.A.	5,600	5,600	ND

NOTE: *The ACL for *B. muricatum* is shared with Guam (1 ACL for the whole archipelago)

The catch shown in Table 23 takes the average of the recent three years as recommended by the Council at its 160th meeting to avoid large fluctuations in catch due to data quality and outliers. NAF indicates no active fisheries as of date.

1.1.13 Best scientific information available

1.1.13.1 Bottomfish fishery

1.1.13.1.1 Stock assessment benchmark

The benchmark stock assessment for the Territory Bottomfish Management Unit Species complex was developed and finalized in October 2007 (Moffitt et al. 2007). This benchmark utilized a Bayesian statistical framework to estimate parameters of a Schaefer model fit to a time series of annual CPUE statistics. The surplus production model included process error in biomass production dynamics and observation error in the CPUE data. This was an improvement to the previous approach of using index-based proxies for B_{MSY} and F_{MSY}. Best available information for the bottomfish stock assessment is as follows:

Input data: The CPUE and catch data used were from the Guam off-shore creel survey. The catch and CPUE were expanded on annual level. CPUE was expressed in line-hours. The data was screened for trips that landed more than 50% BMUS species using the handline gear.

Model: state-space model with explicit process and observation error terms (see Meyer and Millar, 1999).

Fishery independent source for biomass: point estimate of MSY from the Our Living Oceans Report (Humphreys and Moffitt 1999, Moffitt & Humphreys 2009)

1.1.13.1.2 Stock assessment updates

Updates to the 2007 benchmark done in 2012 (Brodziak et al. 2012) and 2015 (Yau et al. 2015). These included a 2-year stock projection table used for selecting the level of risk the fishery will be managed under ACLs. Yau et al. (2015) is considered the best scientific information available for the Territory bottomfish MUS complex after undergoing a WPSAR Tier 3 panel review (Franklin et al. 2015). This was the basis for the P* analysis and SEEM analysis the determined the risk levels to specify ABCs and ACLs.

1.1.13.1.3 Other information available

Approximately every five years PIFSC administers a socioeconomic survey to small boat fishermen in CNMI. This survey consists of about 60 questions regarding a variety of topics, including fishing experiences, market participation, vessels and gear, demographics and household income, and fishermen perspectives. The survey requests participants to identify which MUS they primarily targeted during the previous 12 months, by percentage of trips. Full reports of these surveys can be found at the PIFSC Socioeconomics webpage (Hospital and Beavers 2011)

1.1.13.2 Coral reef fishery

1.1.13.2.1 Stock assessment benchmark

No stock assessment has been generated for the coral reef fisheries. The SDCs using index-based proxies were tested for its applicability in the different MUS in the coral reef fisheries (Hawhee 2007). This analysis was done on a gear level. It paints a dire situation for the shore-based fishery with 43% of the gear/species combination fell below B_{flag} and 33% below MSST with most catch and CPUE trends showing a decline over time. The off-shore fisheries were shown to be less dire with 50% of the gear/species combination fell below B_{flag} and 38% below MSST but the catch and CPUE trends were increasing over time. The inconsistency in the CPUE and catch trends with the SDC results makes this type of assessment to be unreliable.

The first attempt to use a model based approach in assessing the coral reef MUS complexes was done in 2014 using a biomass-based population dynamics model (Sabater and Kleiber 2014). This model was based on the original Martell and Froese (2012) model but was augmented with biomass information to relax the assumption behind carrying capacity. It estimates MSY based on a range of rate of population growth (r) and carrying capacity (K) values. The best available information for the coral reef stock assessment is as follows:

Input data: The catch data was derived from the inshore and off-shore creel surveys. Commercial receipt book information was also used in combination of the creel data. A downward adjustment was done to address for potential overlap due to double reporting.

Model: Biomass Augmented Catch MSY approach based on the original catch-MSY model (Martell and Froese 2012; Sabater and Kleiber 2014).

Fishery independent source for biomass: biomass density from the Rapid Assessment and Monitoring Program of NMFS-CRED was expanded to the hard bottom habitat from 0-30 m (Williams 2010).

This model had undergone a CIE review in 2014 (Cook 2014; Haddon 2014; Jones 2014). This was the basis for the P* analysis that determined the risk levels to specify ABCs

1.1.13.2.2 Stock assessment updates

No updates available for the coral reef MUS complex. However, NMFS-PIFSC is finalizing a length-based model for estimating sustainable yield levels and various biological reference points (Nadon et al. 2015). This can be used on a species level. The Council is also working with a contractor to enhance the BAC-MSY model to incorporate catch, biomass, CPUE, effort, length-based information in an integrated framework (Martell 2015)

1.1.13.2.3 Other information available

Approximately every five years PIFSC administers a socioeconomic survey to small boat fishermen in CNMI. This survey consists of about 60 questions regarding a variety of topics, including fishing experiences, market participation, vessels and gear, demographics and household income, and fishermen perspectives. The survey requests participants to identify which MUS they primarily targeted during the previous 12 months, by percentage of trips. Full reports of these surveys can be found at the PIFSC Socioeconomics webpage (Hospital and Beavers 2011).

PIFSC and the Council conducted a workshop with various stakeholders in CNMI to identify factors and quantify uncertainties associated with the social, economic, ecological, and management of the coral reef fisheries (Sievanen and McCaskey 2014). This was the basis for the SEEM analysis that determined the risk levels to specify ACLs.

1.1.14 Harvest capacity and extent

The MSA defines the term “optimum,” with respect to the yield from a fishery, as the amount of fish which:

- will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems.
- is prescribed on the basis of the MSY from the fishery, as reduced by any relevant social, economic, or ecological factor.
- in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the MSY in such fishery [50 CFR §600.310(f)(1)(i)].

Optimum yield in the coral reef and bottomfish fisheries is prescribed based on the MSY from the stock assessment and the best available scientific information. In the process of specifying ACLs, social, economic, and ecological factors were considered and the uncertainties around those factors defined the management uncertainty buffer between the ABC and ACL. OY for the bottomfish and coral reef fish MUS complexes is defined to be the level of harvest equal to the ACL consistent with the goals and objectives of the Fishery Ecosystem Plans and used by the Council to manage the stock.

The Council recognizes that MSY and OY are long term values whereas the ACLs are yearly snapshots based on the level of fishing mortality at F_{MSY}. There are situations when the long-term means around MSY are going to be lower than ACLs especially if the stock is known to be productive or relatively pristine or lightly fished. One can have catch levels and catch rates exceeding that of MSY over short-term enough to lower the biomass to a level around the estimated MSY and still not jeopardize the stock. In this situation is true for the territory bottomfish multi-species complex.

The harvest extent, in this case, is defined as the level of catch harvested in a fishing year relative to the ACL or OY. The harvest capacity is the level of catch remaining in the annual catch limit that can potentially be used for the total allowable level of foreign fishing (TALFF). Table 24 summarizes the harvest extent and harvest capacity information for CNMI in 2016.

Table 24. Mariana Archipelago – CNMI proportion of harvest extent (values are in percentage), defined as the proportion of fishing year landing relative to the ACL or OY, and the harvest capacity, defined as the remaining portion of the ACL or OY that can potentially be harvested in a given fishing year.

Fishery	MUS	ACL	Catch	Harvest extent (%)	Harvest capacity (%)
Bottomfish	Bottomfish multi-species complex	228,000	23,753	10.4	89.6
Crustacean	Deepwater shrimp	275,570	NAF	0.0	100.0
	Spiny lobster	7,410	688	9.3	90.7
	Slipper lobster	60	101	168.9	-68.9
	Kona crab	6,300	NAF	0.0	100.0
Precious coral	Black coral	2,100	NAF	0.0	100.0
	Precious coral in CNMI expl. area	2,205	NAF	0.0	100.0
Coral Reef	*Selar crumenophthalmus*	77,400	193	0.2	99.8
	Acanthuridae-surgeonfish	302,600	3,564	1.2	98.8
	Carangidae-jacks	44,900	7,686	17.1	82.9
	Crustaceans-crabs	4,400	ND		100.0
	Holocentridae-squirrelfish	66,100	335	0.5	99.5
	Kyphosidae-rudderfish	22,700	342	1.5	98.5
	Labridae-wrasse	55,100	119	0.2	99.8
	Lethrinidae-emperors	53,700	7,757	14.4	85.6
	Lutjanidae-snappers	190,400	646	0.3	99.7
	Mollusk-turbo snails; octopus; clams	9,800	ND	ND	ND
	Mugilidae-mullets	4,500	298	6.6	93.4
	Mullidae-goatfish	28,400	1,089	3.8	96.2
	Scaridae-parrotfish	144,000	1,673	1.2	98.8
	Serranidae-groupers	86,900	284	0.3	99.7
	Siganidae-rabbitfish	10,200	1,858	18.2	81.8
	All other CREMUS combined	7,300	898	12.3	87.7
	Cheilinus undulatus	2,009	23	1.1	98.9
	Bolbometopon muricatum	797	ND	ND	ND
	Carcharhinidae-reef sharks	5,600	ND	ND	ND

1.1.15 Administrative and Regulatory Actions

This summary describes management actions PIRO has taken since the April 2016 Joint FEP Plan Team meeting, as reported to the 166rd to 168th Western Pacific Fishery Management Council meetings held June 2016, October 2016, and March 2017.

September 7, 2016. Final rule. This final rule **removes the medium and large vessel bottomfish prohibited fishing areas in the Commonwealth of the Northern Mariana Islands** (CNMI). Conditions in the fishery that led to establishing the prohibited areas are no longer present, and the restriction is no longer necessary. This rule also makes administrative housekeeping changes to the description of the CNMI management subarea and to the regulations for the CNMI management subarea for crustacean fishing. The intent of this final rule is to improve the viability of the CNMI bottomfish fishery and promote optimum yield while preventing overfishing. This final rule is effective on October 7, 2016.

January 18, 2017 (82 FR 5517). **Pacific Island 2016 Annual Catch Limits and Accountability Measures**. NMFS proposed annual catch limits (ACLs) for Pacific Island bottomfish, crustacean, precious coral, and coral reef ecosystem fisheries, and accountability measures (AMs) to correct or mitigate any overages of catch limits. The proposed ACLs and AMs would be effective for fishing year 2016. The fishing year for each fishery begins on January 1 and ends on December 31, except for precious coral fisheries, which begin July 1 and end on June 30 the following year. Although the 2016 fishing year has ended for most stocks, NMFS evaluates 2016 catches against the 2016 ACLs when data become available in mid-2017. The proposed ACLs and AMs support the long-term sustainability of fishery resources of the U.S. Pacific Islands. The comment period ended February 2, 2017.

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1.2 GUAM FISHERY DESCRIPTIONS

1.2.1 Bottomfish Fishery

Bottomfishing on Guam is a combination of recreational, subsistence, and small-scale commercial fishing. It can be separated into two distinct fisheries separated by depth and species composition. The shallow water complex (<500 feet) makes up the largest portion of the total bottomfish effort and harvest and is comprised primarily of reef-dwelling snappers of the genera *Lutjanus*, *Aphareus*, and *Aprion*, groupers of the genera *Epinephelus*, *Variola*, and *Cephalopholis*, jacks of the genera *Caranx* and *Carangoides*, *Holocentrids* (*Myripristis* spp. and *Sargocentron* spp.), emperors of the genera *Lethrinus*, and *Gymnocranius*, and Dogtooth Tuna (*Gymnosarda unicolor*). The deep water complex (>500 feet) consists primarily of groupers of the genera *Hyporthodus* and *Cephalopholis*, jacks of the genera *Caranx* and *Seriola*, and snappers of the genera *Pristipomoides*, *Etelis*, and *Aphareus*. In recent years, deep water species have made up a significant portion of the expanded bottomfishing catch.

The majority of people in this fishery are either subsistence or part-time commercial, operate boats less than 25 feet in length, target primarily the shallow water bottomfish complex It is not uncommon to intercept fishermen combining bottomfishing with other methods such as trolling, spearing, and jigging to maximize their catch. The high demand for reef fish and bottomfish has made it profitable to sell locally caught bottomfish, although overhead costs such as fuel and gear may be significant factors for in determining a fisherman's selection of fishing method. The demand for local bottomfish, when combined with environmental pressures, however, may be stressing local bottomfish stocks.

The majority of bottom fishing around Guam takes place on offshore banks. Virtually no information exists on the condition of the reefs on offshore banks. On the basis of anecdotal information, most of the offshore banks are in good condition because of their isolation. According to Myers (1997), less than 20 percent of the total coral reef resources harvested in

Guam are taken from the EEZ, primarily because they are associated with less accessible offshore banks. Finfish make up most of the catch in the EEZ. Most offshore banks are deep, remote and subject to strong currents. Generally, these banks are only accessible during calm weather in the summer months (May to August/September). Galvez Bank is the closest and most accessible and, consequently, fished most often. In contrast, the other banks (White Tuna, Santa Rose, Rota) are remote and are generally fished only during exceptionally good weather conditions (Green 1997). Local fishermen report that up to ten commercial boats, with two to three people per boat, and some recreational boats, use the banks when the weather is good (Green 1997).

At present, the banks are fished using two methods: bottomfishing by hook and line and jigging at night for bigeye scad (*Selar crumenophthalmus*; Myers 1997). In recent years, the estimated annual catch in these fisheries has ranged from 14 to 22 metric tons of shallow bottomfish and 3 to 11 metric tons of bigeye scad (Green 1997). The shallow-water component accounted for almost 68 percent (35,002 to 65,162 lbs.) of the aggregate bottomfish landings in fiscal year 1992–94 (Myers 1997). Catch composition of the shallow-bottomfish complex (or coral reef species) is dominated by lethrinids, with a single species (*Lethrinus rubrioperculatus*) alone accounting for 36 percent of the total catch. Other important components of the bottomfish catch include lutjanids, carangids, serranids, and sharks. Holocentrids, mullids, labrids, scombrids, and balistids are minor components. It should be noted that at least two of these species (*Aprion virescens* and *Caranx lugubris*) also range into deeper water and some of the catch of these species occurs in the deepwater fishery.

Species commonly taken in the shallow bottom fishery of Guam:

Aphareus furca
Aprion virescens
Lutjanus kasmira, *L. fulvus*
Carangoides orthogrammus
Caranx lugubris, *C. melampygus*, *C. ignobilis*
Selar crumenophthalmus
Cephalopholis argus, *C. spiloparaea*, *C. urodeta*
Epinephelus fasciatus
Gymnocranius spp.
Lethrinus atkinsoni, *L. erythracanthus, L. olivaceus*, *L. rubrioperculatus*,
L. xanthochilus
Gymnosarda unicolor
Sargocentron spp.
Myripristis spp.
Variola albimarginata, *V. louti*

Species taken in the deep bottom fishery of Guam:
Aphareus rutilans
Aprion virescens
Caranx lugubris

Seriola dumerilii
Cephalopholis igarashiensis, C. sonnerati
Hyporthodus octofasciatus
Etelis carbunculus, E. coruscans
Pristipimoides spp.

1.2.2 Coral Reef Fishery

Shore-based fishing accounts for most of the fish and invertebrate harvest from coral reefs around Guam. The coral reef fishery harvests more than 100 species of fish, including members of the families Acanthuridae, Carangidae, Gerreidae, Holocentridae, Kyphosidae, Labridae, Lethrinidae, Lutjanidae, Mugilidae, Mullidae, Scaridae, and Siganidae (Hensley and Sherwood 1993). There are several pulse fisheries for juvenile fish that can be major components of the coral reef fishery, but totals in these can vary year to year . These include juvenile rabbitfish (manahak and lesso'), juvenile jacks (i'e), and juvenile goatfish (ti'ao).
Common species in the coral reef fishery include:

Naso unicornis, N. lituratus
Acanthurus xanthopterus, A. lineatus, A. triostegus
Caranx melampygus, C. papuensis, i'e
Selar crumenophthalmus
Gerres acinaces
Myripristis spp.
Sargocentron spp.
Neoniphon spp.
Kyphosus cinerascens, K. vaigiensis
Cheilinus undulatus, Cheilinus spp., *Halichoeres* spp.
Lethrinus harak, L. obseletus, L. atkinsoni, Gnathodentex aurolineatus
Lutjanus fulvus, L. monostigma, L. bohar, L. argentimaculatus
Mulloidichthys flavolineatus, M. vanicolensis, ti'ao
Parupeneus multifasciatus, P. barberinus, P. cyclostomus
Ellechelon vaigiensis, Moolgarda engeli, M. seheli
Chlorurus spilurus, C. frontalis,
Scarus psittacus, S. altipinnis, S. rubrioviolaceus, S. ghobban, S. schlegeli
Siganus spinus, S. argenteus, manahak, lesso

Hook and line is the most common method of fishing for coral reef fish on Guam, accounting for around 70% of fishers and gear. Throw net (talaya) is the second most common method, accounting for about 15% of fishers and gear. Other methods include gill net, snorkel spearfishing, SCUBA spearfishing, surround net, drag net, hooks and gaffs, and gleaning.

1.2.3 Fishery Data Collection System

Guam currently has four fishery dependent collection programs which can be described as long-term data collection programs with different approaches for collecting important information on fishery collection methods performed by fishermen. The four programs are the offshore data program, the inshore data program, the commercial fishery program, and the volunteer program. Sportfish Restoration Grant from the US Fish and Wildlife Service provides the significant portion of the funding for these programs. Training of the fishery staff to collect information is rigorous, and year end totals are calculated by an expansion process done with in collaboration with NOAA's Pacific Islands Fishery Science Center (PIFSC). Identification of fish to the species level is the goal of Guam's fishery staff.

The offshore and inshore programs, boat and shore-based creel survey respectively, are long term programs that collect participation, effort, and catch data from fishermen. Collaboration with PIFSC has resulted in a reproducible computer database program that can analyze the data to produce various types of trends that describe status of the various fisheries, both charter and non-charter, in federal and local waters. The volunteer data collection program's goal was to obtain volunteer data from fishermen; however, information for this program was minimal. The commercial receipt book program is an important source of information for fish that enter the commercial market; however, obtaining information from dealers has been sporadic, with less than three (3) dealers throughout the time series providing data. In order to improve this situation, the Council, DAWR and PIFSC partnered to increase vendor participation in the data collection program through the Territory Science Initiative. Extensive training, follow-ups, education, and outreach efforts were conducted to vendors and fishermen to increase participation in data collection.

Oram et al (in press) describes the fishery data collection process for the offshore and inshore programs. In general, DAWR staff collects fishery information through a series of random-stratified surveys for participation (accounts for fishing effort) and catch interviews (accounts for catch composition, size frequency, and catch-per-unit effort). These data are transcribed into the WPacFIN database and the annual catch estimates are expanded from the effort and CPUE information. Monthly commercial vendor reports are tallied at the end of the year and adjusted based on the coverage estimates provided by the vendor themselves or the data collection program staff.

1.2.4 Meta-data Dashboard Statistics

The meta-data dashboard statistics describe the amount of information used or data available to calculate the fishery-dependent information. Creel surveys are sampling based system that requires random-stratified design applied to pre-scheduled surveys. The creel surveys are comprised of: 1) participation run that captures effort and participation estimates and; 2) catch interviews that capture catch, effort, CPUE information, catch composition, size-weight information. The number of sampling days, participation runs, and catch interviews would determine if there are sufficient samples to run the expansion algorithm. The trends of these parameters over time that may infer survey performance. Monitoring the survey performance is critical for explaining the reliability of the expanded information.

Commercial receipt book information depends on the amount of invoices submitted and the number of vendors participating in the program. Fluctuations in these meta-data affect the commercial landing and revenue estimates.

1.2.4.1 Creel surveys meta-data statistics

Calculations: Shore-based data

Interview Days: This is the number of actual days that Creel Survey Data were collected. It's a count of the number of unique dates found in the interview sampling data (the actual sampling date data, include opportunistic interviews).

Participation Runs: Count of the number of unique occurrences of the day/night shift combined with surveyor's initials (the person assigned to conduct the participation survey on a given date). This is compiled annually from the participation header data.

Catch Interviews: Count of the total number of data records found in the interview header data (number of interview headers). This is divided into two categories, interviews conducted during scheduled survey days (Regular), and opportunistic interviews (Opp) which are collected on non-scheduled days.

Calculation: Boat-based data

Sample days: Count of the total number of unique dates found in the boatlog data sampling date data.

Catch Interviews: Count of the total number of data records found in the interview header data (number of interview headers). This is divided into two categories, interviews conducted during scheduled survey days (Regular), and opportunistic interviews (Opp) which are collected on non-scheduled days.

Table 25. Summary of creel survey meta-data describing survey performance parameters with potential influence on the creel survey expansion.

Year	Shore-based				Boat-based		
	# Interview Days	# Participation Runs	# Catch Interviews		# Sample Days	# Catch Interviews	
			Regular	Opp.		Regular	Opp.
1982					46	469	8
1983					47	431	34
1984	12	23	56	0	53	531	0
1985	51	78	367	0	66	812	0
1986	47	74	291	0	49	522	0
1987	45	62	245	0	48	612	0
1988	48	62	280	0	48	949	0
1989	49	63	297	0	48	931	2

Year	Shore-based				Boat-based		
	# Interview Days	# Participation Runs	# Catch Interviews		# Sample Days	# Catch Interviews	
			Regular	Opp.		Regular	Opp.
1990	47	62	485	0	48	1028	0
1991	48	54	497	0	48	1019	1
1992	48	55	611	0	48	1110	0
1993	48	48	598	0	52	1119	0
1994	47	48	702	0	55	1168	0
1995	48	49	764	0	96	1613	4
1996	48	53	679	0	96	1608	0
1997	48	67	915	0	96	1358	0
1998	49	73	880	0	96	1581	0
1999	48	68	940	0	96	1367	3
2000	48	84	791	0	96	1246	1
2001	48	96	753	0	96	908	6
2002	47	94	439	4	84	610	1
2003	48	96	518	10	78	446	0
2004	47	93	337	35	95	530	1
2005	48	96	371	3	97	552	0
2006	49	96	300	0	96	556	0
2007	48	96	243	118	96	500	0
2008	46	96	282	0	96	571	2
2009	47	94	321	1	96	803	0
2010	48	94	299	0	96	902	0
2011	43	96	250	0	96	645	0
2012	47	92	272	0	74	371	0
2013	49	94	257	0	96	561	1
2014	48	92	227	0	90	635	9
2015	45	96	279	46	97	651	13
2016	48	96	281	9	92	886	1
10 YEARS AVG	47	95	271	17	93	653	3
10 YEARS SD	2	2	26	36	7	160	4
20 YEARS AVG	47	90	448	11	93	784	2
20 YEARS SD	1	9	247	27	6	338	3

1.2.4.2 Commercial receipt book statistics

Calculations:
# of Vendors – Count of the number of unique buyer codes found in the commercial purchase header data.

Invoices – Count of the number of unique invoice numbers found in the commercial header data.

Table 26. Summary of commercial receipt book meta-data describing reporting performance parameters with potential influence on total commercial landing estimates (Note: Data will be reported only for years with ≥ 3 vendors reporting).

Year	Number of Vendors	Total Invoices Collected
1980	*	*
1981	*	*
1982	*	*
1983	3	2311
1984	3	2587
1985	*	*
1986	*	*
1987	*	*
1988	*	*
1989	*	*
1990	4	2803
1991	3	2512
1992	3	2737
1993	3	2664
1994	*	*
1995	3	1565
1996	6	1965
1997	7	2923
1998	4	3591
1999	5	3410
2000	3	3868
2001	3	4155
2002	3	3494
2003	*	*
2004	3	3104
2005	3	2649
2006	4	2589
2007	*	*
2008	*	*
2009	*	*
2010	*	*
2011	*	*
2012	*	*

Year	Number of Vendors	Total Invoices Collected
2013	*	*
2014	8	1353
2015	9	1335
2016	5	1529
10 YEARS AVG	3	1609
10 YEARS SD	3	320
20 YEARS SD	3	2430
20 YEARS SD	2	925

1.2.5 Fishery Summary Dashboard Statistics

The Fishery Summary Dashboard Statics section consolidates all fishery dependent information comparing the most recent year with the short-term (recent 10 years) and long-term (recent 20 years). The summary dashboard shows the most current year value the difference between the current year value with the 10-year average and the 20-year average (shown bolded in [brackets]). Trend analysis of the past 10 or 20 years will dictate the trends (increasing, decreasing, or no trend). The right most symbol indicates whether the mean of the short-term and long-term years were above, below, or within one standard deviation of the mean of the full time series.

Legend Key:

- *increasing trend in the time series* — *above 1 standard deviation*

- *decreasing trend in the time series* — *below 1 standard deviation*

- *no trend in the time series* — *within 1 standard deviation*

10,000 [**1,000**] – *point estimate of fishery statistic* [***difference from short/long term average***]

Table 27. Annual indicators for the coral reef and bottomfish fishery describing fishery performance comparing current estimates with the short-term (10 years) and the long-term (20 years) average.

Fishery	Fishery statistics	Short-term (recent 10 years)	Long-term (20 years)
Bottomfish	**Estimated catch (lbs)**		
All species caught in the BF gear	Boat and shore creel data estimated (expanded) total lbs (all BF trips)	**100,434[▼20%]**	**100,434[▼35%]**
	Estimated total lbs (all species) commercial	**No trends available due to confidentiality**	**No trends available due to confidentiality /A**

	purchase data		
Bottomfish management unit species only	Total creel data Estimated (expanded) total lbs (all BF trips)	25,453[▼11%]	25,453 [▼31%]
	Estimated total lbs (all species) commercial purchase data	**No trends available due to confidentiality**	**No trends available due to confidentiality**
	Catch-per-unit effort (lbs/gear-hrs)		
	CPUE (creel data only)	**0.0132[▼33%]**	**0.0132[▼11%]**
	Fishing effort *(only available for creel data)*		
	Estimated (expanded) total bottomfish # of trips	**784[▼9%]**	**784[▼32%]**
	Fishing participants		
	Estimated total # of fishers	**1,213[▲13%]**	**1,213[▲5%]**
	Bycatch		
	Total number of bycatch caught	**1,664[▼9%]**	**1,664[▼34%]**
	# bycatch released	**1,615[▼8%]**	**615[▼32%]**
	# bycatch kept	**70[▲49]**	**N/A**
	Federal permits		
	# federal permit holders (PIRO)		
Coral Reef	**Estimated catch (lbs all gears)**		
	Boat-based creel data (expanded estimate all gears, defined by a list of species?)	**135,155[▼16%]**	**135,155 [▼38%]**
	Shore-based creel (expanded estimate all gears, defined by a list of species?)	**398,139[▼36%]**	**398,139[▼49%]**
	Commercial Purchase	**No trends available due to confidentiality**	**No trends available due to confidentiality**
	Catch-per-unit-effort (lbs/gear-hrs)		
	BB spear	**0.0961[▼57%]**	**0.0961[▼41%]**
	BB SCUBA	**0.0828[▼92%]**	**0.0828[▼95%]**
	BB Gillnet	**0.1993[▼88%]**	**0.1993[▼83%]**
	BB Troll	**0.0075[▼33%]**	**0.0075[▼26%]**
	SB H&L	**0.0006[▼73%]**	**0.0006[▼57%]**
	SB Throw/cast	**0.0051[▼82%]**	**3,045[▼72%]**
	SB Gillnet	**0.0269[▼88%]**	**0.0269[▼82%]**
	SB Spear	**0.029[▼88%]**	**0.029[▼82%]**

	SB H&G	**0.4[▲24%]**	**0.4[▲55%]**
	Fishing effort (# of gear-hours by gear type)		
	BB spear	**6,210[▲64%]**	**6,210[▼29%]**
	BB SCUBA	**11,868[▲811%]**	**11,868[▲305%]**
	BB Gillnet	**189[▼31%]**	**189[▼81%]**
	BB Troll	**10,120,464[▲113%]**	**10,120,464[▲69%]**
	SB H&L	**183,219[▲9%]**	**183,219[▼51%]**
	SB Throw/cast	**14,040[▲134%]**	**14,040[▲44%]**
	SB Gillnet	**4,717[▲237%]**	**4,717[▼51%]**
	SB Spear	**5,520[▲448%]**	**5,520[▲46%]**
	SB H&G	**20[▼76%]**	**20[▼82%]**
	Fishing participants (# of gear)		
	BB spear	**1,127[▼8%]**	**1,127[▼3%]**
	BB SCUBA	**3,311[▲113%]**	**3,311[▲113%]**
	BB Gillnet	**1,412[▲24%]**	**1,412[▲24%]**
	BB Troll	**902[▼10%]**	**902[▼14%]**
	SB H&L	**53,253[▼27%]**	**53,253[▼46%]**
	SB Throw/cast	**11,529[▼19%]**	**11,529[▼36%]**
	SB Gillnet	**10,111[▼5%]**	**10,111[▼42%]**
	SB Spear	**12,215[▲32%]**	**12,215[▼1%]**
	SB H&G	**3,065[▲12%]**	**3,065[▼1%]**
	Bycatch		
	Total number of bycatch caught	**10,678[▼2%]**	**10,678[▼7%]**
	# bycatch released	**10,672[▼2%]**	**10,672[▼7%]**
	# bycatch kept	**N/A**	**N/A**
	Federal permits		
	# federal permit holders (PIRO)		

1.2.6 Catch statistics

This section summarizes the catch statistics for the bottomfish and coral reef fishery in Guam. Estimates of catch are summarized from the creel survey and commercial receipt book data collection programs. Catch statistics provide estimates of annual harvest from the different fisheries. Estimates of fishery removals can provide proxies for the level of fishing mortality and a reference level relative to established quotas. This section also provides detailed level of catch for fishing methods and the top species complex harvested in the coral reef and bottomfish fishery.

1.2.6.1 Catch by data stream

This describes the estimated total catch from the shore and boat-based creel survey program and the commercial landing from the commercial receipt book system. The difference between the creel total and the commercial landing is assumed to be the non-commercial component. However, there are cases where the commercial landing may be higher than the estimated creel total of the commercial receipt book program is able to capture the fishery better than the creel survey (e.g. night time spearfishing)

Calculations: Estimated landings are based on a pre-determined list of species (Appendix 3) identified as the BF Species Complex regardless of the gear used, for each data collection (shore-based creel, boat-based creel and the commercial purchase reports).

Table 28. Summary catch time series of the ALL SPECIES caught using the bottomfishing gear: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system

Year	Creel Survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
1980				*
1981				*
1982	37501		37501	*
1983	46054		46054	21329
1984	47764		47764	43830
1985	69644	158116	227760	*
1986	32851	113388	146239	*
1987	41537	103643	145180	*
1988	70285	135341	205626	*
1989	78327	61565	139892	*
1990	77235	72712	149947	16772
1991	68663	97713	166376	12962
1992	81458	94330	175788	9902
1993	88623	63368	151991	12171
1994	96071	68343	164414	*
1995	93515	92744	186259	12220
1996	136331	64532	200863	9123

Year	Creel Survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
1997	84159	82897	167056	17478
1998	79280	124927	204207	17170
1999	111689	164365	276054	40132
2000	132994	79402	212396	29421
2001	116611	122302	238913	36793
2002	70692	86157	156849	29378
2003	108042	63932	171974	*
2004	99738	75980	175718	32386
2005	71719	51955	123674	25472
2006	72626	46648	119274	22527
2007	51080	64886	115966	*
2008	65612	40171	105783	*
2009	75427	42533	117960	*
2010	55462	29521	84983	*
2011	83633	84010	167643	*
2012	36818	63273	100091	*
2013	60985	154005	214990	*
2014	71075	79254	150329	7876
2015	44722	54858	99580	5653
2016	60689	39745	100434	5854
10 YEARS AVG	60550	65226	125776	14018
10 YEARS SD	13491	34073	38111	6095
20 YEARS AVG	77653	77541	155194	20378
20 YEARS SD	24545	36617	51768	9503

Calculations: Estimated landings are based on a pre-determined list of species (Appendix 3) identified as the BMUS Complex regardless of the gear used, for each data collection (shore-based creel, boat-based creel and the commercial purchase reports).

Table 29. Summary of the available Bottomfish Management Unit Species (BMUS) catch time series: estimated lbs (expanded) from the boat and shore-based creel surveys and estimated total lbs from the commercial purchase system

Year	Creel survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
1980				*
1981				*
1982	20566		20566	*

Year	Creel survey Estimates		Creel Total	Commercial landings
	Boat-based	**Shore-based**		
1983	29226		29226	6255
1984	5949		5949	5329
1985	28558	3229	31787	*
1986	16815	2853	19668	*
1987	8868	1181	10049	*
1988	27550	15921	43471	*
1989	36465	2016	38481	*
1990	30041	22311	52352	5653
1991	29430	19614	49044	3061
1992	34318	26164	60482	2994
1993	53657	14512	68169	4621
1994	44164	16020	60184	*
1995	32694	21273	53967	7054
1996	41915	14583	56498	2069
1997	23402	9474	32876	2519
1998	32333	8944	41277	5008
1999	41148	10081	51229	21385
2000	51493	20405	71898	12793
2001	37953	10406	48359	11376
2002	20888	28024	48912	5907
2003	29681	9398	39079	*
2004	28170	8834	37004	9715
2005	36797	4622	41419	12527
2006	32251	6901	39152	8371
2007	19614	4865	24479	*
2008	36629	978	37607	*
2009	37105	3468	40573	*
2010	23930	491	24421	*
2011	51405	558	51963	*
2012	16795	2152	18947	*
2013	26919	5284	32203	*
2014	15624	973	16597	1585
2015	12659	2641	15300	781
2016	24417	1036	25453	1483
10 YEARS AVG	26510	2245	28754	5041
10 YEARS SD	11393	1684	11142	3109
20 YEARS AVG	29961	6977	36937	7150
20 YEARS	10620	6790	13558	4875

Year	Creel survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
SD				

Calculations: Estimated landings are based on a pre-determined list of species (Appendix 3) identified as the CREMUS Complex regardless of the gear used, for each data collection (shore-based creel, boat-based creel and the commercial purchase reports).

Table 30. Summary of the predefined “coral reef fishery” catch time series (for a discrete list of species – taken from CB lbs and CS lbs from the CREMUS module) from the boat and shore-based creel surveys and the commercial purchase system.

Year	Creel survey Estimates		Creel Total	Commercial Landings
	Boat-based	Shore-based		
1980				*
1981				*
1982	46561		46561	*
1983	92713		92713	116807
1984	119010		119010	137771
1985	175832	2374045	2549877	*
1986	89930	1835095	1925025	*
1987	113979	1484359	1598338	*
1988	156791	1230028	1386819	*
1989	218795	1003600	1222395	*
1990	186325	839544	1025869	55348
1991	261701	1644973	1906674	40575
1992	176364	1125829	1302193	45712
1993	222195	650902	873097	37139
1994	219728	1047164	1266892	*
1995	345397	1213100	1558497	19575
1996	512603	726651	1239254	51174
1997	302800	1276679	1579479	69075
1998	336480	1398251	1734731	163810
1999	495177	1793226	2288403	244562
2000	369625	872514	1242139	247287
2001	365769	1090670	1456439	259032
2002	181302	660796	842098	196277
2003	240647	782974	1023621	*
2004	237517	606001	843518	140878
2005	122366	405779	528145	156459
2006	126254	574611	700865	160440
2007	104421	580832	685253	*

Year	Creel survey Estimates		Creel Total	Commercial Landings
	Boat-based	Shore-based		
2008	129091	382019	511110	*
2009	177020	582288	759308	*
2010	127761	400362	528123	*
2011	304874	568827	873701	*
2012	115199	1148788	1263987	*
2013	127794	941109	1068903	*
2014	217898	491628	709526	78399
2015	160479	685254	845733	55416
2016	135155	398139	533294	38388
10 YEARS AVG	159969	617925	777894	108715
10 YEARS SD	57772	237296	232754	45465
20 YEARS AVG	218881	782037	1000919	141693
20 YEARS SD	107173	375036	458242	62223

1.2.6.2 Expanded catch estimates by fishing methods

Catch information is provided for the top shore-based and boat-based fishing methods that contribute 88% and 83% of the annual catch, respectively.

Calculations: The creel survey time series of catch will be the sum of the estimated weight by selected gear in all strata for all species except for trolling which would exclude PMUS and any pelagic species complex.

Table 31. Expanded catch time series estimates using boat and shore-based creel survey data sets by gear type.

Year	Shore-based methods						Boat-based methods			
	Throw / Cast net	H&L	Gill net	Spear	SCUBA	H&G	Bottom	Spear	SCUBA	Troll
1982							41328	420	3135	123937
1983							50416	1355	4400	163369
1982							41328	420	3135	123937
1983							50416	1355	4400	163369
1984							57412	14108	5460	31381
1985	290483	139928	232855	332730	27599	27599	88045	18737	12761	83121
1986	277966	122886	324764	142553	14328	14328	34515	12545	5145	113431
1987	267033	103228	299575	126602	8303	8303	44459	12448	7474	88728
1988	92198	160109	330751	176295	27279	27279	67037	24712	10649	355895
1989	145294	145870	160742	53740	33068	33068	79972	30930	20839	109347
1990	128098	168286	146771	41514	7255	7255	61401	28871	22273	147962
1991	410511	121397	202099	72128	14529	14529	60753	27898	37027	425439
1992	147088	139635	266640	105519	5772	5772	78175	35162	25226	95229

Year	Shore-based methods						Boat-based methods			
	Throw / Cast net	H&L	Gill net	Spear	SCUBA	H&G	Bottom	Spear	SCUBA	Troll
1993	78743	45678	82728	123739	16160	16160	107130	39434	22848	240017
1994	165445	115773	106061	101810	13361	13361	105283	37555	27244	147642
1995	287102	58430	93047	155562	8333	8333	101073	40554	74734	335980
1996	171267	73516	51514	57594	7243	7243	129708	67447	91810	355081
1997	237621	121070	66400	83280	8635	8635	109346	37363	41920	294010
1998	184009	82907	59538	352543	79548	79548	99600	56443	68197	295881
1999	295979	83426	130957	301378	60545	60545	122930	45200	82024	202357
2000	138629	101432	111422	122105	5569	5569	115836	42403	116071	102066
2001	166037	22968	67707	169649	45798	45798	123975	74369	65103	196609
2002	131417	74898	38422	87072	2258	2258	55448	21711	34766	182742
2003	148783	34153	50897	227898	692	692	82223	22649	42685	107422
2004	119169	43657	25673	109541	718	718	61874	33601	51237	235905
2005	68579	16738	74238	31830	31318	31318	62651	15037	32375	116860
2006	102484	135472	27367	72457	2938	2938	89865	12796	6359	175517
2007	109904	12255	71283	52123	22273	22273	57750	24704	29989	266034
2008	64624	36078	71965	12466	1412	1412	59639	31433	25449	116201
2009	156016	50998	25513	9101	56180	56180	89997	22669	37424	172007
2010	24197	31116	210832	7865	2891	2891	56164	23635	32608	291813
2011	140072	77521	10274	6019	1496	1496	88694	26483	67431	94869
2012	383167	11231	140441	26238	28741	28741	40214	23986	14087	79554
2013	166400	92097	105630	25492	16324	16324	42601	20816	5390	190162
2014	138068	25777	2252	3647	687	687	69300	28088	36140	207655
2015	191145	41323	32549	183589	7018	7018	29395	22371	34607	182096
2016	44818	50373	32240	102581	2864	2864	51010	28277	21728	190980
10 YEARS AVG	141841	42877	70298	42912	13989	13989	58476	25246	30485	179137
10 YEARS SD	95774	24826	62477	54971	16907	16907	18756	3100	15709	65085
20 YEARS AVG	150556	57275	67780	99344	18895	18895	75426	30702	42280	185037
20 YEARS SD	81578	35751	49829	98684	23310	23310	27725	14274	26078	66160

1.2.6.3 Top species in the catch for the boat and shore-based fisheries

The time series for catch is an indicator of fishery performance. Fluctuations in the catch can be attributed to various factors and there is no single explanatory variable for the trends. The 10 species group in the boat and shore-based catch for the coral reef fishery make up 67% and 76%, respectively, of the total annual catches.

Calculations: Catch by species complex is tallied directly from the boat-based expanded species composition data combining all gear types and species, for all strata.

The averages for the table this year were calculated from catch estimates from the entire time series for each of the CREMUS groupings. The average catch for each grouping is ranked from the highest to lowest catch. The dominant groups that make up more than 50% of the catch are reported.

Table 32. Catch time series of the 11 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the boat-based creel data. The CREMUS complex comprise > 67% of the total boat based landing

Year	Boat-based (Estimated Pounds)										
	BF	BMUS	Atul	Empr	Surg	Jack	Parrot	Grpr	Snap	Goat	Rabbit
1982	36818	24033	204	8167	372	6708	5550	197	11	15482	55
1983	45456	38794	28099	10008	805	3525	6573	1049	0	25350	949
1984	47739	16203	37342	13615	377	2431	3414	1768	0	5343	1023
1985	69415	46576	51625	21458	1810	9617	11135	9014	140	24495	3792
1986	32798	19147	22004	4985	274	2597	12464	4819	60	12752	2559
1987	41456	27832	15086	16410	612	5984	8190	6074	104	10699	1431
1988	69816	43983	33015	17110	1404	9206	21395	9479	267	21330	7510
1989	78157	57578	60347	23040	4611	5022	13063	9910	1769	36766	13994
1990	76944	41653	9602	26622	6482	11987	9869	12651	2890	28466	19415
1991	68543	38252	34101	22456	5325	9075	8800	24141	925	28113	12797
1992	81372	48961	10077	22435	2722	12620	12724	22345	662	33492	20403
1993	88038	53460	29291	14546	10341	18740	14840	15689	2535	39912	12141
1994	95496	48621	4064	29001	3782	12925	20321	17515	1247	33248	16635
1995	93475	40231	52227	31910	9210	17330	19972	24169	3736	24207	39683
1996	136284	52486	98881	38313	6257	15045	44234	22113	4069	38692	56172
1997	84115	29766	33040	34447	7808	16178	16443	19358	2867	16676	28141
1998	78428	36965	31118	25408	7459	17235	14625	22108	5079	21121	47571
1999	110857	52531	135339	27982	10098	14615	31614	25786	3925	36644	44710
2000	132620	65682	14008	44050	9056	17020	25512	30770	5147	46038	52732
2001	116039	50371	7979	48878	3775	15352	19296	27856	8545	32508	31109
2002	70639	23806	438	29821	5166	6900	18256	16497	3072	15662	20462
2003	107974	41567	502	22651	2990	24610	39145	18237	1553	21568	18640
2004	99664	36008	1768	20096	1009	12873	38664	19616	731	26895	35195
2005	71661	36432	160	12210	3656	10709	18156	8953	156	30586	18382
2006	72315	37705	1155	10845	4732	7899	23508	2222	204	30063	4258
2007	50968	26558	848	14724	1274	6721	13558	7968	19	15965	8695
2008	65449	36844	10335	11157	6599	9634	11735	7524	1486	32923	24395
2009	75241	38342	11337	23750	2355	13896	8182	7988	272	29187	24717
2010	55038	26821	5887	14076	1460	7115	10554	6788	485	21807	11518

Year	Boat-based (Estimated Pounds)										
	BF	BMUS	Atul	Empr	Surg	Jack	Parrot	Grpr	Snap	Goat	Rabbit
2011	83372	58342	120801	15626	565	7563	12935	4394	304	47213	12235
2012	36646	21718	24936	10018	2470	3547	8333	5206	1349	14748	3313
2013	60122	29742	19878	12591	972	8064	25088	9458	1167	14365	9817
2014	70802	23465	4077	31276	8399	7834	14992	8856	3808	13342	10376
2015	44265	13531	28707	8861	3145	4543	19012	1440	782	10238	4966
2016	60330	26093	2526	11577	1922	4871	23654	11461	895	19401	7643
10 YRS AVG	30146	60223	22933	15366	2916	7379	14804	7108	1057	21919	11768
10 YRS SD	11573	13505	33865	6605	2435	2789	5658	2691	1027	10835	6909
20 YRS AVG	35614	77327	22742	21502	4246	10859	19663	13124	2092	24848	20944
20 YRS SD	12772	24512	36759	11331	2925	5281	8743	8540	2186	10360	14582

Calculations: Catch by species complex is tallied directly from the boat-based expanded species composition data combining all gear types and species, for all strata.

The averages for the table below were calculated from catch estimates from the entire time series for each of the CREMUS grouping. The average catch is ranked from the highest to lowest catch. The dominant groups that make up more than 60% of the catch are reported.

Table 33. Catch time series of the 10 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the shore-based creel data. The CREMUS complex comprise > 91% of the total boat based landing

Year	Shore-based Estimated Pounds									
	Surg	Rabbit	Mlsk	Atul	Goat	Jack	Mull	Empr	Rudd	Parrot
1980	698	105	0	5332	12510	407	0	0	926	14
1981	2820	0	0	8018	19249	96	0	0	70	37
1982	5653	8669	414	6861	18222	495	11	25	135	139
1983	34318	11778	827	16434	54027	1450	38	187	1187	1165
1984	43729	19070	414	33938	38358	3273	133	448	2099	494
1985	374473	142181	71263	76633	278452	246847	177322	22991	286183	373434
1986	89960	49849	139056	71480	239287	58606	37333	28433	382068	25654
1987	148870	41787	166094	88453	174345	126864	115241	24246	396359	20245
1988	90062	102633	104438	60679	177759	114181	90894	61693	308414	34060
1989	107157	61963	115613	58533	184158	99911	87718	32840	201279	38474
1990	75174	65266	66677	44337	163914	93498	72854	42150	146628	25137
1991	654449	64853	59335	83141	135822	158248	81845	88228	120733	165172

Year	Shore-based Estimated Pounds									
	Surg	**Rabbit**	**Mlsk**	**Atul**	**Goat**	**Jack**	**Mull**	**Empr**	**Rudd**	**Parrot**
1992	35800	97424	58022	26928	178428	154378	107371	51948	257963	46443
1993	69434	58201	47650	35108	137306	67838	37682	16652	76592	39821
1994	67787	84956	35097	51274	165098	155192	114900	3148	166932	59713
1995	207512	101497	48436	61417	110475	129118	71848	15242	379147	43424
1996	175387	88301	29975	78665	100500	116383	75547	27632	226029	34044
1997	279690	91219	28987	86126	121223	125406	84064	23876	159474	31845
1998	128020	112397	36176	97609	159228	132918	57841	89410	282705	125761
1999	338931	80679	42143	247500	171479	217003	107578	22790	350313	95443
2000	109941	99154	43045	67386	140325	138928	90729	46031	165407	30468
2001	130344	133032	32759	158486	133812	101052	62539	8059	159220	85651
2002	77101	77890	22117	77967	78161	96909	69751	63881	96130	19996
2003	114647	58936	24383	90896	82292	121470	60424	11038	175732	77380
2004	145363	43707	12625	124872	92269	67583	36187	15313	153563	27612
2005	89801	35394	26751	80365	41684	33136	14946	7798	86794	48914
2006	112414	26976	32644	67658	24894	60494	44158	47455	150512	20048
2007	126325	53375	6926	95832	65468	59927	47520	6852	126525	31517
2008	83398	27226	9225	69813	36179	62540	33575	10021	116257	10899
2009	287492	44460	9299	67315	46494	87111	26251	11616	89147	62106
2010	46279	31096	8870	42708	43356	94261	30564	35424	175183	10594
2011	356739	47440	22256	132707	33655	78417	28030	1258	78623	10428
2012	773398	45041	18001	69482	105037	30655	6622	6686	58198	39413
2013	317957	31367	36369	269702	70828	73827	51406	1796	109334	21017
2014	192250	94438	21325	97943	31480	52781	26881	16534	54198	3609
2015	96961	32157	45798	57761	21163	47439	25860	4142	95792	89898
2016	49038	29276	20594	48435	33191	66166	44890	4933	99168	24348
10 YEARS AVG	43588	232984	19866	95170	48685	65312	32160	9926	100243	30383
10 YEARS SD	18994	209801	12124	63477	23784	18090	12428	9572	33385	25771
20 YEARS AVG	59763	192804	25015	102528	76611	87401	47491	21746	139114	43347
20 YEARS SD	31303	164163	11784	58930	46248	42789	25404	22871	70446	33497

1.2.7 Catch Per Unit Effort (CPUE) Statistics

This section summarizes the estimates for catch-per-unit effort in the boat and shore-based fisheries. The boat-based fisheries include the bottomfishing (handline gear), spearfishing (SCUBA and snorkel), gillnets, and troll that comprise 83% of the total catch. Trolling method are primarily a pelagic fishing method but also catches coral reef fishes like jacks and gray jobfish. The shore-based fisheries include the hook-and-line, throw or cast nets, gillnets, spear, and hook-and-gaff that comprise 88% of the total coral reef fish catch. CPUE is reported as pounds per gear-hours for the shore-based methods whereas in the boat-based methods it's pounds per trip.

Calculations: CPUE is calculated from interview data by gear type using ∑catch /∑ (hours fished*number of fishers) for boat based and ∑catch/∑ (hours fished*number of gears used) for shore based. If the value is blank (empty), then there was no interview collected for that method. Landings from interviews without fishing hours are excluded from the calculations.

Table 34. Catch per unit effort time series by dominant fishing methods from the shore-based fisheries. CPUE estimates were derived from the top three- to five-dominant taxonomic groups that make up more than 50% of the catch. The percentage of catch is shown in parenthesis beside the method.

Year	**Gear CPUE (Lbs/Gear-hr)**				
	H&L	**Castnet**	**Gill Net**	**Spear**	**Hooks and Gaffs**
1984	0.0106	0.1339	0.3507	0.75	1.125
1985	0.0029	0.0224	0.0509	0.0773	0.0975
1986	0.004	0.0224	0.0441	0.0962	0.2393
1987	0.0074	0.0208	0.0515	0.0747	0.0354
1988	0.0027	0.0213	0.0764	0.0805	0.2444
1989	0.0022	0.0136	0.0548	0.0627	0.2545
1990	0.0011	0.0171	0.0309	0.059	0.0551
1991	0.0017	0.0128	0.0305	0.0918	0.069
1992	0.0005	0.0122	0.0255	0.0986	0.0327
1993	0.0003	0.006	0.0181	0.1621	0.0347
1994	0.0004	0.016	0.0208	0.037	0.0734
1995	0.0005	0.0064	0.0117	0.0734	0.0313
1996	0.0003	0.0158	0.022	0.0659	0.0938
1997	0.0004	0.006	0.0134	0.0415	0.0544
1998	0.0005	0.0082	0.0067	0.0544	0.1094
1999	0.0005	0.0076	0.0124	0.0316	0.1925
2000	0.0004	0.0083	0.0189	0.0476	0.0381
2001	0.0004	0.0045	0.0204	0.0575	0.2946
2002	0.0007	0.0152	0.0184	0.0906	0.45
2003	0.0007	0.0034	0.0359	0.1844	0.0256
2004	0.001	0.0051	0.029	0.1257	0.2222
2005	0.0005	0.0019	0.0781	0.1333	0.2593
2006	0.0015	0.0169	0.0373	0.1035	0.2889
2007	0.0007	0.0071	0.1264	0.1555	0.4286
2008	0.0009	0.0064	0.0738	0.0489	0.1333

Year	Gear CPUE (Lbs/Gear-hr)				
	H&L	**Castnet**	**Gill Net**	**Spear**	**Hooks and Gaffs**
2009	0.001	0.1468	0.1294	0.1222	0.3524
2010	0.0003	0.0138	0.2598	0.2708	0.2115
2011	0.0018	0.0203	0.1245	0.7429	0.52
2012	0.002	0.0188	0.1356	0.1527	0.2143
2013	0.0017	0.0438	0.1176	0.0988	0.2639
2014	0.003	0.0141	0.4388	0.4688	0.2857
2015	0.0102	0.0147	0.0673	0.3298	0.4231
2016	0.0006	0.0051	0.0269	0.029	0.4
10 YEARS AVG	0.0022	0.0291	0.15	0.2419	0.3233
10 YEARS SD	0.0028	0.0406	0.1123	0.2107	0.1148
20 YEARS AVG	0.0014	0.0184	0.0885	0.1645	0.2584
20 YEARS SD	0.0021	0.0308	0.1014	0.1712	0.1388

Table 35. Catch per unit effort time series by dominant fishing methods from the boat-based fisheries. CPUE estimates were derived from the top three to five dominant taxonomic groups that make up more than 50% of the catch. The percentage of catch is shown in parenthesis beside the method.

Year	Boat_based Gear CPUE (Lbs/Fisher-hrs)				
	Bottomfishing	**Spear**	**SCUBA**	**Gill Net**	**Troll**
1982	0.0293	0.48	0		0.0162
1983	0.0293	0.2198	0.3956		0.0154
1984	0.023	0.1159	0.3553	3	0.0135
1985	0.0099	0.2025	0.1598	0.5357	0.0098
1986	0.021	0.2915	0.4402	0.5	0.0092
1987	0.0223	0.2312	0.555	0.3195	0.0086
1988	0.0114	0.1518	0.2097	0.6465	0.0057
1989	0.0106	0.1194	0.2343	0.405	0.0048
1990	0.0116	0.1515	0.6306	0.3795	0.0037
1991	0.0116	0.1691	0.4482	0.311	0.0051
1992	0.0106	0.0794	0.1164	0.2381	0.0034
1993	0.0102	0.0637	0.4413	0.6389	0.0041
1994	0.0109	0.0766	0.3632	0.3262	0.0039
1995	0.0029	0.0568	0.2424	0.1213	0.0032
1996	0.0035	0.0586	0.2149	0.4762	0.0034
1997	0.0029	0.0706	0.446	0.2965	0.004
1998	0.0027	0.0252	0.3077	0.1199	0.0035

Year	Boat_based Gear CPUE (Lbs/Fisher-hrs)				
	Bottomfishing	**Spear**	**SCUBA**	**Gill Net**	**Troll**
1999	0.0035	0.0353	0.2839	0.6192	0.0031
2000	0.0052	0.0532	0.2772	0.0661	0.0042
2001	0.0071	0.1912	0.3202	0.3005	0.0069
2002	0.0069	0.0857	0.5128	0.4275	0.0117
2003	0.0172	0.188	0.7129	1.8968	0.0176
2004	0.0144	0.2008	0.786	1.0195	0.0174
2005	0.0171	0.0848	0.7361	0.4407	0.0104
2006	0.023	0.1134	0.3905	1.75	0.0114
2007	0.0226	0.2217	4.0816	0.5214	0.0136
2008	0.0162	0.1087	0.6206	1.5606	0.0102
2009	0.0164	0.0795	1.7182	0.2311	0.0083
2010	0.0081	0.0828	0.3333	0.3787	0.0067
2011	0.027	0.2714	2.6571	0.5	0.0095
2012	0.0341	0.8788	3	10.3504	0.0185
2013	0.0254	0.1598	0.9375	0.4643	0.0147
2014	0.0185	0.1629	1.5469	1.3313	0.0109
2015	0.0163	0.1729	0.5435	0.9467	0.0125
2016	0.0132	0.0961	0.0828	0.1993	0.0075
10 YEARS AVG	0.0198	0.2235	1.5522	1.6484	0.0112
10 YEARS SD	0.0072	0.2263	1.251	2.9332	0.0035
20 YEARS AVG	0.0149	0.1641	1.0147	1.171	0.0101
20 YEARS SD	0.0086	0.1763	1.0437	2.173	0.0046

1.2.8 Effort Statistics

This section summarizes the effort trends in the coral reef and bottomfish fishery. Fishing effort trends provide insights on the level of fishing pressure through time. Effort information is provided for the top shore-based and boat-based fishing methods that contribute 88% and 83% of the annual catch. Trolling method is included in this report because coral reef MUS is also caught using trolling method. Pelagic MUS caught using trolling method is reported in the Pelagic Annual/SAFE report module.

Calculations: Effort estimates (hours) are generated by summing the effort data collected from interviews by gear type. For the Shore-based estimates, data collection started in 1985

Table 36. Time series of effort estimates from the coral reef and bottomfish fisheries. Shore-based fisheries are expressed in gear-hours (expanded total number of hours fishing by total number of gears used). The boat-based fisheries are expressed in number of trips for bottomfish and number of gear hours for spear, SCUBA, gillnet and troll)

Year	SB gear-hours	BB gear-hours

	Cast net	H&L	Gill net	Spear	H&G	Bottom	Spear	SCUBA	Gill net	Troll
1982	15	400	0	208	0	88550	75	1	0	1861110
1983						68800	182	589	0	1748790
1984	224	2914	345	24	8	151267	6723	805	10	1871282
1985	5673	82992	10658	15096	400	585078	4554	5712	84	3269504
1986	3430	52899	14378	3410	117	113442	2065	368	6	2068560
1987	4902	18204	8550	9964	4779	119574	2379	600	435	2554810
1988	8487	34662	9735	6264	225	319473	7565	2360	99	7232525
1989	15810	42120	6336	2184	224	355365	5244	3150	200	5766054
1990	13534	253492	20240	2679	272	282736	2574	1248	880	9510114
1991	13932	368466	17835	1862	1638	246468	2856	2856	1479	8943480
1992	13900	739440	30000	1440	490	243650	9047	10106	966	10802475
1993	12604	796708	18040	1666	1701	305844	12772	3780	612	9979501
1994	6048	978945	21070	7520	722	446641	11834	4816	1300	10291332
1995	19840	673200	40608	7221	384	1309914	30481	20482	12535	15871259
1996	4875	939333	8601	2684	96	1392174	34580	17028	6726	18120337
1997	19760	1120575	31692	5328	294	1168608	14384	4888	5180	11946651
1998	21976	795960	73066	15006	448	1629306	81400	12699	6603	14680458
1999	14351	1234925	52116	26010	504	1278000	26730	15120	2193	10276416
2000	14157	838240	27930	9416	315	655120	18630	13432	14000	9082690
2001	15125	827519	16464	3968	224	467290	6390	6240	1584	5223522
2002	7614	227813	14691	2352	20	321768	7128	1248	648	2089907
2003	18900	345598	2950	1394	195	125473	4698	1961	378	1212228
2004	7885	195202	4662	1050	36	184616	2346	1131	154	1789470
2005	9400	167334	1242	360	54	192185	5628	576	506	1834694
2006	6336	96074	2091	425	45	141240	4020	169	4	2189499
2007	2948	343952	546	418	70	109200	1800	49	140	2062099
2008	5976	164300	1720	266	15	130548	9047	340	462	2361090
2009	4026	185298	255	180	210	255834	7920	110	874	4655826
2010	7313	141860	408	144	156	343568	6000	6	816	6355728
2011	5184	103653	988	70	25	137268	2240	210	2	3450020
2012	6006	122850	1128	550	70	31610	528	70	117	1078093
2013	4221	81774	672	729	72	45567	2115	32	2968	2766308
2014	4544	130062	196	224	28	130130	3696	64	483	3398538
2015	5858	227766	3358	1980	156	70328	3234	425	169	4144434
2016	14040	183219	4717	5520	20	170868	6930	17480	567	6854544
10 YRS AVG	6012	168473	1399	1008	82	142492	4351	1879	660	3712668
10 YRS SD	2925	71281	1421	1594	65	90781	2764	5202	819	1746096
20 YRS AVG	9781	376699	12045	3770	148	379426	10743	3813	1892	4872611

Year	SB gear-hours					BB gear-hours				
	Cast net	H&L	Gill net	Spear	H&G	Bottom	Spear	SCUBA	Gill net	Troll
20 YRS SD	5692	356721	19366	6304	143	442579	17348	5724	3271	3770303

1.2.9 Participants

This section summarizes the estimated number of participants in each fishery type. The information presented here can be used in the impact analysis of potential amendments in the FEPs associated with the bottomfish and coral reef fisheries. The trend in the number of participants over time can also be used as an indicator for fishing pressure.

Calculations:

For Boat-based: Estimated number of participants is calculated by using and average number of fishers out fishing per day multiplied by the numbers of dates in the calendar year by gear type. The total is a combination of weekend and weekday stratum estimates.

For Shore-based: Estimated number of participants is calculated by using and average number of fishers out fishing per day multiplied by the numbers of dates in the calendar year by gear type. The total is a combination of weekend, weekday, day and night stratum estimates.

Table 37. Number of boats participating in the bottomfish fishery and number of gear in the boat and shore-based coral reef fishery. Cells marked with * indicates data is confidential due to less than three entities surveyed or reported.

Year	Bottomfish		Coral Reef BB				Coral Reef SB Fishery				
	No. of fishers	No. of Gears	Spear	SCUBA	Gill net	Troll	H&L	Throw	Gill	Spear	H&G
1982	865	798	1095	365		920					NULL
1983	820	709	852	533		955					NULL
1984	977	847	1519	701	732	1022	101016	18141	18523	7065	2101
1985	971	883	1326	852	1460	952	120562	32345	37904	21282	3931
1986	918	794	913	1049	1095	975	90441	21308	46996	19236	2072
1987	874	829	712	830	1095	964	108511	25715	49381	18297	1978
1988	975	903	987	864	824	1151	98891	23518	42645	25360	5242
1989	931	869	1156	1065	730	1122	125421	26558	28505	10985	4310
1990	1002	883	1338	1116	1004	1247	101800	23666	32991	11233	2896
1991	1049	843	1241	1136	962	1287	215674	39177	64483	15087	6002
1992	1067	886	1330	1243	1098	1335	18693	38170	7674	18606	3673

Year	Bottomfish		Coral Reef BB				Coral Reef SB Fishery				
	No. of fishers	**No. of Gears**	**Spear**	**SCUBA**	**Gill net**	**Troll**	**H&L**	**Throw**	**Gill**	**Spear**	**H&G**
							9		0		
1993	1028	910	1191	1359	776	1236	189891	41884	46720	19527	6296
1994	1103	947	1204	1278	791	1217	217996	33762	43891	18615	4015
1995	1327	1275	1062	1362	1137	1239	246531	37900	48269	21453	7956
1996	1609	1562	1074	1311	864	1253	252664	24115	32650	16408	7127
1997	1816	1581	1033	1406	1000	1215	210044	27784	29222	12944	2550
1998	1393	1305	1046	1396	960	1164	158460	37500	54300	22920	6780
1999	1441	1387	1181	1426	1121	1121	217454	24670	46892	37939	8116
2000	1391	1321	1075	1303	1236	1103	129407	18666	23163	17202	3712
2001	1043	1078	1178	1309	1235	1090	120039	18980	17839	12957	3513
2002	1197	1037	1019	1294	986	1030	90023	17893	12301	7688	1258
2003	924	1092	1344	1488	1095	1127	89197	21763	15239	11908	958
2004	1229	1121	990	1298	854	1011	80756	13365	17001	10720	708
2005	974	965	1019	1251	803	1114	75783	17109	11452	7574	3422
2006	918	956	1153	949	730	1068	71494	21033	14691	12729	3376
2007	1217	1034	1011	1278	730	1166	70126	15512	10631	8669	4152
2008	971	950	1168	1220	961	1141	76860	14365	9150	7961	2287
2009	915	1022	1173	1338	1049	954	89557	17194	10158	6477	4194
2010	964	1040	1081	1095	1773	1024	72969	14491	9133	8760	2609
2011	1008	1001	1363	1369	730	979	74916	14463	7026	6387	2601
2012	1001	953	1007	1708	952	992	98008	15277	14895	7877	2721
2013	1113	1150	1430	973	1209	925	73062	14538	15330	12814	1957
2014	1135	1262	1417	973	1399	947	63891	12664	8950	10617	1857
2015	1180	1095	1417	2281	1186	956	53746	11771	11406	11041	1962
2016	1213	1175	1127	3311	1412	902	53253	11529	10111	12215	3065
10 YEARS AVG	1068	1072	1219	1555	1140	999	72639	14180	10679	9282	2741

Year	Bottomfish		Coral Reef BB				Coral Reef SB Fishery				
	No. of fishers	No. of Gears	Spear	SCUBA	Gill net	Troll	H&L	Throw	Gill	Spear	H&G
10 YEARS SD	96	107	163	692	310	84	13299	1659	2482	2158	803
20 YEARS AVG	1126	1152	1162	1433	1071	1051	98452	18028	17445	12370	3090
20 YEARS SD	164	221	148	514	257	89	45707	6087	12230	6997	1749

1.2.10 Bycatch estimates

This section focuses on MSA § 303(a)(11), which requires that all FMPs establish a standardized reporting methodology to assess the amount and type of bycatch occurring in the fishery, and include conservation and management measures that, to the extent practicable, minimize bycatch and bycatch mortality. The MSA § 303(a)(11) standardized reporting methodology is commonly referred to as a ‘‘Standardized Bycatch Reporting Methodology’’ (SBRM) and was added to the MSA by the Sustainable Fisheries Act of 1996 (SFA). The Council implemented omnibus amendments to FMPs in 2003 to address MSA bycatch provisions and established SBRMs at that time.

The following are the recent bycatch estimates for the boat-based non-bottomfishing gear (Table 38), bottomfish fishery (Table 39), and shore-based fisheries with all gear-types combined (Table 40).

Calculations:

Numbers caught = Sum of the total number of fish or invertebrates found in the raw interview (catch) data, including bycatch.

Numbers kept = Sum of the total number of fish or invertebrates in the raw data that are not marked as bycatch.

Numbers released = caught - kept

% Bycatch = Sum of all bycatch divided by the total catch.

Table 38. Time series of bycatch estimates in the boat-based non-bottomfishing gear type fisheries. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery.

Year	Numbers caught	Kept	Released	% bycatch
1982	5388	5388	0	0
1983	3581	3581	0	0

Year	Numbers caught	Kept	Released	% bycatch
1984	5584	5584	0	0
1985	8138	8138	0	0
1986	4829	4829	0	0
1987	4895	4895	0	0
1988	8113	8113	0	0
1989	12393	12393	0	0
1990	7645	7645	0	0
1991	9338	9338	0	0
1992	7352	7352	0	0
1993	9398	9398	0	0
1994	9843	9843	0	0
1995	17776	17776	0	0
1996	20931	20931	0	0
1997	19108	19108	0	0
1998	16428	16428	0	0
1999	19827	19827	0	0
2000	23373	23335	38	0.0016
2001	10409	10344	65	0.0062
2002	5560	5520	40	0.0072
2003	8543	8538	5	0.0006
2004	5851	5839	12	0.0021
2005	4012	4006	6	0.0015
2006	7176	7172	4	0.0006
2007	5611	5538	73	0.013
2008	9341	9340	1	0.0001
2009	11710	11707	3	0.0003
2010	8588	8588	0	0
2011	21232	21231	1	0
2012	12199	12199	0	0
2013	11834	11806	28	0.0024
2014	8814	8789	25	0.0028
2015	8995	8995	0	0
2016	10678	10672	6	0.0006
10 YEARS AVG	10900	10887	14	0.0019
10 YEARS SD	3921	3931	22	0.0038
20 YEARS AVG	11464	11449	15	0.002
20 YEARS SD	5485	5489	22	0.0032

Table 39. Time series of bycatch estimates in the bottomfish fishery. Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery.

Year	Numbers caught	Kept	Released	% bycatch
1982	1597	1597	0	0
1983	1507	1507	0	0
1984	3347	3347	0	0
1985	4840	4840	0	0
1986	1624	1624	0	0
1987	2519	2519	0	0
1988	3002	3002	0	0
1989	3562	3562	0	0
1990	2870	2870	0	0
1991	2783	2783	0	0
1992	2527	2527	0	0
1993	2893	2893	0	0
1994	3730	3730	0	0
1995	4985	4985	0	0
1996	5244	5244	0	0
1997	4342	4342	0	0
1998	5138	5138	0	0
1999	4938	4938	0	0
2000	3905	3373	532	0.1362
2001	3896	3273	623	0.1599
2002	2504	2151	353	0.141
2003	1888	1697	191	0.1012
2004	1804	1682	122	0.0676
2005	1706	1640	66	0.0387
2006	2188	2043	145	0.0663
2007	1372	1233	139	0.1013
2008	1657	1536	121	0.073
2009	2851	2774	77	0.027
2010	2588	2559	29	0.0112
2011	2128	2083	45	0.0211
2012	924	887	37	0.04
2013	1222	1178	44	0.036
2014	2452	2283	169	0.0689
2015	1420	1350	70	0.0493
2016	1664	1617	47	0.0282
10 YEARS AVG	1828	1750	78	0.0456
10 YEARS SD	610	605	46	0.0264

Year	Numbers caught	Kept	Released	% bycatch
20 YEARS AVG	2529	2389	141	0.0583
20 YEARS SD	1225	1206	167	0.0471

Table 40. Time series of bycatch estimates in the shore-based fishery (all gears combined). Percent bycatch is calculated from the numbers caught and identified as bycatch versus all caught in the fishery.

Year	Numbers caught	Kept	Released	% bycatch
1984	1845	1845	0	0
1985	10200	10200	0	0
1986	9172	9169	3	0.0003
1987	9860	9860	0	0
1988	16199	16199	0	0
1989	8802	8802	0	0
1990	8817	8817	0	0
1991	9880	9880	0	0
1992	6753	6753	0	0
1993	30916	30916	0	0
1994	6013	6013	0	0
1995	8360	8360	0	0
1996	3385	3385	0	0
1997	9233	9216	17	0.0018
1998	11589	11580	9	0.0008
1999	12503	12441	62	0.005
2000	7861	7831	30	0.0038
2001	8653	8593	60	0.0069
2002	3122	3114	8	0.0026
2003	5364	5345	19	0.0035
2004	2655	2611	44	0.0166
2005	2684	2654	30	0.0112
2006	3928	3851	77	0.0196
2007	3361	3238	123	0.0366
2008	5359	5282	77	0.0144
2009	3254	3160	94	0.0289
2010	4321	4222	99	0.0229
2011	5262	5187	75	0.0143
2012	5590	5559	31	0.0055
2013	3300	2893	407	0.1233
2014	4732	4622	110	0.0232
2015	4823	4775	48	0.01
2016	3904	3782	122	0.0313

10 YEARS AVG	4391	4272	119	0.031
10 YEARS SD	850	913	100	0.0321
20 YEARS AVG	5575	5498	77	0.0191
20 YEARS SD	2821	2848	84	0.026

1.2.11 Number of federal permit holders

In Guam, the following Federal permits are required for fishing in the EEZ:

1.2.11.1 Guam Large Vessel Bottomfish Permit

This permit is required for any large vessel (50 feet or longer in overall length) fishing for, landing, or transshipping bottomfish management unit species in the EEZ seaward of the Territory of Guam. The permit expires one year after the date of issuance. Large vessels are prohibited from bottomfishing in the Guam large vessel prohibited area. Vessel operators must submit a logbook to NMFS within 72 hours after landing.

1.2.11.2 Special Coral Reef Ecosystem Permit

The coral reef ecosystem special permit is required for anyone fishing for coral reef ecosystem management unit species in a low-use MPA, fishing for species on the list of Potentially Harvested Coral Reef Taxa, or using fishing gear not specifically allowed in the regulations. The permit expires one year after the date of issuance. Permit holder must submit a logbook to NMFS within 30 days of each landing of coral reef harvest.

A transshipment permit is required for any receiving vessel used to land or transship potentially harvested coral reef taxa, or any coral reef ecosystem management unit species caught in a low-use MPA. Exceptions to this permit requirement are made for anyone issued a permit to fish under the other western Pacific fishery management plans (pelagic, bottomfish and seamount groundfish, crustacean, or precious corals) who catch coral reef management unit species incidentally while fishing for the management unit species covered by the permit they possess. Permit holders must submit a logbook to NMFS within seven days following the date the vessel arrived in port to land transshipped fish. Regulations governing this fishery can be found in the Code of Federal Regulations, Title 50, Part 665.

1.2.11.3 Western Pacific Precious Corals Permit

This permit is required for anyone harvesting or landing black, bamboo, pink, red, or gold corals in the EEZ in the western Pacific. The permit expires one year from the date of issuance. Permit holders must submit a logbook to NMFS within 72 hours of landing. Specific conditions are associated with various established, provisional, and exploratory areas throughout the region.

1.2.11.4 Western Pacific Crustaceans Permit (Lobster or Deepwater Shrimp)

A permit is required by the owner of a U.S. fishing vessel used to fish for lobster or deepwater shrimp in the EEZ around American Samoa, Guam, Hawaii, and the Pacific Remote Islands Areas, and in the EEZ seaward of 3 nautical miles of the shoreline of the Northern Mariana Islands. The permit expires one year after the date of issuance. Permit holders must submit a logbook to NMFS within 72 hours of landing (except when fishing in the Pacific Remote Island Areas – those reports are due within 30 days).

There is no record of special coral reef or precious coral fishery permits issued for the EEZ around Guam since 2007. Table 41 provides the number of permits issued for Guam fisheries between 2007 and 2017. Historical data are from the PIFSC accessed on February 9, 2017 and 2017 data are from the PIRO Sustainable Fisheries Division permits program as of February 3, 2017.

Table 41. Number of federal permits holders between 2007 and 2017 for the crustacean and bottomfish fisheries of Guam

Guam Fisheries	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Lobster	1	6*	*4							1**	
Shrimp				2*	*1					1	
Bottomfish	1	2	2	1	1	4	2	2	1	1	1

*Permits apply to multiple areas and may include American Samoa, Guam, CNMI, and PRIA.

**Area 5 CNMI and Guam

1.2.12 Status Determination Criteria

1.2.12.1 Bottomfish Fishery

Overfishing criteria and control rules are specified and applied to individual species within the multi-species stock whenever possible. When this is not possible, they are based on an indicator species for the multi-species stock. It is important to recognize that individual species would be affected differently based on this type of control rule, and it is important that for any given species fishing, mortality does not currently exceed a level that would result in excessive depletion of that species. No indicator species are being used for the bottomfish multi-species stock complexes and the coral reef species complex. Instead, the control rules are applied to each stock complex as a whole.

The MSY control rule is used as the maximum fishing mortality threshold (MFMT). The MFMT and minimum stock size threshold (MSST) are specified based on recommendations in Restrepo et al. (1998) and both are dependent on the natural mortality rate (M) (Table 42). The value of M used to determine the reference point values are not specified in this document. The latest estimate, published annually in the SAFE report, is used and the value is occasionally re-estimated using the best available information. The range of M among species within a stock complex is taken into consideration when estimating and choosing the M to be used for the purpose of computing the reference point values.

In addition to the thresholds MFMT and MSST, a warning reference point, B_{FLAG}, is specified at some point above the MSST to provide a trigger for consideration of management action prior to B reaching the threshold. MFMT, MSST, and B_{FLAG} are specified as indicated in Table 44.

Table 42. Overfishing threshold specifications for the bottomfish management unit species in Guam

MFMT	MSST	B_{FLAG}
$F(B) = \frac{F_{MSY} B}{c\, B_{MSY}}$ for $B \le c\, B_{MSY}$ $F(B) = F_{MSY}$ for $B > c\, B_{MSY}$	$c\, B_{MSY}$	B_{MSY}
where c = max (1-M, 0.5)		

Standardized values of fishing effort (E) and catch-per-unit-effort (CPUE) are used as proxies for F and B, respectively, so E_{MSY}, $CPUE_{MSY}$, and $CPUE_{FLAG}$ are used as proxies for F_{MSY}, B_{MSY}, and B_{FLAG}, respectively.

In cases where reliable estimates of $CPUE_{MSY}$ and E_{MSY} are not available, they will be estimated from catch and effort times series, standardized for all identifiable biases. $CPUE_{MSY}$ would be calculated as half of a multi-year average reference CPUE, called $CPUE_{REF}$. The multi-year reference window would be objectively positioned in time to maximize the value of $CPUE_{REF}$. E_{MSY} would be calculated using the same approach or, following Restrepo et al. (1998), by setting E_{MSY} equal to E_{AVE}, where E_{AVE} represents the long-term average effort prior to declines in CPUE. When multiple estimates are available, the more precautionary one is used.

Since the MSY control rule specified here applies to multi-species stock complexes, it is important to ensure that no particular species within the complex has a mortality rate that leads to excessive depletion. In order to accomplish this, a secondary set of reference points is specified to evaluate stock status with respect to recruitment overfishing. A secondary “recruitment overfishing” control rule is specified to control fishing mortality with respect to that status. The rule applies only to those component stocks (species) for which adequate data are available. The ratio of a current spawning stock biomass proxy (SSB_{Pt}) to a given reference level (SSB_{PREF}) is used to determine if individual stocks are experiencing recruitment overfishing. SSBP is CPUE scaled by percent mature fish in the catch. When the ratio SSB_{Pt}/SSB_{PREF}, or the “SSBP ratio” (SSBPR) for any species drops below a certain limit ($SSBPR_{MIN}$), that species is considered to be recruitment overfished and management measures will be implemented to reduce fishing mortality on that species. The rule applies only when the SSBP ratio drops below the $SSBPR_{MIN}$, but it will continue to apply until the ratio achieves the “SSBP ratio recovery target” ($SSBPR_{TARGET}$), which is set at a level no less than SSB_{PRMIN}. These two reference points and their associated recruitment overfishing control rule, which prescribe a target fishing mortality rate ($F_{RO-REBUILD}$) as a function of the SSBP ratio, are specified as indicated in Table 43. Again, E_{MSY} is used as a proxy for F_{MSY}.

Table 43. Rebuilding control rules for the bottomfish management unit species in Guam

$F_{RO-REBUILD}$	$SSBPR_{MIN}$	$SSBPR_{TARGET}$

$F(SSBPR) = 0$ for $SSBPR \leq 0.10$ $F(SSBPR) = 0.2\,F_{MSY}$ for $0.10 < SSBPR \leq SSBPR_{MIN}$ $F(SSBPR) = 0.5\,F_{MSY}$ for $SSBPR_{MIN} < SSBPR \leq SSBPR_{TARGET}$	0.20	0.30

1.2.12.2 Coral Reef Fishery

Available biological and fishery data are poor for all coral reef ecosystem management unit species in the Mariana Islands. There is scant information on the life histories, ecosystem dynamics, fishery impact, community structure changes, yield potential, and management reference points for many coral reef ecosystem species. Additionally, total fishing effort cannot be adequately partitioned between the various management unit species (MUS) for any fishery or area. Biomass, maximum sustainable yield, and fishing mortality estimates are not available for any single MUS. Once these data are available, fishery managers can establish limits and reference points based on the multi-species coral reef ecosystem as a whole.

When possible, the MSY control rule should be applied to the individual species in a multi-species stock. When this is not possible, MSY may be specified for one or more species; these values can then be used as indicators for the multi-species stock's MSY.

Individual species that are part of a multi-species complex will respond differently to an OY-determined level of fishing effort (F_{OY}). Thus, for a species complex that is fished at F_{OY}, managers still must track individual species' mortality rates in order to prevent species-specific population declines that would lead to depletion.

For the coral reef fishery, the multi-species complex as a whole is used to establish limits and reference points for each area. When possible, available data for a particular species are used to evaluate the status of individual MUS stocks in order to prevent recruitment overfishing. When better data and the appropriate multi-species stock assessment methodologies become available, all stocks will be evaluated independently, without proxy.

Establishing Reference Point Values

Standardized values of catch per unit effort (CPUE) and effort (E) are used to establish limit and reference point values, which act as proxies for relative biomass and fishing mortality, respectively. Limits and reference points are calculated in terms of $CPUE_{MSY}$ and E_{MSY} included in Table 44.

Table 44. Status determination criteria for the coral reef management unit species using CPUE based proxies

Value	Proxy	Explanation
MaxFMT (F_{MSY})	E_{MSY}	0.91 $CPUE_{MSY}$
F_{OY}	0.75 E_{MSY}	suggested default scaling for target
B_{MSY}	$CPUE_{MSY}$	operational counterpart
B_{OY}	1.3 $CPUE_{MSY}$	simulation results from Mace (1994)
MinSST	0.7 $CPUE_{MSY}$	suggested default (1-M)B_{MSY} with M=0.3*
B_{FLAG}	0.91 $CPUE_{MSY}$	suggested default (1-M)B_{OY} with M=0.3*

When reliable estimates of E_{MSY} and $CPUE_{MSY}$ are not available, they are generated from time series of catch and effort values, standardized for all identifiable biases using the best available analytical tools. $CPUE_{MSY}$ is calculated as one-half a multi-year moving average reference CPUE ($CPUE_{REF}$).

1.2.12.3 Current Stock Status

1.2.12.3.1 Bottomfish

Biological and other fishery data are poor for all bottomfish species in the Mariana Archipelago. Generally, data are only available on commercial landings by species and catch-per-unit-effort (CPUE) for the multi-species complexes as a whole. At this time it is not possible to partition these effort measures among the various bottomfish MUS. The most recent stock assessment update (Yau et al. 2015) for the Guam bottomfish management unit species complex (comprised of 17 species of shallow and deep species of snapper, grouper, jacks, and emperors) was based on estimate of total catch, an abundance index derived from the nominal CPUE generated from the creel surveys, and a fishery-independent point estimate of MSY from the Our Living Oceans Report (Humphreys and Moffitt 1999, Moffitt & Humphreys 2009). The assessment utilized a state-space surplus production model with explicit process and observation error terms (Meyer and Millar 1999). Determinations of overfishing and overfished status can then be made by comparing current biomass and harvest rates to MSY level reference points. To date, the Guam BMUS is not subject to overfishing and is not overfished (Table 45).

Table 45. Stock assessment parameters for the Guam BMUS complex (Yau et al 2015)

Parameter	Value	Notes	Status
MSY	56.13 ± 7.79	Expressed in 1000 lbs (± std error)	
H_{2013}	0.123	Expressed in percentage	
H_{MSY}	0.352 ± 0.059	Expressed in percentage (± std error)	
H/H_{MSY}	0.356		No overfishing occurring
B_{2013}	264.7	Expressed in thousand pounds	
B_{MSY}	162.3 ± 23.8	Expressed in 1000 lbs (± std error)	
B/ B_{MSY}	1.63		Not overfished

1.2.12.3.2 Coral reef

The application of the SDCs for the management unit species in the coral reef fisheries is limited due to various challenges. First, the thousands of species included in the coral reef MUS makes the SDC and status determination impractical. Second, the CPUE derived from the creel survey is based on the fishing method and there is no species-specific CPUE information available. In order to allocate the fishing method level CPUE to individual species, the catch data (the value of catch is derived from CPUE hence there is collinearity) will have to be identified to species level and CPUE will be parsed out by species composition. The third challenge is that there is very little species-level identification applied to the creel surveys. There has been no attempt to estimate MSY for the coral reef MUS until the 2007 re-authorization of MSA that requires the Council to specify ACLs for species in the FEPs.

For ACL specification purposes, MSYs in the coral reef fisheries are determined by using the Biomass-Augmented Catch-MSY approach (Sabater and Kleiber 2014). This method estimates MSY using plausible combination rates of population increase (denoted by r) and carrying capacity (denoted by k) assumed from the catch time series, resilience characteristics (from FishBase), and biomass from existing underwater census surveys done by the Pacific Island Fisheries Science Center. This method was applied to species complexes grouped by taxonomic families. The most recent MSY estimates are found in Table 46. The SSC utilized the MSYs for the coral reef MUS complexes as the OFLs.

Table 46. Best available MSY estimates for the coral reef MUS in Guam

Coral Reef MUS Complex	**MSY (lbs)**
Selar crumenophthalmus – atulai or bigeye scad	61,300
Acanthuridae – surgeonfish	118,000
Carangidae – jacks	31,700
Crustaceans – crabs	8,600
Holocentridae – squirrelfish	13,900
Kyphosidae – chubs/rudderfish	10,300
Labridae – wrasses[1]	28,500
Lethrinidae – emperors	78,000
Lutjanidae – snappers	21,800
Mollusks – turbo snail; octopus; giant clams	29,000
Mugilidae – mullets	26,200
Mullidae – goatfish	16,400
Scaridae – parrotfish[2]	87,100
Serranidae – groupers	28,600
Siganidae – rabbitfish	19,700
All Other CREMUS Combined - Other CRE-finfish - Other invertebrates - Misc. bottomfish - Misc. reef fish - Misc. shallow bottomfish	211,300
Cheilinus undulatus – humphead (Napoleon) wrasse	N.A.
Bolbometopon muricatum – bumphead parrotfish	N.A.
Carcharhinidae – reef sharks	2,900

1.2.13 Overfishing Limit, Acceptable Biological Catch, and Annual Catch Limits

1.2.13.1 Brief description of the ACL process

The Council developed a Tiered system of control rules to guide the specification of ACLs and Accountability Measures (AMs) (WPRFMC 2011). The process starts with the use of the best scientific information available (BSIA) in the form of, but not limited to, stock assessments, published paper, reports, or available data. These information are classified to the different Tiers in the control rule ranging from Tier 1 (most information available typically an assessment) to Tier 5 (catch-only information). The control rules are applied to the BSIA. Tiers 1 to 3 would involve conducting a Risk of Overfishing Analysis (denoted by P*) to quantify the scientific uncertainties around the assessment to specify the Acceptable Biological Catch (ABC). This would lower the ABC from the OFL (MSY-based). A Social, Ecological, Economic, and Management (SEEM) Uncertainty Analysis is performed to quantify the uncertainties from the SEEM factors. The buffer is used to lower the ACL from the ABC. For Tier 4 which are stocks with MSY estimates but no active fisheries, the control rule is 91% of MSY. For Tier 5 which has catch-only information, the control rule is a third reduction in the median catch depending on the qualitative evaluation on what the stock status is based on expert opinion. ACL specification can choose from a variety of method including the above-mentioned SEEM analysis or a percentage buffer (% reduction from ABC based on expert opinion) or the use of an Annual Catch Target. Specifications are done on an annual basis but the Council normally specifies a multi-year specification.

The Accountability Measure for the coral reef and bottomfish fisheries in Guam is an overage adjustment. The ACL is downward adjusted with the amount of overage from the ACL based on a three-year running average.

1.2.13.2 Current OFL, ABC, ACL, and recent catch

The most recent multiyear specification of OFL, ABC, and ACL for the coral reef fishery was completed in the 160th Council meeting on June 25 to 27, 2014. The specification covers fishing year 2015, 2016, 2017, and 2018 for the coral reef MUS complexes. A P* and SEEM analysis was performed for this multiyear specification (NMFS 2015). For the bottomfish, it was a roll over from the previous specification since an assessment update was not available for fishing year 2015.

Table 47. Mariana Archipelago – Guam ACL table with 2016 catch (values are in pounds)

Fishery	MUS	OFL	ABC	ACL	Catch
Bottomfish	Bottomfish multi-species complex	71,000	66,800	66,800	22,727
Crustacean	Deepwater shrimp	N.A.	48,488	48,488	
	Spiny lobster	4,600	3,300	3,135	876
	Slipper lobster	N.A.	20	20	0
	Kona crab	N.A.	1,900	1,900	
Precious coral	Black coral	8,250	700	700	
	Precious coral in CNMI expl. area	N.A.	2,205	2,205	
Coral Reef	*Selar crumenophthalmus*	61,300	52,300	50,200	16,423
	Acanthuridae-surgeonfish	118,000	101,700	97,600	20,146
	Carangidae-jacks	31,700	29,900	21,201	26,607
	Crustaceans-crabs	8,600	7,600	7,300	1,320
	Holocentridae-squirrelfish	13,900	12,000	11,400	2,631
	Kyphosidae-rudderfish	10,300	9,800	9,600	6,249
	Labridae-wrasse	28,500	25,800	25,200	2,168
	Lethrinidae-emperors	78,000	58,000	53,000	21,141
	Lutjanidae-snappers	21,800	18,600	18,000	5,783
	Mollusk-turbo snails; octopus; clams	29,000	25,000	23,800	10,708
	Mugilidae-mullets	26,200	19,400	17,900	831
	Mullidae-goatfish	16,400	15,600	15,300	9,370

	Scaridae-parrotfish	87,100	75,000	71,600	8,269
	Serranidae-groupers	28,600	23,700	22,500	6,281
	Siganidae-rabbitfish	19,700	19,500	18,600	7,043
	All other CREMUS combined	211,300	191,300	185,000	49,402
	Cheilinus undulatus	N.A.	1,960	1,960	106
	Bolbometopon muricatum	N.A.	797	797*	
	Carcharhinidae-reef sharks	2,900	2,000	1,900	1,578

NOTE: *The ACL for *B. muricatum* is shared with CNMI (1 ACL for the whole archipelago)

The catch shown in Table 47 takes the average of the recent three years as recommended by the Council at its 160th meeting to avoid large fluctuations in catch due to data quality and outliers. NAF indicates no active fisheries as of date.

The ACL for jacks was reduced from 29,300 lbs in 2015 to 21,201 lbs for 2016 due to the overage in 2015 of 8,099 lbs because of the spike in catch in 2013 of 59,468 lbs. NMFS applied the reduction to the ACL by the amount of the overage (82 FR 5517 2017-01-18) based on the Council's accountability measure for this data poor stock.

1.2.14 Best scientific information available

1.2.14.1 Bottomfish fishery

1.2.14.1.1 Stock assessment benchmark

The benchmark stock assessment for the Territory Bottomfish Management Unit Species complex was developed and finalized in October 2007 (Moffitt et al. 2007). This benchmark utilized a Bayesian statistical framework to estimate parameters of a Schaefer model fit to a time series of annual CPUE statistics. The surplus production model included process error in biomass production dynamics and observation error in the CPUE data. This was an improvement to the previous approach of using index-based proxies for B_{MSY} and F_{MSY}. Best available information for the bottomfish stock assessment is as follows:

Input data: The CPUE and catch data used were from the Guam off-shore creel survey. The catch and CPUE were expanded on an annual level. CPUE was expressed in line-hours. The data was screened for trips that landed more than 50% BMUS species using the handline gear.

Model: state-space model with explicit process and observation error terms (see Meyer and Millar, 1999).

Fishery independent source for biomass: point estimate of MSY from the Our Living Oceans Report (Humphreys and Moffitt 1999, Moffitt & Humphreys 2009)

1.2.14.1.2 Stock assessment updates

Updates to the 2007 benchmark done in 2012 (Brodziak et al. 2012) and 2015 (Yau et al. 2015). These included a three-year stock projection table used for selecting the level of risk the fishery will be managed under ACLs. Yau et al. (2015) is considered the best scientific information available for the Territory bottomfish MUS complex after undergoing a WPSAR Tier 3 panel review (Franklin et al. 2015). This was the basis for the P* analysis and SEEM analysis that determined the risk levels to specify ABCs and ACLs.

1.2.14.1.3 Other information available

Approximately every five years PIFSC administers a socioeconomic survey to small boat fishermen in Guam. This survey consists of about 60 questions regarding a variety of topics, including fishing experiences, market participation, vessels and gear, demographics and household income, and fishermen perspectives. The survey requests participants to identify which MUS they primarily targeted during the previous 12 months, by percentage of trips. Full reports of these surveys can be found at the PIFSC Socioeconomics webpage (Hospital and Beavers 2011)

1.2.14.2 Coral reef fishery

1.2.14.2.1 Stock assessment benchmark

No stock assessment has been generated for the coral reef fisheries. The SDCs using index-based proxies were tested for its applicability in the different MUS in the coral reef fisheries (Hawhee 2007). This analysis was done on a gear level. It paints a dire situation for the shore-based fishery with 43% of the gear/species combination falling below Bflag and 33% below MSST with most catch and CPUE trends showing a decline over time. The off-shore fisheries were shown to be less dire with 50% of the gear/species combination falling below Bflag and 38% below MSST - but the catch and CPUE trends were increasing over time. The inconsistency in the CPUE and catch trends with the SDC results makes this type of assessment to be unreliable.

The first attempt to use a model-based approach in assessing the coral reef MUS complexes was done in 2014 using a biomass-based population dynamics model (Sabater and Kleiber 2014). This model was based on the original Martell and Froese (2012) model but was augmented with biomass information to relax the assumption behind carrying capacity. It estimates MSY based on a range of rate of population growth (*r*) and carrying capacity (K) values. The best available information for the coral reef stock assessment is as follows:

Input data: The catch data was derived from the inshore and off-shore creel surveys. Commercial receipt book information was also used in combination with the creel data. A downward adjustment was done to address for potential overlap due to double reporting.

Model: Biomass Augmented Catch MSY approach based on the original catch-MSY model (Martell and Froese 2012; Sabater and Kleiber 2014).

Fishery independent source for biomass: biomass density from the Rapid Assessment and Monitoring Program of NMFS-CREP was expanded to the hard bottom habitat from 0-30 m (Williams 2010).

This model had undergone a CIE review in 2014 (Cook 2014; Haddon 2014; Jones 2014). This was the basis for the P* analysis that determined the risk levels to specify ABCs

1.2.14.2.2 Stock assessment updates

No updates available for the coral reef MUS complex. However, NMFS-PIFSC is finalizing a length-based model for estimating sustainable yield levels and various biological reference points (Nadon et al. 2015). This can be used on a species level. The Council is also working with a contractor to enhance the BAC-MSY model to incorporate catch, biomass, CPUE, effort, and length-based information in an integrated framework (Martell 2015)

1.2.14.2.3 Other information available

Approximately every five years PIFSC administers a socioeconomic survey to small boat fishermen in Guam. This survey consists of about 60 questions regarding a variety of topics, including fishing experiences, market participation, vessels and gear, demographics and household income, and fishermen perspectives. The survey requests participants to identify which MUS they primarily targeted during the previous 12 months, by percentage of trips. Full reports of these surveys can be found at the PIFSC Socioeconomics webpage (Hospital and Beavers 2011).

PIFSC and the Council conducted a workshop with various stakeholders in CNMI to identify factors and quantify uncertainties associated with the social, economic, ecological, and management of the coral reef fisheries (Sievanen and McCaskey 2014). This was the basis for the SEEM analysis that determined the risk levels to specify ACLs.

1.2.15 Harvest capacity and extent

The MSA defines the term "optimum," with respect to the yield from a fishery, as the amount of fish which:

- will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems.
- is prescribed on the basis of the MSY from the fishery, as reduced by any relevant social, economic, or ecological factor.
- in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the MSY in such a fishery [50 CFR §600.310(f)(1)(i)].

Optimum yield in the coral reef and bottomfish fisheries is prescribed based on the MSY from the stock assessment and the best available scientific information. In the process of specifying ACLs, social, economic, and ecological factors were considered and the uncertainties around those factors defined the management uncertainty buffer between the ABC and ACL. OY for the bottomfish and coral reef fish MUS complexes is defined to be the level of harvest equal to the ACL consistent with the goals and objectives of the Fishery Ecosystem Plans and used by the Council to manage the stock.

The Council recognizes that MSY and OY are long-term values whereas the ACLs are yearly snapshots based on the level of fishing mortality at F_{MSY}. There are situations when the long-term means around MSY are going to be lower than ACLs especially if the stock is known to be productive or relatively pristine or lightly fished. One can have catch levels and catch rates exceeding that of MSY over short-term enough to lower the biomass to a level around the estimated MSY and still not jeopardize the stock. This situation is true for the territory bottomfish multi-species complex.

The harvest extent, in this case, is defined as the level of catch harvested in a fishing year relative to the ACL or OY. The harvest capacity is the level of catch remaining in the annual catch limit that can potentially be used for TALLF. Table 48 summarizes the harvest extent and harvest capacity information for Guam in 2016.

Table 48. Mariana Archipelago – Guam proportion of harvest extent (values are in percentage), defined as the proportion of fishing year landing relative to the ACL or OY, and the harvest capacity, defined as the remaining portion of the ACL or OY that can potentially be harvested in a given fishing year.

Fishery	MUS	ACL	Catch	Harvest extent (%)	Harvest capacity (%)
Bottomfish	Bottomfish multi-species complex	66,800	22,727	34	66
Crustacean	Deepwater shrimp	48,488	N.A.F	0	100
	Spiny lobster	3,135	743	24	76
	Slipper lobster	20	ND		
	Kona crab	1,900	N.A.F		
Precious coral	Black coral	700	N.A.F		
	Precious coral in CNMI expl. area	2,205	N.A.F		
Coral Reef	*Selar crumenophthalmus*	50,200	16,423	33	67
	Acanthuridae-surgeonfish	97,600	20,146	21	79
	Carangidae-jacks	29,300	26,607	125	-25
	Crustaceans-crabs	7,300	1,320	18	82
	Holocentridae-squirrelfish	11,400	2,631	23	77
	Kyphosidae-rudderfish	9,600	6,249	65	35
	Labridae-wrasse	25,200	2,168	9	91
	Lethrinidae-emperors	53,000	21,141	40	60
	Lutjanidae-snappers	18,000	5,783	32	68
	Mollusk-turbo snails; octopus; clams	23,800	10,708	45	55
	Mugilidae-mullets	17,900	831	5	95
	Mullidae-goatfish	15,300	9,370	61	39
	Scaridae-parrotfish	71,600	8,269	12	88
	Serranidae-groupers	22,500	6,281	28	72
	Siganidae-rabbitfish	18,600	7,043	38	62
	All other CREMUS combined	185,000	49,402	27	73
	Cheilinus undulatus	1,960	106	5	95
	Bolbometopon muricatum	797*	ND		
	Carcharhinidae-reef sharks	1,900	1,578	83	17

1.2.16 Other relevant ocean uses and fishery-related information

1.2.16.1 Marine preserves

Guam has 5 locally managed Marine Preserves (MPAs); Achang Reef Flat, in Merizo, Sasa Bay in Piti, Piti Bombholes in Piti, Tumon Bay in Tumon, and Pati Point, located in Yigo. A total of 11.8% of Guam's coastline is within the MPAs.

In 2016, there were 9 cases of illegal fishing in the MPAs involving 17 persons. There was also one illegal fishing arrest, involving spearing of lobsters..

1.2.16.2 Local environmental co-variates

There were 111 high surf advisory days in 2016, a decrease from 122 in 2015. 21 of these dates were during August, normally a month with relatively calm weather conditions.

In early 2010, the U.S. military began exercises in an area south and southeast of Guam designated W-517. W-517 is a special use airspace (SUA) (approximately 14,000 nm2) that overlays deep open ocean approximately 50 miles south-southwest of Guam. Exercises in W-517 generally involve live fire and/or pyrotechnics When W-517 is in use, a notice to mariners (NTM) is issued, and vessels attempting to use the area are advised to be cautious of objects in the water and other small vessels. This discourages access to virtually all banks south of Guam, including Galvez, Santa Rosa, White Tuna, and other popular fishing areas. From 1982-2015, DAWR surveys recorded more than 2930 trolling and bottom fishing trips to these southern banks, an average of more than 83 trips per year. The number of NTM in 2016 was 64, equaling 123 closure days. This compares to 109 closure days in 2015. This certainly impacted the number of available fishing days south of Guam.

1.2.17 Administrative and Regulatory Actions

No actions have been taken for Guam fisheries since the April 2016 Joint FEP Plan Team meeting, as reported to the 166th to 168th Western Pacific Fishery Management Council meetings held June 2016, October 2016, and March 2017. One proposed rule was published as described below.

January 18, 2017 (82 FR 5517). **Pacific Island 2016 Annual Catch Limits and Accountability Measures**. NMFS proposed annual catch limits (ACLs) for Pacific Island bottomfish, crustacean, precious coral, and coral reef ecosystem fisheries, and accountability measures (AMs) to correct or mitigate any overages of catch limits. The proposed ACLs and AMs would be effective for fishing year 2016. The fishing year for each fishery begins on January 1 and ends on December 31, except for precious coral fisheries, which begin July 1 and end on June 30 the following year. Although the 2016 fishing year has ended for most stocks, NMFS evaluates 2016 catches against the 2016 ACLs when data become available in mid-2017. The proposed ACLs and AMs support the long-term sustainability of fishery resources of the U.S. Pacific Islands. The comment period ended February 2, 2017.

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2 ECOSYSTEM CONSIDERATIONS

2.1 CORAL REEF ECOSYSTEM PARAMETERS

2.1.1 Regional Reef Fish Biomass

Description: 'Reef fish biomass' is mean biomass of reef fishes per unit area derived from visual survey data (details of survey program below) between 2009 and 2015.

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

- ✓ American Samoa
- ✓ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ✓ Main Hawaiian Islands
- ✓ Northwest Hawaiian Islands
- ✓ Pacific Remote Island Areas

Spatial Scale:

- ✓ Regional
- ☐ Archipelagic
- ☐ Island
- ☐ Site

Data Source: Data used to generate biomass estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods are described in detail elsewhere (http://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_15-07.pdf), but in brief involve teams of divers conducting stationary point count cylinder (SPC) surveys within a target domain of <30m hard-bottom habitat at each island, stratified by depth zone and, for larger islands, by section of coastline. For consistency among islands, only data from forereef habitats is used here. At each SPC, divers record the number, size and species of all fishes within or passing through paired 15m-diameter cylinders in the course of a standard count procedure. Fish sizes and abundance are converted to biomass using standard length-to-weight conversion parameters, taken largely from FishBase (http://www.fishbase.org), and converted to biomass per unit area, by dividing by the area sampled per survey. Site-level data were pooled into island-scale values by first calculating mean and variance within strata, and then calculating weighted island-scale mean and variance using the formulas given in (Smith et al., 2011), with strata weighted by their respective sizes.

Rationale: Reef Fish biomass, i.e. the weight of fish per unit area has been widely used as an indicator of relative status, and has repeatedly been shown to be changes in fishing pressure, habitat quality, and oceanographic regime.

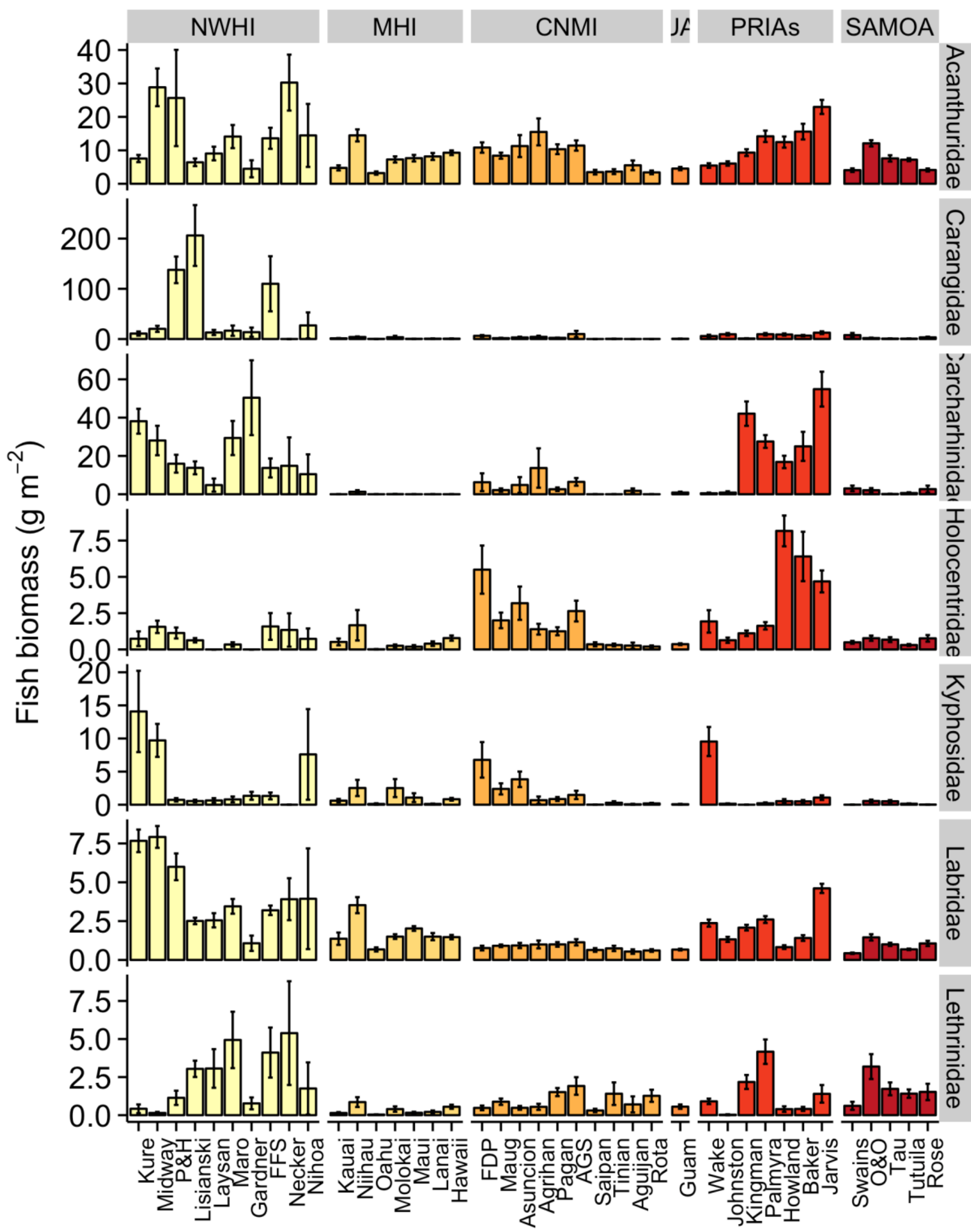
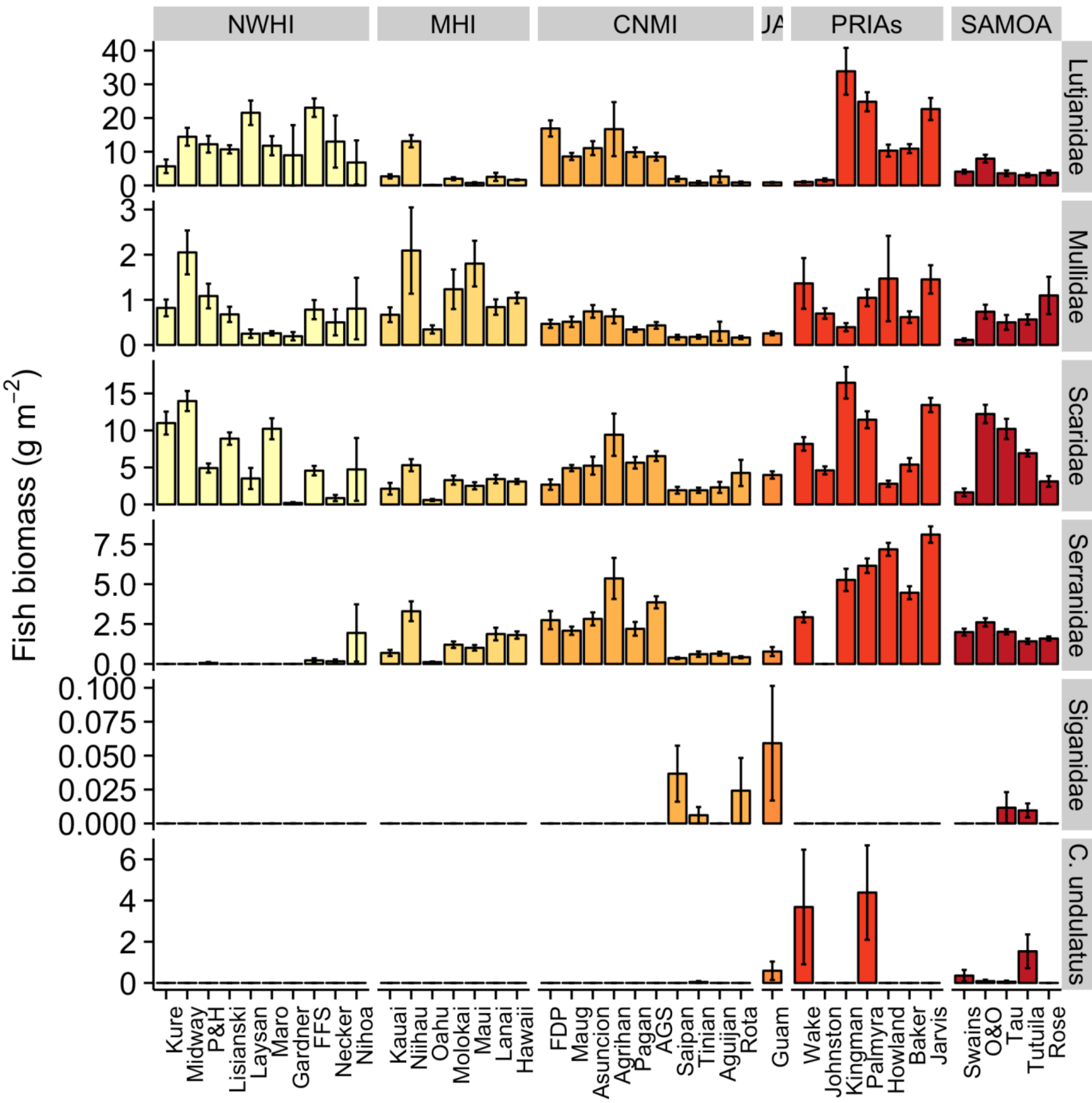


Figure 1. Mean fish biomass by Coral Reef Management Unit Species (CREMUS) grouping per US Pacific reef area. Mean fish biomass (± standard error) per CREMUS grouping per reef area pooled across survey years (2009-2015). Islands ordered within region by latitude. Continues to next page.



2.1.2 CNMI Reef Fish Biomass

Description: 'Reef fish biomass' is mean biomass of reef fishes per unit area derived from visual survey data (details of survey program below) between 2009 and 2015.

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

- ☐ American Samoa
- ☐ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Data used to generate biomass estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods are described in detail elsewhere (http://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_15-07.pdf), but in brief involve teams of divers conducting stationary point count cylinder (SPC) surveys within a target domain of <30m hard-bottom habitat at each island, stratified by depth zone and, for larger islands, by section of coastline. For consistency among islands, only data from forereef habitats is used here. At each SPC, divers record the number, size and species of all fishes within or passing through paired 15m-diameter cylinders in the course of a standard count procedure. Fish sizes and abundance are converted to biomass using standard length-to-weight conversion parameters, taken largely from FishBase (http://www.fishbase.org), and converted to biomass per unit area, by dividing by the area sampled per survey. Site-level data were pooled into island-scale values by first calculating mean and variance within strata, and then calculating weighted island-scale mean and variance using the formulas given in (Smith et al., 2011), with strata weighted by their respective sizes.

Rationale: Reef Fish biomass, i.e. the weight of fish per unit area, has been widely used as an indicator of relative status, and has repeatedly been shown to be changes in fishing pressure, habitat quality, and oceanographic regime.

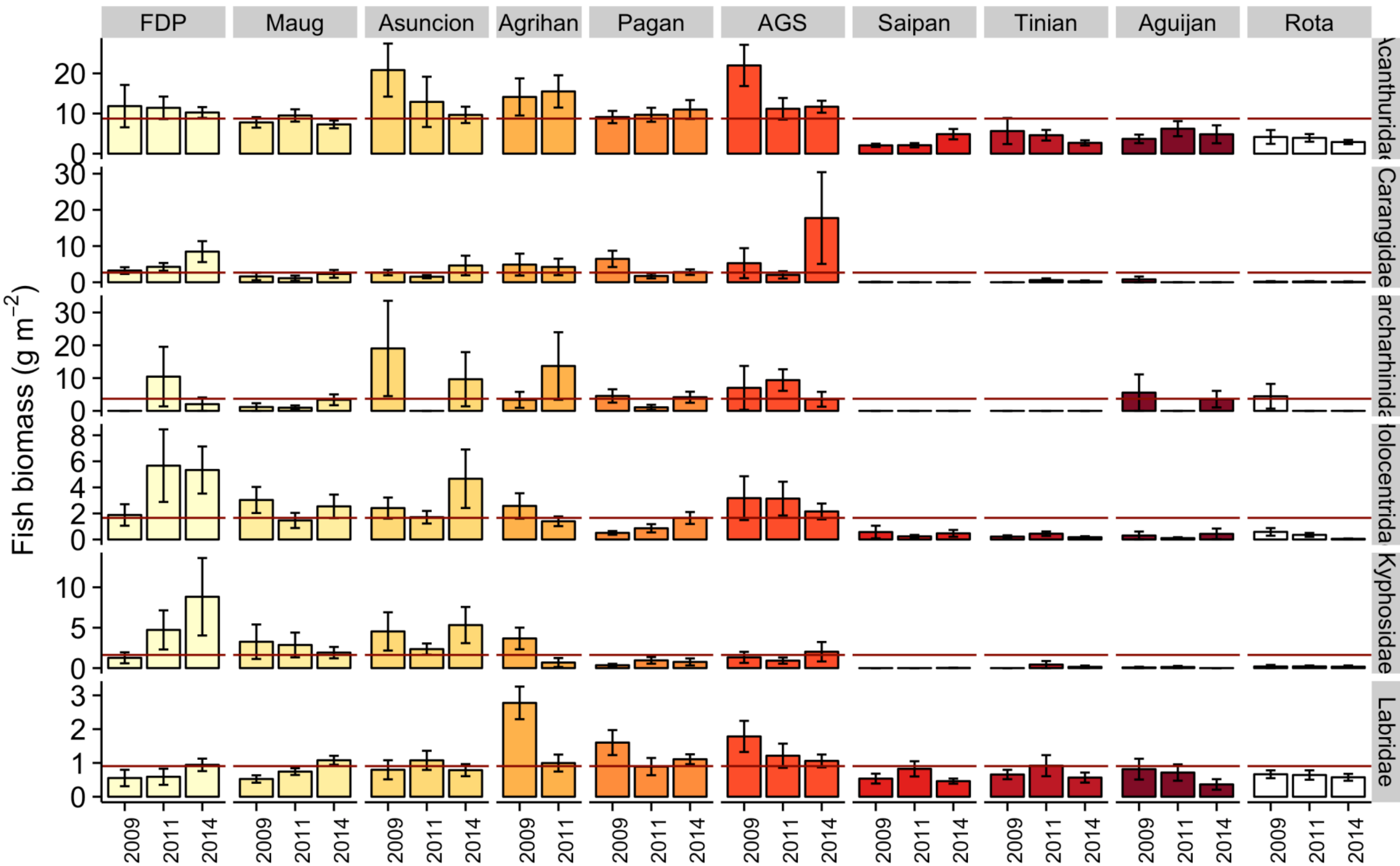
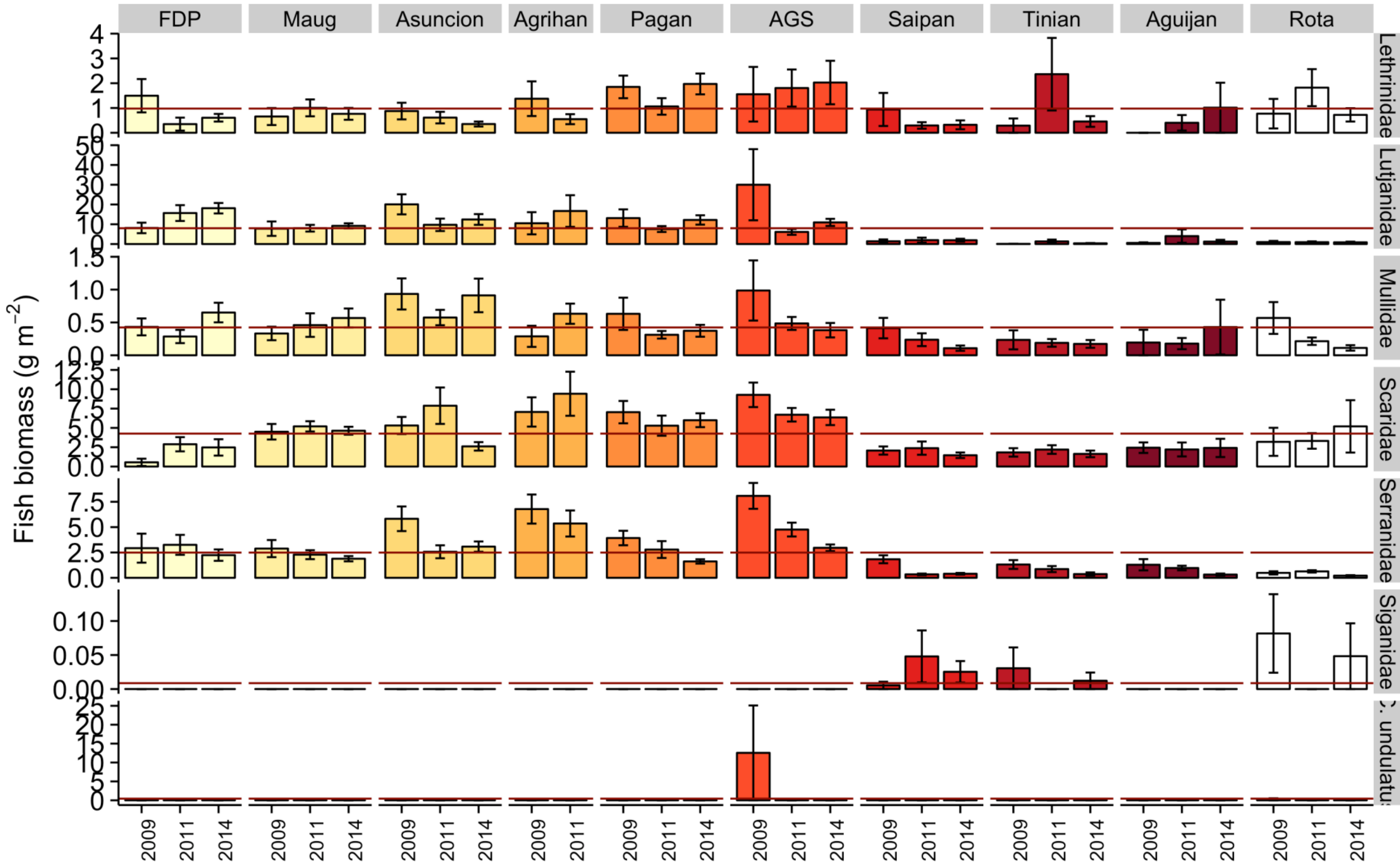


Figure 2. Mariana archipelago mean reef fish biomass. Anatahan, Guguan, and Sarigan have been grouped. Continues to next page.


FDP
Maug
Asuncion
Agrihan
Pagan
AGS
Saipan
Tinian
Aguijan
Rota
Lethrinidae
Lutjanidae
Mullidae
Scaridae
Serranidae
Siganidae
Fish biomass (g m^{-2})
2009
2011
2014

2.1.3 CNMI Archipelagic Mean Fish Size

Description: 'Mean fish size' is mean size of reef fishes > 10 cm TL (i.e. excluding small fishes) derived from visual survey data (details of survey program below) between 2009 and 2015.

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

- ☐ Regional
- ☐ American Samoa
- ☐ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Data used to generate mean size estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods are described in detail elsewhere (http://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_15-07.pdf), but in brief involve teams of divers conducting stationary point count cylinder (SPC) surveys within a target domain of <30m hard-bottom habitat at each island, stratified by depth zone and, for larger islands, by section of coastline. For consistency among islands, only data from forereef habitats is used here. At each SPC, divers record the number, size (total length, TL) and species of all fishes within or passing through paired 15m-diameter cylinders in the course of a standard count procedure. Fishes smaller than 10 cm TL are excluded so that the fish assemblage measured more closely reflects fishes that are potentially fished, and so that mean sizes are not overly influenced by variability in space and time of recent recruitment. Site-level data were pooled into island-scale values by first calculating mean and variance within strata, and then calculating weighted island-scale mean and variance using the formulas given in (Smith et al., 2011), with strata weighted by their respective sizes.

Rationale: Mean size is important as mean size is widely used as an indicator of fishing pressure – not only do fishers sometimes preferentially target large individuals, but also because one effect of fishing is to reduce the number of fishes reaching older (and larger) size classes. Large fishes also contribute disproportionately to community fecundity and can have important ecological roles – for example, excavating bites by large parrotfishes probably have a longer lasting impact on reef benthos than bites by smaller fishes.

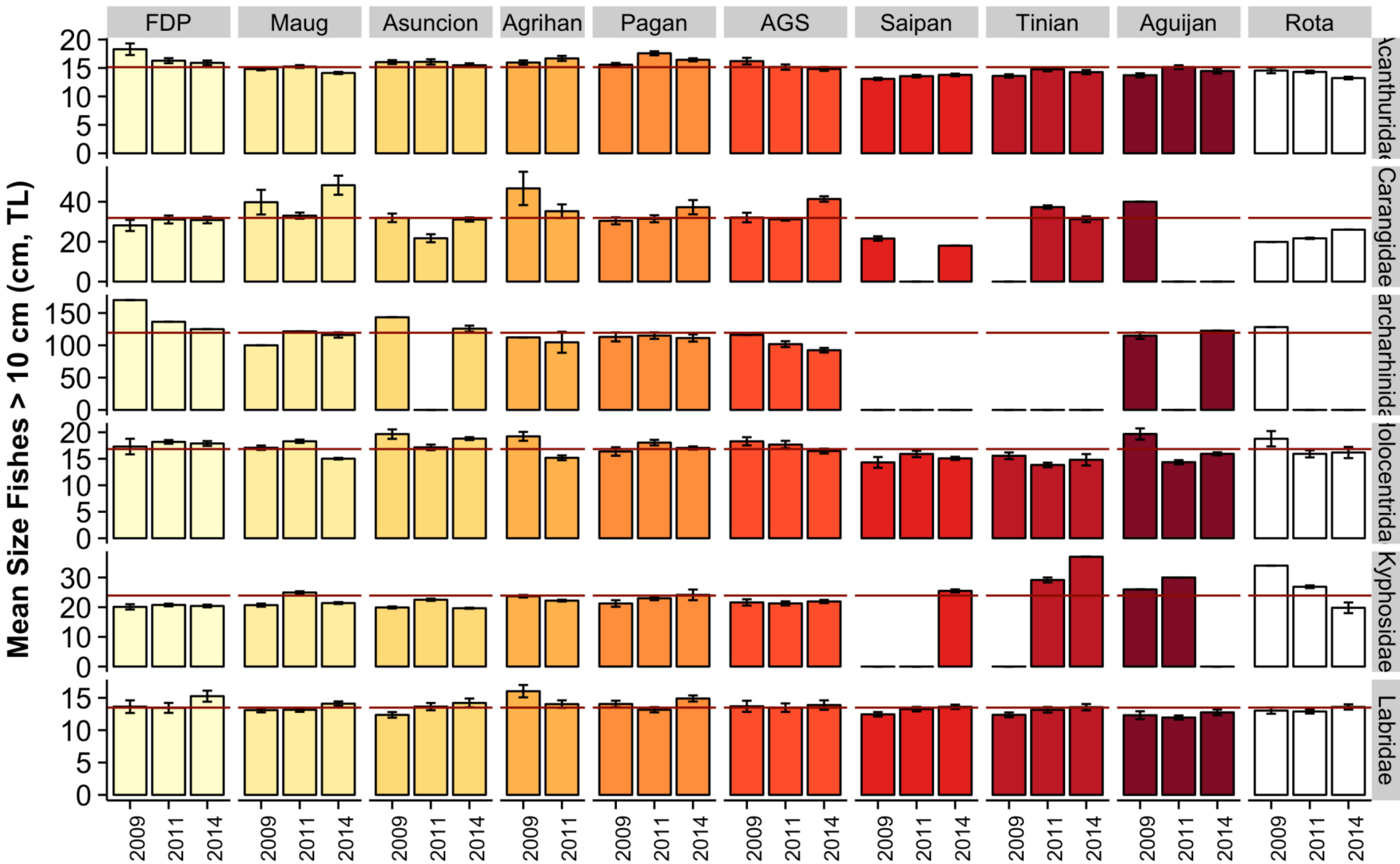
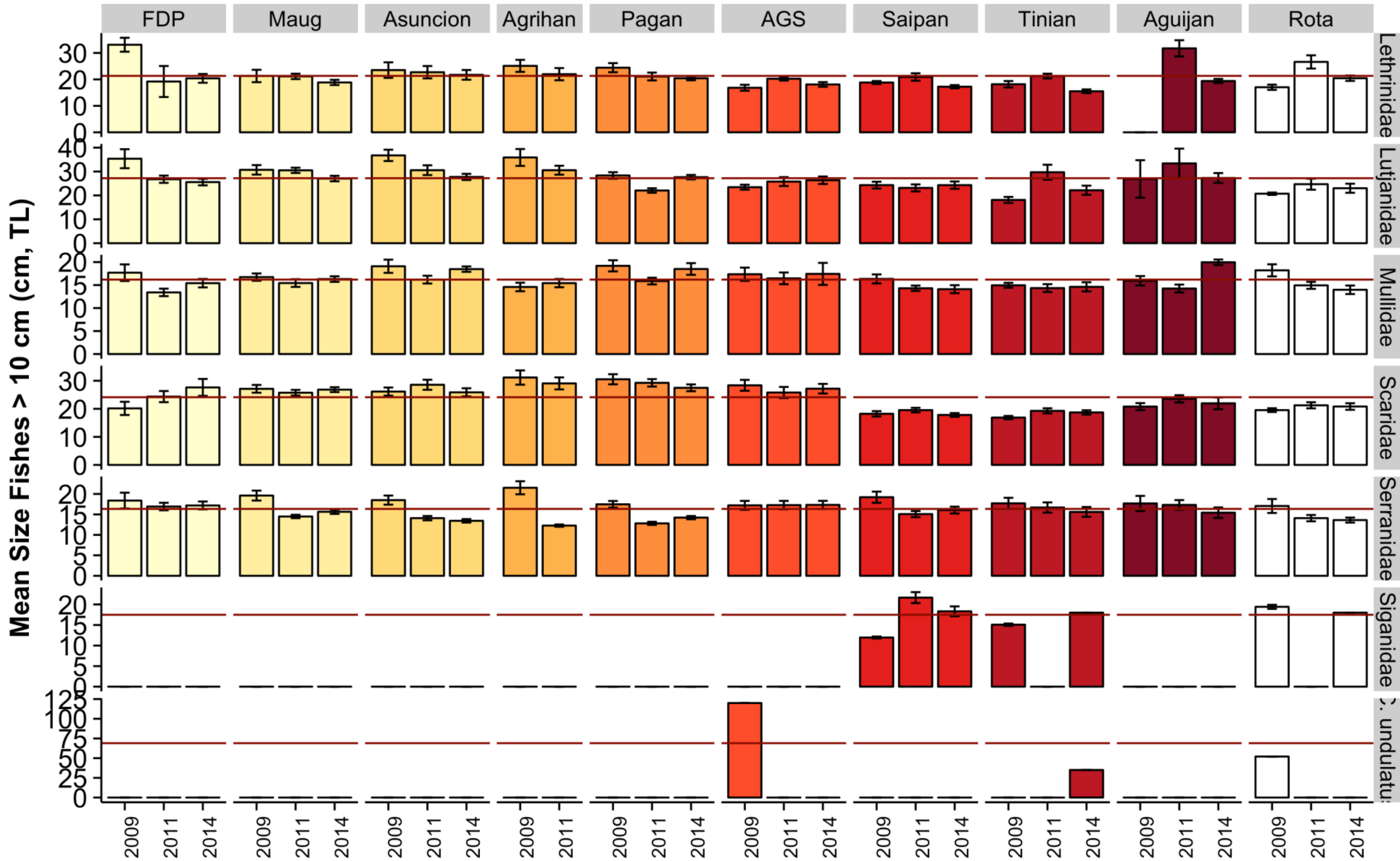


Figure 3. Mariana Archipelago mean fish size. anatahan, Guguan, and Sarigan have been grouped. Continues to next page.


FDP
Maug
Asuncion
Agrihan
Pagan
AGS
Saipan
Tinian
Aguijan
Rota
Lethrinidae
Lutjanidae
Mullidae
Scaridae
Serranidae
Siganidae
C. undulatus
Mean Size Fishes > 10 cm (cm, TL)
2009
2011
2014

2.1.4 CNMI Reef Fish Population Estimates

Description: Reef fish population estimates are made by multiplying mean biomass per unit area by estimated area of hardbottom in a consistent habitat across all islands (specifically, the area of hardbottom forereef habitat in < 30m water).

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

- ☐ Regional
- ☐ American Samoa
- ☐ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Data used to generate mean size estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods and sampling design, and methods to generate reef fish biomass are described above (SECTION: REEF FISH BIOMASS). Those estimates are converted to population estimates by multiplying biomass (g/m2) per island by the estimated area of hardbottom habitat <30m deep at the island, which is the survey domain for the monitoring program that biomass data comes from. Estimated habitat areas per island are derived from GIS bathymetry and habitat maps maintained by NOAA Coral Reef Ecosystems Program. It is important to recognize that many reef fishes taxa are present in other habitats and in deeper water than is surveyed by that program, and even that some taxa likely have the majority of their populations in deeper water. Additionally, fish counts have the potential to be biased by the nature of fish responses to divers: curious fishes, particularly in locations where divers are not perceived as a threat, will tend to be overcounted by visual survey, and skittish fishes will tend to be undercounted. Likely numbers of jacks and sharks in some locations (particularly the NWHI) are overcounted by visual survey.

Nevertheless, in spite of these issues, the data shown here are consistently gathered across space and time.

Rationale: These data have utility in understanding the size of populations from which fishery harvests are extracted.

Table 49. Reef fish population estimates for CNMI.

Note: Fish species are pooled by CREMUS groupings. Estimated population biomass is for 0-30 m hardbottom habitat only. (n) is number of sites surveyed per island. Each site is surveyed by means of two to four, 7.5 m diameter SPCs. However, those are not considered to be independent samples, so data from those is pooled to site level before other analysis. 'AGS' is a combined value for Alamagan, Guguan, and Sarigan. Those three small islands situated between Saipan and Pagan are treated as a single unit by the monitoring program which is the source of visual survey data here.

			ESTIMATED POPULATION BIOMASS (metric Tonnes) in SURVEY DOMAIN OF <30m HARDBOTTOM					
ISLAND	Total Area of reef (Ha)	N	Acanthuridae	Carangidae	Carcharhinids	Holocentridae	Kyphosidae	Labridae
Farallon de Pajaros	138.5	23	15.0	8.8	8.7	7.6	9.4	1.1
Maug	313.9	70	26.4	5.4	6.8	6.3	7.5	2.9
Asuncion	248.6	41	28.0	7.7	12.0	7.9	9.5	2.3
Agrihan	850.6	20	131.9	36.0	116.4	11.9	5.8	8.5
Pagan	1,512.9	72	156.3	34.2	39.6	19.0	13.0	15.1
AGS	743.9	57	85.0	73.6	48.0	19.7	11.0	8.5
Saipan	4,846.6	78	168.5	0.3	-	17.3	0.7	31.2
Tinian	1,414.2	38	51.4	5.9	-	4.4	4.2	10.5
Aguijan	405.6	23	22.4	-	7.2	1.1	0.3	2.2
Rota	1,331.4	52	45.4	2.1	-	2.7	2.5	8.1
TOTAL	**11,806.1**	**474**	**689.4**	**164.1**	**186.0**	**95.5**	**63.5**	**88.8**

ISLAND	Total Area of reef (Ha)	N	Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae	Siganidae
Farallon de Pajaros	138.5	23	0.7	23.4	0.6	3.7	3.8	-
Maug	313.9	70	2.8	27.0	1.6	15.4	6.5	-
Asuncion	248.6	41	1.2	27.5	1.8	13.0	7.0	-
Agrihan	850.6	20	4.7	142.1	5.4	80.1	45.6	-
Pagan	1,512.9	72	22.9	149.6	5.2	85.3	33.3	-
AGS	743.9	57	14.3	63.5	3.2	48.6	28.7	-
Saipan	4,846.6	78	14.9	94.4	8.4	93.1	17.8	1.8
Tinian	1,414.2	38	19.9	11.7	2.6	27.1	8.7	0.1
Aguijan	405.6	23	2.9	10.7	1.2	9.4	2.6	-
Rota	1,331.4	52	16.9	11.9	2.2	56.6	5.6	0.3

TOTAL	**11,806.1**	**474**	**102.1**	**508.8**	**30.5**	**405.3**	**140.4**	**2.3**

Note (1): No *Bolbometopon muricatum* were observed during these surveys in CNMI
(2) *Cheilinus undulatus* were recorded at Tinian (0.7 t)

2.1.5 Guam Reef Fish Biomass

Description: 'Reef fish biomass' is mean biomass of reef fishes per unit area derived from visual survey data (details of survey program below) between 2009 and 2015.

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

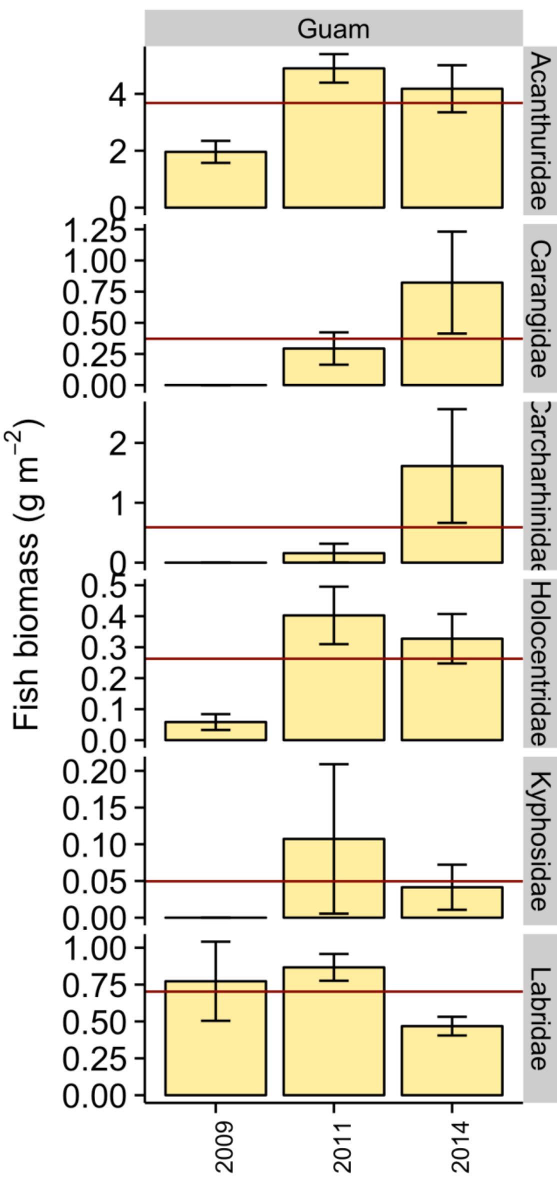
- ☐ American Samoa
- ✓ Guam
- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Data used to generate biomass estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods are described in detail elsewhere (http://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_15-07.pdf), but in brief involve teams of divers conducting stationary point count cylinder (SPC) surveys within a target domain of <30m hard-bottom habitat at each island, stratified by depth zone and, for larger islands, by section of coastline. For consistency among islands, only data from forereef habitats is used here. At each SPC, divers record the number, size and species of all fishes within or passing through paired 15m-diameter cylinders in the course of a standard count procedure. Fish sizes and abundance are converted to biomass using standard length-to-weight conversion parameters, taken largely from FishBase (http://www.fishbase.org), and converted to biomass per unit area, by dividing by the area sampled per survey. Site-level data were pooled into island-scale values by first calculating mean and variance within strata, and then calculating weighted island-scale mean and variance using the formulas given in (Smith et al., 2011), with strata weighted by their respective sizes.

<u>Rationale:</u> Reef Fish biomass, i.e. the weight of fish per unit area has been widely used as an indicator of relative status, and has repeatedly been shown to be changes in fishing pressure, habitat quality, and oceanographic regime.



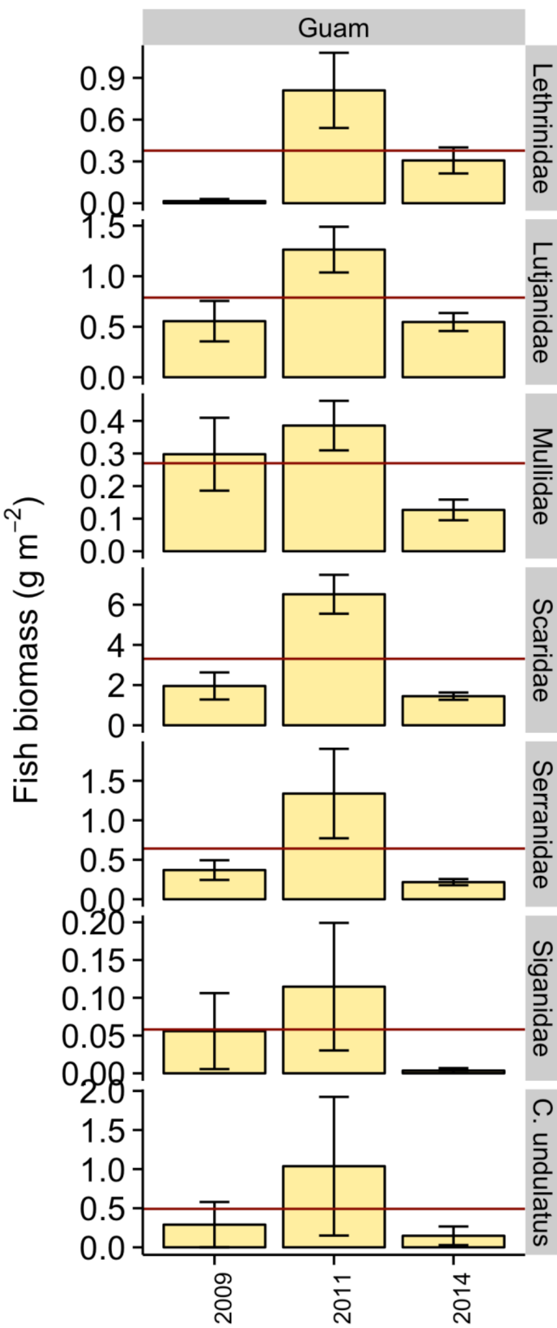


Figure 4. Guam reef fish biomass.

2.1.6 Guam Archipelagic Mean Size

Description: 'Mean fish size' is mean size of reef fishes > 10 cm TL (i.e. excluding small fishes) derived from visual survey data (details of survey program below) between 2009 and 2015 .

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

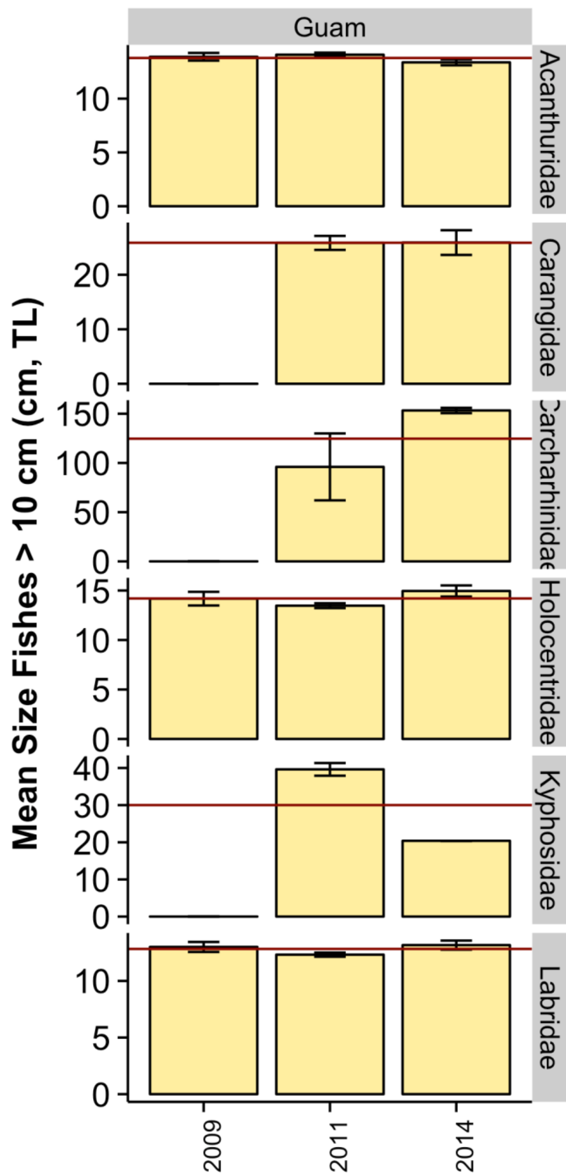
- ☐ Regional
- ☐ American Samoa
- ✓ Guam
- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Data used to generate mean size estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods are described in detail elsewhere (http://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_15-07.pdf), but in brief involve teams of divers conducting stationary point count cylinder (SPC) surveys within a target domain of <30m hard-bottom habitat at each island, stratified by depth zone and, for larger islands, by section of coastline. For consistency among islands, only data from forereef habitats is used here. At each SPC, divers record the number, size (total length, TL) and species of all fishes within or passing through paired 15m-diameter cylinders in the course of a standard count procedure. Fishes smaller than 10 cm TL are excluded so that the fish assemblage measured more closely reflects fishes that are potentially fished, and so that mean sizes are not overly influenced by variability in space and time of recent recruitment. Site-level data were pooled into island-scale values by first calculating mean and variance within strata, and then calculating weighted island-scale mean and variance using the formulas given in (Smith et al., 2011), with strata weighted by their respective sizes.

Rationale: Mean size is important as\mean size is widely used as an indicator of fishing pressure – not only do fishers sometimes preferentially target large individuals, but also because one effect of fishing is to reduce the number of fishes reaching older (and larger) size classes. Large fishes also contribute disproportionately to community fecundity and can have important ecological roles – for example, excavating bites by large parrotfishes probably have a longer lasting impact on reef benthos than bites by smaller fishes.



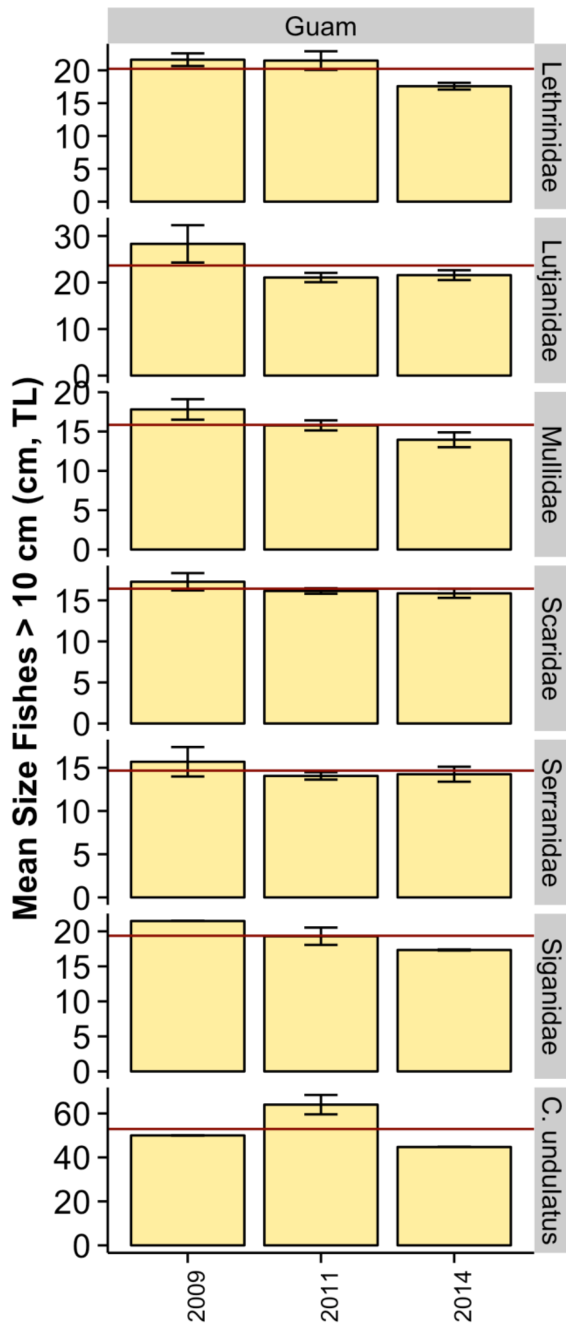


Figure 5. Guam mean fish size.

2.1.7 Guam Reef Fish Population Estimates

Description: Reef fish population estimates are made by multiplying mean biomass per unit area by estimated area of hardbottom in a consistent habitat across all islands (specifically, the area of hardbottom forereef habitat in < 30m water).

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

- ☐ Regional
- ☐ American Samoa
- ✓ Guam
- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Data used to generate mean size estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods and sampling design, and methods to generate reef fish biomass are described above (SECTION: REEF FISH BIOMASS). Those estimates are converted to population estimates by multiplying biomass (g/m2) per island by the estimated area of hardbottom habitat <30m deep at the island, which is the survey domain for the monitoring program that biomass data comes from. Estimated habitat areas per island are derived from GIS bathymetry and habitat maps maintained by NOAA Coral Reef Ecosystems Program. It is important to recognize that many reef fishes taxa are present in other habitats and in deeper water than is surveyed by that program, and even that some taxa likely have the majority of their populations in deeper water. Additionally, fish counts have the potential to be biased by the nature of fish responses to divers: curious fishes, particularly in locations where divers are not perceived as a threat, will tend to be overcounted by visual survey, and skittish fishes will tend to be undercounted. Likely numbers of jacks and sharks in some locations (particularly the NWHI) are overcounted by visual survey. Nevertheless, in spite of these issues, the data shown here are consistently gathered across space and time.

Rationale: These data have utility in understanding the size of populations from which fishery harvests are extracted.

Table 50. Reef fish population estimates for Guam. Fish species are pooled by CREMUS groupings. Estimated population biomass is for 0-30 m hardbottom habitat only. (n) is number of sites surveyed per island. Each site is surveyed by means of two to four 7.5 m diameter SPCs. However, those are not considered to be independent samples, so data from those is pooled to site level before other analysis.

ISLAND	Total Area of reef (Ha)	N	ESTIMATED POPULATION BIOMASS (metric Tonnes) in SURVEY DOMAIN OF <30m HARDBOTTOM					
			Acanthuridae	Carangidae	Carcharhinids	Holocentridae	Kyphosidae	Labridae
Guam	7,295.7	238	331.1	40.7	64.6	26.6	5.4	48.7
			Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae	Siganidae
			40.8	66.0	18.7	290.6	56.7	4.3

Note (1): No *Bolbometopon muricatum* were observed during these surveys in Guam
(2) *Cheilinus undulatus* were recorded at Guam (43.2 t)

2.2 LIFE HISTORY AND LENGTH DERIVED PARAMETERS

The SAFE Report will serve as the repository of available life history information for the Western Pacific region. Life history data - particularly age and growth information - inform the stock assessment on fish productivity and population dynamics. Some assessments - particularly for data-poor stocks like coral reefs - utilize information from other areas that introduce errors and uncertainties in the population estimates. An archipelago-specific life history parameter ensures accuracy in the input parameters used in the assessment. The NMFS BioSampling Program allows for significant collection of life history samples like otoliths and gonads from priority species in the bottomfish and coral reef fisheries. These life history samples, once processed and data extracted, will contribute to the body of scientific information for the two data-poor fisheries in the region. The life history information available from the region will be monitored by the Fishery Ecosystem Plan Team and will be tracked through this section of the report.

This section will be divided into two fisheries: 1) coral reef; and 2) bottomfish. Within each fishery, the available life history information will be described under the age, growth, and reproductive maturity section. The section labelled fish length-derived parameters summarizes available information derived from sampling the fish catch or the market. Monitoring length information provides insight on the state of the fish stock where the change in length can be used as an indicator of population level mortality. Length-weight conversion coefficients provide area-specific values to convert length from fishery dependent and fishery independent data collection to weight or biomass.

2.2.1 CNMI Coral Reef Ecosystem – Reef Fish Life History

2.2.1.1 Age & Growth and Reproductive Maturity

Description: Age determination is based on counts of yearly growth marks (annuli) and/or daily growth increments (DGIs) internally visible within transversely-cut, thin sections of sagittal otoliths. Validated age determination, particularly for long-lived (≥30 years) fish, is based on an environmental signal (bomb radiocarbon ^{14}C) produced during previous atmospheric thermonuclear testing in the Pacific and incorporated into the core regions of sagittal otolith and other aragonite-based calcified structures such as hermatypic corals. This technique relies on developing a regionally-based aged coral core reference series for which the rise, peak, and decline of ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. This technique provides age estimates independent of age estimates based on visual counts of annuli or DGIs. The relation between age and fish length is evaluated by fitting this data to a von Bertalanffy growth function based on statistical analyses. The resulting von Bertalanffy growth function predicts the pattern of growth over time for that particular species. This function typically uses three coefficients (L_∞, k, and t_0) which together characterize the shape of the length-at-age growth relationship. The ^{14}C derived ages typically provide more accurate estimates of older ages (≥30 years) and hence more realistic values of T_{max} compared to annuli or DGI-based counts of otolith sections.

Length at reproductive maturity is based on the histological analyses of small tissue samples of gonad material that are typically collected along with otoliths when a fish is processed for life history studies. The gonad tissue sample is preserved then subsequently cut into five micron sections, stained, and sealed onto a glass slide for subsequent examination. Based on standard cell structure features and developmental stages within ovaries and testes, the gender, developmental stage, and maturity status (immature or mature) is determined via microscopic evaluation. The percent of mature samples for a given length interval are assembled for each sex and these data are fitted to a three- or four-parameter logistic function to determine the best fit of these data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish have achieved reproductive maturity (L_{50}). For species that undergo sex reversal (primarily female to male in the tropical Pacific region) - such as groupers and deeper-water emperors among the bottomfishes, and for parrotfish, shallow-water emperors, and wrasses among the coral reef fishes - standard histological criteria are used to determine gender and reproductive developmental stages that indicate the transitioning or completed transition from one sex to another. These data are similarly analyzed using a three or four-parameter logistic function to determine the best fit of the data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish of a particular species have or are undergoing sex reversal ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the von Bertalanffy growth function for that species and using the corresponding L_{50} and $L\Delta_{50}$ values to obtain the corresponding age value from this growth function. In studies where both age & growth and reproductive maturity are concurrently determined, estimates of A_{50} and $A\Delta_{50}$ are derived directly by fitting the percent of mature samples for each age (one-year) interval to a three- or four-parameter logistic function using statistical analyses. The mid-point of this fitted logistic function provides a direct estimate of the age at which 50% of fish of a particular species have achieved reproductive maturity (A_{50}) and sex reversal ($A\Delta_{50}$).

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ☐ American Samoa
- ☐ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

<u>Data Source</u>: Sources of data are directly derived from market samples collected by the CNMI contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the "Reference" column in Table 49 for specific details on data sources by species.

<u>Parameter definitions:</u>

T_{max} (maximum age) – The maximum observed age revealed from an otolith-based age determination study. T_{max} values can be derived from ages determined by annuli counts of sagittal otolith sections and/or bomb radiocarbon (^{14}C) analysis of otolith core material.

L_∞ (asymptotic length) – One of three coefficients of the von Bertalanffy growth function (VBGF) that measures the mean maximum length at which the growth curve plateaus and no longer increases in length with increasing age. This coefficient reflects the mean maximum length and not the observed maximum length.

k (growth coefficient) – One of three coefficients of the VBGF that measures the shape and steepness by which the initial portion of the growth function approaches its mean maximum length (L_∞).

t_0 (hypothetical age at length zero) – One of three coefficients of the VBGF whose measure is highly influenced by the other two VBGF coefficients (k and L_∞) and typically assumes a negative value when specimens representing early growth phases (0+ to 1+ ages) are not available for age determination.

M (natural mortality) – This is a measure of mortality rate for a fish stock not under the influence of fishing pressure and is considered to be directly related to stock productivity (i.e., high M indicates high productivity and low M indicates low stock productivity). M can be derived through use of various equations that link M to T_{max} and k, or in some instances, by calculating the value of the slope from a regression fit to a declining catch curve (regression of the natural logarithm of abundance versus age class) derived from fishing an unfished or lightly fished population.

A_{50} (age at 50% maturity) – Age at which 50% of the sampled stock under study has attained reproductive maturity. This parameter is best determined based on studies that concurrently determine both age (otolith-based age data) and reproductive maturity status (logistic function fitted to percent mature by age class with maturity determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating A_{50} is to use an existing L_{50} estimate to find the corresponding age (A_{50}) from an existing VBGF curve.

$A\Delta_{50}$ (age of sex switching) – Age at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal. This parameter is best determined based on studies that concurrently determines both age (otolith-based age data) and reproductive sex reversal status (logistic function fitted to percent sex reversal by age class with sex reversal determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating $A\Delta_{50}$ is to use an existing $L\Delta_{50}$ estimate to find the corresponding age ($A\Delta_{50}$) from the VBGF curve.

L_{50} (length at which 50% of a fish species are capable of spawning) – Length (usually in terms of fork length) at which 50% of the females of a sampled stock under study has attained reproductive maturity; this is the length associated with A_{50} estimates. This parameter is derived using a logistic function to fit the percent mature data by length class with maturity status best determined via microscopic analyses of gonad histology preparations). L_{50} information is typically more available than A_{50} since L_{50} estimates do not require knowledge of age & growth.

$L\Delta_{50}$ (length of sex switching) – Length (usually in terms of fork length) at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal; this is the length associated with $A\Delta_{50}$ estimates. This parameter is derived using a logistic function to fit the percent sex reversal data by length class with sex reversal status best determined via microscopic analyses of gonad histology preparations). $L\Delta_{50}$ information is typically more available than $A\Delta_{50}$ since $L\Delta_{50}$ estimates do not require knowledge of age & growth.

Rationale: These nine life-history parameters provide basic biological information at the species level to evaluate the productivity of a stock - an indication of the capacity of a stock to recover once it has been depleted. Currently, the assessment of coral reef fish resources in American Samoa is data-limited. Knowledge of these life-history parameters support current efforts to characterize the resilience of these resources and also provide important biological inputs for future stock assessment efforts and enhance our understanding of the specieslikely role and status as a component of the overall ecosystem. Furthermore, knowledge of life histories across species at the taxonomic level of families or among different species that are ecologically or functionally similar can provide important information on the diversity of life histories and the extent to which species can be grouped (based on similar life histories) for future multi-species assessments.

Table 51. Available age, growth, and reproductive maturity information for coral reef species targeted for life history sampling (otoliths and gonads) in CNMI. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

Species	*Age, growth, and reproductive maturity parameters*									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Calotomus carolinus										
Chlorurus spilurus										
Lethrinus								213[b]	X[a]	

atkinsoni										
Lethrinus obsoletus	13[d]	25.1[d]	0.6[d]	3.0 (L_0)[d]	0.32[d]	3.8 (f), 2.8 (m)[d]	X[a]	22.9 (f), 19.9 (m)[d]	X[a]	[d]Taylor et. al. (2016)
Mulloidichthys flavolineatus										
Naso unicornis							NA	238[b]	NA	
Parupeneus barberinus							NA		NA	
Sargocentron tiere							NA		NA	
Siganus argenteus	7[d]	274[d]	0.9[d]	-0.3[d]	0.56[d]	1.3[d]	NA	218[d]	NA	[d]Taylor et. al. (2016)

[a] signifies estimate pending further evaluation in an initiated and ongoing study
[b] signifies a preliminary estimate taken from ongoing analyses
[c] signifies an estimate documented in an unpublished report or draft manuscript
[d] signifies an estimate documented in a finalized report or published journal article (including in press)

2.2.1.2 Fish Length Derived Parameters

Description: The NMFS Commercial Fishery BioSampling Program started in 2009. This program has two components: First is the Field/Market Sampling Program and the second is the Life History Program, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear & area fished)
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially)
- Accurate species identification
- Develop accurate local length-weight curves

In CNMI, the BioSampling is focused on the commercial coral reef spear fishery with occasional sampling of the bottomfish fishery occurring locally and less frequently at the northern islands. Sampling is conducted in partnership with the fish vendors. The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information. Specific for CNMI, the program collects Daily Vendor Logs for reef fish that includes basic catch and effort information.

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ☐ American Samoa
- ☐ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: NMFS BioSampling Program

Parameter definitions:

L_{max}* – *maximum fish length is the longest fish per species recorded in the BioSampling Program from the commercial spear fishery. This value is derived from measuring the fork length of individual samples for species occurring in the spear fishery.

L_{bar}* – *mean length is the average value of all lengths recorded from the commercial spear fishery. This can be influenced by gear selectivity since the commercial spear fishery has a typical size target based on customer demand. This can also be influenced by size regulations.

n – sample size is the total number of samples accumulated for each species recorded in the commercial spear fishery.

$N_{L\text{-}W}$* – *sample size for L-W regression is the number of samples used to generate the a & b coefficients.

a & b – length-weight coefficients are the coefficients derived from the regression line fitted to all length- and weight-measured per species in the commercial spear fishery. These values are used to convert length information to weight. Values are influenced by the life history characteristics of the species, geographic location, population status, and nature of the fisheries from which the species are harvested.

Rationale: Length-derived information is being used as an indicator of population status particularly for data poor stocks like coral reef fish. Average length (L_{bar}) was used as a principal stock assessment indicator variable for exploited reef fish population (Nadon et al 2015). Average length was also shown to be correlated with population size (Kerr and Dickle 2001). Maximum length (L_{max}), typically coupled with maximum age, is typically used as a proxy for fish longevity which has implications on the productivity and susceptibility of a species to fishing pressure. The length-weight coefficients (a & b values) are used to convert length to weight for fishery-dependent and fishery-independent data collection where length are typically recorded but weight is the factor being used for management. This section of the report presents the best available information for the length-derived variables for the CNMI coral reef and bottomfish fisheries.

Table 52. Available length-derived information for various coral reef species in CNMI.

Species	***Length derived parameters***						**Reference**
	L_{max}	L_{bar}	***N***	***L-W***	***a***	***b***	
Naso lituratus	30.1	20.26	17,478	3,813	0.0167	3.1022	
Acanthurus lineatus	23.5	18.33	15,772	4,901	0.0383	2.8718	
Siganus argenteus	34.1	20.82	11,867	3,662	0.0133	3.1007	
Mulloidichthys flavolineatus	31.4	18.08	9,596	2,357	0.0137	3.0547	
Naso unicornis	53.6	29.62	8,323	4,349	0.0266	2.9115	
Siganus spinus	25.6	16.64	7,685	1,078	0.0118	3.1459	
Parupeneus barberinus	37.3	21.73	7,597	2,706	0.0175	3.0119	
Selar crumenophthalmus	26.5	19.08	4922	2654	0.0051	3.3958	
Scarus ghobban	38.1	24.07	4,964	1,502	0.0124	3.1271	
Lethrinus atkinsoni	35.1	21.06	4,306	2,095	0.0163	3.0971	
Lethrinus obsoletus	29.0	21.10	3,673	1,472	0.0171	3.0313	
Mulloidichthys vanicolensis	28.0	18.94	3233	701	0.0103	3.1948	
Scarus rubroviolaceus	52.6	34.49	3141	1,791	0.0087	3.2447	
Chlorurus sordidus	30.8	22.33	3346	956	0.0173	3.0795	
Siganus punctatus	34.8	20.82	2798	833	0.0129	3.1911	
Sargocentron spiniferum	34.6	20.31	2589	684	0.0245	2.9780	
Myripristis murdjan	22.3	16.84	2488	823	0.1699	2.3426	
Scarus psittacus	28.9	21.24	2466	771	0.0212	2.9928	
Acanthurus nigricauda	26.3	20.07	2354	799	0.0217	3.0583	
Cheilinus trilobatus	35.2	24.06	2223	1,196	0.0470	2.7156	
Hipposcarus longiceps	52.0	29.10	2194	615	0.0149	3.0624	
Panulirus penicillatus	17.0	9.05	2043	1,119	1.4849	2.6925	
Leptoscarus vaigiensis	35.2	26.31	1982	807	0.0234	2.8648	
Calotomus carolinus	31.0	24.21	1734	662	0.0156	3.1012	
Myripristis violacea	20.6	15.54	1796	514	0.1361	2.4356	

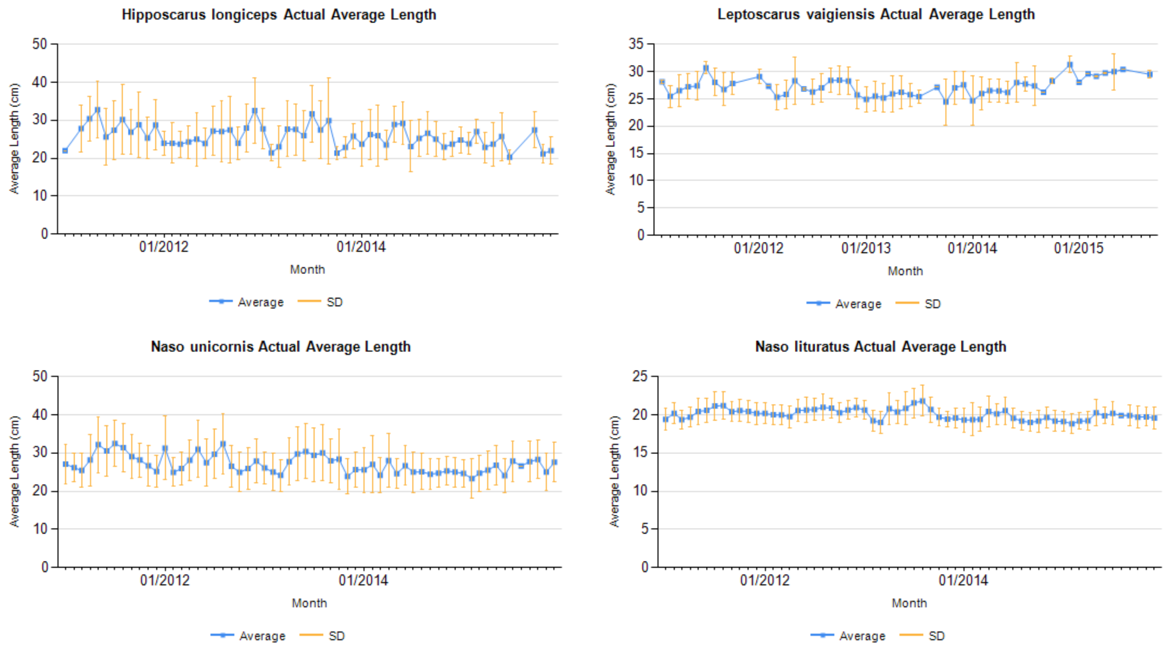
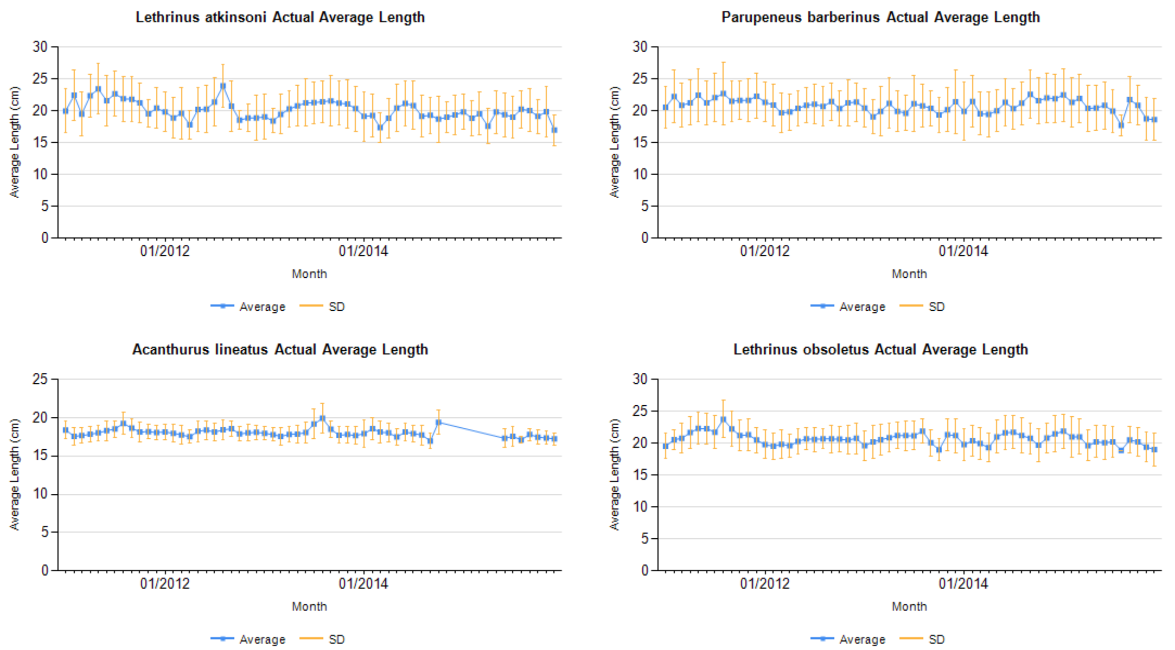
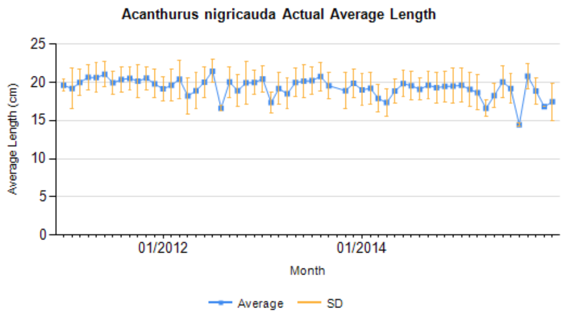
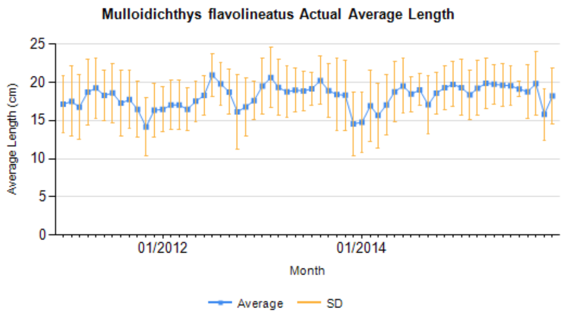
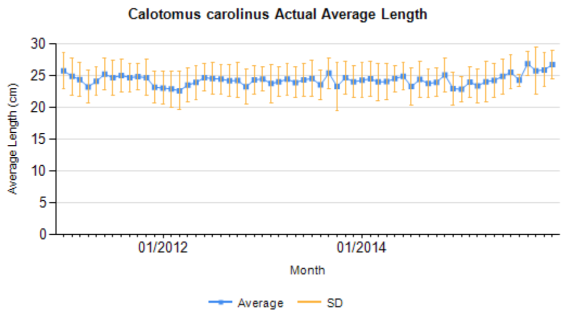


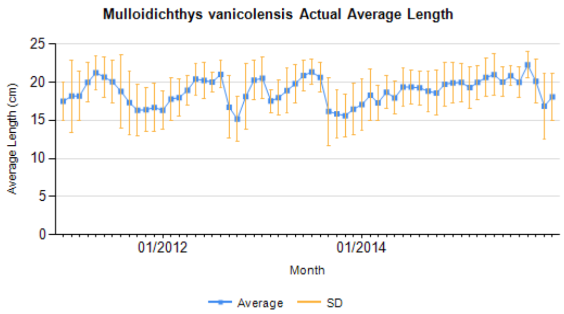
Figure 6. Average length over time of representative CNMI coral reef fish management unit species derived from the BioSampling Program. Continues to next two pages.

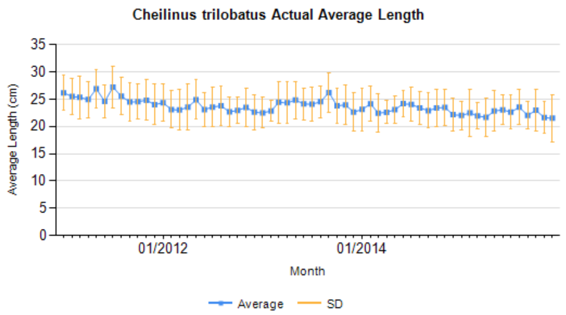


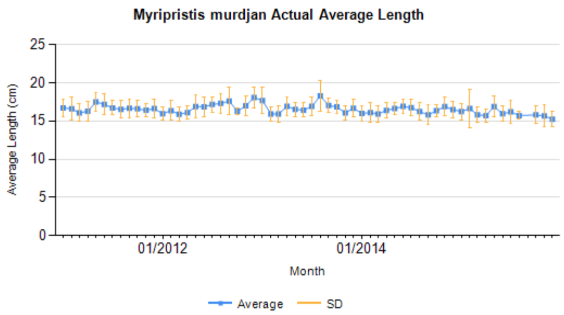

Acanthurus nigricauda Actual Average Length
Average Length (cm)
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

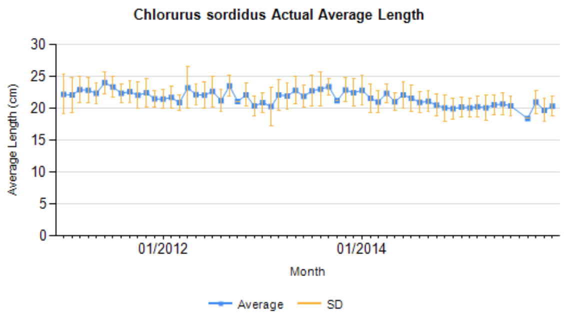

Mulloidichthys flavolineatus Actual Average Length
Average Length (cm)
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

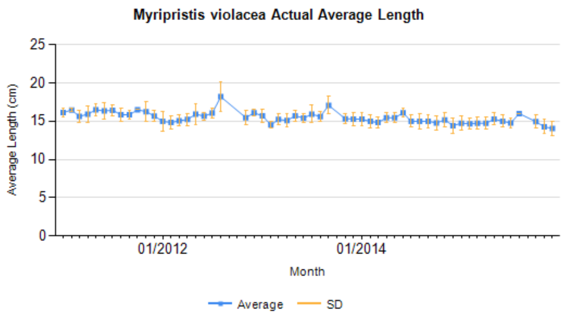

Calotomus carolinus Actual Average Length
Average Length (cm)
30
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

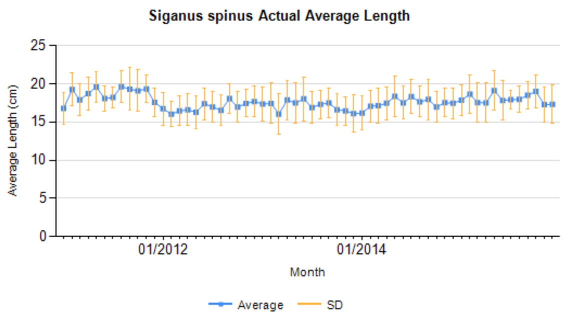

Mulloidichthys vanicolensis Actual Average Length
Average Length (cm)
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

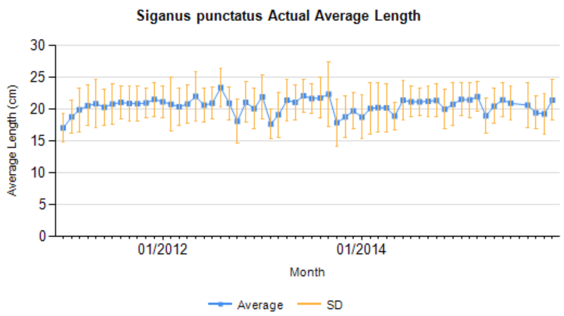

Cheilinus trilobatus Actual Average Length
Average Length (cm)
35
30
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

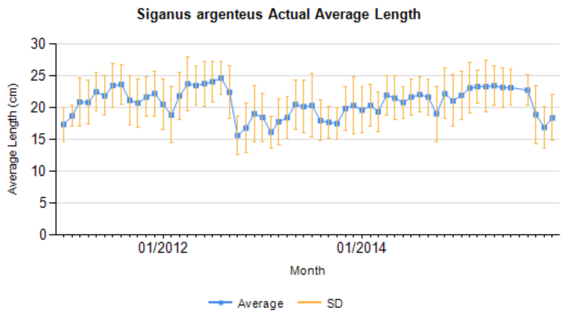

Myripristis murdjan Actual Average Length
Average Length (cm)
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

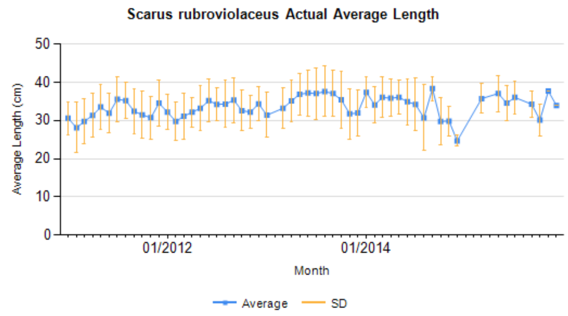

Chlorurus sordidus Actual Average Length
Average Length (cm)
30
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

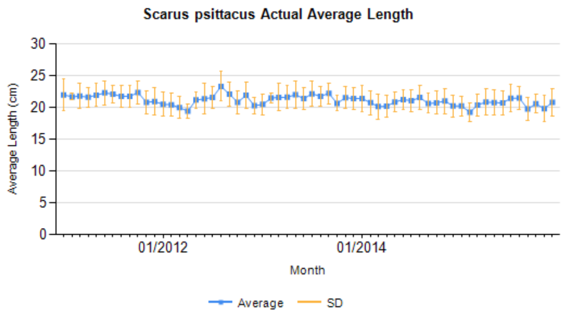

Myripristis violacea Actual Average Length
Average Length (cm)
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

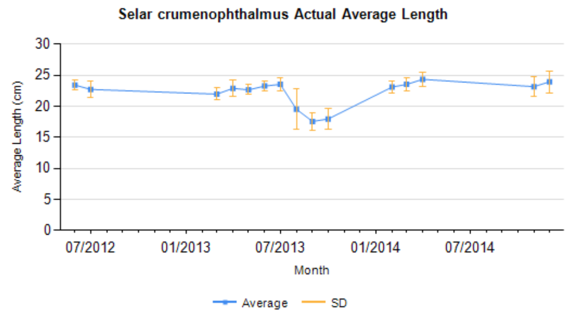

Siganus spinus Actual Average Length
Average Length (cm)
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

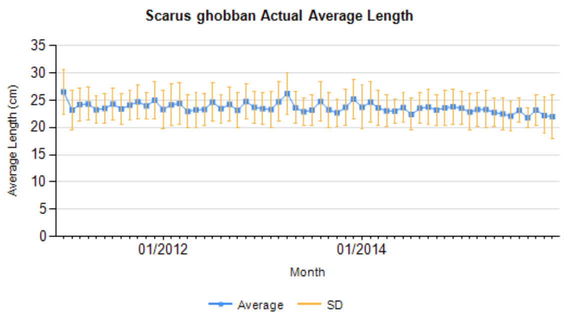

Siganus punctatus Actual Average Length
Average Length (cm)
30
25
20
15
10
5
0
01/2012
01/2014
Month
Average
SD

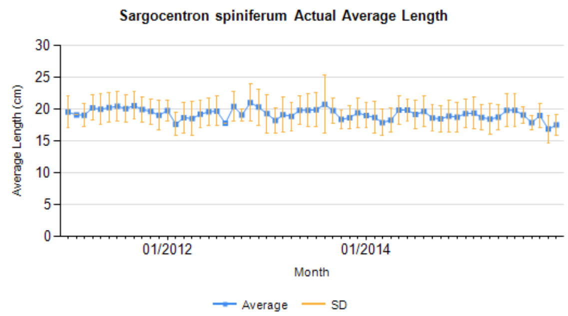

Siganus argenteus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
01/2012
01/2014
Month
Average
SD


Scarus rubroviolaceus Actual Average Length
Average Length (cm)
0
10
20
30
40
50
01/2012
01/2014
Month
Average
SD


Scarus psittacus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
01/2012
01/2014
Month
Average
SD


Selar crumenophthalmus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
07/2012
01/2013
07/2013
01/2014
07/2014
Month
Average
SD


Scarus ghobban Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
35
01/2012
01/2014
Month
Average
SD


Sargocentron spiniferum Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
01/2012
01/2014
Month
Average
SD

2.2.2 CNMI Bottomfish Ecosystem – Bottomfish Life History

2.2.2.1 Age & Growth and Reproductive Maturity

Description: Age determination is based on counts of yearly growth marks (annuli) and/or daily growth increments (DGIs) internally visible within transversely-cut, thin sections of sagittal otoliths. Validated age determination, particularly for long-lived (≥30 years) fish, is based on an environmental signal (bomb radiocarbon ^{14}C) produced during previous atmospheric thermonuclear testing in the Pacific and incorporated into the core regions of sagittal otolith and other aragonite-based calcified structures such as hermatypic corals. This technique relies on developing a regionally-based aged coral core reference series for which the rise, peak, and decline of ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. This technique provides age estimates independent of age estimates based on visual counts of annuli or DGIs. The relation between age and fish length is evaluated by fitting this data to a von Bertalanffy growth function based on statistical analyses. The resulting von Bertalanffy growth function predicts the pattern of growth over time for that particular species. This function typically uses three coefficients (L_∞, k, and t_0) which together characterize the shape of the length-at-age growth relationship. The ^{14}C derived ages typically provide more accurate estimates of older ages (≥30 years) and hence more realistic values of T_{max} compared to annuli or DGI-based counts of otolith sections.

Length at reproductive maturity is based on the histological analyses of small tissue samples of gonad material that are typically collected along with otoliths when a fish is processed for life history studies. The gonad tissue sample is preserved then subsequently cut into five-micron sections, stained, and sealed onto a glass slide for subsequent examination. Based on standard cell structure features and developmental stages within ovaries and testes, the gender, developmental stage, and maturity status (immature or mature) is determined via microscopic evaluation. The percent of mature samples for a given length interval are assembled for each sex and these data are fitted to a three- or four-parameter logistic function to determine the best fit of these data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish have achieved reproductive maturity (L_{50}). For species that undergo sex reversal (primarily female to male in the tropical Pacific region), such as groupers and deeper-water emperors among the bottomfishes, and for parrotfish, shallow-water emperors, and wrasses among the coral reef fishes, standard histological criteria are used to determine gender and reproductive developmental stages that indicate the transitioning or completed transition from one sex to another. These data are similarly analyzed using a 3- or 4-parameter logistic function to determine the best fit of the data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish of a particular species have or are undergoing sex reversal ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the von Bertalanffy growth function for that species and using the corresponding L_{50} and $L\Delta_{50}$ values to obtain the corresponding age value from this growth function. In studies where both age & growth and reproductive maturity are concurrently determined, estimates of A_{50} and $A\Delta_{50}$ are derived directly by fitting the percent of mature samples for each age (one-year) interval to a three- or four-parameter logistic function using statistical analyses. The mid-point of this fitted logistic function provides a direct estimate of the age at which 50% of fish of a particular species have achieved reproductive maturity (A_{50}) and sex reversal ($A\Delta_{50}$).

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ☐ American Samoa
- ☐ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Sources of data are directly derived from field samples collected at sea on NOAA research vessels and from the CNMI contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the "Reference" column in Table 51 for specific details on data sources by species.

Parameter definitions:

***T_{max}* (maximum age) –** The maximum observed age revealed from an otolith-based age determination study. T_{max} values can be derived from ages determined by annuli counts of sagittal otolith sections and/or bomb radiocarbon (^{14}C) analysis of otolith core material.

***L_∞* (asymptotic length) –** One of three coefficients of the von Bertalanffy growth function (VBGF) that measures the mean maximum length at which the growth curve plateaus and no longer increases in length with increasing age. This coefficient reflects the mean maximum length and not the observed maximum length.

***k* (growth coefficient) –** One of three coefficients of the VBGF that measures the shape and steepness by which the initial portion of the growth function approaches its mean maximum length (L_∞).

***t_0* (hypothetical age at length zero) –** One of three coefficients of the VBGF whose measure is highly influenced by the other two VBGF coefficients (k and L_∞) and typically assumes a negative value when specimens representing early growth phases (0+ to 1+ ages) are not available for age determination.

***M* (natural mortality) –** This is a measure of mortality rate for a fish stock not under the influence of fishing pressure and is considered to be directly related to stock productivity (i.e., high M indicates high productivity and low M indicates low stock productivity). M can be derived through use of various equations that link M to T_{max} and k, or in some instances, by calculating the value of the slope from a regression fit to a declining catch curve (regression of the natural logarithm of abundance versus age class) derived from fishing an unfished or lightly fished population.

A_{50} (age at 50% maturity) – Age at which 50% of the sampled stock under study has attained reproductive maturity. This parameter is best determined based on studies that concurrently determine both age (otolith-based age data) and reproductive maturity status (logistic function fitted to percent mature by age class with maturity determined via microscopic analyses of gonad histology preparations. A more approximate means of estimating A_{50} is to use an existing L_{50} estimate to find the corresponding age (A_{50}) from an existing VBGF curve.

$A\Delta_{50}$ (age of sex switching) – Age at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal. This parameter is best determined based on studies that concurrently determines both age (otolith-based age data) and reproductive sex reversal status (logistic function fitted to percent sex reversal by age class with sex reversal determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating $A\Delta_{50}$ is to use an existing $L\Delta_{50}$ estimate to find the corresponding age ($A\Delta_{50}$) from the VBGF curve.

L_{50} (length at which 50% of a fish species are capable of spawning) – Length (usually in terms of fork length) at which 50% of the females of a sampled stock under study has attained reproductive maturity; this is the length associated with A_{50} estimates. This parameter is derived using a logistic function to fit the percent mature data by length class with maturity status best determined via microscopic analyses of gonad histology preparations. L_{50} information is typically more available than A_{50} since L_{50} estimates do not require knowledge of age & growth.

$L\Delta_{50}$ (length of sex switching) – Length (usually in terms of fork length) at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal; this is the length associated with $A\Delta_{50}$ estimates. This parameter is derived using a logistic function to fit the percent sex reversal data by length class with sex reversal status best determined via microscopic analyses of gonad histology preparations. $L\Delta_{50}$ information is typically more available than $A\Delta_{50}$ since $L\Delta_{50}$ estimates do not require knowledge of age & growth.

Rationale: These nine life history parameters provide basic biological information at the species level to evaluate the productivity of a stock - an indication of the capacity of a stock to recover once it has been depleted. Currently, the assessment of coral reef fish resources in American Samoa is data-limited. Knowledge of these life history parameters support current efforts to characterize the resilience of these resources and also provide important biological inputs for future stock assessment efforts and enhance our understanding of the species likely role and status as a component of the overall ecosystem. Furthermore, knowledge of life histories across species at the taxonomic level of families or among different species that are ecologically or functionally similar can provide important information on the diversity of life histories and the extent to which species can be grouped (based on similar life histories) for future multi-species assessments.

Table 53. Available age, growth, and reproductive maturity information for bottomfish species targeted for life history sampling (otoliths and gonads) in CNMI. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

Species	*Age, growth, and reproductive maturity parameters*									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Aphareus rutilans	Y	Y	Y	Y			NA		NA	Y-Ralston & Williams (1988)
Aprion virescens							NA		NA	
Etelis carbunculus							NA		NA	
Etelis coruscans	Y	Y	Y	Y			NA		NA	Y-Ralston & Williams (1988)
Monotaxis grandoculis										
Pristipomoides auricilla	Y	Y	Y	Y			NA		NA	Y-Ralston & Williams (1988)
Pristipomoides filamentosus							NA		NA	
Pristipomoides flavipinnis							NA		NA	
Pristipomoides sieboldii	Y	Y	Y	Y			NA		NA	Y-Ralston & Williams (1988)
Pristpomoides zonatus	Y	Y	Y	Y			NA		NA	Y-Ralston & Williams (1989)
Variola louti										

[a] signifies estimate pending further evaluation in an initiated and ongoing study
[b] signifies a preliminary estimate taken from ongoing analyses
[c] signifies an estimate documented in an unpublished report or draft manuscript
[d] signifies an estimate documented in a finalized report or published journal article (including in press)

2.2.2.2 Fish Length Derived Parameters

<u>Description</u>: The NMFS Commercial Fishery BioSampling Program started in 2009. This program has two components: First is the Field/Market Sampling Program and the second is the

Life History Program, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear & area fished)
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially)
- Accurate species identification
- Develop accurate local length-weight curves

In CNMI, the BioSampling is focused on the commercial coral reef spear fishery with occasional sampling of the bottomfish fishery occurring locally and less frequently at the northern islands. Sampling is conducted in partnership with the fish vendors. The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information. Specific for CNMI, the program collects Daily Vendor Logs for bottomfish that includes basic catch and effort information.

Category:
- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:
- ☐ American Samoa
- ☐ Guam
- ✓ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:
- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: NMFS BioSampling Program

Parameter definitions:
***L_{max}* – maximum fish length** is the longest fish per species recorded in the BioSampling Program from the commercial bottomfish fishery. This value is derived from measuring the fork length of individual samples for species occurring in the spear fishery.

***L_{bar}* – mean length** is the average value of all lengths recorded from the commercial spear fishery. This can be influenced by gear selectivity since the commercial bottomfish fishery has a typical size target based on customer demand. This can also be influenced by size regulations.

***n* – sample size** is the total number of samples accumulated for each species recorded in the commercial bottomfish fishery.

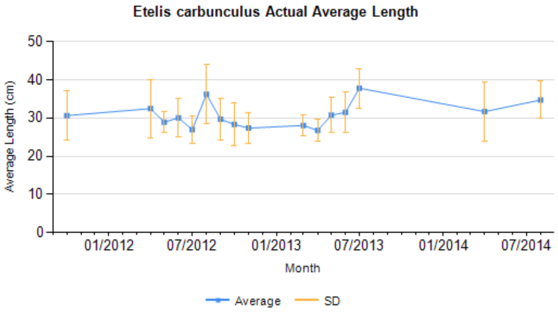
***N_{L-W}* – sample size for L-W regression** is the number of samples used to generate the a & b coefficients.

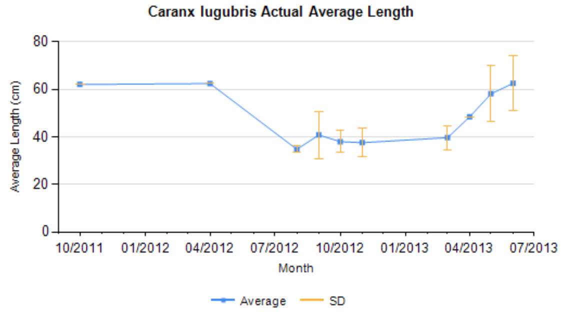
***a & b* – length-weight coefficients** are the coefficients derived from the regression line fitted to all length and weight measured per species in the commercial bottomfish fishery. These values are used to convert length information to weight. Values are influenced by the life history characteristics of the species, geographic location, population status, and nature of the fisheries from which the species are harvested from.

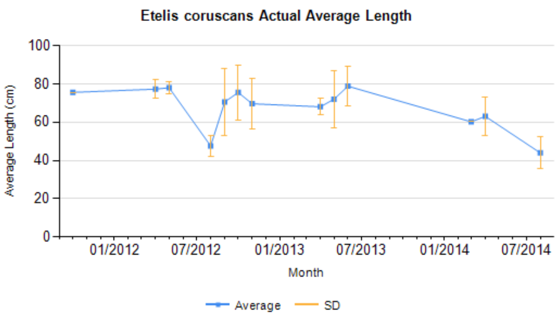
Rationale: Length-derived information is being used as an indicator of population status particularly for data poor stocks like coral reef fish. Average length (L_{bar}) was used as a principal stock assessment indicator variable for exploited reef fish population (Nadon et al 2015). Average length was also shown to be correlated with population size (Kerr and Dickle 2001). Maximum length (L_{max}), typically coupled with maximum age, is typically used as a proxy for fish longevity which has implications on the productivity and susceptibility of a species to fishing pressure. The length-weight coefficients (a & b values) are used to convert length to weight for fishery-dependent and fishery-independent data collection where length are typically recorded but weight is the factor being used for management. This section of the report presents the best available information for the length-derived variables for the bottomfish fisheries.

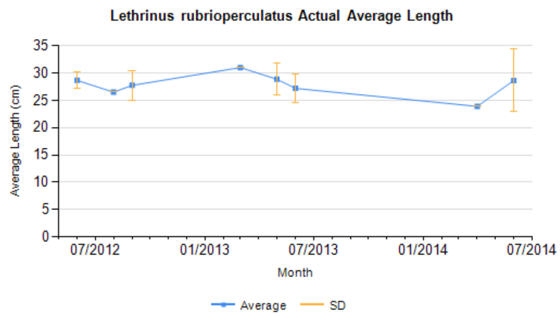
Table 54. Available length-derived information for various bottomfish species in CNMI.

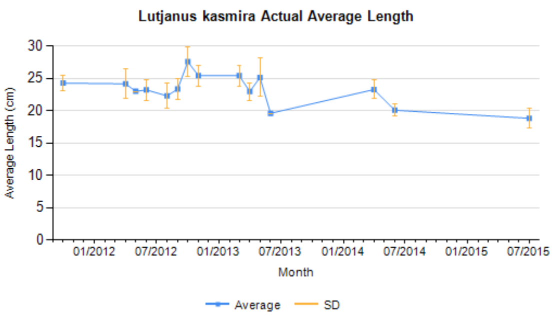
Species	***Length derived parameters***						**Reference**
	L_{max}	***L_{bar}***	***N***	***L-W***	***a***	***b***	
Lethrinus rubrioperculatus	38.0	28.01	1,353	1,021	0.0185	2.9897	
Etelis carbunculus	53.5	30.18	685	685	0.0150	3.0430	
Pristipomoides auricilla	39.5	28.59	465	465	0.0189	3.0060	
Pristipomoides zonatus	45.4	32.99	371	370	0.0180	3.0411	
Etelis coruscans	96.4	72.50	325	325	0.0716	2.6147	
Lutjanus kasmira	32.5	24.84	258	258	0.0087	3.2307	
Pristipomoides flavipinnis	51.5	37.05	168	168	0.0133	3.0762	
Pristipomoides argyrogrammicus	31.6	24.44	150	150	0.0174	3.0464	
Pristipomoides filamentosus	58.5	39.97	123	123	0.0773	2.5914	
Caranx lugubris	82.5	46.07	122	122	0.0309	2.8768	

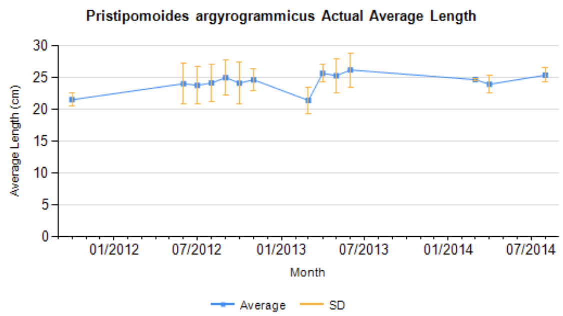

Etelis carbunculus Actual Average Length
Average Length (cm)
0
10
20
30
40
50
01/2012
07/2012
01/2013
07/2013
01/2014
07/2014
Month
Average
SD


Caranx lugubris Actual Average Length
Average Length (cm)
0
20
40
60
80
10/2011
01/2012
04/2012
07/2012
10/2012
01/2013
04/2013
07/2013
Month
Average
SD


Etelis coruscans Actual Average Length
Average Length (cm)
0
20
40
60
80
100
01/2012
07/2012
01/2013
07/2013
01/2014
07/2014
Month
Average
SD


Lethrinus rubrioperculatus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
35
07/2012
01/2013
07/2013
01/2014
07/2014
Month
Average
SD


Lutjanus kasmira Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
01/2012
07/2012
01/2013
07/2013
01/2014
07/2014
01/2015
07/2015
Month
Average
SD


Pristipomoides argyrogrammicus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
01/2012
07/2012
01/2013
07/2013
01/2014
07/2014
Month
Average
SD

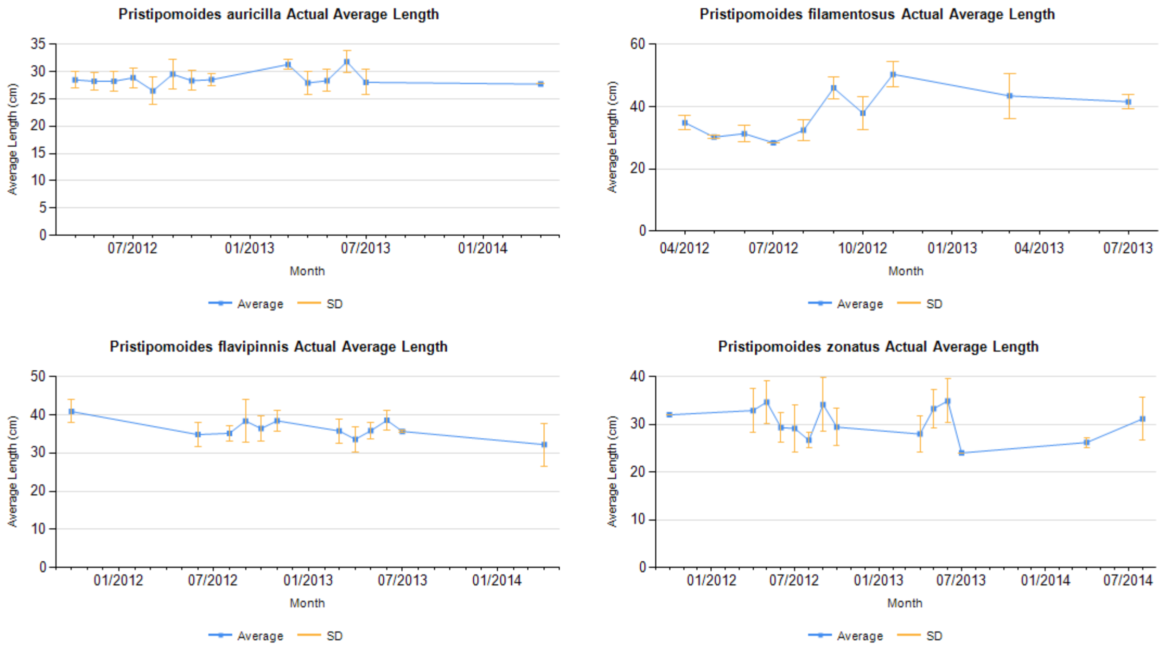


Figure 7. Average length over time of representative CNMI bottomfish management unit species derived from the BioSampling Program.

2.2.2.3 References

Nadon, Marc O., et al. "Length-based assessment of coral reef fish populations in the Main and northwestern Hawaiian islands." *PloS one* 10.8 (2015): e0133960.

Kerr, Stephen R., and Lloyd Merlin Dickie. *The biomass spectrum: a predator-prey theory of aquatic production*. Columbia University Press, 2001.

2.2.3 Guam Coral Reef Ecosystem – Reef Fish Life History

2.2.3.1 Age & Growth and Reproductive Maturity

Description: Age determination is based on counts of yearly growth marks (annuli) and/or daily growth increments (DGIs) internally visible within transversely-cut thin sections of sagittal otoliths. Validated age determination, particularly for long-lived (≥30 years) fish, is based on an environmental signal (bomb radiocarbon ^{14}C) produced during previous atmospheric thermonuclear testing in the Pacific and incorporated into the core regions of sagittal otolith and other aragonite-based calcified structures such as hermatypic corals. This technique relies on developing a regionally-based aged coral core reference series for which the rise, peak, and decline of ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. This technique provides age estimates independent of age estimates based on visual counts of annuli or DGIs. The relation between age and fish length is evaluated by fitting this data to a von Bertalanffy growth function based on statistical analyses. The resulting von Bertalanffy growth function predicts the pattern of growth over time for that particular species. This function typically uses three coefficients (L_∞, k, and t_0) which together characterize the shape of the length-at-age growth relationship. The ^{14}C derived ages typically provide more accurate estimates of older ages (≥30 years) and hence more realistic values of T_{max} compared to annuli or DGI-based counts of otolith sections.

Length at reproductive maturity is based on the histological analyses of small tissue samples of gonad material that are typically collected along with otoliths when a fish is processed for life history studies. The gonad tissue sample is preserved then subsequently cut into five-micron sections, stained, and sealed onto a glass slide for subsequent examination. Based on standard cell structure features and developmental stages within ovaries and testes, the gender, developmental stage, and maturity status (immature or mature) is determined via microscopic evaluation. The percent of mature samples for a given length interval are assembled for each sex and these data are fitted to a three- or four-parameter logistic function to determine the best fit of these data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish have achieved reproductive maturity ($\boldsymbol{L_{50}}$). For species that undergo sex reversal (primarily female to male in the tropical Pacific region), such as groupers and deeper-water emperors among the bottomfishes, and for parrotfish, shallow-water emperors, and wrasses among the coral reef fishes, standard histological criteria are used to determine gender and reproductive developmental stages that indicate the transitioning or completed transition from one sex to another. These data are similarly analyzed using a 3- or 4-parameter logistic function to determine the best fit of the data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish of a particular species have or are undergoing sex reversal ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the von Bertalanffy growth function for that species and using the corresponding $\boldsymbol{L_{50}}$ and $L\Delta_{50}$ values to obtain the corresponding age value from this growth function. In studies where both age & growth and reproductive maturity are concurrently determined, estimates of A_{50} and $A\Delta_{50}$ are derived directly by fitting the percent of mature samples for each age (one-year) interval to a three- or four-parameter logistic function using statistical analyses. The mid-point of this fitted logistic function provides a direct estimate of the age at which 50% of fish of a particular species have achieved reproductive maturity (A_{50}) and sex reversal ($A\Delta_{50}$).

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ☐ American Samoa
- ✓ Guam
- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Sources of data are directly derived from market samples collected by the Guam contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the "Reference" column in Table 53 for specific details on data sources by species.

Parameter definitions:

T_{max} (maximum age) – The maximum observed age revealed from an otolith-based age determination study. T_{max} values can be derived from ages determined by annuli counts of sagittal otolith sections and/or bomb radiocarbon (^{14}C) analysis of otolith core material.

L_∞ (asymptotic length) – One of three coefficients of the von Bertalanffy growth function (VBGF) that measures the mean maximum length at which the growth curve plateaus and no longer increases in length with increasing age. This coefficient reflects the mean maximum length and not the observed maximum length.

k (growth coefficient) – One of three coefficients of the VBGF that measures the shape and steepness by which the initial portion of the growth function approaches its mean maximum length (L_∞).

t_0 (hypothetical age at length zero) – One of three coefficients of the VBGF whose measure is highly influenced by the other two VBGF coefficients (k and L_∞) and typically assumes a negative value when specimens representing early growth phases (0+ to 1+ ages) are not available for age determination.

***M* (natural mortality) –** This is a measure of mortality rate for a fish stock not under the influence of fishing pressure and is considered to be directly related to stock productivity (i.e., high *M* indicates high productivity and low *M* indicates low stock productivity). *M* can be derived through use of various equations that link *M* to T_{max} and *k*, or in some instances, by calculating the value of the slope from a regression fit to a declining catch curve (regression of the natural logarithm of abundance versus age class) derived from fishing an unfished or lightly fished population.

A_{50} (age at 50% maturity) – Age at which 50% of the sampled stock under study has attained reproductive maturity. This parameter is best determined based on studies that concurrently determine both age (otolith-based age data) and reproductive maturity status (logistic function fitted to percent mature by age class with maturity determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating A_{50} is to use an existing L_{50} estimate to find the corresponding age (A_{50}) from an existing VBGF curve.

$A\Delta_{50}$ (age of sex switching) – Age at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal. This parameter is best determined based on studies that concurrently determines both age (otolith-based age data) and reproductive sex reversal status (logistic function fitted to percent sex reversal by age class with sex reversal determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating $A\Delta_{50}$ is to use an existing $L\Delta_{50}$ estimate to find the corresponding age ($A\Delta_{50}$) from the VBGF curve.

L_{50} (length at which 50% of a fish species are capable of spawning) – Length (usually in terms of fork length) at which 50% of the females of a sampled stock under study has attained reproductive maturity; this is the length associated with A_{50} estimates. This parameter is derived using a logistic function to fit the percent mature data by length class with maturity status best determined via microscopic analyses of gonad histology preparations). L_{50} information is typically more available than A_{50} since L_{50} estimates do not require knowledge of age & growth.

$L\Delta_{50}$ (length of sex switching) – Length (usually in terms of fork length) at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal; this is the length associated with $A\Delta_{50}$ estimates. This parameter is derived using a logistic function to fit the percent sex reversal data by length class with sex reversal status best determined via microscopic analyses of gonad histology preparations. $L\Delta_{50}$ information is typically more available than $A\Delta_{50}$ since $L\Delta_{50}$ estimates do not require knowledge of age & growth.

Rationale: These nine life history parameters provide basic biological information at the species level to evaluate the productivity of a stock - an indication of the capacity of a stock to recover once it has been depleted. Currently, the assessment of coral reef fish resources in American Samoa is data-limited. Knowledge of these life history parameters support current efforts to characterize the resilience of these resources and also provide important biological inputs for future stock assessment efforts and enhance our understanding of the species-likely role and status as a component of the overall ecosystem. Furthermore, knowledge of life histories across species at the taxonomic level of families or among different species that are ecologically or functionally similar can provide important information on the diversity of life histories and the extent to which species can be grouped (based on similar life histories) for future multi-species assessments.

Table 55. Available age, growth, and reproductive maturity information for coral reef species targeted for life history sampling (otoliths and gonads) in Guam. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

Species	Age, growth, and reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Calatomus carolinus	3[d]	263[d]	0.91[d]	-0.065[d]		1.14[d]		168[d]	213[d]	[d]Taylor & Choat (2014)
Oxycheilinus unifasciatus										
Chlorurus frontalis	11[d]	372[d]	0.71[d]	-0.058[d]		1.55[d]		240[d]	343[d]	[d]Taylor & Choat (2014)
Chlorurus microrhinos	11[d]	457[d]	0.34[d]	-0.097[d]		3.7[d]		308[d]	378[d]	[d]Taylor & Choat (2014)
Chlorurus spilurus	9[d]	218[d]	0.95[d]	-0.075[d]		1.3[d]		144[d]	207[d]	[d]Taylor & Choat (2014)
Hipposcarus longiceps	10[b]	433[b]	0.81[b]	-0.029[b]						
Naso lituratus	13d	204[d]	0.93[d]	-0.30[d]		2.4 (m)[d]		145 (f), 178 (m)[d]		[d]Taylor et. al. (2014)
Naso unicornis	23[d]	493 d	0.22[d]	-0.48[d]		4.0 (f), 3.2 (m)[d]		292 (f), 271 (m)[d]		[d]Taylor et. al. (2014)
Scarus altipinnis	14[d]	339[d]	0.66[d]	-0.069[d]		2.89[d]		251[d]	337[d]	[d]Taylor & Choat (2014)
Scarus forsteni	12[d]	281[d]	0.88[d]	-0.062[d]		1.79[d]		216[d]	271[d]	[d]Taylor & Choat (2014)
Scarus psittacus	6[d]	207[d]	0.91[d]	-0.083[d]		1.36[d]		103[d]	193[d]	[d]Taylor & Choat (2014)
Scarus rubroviolaceus	6[d]	376[d]	0.66[d]	-0.062[d]		1.91[d]		271[d]	329[d]	[d]Taylor & Choat (2014)
Scarus schlegeli	8[d]	252[d]	1.03[d]	-0.06[d]		1.99[d]		197[d]	220[d]	[d]Taylor & Choat (2014)
Siganus punctatus							NA		NA	

[a] signifies estimate pending further evaluation in an initiated and ongoing study
[b] signifies a preliminary estimate taken from ongoing analyses
[c] signifies an estimate documented in an unpublished report or draft manuscript
[d] signifies an estimate documented in a finalized report or published journal article (including in press)

2.2.3.2 Fish Length Derived Parameters

Description: The NMFS Commercial Fishery BioSampling Program started in 2009. This program has two components: First is the Field/Market Sampling Program and the second is the Life History Program, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear & area fished)
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially)
- Accurate species identification
- Develop accurate local length-weight curves

In American Samoa, the BioSampling is focused on the commercial coral reef spear fishery with occasional sampling of the bottomfish fishery occurring locally and less frequently at the banks. Sampling is conducted in direct partnership with the spear fisherman. The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information.

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ☐ American Samoa
- ✓ Guam
- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:

- ☐ Regional
- ☐ Archipelagic

- ✓ Island
- ☐ Site

<u>Data Source</u>: NMFS BioSampling Program

<u>Parameter definition</u>:
L_{max}* – *maximum fish length is the longest fish per species recorded in the BioSampling Program from the commercial spear fishery. This value is derived from measuring the fork length of individual samples for species occurring in the spear fishery.

L_{bar}* – *mean length is the average value of all lengths recorded from the commercial spear fishery. This can be influenced by gear selectivity since the commercial spear fishery has a typical size target based on customer demand. This can also be influenced by size regulations.

n* – *sample size is the total number of samples accumulated for each species recorded in the commercial spear fishery.

N_{L-W}* – *sample size for L-W regression is the number of samples used to generate the a & b coefficients.

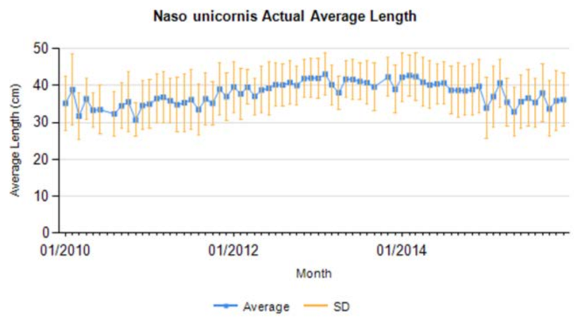
a & b* – *length-weight coefficients are the coefficients derived from the regression line fitted to all length and weight measured per species in the commercial spear fishery. These values are used to convert length information to weight. Values are influenced by the life history characteristics of the species, geographic location, population status, and nature of the fisheries from which the species are harvested

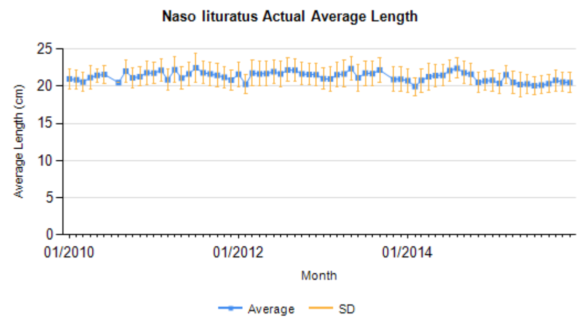
<u>Rationale</u>: Length-derived information is being used as an indicator of population status particularly for data-poor stocks like coral reef fish. Average length (L_{bar}) was used as a principal stock assessment indicator variable for exploited reef fish population (Nadon et al 2015). Average length was also shown to be correlated with population size (Kerr and Dickle 2001). Maximum length (L_{max}), typically coupled with maximum age, is typically used as a proxy for fish longevity which has implications on the productivity and susceptibility of a species to fishing pressure. The length-weight coefficients (a & b values) are used to convert length to weight for fishery dependent and fishery independent data collection where length are typically recorded but weight is the factor being used for management. This section of the report presents the best available information for the length-derived variables for the CNMI coral reef and bottomfish fisheries.

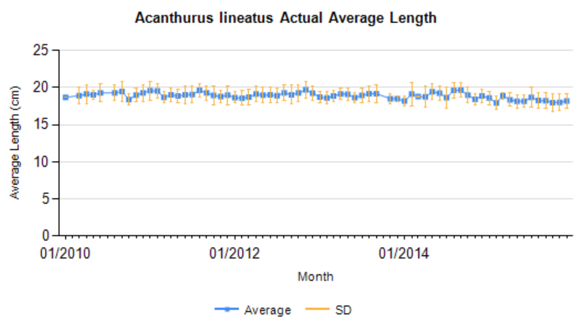
Table 56. Available length derived information for various coral reef species in Guam.

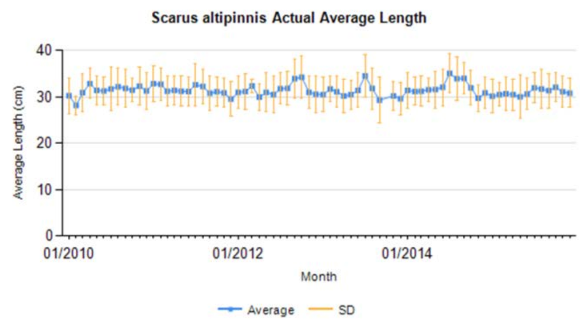
Species	***Length derived parameters***						**Reference**
	L_{max}	***L_{bar}***	***n***	***L-W***	***a***	***b***	
Naso unicornis	57.2	38.02	15461		0.0278	2.9135	2010-2015 Guam Biosampling

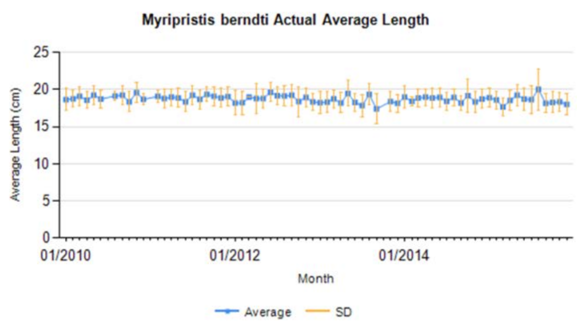
							Database
Naso lituratus	29.6	21.35	16702		0.0223	3.0264	
Acanthurus lineatus	28.9	19.04	4325		0.0473	2.8110	
Scarus altipinnis	46.4	31.16	3913		0.0207	3.0040	
Myripristis bendti	29.4	18.63	3903		0.0858	2.5911	
Siganus argenteus	34.5	21.71	3653		0.0163	3.0428	
Acanthurus nigricauda	29.1	21.40	3500		0.0511	2.7811	
Hipposcarus longiceps	51.4	37.30	3149		0.0172	3.0320	
Scarus schlegeli	36.2	25.19	2787		0.0205	3.0033	
Siganus punctatus	32.0	23.97	2619		0.0199	3.0690	
Monotaxis grandoculis	48.9	29.17	2388		0.0440	2.8384	
Scarus rubroviolaceus	47.8	31.91	2192		0.0114	3.1812	
Lethrinus obsoletus	34.7	22.15	2273		0.0169	3.0471	
Scarus forsteni	39.1	28.13	1801		0.0149	3.1169	
Lutjanus gibbus	43.5	29.99	1687		0.0195	3.0274	
Panulirus penicillatus							
Parupeneus insularis	28.5	21.89	1560		0.0178	3.0865	
Siganus spinus	27.5	16.53	1670		0.0353	2.7886	
Lethrinus atkinsoni	*33.7*	*21.93*	*1644*		*0.0215*	*3.0217*	
Chlorurus microrhinus	*50.5*	*32.54*	*1527*		*0.0187*	*3.0520*	
Chlorurus sordidus	*33.1*	*22.39*	*1234*		*0.0208*	*3.0293*	
Kyphosus cinerascens	*50.7*	*29.94*	*1146*		*0.0323*	*2.9267*	

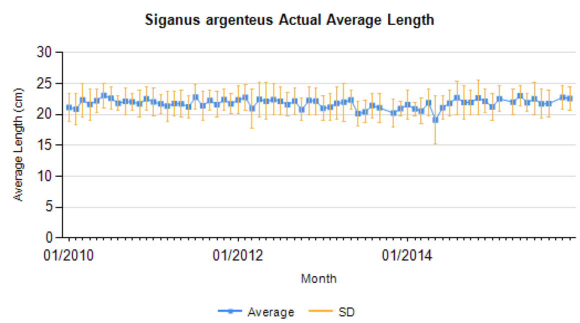

Naso unicornis Actual Average Length
Average Length (cm)
0
10
20
30
40
50
01/2010
01/2012
01/2014
Month
Average
SD

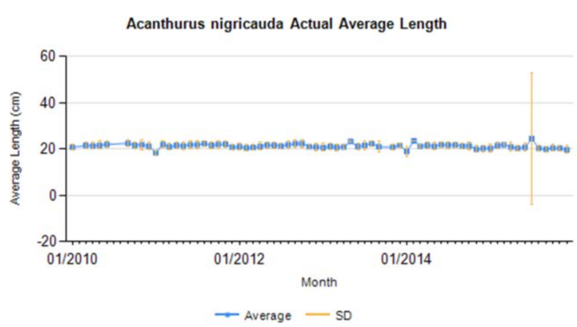

Naso lituratus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
01/2010
01/2012
01/2014
Month
Average
SD

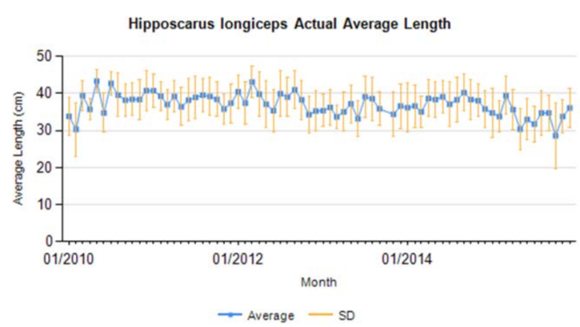

Acanthurus lineatus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
01/2010
01/2012
01/2014
Month
Average
SD

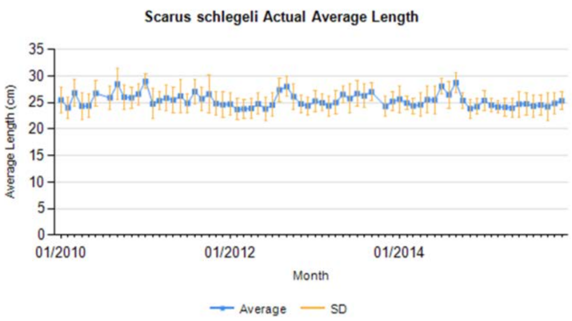

Scarus altipinnis Actual Average Length
Average Length (cm)
0
10
20
30
40
01/2010
01/2012
01/2014
Month
Average
SD

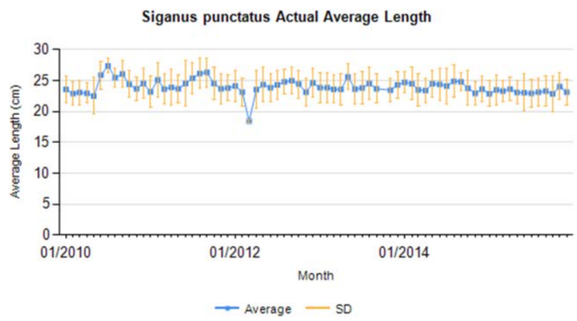

Myripristis berndti Actual Average Length
Average Length (cm)
0
5
10
15
20
25
01/2010
01/2012
01/2014
Month
Average
SD

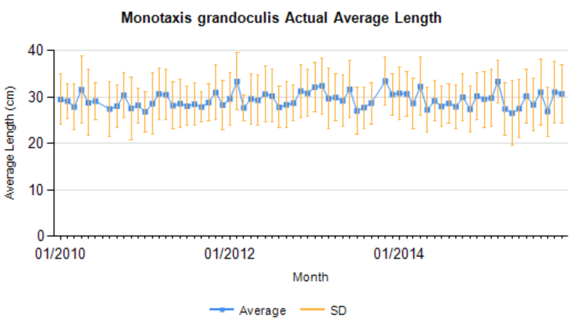

Siganus argenteus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
01/2010
01/2012
01/2014
Month
Average
SD

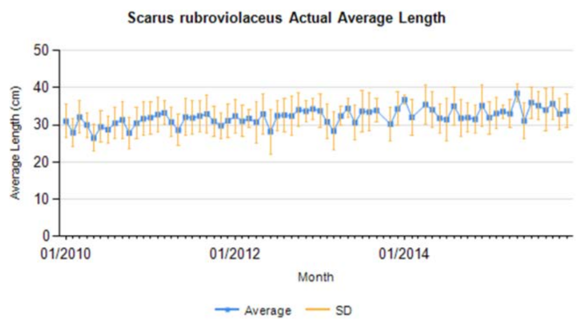

Acanthurus nigricauda Actual Average Length
Average Length (cm)
-20
0
20
40
60
01/2010
01/2012
01/2014
Month
Average
SD

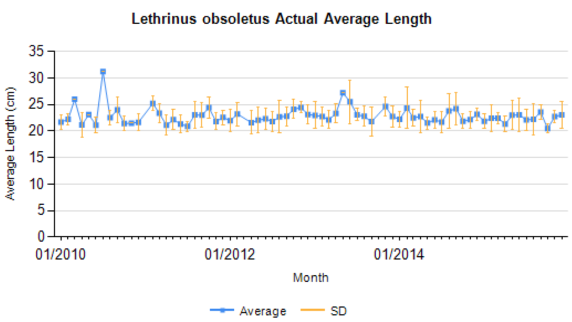

Hipposcarus longiceps Actual Average Length
Average Length (cm)
0
10
20
30
40
50
01/2010
01/2012
01/2014
Month
Average
SD

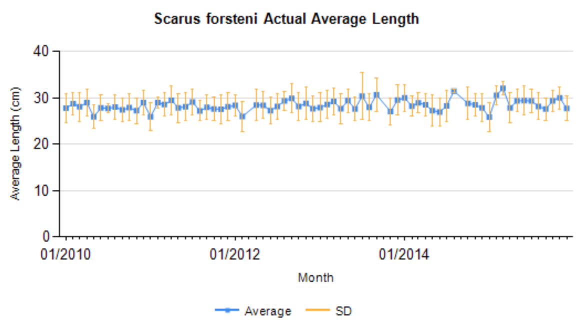

Scarus schlegeli Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
35
01/2010
01/2012
01/2014
Month
Average
SD

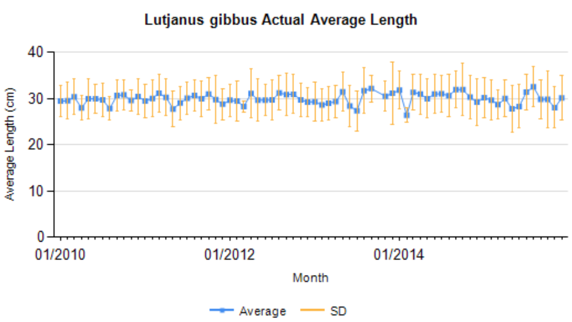

Siganus punctatus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
01/2010
01/2012
01/2014
Month
Average
SD


Monotaxis grandoculis Actual Average Length
Average Length (cm)
0
10
20
30
40
01/2010
01/2012
01/2014
Month
Average
SD


Scarus rubroviolaceus Actual Average Length
Average Length (cm)
0
10
20
30
40
50
01/2010
01/2012
01/2014
Month
Average
SD


Lethrinus obsoletus Actual Average Length
Average Length (cm)
0
5
10
15
20
25
30
35
01/2010
01/2012
01/2014
Month
Average
SD


Scarus forsteni Actual Average Length
Average Length (cm)
0
10
20
30
40
01/2010
01/2012
01/2014
Month
Average
SD


Lutjanus gibbus Actual Average Length
Average Length (cm)
0
10
20
30
40
01/2010
01/2012
01/2014
Month
Average
SD

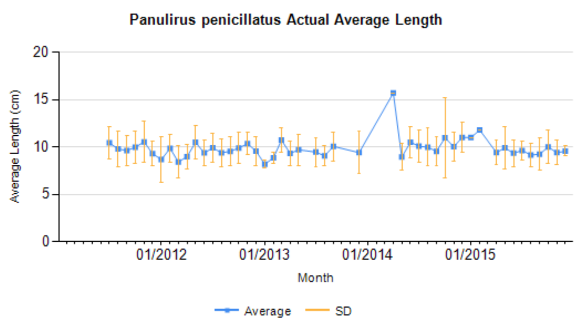

Panulirus penicillatus Actual Average Length
Average Length (cm)
0
5
10
15
20
01/2012
01/2013
01/2014
01/2015
Month
Average
SD

Figure 8. Average length over time of representative Guam coral reef fish management unit species derived from the BioSampling Program.

2.2.4 Guam Bottomfish Ecosystem – Bottomfish Life History

2.2.4.1 Age & Growth and Reproductive Maturity

<u>Description</u>: Age determination is based on counts of yearly growth marks (annuli) and/or daily growth increments (DGIs) internally visible within transversely-cut thin sections of sagittal otoliths. Validated age determination, particularly for long-lived (≥30 years) fish, is based on an environmental signal (bomb radiocarbon ^{14}C) produced during previous atmospheric thermonuclear testing in the Pacific and incorporated into the core regions of sagittal otolith and other aragonite-based calcified structures such as hermatypic corals. This technique relies on developing a regionally-based aged coral core reference series for which the rise, peak, and decline of ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. This technique provides age estimates independent of age estimates based on visual counts of annuli or DGIs. The relation between age and fish length is evaluated by fitting this data to a von Bertalanffy growth function based on statistical analyses. The resulting von Bertalanffy growth function predicts the pattern of growth over time for that particular species. This function typically uses three coefficients (L_∞, *k*, and t_0) which together characterize the shape of the length-at-age growth relationship. The ^{14}C derived ages typically provide more accurate estimates of older ages (≥30 years) and hence more realistic values of T_{max} compared to annuli or DGI-based counts of otolith sections.

Length at reproductive maturity is based on the histological analyses of small tissue samples of gonad material that are typically collected along with otoliths when a fish is processed for life history studies. The gonad tissue sample is preserved then subsequently cut into five micron sections, stained, and sealed onto a glass slide for subsequent examination. Based on standard cell structure features and developmental stages within ovaries and testes, the gender, developmental stage, and maturity status (immature or mature) is determined via microscopic evaluation. The percent of mature samples for a given length interval are assembled for each sex and these data are fitted to a three- or four-parameter logistic function to determine the best fit of these data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish have achieved reproductive maturity (L_{50}). For species that undergo sex reversal (primarily female to male in the tropical Pacific region), such as groupers and deeper-water emperors among the bottomfishes, and for parrotfish, shallow-water emperors, and wrasses among the coral reef fishes, standard histological criteria are used to determine gender and reproductive developmental stages that indicate the transitioning or completed transition from one sex to another. These data are similarly analyzed using a three- or four-parameter logistic function to determine the best fit of the data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish of a particular species have or are undergoing sex reversal ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the von Bertalanffy growth function for that species and using the corresponding L_{50} and $L\Delta_{50}$ values to obtain the corresponding age value from this growth function. In studies where both age & growth and reproductive maturity are concurrently determined, estimates of A_{50} and $A\Delta_{50}$ are derived directly by fitting the percent of mature samples for each age (one-year) interval to a three- or four-parameter logistic function using statistical analyses. The mid-point of this fitted logistic function provides a direct estimate of the age at which 50% of fish of a particular species have achieved reproductive maturity (A_{50}) and sex reversal ($A\Delta_{50}$).

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ☐ American Samoa
- ✓ Guam

- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands:
- ☐ Pacific Remote Island Areas

Spatial Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: Sources of data are directly derived from field samples collected at sea on NOAA research vessels and from the Guam contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the "Reference" column in Table 55 for specific details on data sources by species.

Parameter definitions:

T_{max} (maximum age) – The maximum observed age revealed from an otolith-based age determination study. T_{max} values can be derived from ages determined by annuli counts of sagittal otolith sections and/or bomb radiocarbon (^{14}C) analysis of otolith core material.

L_∞ (asymptotic length) – One of three coefficients of the von Bertalanffy growth function (VBGF) that measures the mean maximum length at which the growth curve plateaus and no longer increases in length with increasing age. This coefficient reflects the mean maximum length and not the observed maximum length.

***k* (growth coefficient) –** One of three coefficients of the VBGF that measures the shape and steepness by which the initial portion of the growth function approaches its mean maximum length (L_∞).

t_0 (hypothetical age at length zero) – One of three coefficients of the VBGF whose measure is highly influenced by the other two VBGF coefficients (*k* and L_∞) and typically assumes a negative value when specimens representing early growth phases (0+ to 1+ ages) are not available for age determination.

***M* (natural mortality) –** This is a measure of mortality rate for a fish stock not under the influence of fishing pressure and is considered to be directly related to stock productivity (i.e., high *M* indicates high productivity and low *M* indicates low stock productivity). *M* can be derived through use of various equations that link *M* to T_{max} and *k*, or in some instances, by calculating the value of the slope from a regression fit to a declining catch curve (regression of the natural logarithm of abundance versus age class) derived from fishing an unfished or lightly-fished population.

***A_{50}* (age at 50% maturity)** – Age at which 50% of the sampled stock under study has attained reproductive maturity. This parameter is best determined based on studies that concurrently determine both age (otolith-based age data) and reproductive maturity status (logistic function fitted to percent mature by age class with maturity determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating A_{50} is to use an existing L_{50} estimate to find the corresponding age (A_{50}) from an existing VBGF curve.

***$A\Delta_{50}$* (age of sex switching)** – Age at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal. This parameter is best determined based on studies that concurrently determines both age (otolith-based age data) and reproductive sex reversal status (logistic function fitted to percent sex reversal by age class with sex reversal determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating $A\Delta_{50}$ is to use an existing $L\Delta_{50}$ estimate to find the corresponding age ($A\Delta_{50}$) from the VBGF curve.

***L_{50}* (length at which 50% of a fish species are capable of spawning)** – Length (usually in terms of fork length) at which 50% of the females of a sampled stock under study has attained reproductive maturity; this is the length associated with A_{50} estimates. This parameter is derived using a logistic function to fit the percent mature data by length class with maturity status best determined via microscopic analyses of gonad histology preparations). L_{50} information is typically more available than A_{50} since L_{50} estimates do not require knowledge of age & growth.

***$L\Delta_{50}$* (length of sex switching)** – Length (usually in terms of fork length) at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal; this is the length associated with $A\Delta_{50}$ estimates. This parameter is derived using a logistic function to fit the percent sex reversal data by length class with sex reversal status best determined via microscopic analyses of gonad histology preparations). $L\Delta_{50}$ information is typically more available than $A\Delta_{50}$ since $L\Delta_{50}$ estimates do not require knowledge of age & growth.

<u>Rationale</u>: These nine life history parameters provide basic biological information at the species level to evaluate the productivity of a stock - an indication of the capacity of a stock to recover once it has been depleted. Currently, the assessment of coral reef fish resources in American Samoa is data-limited. Knowledge of these life history parameters support current efforts to characterize the resilience of these resources and also provide important biological inputs for future stock assessment efforts and enhance our understanding of the species-likely role and status as a component of the overall ecosystem. Furthermore, knowledge of life histories across species at the taxonomic level of families or among different species that are ecologically or functionally similar can provide important information on the diversity of life histories and the extent to which species can be grouped (based on similar life histories) for future multi-species assessments.

Table 57. Available age, growth, and reproductive maturity information for bottomfish species targeted for life history sampling (otoliths and gonads) in Guam. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth

parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

Species	Age, growth, and reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Aphareus rutilans							NA		NA	
Aprion virescens							NA		NA	
Etelis carbunculus							NA		NA	
Etelis coruscans							NA		NA	
Monotaxis grandoculis								228[b]	X[a]	
Pristipomoides auricilla							NA		NA	
Pristipomoides filamentosus							NA		NA	
Pristipomoides flavipinnis							NA		NA	
Pristipomoides sieboldii							NA		NA	
Pristpomoides zonatus							NA		NA	
Variola louti								220[b]	X[a]	

[a] signifies estimate pending further evaluation in an initiated and ongoing study
[b] signifies a preliminary estimate taken from ongoing analyses
[c] signifies an estimate documented in an unpublished report or draft manuscript
[d] signifies an estimate documented in a finalized report or published journal article (including in press)

2.2.4.2 Fish Length Derived Parameters

Description: The NMFS Commercial Fishery BioSampling Program started in 2009. This program has two components: First is the Field/Market Sampling Program and the second is the Life History Program, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear & area fished)
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially)
- Accurate species identification
- Develop accurate local length-weight curves

In Guam, the BioSampling is focused on the commercial fishery. Sampling is conducted in partnership with the Guam Fisherman's Cooperative Association (GFCA). The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information. More specific fishery information such as gear information, species composition and total catch information is recorded through the log book system implemented by GFCA and transcribed into the database maintained by the Western Pacific Fishery Information Network.

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ☐ American Samoa
- ✓ Guam
- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands
- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:

- ☐ Regional
- ☐ Archipelagic
- ✓ Island
- ☐ Site

Data Source: NMFS BioSampling Program

Parameter definition:

L_{max} ***– maximum fish length*** is the longest fish per species recorded in the BioSampling Program from the commercial spear fishery. This value is derived from measuring the fork length of individual samples for species occurring in the spear fishery.

L_{bar} ***– mean length*** is the average value of all lengths recorded from the commercial spear fishery. This can be influenced by gear selectivity since the commercial spear fishery has a typical size target based on customer demand. This can also be influenced by size regulations.

n – sample size is the total number of samples accumulated for each species recorded in the commercial spear fishery.

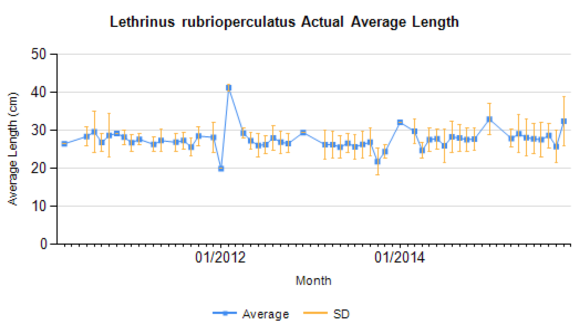
N_{L-W} ***– sample size for L-W regression*** is the number of samples used to generate the a & b coefficients

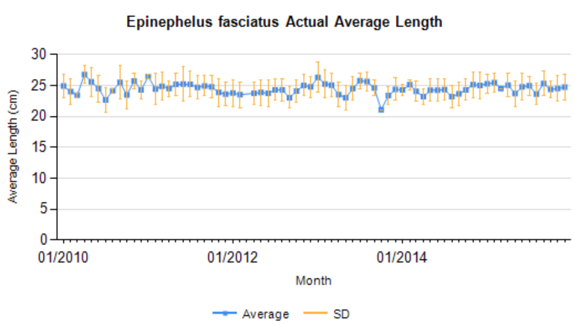
a & b – length-weight coefficients are the coefficients derived from the regression line fitted to all length and weight measured per species in the commercial spear fishery. These values are used to convert length information to weight. Values are influenced by the life history characteristics of the species, geographic location, population status, and nature of the fisheries from which the species are harvested from.

Rationale: Length-derived information is being used as an indicator of population status particularly for data-poor stocks like coral reef fish. Average length (L_{bar}) was used as a principal stock assessment indicator variable for exploited reef fish population (Nadon et al 2015). Average length was also shown to be correlated with population size (Kerr and Dickle 2001). Maximum length (L_{max}), typically coupled with maximum age, is typically used as a proxy for fish longevity which has implications on the productivity and susceptibility of a species to fishing pressure. The length-weight coefficients (a & b values) are used to convert length to weight for fishery dependent and fishery independent data collection where length are typically recorded but weight is the factor being used for management. This section of the report presents the best available information for the length-derived variables for the CNMI coral reef and bottomfish fisheries.

Table 58. Available length derived information for various bottomfish species in Guam.

Species	***Length derived parameters***						**Reference**
	L_{max}	***L_{bar}***	***n***	***L-W***	***a***	***b***	
Lethrinus rubrioperculatus	46.6	27.10	3374		0.0248	2.9158	2010-2015 Guam Biosampling Database
Epinephelus fasciatus	35.8	24.01	3033		0.0141	3.0303	
Pristipomoides auricilla	39.0	28.18	1732		0.0152	3.0742	





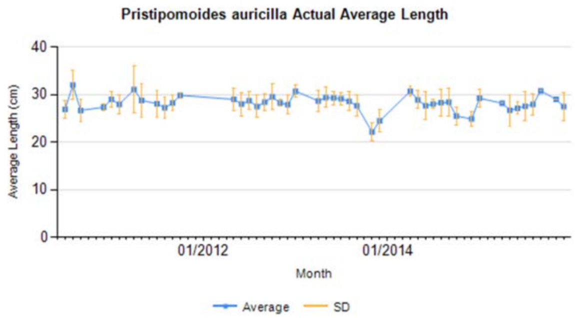


Figure 9. Average length over time of representative Guam bottomfish management unit species derived from the BioSampling Program

2.3 SOCIOECONOMICS

This section outlines the pertinent economic, social, and community information available for assessing the successes and impacts of management measures or the achievements of the Fishery Ecosystem Plan for the Marianas Archipelago (Western Pacific Regional Fishery Management Council, 2016). It meets the objective “Support Fishing Communities” adopted at the 165th Council meeting; specifically, it identifies the various social and economic groups within the region’s fishing communities and their interconnections. The section begins with an overview of the socioeconomic context for the region, then provides a summary of relevant studies and data for CNMI and Guam, followed by summaries of relevant studies and data for each fishery in CNMI and Guam.

In 1996, the Magnuson-Stevens Fishery Conservation and Management Act’s National Standard 8 (NS8) specified that conservation and management measures take into account the importance of fishery resources to fishing communities, to provide for their sustained participation in fisheries and to minimize adverse economic impacts, provided that these considerations do not compromise the achievement of conservation. Unlike other regions of the U.S., the settlement of the Western Pacific region was intimately tied to the sea (Figure 10), which is reflected in local culture, customs, and traditions.

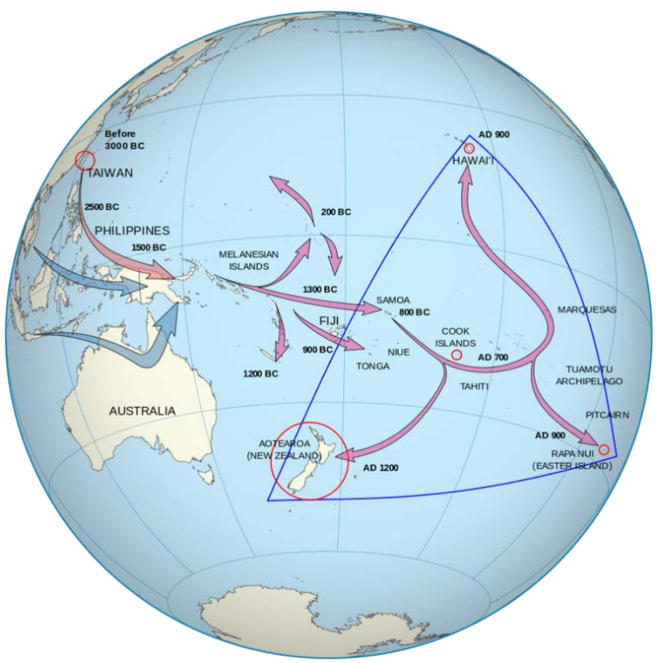


Figure 10. Settlement of the Pacific Islands, courtesy Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Polynesian_Migration.svg.

Polynesian voyagers relied on the ocean and marine resources on their long voyages in search of new islands, as well as in sustaining established island communities. Today, the population of the region also represents many Asian cultures from Pacific Rim countries, which reflect similar importance of marine resources. Thus, fishing and seafood are integral local community ways of life. This is reflected in the amount of seafood eaten in the region in comparison to the rest of the United States, as well as the language, customs, ceremonies, and community events. It can also affect seasonality in prices of fish. Because fishing is such an integral part of the culture, it is difficult to cleanly separate commercial from non-commercial fishing, with most trips involving multiple motivations and multiple uses of the fish caught. While economics are an important consideration, fishermen report other motivations such as customary exchange as being equally, if not more, important. Due to changing economies and westernization, recruitment of younger fishermen is becoming a concern for the sustainability of fishing and fishing traditions in the region.

The Marianas Archipelago consists of the Commonwealth of the Northern Mariana Islands (CNMI) at the northern end of the archipelago and Guam, the southernmost island. These are typically treated as two jurisdictions, which will be presented separately in the rest of this chapter.

2.3.1 Response to Previous Council Recommendations

At its 165th meeting held in Honolulu, HI, the Council approved modifications to the FEP objectives, one of which is to identify the various social and economic groups within the region's fishing communities and their interconnections, in support of fishing communities. This chapter meets this objective.

At its 166th meeting held in Tumon, Guam, the Council recommended NMFS Pacific Islands Fisheries Science Center (PIFSC) to conduct an economic survey in the CNMI to determine the expense and expenditure differences in fisheries between Saipan, Tinian, Rota and Guam to determine the differences between the islands as well as between the fishery sectors. The Council also recommended NMFS PIFSC design and implement a socio-economic survey to determine the fisheries opportunities and impacts of increased recent development in the CNMI, given the new hotels and casinos in Saipan. A small boat cost-earnings survey is scheduled for the Marianas in 2018-2019 that will address both of these recommendations.

In addition, the Council directed staff to develop a brief report identifying data sources, quality and coverage for each required socioeconomic parameter in the annual/SAFE reports, as resources permit. This report should also identify the quality and coverage of this data, as well as any gaps. This data synthesis was conducted and used to guide the development of this chapter.

The Council also directed the Plan Team to consider for future Annual/SAFE reports:

- to include the human perspective, the importance of the community, and the extended cultural and social values of fishing in the dashboard summary format. This chapter is the first effort at including the importance of community and extended cultural and social values into a SAFE report in this region.
- to break out trip costs by island for the CNMI sections of the report, as trip costs vary by island. This chapter provides a reference to existing data on island-specific trip costs.
- to explore partnering with the CNMI Department of Commerce on efforts to address socioeconomic data gaps in the CNMI SAFE/annual report. The CNMI Department of Commerce Statistical Yearbook was reviewed in the development of this chapter. Information on fishing as an occupation is only reported in aggregate with farming and forestry. In addition, fishing in CNMI is a continuum of commercial to non-commercial activities that many do not consider a profession. For these reasons, occupational

information was not included in this chapter. The other section relevant to fishing summarizes the amounts and values of commercial fish landings, which is already reported by PIFSC. In addition, the yearbook has not received new data on fish and fisheries since 2004.

- to include enhanced information on social, economic and cultural impacts of a changing climate and increased pressure on the ocean and its resources. PIFSC developed a Regional Action Plan and Climate Science Strategy as a first step in providing this information (Polovina et al., 2016).

2.3.2 CNMI

2.3.2.1 Introduction

An overview of CNMI history, culture, geography, and relationship with the U.S. is described in Section 1.3 of the Fishery Ecosystem Plan for the Mariana Archipelago (Western Pacific Regional Fishery Management Council, 2016). Over the past decade, a number of studies have synthesized more specifics about the role of fishing and marine resources across CNMI, as well as information about the people who engage in the fisheries or use fishery resources.

The ancestors of the indigenous Chamorros first arrived in the Marianas around 3,500 years ago and relied on seafood as their principal source of protein (see Chapter 1, Allen and Amesbury 2012, and Grace McCaskey 2014). Similar to other archipelagos in the Western Pacific, fish and marine resources have played a central role in shaping the social, cultural, and economic fabric of CNMI that continues today. They fished for both reef and pelagic species, collected mollusks and other invertebrates and caught sea turtles. The occupation of CNMI by foreign nations dramatically changed the island’s ecosystems, reshaped communities, and disrupted fishing traditions. In the 17th and 18th centuries, Spanish colonizers destroyed the Chamorros’ seagoing canoes, suppressed offshore fishing practices, and relocated populations from their traditional home. CNMI was briefly occupied by Germany from 1899 to the beginning of WWII. During WWII, CNMI was occupied by the Japanese military, and then was captured by the United States. Throughout this time, fishing has remained an important activity. Later immigrants to the islands from East and Southeast Asia also possessed a strong fishing tradition. Today, only Saipan, Rota, and Tinian are permanently inhabited, with 90% of the population on the island of Saipan.

2.3.2.2 People who Fish

Allen and Amesbury (2012) summarized results of studies that demonstrated the sociocultural importance of fishing to Saipan residents. In a 2005 study, most of the active or commercial fishermen who responded to the survey had fished more than 10 years. They most often participated in snorkel spear fishing at night (participated in by 73% of the fishermen) and snorkel spear fishing during daytime (58% of the fishermen), followed by hook-and-line less than 100 ft. deep (36%), trolling (21%) cast net (talaya; 14%) hook-and-line more than 100 ft. deep (9%), trapping (octopus, crabs, etc.; 19%), foraging the reef (8%); 18% said they participated in one or more other techniques. Less than a third (30%) said they owned a boat. Their primary reasons for fishing were social and cultural, including that they just really like fishing (32%), they need the fish to feed their family (23%), giving catch to family and friends strengthened social bonds (13%), their family has always fished (12%), and it strengthens bonds with their children/family (6%). Only 4% said they needed the money from the fish they sold. Other motivations included strengthening the bond with their fellow fishermen, fishing to catch fish for fiestas/parties, and seasonal fishing for manahak, ti'ao, and i'e (2% each).

The fishermen reported fishing an average of 71 days a year, with 26% going once every 2-3 days and 24% fishing once every 2 weeks. They also reported a decrease in their amount of fishing over time, fishing an average of 93 days a year 10 years ago. Saipan reef fish were the most frequently caught species (caught by 54% of the fishermen), followed by shallow-water bottomfish (23%) and reef invertebrates such as octopus, shellfish and crabs (14%).

As in other parts of the region, much of their catch was consumed by themselves and immediate family (70%), with another 20% consumed by extended family and friends. Only 8% of the catch was sold. Only 18 respondents identified themselves as commercial fishermen. They reported a median monthly income of $200 from fishing, with a mean (average) of just over $1,000. Costs exceeded sales for almost every income category of fishermen, suggesting that for most fishermen, fishing is not a business but rather that they sell their catch simply to recover some of the costs.

While fish remains an important part of the local diet and an integral part of the people’s history and culture, adaptation to and integration with a more westernized lifestyle appears to have changed people’s diets on Saipan. Nearly half (45%) of the survey respondents reported eating “somewhat less fish” than they did 10 years ago, although the majority still ate fish between 1 and 3 times a week. The majority also purchased their fish from a store or restaurant (40%) while 31% purchase fish from roadside vendors. Less common was acquiring fish from an extended relative/friend (13%) or their own catch (11%). Most of the fish consumed came from the U.S. mainland (41%), while the next most important source was from inside Saipan’s reef (31%), deep water or pelagic fish caught off Saipan (23%), or imported from other Pacific islands such as Chuuk (10%).

Few other surveys have been conducted on fishing in general in CNMI. A household survey conducted in 2012 found that 37% of respondents said they or someone else in their household was a fisherman (Kotowicz and Allen, 2015). Respondents from fishing households tended to be younger, have lower education levels, and have a higher rate of unemployment than respondents from non-fishing households.

While proportionally few residents own a boat, more than 400 vessels were registered in the CNMI small boat fleet between 2010 and 2011 (see Allen and Amesbury, 2012 for review). More than 200 of the vessels were active and operating in CNMI waters, and more than 100 of the vessels were involved in fishing activities. The active small boat fleet targets tunas, other small pelagics (through trolling), and bottomfish, although with the increases in the price of gas, pelagic fishing has dropped off somewhat. The fish are marketed locally, given away to family and friends, or used for ceremonial purposes such as parties, culturally significant fiestas, and each village’s patron saint’s day.

On Saipan, fisheries managers estimated the active small boat fleet at approximately 100 vessels in 2010-2011. Full-time commercial fishing is primarily conducted by ethnic nonindigenous minorities, namely Filipino residents (who fish primarily as independent owners and/or operators) and recent immigrants from the Federated States of Micronesia (who are primarily employed for wages). Chamorro and Carolinians, in contrast, primarily fish for recreational and subsistence purposes, selling catch to recoup costs. A few vessel owner operators are considered "pescadors", a term used to refer to fishermen who provide fish for important community and familial events. Pescadors customarily provide 100-200 lbs. of reef fish for cooked dishes and pelagic species for kelaguen (a raw fish dish) for community and family celebrations. The system of seafood distribution underwent significant changes from approximately 2000-2010 with the establishment of large seafood vendors. In contrast to individual fishermen/vendors who only market their own catch, large vendors typically own and operate a number of vessels and purchase catch from independent fishermen to sell, which is reportedly depressing prices. In addition, increases in fuel prices, low market prices for fish, and downturns in the domestic economy have led to a general decline in participation in this fishery since 2000, with respect to numbers of fishermen, trips, landings, and seafood purchasers. The Saipan Fishermen's Association (SFA) is a nonprofit organization established in 1985 that holds annual fishing derbies and participated in community involvement projects, such as beach cleanup.

On Tinian, estimates of fleet size range from 15 to 20 vessels in 2010-2011. An estimated 1-3 fishermen fished consistently with the primary intent of selling fish. Respondents suggested that fishing and eating of fish was more habitual, rather than geared toward a particular event. Increasing fuel prices have reportedly led to the decline in number of active fishermen, and fishermen frequently sell fish to cover fuel costs. Three restaurants and two stores in Tinian purchase fish, although fishermen also sell house to house and commonly have an established clientele. A few charter boats serve tourist clientele, however they do not land much catch and even trolling trips serve more as photo opportunities. Charter boats are reportedly owned by nonlocal residents and target tourists from their country of origin (Japan, China, or Korea).

On Rota fishermen target pelagic species when in season, fishing for bottomfish the rest of the year. Like on the other islands, the number and activity of fishermen have declined as a result of increased fuel prices. Family members will often make requests for certain kinds of fish, but they will also contribute money to purchase fuel for a fishing trip. In addition, fishermen will often check demand with local restaurants, based on fuel prices. In 2010-2011, fishermen sold catch to 3 restaurants, or to neighbors and friends within the community (door to door or from a cooler on the roadside). One general store in sold fish caught by a family member, who fishes specifically to sell. Rota holds one fishing derby in celebration of San Francisco, the saint of their island.

A survey of the small boat fleet was also conducted in 2011 (see Hospital and Beavers, 2014 for full report). On average, respondents were 41 years old and had been boat fishing for an average of 15 years, providing evidence of a deep tradition of boat fishing in the CNMI. They were more likely to identify themselves as Chamorro relative to the general population of the CNMI, although they were equally likely to have been born in the CNMI. In general, fishermen were more educated then the general population and of comparable affluence. Pelagic trolling as the most popular gear type, followed by deepwater bottomfish fishing, shallow-water bottomfish, and spear fishing. Most (71%) fishermen reported fishing at a Fish Aggregating Device (FAD) during the past 12 months, and on nearly 22% of their fishing trips. A high degree of seasonal fishing effort was reported across most subgroups of the fleet, although fishermen on Tinian and Rota were more likely to fish year-round.

A majority of fishermen (74%) reported selling at least a portion of their catch in the past 12 months. However, less than half (43%) of survey respondents indicated that they could always sell all the fish that they wanted. A significant percentage of fish caught was consumed at home (28%) or given away to relatives, friends, or for cultural events (38%), reflecting the strong family and social connections associated with fishing in the CNMI. Approximately 29% of fish catch was sold, with the remaining catch either released (2%) or exchanged for goods and services (3%). Even fishermen who regularly sell fish still retain approximately 22% of their catch for home consumption and participation in traditional fish-sharing networks and customary exchange. Additionally, 91% consider the bottomfish they catch to be an important source of food, and 93% consider reef fish to be an important source of food. These findings validate the importance of fishing in building and maintaining social and community networks, perpetuating fishing traditions, and providing fish to local communities as a source of food security.

Fishing in the CNMI is a social activity; only 3% of fishermen reported to fish alone, while 70% reported that their boat is used without them on occasion. In addition, the majority of fishermen (57%) agreed that as a fisherman, they are respected by the greater community. While nearly a third of respondents were neutral (27%) and some were hesitant to express an opinion or simply did not know (13%), the study found that very few (3%) felt that they were not respected by the community.

The designation of the Marianas Trench Marine National Monument (the Monument) in 2009 has resulted in concerns about loss of fishing access (see Richmond and Kotowicz, 2015, Kotowicz and Richmond, 2013, and Kotowicz and Allen, 2015). Despite long distance, high cost, and inconvenience, travel to the areas now protected by the Monument were rare but culturally significant events, and fishing was an essential component.

Overall, the CNMI small boat fisheries are a complex mix of subsistence, cultural, recreational, and quasi-commercial fishermen whose fishing behaviors provide evidence of the importance of fishing to the people of the CNMI. For nearly all fishery participants, the social and cultural motivations for fishing far outweigh any economic prospects. Nearly all fishermen supplement their income with other jobs and are predominantly subsistence fishermen, selling occasionally to recover trip expenses.

2.3.2.3 Costs of Fishing

Since 2009, the PIFSC Socioeconomics Program has maintained a continuous economic data collection program on Saipan through collaboration with the PIFSC Western Pacific Fisheries Information Network (WPacFIN). The economic data collection program gathers fishing expenditure data for boat-based reef fish, bottomfish, and pelagic fishing trips on an ongoing basis. Data for fishing trip expenses include; gallons of fuel used, price per gallon of fuel, cost of ice used, cost of bait & chum used, cost of fishing gear lost, and the engine type of the boat. These economic data are collected from same subset of fishing trips as the boat-based creel survey carried out by the local fisheries management agencies and WPacFIN.

These data are currently under PIFSC editorial review and future versions of this report will include a time-series of Saipan boat-based trip costs by target species and/or gear. Metadata for these data are available online (PIFSC Socioeconomics Program, 2016).

Island-specific (Saipan, Tinian, and Rota) trip cost estimates from 2011 for bottomfish and reef-fish fishing trips are available in Hospital and Beavers (2014). Other relevant cost information in Hospital and Beavers (2014) include estimates of annual fishing expenditures (fixed costs) and levels of investment in the fishery.

2.3.2.4 CNMI Bottomfish Fishery

Bottomfish was one of the gear types included in the 2011 Small Boat Survey (Hospital and Beavers, 2014). Overall fisher demographics and catch disposition were summarized in section 2.3.2.2. Approximately 68% of respondents reported fishing for deepwater bottomfish and 65% for shallow-water bottomfish, with 41% identifying deepwater bottomfish as their primary target and 49% identifying shallow-water bottomfish as their primary target. Approximately 37% of trips included some form of bottomfish fishing. In general, deepwater bottomfish fishing appears to be associated with more commercially-motivated fishermen. Fishers who primarily targeted bottomfish sold over half of their catch (52%) to friends, neighbors, and co-workers. They self-identified primarily as subsistence fishers (58% selected this category) and recreational expense fishers (41%), although respondents spanned all response categories (full-time commercial, part-time commercial, recreational expense, purely recreational, subsistence, and cultural). Almost half identified multiple motivations (49%).

2.3.2.4.1 Commercial Participation, Landings, Revenue, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the CNMI bottomfish fishery. Supporting figures and tables will be added in future reports.

2.3.2.5 CNMI Crustacean Fishery

There is currently no socioeconomics information specific to this fishery. Subsequent reports will include new data as resources allow.

2.3.2.5.1 Commercial Participation, Landings, Revenue, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the CNMI crustacean fishery. Supporting figures and tables will be added in future reports.

2.3.2.6 CNMI Coral Reef Fishery

Coral reef fish were also included in the 2011 Small Boat Survey (Hospital and Beavers, 2014). Overall fisher demographics and catch disposition were summarized in section 2.3.2.2. Not surprisingly, fishermen targeting reef fish, on average, are slightly younger than others, likely due to the physical requirements of reef fishing (primarily spear fishing). Approximately 54% of respondents reported atulai fishing, 50% spearfishing, and 12% net fishing. Atulai was identified as the primary target by 46% while 38% indicated spearfishing, and 14% net fishing as their primary gear type. Fishers who primarily targeted reef fish sold almost half of their catch (45%) to friends, neighbors, and co-workers. They self-identified primarily as subsistence fishers (44% selected this category) and cultural fishers (38%), although respondents spanned all response categories (full-time commercial, part-time commercial, recreational expense, purely recreational, subsistence, and cultural). Over one-third identified multiple motivations (38%).

In addition to playing an important role in subsistence and cultural fishing, coral reef ecosystems have been estimated at a value of $61 million (Saipan only), 70% of which is accounted for by tourism (Grace McCaskey, 2014).

2.3.2.6.1 Commercial Participation, Landings, Revenue, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the CNMI coral reef fishery. Supporting figures and tables will be added in future reports.

2.3.2.7 CNMI Precious Coral Fishery

There is currently no socioeconomics information specific to this fishery. Subsequent reports will include new data as resources allow.

2.3.2.7.1 Commercial Participation, Landings, Revenue, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the CNMI precious coral fishery. Supporting figures and tables will be added in future reports.

2.3.3 Guam

2.3.3.1 Introduction

An overview of Guam's history, culture, geography, and relationship with the U.S. is described in Section 1.3 of the Fishery Ecosystem Plan for the Mariana Archipelago (Western Pacific Regional Fishery Management Council, 2016b). Guam is the largest and southernmost island of the archipelago. It is also the largest and most heavily populated island in Micronesia. Over the past decade, a number of studies have synthesized more specifics about the role of fishing and marine resources across Guam, as well as information about the people who engage in the fisheries or use fishery resources.

The ancestors of the indigenous Chamorros first arrived in the Marianas around 3,500 years ago and were expert fishermen and seafarers, relying on seafood as their principal source of protein (see Chapter 1, Allen and Bartram, 2008, Grace McCaskey 2014, Hospital and Beavers 2012). They fished on the high seas in large sailing canoes (proas) and used numerous methods to catch reef and bottomfish from boats Similar to other archipelagos in the Western Pacific, fish and marine resources have played a central role in shaping the social, cultural, and economic fabric of Guam that continues today. Chamorros fished for both reef and pelagic species, collected mollusks and other invertebrates and caught sea turtles.

The occupation of Guam by foreign nations dramatically changed the island's ecosystems, reshaped communities, and disrupted fishing traditions. In the 17th and 18th centuries, Spanish colonizers destroyed the Chamorros' seagoing canoes, suppressed offshore fishing practices, and relocated populations from their traditional home. Following the Spanish-American War in 1898, the U.S. Navy took control of Guam, until it was occupied by Japan from 1941 to 1944. Guam became a U.S. territory in 1950, and the U.S. military is currently in the process of building up an even greater presence on the island. Throughout this time, fishing has remained an important activity, although by the beginning of the American period in 1898, the indigenous inhabitants had lost many of their seafaring and fishing skills and even the native names of many of the offshore species. Later immigrants to the islands from East and Southeast Asia also possessed a strong fishing tradition. In 2000, for Guam's population that identified as a single ethnicity 37% were Chamorro, followed by 32% Asian (about 80% of whom were Filipino), 17% other Pacific Islander, 7% white and 1% black. Despite rapid socioeconomic change, households still reflect the traditional pattern of extended families with multigenerational clustering of relatives, especially in Guam's southern villages. Social occasions such as neighborhood parties, wedding and baptismal parties, wakes and funerals, and especially the village fiestas that follow the religious celebrations of village patron saints all require large quantities of fish and other traditional foods, reflecting the role of fish in maintaining social ties and cultural identities. Sometimes fish are also sold to earn money to buy gifts for friends and relatives on important Catholic religious occasions such as novenas, births and christenings, and other holidays.

Since the late 1970s, Guam's most important commercial fisheries activity has been its role as a major regional fish transshipment center and resupply base for domestic and foreign tuna fishing fleets. Services provided include fueling, provisioning, unloading, air and sea transshipment, net and vessel repairs, crew repatriation, medical care, and warehousing. Among Guam's advantages as a home port are well-developed and highly efficient port facilities in Apra Harbor; an availability of relatively low-cost vessel fuel; a well-established marine supply/repair industry; and recreational amenities for crew shore leave. In addition, the territory is exempt from the Nicholson Act, which prohibits foreign ships from landing their catches in U.S. ports. Initially, the majority of vessels calling in Apra Harbor to discharge frozen tuna for transshipment were Japanese purse seine boats and carrier vessels. In the late 1980s, Guam became an important port for Japanese and Taiwanese longline fleets, but port calls have steadily declined and the transshipment volume has also declined accordingly. By the early 1990s, an air transshipment operation was also established on Guam. Fresh tuna was flown into Guam from the Federated States of Micronesia and elsewhere on air cargo planes and out of Guam to the Japanese market on wide-body passenger planes. Further, vessels from Japan and Taiwan also landed directly into Guam where their fish was packed and transshipped by air to Japan. A second air transshipment operation began in the mid-1990s; it was transporting to Europe fish that did not meet Japanese sashimi market standards, but this has since ceased operations. Moreover, the entire transshipment industry has contracted markedly with only a few operators still making transshipments to Japan. Annual volumes of tuna transshipped of between 2007 and 2011 averages about 3,400 mt, with a 2012 estimate of 2,222 mt, compared to over 12,000 mt at the peak of operations between 1995 and 2001. As early as 2006, it was noted that the Port of Guam had lost much of its competitive advantage compared to alternative transshipment locations in the western Pacific and elsewhere, a trend that may not be reversible.

Otherwise, commercial fisheries have a relatively minor contribution to Guam's economy; the social and cultural importance of fisheries in Guam dwarfs their commercial value. Nearly all Guam domestic fishermen hold jobs outside the fishery, with fishing typically supplementing family subsistence. High value is placed on sharing one's fish catch with relatives and friends, and this social obligation extends to part-time and full-time commercial fishermen alike. A 2005 survey of Guam households found that nearly one-quarter (24 percent) of the fish consumed was caught by the respondent or an immediate family member, and an additional 14 percent was caught by a friend or extended family member (Allen and Bartram, 2008). However, a little more than half (51 percent) of the fish consumed was purchased at a store or restaurant and 9 percent was purchased at a flea market or from a roadside stand. The same study found that annual seafood consumption in Guam is estimated to be about 60 lbs. per capita, with approximately 43% imported from the U.S.

The Westernization of Guam, particularly since World War II, not only resulted in a transition from a subsistence to wage-based economy but also contributed to dramatic changes in eating patterns, including lower seafood consumption. Indeed, recent years have seen steady declines in the market demand for fresh local fish across Guam (Hospital and Beavers, 2012). While some families continue to supplement their diet by fishing and farming, no existing communities are completely dependent on local fishing as a source of food. A household survey conducted in 2016 found that only 29% of respondents participate in fishing (National Coral Reef Monitoring Program, 2016a).

Allen and Bartram (2008) reviewed the history of shoreline and inshore fishing on Guam. They noted that the number of people engaged in shore fishing in the 1970s was surprisingly large, given that about 90% of the food consumed on the island was imported. A study conducted in 1975 found that 65% of households reported some participation in fishing, which was presumably shore fishing as a result of the low level of boat ownership at the time. Creel surveys conducted by the Guam Division of Aquatic and Wildlife Resources indicated that catch-per-unit-effort (CPUE) in Guam’s shore-based fisheries for reef fish (pole, spear, cast net, surround and gill net) declined sharply in the 1980s and had not recovered by 2008. Offshore (boat-based) catches of reef-associated fish were relatively constant between1992 and 2008, whereas inshore catches that accounted for the majority of the reef fish harvest during the 1990s accounted for the minority of the total harvest by 2008. Much of the traditional harvest targets seasonal runs of juvenile rabbitfish, goatfish, bigeye scad (atulai, Selar Crumenophthalmus) and jacks family (i’e, family Carangidae). A study in 2007 estimated that Guam’s coral reef resources were valued at close to $127 million per year, primarily driven by the island’s important tourism industry (Grace McCaskey, 2014). Nearly 1.2 million people visited Guam in 2010, many of them attracted by reef-related activities, such as snorkeling and scuba diving.

As recently as the early 1970s, relatively few people in Guam fished offshore, because boats and deep-sea fishing equipment were prohibitively expensive (Allen and Bartram, 2008). During the economic boom from the late 1980s through most of the 1990s, Guam developed a small boat fishery that conducts trolling and bottomfishing, mostly within 30 miles of shore.

The Guam Fishermen’s Cooperative Association (GFCA) plays an important role in preserving important fishing traditions. It began operations in 1976 and was incorporated in 1977. In 2006 its membership included 164 full-time and part-time fishermen from every district on Guam, and it processed and marketed approximately 80% of the local commercial catch. In addition, it plays a role in fisheries data collection, marine education and training, and fisheries conservation and management. The GFCA strives to provide benefits not just to fishermen but to residents throughout Guam, benefitting the broader Guam community. It utilizes a Hazard Analysis and Critical Control Point (HACCP) system to ensure safe seafood, and tests fish for potential toxins or whenever requested by the Guam Department of Health and Sanitation. It has also become a focal point for community activities such as the Guam Marianas International Fishing Derby, cooking competitions, the Guam Fishermen’s Festival, dissemination of educational materials on marine resources, vessel safety and seafood preparation, public meetings on resource management issues, and communications via radio base to relay information and coordinate rescues. It also has adopted a policy of purchasing local origin products that benefits 40 small businesses on Guam, regularly donates seafood for village functions and charitable activities, and provides assistance to victims of periodic typhoons with emergency supplies of ice and fuel. In addition, the GFCA has become a voice for Guam fishermen in the policy arena to ensure that concerns of fishermen are incorporated into issues such as the military buildup and loss of fishing grounds due to establishment of Marine Preserve Areas.

Fishing in Guam continues to be important not only in contributing to the subsistence needs of the Chamorro and other residents but in preserving their histories and identities. Knowledge of how fish are distributed and consumed locally is crucial to understanding the social and cultural significance of fishing on Guam.

2.3.3.2 People who Fish

Few studies have been conducted on fishing in Guam in general. A household survey conducted in 2012 found that 35% of respondents said they or someone else in their household was a fisherman (Kotowicz and Allen, 2015). Respondents from fishing households tended to have lower education levels and have a higher rate of unemployment than respondents from non-fishing households.

As described in Allen and Bartram (2008), in 1999 a detailed study of the inshore fishing behaviors and spatial patterns was conducted for the three largest resident fishing cultures on Guam: Chamorro, Micronesian and Filipino. At that time, Chamorros comprised about ¾ of the fishing parties encountered, while Micronesians constituted about 17 percent of the fishing parties and Filipinos about 7 percent. A number of contemporary reef fishing methods on Guam were observed, including gleaning, hand line, rod and reel, talaya (cast net), tekken (gill net), chenchulu (surround net), and spearfishing. Explicit rules governing permanent marine ownership were not observed, but Chamorro fishermen maintained a strong identification with village and municipal space. This village relationship included the reef during the early part of the 20th century but that has since largely disappeared. Instead, a system of “pliant tenure” (a vestige of traditional marine tenure) was recognized: while any reef area is publicly accessible, fishermen act according to a system of temporary ownership or pliant tenure of reef area. These rules were understood and incorporated by Chamorro and immigrant fishers alike. Respondents voiced concern about the loss of fishing grounds through designation of marine reserves and tourist watercraft activities. They viewed reduced coastal access as threatening the perpetuation of cultural identity and practice by reducing ability to teach and practice traditions such as communal harvests and distribution of the catches, which reinforce family cohesion and communal identity. These practices were further jeopardized by the U.S. buildup of military personnel and families in recent years.

In the mid-1980s Guam fisheries were characterized as including (1) a small number of true commercial fishermen, (2) subsistence/recreational fishermen who regularly sell part of their catch, (3) a large number of subsistence fishermen who rarely sell any of their catch, and (4) a substantial number of recreational fishermen. Approximately 60% of catch was noncommercial, with fish sales primarily used to generate revenue to pay for fuel costs. A similar pattern continues in recent years.

In 2011, a survey was conducted of the small boat fleet, which included questions about trolling, bottomfishing, and reef fishing. On average, fishermen responding to the survey were 44 years old and reported to have been boat fishing for an average of 20 years. Respondents were also more educated and more affluent then the general population. The majority of respondents described themselves as Chamorro (72%) followed by white (23%) with relatively small proportions of Filipinos (6%), Micronesians (6%), other ethnicities (5%), and Carolinians (1%). There was considerable evidence of co-ownership and sharing of fishing vessels. In addition, fishermen reported the use of multiple gear types, with pelagic trolling as the most popular gear type followed by shallow-water bottomfish fishing and deepwater bottomfish fishing. Almost all (96%) fishermen reported fishing at a Fish Aggregating Device (FAD) during the past 12 months, and on nearly half (53%) of their fishing trips. Fishing for bottomfish and reef fish was highly seasonal compared to pelagics; whereas over half of the survey respondents (54%) fished all year for pelagics, only 16% fished year-round for bottomfish and reef fish.

Approximately 70% of fishermen reported selling at least a portion of their fish, and 82% of could always sell all the fish that they wanted to sell. However, nearly 30% reported that they had not sold any fish in the past 12 months, and nobody reported selling all the fish they caught. Instead, cost recovery was cited as the primary motivation for the sale of fish, with fish sales contributing very little to personal income for the majority (59%). In fact, 64% of fishermen reporting the sale of fish earned fishing revenues of less than $1000, which would not cover overall trip expenditures for the year. Sale of pelagic fish contributes to nearly 67% of fishing income, with another 20% from bottomfish revenues, and the rest from reef fish.

While respondents sold approximately 24% of their total catch, 29% was consumed at home, while 42% was given away. The remaining catch was either released (2%) or exchanged for goods and services (3%). This diversity of catch disposition extends to fishermen who regularly sell fish, as they still retain approximately 30% of their catch for home consumption and participation in traditional fish-sharing networks and customary exchange. Additionally, 78% consider the pelagic fish they catch to be an important source of food, 79% for bottomfish, and 85% for reef fish. These findings validate the importance of fishing in terms of building and maintaining social and community networks, perpetuating fishing traditions, and providing food security to local communities.

Like with CNMI, fishing on Guam is a social activity. Only 7% of fishermen reported fishing alone, and 45% reported that their boat is used without them on occasion. In addition, 61% reported to be a member of a fishing club, association or group. The majority of fishermen (60%) also agreed that as a fisherman, they are respected by the Guam community. Very few felt that they were not respected by the community.

There was also an open-ended portion of the survey that asked for comments. The two most prevalent themes were that of a rising population and rising fuel costs. Many believed that the expanding population would increase the demand for fish and number of fishermen, yet at the same time, others noted that fuel costs and economic considerations could restrict fishing. In addition, there was concern about the designation of Marianas Trench Marine National Monument, especially since respondents felt that the Marine Preserve Areas established in 1997 had already displaced them from their traditional fishing grounds. Military exercises also affected fishing trips. Other studies have also documented concerns about fishing access related to the designation of the Monument (see Richmond and Kotowicz, 2015, Kotowicz and Richmond 2013, and Kotowicz and Allen, 2015). Despite long distance, high cost, and inconvenience, travel to the areas now protected by the Monument were rare but culturally significant events, and fishing was an essential component.

Similar to CNMI, Guam's small boat fisheries are a complex mix of subsistence, cultural, recreational, and quasi-commercial fishermen whose fishing behaviors provide evidence of the importance of fishing to the island of the Guam. For nearly all fishery participants, the social and cultural motivations for fishing far outweigh any economic prospects. Nearly all fishermen supplement their income with other jobs and are predominantly subsistence fishermen, selling occasionally to recover trip expenses.

2.3.3.3 Costs of Fishing

Since 2012, the PIFSC Socioeconomics Program has maintained a continuous economic data collection program on Guam through collaboration with the PIFSC Western Pacific Fisheries Information Network (WPacFIN). The economic data collection gathers fishing expenditure data for boat-based reef fish, bottomfish, and pelagic fishing trips on an ongoing basis. Data for fishing trip expenses include; gallons of fuel used, price per gallon of fuel, cost of ice used, cost of bait & chum used, cost of fishing gear lost, and the engine type of the boat. These economic data are collected from same subset of fishing trips as the boat-based creel survey carried out by the local fisheries management agencies and WPacFIN.

These data are currently under PIFSC editorial review and future versions of this report will include a time-series of Guam boat-based trip costs by target species and/or gear. Metadata for these data are available online (PIFSC Socioeconomics Program, 2016).

Guam trip cost estimates from 2011 for bottomfish and reef-fish fishing trips are available in Hospital and Beavers (2012). Other relevant cost information in Hospital and Beavers (2012) include estimates of annual fishing expenditures (fixed costs) and levels of investment in the fishery.

2.3.3.4 Guam Bottomfish Fishery

Allen and Bartram (2008) reviewed the history of the bottomfish fishery on Guam, which consists of a shallow-water and deepwater complex. They noted that during the 1980s and 1990s, bottomfish fishing was a highly seasonal small-scale commercial, subsistence, and recreational fishery. The majority of the participants operated vessels less than 25 ft. long and targeted the shallow-water bottomfish complex because of the lower expenditure and relative ease of fishing close to shore. The commercially oriented vessels tended to be longer than 25 ft., concentrating effort on the deepwater bottomfish complex. Both deepwater and shallow-water bottomfish are also important target species of the charter fishing fleet, and charter trips accounted for about 15–20% of all bottomfishing trips from 1995 through 2000. In 1998, the charter fleet attracted approximately 3% of visitors to Guam and consisted of about 12 core boats.

Bottomfish was one of the gear types included in the 2011 Small Boat Survey (Hospital and Beavers, 2014). Overall fisher demographics and catch disposition were summarized in section 2.3.3.2. Approximately 57% of respondents reported fishing for deepwater bottomfish and 59% for shallow-water bottomfish, with 52% identifying deepwater bottomfish as their primary target and 49% identifying shallow-water bottomfish as their primary target. Fishers who primarily targeted bottomfish their catch mainly through the Guam Fisherman's Cooperative Association (55%), or to friends, neighbors, and co-workers (41%). For the most part, they self-identified as recreational expense fishers (40% selected this category), cultural fishers (35%), subsistence fishers (35%), purely recreational fishers (30%), although respondents spanned all response categories except full-time commercial (i.e., part-time commercial, recreational expense, purely recreational, subsistence, and cultural). Half identified multiple motivations (54%).

2.3.3.4.1 Commercial Participation, Landings, Revenue, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the Guam bottomfish fishery. Supporting figures and tables will be added in future reports.

2.3.3.5 Guam Crustacean Fishery

There is currently no socioeconomics information specific to this fishery. Subsequent reports will include new data as resources allow.

2.3.3.5.1 Commercial Participation, Landings, Revenues, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the Guam crustacean fishery. Supporting figures and tables will be added in future reports.

2.3.3.6 Guam Coral Reef Fishery

Coral reef fish were also included in the 2011 Small Boat Survey (Hospital and Beavers, 2014). Overall fisher demographics and catch disposition were summarized in section 2.3.3.2. Approximately 33% of respondents reported atulai fishing, 32% spearfishing, and 8% net fishing. Atulai was identified as the primary target by 31% while 20% indicated spearfishing, and 4% net fishing as their primary gear type. Fishers who primarily targeted reef fish sold their catch mainly through the Guam Fisherman's Cooperative Association (37%) to friends, neighbors, and co-workers (51%). For the most part, they self-identified as subsistence fishers (46% selected this category), purely recreational fishers (46%), cultural fishers (38.5%), and recreational expense fishers (31%) although respondents spanned all response categories except full-time commercial (i.e., part-time commercial, recreational expense, purely recreational, subsistence, and cultural). Over half identified multiple motivations (54%).

2.3.3.6.1 Commercial Participation, Landings, Revenue, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the Guam coral reef fishery. Supporting figures and tables will be added in future reports.

2.3.3.7 Guam Precious Coral Fishery

There is currently no socioeconomics information specific to this fishery. Subsequent reports will include new data as resources allow.

2.3.3.7.1 Commercial Participation, Landings, Revenues, Prices

This section will describe trends in commercial participation, landings, revenues and prices, as data allows, for the Guam precious coral fishery. Supporting figures and tables will be added in future reports.

2.3.4 Ongoing Research and Information Collection

Social indicators are being compiled for CNMI and Guam, in accordance with a national project to describe and evaluate community well-being in terms of social, economic, and psychological welfare (https://www.st.nmfs.noaa.gov/humandimensions/social-indicators/index). In addition, a web-based tool is being developed to compile relevant socioeconomic data into a "Community Snapshot" by Census County Division or equivalent. An update to the CNMI Fishing Community Profile is also in preparation. Efforts are underway to update the 2011 Marianas Archipelago Small Boat Cost-Earnings Survey and PIFSC hopes to field a new survey in the coming years.

2.3.5 Relevant PIFSC Economics and Human Dimensions Publications: 2016

No publications specific to the Marianas Archipelago were produced in 2016.

2.3.6 References

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2.4 PROTECTED SPECIES

This section of the report summarizes information on protected species interactions in fisheries managed under the Mariana FEP. Protected species covered in this report include sea turtles, seabirds, marine mammals, sharks, and corals. Most of these species are protected under the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), and/or the Migratory Bird Treaty Act (MBTA). A list of protected species found in or near Mariana Archipelago waters and a list of critical habitat designations in the Pacific Ocean are included in Appendix B.

2.4.1 Indicators for Monitoring Protected Species Interactions in the Marianas FEP Fisheries

This report monitors the status of protected species interactions in the Marianas FEP fisheries using proxy indicators such as fishing effort, and changes in gear types as these fisheries do not have observer coverage. Creel surveys and logbook programs are not expected to provide reliable data about protected species interactions. Discussion of protected species interactions is focused on fishing operations in federal waters and associated transit through Territorial waters. No interactions with protected species have been documented to date.

2.4.1.1 FEP Conservation Measures

Bottomfish, precious coral, coral reef and crustacean fisheries managed under this FEP have not had reported interactions with protected species, and no specific regulations are in place to mitigate protected species interactions. Destructive gear such as bottom trawls, bottom gillnets, explosives and poisons are prohibited under this FEP, and these provide benefit to protected species by preventing potential interactions with non-selective fishing gear.

2.4.1.2 ESA Consultations

ESA consultations were conducted by NMFS and the U.S. Fish and Wildlife Service (for species under their jurisdiction) to ensure ongoing fisheries operations managed under the Marianas FEP are not jeopardizing the continued existence of any listed species or adversely modifying critical habitat. The results of these consultations conducted under section 7 of the ESA are briefly described below and summarized in Table 59.

Table 59. Summary of ESA consultations for Mariana Archipelago FEP Fisheries

Fishery	Consultation date	Consultation type[a]	Outcome[b]	Species
Bottomfish (CNMI & Guam)	3/8/2008	BiOp	NLAA	Loggerhead sea turtle
	6/3/2008	LOC	NLAA	Green sea turtle, olive ridley sea turtle, hawksbill sea turtle, leatherback sea turtle, blue whale, fin whale, humpback whale, sei whale sperm whale
Coral reef ecosystem (CNMI & Guam)	3/7/2002	LOC	NLAA	Loggerhead sea turtle, leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, sei whale, sperm whale

Fishery	**Consultation date**	**Consultation type**[a]	**Outcome**[b]	**Species**
	5/22/2002	LOC (USFWS)	NLAA	Green, hawksbill, leatherback, loggerhead and olive ridley turtles, Newell's shearwater, short-tailed albatross, Laysan duck, Laysan finch, Nihoa finch, Nihoa millerbird, Micronesian megapode, 6 terrestrial plants
Coral reef ecosystem (CNMI)	6/3/2008	LOC	NLAA	Green sea turtle, olive ridley sea turtle, hawksbill sea turtle, leatherback sea turtle, blue whale, fin whale, humpback whale, sei whale, sperm whale
Crustaceans (CNMI & Guam)	9/28/2007	LOC	NLAA	Green sea turtle, loggerhead sea turtle, olive ridley sea turtle, hawksbill sea turtle, leatherback sea turtle, blue whale, humpback whale, sei whale, sperm whale
Precious corals (CNMI & Guam)	10/4/1978	BiOp	Does not constitute threat	Sperm whale, leatherback sea turtle
Precious corals (Guam)	12/20/2000	LOC	NLAA	Humpback whale, green sea turtle, hawksbill sea turtle
All fisheries	4/29/2015	BE & LOC	NLAA	Reef-building corals, scalloped hammerhead shark (Indo-west Pacific DPS)

[a] BiOp = Biological Opinion; LOC = Letter of Concurrence; BE = Biological Evaluation

[b] LAA = likely to adversely affect; NLAA = not likely to adversely affect.

Bottomfish Fishery

In a Biological Opinion issued on March 8, 2002, NMFS concluded that the ongoing operation of the Western Pacific Region's bottomfish and seamount fisheries was not likely to jeopardize the continued existence of any threatened or endangered species under NMFS's jurisdiction or destroy or adversely modify any critical habitat. An informal consultation completed by NMFS on June 3, 2008 concluded that Mariana Archipelago bottomfish fisheries are not likely to adversely affects four sea turtle species (leatherback, olive ridley, green and hawksbill turtles) and five marine mammal species (humpback, blue, fin, sei and sperm whales). NMFS also concluded in an informal consultation dated April 29, 2015 that fisheries managed under the Mariana Archipelago FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

Crustacean Fishery

An informal consultation completed by NMFS on September 28, 2007 concluded that Mariana Archipelago crustacean fisheries are not likely to adversely affect five sea turtle species (loggerhead, leatherback, olive ridley, green and hawksbill turtles) and five marine mammal species (humpback, blue, fin, sei and sperm whales). NMFS also concluded in an informal consultation dated April 29, 2015 that fisheries managed under the Mariana Archipelago FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

Coral Reef Fishery
An informal consultation completed by NMFS on March 7, 2002 concluded that fishing activities conducted under the Coral Reef Ecosystems FMP are not likely to adversely affect endangered or threatened species or critical habitat under NMFS's jurisdiction. On May 22, 2002, the USFWS concurred with the determination of NMFS that the activities conducted under the Coral Reef Ecosystems FMP are not likely to adversely affect listed species under USFWS's exclusive jurisdiction (i.e., seabirds and terrestrial plants) and listed species shared with NMFS (i.e., sea turtles).

An informal consultation completed by NMFS in June 3, 2008 concluded that CNMI coral reef fisheries are not likely to adversely affect adversely affects four sea turtle species (leatherback, olive ridley, green and hawksbill turtles) and five marine mammal species (humpback, blue, fin, sei and sperm whales). NMFS also concluded in an informal consultation dated April 29, 2015 that fisheries managed under the Mariana Archipelago FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

Precious Coral Fishery
In a Biological Opinion issued on October 4, 1978, NMFS concluded that the ongoing operation of the Western Pacific Region's precious coral fisheries was not likely to jeopardize the continued existence of any threatened or endangered species under NMFS's jurisdiction or destroy or adversely modify critical habitat. An informal consultation completed by NMFS on December 20, 2000 concluded that Mariana Archipelago precious coral fisheries are not likely to adversely affect humpback whales, green turtles or hawksbill turtles. NMFS also concluded in an informal consultation dated April 29, 2015 that fisheries managed under the Mariana Archipelago FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

2.4.1.3 Non-ESA Marine Mammals

The MMPA requires NMFS to annually publish a List of Fisheries (LOF) that classifies commercial fisheries in one of three categories based on the level of mortality and serious injury of marine mammals associated with that fishery. According to the 2017 LOF (82 FR 3655, January 12, 2017), the Guam and CNMI bottomfish fisheries operating under the Marianas FEP are classified as Category III fisheries (i.e. a remote likelihood of or no known incidental mortality and serious injury of marine mammals).

2.4.2 Status of Protected Species Interactions in the Marianas FEP Fisheries

Bottomfish Fishery
There are no observer data available for the Guam and CNMI bottomfish fisheries. However based on current ESA consultations, these fisheries are not expected to interact with any ESA-listed species in Federal waters around Guam or CNMI. NMFS has also concluded that the Mariana Archipelago bottomfish commercial fisheries will not affect marine mammals in any manner not considered or authorized under the Marine Mammal Protection Act.

Based on fishing effort and other characteristics described in Chapter 1 of this report, no notable changes have been observed in the fishery. There is no other information to indicate that impacts to protected species from this fishery have changed in recent years.

Crustacean Fishery
There are currently no crustacean fisheries operating in federal waters around Guam or CNMI. However based on current ESA consultations, crustacean fisheries are not expected to interact with any ESA-listed species in Federal waters around Guam or CNMI. NMFS has also concluded that the Mariana Archipelago crustacean commercial fisheries will not affect marine mammals in any manner not considered or authorized under the Marine Mammal Protection Act.

Coral Reef Fishery
There are no observer data available for the Guam and CNMI coral reef fisheries. However based on current ESA consultations, these fisheries are not expected to interact with any ESA-listed species in Federal waters around Guam or CNMI. NMFS has also concluded that the Mariana Archipelago coral reef commercial fisheries will not affect marine mammals in any manner not considered or authorized under the Marine Mammal Protection Act.

Based on fishing effort and other characteristics described in Chapter 1 of this report, no notable changes have been observed in the fishery. There is no other information to indicate that impacts to protected species from this fishery have changed in recent years.

Precious Coral Fishery
There are currently no precious coral fisheries operating in federal waters around Guam and CNMI. However based on current ESA consultations, precious coral fisheries are not expected to interact with any ESA-listed species in Federal waters around Guam or CNMI. NMFS has also concluded that the Mariana Archipelago precious coral commercial fisheries will not affect marine mammals in any manner not considered or authorized under the Marine Mammal Protection Act.

2.4.3 Identification of Emerging Issues

Several species are currently candidates for listing under the ESA, and several more ESA-listed species are being evaluated for critical habitat designation (**Table 60**). If these species are listed or critical habitat are designated, they will be included in this SAFE report and impacts from FEP-managed fisheries will be evaluated under applicable mandates.

Table 60. Candidate ESA species, and ESA-listed species being evaluated for critical habitat designation.

Species		Listing process			Post-listing activity	
Common name	**Scientific name**	**90-day finding**	**12-month finding / Proposed rule**	**Final rule**	**Critical Habitat**	**Recovery Plan**
Oceanic whitetip shark	*Carcharhinus longimanus*	Positive (81 FR 1376, 1/12/2016)	Positive, threatened (81 FR 96304, 12/29/2016)	Public comment period closed 3/29/2017, final rule expected 12/29/2017	N/A	N/A
Pacific bluefin tuna	*Thunnus orientalis*	Positive (81 FR 70074, 10/11/2016)	In progress, expected 6/2017	N/A	N/A	N/A
Chambered nautilus	*Nautilus pompilius*	Positive (81 FR 58895, 8/26/2016)	In progress, expected 5/2017	N/A	N/A	N/A
Giant manta ray	*Manta birostris*	Positive (81 FR 8874, 2/23/2016)	Positive, threatened (82 FRN 3694, 1/12/2017)	Public comment period closed 3/13/2017, final rule expected 1/2018	N/A	N/A
Reef manta ray	*Manta alfredi*	Positive (81 FR 8874, 2/23/2016)	Not warranted (82 FRN 3694, 1/12/2017)	N/A	N/A	N/A
Corals	N/A	Positive for 82 species (75 FR 6616, 2/10/2010)	Positive for 66 species (77 FR 73219, 12/7/2012)	20 species listed as threatened (79 FR 53851, 9/10/2014)	In development, proposal expected 2017	In development, expected TBA, interim recovery outline in place
Green sea turtle	*Chelonia mydas*	Positive (77 FR 45571, 8/1/2012)	Identification of 11 DPSs, endangered and threatened (80 FR 15271, 3/23/2015)	11 DPSs listed as endangered and threatened (81 FR 20057, 4/6/2016)	In development, proposal expected 2017	TBA

2.4.4 Identification of research, data and assessment needs

The following research, data and assessment needs for insular fisheries were identified by the Council's Protected Species Advisory Committee and Plan Team:

- Improve the precision of non-commercial fisheries data to improve understanding of potential protected species impacts.
- Define and evaluate innovative approaches to derive robust estimates of protected species interactions in insular fisheries.

2.5 CLIMATE AND OCEANIC INDICATORS

2.5.1 Introduction

The 2016 Annual Report includes a chapter on indicators of current and changing climate and related oceanic conditions in the geographic areas for which the Western Pacific Regional Fishery Management Council has responsibility. There are a number of reasons for the Council's decision to provide and maintain an evolving discussion of climate conditions as an integral and continuous consideration in their deliberations, decisions and reports:

- Emerging scientific and community understanding of the impacts of changing climate conditions on fishery resources, the ecosystems that sustain those resources and the communities that depend upon them;
- Recent Federal Directives including the 2010 implementation of a National Ocean Policy that identified Resiliency and Adaptation to Climate Change and Ocean Acidification as one of nine National priorities; the development of a Climate Science Strategy by the National Marine Fisheries Service (NMFS) in 2015 and the ongoing development of Pacific Regional Climate Science program;
- The Council's own engagement with the National Oceanic and Atmospheric Administration (NOAA) as well as jurisdictional fishery management agencies in American Samoa, the Commonwealth of the Northern Mariana Islands, Guam, Hawaii as well as fishing industry representatives and local communities in those jurisdictions; and
- Deliberations of the Council's Marine Planning and Climate Change Committee.

Beginning with the 2015 Report, the Council and its partners have described changes in a series of climate and oceanic indicators that will grow and evolve over time as they become available and their relevance to Western Pacific fishery resources becomes clear.

2.5.2 Conceptual Model

In developing this chapter, the Council relied on a number of recent reports conducted in the context of the U.S. National Climate Assessment including, most notably, the 2012 Pacific Islands Regional Climate Assessment (PIRCA) and the Ocean and Coasts chapter of the 2014 report on a Pilot Indicator System prepared by the National Climate Assessment and Development Advisory Committee (NCADAC).

The Advisory Committee Report presented a possible conceptual framework designed to illustrate how climate factors can connect to and interact with other ecosystem components to ocean and coastal ecosystems and human communities. The Council adapted this model with considerations relevant to the fishery resources of the Western Pacific Region:

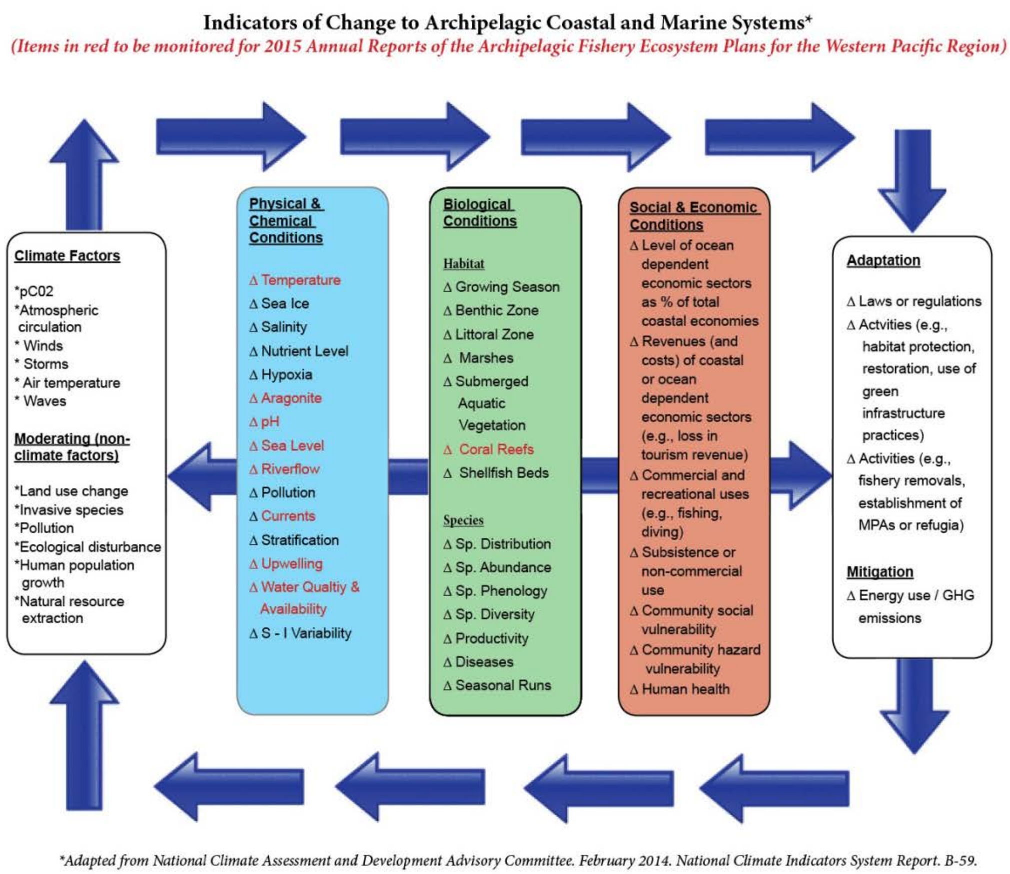


Figure 11. Indicators of change to archipelagic coastal and marine systems.

As described in the 2014 NCADAC report, the conceptual model represents a "simplified representation of climate and non-climate stressors in coastal and marine ecosystems." For the purposes of this Annual Report, the modified Conceptual Model allows the Council and its partners to identify indicators of interest to be monitored on a continuing basis in coming years. The indicators shown in red were considered for inclusion in the 2016 Annual Report; the specific indicators used in the Report are listed in Section 2.3.

Other indicators will be added over time as datasets become available and understanding of the nature of the causal chain from stressors to impacts emerges.

The Council also hopes that this Conceptual Model can provide a guide for future monitoring and research that will enable the Council and its partners to move from observations and correlations to understanding the specific nature of interactions and developing capabilities to predict future changes of importance in developing, evaluating and adapting ecosystem-fishery plans in the Western Pacific Region.

2.5.3 Selected Indicators

The primary goal for selecting the Indicators used in this (and future reports) is to provide fisheries-related communities, resource managers and businesses with a climate-related situational awareness. In this context, Indicators were selected to:

- Be fisheries-relevant and informative
- Build intuition about current conditions in light of changing climate
- Provide historical context and
- Recognize patterns and trends.

For the 2016 report on Western Pacific Pelagic resources, the Council has included the following climate and oceanic indicators:

Atmospheric Carbon Dioxide (at Mauna Loa Observatory) --Increasing atmospheric CO_2 is a primary measure of anthropogenic climate change.

Ocean pH (at Station ALOHA) **–** Ocean pH provides a measure of ocean acidification. Increasing ocean acidification limits the ability of marine organisms to build shells and other hard structures.

Oceanic Niño Index (ONI) – Sea surface temperature anomaly from Niño 3.4 region (5°N - 5°S, 120° - 170°W). This index is used to determine the phase of the El Niño **–** Southern Oscillation (ENSO), which has implications across the region affecting migratory patterns of key commercial fish stocks which, in turn, affect the location, safety and costs of commercial fishing.

Pacific Decadal Oscillation (PDO) – Sea surface temperature anomaly from Niño 3.4 region (5°N - 5°S, 120° - 170°W). This index is used to determine the phase of the El Niño **–** Southern Oscillation (ENSO), which has implications across the region affecting migratory patterns of key commercial fish stocks which, in turn, affect the location, safety and costs of commercial fishing.

Sea Surface Temperature – Monthly sea surface temperature anomaly from 2003-2015 from the AVHRR instrument aboard the NOAA Polar Operational Environmental Satellite (POES). Sea surface temperature is one of the most directly observable measures we have for tracking increasing ocean temperature.

Sea Surface Temperature Anomaly – Sea surface temperature anomaly highlights long term trends. Filtering out seasonal cycle is one of the most directly observable measures we have for tracking increasing ocean temperature.

Degree Heating Weeks (DHW) – DHW from the CoralReefWatch team provide the best available metric to track exposure of coral reef ecosystems to anomalously high temperature events

Sea Level (Sea Surface Height) and Anomaly – Rising sea levels can result in a number of coastal impacts, including inundation of infrastructure, increased damage resulting from storm-driven waves and flooding, and saltwater intrusion into freshwater supplies. NOTE that no water level gauges are available in Pacific Remote Island Areas (PRIA) so only regional information on this indicator are included.

Heavy Weather (Tropical Cyclones) – Measures of tropical cyclone occurrence, strength, and energy. Tropical cyclones have the potential to significantly impact fishing operations.

Wave Data – To describe patterns in wave forcing, we present data from the Wave Watch 3 global wave model run by the Department of Ocean and Resources Engineering at the University of Hawaiʻi in collaboration with NOAA/NCEP and NWS Honolulu. Wave forcing can have major implications for both coastal ecosystems and pelagic fishing operations.

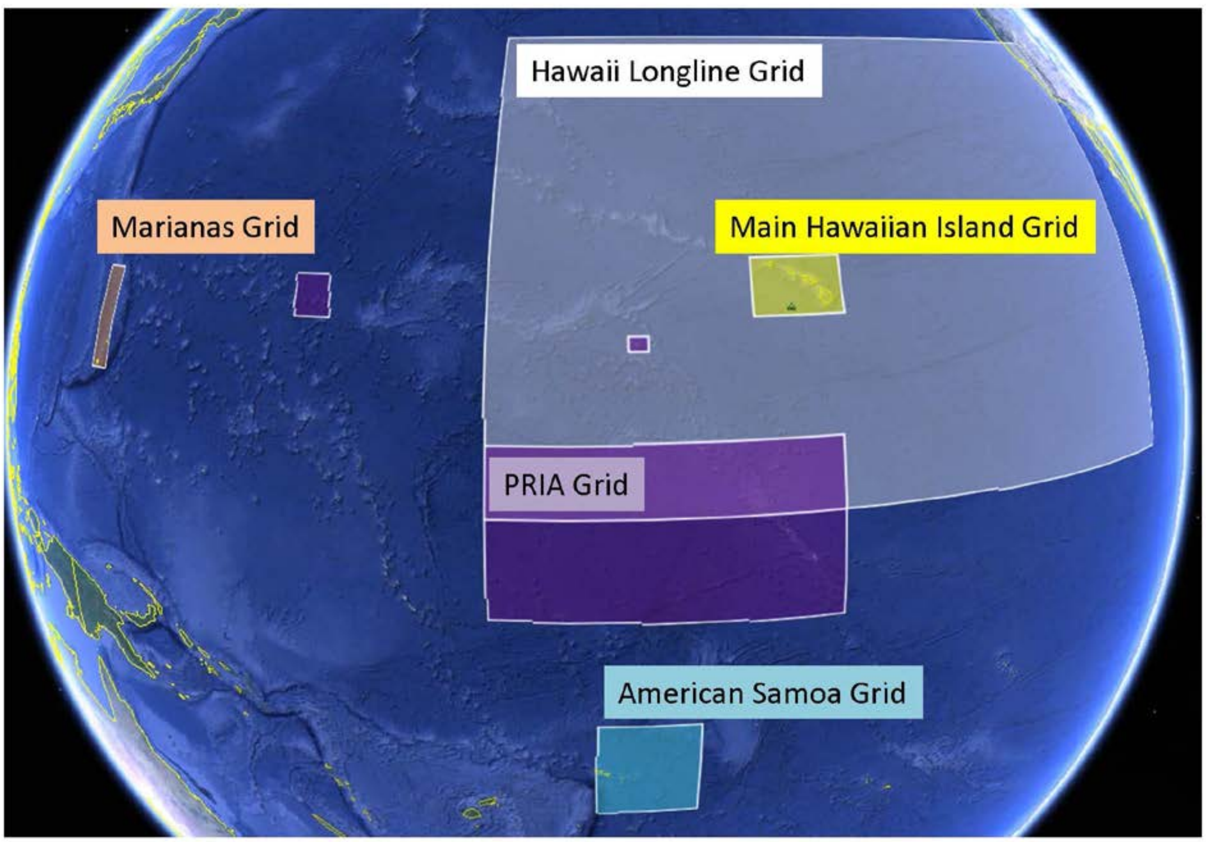


Figure 12. Regional Spatial Grids.

Table 61. Climate and Ocean Indicator Summary - Marianas.

Indicator	Definition and Rationale	Indicator Status
Atmospheric Concentration of Carbon Dioxide (CO_2)	Atmospheric concentration CO_2 at Mauna Loa Observatory. Increasing atmospheric CO_2 is a primary measure of anthropogenic climate change.	Trend: increasing exponentially 2017: time series maximum 406.43 ppm
Oceanic pH	Ocean surface pH at Station ALOHA. Ocean pH provides a measure of ocean acidification. Increasing ocean acidification limits the ability of marine organisms to build shells and other hard structures.	Trend: pH is decreasing at a rate of 0.039 pH units per year, equivalent to 0.4% increase in acidity per year
Oceanic Niño Index (ONI)	Sea surface temperature anomaly from Niño 3.4 region (5°N - 5°S, 120° - 170°W). This index is used to determine the phase of the El Niño – Southern Oscillation (ENSO), which has implications across the region, affecting migratory patterns of key commercial fish stocks which in turn affect the location, safety, and costs of commercial fishing.	2015: Strong El Niño 2016: weak La Niña dissipating, potential rapid return to El Niño
Pacific Decadal Oscillation (PDO)	The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period).	2016: Strong Positive Phase
Sea Surface Temperature[1] (SST)	Satellite remotely-sensed sea surface temperature. SST is projected to rise, and impacts phenomena ranging from winds to fish distribution.	2013 & 2014 showed high temperature anomalies relative to record.
Degree Heating Weeks (DHW)	Satellite remotely-sensed sea surface temperature, transformed to a metric relevant for coral bleaching. Each degree heating week indicates a one degree excess over long term summer means (Maximum Monthly Mean SST), that persists for a week. At 4 DHW, bleaching is expected, at 8 DHW bleaching is expected to be widespread and to induce mortality.	2013, 2014, and 2016 showed extreme high temperature anomalies, with values surpassing 8 DHW in 2013 & 2014, and 4 DHW in 2016.
Tropical Cyclones	Measures of tropical cyclone occurrence, strength, and energy. Tropical cyclones have the potential to significantly impact fishing operations.	Eastern Pacific, 2016: 21 named storms, 11 hurricanes, 5 major. Central Pacific, 2016: 7 named storms, 3 hurricanes, 2 major. Western Pacific 2016: 26 named storms, 13 typhoons, 6 major
Sea Level/Sea Surface Height	Monthly mean sea level time series, including extremes. Data from satellite altimetry & in situ tide gauges. Rising sea levels can result in a number of coastal impacts, including inundation of infrastructure, increased damage resulting from storm-driven waves and flooding, and saltwater intrusion into freshwater	As measured by tide gauges in Apra Harbor, Guam, sea level showed a decline for most of 2015 reaching approximately 0.15 below average at its lowest point.

[1] 2016 data are incomplete.

	supplies.	
Wave Energy	WaveWatch III (WW3) Global Wave Model" run by UH Department of Ocean Resources & Engineering in collaboration with NOAA/NCEP & NOAA/NWS-Pacific Wave forcing can have major implications for both coastal ecosystems and pelagic fishing operations.	Significant wave heights varied throughout the Mariana Archipelago from between 1.0-1.5m for Guam and Saipan to between 2.0-2.5m in Pagan & Maug.

2.5.3.1 Atmospheric Concentration of Carbon Dioxide (CO_2)) Mauna Loa.

Description: Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii in ppm from March 1958 to present. The carbon dioxide data is measured as the mole fraction in dry air, on Mauna Loa. A dry mole fraction is defined as the number of molecules of carbon dioxide divided by the number of molecules of dry air multiplied by one million (ppm). This constitutes the longest record of direct measurements of CO_2 in the atmosphere. The measurements were started by C. David Keeling of the Scripps Institution of Oceanography in March of 1958 at a facility of the National Oceanic and Atmospheric Administration [Keeling, 1976]. NOAA started its own CO_2 measurements in May of 1974, and they have run in parallel with those made by Scripps since then [Thoning, 1989].

The observed increase in monthly average carbon dioxide data is due primarily to CO_2 emissions from fossil fuel burning. Carbon dioxide remains in the atmosphere for a very long time, and emissions from any location mix throughout the atmosphere in about one year. The annual oscillations at Mauna Loa, Hawaii are due to the seasonal imbalance between the photosynthesis and respiration of plants on land. During the summer photosynthesis exceeds respiration and CO_2 is removed from the atmosphere, whereas outside the growing season respiration exceeds photosynthesis and CO_2 is returned to the atmosphere. The seasonal cycle is strongest in the northern hemisphere because of the presence of the continents. The difference in CO_2 between Mauna Loa and the South Pole has increased over time as the global rate of fossil fuel burning, most of which takes place in the northern hemisphere, has accelerated.

Timeframe: Yearly (by month)

Region/Location: Hawaii but representative of global concentration of carbon dioxide.

Data Source: "Full Mauna Loa CO_2 record" at http://www.esrl.noaa.gov/gmd/ccgg/trends/ , NOAA ESRL Global Monitoring Division. The National Oceanic and Atmospheric Administration (NOAA) Global Monitoring Division provides high-precision measurements of the abundance and distribution of long-lived greenhouse gases that are used to calculate global average concentrations.

Measurement Platform: In-situ Station

Rationale: Atmospheric carbon dioxide is a measure of what human activity has already done to affect the climate system through greenhouse gas emissions. It provides quantitative information in a simplified, standardized format that decision makers can easily understand. This indicator demonstrates that the concentration (and, in turn, the warming influence) of greenhouse gases in the atmosphere has increased substantially over the last several decades. In January of 2017, the monthly mean concentration of $C0_2$ was 406.43 ppm. In January of 1959, the onset year, it was 315.62 ppm. It passed 350 ppm in 1988.

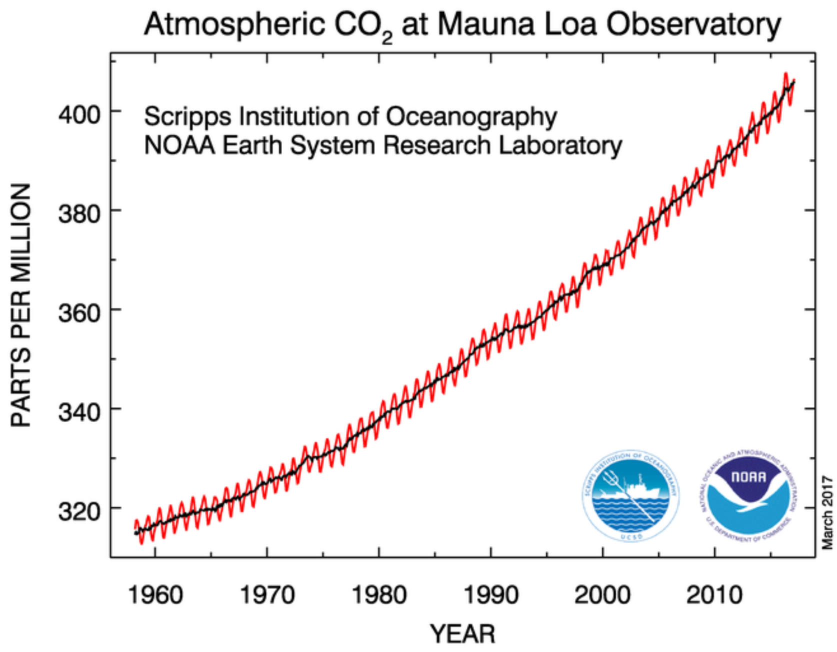


Figure 13. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data.

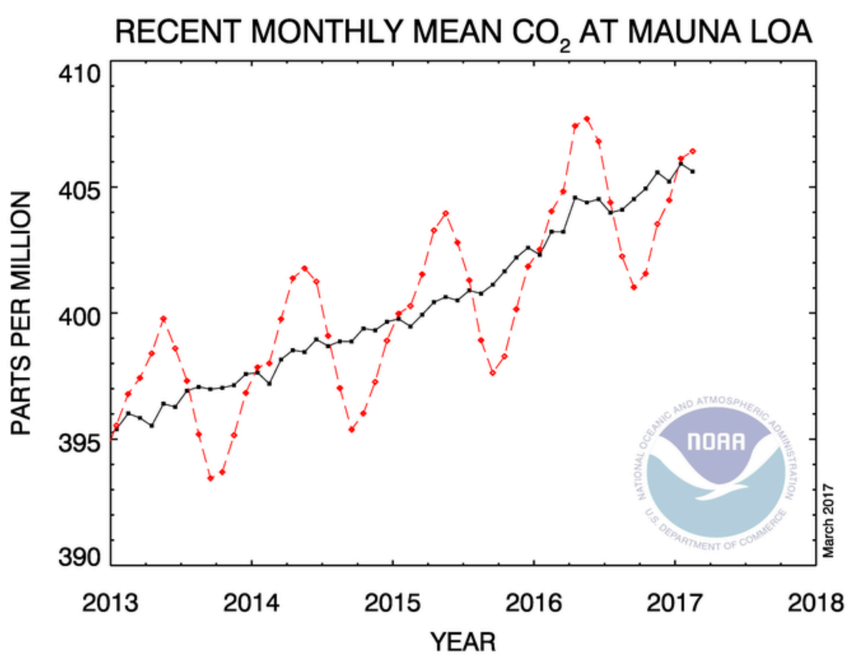


Figure 14. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii, 2013-2017. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data.

2.5.3.2 Ocean pH:

Description: Trends in surface (0-10m) pH and pCO2 at Station ALOHA, North of Oahu (22° 45' N, 158° W), collected by the Hawai'i Ocean Time-series (HOT). Red dots represent directly measured pH, blue dots represent pH calculated from total alkalinity (TA) and dissolved inorganic carbon (DIC).

The 25+ year time-series at Station ALOHA represents the best available documentation of the significant downward trend of ocean pH since 1989. Actual ocean pH varies in both time and space, but over last 25 years, the HOTS Station ALOHA time series has shown a significant linear decrease of -0.0386 pH units, or roughly a 9% increase in acidity ([H+]) over that period. With the new year of data added since the last SAFE report (i.e. 2015 data), this declining trend continues.

Timeframe: Updated Monthly

Region/Location: North Oahu.

Data Source/Responsible Party: Hawai'i Ocean Time Series. (http://hahana.soest.hawaii.edu/hot/)

Measurement Platform: Oceanographic research station, shipboard collection.

Rationale: Increasing ocean acidification affects coral reef growth and health, which in turn affects the health of coral reef ecosystems and the ecosystems and resources that they sustain. Monitoring pH on a continuous basis provides a foundational basis for documenting, understanding and, ultimately, predicting the effects of ocean acidification.

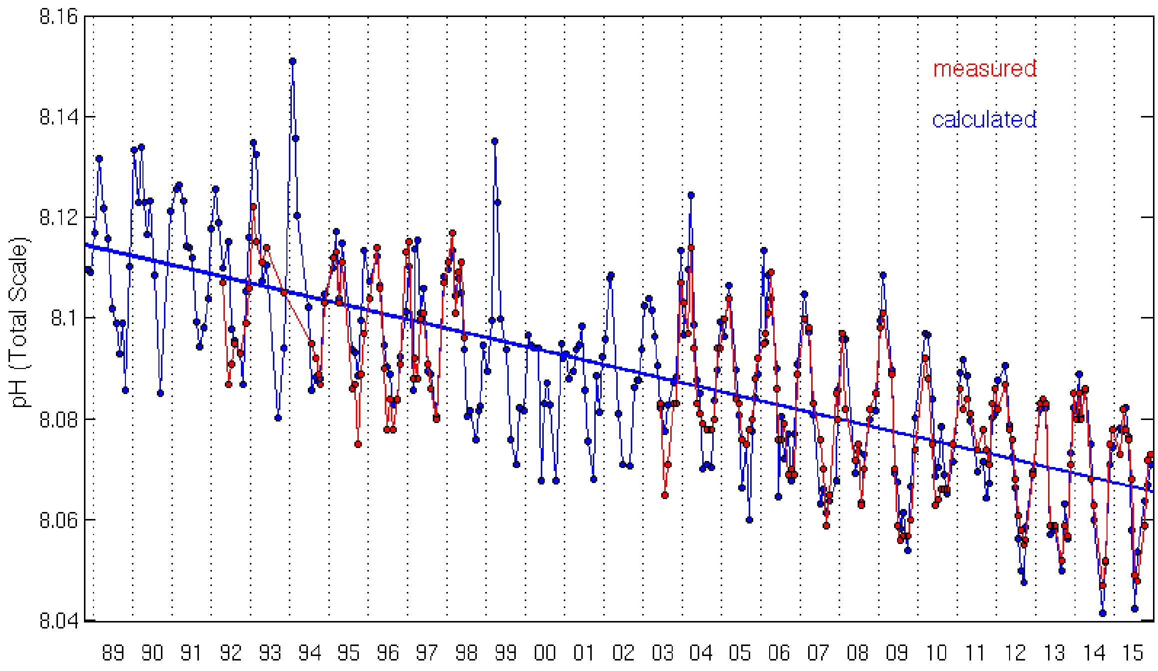


Figure 15. pH Trend at Station Aloha, 1989-2015.

2.5.3.3 Oceanic Niño Index (ONI)

Description: Warm (red) and cold (blue) periods based on a threshold of +/- 0.5°C for the Oceanic Niño Index (ONI) [three-month running mean of ERSST.v4 SST anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W)], based on centered 30-year base periods updated every five years.

For historical purposes, periods of below and above normal sea surface temperatures (SSTs) are colored in blue and red when the threshold is met for a minimum of five consecutive overlapping seasons. The ONI is one measure of the El Niño-Southern Oscillation, and other indices can confirm whether features consistent with a coupled ocean-atmosphere phenomenon accompanied these periods.

Description was inserted from:
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Timeframe: Every three months.

Region/Location: Niño 3.4 Region: 5°S - 5°N, 120°-170°W

Data Source/Responsible Party: NOAA NCEI Equatorial Pacific Sea Surface Temperatures (www.ncdc.noaa.gov/teleconnections/enso/indicators/sst.php)

Measurement Platform: In-situ Station, Satellite, Model, Other…

Rationale:

The ONI focuses on ocean temperature which has the most direct effect on those fisheries. The atmospheric half of this Pacific basin oscillation is measured using the Southern Oscillation Index.

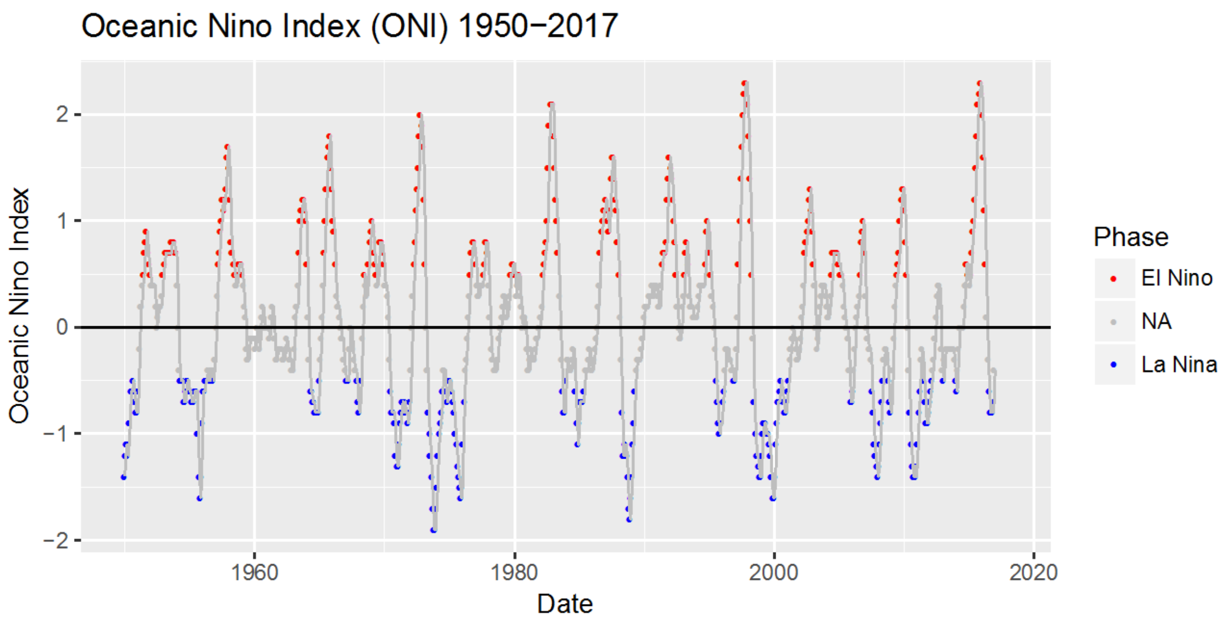


Figure 16. Oceanic Nino Index, 1950-2017.

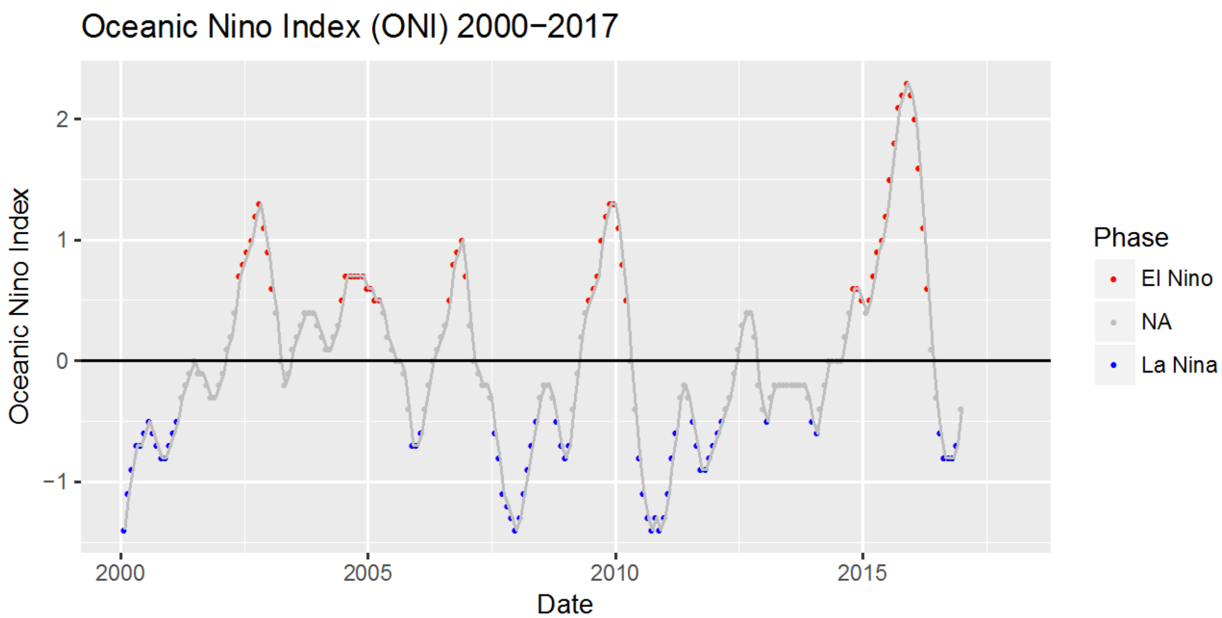


Figure 17. Oceanic Nino Index, 2000-2017.

2.5.3.4 Pacific Decadal Oscillation (PDO)

Description: The "Pacific Decadal Oscillation" (PDO) is a long-lived El Niño-like pattern of Pacific climate variability. While the two climate oscillations have similar spatial climate fingerprints, they have very different behavior in time. Fisheries scientist Steven Hare coined the term "Pacific Decadal Oscillation" (PDO) in 1996 while researching connections between Alaska salmon production cycles and Pacific climate (his dissertation topic with advisor Robert Francis). Two main characteristics distinguish PDO from El Niño/Southern Oscillation (ENSO): first, 20th century PDO "events" persisted for 20-to-30 years, while typical ENSO events persisted for 6 to 18 months; second, the climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the tropics - the opposite is true for ENSO. Several independent studies find evidence for just two full PDO cycles in the past century: "cool" PDO regimes prevailed from 1890-1924 and again from 1947-1976, while "warm" PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990's. Shoshiro Minobe has shown that 20th century PDO fluctuations were most energetic in two general periodicities, one from 15-to-25 years, and the other from 50-to-70 years.

Major changes in northeast Pacific marine ecosystems have been correlated with phase changes in the PDO; warm eras have seen enhanced coastal ocean biological productivity in Alaska and inhibited productivity off the west coast of the contiguous United States, while cold PDO eras have seen the opposite north-south pattern of marine ecosystem productivity.

Causes for the PDO are not currently known. Likewise, the potential predictability for this climate oscillation are not known. Some climate simulation models produce PDO-like oscillations, although often for different reasons. The mechanisms giving rise to PDO will determine whether skillful decades-long PDO climate predictions are possible. For example, if PDO arises from air-sea interactions that require 10 year ocean adjustment times, then aspects of the phenomenon will (in theory) be predictable at lead times of up to 10 years. Even in the absence of a theoretical understanding, PDO climate information improves season-to-season and year-to-year climate forecasts for North America because of its strong tendency for multi-season and multi-year persistence. From a societal impacts perspective, recognition of PDO is important because it shows that "normal" climate conditions can vary over time periods comparable to the length of a human's lifetime.

[Description inserted from: http://research.jisao.washington.edu/pdo/]

Timeframe: Monthly.

Region/Location: North Pacific

Data Source/Responsible Party: Joint Institute for the Study of the Atmosphere and Ocean (JISAO, UW) (http://research.jisao.washington.edu/pdo/PDO.latest.txt)

Measurement Platform: In-situ Station, Satellite, Model, Other…

Rationale: The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period). Digital values of our PDO index are available from Nate Mantua's anonymous ftp directory (linked here). Please send email to Nate (nate.mantua@noaa.gov) or Steven Hare (hare@iphc.washington.edu) to let them know that you have obtained this data. Nate updates the PDO index every two or three months.

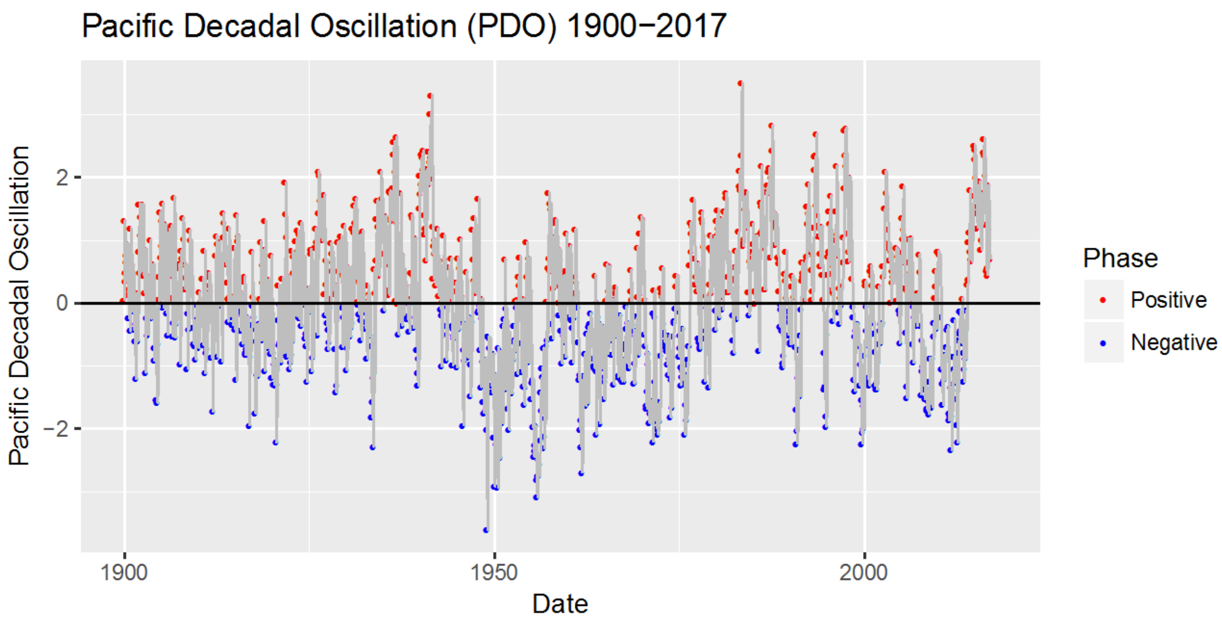


Figure 19. Pacific Decadal Oscillation, 1900-2017.

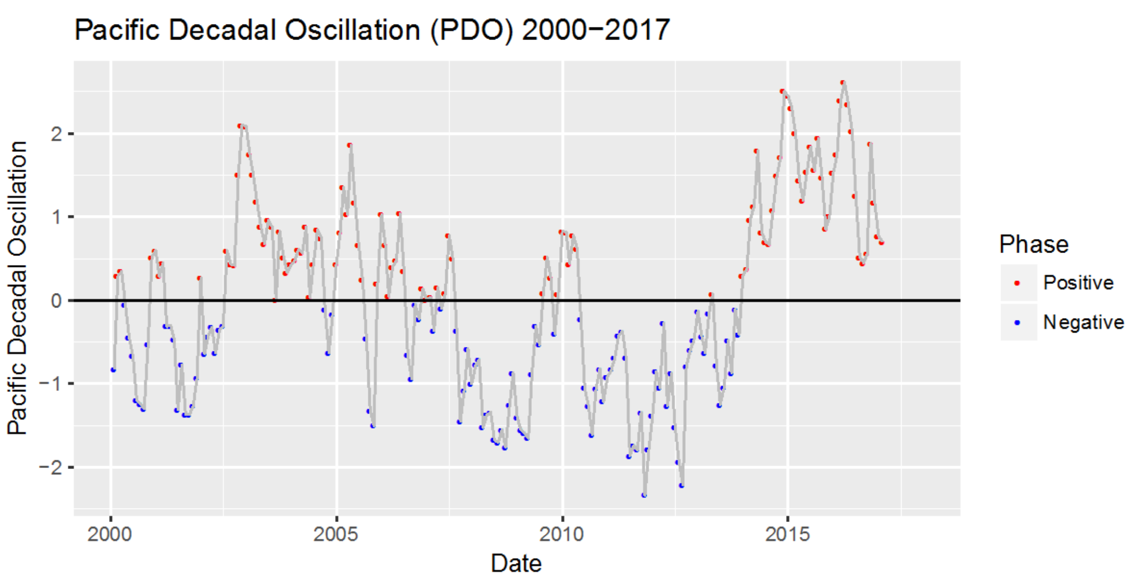
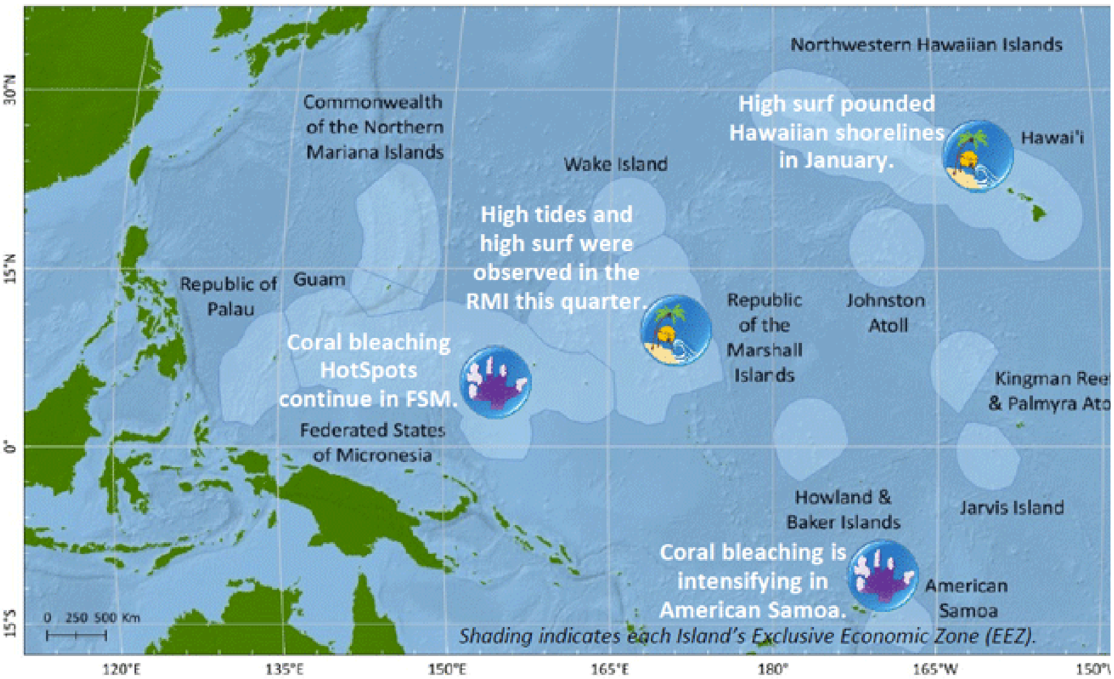


Figure 20. Pacific Decadal Oscillation, 2000-2017.

The Climate Impacts and Outlook Q4 2016
From: http://www.pacificcis.org/dashboard



Significant Events and Archipelagic Impacts

Near-normal rainfall was recorded in parts of the Common wealth of the Northern Mariana Islands, while above-normal rainfall was reported in Guam. Much below normal rainfall was reported in Hawaii, while most of the Federated States of Micronesia, the Republic of Palau, and the Marshall Islands were above normal. Near normal rains were observed in American Samoa.

There were a total of 31 tropical cyclones in the western North Pacific during 2016.

Facilities and Infrastructure – A series of large NW swell events in early-to-mid November led to sharp erosion at Sunset Beach, north shore, Oahu. The high swell and morning high tide of 2016-11-14 allowed wave run-up to cross the highway in Waianae, west shore, Oahu and select sections of the coastal highway on the north shore of Oahu. Coastal wave run-up was also high enough to cross select sections of the highway on the north shore 2017-01-13, -25, and -30. Meanwhile, gale-force trade winds 2017-01-21 and -22 had seas to 17 feet as measured by a wave buoy off Kailua, Oahu. It caused minor coastal wave run-up.

Water Resources – Despite high surf, high tides, and higher than normal sea levels, long-period swell did not affect the capital of the RMI during the quarter. Water reservoir levels in the Majuro, FSM, and Koror remain adequate with regularly-occurring rains, however the northern Marshall Islands are very dry.

Natural Resources – Eddy kinetic energy near Hawaii has been unusually high over the last quarter. Eddies (gyres) have important biological implications in that they can drive upwelling of cooler, nutrient rich water that influences ocean temperatures and fuels a localized increase in phytoplankton production, an essential source of energy for higher trophic groups. In American Samoa, coral bleaching patterns are evident on the reef slope areas around 30-50ft along a large portion of the main island of Tutuila. Meanwhile, Hot Spots in the Northern Hemisphere remain concentrated around the Federated States of Micronesia (FSM) and the western Pacific, where a Bleaching Watch is in effect. In Fiji, water temperatures in the shallow back reefs have spiked to 34°C and bleaching is intensifying there.

Figure 21. Q4 2016 Climate Impact and Outlook Infographic.

2.5.3.5 Sea Surface Temperature

Description: Monthly sea surface temperature from 2003-2016 from the Advanced Very High Resolution Radiometer (AVHRR) instrument aboard the NOAA Polar Operational Environmental Satellite (POES). These data take us back to 2003. If we were to blend this record with Pathfinder, we could reach back to 1981.

***Background Below Inserted From** *CoastWatch West Coast Node.** We would like to acknowledge the NOAA CoastWatch Program and the NOAA NWS Monterey Regional Forecast Office.

Short Description: The global area coverage (GAC) data stream from NOAA | NESDIS | OSDPD provides a high-quality sea surface temperature product with very little cloud contamination. This data is used for a variety of fisheries management projects, including the El Niño Watch Report, which stress data quality over high spatial resolution.

Technical Summary: CoastWatch offers global sea surface temperature (SST) data from the Advanced Very High Resolution Radiometer (AVHRR) instrument aboard NOAA's Polar Operational Environmental Satellites (POES). Two satellites are currently in use, NOAA-17 and NOAA-18. The AVHRR sensor is a five-channel sensor comprised of two visible radiance channels and three infrared radiance channels. During daytime satellite passes, all five radiance channels are used. During nighttime passes, only the infrared radiance channels are used.

The POES satellite stores a sub-sample of the AVHRR radiance measurements onboard, generating a global data set. The satellite downloads this dataset once it is within range of a receiving station. The sub-sampling reduces the resolution of the original data from 1.47km for the HRPT SST product to 11km for the global data product.

AVHRR radiance measurements are processed to SST by NOAA's National Environmental Satellite, Data, and Information Service (NESDIS), Office of Satellite Data Processing and Distribution (OSDPD) using the non-linear sea surface temperature (NLSST) algorithm detailed in *Walton et al., 1998*. SST values are accurate to within 0.5 degrees Celsius. Ongoing calibration and validation efforts by NOAA satellites and information provide for continuity of quality assessment and algorithm integrity (e.g., *Li et al., 2001a and Li et al., 2001b*). In addition, the CoastWatch West Coast Regional Node (WCRN) runs monthly validation tests for all SST data streams using data from the NOAA National Weather Service and National Data Buoy Center (NDBC).

The data are cloud screened using the CLAVR-x method developed and maintained by NOAA Satellites and Information (e.g., *Stowe et al., 1999*). The data are mapped to an equal angle grid (0.1 degrees latitude by 0.1 degrees longitude) using a simple arithmetic mean to produce individual and composite images of various durations (e.g., 1, 3, 8, 14-day).

Timeframe: 2003-2016. Daily data available. Monthly means shown.

Region/Location: Global.

Data Source: "SST, POES AVHRR, GAC, Global, Day and Night (Monthly Composite)" http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdAGsstamday.html.

Measurement Platform: *AVHRR, POES Satellite*

Rationale: Sea surface temperature is one of the most directly observable measures we have for tracking increasing ocean temperature.

References: Li, X., W. Pichel, E. Maturi, P. Clemente-Colón, and J. Sapper, 2001a. Deriving the operational nonlinear multi-channel sea surface temperature algorithm coefficients for NOAA-15 AVHRR/3, Int. J. Remote Sens., Volume 22, No. 4, 699 - 704.

Li, X, W. Pichel, P. Clemente-Colón, V. Krasnopolsky, and J. Sapper, 2001b. Validation of coastal sea and lake surface temperature measurements derived from NOAA/AVHRR Data, Int. J. Remote Sens., Vol. 22, No. 7, 1285-1303.

Stowe, L. L., P. A. Davis, and E. P. McClain, 1999. Scientific basis and initial evaluation of the CLAVR-1 global clear/cloud classification algorithm for the advanced very high resolution radiometer. J. Atmos. Oceanic Technol., 16, 656-681.

Walton C. C., W. G. Pichel, J. F. Sapper, D. A. May, 1998. The development and operational application of nonlinear algorithms for the measurement of sea surface temperatures with the NOAA polar-orbiting environmental satellites, J. Geophys. Res., 103: (C12) 27999-28012.

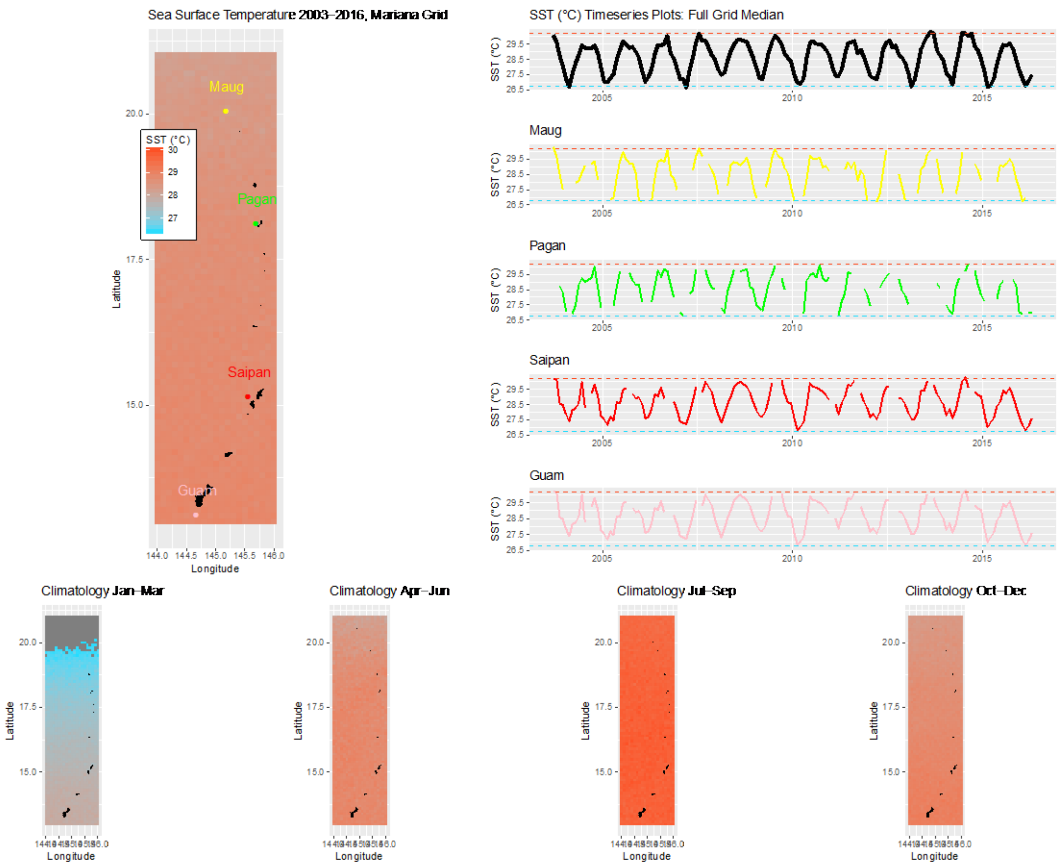


Figure 22. Sea surface temperature plots for the Mariana Regional Grid.

2.5.3.6 Sea Surface Temperature Anomaly

Description: Monthly sea surface temperature anomaly from 2003-2016 from the AVHRR instrument aboard the NOAA Polar Operational Environmental Satellite (POES), compared against the Casey and Cornillon Climatology (Casey and Cornillion 1999). These data take us back to 2003. If we were to blend this record with Pathfinder, we could reach back to 1981.

Background Below Inserted From [Coastwatch West Coast Node](http://coastwatch.pfeg.noaa.gov/infog/AG_tanm_las.html):
[http://coastwatch.pfeg.noaa.gov/infog/AG_tanm_las.html]. We would like to acknowledge the NOAA CoastWatch Program and the NOAA NESDIS Office of Satellite Data Processing and Distribution.

Short Description:
The SST anomaly product is used to show the difference between the surface temperature at a given time and the temperature that is normal for that time of year. This effectively filters out seasonal cycles and allows one to view intra-seasonal and inter-annual signals in the data. The global SST anomaly product is produced by comparing the AVHRR GAC SST with a climatology by *Casey and Cornillon, 1999*, for the region and time period specified. The AVHRR GAC SST is a high quality data set provided by NOAA | NESDIS | OSDPD.

Technical Summary:
SST anomaly data are distributed at 11km resolution. AVHRR GAC SST values are accurate to within plus or minus 0.5 degrees Celsius. The time-averaged SST from AVHRR GAC is compared to the climatological SST from *Casey and Cornillon, 1999*, for the specific time period and region. The data are mapped to an equal angle grid of 0.1 degrees latitude by 0.1 degrees longitude using a simple arithmetic mean to produce composite images of various duration (e.g., 1, 3, 8, 14-day).

Reference: Casey, K.S. and P. Cornillon. 1999. A comparison of satellite and in situ based sea surface temperature climatologies. J. Climate. Vol. 12, no. 6, 1848-1863.

Timeframe: 2003-2015. Daily data available. Monthly means shown.

Region/Location: Global.

Data Source: "SST Anomaly, POES AVHRR, Casey and Cornillon Climatology, Global (Monthly Composite)"
http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdAGtanmmday_LonPM180.html

Measurement Platform: *POES, AVHRR Satellite*

Rationale: Sea surface temperature anomaly highlights long-term trends. Filtering out seasonal cycle is one of the most directly observable measures we have for tracking increasing ocean temperature.

References: Casey, K.S. and P. Cornillon. 1999. A comparison of satellite and in situ based sea surface temperature climatologies. J. Climate. Vol. 12, no. 6, 1848-1863.

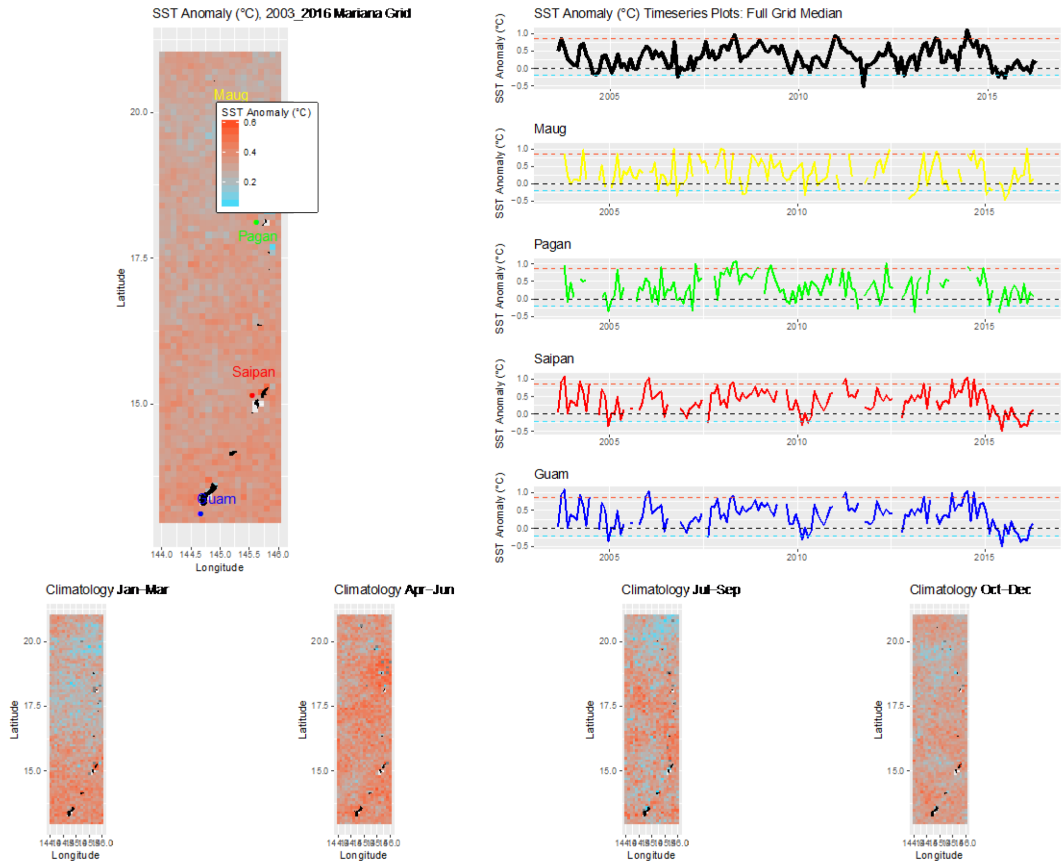


Figure 23. Sea surface temperature anomaly for the Mariana Regional Grid.

2.5.3.7 Degree Heating Weeks (Coral Bleaching)

Description: The NOAA Coral Reef Watch program's satellite data provide current reef environmental conditions to quickly identify areas at risk for coral bleaching, where corals lose the symbiotic algae that give them their distinctive colors. If a coral is severely bleached, disease and partial mortality become likely, and the entire colony may die.

Continuous monitoring of sea surface temperature at global scales provides researchers and stakeholders with tools to understand and better manage the complex interactions leading to coral bleaching. When bleaching conditions occur, these tools can be used to trigger bleaching response plans and support appropriate management decisions.

[Descriptions from: https://coralreefwatch.noaa.gov/satellite/index.php]

Technical Summary: The NOAA Coral Reef Watch (CRW) daily 5-km satellite coral bleaching Degree Heating Week (DHW) product presented here shows accumulated heat stress, which can lead to coral bleaching and death. The scale goes from 0 to 20 °C-weeks. The DHW product accumulates the instantaneous bleaching heat stress (measured by Coral Bleaching HotSpots) during the most-recent 12-week period. It is directly related to the timing and intensity of coral bleaching. Significant coral bleaching usually occurs when DHW values reach 4 °C-weeks. By the time DHW values reach 8 °C-weeks, widespread bleaching is likely and significant mortality can be expected.

Timeframe: 2013-2016. Weekly 5 km data.

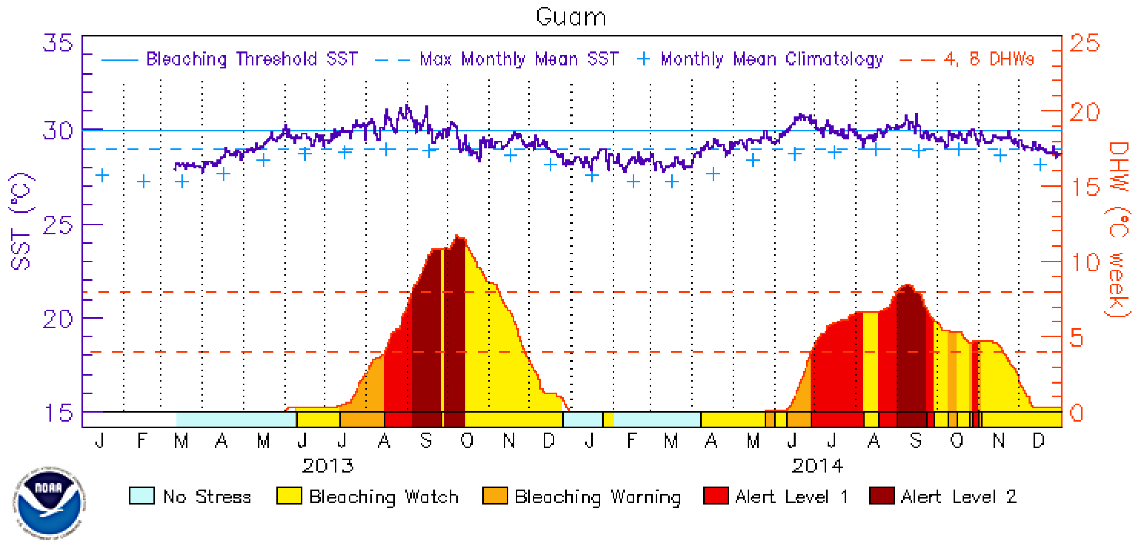
Region/Location: Global.

Data Source: NOAA Coral Reef Watch. 2013, updated daily. *NOAA Coral Reef Watch Daily Global 5-km Satellite Virtual Station Time Series Data for Southeast Florida*, Mar. 12, 2013-Mar. 11, 2014. College Park, Maryland, USA: NOAA Coral Reef Watch. Data set accessed 2017-03-21 at http://coralreefwatch.noaa.gov/vs/index.php

Measurement Platform: CRW operational near-real-time nighttime SST product: AVHRR,

Rationale: Degree Heating Weeks are the best available metric to track coral bleaching relevant high temperature exposure.

References: Liu, G., A.E. Strong, W.J. Skirving and L.F. Arzayus (2006). Overview of NOAA Coral Reef Watch Program's Near-Real-Time Satellite Global Coral Bleaching Monitoring Activities. *Proceedings of the 10th International Coral Reef Symposium, Okinawa*: 1783-1793.


Guam
Bleaching Threshold SST
Max Monthly Mean SST
Monthly Mean Climatology
4, 8 DHWs
SST (°C)
DHW (°C week)
35
30
25
20
15
25
20
15
10
5
0
J F M A M J J A S O N D J F M A M J J A S O N D
2013
2014
No Stress
Bleaching Watch
Bleaching Warning
Alert Level 1
Alert Level 2

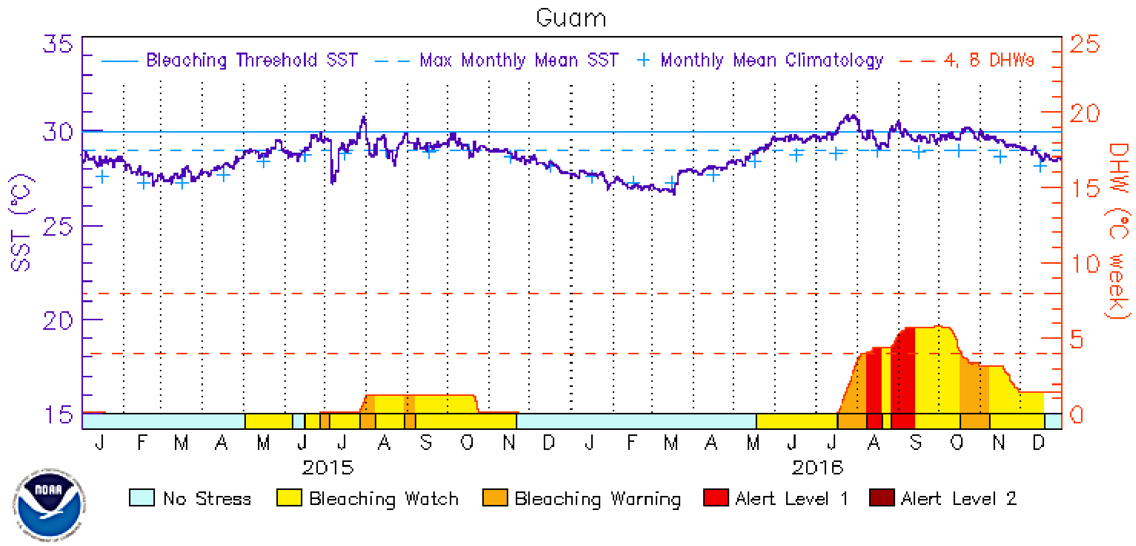
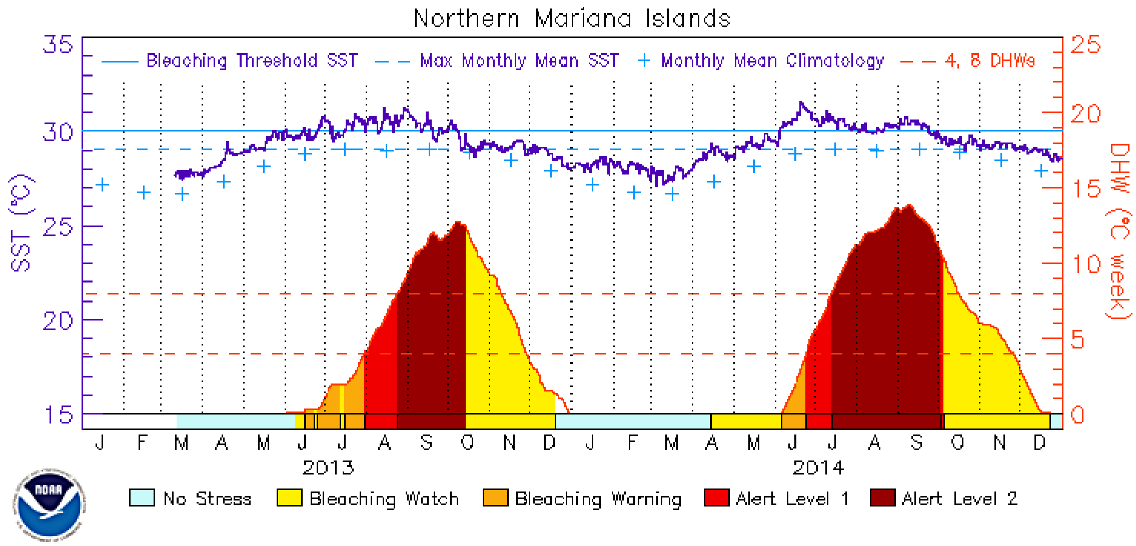

Guam
Bleaching Threshold SST
Max Monthly Mean SST
Monthly Mean Climatology
4, 8 DHWs
SST (°C)
DHW (°C week)
35
30
25
20
15
25
20
15
10
5
0
J F M A M J J A S O N D J F M A M J J A S O N D
2015
2016
No Stress
Bleaching Watch
Bleaching Warning
Alert Level 1
Alert Level 2

Figure 24. Degree Heating Weeks Timeseries in the Guam, 2013-2016.



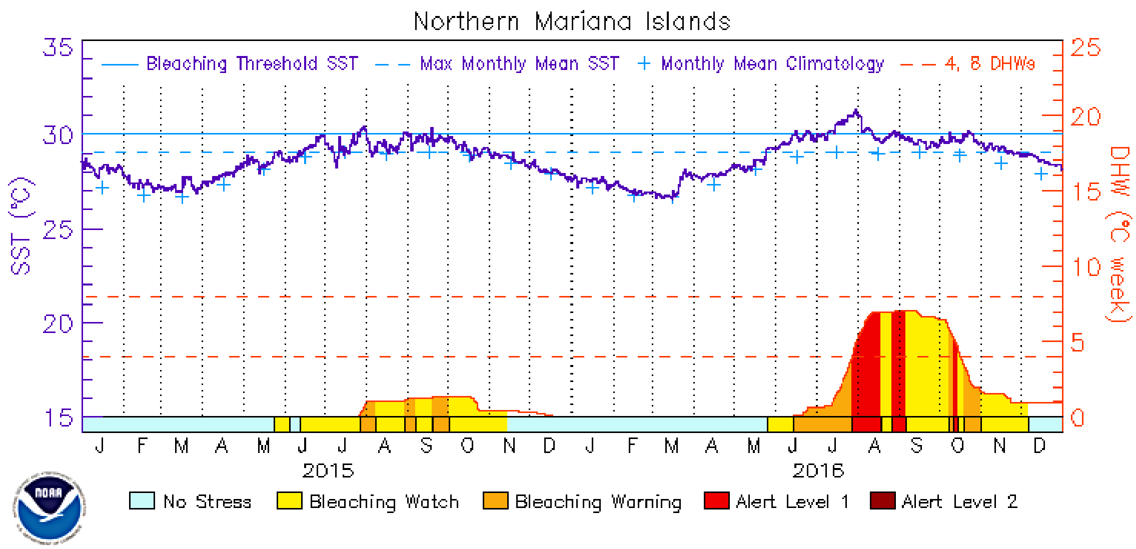


Figure 25. Degree Heating Weeks Timeseries in the Commonwealth of the Northern Marianas, 2013-2016.

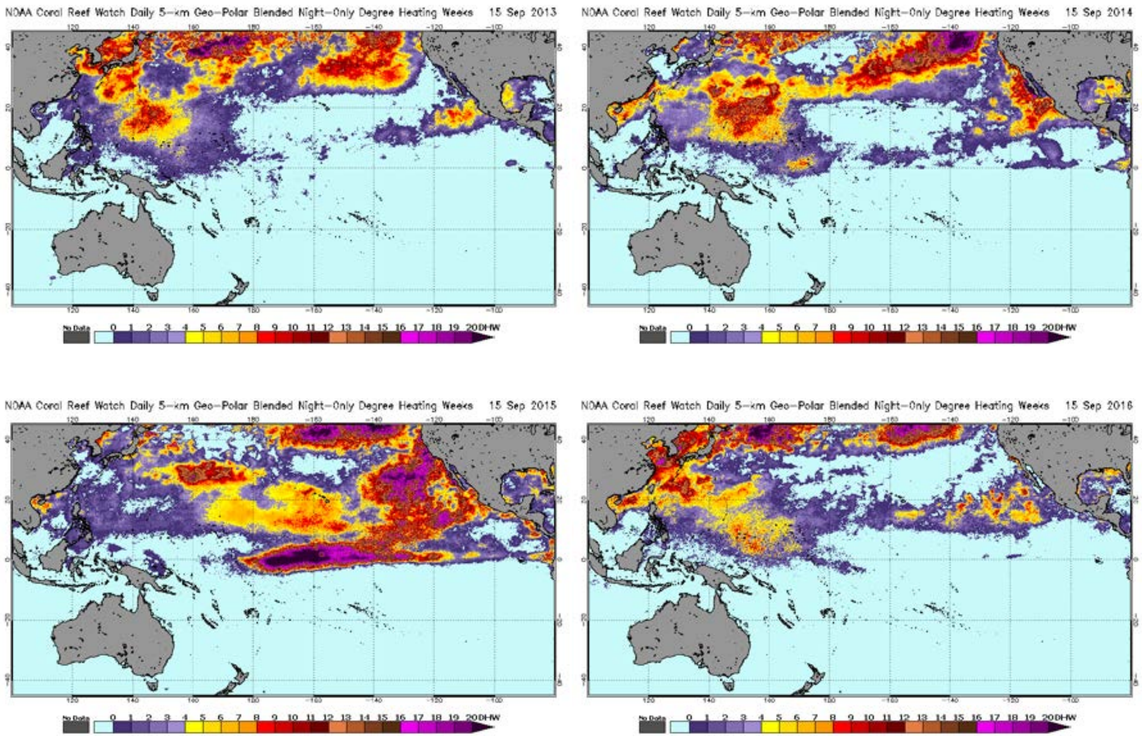


Figure 26. Degree Heating Weeks Maps, showing Annual DHW Maximum (Sep 15, 2013-2016) across the Pacific Ocean.

2.5.3.8 Heavy Weather (Tropical Cyclones)

Description: This indicator uses historical data from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) International Best Track Archive for Climate Stewardship (IBTrACS) to track the number of tropical cyclones in the western, central, and south Pacific basins. This indicator also monitors the Accumulated Cyclone Energy (ACE) Index and the Power Dissipation Index (PDI) which are two ways of monitoring the frequency, strength, and duration of tropical cyclones based on wind speed measurements.

The annual frequency of storms passing through the western North Pacific basin is tracked and a stacked time series plot will show the representative breakdown of the Saffir-Simpson hurricane categories. Three solid lines across the graph will also be plotted representing a) the annual long-term average number of named storms, b) the annual average number of typhoons, and c) the annual average number of major typhoons (Cat 3 and above). Three more lines will also be shown (in light gray) representing the annual average number of named-storms for ENSO a) neutral, b) warm, and c) cool.

Every cyclone has an ACE Index value, which is a number based on the maximum wind speed measured at six-hourly intervals over the entire time that the cyclone is classified as at least a tropical storm (wind speed of at least 34 knot; 39 mph). Therefore, a storm's ACE Index value accounts for both strength and duration. This plot will show the historical ACE values for each typhoon season and will have a solid line representing the annual average ACE value. Three more lines will also be shown (in light gray) representing the annual average ACE values for ENSO a) neutral, b) warm, and c) cool.

Timeframe: Yearly

Region/Location: Hawaii and U.S. Affiliated Pacific Islands

Data Source/Responsible Party: NCDC's International Best Track Archive for Climate Stewardship (IBTrACS).

Measurement Platform: Satellite

Rationale: The effects of tropical cyclones are numerous and well-known. At sea, storms disrupt and endanger shipping traffic as well as fishing effort and safety. The Hawaii longline fishery, for example, had serious problems between August and November 2015 with vessels dodging storms at sea, delayed departures and inability to make it safely back to Honolulu because of bad weather. When cyclones encounter land, their intense rains and high winds can cause severe property damage, loss of life, soil erosion, and flooding. The associated storm surge, the large volume of ocean water pushed toward shore by the cyclone's strong winds, can cause severe flooding and destruction.

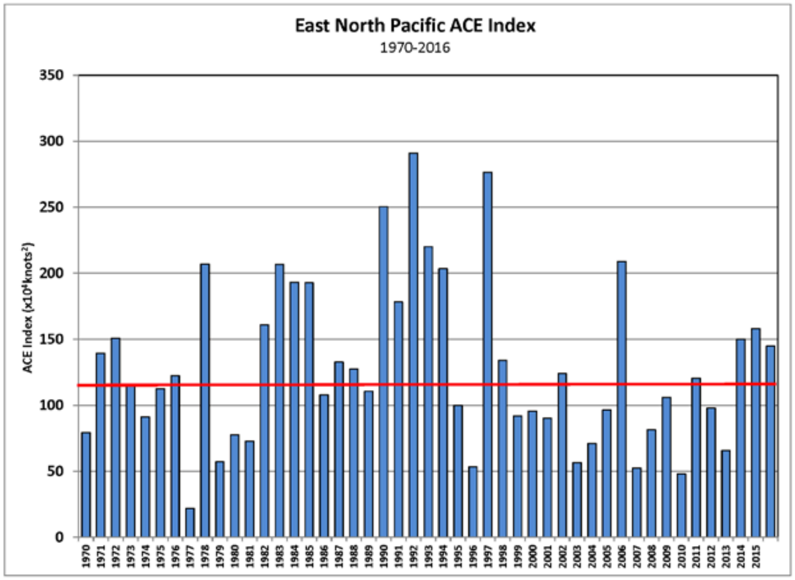


Figure 27. 2016 East Pacific Tropical Cyclone ACE 1970-2016. Source: NOAA's National Hurricane Center

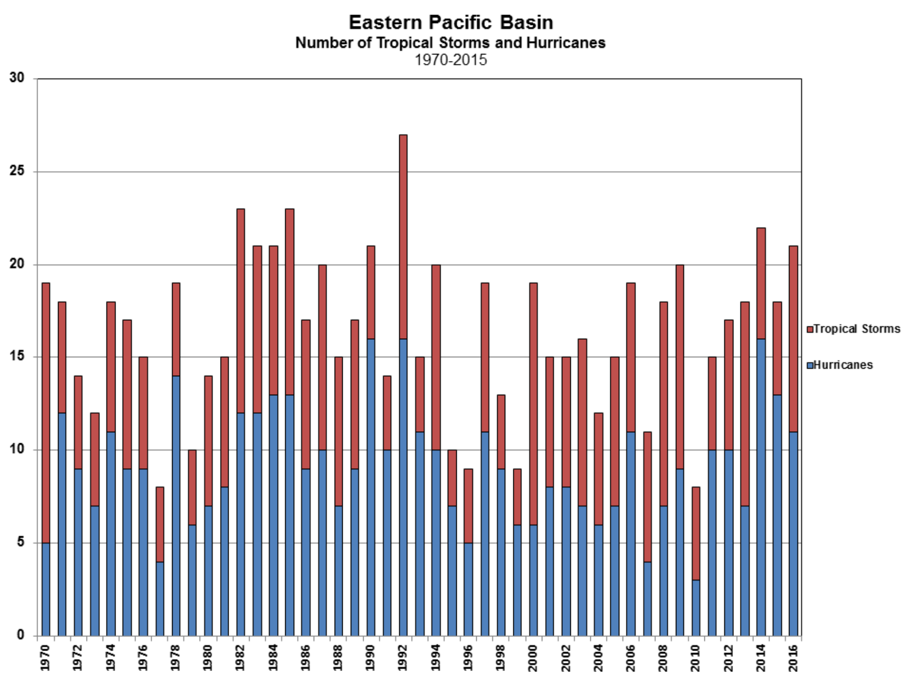


Figure 28. East Pacific tropical cyclone count 1970-2016. Source: NOAA's National Hurricane Center

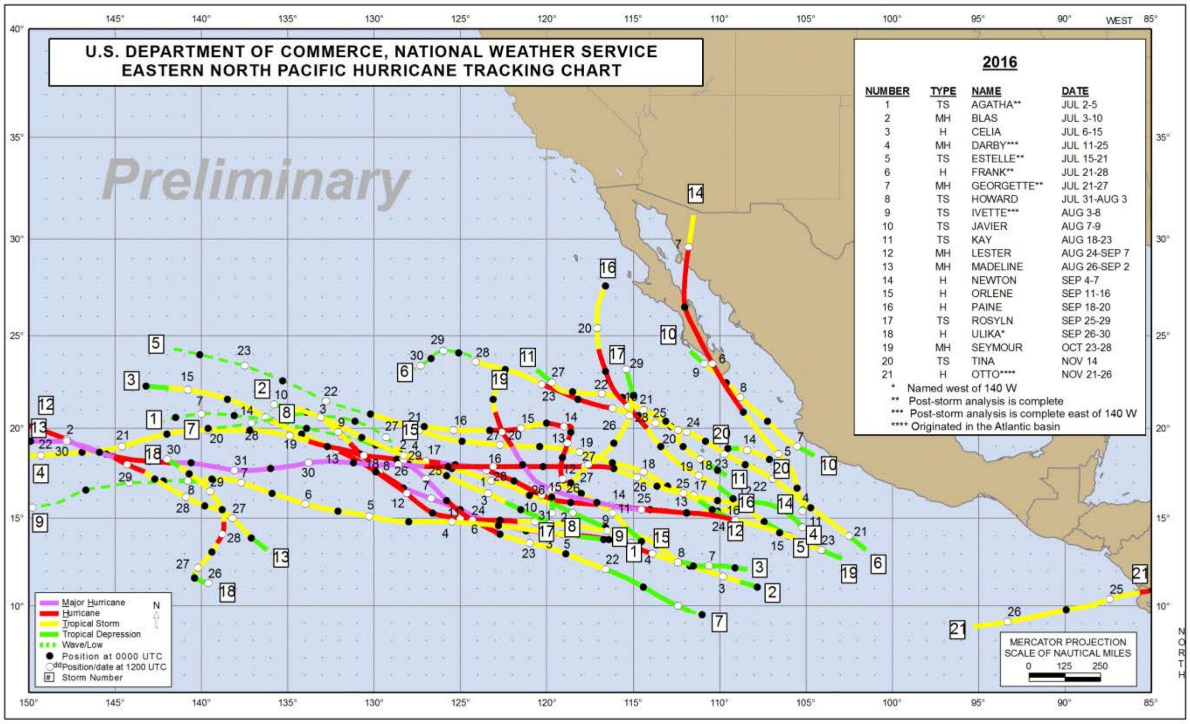


Figure 29. 2015 Eastern Pacific Tropical Cyclone Tracks. Source: NOAA's National Hurricane Center

The NOAA National Centers for Environmental Information, State of the Climate: Hurricanes and Tropical Storms for Annual 2015, published online January 2016, notes that "the 2015 East Pacific hurricane season had 18 named storms, including 13 hurricanes, nine of which became major. The 1981-2010 average number of named storms in the East Pacific is 16.5, with 8.9 hurricanes, and 4.3 major hurricanes. This is the first year since reliable record keeping began in 1971 that the eastern Pacific saw nine major hurricanes. The Central Pacific also saw an above-average tropical cyclone season, with 14 named storms, eight hurricanes, and five major hurricanes, the most active season since reliable record-keeping began in 1971. Three major hurricanes (Ignacio, Kilo and Jimena) were active across the two adjacent basins at the same time, the first time this occurrence has been observed. The ACE index for the East Pacific basin during 2015 was 158 (x10^4 knots^2), which is above the 1981-2010 average of 132 (x10^4 knots^2) and the highest since 2006. The Central Pacific basin ACE during 2015 was 124 (x10^4 knots^2)."

Inserted from: http://www.ncdc.noaa.gov/sotc/tropical-cyclones/201513

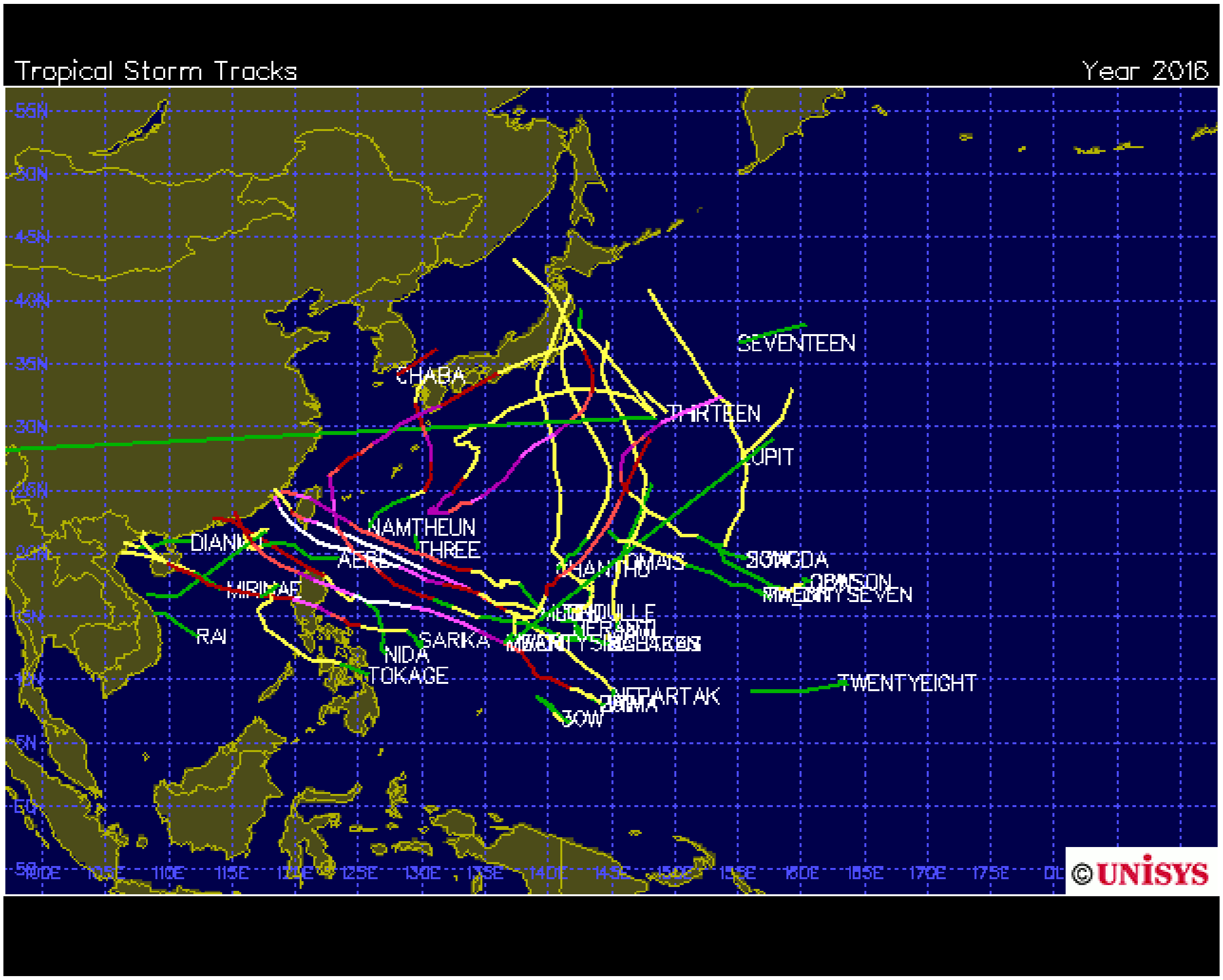


Figure 30. Western Pacific Cyclone Tracks 2016. Source: http://weather.unisys.com/hurricane/w_pacific/2016

References: NOAA National Centers for Environmental Information, State of the Climate: Hurricanes and Tropical Storms for Annual 2016, published online January 2016, retrieved on August 5, 2016 from http://www.ncdc.noaa.gov/sotc/tropical-cyclones/201513.

2.5.3.9 Sea Level (Sea Surface Height and Anomaly)

Description: Monthly mean sea level time series, including extremes

Timeframe: Monthly

Region/Location: Observations from selected sites within the Hawaiian Archipelago

Data Source/Responsible Party: Basin-wide context from satellite altimetry:
http://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/el-nino-bulletin.html

Quarterly time series of mean sea level anomalies from satellite altimetry:
http://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/archive/index.cfm?y=2015

Sea Surface Height and Anomaly from NOAA Ocean Service, Tides and Currents, Sea Level Trends https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1612340

Measurement Platform: Satellite and *in situ* tide gauges

Rationale: Rising sea levels can result in a number of coastal impacts, including inundation of infrastructure, increased damage resulting from storm-driven waves and flooding, and saltwater intrusion into freshwater supplies.

2.5.3.9.1 Basin-Wide Perspective

This image of the mean sea level anomaly for February 2016 compared to 1993-2013 climatology from satellite altimetry provides a glimpse into how the 2015-2016 El Niño continues to affect sea level across the Pacific Basin. The image captures the fact that sea level continues to be lower in the Western Pacific and higher in the Central and Eastern Pacific (a standard pattern during El Niño events.) This basin-wide perspective provides a context for the location-specific sea level/sea surface height images that follow.

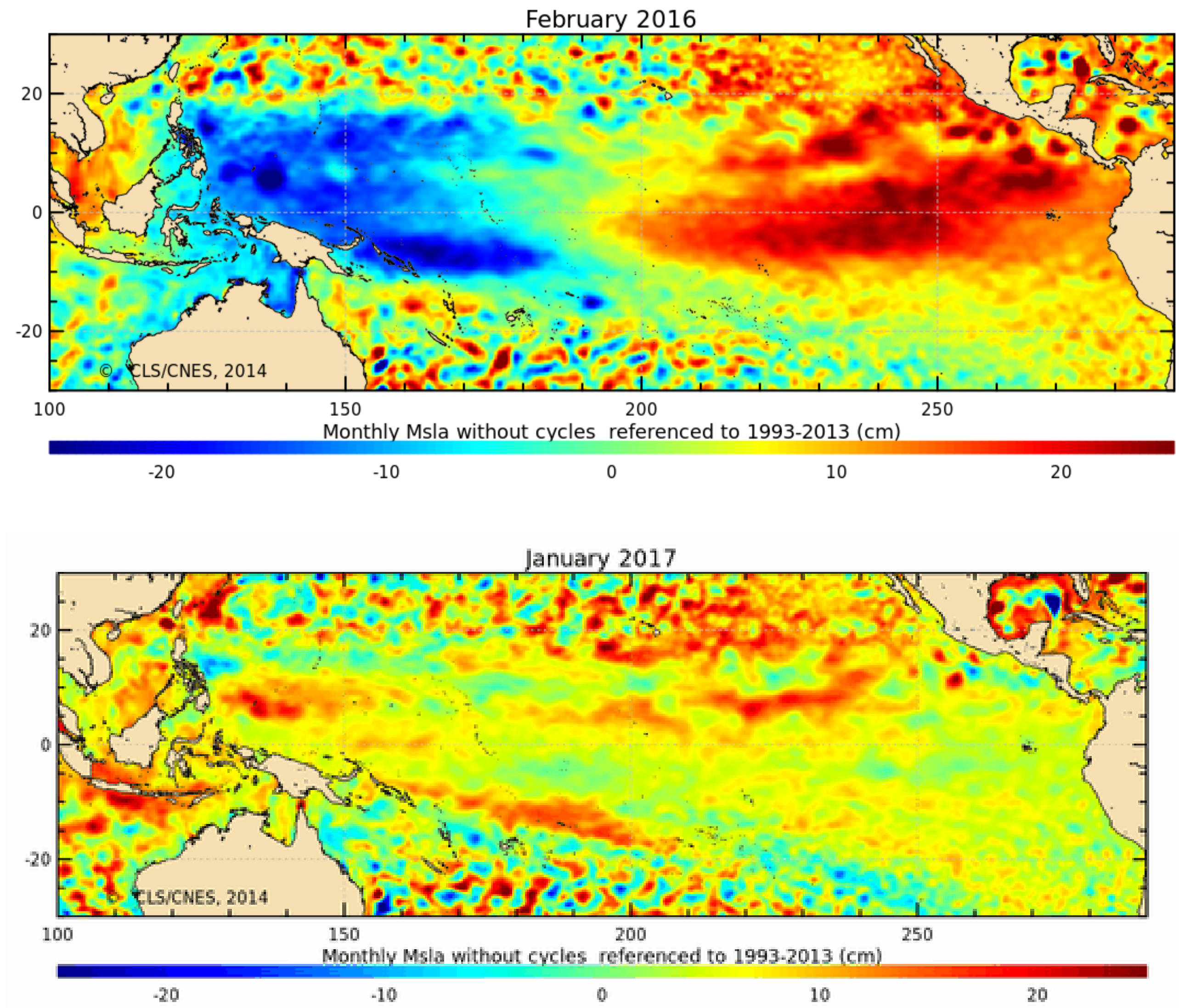
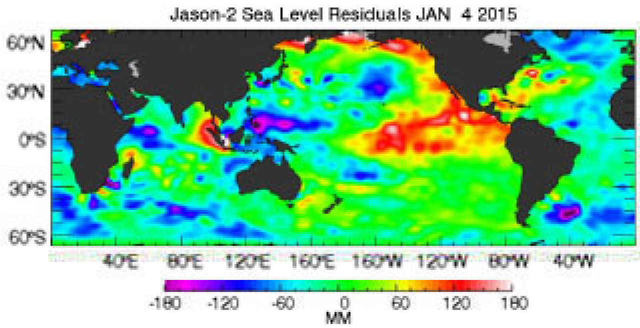
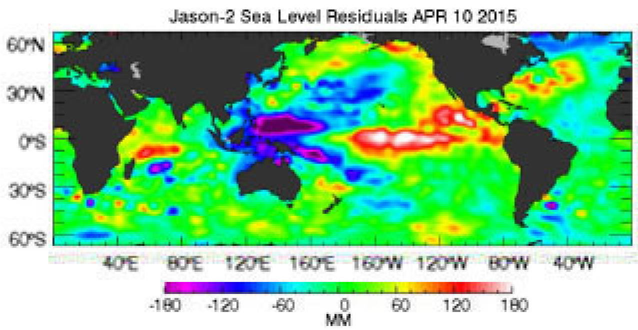
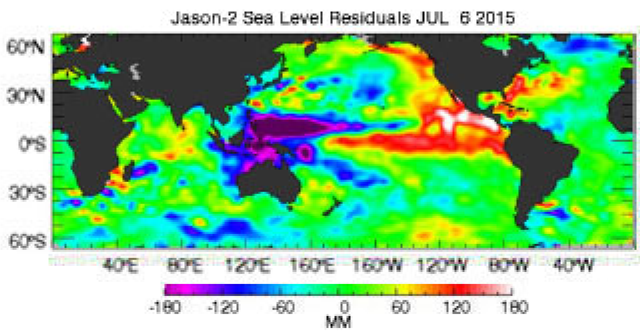
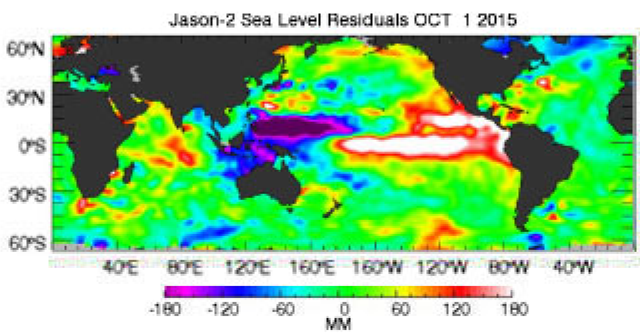


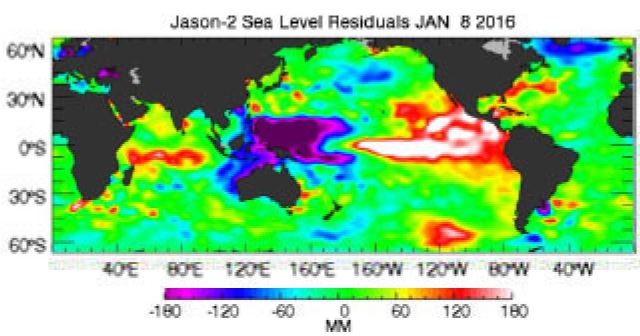
Figure 31. Comparing mean sea level anomaly for February 2016 (El Niño), and January 2017 (Neutral) .



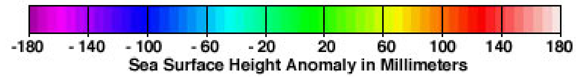


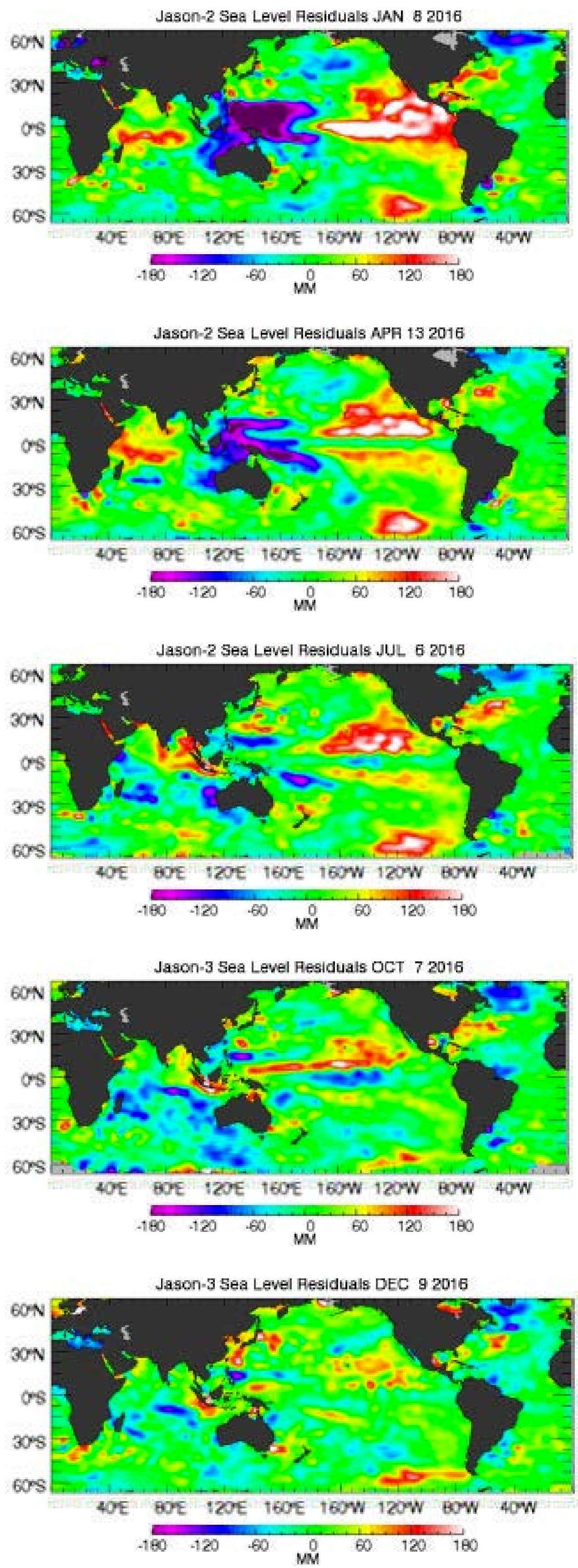




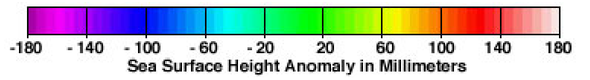


Quarterly time series of mean sea level anomalies during 2015 provide a glimpse into the evolution of the 2015-2016 El Niño throughout the year using satellite altimetry measurements of sea level height (http://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/archive/index.cfm?y=2015**)**





Quarterly time series of mean sea level anomalies during 2016 provide a glimpse into the dissipation of the 2015-2016 El Niño throughout the year using satellite altimetry measurements of sea level height (http://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/archive/index.cfm?y=2016**)**



2.5.3.9.2 Local Sea Level

These time-series from *in situ* tide gauges provide a perspective on sea level trends within each Archipelago (Tide Station Time Series from NOAA/COOPS).

The following figures and descriptive paragraphs were inserted from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1630000.

Figure 32 shows the monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The long-term linear trend is also shown, including its 95% confidence interval. The plotted values are relative to the most recent Mean Sea Level datum established by CO-OPS. The calculated trends for all stations are available as a table in millimeters/year and in feet/century (0.3 meters = 1 foot). If present, solid vertical lines indicate times of any major earthquakes in the vicinity of the station and dashed vertical lines bracket any periods of questionable data or datum shift.

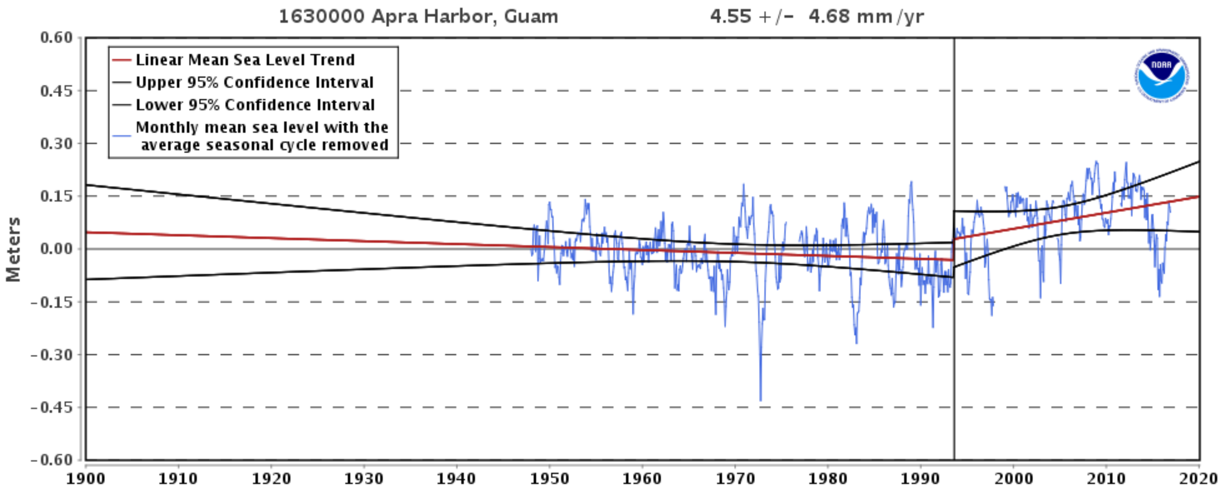


Figure 32. Local sea level at Apra Harbor, Guam, 1900-2016.

The monthly extreme water levels include a Mean Sea Level (MSL) trend of 8.45 millimeters/year with a 95% confidence interval of +/- 8.88 millimeters/year based on monthly MSL data from 1993 to 2006, which is equivalent to a change of 2.77 feet in 100 years. Figure 33 shows the monthly highest and lowest water levels with the 1%, 10%, 50%, and 99% annual exceedance probability levels in red, orange, green, and blue. The plotted values are in meters relative to the Mean Higher High Water (MHHW) or Mean Lower Low Water (MLLW) datums established by CO-OPS (1 foot = 0.3 meters). On average, the 1% level (red) will be exceeded in only one year per century, the 10% level (orange) will be exceeded in ten years per century, and the 50% level (green) will be exceeded in fifty years per century. The 99% level (blue) will be exceeded in all but one year per century, although it could be exceeded more than once in other years.

1630000 Apra Harbor, Guam,

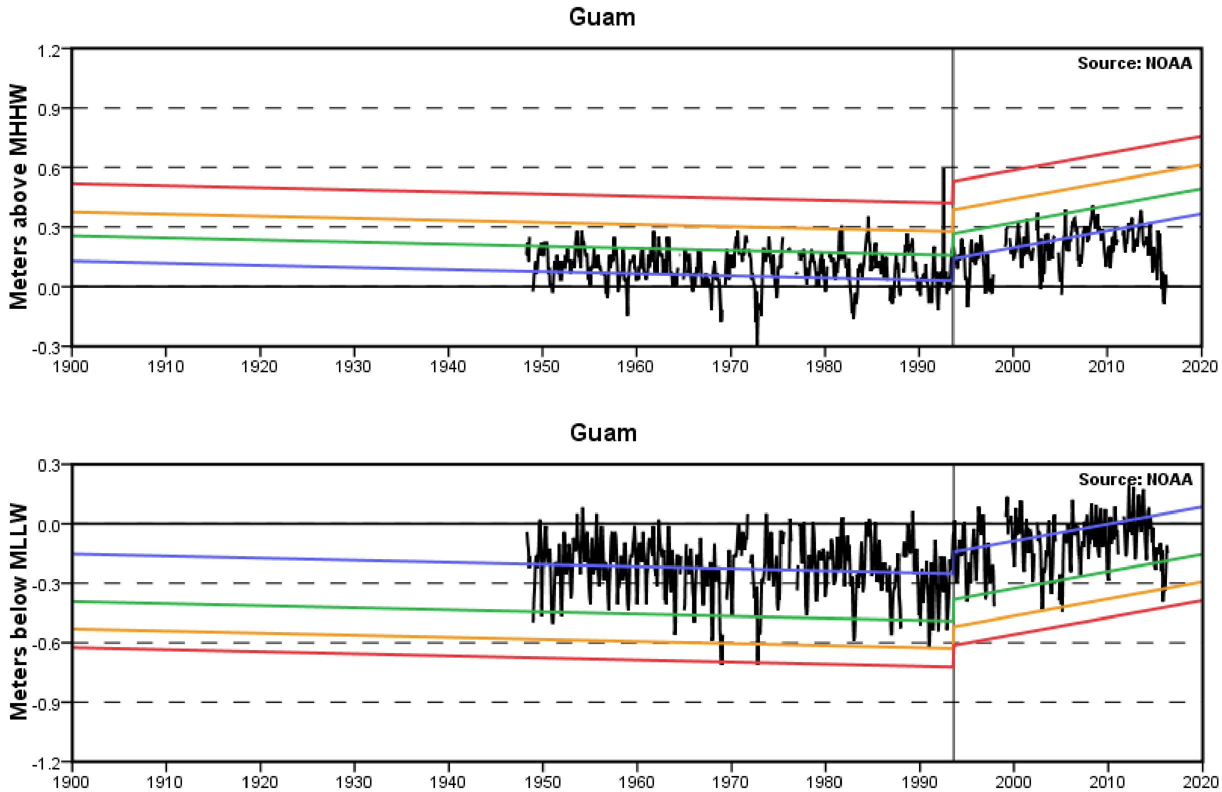


Figure 33. Monthly extreme water levels below and above MLLW and MHHW in Guam, 1900-2016.

2.5.3.10 Wave Watch 3 Global Wave Model

Description: To describe patterns in wave forcing, we present data from the Wave Watch 3 global wave model run by the Department of Ocean and Resources Engineering at the University of Hawai‘i in collaboration with NOAA/NCEP and NWS Honolulu. PacIOOS describes the model at http://oos.soest.hawaii.edu/pacioos/focus/modeling/wave_models.php: “The global model is initialized daily and is forced with NOAA/NCEP's global forecast system (GFS) winds. This model is designed to capture the large-scale ocean waves, provide spectral boundary conditions for the Hawai‘i and Mariana Islands regional WW3 model, and most importantly, the 7 day model outputs a 5 day forecast.”

Data presented here come from the global model, but regional WW3 models with higher resolution exist for Hawaii, Marianas and Samoa, and in some cases, very high resolution SWAN models exist for islands within those groups.

Timeframe: 2010-2016, Daily data.

Region/Location: Global.

Data Source: “WaveWatch III (WW3) Global Wave Model”: http://oos.soest.hawaii.edu/erddap/griddap/NWW3_Global_Best.html

Measurement Platform: *Global Forecast System Winds, WW3 model*

Rationale: Wave forcing can have major implications for both coastal ecosystems and pelagic fishing operations.

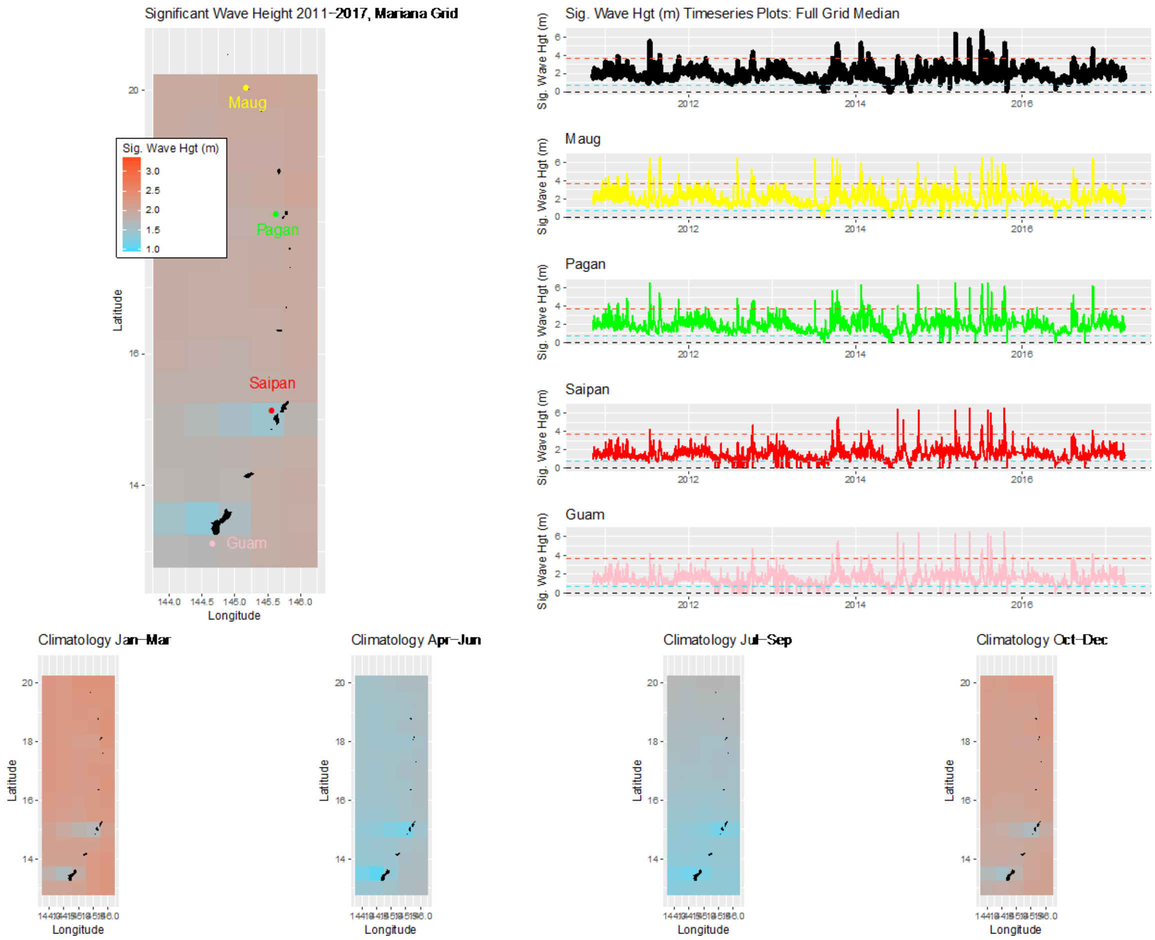


Figure 34. Wave watch summary for Mariana regional grid.

2.5.4 Observational and Research Needs

Through preparation of the 2016 Archipelagic Annual Reports, the Council has identified a number of observational and research needs that, if addressed, would improve the information content of future Climate and Ocean Indicators chapters. This information would provide fishery managers, fishing industry and community stakeholders with better understanding and predictive capacity vital to sustaining resilient and vibrant fishery systems in the Western Pacific.

- Emphasize the importance of continuing the climate and ocean indicators used in this report so that a consistent, long-term record can be maintained;
- Develop agreements among stakeholders and research partners to ensure the sustainability, availability and accessibility of climate and ocean indicators, their associated datasets and analytical methods used in this and future reports;
- Improve monitoring and understanding of the impacts of changes in ocean temperature, pH and ocean acidity, ocean oxygen content and hypoxia, and sea level rise through active collaboration by all fishery stakeholders and research partners;
- Develop, test and provide access to additional climate and ocean indicators that can improve the Archipelagic Conceptual Model;
- Explore the connections among sea surface conditions, stratification and mixing;
- Investigate the connections between climate variables and other indicators in the Archipelagic Conceptual Model to improve understanding of changes in physical, biochemical, biologic and socio-economic processes and their interactions in the regional ecosystem;
- Develop predictive models that can be used for scenario planning to account for unexpected changes and uncertainties in the regional ecosystem and fisheries;
- Foster applied research in ecosystem modeling to better describe current conditions and to better anticipate the future under alternative models of climate and ocean change including changes in expected human benefits and their variability;
- Improve understanding of the connections between PDO and fisheries ecosystems beyond the North Pacific;
- Improve understanding of mahi and swordfish size in relation to the orientation of the Transition Zone Chlorophyll Front (TZCF);
- Explore the biological implications of tropical cyclones;
- Standardize fish community size structure data for gear type;
- Clarify and elucidate the interactions among (1) changes in climate, (2) ecosystems and (3) social, economic and cultural impacts on fishing communities;
- Explore the implications and effectiveness of large marine protected areas including intergenerational losses of knowledge due to lack of access to traditional fishing areas;
- Cultural knowledge and practices for adapting to changing climate in the past and how they might contribute to future climate adaptation.
- Enhanced information on social, economic and cultural impacts of a changing climate and increased pressure on the ocean and its resources.
- Analysis of potential relationship between traditional runs of fish and climate change indicators.
- Explore the use of electronic monitoring and autonomous vehicles including small vessel prototypes.

- Explore additional and/or alternative climate and ocean that may have important effects on archipelagic fisheries systems including:
    - Ocean currents and anomalies;
    - Near-surface wind velocities and anomalies;
    - Wave forcing anomalies and wave power;
    - Storm frequency;
    - Estimates of phytoplankton abundance and size from satellite remotely-sensed SST and chlorophyll measurements;
    - Nutrients;
    - Eddy kinetic energy (EKE) which can be derived from satellite and remotely-sensed sea surface height data and can be indicative of productivity-enhancing eddies;
    - Time series of species richness and diversity from catch data which could potentially provide insight into how the ecosystem is responding to physical climate influences;
    - Identifying and monitoring key socio-economic and cultural indicators of the impacts of changing climate on resources, fishing communities, operations and resilience and;
    - Cultural knowledge and practices for adapting to changing climate in the past and how they might contribute to future climate adaptation.

2.5.5 A Look to the Future

Future Annual Reports will include additional indicators as they become available and their relevance to the development, evaluation and revision of ecosystem-fishery plans becomes clear. Working with national and jurisdictional partners, the Council will make all datasets used in the preparation of this and future reports available and easily accessible.

2.6 ESSENTIAL FISH HABITAT

2.6.1 Introduction

The Magnuson-Stevens Fishery Conservation and Management Act includes provisions concerning the identification and conservation of essential fish habitat (EFH), and under the EFH final rule, habitat areas of particular concern (HAPC) (50 Code of Federal Regulations [CFR] 600.815). The Magnuson-Stevens Act defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." HAPC are those areas of EFH identified pursuant to 50 CFR 600.815(a)(8), and meeting one or more of the following considerations: (1) ecological function provided by the habitat is important; (2) habitat is sensitive to human-induced environmental degradation; (3) development activities are, or will be, stressing the habitat type; or (4) the habitat type is rare.

The National Marine Fisheries Service (NMFS) and regional Fishery Management Councils (Councils) must describe and identify EFH in fishery management plans (FMPs), minimize to the extent practicable the adverse effects of fishing on EFH, and identify other actions to encourage the conservation and enhancement of EFH. Federal agencies that authorize, fund, or undertake actions that may adversely affect EFH must consult with NMFS, and NMFS must provide conservation recommendations to federal and state agencies regarding actions that would adversely affect EFH. Councils also have the authority to comment on federal or state agency actions that would adversely affect the habitat, including EFH, of managed species.

The EFH Final Rule strongly recommends regional fisheries management councils and NMFS to conduct a review and revision of the EFH components of fisheries management plans every five years (600.815(a)(10)). The council's FEPs state that new EFH information should be reviewed, as necessary, during preparation of the annual reports by the Plan Teams. Additionally, the EFH Final Rule states: "Councils should report on their review of EFH information as part of the annual Stock Assessment and Fishery Evaluation (SAFE) report prepared pursuant to §600.315(e)." The habitat portion of the annual report is designed to meet the FEP requirements and EFH Final Rule guidelines regarding EFH reviews.

National Standard 2 guidelines recommend that the SAFE report summarize the best scientific information available concerning the past, present, and possible future condition of EFH described by the FEPs.

2.6.1.1 EFH Information

The EFH components of fisheries management plans include the description and identification of EFH, lists of prey species and locations for each managed species, and optionally, habitat areas of particular concern. Impact-oriented components of FMPs include federal fishing activities that may adversely affect EFH; non-federal fishing activities that may adversely affect EFH; non-fishing activities that may adversely affect EFH; conservation and enhancement recommendations; and a cumulative impacts analysis on EFH. The last two components include the research and information needs section, which feeds into the Council's Five Year Research Priorities, and the EFH update procedure, which are described in the FEP but implemented in the annual report.

The Council has described EFH for five management unit species (MUS) under its management authority: pelagic (PMUS), bottomfish (BMUS), crustaceans (CMUS), coral reef ecosystem

(CREMUS), and precious corals (PCMUS). The Mariana FEP describes EFH for the BMUS, CMUS, CREMUS, and PCMUS.

EFH reviews of the biological components, including the description and identification of EFH, lists of prey species and locations, and HAPC, consist of three to four parts:

- Updated species descriptions, which can be found appended to the SAFE report. These can be used to directly update the FEP.
- Updated EFH levels of information tables, which can be found in Section 0.
- Updated research and information needs, which can be found in Section 2.6.5. These can be used to directly update the FEP.
- An analysis that distinguishes EFH from all potential habitats used by the species, which is the basis for an options paper for the Council. This part is developed if enough information exists to refine EFH.

2.6.1.2 Habitat Objectives of FEP

The habitat objective of the FEP is to refine EFH and minimize impacts to EFH, with the following subobjectives:

a. Review EFH and HAPC designations every five years based on the best available scientific information and update such designations based on the best available scientific information, when available
b. Identify and prioritize research to: assess adverse impacts to EFH and HAPC from fishing (including aquaculture) and non-fishing activities, including, but not limited to, activities that introduce land-based pollution into the marine environment.

This annual report reviews the precious coral EFH components and non-fishing impacts components, resetting the five-year timeline for review. The Council’s support of non-fishing activities research is monitored through the program plan and five year research priorities, not the annual report.

2.6.1.3 Response to Previous Council Recommendations

At its 168th meeting held in Honolulu, HI, the Council adopted the EFH Agreement and directed staff to incorporate it into the Regional Operating Agreement, as necessary. The habitat expert on the plan team is ideally the PIFSC staffer with 5 year EFH responsibilities outlined in the EFH Agreement. The Plan Team reviews EFH information as necessary and recommends update to the Council.

2.6.2 Habitat Use by MUS and Trends in Habitat Condition

The Mariana Archipelago is a chain of islands in the western Pacific roughly oriented north-south. It is anchored at the southern end by the relatively large island of Guam at 13.5° north latitude. The Commonwealth of the Northern Mariana Islands (CNMI) stretch off to the north. The entire chain is approximately 425 miles long. The archipelago was named by Spanish explorers in the 16th Century in honor of Spanish Queen Mariana of Austria.

The total land area of Guam is approximately 212 square miles and its EEZ is just over 84,000 square miles. The CNMI consists of 14 main islands. From north to south these are: Farallon de

Pajaros, Maug, Asuncion, Agrihan, Pagan, Alamagan, Guguan, Sarigan, Anatahan, Farallon de Medinilla, Saipan, Tinian, Aguijan, and Rota. Only Saipan, Rota, and Tinian are permanently inhabited, with 90% of the population residing on the island of Saipan. The total land area of the CNMI is 176.5 square miles and its EEZ is almost 300,000 square miles.

Guam and the southern islands of the CNMI are limestone, with level terraces and fringing coral reefs. The CNMI's northern islands are volcanic and sparsely inhabited, with active volcanoes on several islands, including Anatahan, Pagan, and Agrihan (the highest, at 3,166 feet). The archipelago has a tropical maritime climate moderated by seasonal northeast trade winds. While there is little seasonal temperature variation, there is a dry season (December to June) and a rainy season (July to November). The rainy season coincides with the northern hemisphere hurricane season, and the Mariana Archipelago is periodically impacted by powerful typhoons.

The Mariana Trench is located to the east of the chain. The trench includes the deepest point in the world's oceans. The vertical measurement from the seafloor to Saipan's highest point (Mount Tapotchau) is 37,752 ft.

Essential fish habitat in the Marianas for the four MUS comprises all substrate from the shoreline to the 700 m isobath. The entire water column is described as EFH from the shoreline to the 700 m isobath, and the water column to a depth of 400 m is described as EFH from the 700 m isobath to the limit or boundary of the exclusive economic zone (EEZ). While the coral reef ecosystems surrounding the islands in the Marianas have been the subject of a comprehensive monitoring program through the PIFSC Coral Reef Ecosystem Division (CRED) biennially since 2003, surveys are focused on the nearshore environments surrounding the islands, atolls and reefs (PIFSC 2011). Remote reefs and shoals were surveyed in some years.

The mission of the PIFSC Coral Reef Ecosystem Division (CRED) is to "provide high-quality, scientific information about the status of coral reef ecosystems of the U.S. Pacific islands to the public, resource managers, and policymakers on local, regional, national, and international levels" (PIFSC 2011). CRED's Reef Assessment and Monitoring Program (RAMP) conducts comprehensive ecosystem monitoring surveys at about 50 island, atoll, and shallow bank sites in the Western Pacific Region on a one to three year schedule (PIFSC 2008). CRED coral reef monitoring reports provide the most comprehensive description of nearshore habitat quality in the region. The benthic habitat mapping program provides information on the quantity of habitat.

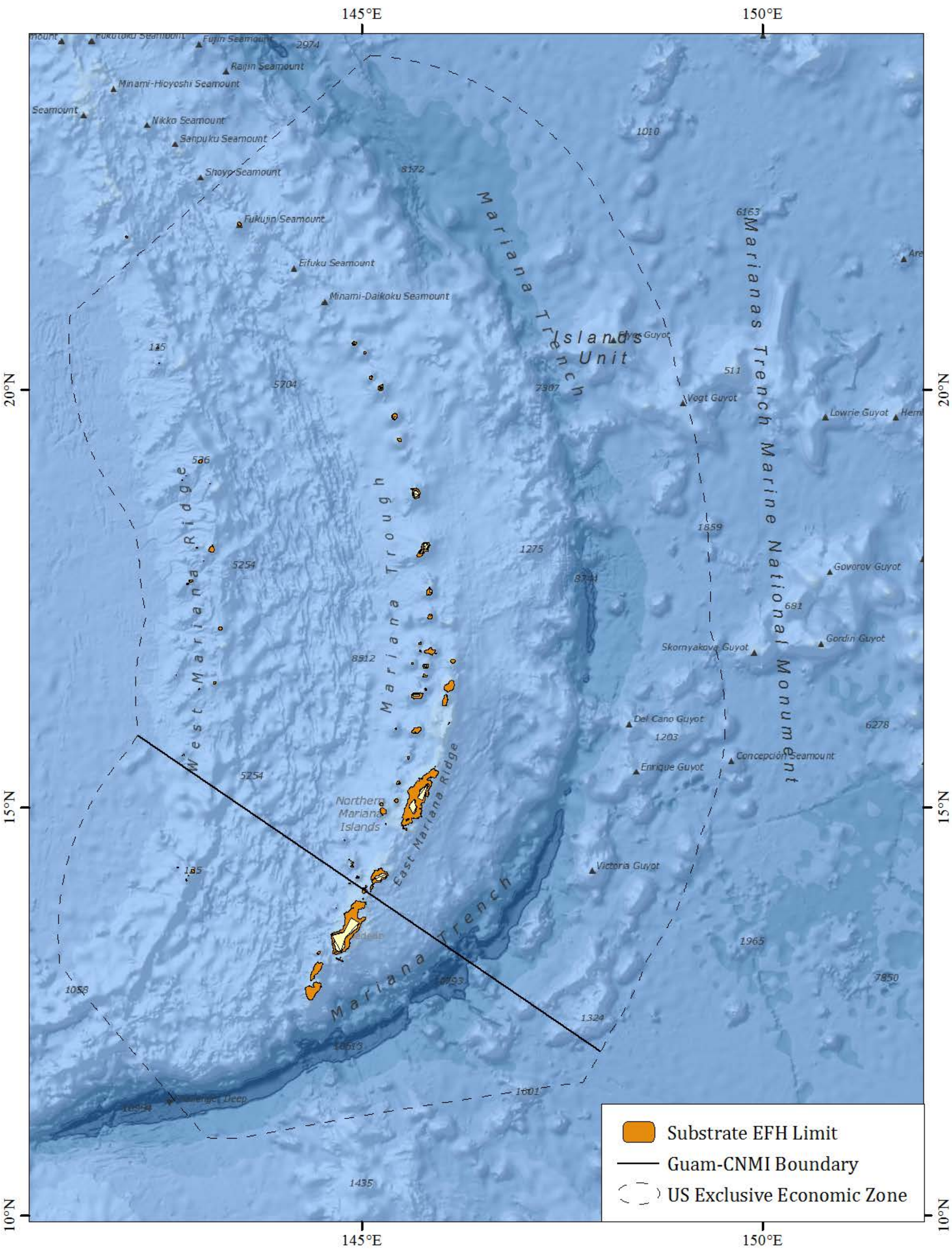


Figure 35. Substrate EFH Limit of 700 m isobath around the islands and surrounding banks of the Mariana Archipelago. Data Source: GMRT.

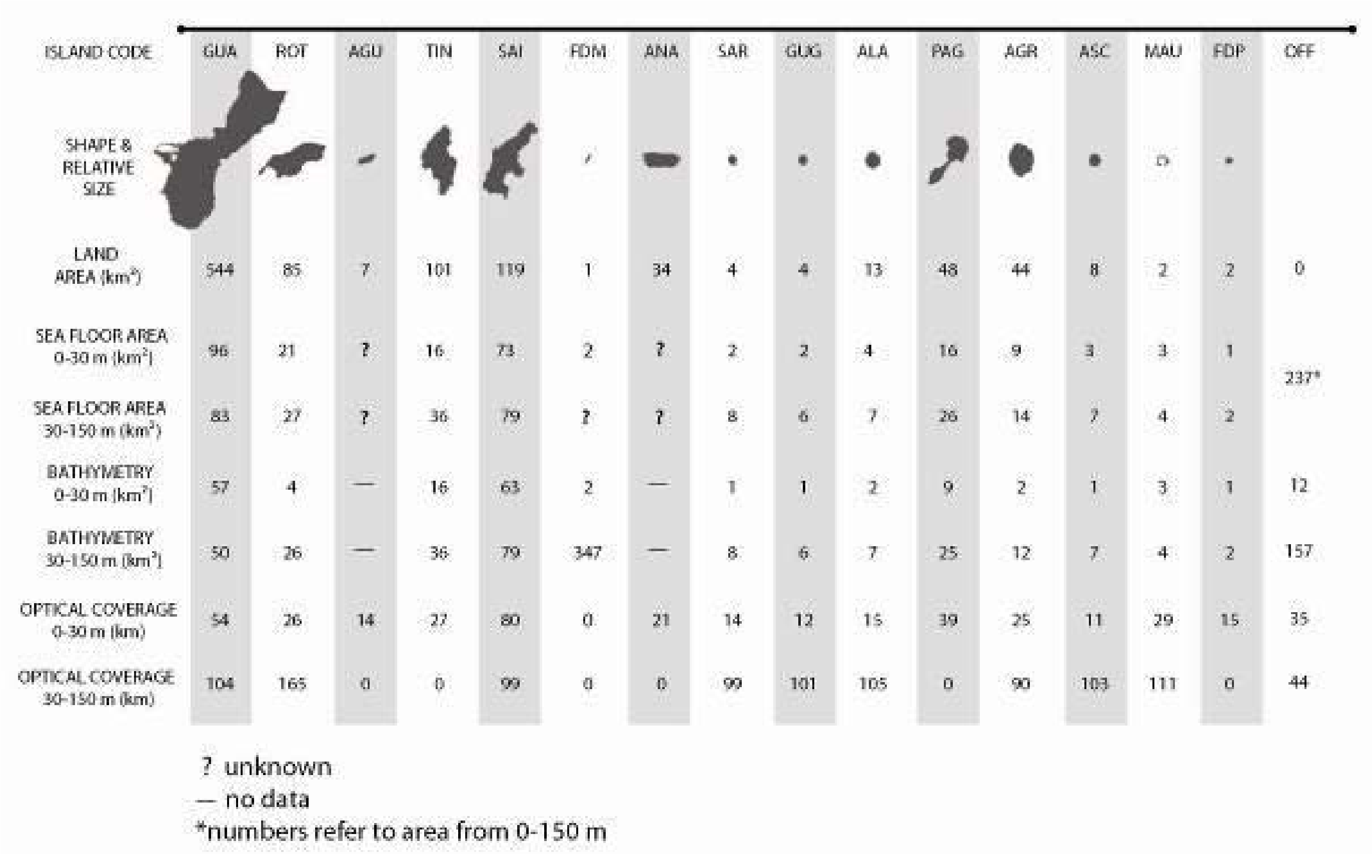
2.6.2.1 Habitat Mapping

Interpreted IKONOS benthic habitat maps in the 0 – 30 m depth range have been completed for all islands in the CNMI (CRCP 2011). Mapping products for the Marianas are available from the Pacific Islands Benthic Habitat Mapping Center.

Table 62. Summary of habitat mapping in the Marianas

Depth Range	Timeline/Mapping Product	Progress	Source
0-30 m	IKONOS Benthic Habitat Maps	All Islands	CRCP 2011
	2000-2010 Bathymetry	70%	DesRochers 2016
	2011-2015 Multibeam Bathymetry	-	DesRochers 2016
	2011-2015, Satellite Worldview 2 Bathymetry	15%	DesRochers 2016
30-150 m	2000-2010 Bathymetry	85%	DesRochers 2016
	2011-2015 Multibeam Bathymetry	-	DesRochers 2016
15-2000 m	Multibeam Bathymetry	Complete around all islands except Guam, Rota, and Agrigan	Pacific Islands Benthic Habitat Mapping Center
	Derived Products	Backscatter available for all 60 m multibeam Geomorphology products – see website	Pacific Islands Benthic Habitat Mapping Center

The land and seafloor area surrounding the islands of the Marianas as well as primary data coverage are reproduced from CRCP 2011 in Figure 36.



ISLAND CODE	GUA	ROT	AGU	TIN	SAI	FDM	ANA	SAR	GUG	ALA	PAG	AGR	ASC	MAU	FDP	OFF
SHAPE & RELATIVE SIZE																
LAND AREA (km²)	544	85	7	101	119	1	34	4	4	13	48	44	8	2	2	0
SEA FLOOR AREA 0-30 m (km²)	96	21	?	16	73	2	?	2	2	4	16	9	3	3	1	237*
SEA FLOOR AREA 30-150 m (km²)	83	27	?	36	79	?	?	8	6	7	26	14	7	4	2	
BATHYMETRY 0-30 m (km²)	57	4	—	16	63	2	—	1	1	2	9	2	1	3	1	12
BATHYMETRY 30-150 m (km²)	50	26	—	36	79	347	—	8	6	7	25	12	7	4	2	157
OPTICAL COVERAGE 0-30 m (km)	54	26	14	27	80	0	21	14	12	15	39	25	11	29	15	35
OPTICAL COVERAGE 30-150 m (km)	104	165	0	0	99	0	0	99	101	105	0	90	103	111	0	44

? unknown
— no data
*numbers refer to area from 0-150 m

Figure 36. Marianas Land and Seafloor Area and Primary Data Coverage from CRCP 2011.

2.6.2.2 Benthic Habitat

Juvenile and adult life stages of coral reef MUS and crustaceans including spiny and slipper lobsters and Kona crab extends from the shoreline to the 100 m isobath (64 FR 19067, April 19, 1999). All benthic habitat is considered EFH for crustaceans species (64 FR 19067, April 19, 1999), while the type of bottom habitat varies by family for coral reef species (69 FR 8336, February 24, 2004). Juvenile and adult bottomfish EFH extends from the shoreline to the 400 m isobath (64 FR 19067, April 19, 1999), and juvenile and adult deepwater shrimp habitat extends from the 300 m isobath to the 700 m isobath (73 FR 70603, November 21, 2008).

2.6.2.2.1 RAMP Indicators

Benthic percent cover of coral, macroalgae, and crustose coralline algae from CRED are found in the following tables. CRED uses the benthic towed-diver survey method to monitor changes in benthic composition. In this method, "a pair of scuba divers (one collecting fish data, the other collecting benthic data) is towed about 1 m above the reef roughly 60 m behind a small boat at a constant speed of about 1.5 kt. Each diver maneuvers a towboard platform, which is connected to the boat by a bridle and towline and outfitted with a communications telegraph and various survey equipment, including a downward-facing digital SLR camera (Canon EOS 50D, Canon Inc., Tokyo). The benthic towed diver records general habitat complexity and type (e.g., spur and groove, pavement), percent cover by functional-group (hard corals, stressed corals, soft corals, macroalgae, crustose coralline algae, sand, and rubble) and for macroinvertebrates (crown-of-thorns seastars, sea cucumbers, free and boring urchins, and giant clams).

Towed-diver surveys are typically 50 min long and cover about two to three km of habitat. Each survey is divided into five-min segments, with data recorded separately per segment to allow for later location of observations within the ~ 200-300 m length of each segment. Throughout each survey, latitude and longitude of the survey track are recorded on the small boat using a GPS; and after the survey, diver tracks are generated with the GPS data and a layback algorithm that accounts for position of the diver relative to the boat. (PIFSC Website, 2016).

Table 63. Mean percent cover of live coral from RAMP sites collected from towed-diver surveys in the Marianas

	2003	2005	2007	2009	2011	2014
Agrihan	16.03	15.45	13.68	16.03	19.83	
Aguijan	17.88	17.25	11.68	15.61	21.88	33.46
Alamagan	18.23	17.39	22.21	23.34	30.28	27.58
Anatahan	7.93					
Arakane	24.06	11.83				
Asuncion	18.15	15.58	15.66	18.57	28	40.56
Farallon de Pajaros	10.13	4.82	4.94	11.28	11.69	16.45
Guam	19.58	23.3	11.72	13.71	19.06	17.58
Guguan	23	10.18	26.58	24.97	30.23	37.23
Maug	26.86	21.43	26.25	28.09	38	46.17
Pagan	18.51	9.84	12.04	13.09	16.23	27.87
Pathfinder	24.17	24.75				
Rota	8.98	6.04	4.36	4.45	9.94	17.39
Saipan	20.85	10.63	10.18	10.18	13.73	24.99
Santa Rosa	7.31	7.8				
Sarigan	18.02	12.88	14.21	23.37	18.01	31.98
Stingray	54.86					
Supply	38.75					
Tatsumi	7.92					
Tinian	12.46	8.99	8.08	9.33	12.02	17.37

Table 64. Mean percent cover of macroalgae from RAMP sites collected from towed-diver surveys in the Marianas

	2003	2005	2007	2009	2011	2014
Agrihan	48.25	22.65	8.55	3.2	4.63	
Aguijan	44.56	38.81	28.31	20.8	21.52	25.1
Alamagan	41.21	26.03	15.65	15.47	12.81	8.33

Anatahan	14.31					
Arakane	52.26	45.75				
Asuncion	51.1	5.37	19.11	7.54	7.47	3.86
Farallon de Pajaros	60.2	4.32	3.38	0.05	0.91	0.18
Guam	46.19	52.67	43.22	26.82	29.61	41.64
Guguan	45	10.18	19.5	17	12.59	8.66
Maug	45.91	27.2	8.17	3.26	4.37	12.01
Pagan	45.96	18.4	16.74	9.84	7.36	19.3
Pathfinder	37.29	29				
Rota	54.34	56.05	38.76	30.95	35.16	29.33
Saipan	48.57	30.75	31.87	20.39	15.26	25.18
Santa Rosa	42.5	70.54				
Sarigan	42.23	23.95	16.47	12.51	9.41	11.55
Stingray	33.89					
Supply	19.17					
Tatsumi	67.22					
Tinian	46.94	56.38	39.95	30.4	25.92	34.91

Table 65. Mean percent cover of crustose coralline algae from RAMP sites collected from towed-diver surveys in the Marianas

	2003	2005	2007	2009	2011	2014
Agrihan	8.64	5.7	9.94	5.57	3.91	
Aguijan	14.69	10.59	12.67	7.32	11.47	18.33
Alamagan	7.63	4.85	10.29	5.33	4.29	6.25
Anatahan	7.72					
Arakane	5.28	3.58				
Asuncion	7.96	8.99	9.53	3.67	4.62	2.19
Farallon de Pajaros	3.44	8.03	5.39	2.94	2.29	0.05
Guam	12.75	4.04	8.54	6.13	9.39	6.9
Guguan	17.13	15	12.95	14.59	7.35	9.91
Maug	10.22	7.53	12.32	7.73	5.38	8.23
Pagan	6.61	12.41	14.16	8.42	6.33	2.48
Pathfinder	5.56	10				
Rota	18.39	4.56	12.42	5.22	6.67	5.49
Saipan	10.04	8.74	15.03	8.27	6.31	5.61
Santa Rosa	7.13	0.55				
Sarigan	10.64	3.24	7.58	3.84	2.59	4.57
Stingray	1.54					

Supply	35					
Tatsumi	6.11					
Tinian	6.25	5.18	16.16	4.07	7.59	5.96

2.6.2.3 Oceanography and Water Quality

The water column is also designated as EFH for selected MUS life stages at various depths. For larval stages of all species except deepwater shrimp, the water column is EFH from the shoreline to the EEZ. Coral reef species egg and larval EFH is to a depth of 100 m; crustaceans, 150m; and bottomfish, 400 m. Please see the Ecosystem and Climate Change section for information related to oceanography and water quality.

2.6.3 Report on Review of EFH Information

Two EFH reviews were completed this year:

- Review of precious corals biological components (Appendix C)
- Omnibus review of non-fishing impacts to EFH, cumulative impacts, and conservation and enhancement recommendations (Appendix D)

2.6.4 EFH Levels

NMFS guidelines codified at 50 C.F.R. § 600.815 recommend Councils organize data used to describe and identify EFH into the following four levels:

1. Level 1: Distribution data are available for some or all portions of the geographic range of the species.
2. Level 2: Habitat-related densities of the species are available.
3. Level 3: Growth, reproduction, or survival rates within habitats are available.
4. Level 4: Production rates by habitat are available.

The Council adopted a fifth level, denoted Level 0, for situations in which there is no information available about the geographic extent of a particular managed species' life stage. The existing level of data for individual MUS in each fishery are presented in tables per fishery. Each fishery section also includes the description of EFH, method used to assess the value of the habitat to the species, description of data sources used if there was analysis; and description of method for analysis.

2.6.4.1 Precious Corals

Essential Fish Habitat for precious corals was originally designated in Amendment 4 to the Precious Corals Fishery Management Plan (64 FR 19067, April 19, 1999), using the level of data found in the table.

Table 66. Level of EFH information available for the Western Pacific precious corals management unit species complex.

Note: all observations are from the Hawaiian Islands.

Species	Pelagic phase (larval stage)	Benthic phase	Source(s)

Species	Pelagic phase (larval stage)	Benthic phase	Source(s)
Pink Coral (*Corallium*)			
Pleurocorallium secundum (prev. *Corallium secundum)*	0	1	Figueroa & Baco, 2014 HURL Database
C. regale	0	1	HURL Database
Hemicorallium laauense (prev. C. laauense)	0	1	HURL Database
Gold Coral			
Kulamanamana haumeaae (prev.	0	1	Sinniger, *et al.* (2013) HURL Database
Callogorgia gilberti	0	1	HURL Database
Narella spp.	0	1	HURL Database
Bamboo Coral			
Lepidisis olapa	0	1	HURL Database
Acanella spp.	0	1	HURL Database
Black Coral			
Antipathes griggi (prev. *Antipathes dichotoma)*	0	2	Opresko, 2009 HURL Database
A. grandis	0	1	HURL Database
Myriopathes ulex (prev. *A. ulex)*	0	1	Opresko, 2009 HURL Database

2.6.4.2 Bottomfish and Seamount Groundfish

Essential Fish Habitat for bottomfish and seamount groundfish was originally designated in Amendment 6 to the Bottomfish and Seamount Groundfish FMP (64 FR 19067, April 19, 1999).

Table 67. Level of EFH information available for Western Pacific bottomfish and seamount groundfish management unit species complex.

Life History Stage	Eggs	Larvae	Juvenile	Adult
Bottomfish: (scientific/english common)				
Aphareus rutilans (red snapper/silvermouth)	0	0	0	2
Aprion virescens (gray snapper/jobfish)	0	0	1	2
Caranx ignoblis (giant trevally/jack)	0	0	1	2
C lugubris (black trevally/jack)	0	0	0	2
Epinephelus faciatus (blacktip grouper)	0	0	0	1
E quernus (sea bass)	0	0	1	2
Etelis carbunculus (red snapper)	0	0	1	2
E coruscans (red snapper)	0	0	1	2
Lethrinus amboinensis (ambon emperor)	0	0	0	1
L rubrioperculatus (redgill emperor)	0	0	0	1
Lutjanus kasmira (blueline snapper)	0	0	1	1

Life History Stage	Eggs	Larvae	Juvenile	Adult
Pristipomoides auricilla (yellowtail snapper)	0	0	0	2
P filamentosus (pink snapper)	0	0	1	2
P flavipinnis (yelloweye snapper)	0	0	0	2
P seiboldi (pink snapper)	0	0	1	2
P zonatus (snapper)	0	0	0	2
Pseudocaranx dentex (thicklip trevally)	0	0	1	2
Seriola dumerili (amberjack)	0	0	0	2
Variola louti (lunartail grouper)	0	0	0	2
Seamount Groundfish:				
Beryx splendens (alfonsin)	0	1	2	2
Hyperoglyphe japonica (ratfish/butterfish)	0	0	0	1
Pseudopentaceros richardsoni (armorhead)	0	1	1	3

2.6.4.3 Crustaceans

Essential Fish Habitat for crustaceans MUS was originally designated in Amendment 10 to the Crustaceans FMP (64 FR 19067, April 19, 1999). EFH definitions were also approved for deepwater shrimp through an amendment to the Crustaceans FMP in 2008 (73 FR 70603, November 21, 2008).

Table 68. Level of EFH information available for the Western Pacific crustacean management unit species complex.

Life History Stage	Eggs	Larvae	Juvenile	Adult
Crustaceans: (english common\scientific)				
Spiny lobster (*Panulirus marginatus*)	2	1	1-2	2-3
Spiny lobster (*Panulirus pencillatus*)	1	1	1	2
Common slipper lobster (*Scyllarides squammosus*)	2	1	1	2-3
Ridgeback slipper lobster (*Scyllarides haanii*)	2	0	1	2-3
Chinese slipper lobster (*Parribacus antarcticus*)	2	0	1	2-3
Kona crab (*Ranina ranina*)	1	0	1	1-2

2.6.4.4 Coral Reef

Essential Fish Habitat for coral reef ecosystem species was originally designated in the Coral Reef Ecosystem FMP (69 FR 8336, February 24, 2004). An EFH review of CREMUS will not be undertaken until the Council completes its process of redesignating certain CREMUS into the ecosystem component classification. Ecosystem component species do not require EFH designations, as they are not a managed species.

2.6.5 Research and Information Needs

Based, in part, on the information provided in the tables above the Council identified the following scientific data which are needed to more effectively address the EFH provisions:

2.6.5.1 All FMP Fisheries

- Distribution of early life history stages (eggs and larvae) of management unit species by habitat

- Juvenile habitat (including physical, chemical, and biological features that determine suitable juvenile habitat)
- Food habits (feeding depth, major prey species etc)
- Habitat-related densities for all MUS life history stages
- Growth, reproduction and survival rates for MUS within habitats

2.6.5.2 Bottomfish Fishery

- Inventory of marine habitats in the EEZ of the Western Pacific region
- Data to obtain a better SPR estimate for American Samoa's bottomfish complex
- Baseline (virgin stock) parameters (CPUE, percent immature) for the Guam/NMI deep-water and shallow-water bottomfish complexes
- High resolution maps of bottom topography/currents/water masses/primary productivity
- Habitat utilization patterns for different life history stages and species

2.6.5.3 Crustaceans Fishery

- Identification of post-larval settlement habitat of all CMUS
- Identification of "source/sink" relationships in the NWHI and other regions (ie, relationships between spawning sites settlement using circulation models, genetic techniques, etc)
- Establish baseline parameters (CPUE) for the Guam/Northern Marinas crustacean populations
- Research to determine habitat-related densities for all CMUS life history stages in American Samoa, Guam, Hawaii and NMI
- High resolution mapping of bottom topography, bathymetry, currents, substrate types, algal beds, habitat relief

2.6.5.4 Precious Corals Fishery

- Distribution, abundance and status of precious corals in the CNMI and Guam.

2.6.6 References

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2.7 MARINE PLANNING

2.7.1 Introduction

Marine planning is a science-based tool being utilized regionally, nationally and globally to identify and address issues of multiple human uses, ecosystem health and cumulative impacts in the coastal and ocean environment. The Council's efforts to formalize incorporation of marine planning in its actions began in response to Executive Order 13547, Stewardship of the Ocean, Our Coasts, and the Great Lakes. Executive Order 13158, Marine Protected Areas (MPAs), proposes that agencies strengthen the management, protection, and conservation of existing MPAs, develop a national system of MPAs representing diverse ecosystems, and avoid causing harm to MPAs through federal activities. MPAs, or marine managed areas (MMAs) are one tool used in fisheries management and marine planning.

At its 165th meeting in March 2016, in Honolulu, Hawai`i, the Council approved the following objective for the FEPs: Consider the Implications of Spatial Management Arrangements in Council Decision-making. The following sub-objectives apply:

a. Identify and prioritize research that examines the positive and negative consequences of areas that restrict or prohibit fishing to fisheries, fishery ecosystems, and fishermen, such as the Bottomfish Fishing Restricted Areas, military installations, NWHI restrictions, and Marine Life Conservation Districts.

b. Establish effective spatially-based fishing zones.

c. Consider modifying or removing spatial-based fishing restrictions that are no longer necessary or effective in meeting their management objectives.

d. As needed, periodically evaluate the management effectiveness of existing spatial-based fishing zones in Federal waters.

In order to monitor implementation of this objective, this annual report includes the Council's spatially-based fishing restrictions or marine managed areas (MMAs), the goals associated with those, and the most recent evaluation. Council research needs are identified and prioritized through the 5 Year Research Priorities and other processes, and are not tracked in this report.

In order to meet the EFH and National Environmental Policy Act (NEPA) mandates, this annual report tracks activities that occur in the ocean that are of interest to the Council, and incidents or facilities that may contribute to cumulative impact. The National Marine Fisheries Service (NMFS) is responsible for NEPA compliance, and the Council must assess the environmental effects of ocean activities for the FEP's EFH cumulative impacts section. These are redundant efforts; therefore, this report can provide material or suggest resources to meet both mandates.

2.7.2 Response to Previous Council Recommendations

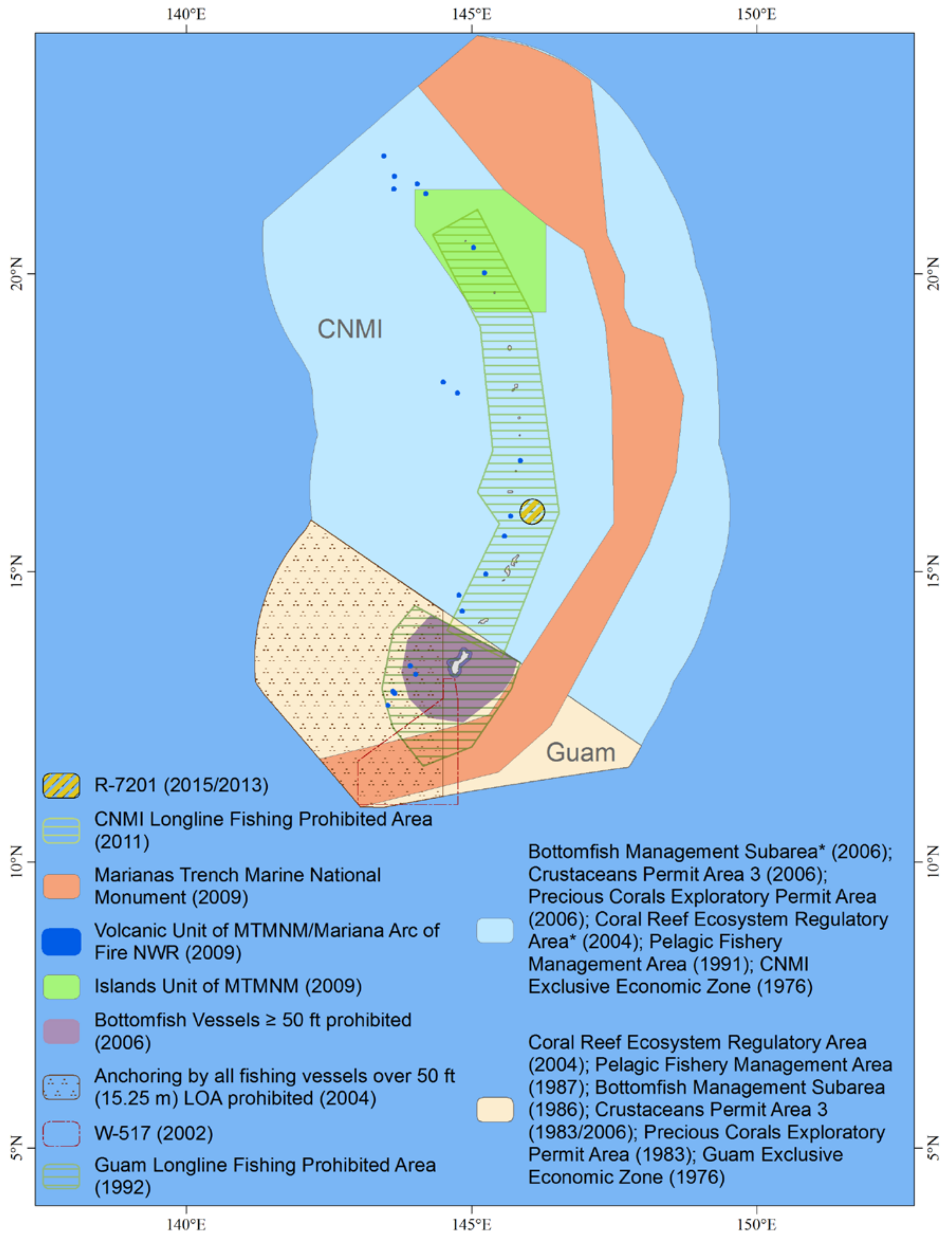
At its 160th meeting, Regarding CNMI Fisheries, the Council:
Directed staff to prepare the final amendment package for transmittal to NMFS with the proposed action being the removal of the 50 nautical mile closure for bottomfish vessels over 40

feet in length around the southern islands of Rota, Tinian, Aguijan and FDM and 10 nm around Alamagan.

NMFS approved Amendment 4 to the Marianas Archipelago FEP and published the final rule, removing the CNMI bottomfish vessel closures, on September 7, 2016.

2.7.3 Marine Managed Areas established under FEPs

Council-established marine managed areas (MMAs) were compiled in Table 69 from 50 CFR § 665, Western Pacific Fisheries, the Federal Register, and Council amendment documents. Geodesic areas were calculated in square kilometers in ArcGIS 10.2. All regulated fishing areas and large scale access restrictions, including the Mariana Trench Marine National Monument, are shown in Figure 37.



* The Coral Reef Ecosystem Regulatory Area excluded the portion of EEZ waters 0-3 miles around the CNMI. The Bottomfish Management Subarea was divided in the CNMI Inshore Area, which was that portion of the EEZ shoreward of 3 nautical miles of the shoreline of CNMI, and the CNMI Offshore Area, which was that portion of the EEZ seaward of 3 nautical miles from the CNMI shoreline.

Figure 37. Regulated fishing areas of the Mariana Archipelago, including large access restrictions.

Table 69. MMAs established under FEPs from 50 CFR § 665.

Name	FEP	Island	50 CFR /FR /Amendment Reference	Marine Area (km²)	Fishing Restriction	Goals	Most Recent Evaluation	Review Deadline
Pelagic Restrictions								
Guam Longline Prohibited Area	Pelagic	Guam	665.806(a)(3) 57 FR 7661 Pelagic FMP Am. 5	50,192.88	Longline fishing prohibited	Prevent gear conflicts between longline vessels and troll/handline vessels	1992	-
CNMI Longline Prohibited Area	Pelagic		665.806(a)(4) 76 FR 37287	88,112.68	Longline fishing prohibited	Reduce potential for nearshore localized fish depletion from longline fishing, and to limit catch competition and gear conflicts between the CNMI-based longline and trolling fleets	2011	-
Bottomfish Restrictions								
Guam Large Vessel Prohibited Area	Mariana Archipelago	Guam	665.403(a) 71 FR 64474 Bottomfish FMP Am. 9	29,384.06	Vessels ≥ 50 feet prohibited	To maintain viable participation and bottomfish catch rates by small vessels in the fishery	2006	-
Other Restrictions								
Guam No Anchor Zone	Mariana Archipelago	Guam	665.399 69 FR 8336 Coral Reef Ecosystem FEP	138,992.51	Anchoring by all fishing vessels ≥ 50 ft prohibited on the offshore southern banks located in the U.S. EEZ off Guam	Minimize adverse human impacts on coral reef resources	2004	-

2.7.4 Fishing Activities and Facilities

The small-boat bottomfish fishery in Guam and the CNMI relies on boat ramp access. Recent activities to support the Guam fishery follow.

On Guam, the makeshift ramp at Ylig Bay was eliminated in 2010. Widening of the main road on the southeast coast of Guam will cause removal of the ramp. In December 2006, a new launch ramp and facility was opened in Acfayan Bay, located in the village on Inarajan on the southeast coast of Guam. Monitoring of this ramp for pelagic fishing activity began at the start of 2007. In early 2007, this facility was damaged by heavy surf and has yet to be repaired. Monitoring of this ramp is currently on hold until the ramp is repaired. The current financial situation in Guam makes it unlikely this ramp will be repaired in the near future. DAWR staff are meeting with land owners and Department of Public Works officials to develop a new boat launching facility in Talofofo Bay on the east side of Guam, and land ownership may determine final placement.

There are no offshore aquaculture projects in Federal waters, proposed or existing, in CNMI or Guam.

2.7.5 Non-Fishing Activities and Facilities

The following section includes activities or facilities associated with known uses and predicted future uses. The Plan Team will add to this section as new facilities are proposed and/or built.

2.7.5.1 Alternative energy facilities

There are no alternative energy facilities in Federal or local waters, proposed or existing, in Guam or CNMI.

2.7.5.2 Military training and testing activities and impacts

The Department of Defense major planning activities in the region are summarized below.

Action	Description	Phase	Impacts
Guam and CNMI Military Relocation SEIS	Relocate Marines to Guam and build a cantonment/family housing unit on Finegayan/AAFB, a live-fire individual training range complex at the Ritidian Unit of the Guam National Wildlife Refuge	ROD published August 29, 2015 Suit filed for segmentation and range of reasonable alternatives under NEPA, requesting that DON vacate the ROD. DOJ asked US District Court for the NMI to dismiss the plaintiff's complaint with prejudice to prevent refiling (http://www.saipantribune.com/index.php/doj-federal-court-lacks-jurisdiction/). Hearing scheduled April 6 (http://www.civilbeat.org/2017/03/the-u-s-military-wont-bomb-pagan-or-tinian-just-yet/?mc_cid=1a464a317d&mc_eid=abaf3b9d93).	Surface danger zone established at Ritidian – access restricted during training. Access will be negotiated between the Navy and USFWS. Northern District Wastewater Treatment Plant is non-compliant with NPDES permit; until plant is upgraded, increased wastewater discharge associated with buildup will significantly impact nearshore water quality. DOD to fund plant upgrades – see Economic Adjustment Committee Implementation Plan.
Mariana Islands Training and Testing	Continue Navy testing and training activities; include use of active sonar and explosives within the Mariana Islands Range Complex; pier-side sonar maintenance and testing in Apra Harbor	ROD Published August 4, 2015	Surface danger zones established – access restricted during training and testing Explosives and anchoring may damage shallow reef systems or hard bottom habitat.
CNMI Joint Military Training	Establish unit and combined level training ranges on Tinian and Pagan	Supplemental Draft EIS expected in late 2018 with ROD in 2020. See Relocation SEIS above. (http://www.civilbeat.org/2017/03/the-u-s-military-wont-bomb-pagan-or-tinian-just-yet/?mc_cid=1a464a317d&mc_eid=abaf3b9d93).	Significant access and habitat impacts.
Divert Activities and Exercises, Air Force, Marianas	Improve airports in CNMI for expanding mission requirements in Western Pacific	ROD published December 8, 2016.	Adverse impacts to EFH minimal; access near Port of Tinian fuel transfer facility affected
Garapan Anchorage *June 2015 CNMI Advisory Panel Meeting Report*	Military Pre-Positioned Ships anchor and transit	Expired Memorandum of Understanding with the CNMI government. After transfer of submerged lands to CNMI, CNMI may be able to charge anchorage fees to the DOD. As of June 2015, MOU had not been signed.	Access, invasive species, unmitigated damage to reefs
Farallon de Medinilla	Restricted airspace covering the island to 12 nmi radius to conduct military training scenarios using air-to-ground ordnance delivery, naval gunfire, lasers and special operations training.	Final rule published March 13, 2017, effective June 22, 2017, designating a new area, R-2701A, that surrounds existing R-2701, encompassing airspace between a 3 nmi radius and 12 nmi radius of FDM (47 FR 13389). Proposed surface danger zone to 12 nmi. Damage to submerged lands and fisheries to be included within consultation establishing continued US interest in the island and compensation to the CNMI (Report to the President on 902 Consultations, 2017)	Access – to fishing grounds and transit to fishing grounds - and damage to submerged lands

2.7.6 Pacific Islands Regional Planning Body Report

The Council is a member of the Pacific Islands RPB and as such, the interests of the Council will be incorporated into the regional CMS plan. It is through the Council member that the Council may submit recommendations to the Pacific Islands RPB.

The Pacific Islands RPB met in Honolulu from February 15-16, 2017. The RPB's American Samoa Ocean Planning Team has developed its goals and objectives on which the RPB provided comments and endorsement. The RPB, by consensus, decided to:

- revise its charter with select Maritime Administration comments, a glossary or terms of reference, and handle standard operating procedure concerns through internal documentation rather than amendments to the Charter;
- kick off a Marianas Ocean Planning Team later in 2017; and
- defer the decision on beginning planning in the PRIA until an update is received on the Pacific Remote Islands Marine National Monument Management Plan at the next RPB teleconference.

The American Samoa Ocean Planning Team will continue its work concurrently with a stakeholder assessment. The Data Team will continue its work per the work plan developed in 2016.

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3 DATA INTEGRATION

At the 2016 joint meeting of the Archipelagic and Pelagic Fishery Ecosystem Plan Team, the teams recommended the Council, in coordination with NMFS, organize a workshop in developing the Data Integration Chapter of the Annual/SAFE Report. The workshop was convened on November 30 and December 1, 2017. The goal of the workshop was to identify policy-relevant fishery ecosystem relationships, as well as analytical procedures that can be utilized to examine those relationships, that could be the bases of the data integration chapter ("Chapter 3") of the western Pacific region's (WPR) five annual Stock Assessment and Fishery Evaluation (SAFE) reports. Such variables include, for example, catch, number of fishing trips, primary productivity, and climate and weather attributes.

The Western Pacific Regional Fishery Management Council (Council) hosted the workshop. Participants included staff from the National Marine Fisheries Service (NMFS) Pacific Islands Fisheries Science Center (PIFSC) and Pacific Islands Regional Office (PIRO), the Council, and Triton Aquatics, a Hawaii-based consulting company.

Name	**Affiliation**	**Name**	**Affiliation**
Keith Bigelow	PIFSC	Kevin Kelley	Consultant/PIRO
Chris Boggs	PIFSC	Eric Kingma	Council
Rusty Brainard	PIFSC	Don Kobayashi	PIFSC
Paul Dalzell	Council	Tom Oliver	PIFSC
Joshua DeMello	Council	Michael Parke	PIFSC
Stefanie Dukes	PIFSC	Frank Parrish	PIFSC
Sarah Ellgen	PIRO	Marlowe Sabater	Council
Jamison Gove	PIFSC	Sylvia Spalding	Council
Justin Hospital	PIFSC	Rebecca Walker	Council
Asuka Ishizaki	Council	Mariska Weijerman	PIFSC
Ariel Jacobs	PIRO	Ivor Williams	PIFSC

Several background presentations were given to contextualize the discussions. The following were the background presentations:

1. EBFM and adaptive management in the SAFE report process
2. Examples of fishery ecosystem integration efforts from other regions
3. FEP Objectives and Management Measures

4. Past attempts at Data Integration: Environmental, Social, and Economic Variables Known to Influence Fisheries

Following these background presentations and discussions, participants were segregated into two smaller working groups to brainstorm island and pelagic fishery and environmental/ecological relationships that may be of use in the context of Chapter 3. These relationships could be bivariate or multivariate. Several guided questions were provided for every combination of variables:

1. What can we reasonably expect to learn from or monitor with the results?
2. How does it inform Council decision-making, consistent with the purposes of the FEP?
3. Is it part of an ongoing research initiative?

The archipelagic fisheries group developed nearly 30 relationships to examine across bottomfish, coral reef, and crustacean fisheries, while the pelagic breakout group developed 11 relationships for pelagic fisheries, including protected species. The prioritized relationships are as follows:

Relationships	**FEP**	**Score**	**Rank**
bottomfish catch/effort/cpue/species composition and benthos/substrate (depth, structure)	All	22	3
bottomfish catch/effort/cpue/species composition and PDO	All	20	3
coral reef fish fishery/biomass and temperature-derived variable	All	20	3
akule/opelu and rainfall (HI and GU)	HI	20	3
bottomfish catchability and wind speed	All	19	3
reef fish catch and biomass and Chl-a (with phase lag)	All	19	3
bottomfish catch and CPUE and moon phase	All	19	3
bottomfish catch/effort/cpue/species composition and sea-level height (eddy feature)	All	18	2
coral reef fish fishery/biomass and PDO	All	18	2
green/red spiny lobster catch/cpue vertical relief	HI	18	2
green/red spiny lobster and PDO	HI	18	2
bottomfish catchability and fishing conditions (surface, subsurface current, speed and direction)	All	17	2
coral reef fish abundance and moon phase	All	17	2
coral reef fish fishery/biomass and El Nino	All	17	2
coral reef fish fishery/biomass and sea-level height	All	17	2
coral reef fish fishery/biomass and pH	All	17	2
bottomfish catch/effort/cpue/species composition and temperature-derived	All	16	2

variable (temp. at depth)			
bottomfish catch/effort/cpue/species composition and Chl-a	All	16	2
bottomfish catch/effort/cpue/species composition and rainfall	All	16	2
coral reef fish catch and biomass (family; trophic guilds) and structural complexity and benthic habitat information	All	16	2
bottomfish catch/effort/cpue/species composition and DO	All	15	2
coral reef fish fishery/biomass and rainfall	All	14	2
bottomfish catch/effort/cpue/species composition and pH	All	13	2
bottomfish CPUE and shark/predator biomass/abundance	All	12	2
coral reef fish fishery/biomass and salinity	All	12	2
coral reef fish fishery/biomass and DO	All	12	2
bottomfish catch/effort/cpue/species composition and salinity	All	10	1

The development of the data integration chapter is work in progress that has a 2-3 year timeline. The workshop produced a long list of fishery and ecosystem variable combinations that comprise a significant workload that the participants could not currently take on. The Council hired a contractor that will conduct the exploratory data analysis on the different variable combinations and determine which relationships are worth using in Chapter 3. The contractor is expected to deliver the results at the end of 2017.

Appendix A: Species lists for the Mariana Archipelago FEP

CNMI

1. Bottomfish Multi-species Stock Complex (FSSI)

DFW Creel Species Code	Species Name	Scientific Name
214	red snapper, silvermouth (lehi)	*Aphareus rutilans*
213	grey snapper, jobfish	*Aprion virescens*
112	giant trevally, jack	*Caranx ignoblis*
111	black trevally, jack	*Caranx lugubris*
231	blacktip grouper	*Epinephelus fasciatus*
241	lunartail grouper (lyretail grouper)	*Variola lauti*
203	red snapper (ehu)	*Etelis carbunculus*
210	red snapper (onaga)	*Etelis coruscans*
NONE	ambon emperor	*Lethrinus amboinenis*
350	redgill emperor	*Lethrinus rubrioperculatus*
253	blueline snapper	*Lutjanus kasmira*
NONE	yellowtail snapper	*Pristipomoides auricilla*
212	pink snapper (paka)	*Pristipomoides filamentosus*
209	yelloweye snapper	*Pristipomoides flavipinnis*
207	pink snapper (kalekale)	*Pristipomoides seiboldi*
204	flower snapper (gindai)	*Pristipomoides zonatus*
220	amberjack	*Seriola dumerili*

2. Crustacean deep-water shrimp complex (non-FSSI)

DFW Creel Species Code	Species Name	Scientific Name
508	deepwater shrimp	*Heterocarpus* spp.

3. Crustacean spiny lobster complex (non-FSSI)

DFW Creel Species Code	Species Name	Scientific Name
504	spiny lobster	*Panulirus marginatus*
504	spiny lobster	*Panulirus penicillatus*

4. Crustacean slipper lobster complex (non-FSSI)

DFW Creel Species Code	Species Name	Scientific Name
505	Slipper lobster	Scyllaridae

5. Crustacean Kona crab complex (non-FSSI)

DFW Creel Species Code	Species Name	Scientific Name
502	Kona crab	*Ranina ranina*

6. Precious coral black coral complex (non-FSSI)

DFW Creel Species Code	**Species Name**	**Scientific Name**
none	Black Coral	*Anitpathes dichotoma*
none	Black Coral	*Antipathes grandis*
none	Black Coral	*Antipathes ulex*

7. Exploratory area precious coral (except black coral) (non-FSSI)

DFW Creel Species Code	**Species Name**	**Scientific Name**
none	Pink coral	*Corallium secundum*
none	Pink coral	*Corallium regale*
none	Pink coral	*Corallium laauense*
none	Bamboo coral	*Lepidisis olapa*
none	Bamboo coral	*Acanella* spp.
none	Gold Coral	*Gerardia* spp.
none	Gold Coral	*Callogorgia gilberti*
none	Gold Coral	*Narella* spp.
none	Gold Coral	*Calyptrophora* spp.

8. Coral reef ecosystem (non-FSSI)

DFW Creel Species Code	Species Name	Scientific Name	Grouping
357	Bigeye Emperor	*Monotaxis grandoculus*	Lethrinidae
353	Blackspot Emperor	*Lethrinus harak*	Lethrinidae
310	Emperor (mafute/misc.)	*Lethrinus sp.*	Lethrinidae
356	Flametail Emperor	*Lethrinus fulvus*	Lethrinidae
351	Longnose Emperor	*Lethrinus olivaceus*	Lethrinidae
352	Orangefin Emperor	*Lethrinus erythracanthus*	Lethrinidae
361	Ornate Emperor	*Lethrinus ornatus*	Lethrinidae
358	Stout Emperor	*Gymnocranius sp.*	Lethrinidae
355	Yellowlips Emperor	*Lethrinus xanthochilis*	Lethrinidae
359	Yellowspot emperor	*Gnathodentex aurolineatus*	Lethrinidae
354	Yellowstripe Emperor	*Lethrinus obsoletus*	Lethrinidae
362	Yellowtail Emperor	*Lethrinus atkinsoni*	Lethrinidae
115	Bigeye Trevally	*Caranx sexfasciatus*	Carangidae
113	Bluefin Trevally	*Caranx melampygus*	Carangidae
114	Brassy Trevally	*Caranx papuesis*	Carangidae
105	EE: Juvenile Jacks	*Canranx sp.*	Carangidae
104	Jacks (misc.)	*Caranx sp.*	Carangidae
101	Leatherback	*Scomberoides lysan*	Carangidae
103	Mackerel Scad	*Decapterus macarellus*	Carangidae
410	Rainbow Runner	*Elagatis bipinnulatus*	Carangidae
117	Small-spotted pompano	*Trachinotus bailloni*	Carangidae
116	Snubnose pompano	*Trachinotus blochii*	Carangidae

110	Yellow Spotted Trevally	*Carangoides orthogrammus*	Carangidae
380	Bluebanded Surgeonfish	*Acanthurus lineatus*	Acanthuridae
383	Bluelined Surgeon	*Acanthurus nigroris*	Acanthuridae
384	Bluespine Unicornfish	*Naso unicornis*	Acanthuridae
381	Convict Tang	*Acanthurus triostegus*	Acanthuridae
319	Orangespine Unicornfish	*Naso lituratus*	Acanthuridae
318	Surgeonfish (misc.)	*Acanthurus sp.*	Acanthuridae
320	Unicornfish (misc.)	*Naso sp.*	Acanthuridae
382	Yellowfin Surgeonfish	*Acanthurus xanthopterus*	Acanthuridae
102	Bigeye Scad	*Selar crumenopthalmus*	Atulai
239	Coral Grouper	*Epinephelus corallicola*	Serranidae
237	Flagtail Grouper	*Cephalopholis urodeta*	Serranidae
206	Grouper (misc.)	*Serannidae*	Serranidae
233	Highfin Grouper	*Epinephelus maculatus*	Serranidae
234	Honeycomb Grouper	*Epinephelus merra*	Serranidae
235	Marbled Grouper	*Epinephelus polyphekadion*	Serranidae
236	Peacock Grouper	*Cephalopholis argus*	Serranidae
244	Pink Grouper	*Saloptia powelli*	Serranidae
238	Saddleback Grouper	*Plectropomus laevis*	Serranidae
242	Tomato Grouper	*Cephanopholis sonnerati*	Serranidae
240	White Lyretail Grouper	*Variola albimarginata*	Serranidae
243	Yellow Banded Grouper	*Cephalopholis igarashiensis*	Serranidae
316	Snapper (misc. shallow)	*Lutjanidae*	Lutjanidae
250	Humpback Snapper	*Lutjanus gibbus*	Lutjanidae

251	Onespot Snapper	*Lutjanus monostigmus*	Lutjanidae
254	Red Snapper	*Lutjanus bohar*	Lutjanidae
208	Smalltooth Jobfish	*Aphareus furca*	Lutjanidae
371	Dash & Dot Goatfish	*Parupeneus barberrinus*	Mullidae
321	Goatfish (juvenile-misc)	*Mullidae*	Mullidae
322	Goatfish (misc.)	*Mullidae*	Mullidae
323	Sidespot Goatfish	*Parupeneus pleurostigma*	Mullidae
372	Two-barred Goatfish	*Parupeneus bifasciatus*	Mullidae
370	Yellowstripe Goatfish	*Mulloidichthys flavolineatus*	Mullidae
314	Parrotfish (misc.)	*Scarus sp.*	Scaridae
315	Seagrass Parrotfish	*Leptoscarus vaigiensis*	Scaridae
506	Octopus	*Octopus sp.*	Mollusk
510	Squid	*Teuthida*	Mollusk
516	Trochus	*Trochus sp.*	Mollusk
522	Clam/bivalve	*Bivalvia*	Mollusk
106	Mullet	*Mugilidae*	Mugilidae
304	Rabbitfish (hitting)	*Siganus sp.*	Siganidae
306	Rabbitfish (h.feda)	*Siganus puntatus*	Siganidae
307	Rabbitfish (menahac)	*Siganus sp.*	Siganidae
308	Rabbitfish (sesjun)	*Siganus spinus*	Siganidae
	Bolbometopon muricatum	*Bumphead parrotfish*	
391	Cheilinus undulatus	*Napoleon wrasse*	
	Reef sharks (misc)	*Carcharhinidae*	Carcharhinidae
	Hammerhead shark	*Sphyrnidae*	Carcharhinidae

338	Angelfish	*Pomacanthidae*	Other CRE-Finfish
338	Butterflyfish	*Chaetodontidae*	Other CRE-Finfish
324	Bigeye/glasseye	*Heteropriacanthus cruentatus*	Other CRE-Finfish
396	Blue Razorfish	*Xyrichtys pavo*	Other CRE-Finfish
397	Bronzespot Razorfish	*Xyrichtys celebicus*	Other CRE-Finfish
260	Cardinal Misc.	*Apogonidae*	Other CRE-Finfish
162	Cornetfish	*Fistularia commersonii*	Other CRE-Finfish
332	Damselfish	*Pomacentridae*	Other CRE-Finfish
341	Filefish (misc)	*Monacanthidae*	Other CRE-Finfish
340	Flounder (misc)	*Bothus sp.*	Other CRE-Finfish
328	Fusilier (misc.)	*Caesionidae*	Other CRE-Finfish
325	Goggle-eye	*Priacanthus hamrur*	Other CRE-Finfish
195	Lizardfish misc.	*Synodontidae*	Other CRE-Finfish
180	Milkfish	*Chanos chanos*	Other CRE-Finfish
329	Mojarra	*Gerres sp.*	Other CRE-Finfish
140	Moray eel	*Muraenidae*	Other CRE-Finfish
170	Needlefish	*Belonidae*	Other CRE-Finfish
343	Picasso Trigger	*Rhinecanthus aculeatus*	Other CRE-Finfish
348	Pufferfish	*Tetraodontidae*	Other CRE-Finfish
395	Razorfish (misc)	*Tribe Novaculini*	Other CRE-Finfish
130	Scorpionfishes	*Scorpaenidae*	Other CRE-Finfish
330	Sweetlips	*Plectorhinchus picus*	Other CRE-Finfish
342	Triggerfish (misc.)	*Balistidae*	Other CRE-Finfish
163	Trumpetfish	*Aulostomus chinensis*	Other CRE-Finfish

344	Wedge Trigger	*Rhinecanthus rectangulus*	Other CRE-Finfish
312	Squirrelfish	*Holocentridae*	Squirrelfish
313	Soldierfish (misc.)	*Holocentridae*	Squirrelfish
302	Wrasse	*Labridae*	Wrasse
390	Tripletail Wrasse	*Cheilinus trilobatus*	Wrasse
309	Rudderfish (guilli)	*Kyphosus sp.*	Rudderfish
373	Highfin Rudderfish Silver	*Kyphosus cinerascens*	Rudderfish
374	Highfin Rudderfish Brown	*Kyphosus sp.*	Rudderfish
200	Bottomfish (misc)	*n/a*	Misc. Bottomfish
300	Reef fish (misc)	*n/a*	Misc. Reef Fish
	Shallow bottom	*n/a*	Misc. Shallow bottomfish
501	Crabs (misc)	*n/a*	Crustaceans
503	Coconut Crab	*Birgus latro*	Crustaceans
500	Invertebrates	*n/a*	Other Invertebrates
514	Sea Cucumber	*Cucumariidae*	Other Invertebrates
600	Seaweeds	*n/a*	Algae
602	Lemu	*n/a*	Algae

GUAM

1. Bottomfish Multi-species Stock Complex (FSSI)

DAWR Creel Species Code	**Species Name**	**Scientific Name**
32302	red snapper, silvermouth (lehi)	Aphareus rutilans
32303	grey snapper, jobfish	Aprion virescens
31404	giant trevally, jack	Caranx ignoblis
31405	black trevally, jack	Caranx lugubris
28919	blacktip grouper	Epinephelus fasciatus
28941	lunartail (lyretail) grouper	Variola lauti
32304	red snapper (ehu)	Etelis carbunculus
32305	red snapper (onaga)	Etelis coruscans
32818	ambon emperor	Lethrinus amboinenis
32809	redgill emperor	Lethrinus rubrioperculatus
32310	blueline snapper	Lutjanus kasmira
32317	yellowtail snapper	Pristipomoides auricilla
32318	pink snapper (paka)	Pristipomoides filamentosus
32319	yelloweye snapper	Pristipomoides flavipinnis
32320	pink snapper (kalekale)	Pristipomoides seiboldi
32321	snapper (gindai)	Pristipomoides zonatus
31414	amberjack	Seriola dumerili

2. Crustacean deep-water shrimp complex (non-FSSI)

DAWR Creel Species Code	Species Name	Scientific Name
67600	deepwater shrimp	Heterocarpus spp.
67601	deepwater shrimp	Pandalus Unid sp 1
67602	deepwater shrimp	Pandalidae
67603	deepwater shrimp	Pandalidae

3. Crustacean spiny lobster complex (non-FSSI)

DAWR Creel Species Code	Species Name	Scientific Name
67913	spiny lobster	Panulirus marginatus
67915	spiny lobster	Panulirus penicillatus

4. Crustacean slipper lobster complex (non-FSSI)

DAWR Creel Species Code	Species Name	Scientific Name
67954	slipper lobster	Scyllaridae
67955	slipper lobster	Scyllaridae

5. Crustacean Kona crab complex (non-FSSI)

DAWR Creel Species Code	Species Name	Scientific Name
69150	Kona crab	Ranina ranina

6. Precious coral black coral complex (non-FSSI)

DAWR Creel Species Code	Species Name	Scientific Name
none	Black Coral	Anitpathes dichotoma
none	Black Coral	Antipathes grandis
none	Black Coral	Antipathes ulex

7. Exploratory area precious coral (except black coral) (non-FSSI)

DAWR Creel Species Code	Species Name	Scientific Name
none	Pink coral	Corallium secundum
none	Pink coral	Corallium regale
none	Pink coral	Corallium laauense
none	Bamboo coral	Lepidisis olapa
none	Bamboo coral	Acanella spp.
none	Gold Coral	Gerardia spp.
none	Gold Coral	Callogorgia gilberti
none	Gold Coral	Narella spp.

none	Gold Coral	Calyptrophora spp.

8. Coral reef ecosystem (non-FSSI)

DAWR Creel Species Code	Species Name	Scientific Name	Species grouping
41201	Achilles tang	Acanthurus achilles	Acanthuridae
41232	Bariene's surgeonfish	Acanthurus bariene	Acanthuridae
41207	Ringtail surgeonfish	Acanthurus blochii	Acanthuridae
41234	Chronixis surgeonfish	Acanthurus chronixis	Acanthuridae
41202	Eye-striped surgeonfish	Acanthurus dussumieri	Acanthuridae
41204	Whitespotted surgeonfish	Acanthurus guttatus	Acanthuridae
41239	Whitebar surgeonfish	Acanthurus leucocheilus	Acanthuridae
41205	Palelipped surgeonfish	Acanthurus leucopareius	Acanthuridae
41206	Blue-banded surgeonfish	Acanthurus lineatus	Acanthuridae
41235	White-Freckled surgeonfish	Acanthurus maculiceps	Acanthuridae
41233	Elongate surgeonfish	Acanthurus mata	Acanthuridae
41203	Whitecheek surgeonfish	Acanthurus nigricans	Acanthuridae
41208	Blackstreak surgeonfish	Acanthurus nigricauda	Acanthuridae
41209	Brown surgeonfish	Acanthurus nigrofuscus	Acanthuridae
41210	Bluelined surgeonfish	Acanthurus nigroris	Acanthuridae
41240	Surgeonfish	Acanthurus nubilus	Acanthuridae
41211	Orangeband surgeonfish	Acanthurus olivaceus	Acanthuridae
41212	Mimic surgeonfish	Acanthurus pyroferus	Acanthuridae

41243	Surgeonfishes/tangs	Acanthuridae	Acanthuridae
41200	Surgeonfishes/tangs	Acanthuridae	Acanthuridae
41213	Thomson's surgeonfish	Acanthurus thompsoni	Acanthuridae
41214	Convict tang	Acanthurus triostegus	Acanthuridae
41215	Yellowfin surgeonfish	Acanthurus xanthopterus	Acanthuridae
41216	Twospot bristletooth	Ctenochaetus binotatus	Acanthuridae
41217	Black surgeonfish	Ctenochaetus hawaiiensis	Acanthuridae
41236	Blue-spotted Bristletooth	Ctenochaetus marginatus	Acanthuridae
41218	Striped bristletooth	Ctenochaetus striatus	Acanthuridae
41231	Yellow-eyed bristletooth	Ctenochaetus strigosus	Acanthuridae
41237	Tomini's surgeonfish	Ctenochaetus tominiensis	Acanthuridae
41219	Whitemargin unicornfish	Naso annulatus	Acanthuridae
41220	Humpback unicornfish	Naso brachycentron	Acanthuridae
41221	Spotted unicornfish	Naso brevirostris	Acanthuridae
41241	Gray unicornfish	Naso caesius	Acanthuridae
41222	Black tongue unicornfish	Naso hexacanthus	Acanthuridae
41223	Orangespine unicornfish	Naso lituratus	Acanthuridae
41238	Naso tang	Naso lopezi	Acanthuridae
41242	Barred unicornfish	Naso thynnoides	Acanthuridae
41224	Humpnose unicornish	Naso tuberosus	Acanthuridae
41225	Bluespine unicornfish	Naso unicornis	Acanthuridae
41226	Bignose unicornfish	Naso vlamingii	Acanthuridae
41227	Hepatus tang	Paracanthurus hepatus	Acanthuridae

41228	Yellow tang	Zebrasoma flavescens	Acanthuridae
41229	Brown tang	Zebrasoma scopas	Acanthuridae
41230	Pacific sailfin tang	Zebrasoma veliferum	Acanthuridae
31401	Pennantfish/threadfin	Alectis ciliaris	Carangidae
31402	Malabar Trevally	Alectis indicus	Carangidae
31400	Jack (misc)	Carangidae	Carangidae
31420		Carangini	Carangidae
31419	Blue kingfish trevally	Carangoides caeruleopinnatus	Carangidae
31431	Shadow kingfish	Carangoides dinema	Carangidae
31422	Bar jack	Carangoides ferdau	Carangidae
31433	Yellow dotted trevally	Carangoides fulvoguttatus	Carangidae
31438	Headnotch trevally	Carangoides hedlandensis	Carangidae
31403	Goldspot trevally	Carangoides orthogrammus	Carangidae
31424	Barcheek trevally	Carangoides plagiotaenia	Carangidae
31425	Jacks (misc)	Carangoides talamparoides	Carangidae
31437	Trevally	Carangoides uii	Carangidae
31429	Trevally	Caranx i'e'	Carangidae
31406	Bluefin trevally	Caranx melampygus	Carangidae
31428	Brassy trevally	Caranx papuensis	Carangidae
31407	Bigeye trevally	Caranx sexfasciatus	Carangidae
31408	Mackerel scad	Decapterus macarellus	Carangidae

31423	Mackerel scad	Decapterus macrosoma	Carangidae
31421	Round scad	Decapterus maruadsi	Carangidae
31430	Round scad	Decapterus russelli	Carangidae
31409	Rainbow runner	Elagatis bipinnulatus	Carangidae
31410	Golden trevally	Gnathanodon speciosus	Carangidae
31439		Megalaspis cordyla	Carangidae
31435	Pilotfish	Naucrates ductor	Carangidae
31440	Elagatis, Scomberoides	Naucratini	Carangidae
31412	Leatherback	Scomberoides lysan	Carangidae
31415	Almaco jack	Seriola rivoliana	Carangidae
31416	Small spotted pompano	Trachinotus bailloni	Carangidae
31417	Silver or Snubnose pompano	Trachinotus blochii	Carangidae
31432	Mandibular kingfish	Ulua mandibularis	Carangidae
31418	Kingfish	Uraspis helvola	Carangidae
31436	Deep trevally	Uraspis secunda	Carangidae
31434	Whitemouth trevally	Uraspis uraspis	Carangidae
31413	Atulai	Selar crumenophthalmus	Atulai
31426	Atulai	Atule mate	Atulai
31427	Atulai	Selar boops	Atulai
32800	Emperors	Lethrinidae	Lethrinidae
32801	Yellow-Spot Emperor	Gnathodentex aurolineatus	Lethrinidae
32802	Grey Bream	Gymnocranius griseus	Lethrinidae
32804	Thumbprint Emperor	Lethrinus harak	Lethrinidae
32805	Yellowtail Emperor	Lethrinus atkinsoni	Lethrinidae

32806	Longface Emperor	Lethrinus olivaceus	Lethrinidae
32807	Ornate Emperor	Lethrinus ornatus	Lethrinidae
32808	Orange-Striped Emperor	Lethrinus obsoletus	Lethrinidae
32810	Black-Blotch Emperor	Lethrinus semicinctus	Lethrinidae
32811	Yellowlip Emperor	Lethrinus xanthochilus	Lethrinidae
32812	Bigeye Emperor	Monotaxis grandoculus	Lethrinidae
32813	Japanese Bream	Gymnocranius euanus	Lethrinidae
32814	Orange-Spotted Emperor	Lethrinus erythracanthus	Lethrinidae
32815	Large-Eye Bream	Wattsia mossambica	Lethrinidae
32816	Stout Emperor	Gymnocranius sp	Lethrinidae
32817	Smtoothed Emperor	Lethrinus microdon	Lethrinidae
32819	Longspine Emperor	Lethrinus genivittatus	Lethrinidae
32820	Pinkear Emperor	Lethrinus lentjan	Lethrinidae
32821	Blue-Spotted Bream	Gymnocranius microdon	Lethrinidae
32822	Longfin Emperor	Lethrinus erythropterus	Lethrinidae
32823	Blue-Lined Bream	Gymnocranius grandoculus	Lethrinidae
32824	Slender Emperor	Lethrinus variegatus	Lethrinidae
36402	Bucktooth Parrotfish	Calotomus carolinus	Scaridae
36420	Spineytooth Parrotfish	Calotomus spinidens	Scaridae
36403	Bicolor Parrotfish	Cetoscarus bicolor	Scaridae
36422	Parrotfish	Chlorurus bleekeri	Scaridae
36431	Parrotfish	Chlorurus bowersi	Scaridae
36408	Tan-Faced Parrotfish	Chlorurus frontalis	Scaridae
36410	Steephead Parrotfish	Chlorurus microrhinos	Scaridae

36433	Parrotfish	Chlorurus pyrrhurus	Scaridae
36416	Bullethead Parrotfish	Chlorurus sordidus	Scaridae
36404	Parrotfish	Hipposcarus longiceps	Scaridae
36405	Seagrass Parrotfish	Leptoscarus vaigiensis	Scaridae
36400	Parrotfishes	Scaridae	Scaridae
36406	Fil-Finned Parrotfish	Scarus altipinnis	Scaridae
36429	Parrotfish	Scarus chameleon	Scaridae
36423	Parrotfish	Scarus dimidiatus	Scaridae
36419	Parrotfish	Scarus festivus	Scaridae
36434	Yellowfin Parrotfish	Scarus flavipectoralis	Scaridae
36417	Tricolor Parrotfish	Scarus forsteni	Scaridae
36407	Vermiculate Parrotfish	Scarus frenatus	Scaridae
36409	Blue-Barred Parrotfish	Scarus ghobban	Scaridae
36411	Parrotfish	Scarus globiceps	Scaridae
36424	Java Parrotfish	Scarus hypselosoma	Scaridae
36418	Parrotfish	Scarus sp.	Scaridae
36432	Black Parrotfish	Scarus niger	Scaridae
36412	Parrotfish	Scarus oviceps	Scaridae
36425	Greenthroat Parrotfish	Scarus prasiognathos	Scaridae
36413	Pale Nose Parrotfish	Scarus psittacus	Scaridae
36426	Parrotfish	Scarus quoyi	Scaridae
36427	Parrotfish	Scarus rivulatus	Scaridae
36414	Parrotfish	Scarus rubroviolaceus	Scaridae
36415	Chevron Parrotfish	Scarus schlegeli	Scaridae

36428	Parrotfish	Scarus spinus	Scaridae
36435	Tricolor Parrotfish	Scarus tricolor	Scaridae
36421	Parrotfish	Scarus xanthopleura	Scaridae
33200	Goatfishes	Mullidae	Mullidae
33201	Yellowstriped Goatfish	Mulloidichthys flavolineatus	Mullidae
33202	Orange Goatfish	Mulloidichthys pflugeri	Mullidae
33219	Juvenile Goatfish	Mulloidichthys ti'ao	Mullidae
33203	Yellowfin Goatfish	Mulloidichthys vanicolensis	Mullidae
33216		Parupeneus barberinoides	Mullidae
33204	Dash And Dot Goatfish	Parupeneus barberinus	Mullidae
33205		Parupeneus bifasciatus	Mullidae
33210	White-Lined Goatfish	Parupeneus ciliatus	Mullidae
33206	Yellow Goatfish	Parupeneus cyclostomus	Mullidae
33208	Redspot Goatfish	Parupeneus heptacanthus	Mullidae
33214	Indian Goatfish	Parupeneus indicus	Mullidae
33211	Multibarred Goatfish	Parupeneus multifasciatus	Mullidae
33209	Sidespot Goatfish	Parupeneus pleurostigma	Mullidae
33217	Goatfish	Parupeneus sp	Mullidae
33218	Goatfish	Upeneus arge	Mullidae
33212	Band-Tailed Goatfish	Upeneus taeniopterus	Mullidae
33215	Blackstriped Goatfish	Upeneus tragula	Mullidae
33213	Yellowbanded Goatfish	Upeneus vittatus	Mullidae

54501	Spiney Chiton	Acanthopleura spinosa	Mollusks
54410	Bubble Shells,Sea Hares	Acteonidae	Mollusks
54603	Antique Ark	Anadara antiquata	Mollusks
54602	Indo-Pacific Ark	Arca navicularis	Mollusks
54601	Ventricose Ark	Arca ventricosa	Mollusks
54600	Ark Shells	Arcidae	Mollusks
57742	Common Paper Nautilus	Argonauta argo	Mollusks
57745	Gruner'S Paper Nautilus	Argonauta gruneri	Mollusks
57741	Brown Paper Nautilus	Argonauta hians	Mollusks
57743	Nodose Paper Nautilus	Argonauta nodosa	Mollusks
57744	Noury'S Paper Nautilus	Argonauta nouri	Mollusks
57740	Paper Nautiluses	Argonautidae	Mollusks
56896	Pacific Sand Clam	Asaphis violescens	Mollusks
56891	Gaudy Sand Clam	Aspaphis deflorata	Mollusks
51751	Peron'S Sea Butterfly	Atlanta peroni	Mollusks
51750		Atlantidae	Mollusks
54424	Wh Pacific Atys	Atys naucum	Mollusks
54604	Almond Ark	Babatia amygdalumtostum	Mollusks
50840	Goblets,Dwarf Tritons	Buccinidae	Mollusks
54421	Ampule Bubble	Bulla ampulla	Mollusks
54420	Bubble Shells	Bullidae	Mollusks
54422	Lined Bubble	Bullina lineata	Mollusks
50796	Giant Frog Shell	Bursa bubo	Mollusks
50791	Warty Frog Shell	Bursa bufonia	Mollusks

50792	Blood-Stain Frog Shell	Bursa cruentata	Mollusks
50793	Granulate Frog Shell	Bursa granularis	Mollusks
50799	Lamarck'S Frog Shell	Bursa lamarcki	Mollusks
50798	Red-Mth Frog Shell	Bursa lissostoma	Mollusks
50794	Udder Frog Shell	Bursa mammata	Mollusks
50797	Ruddy Frog Shell	Bursa rebeta	Mollusks
50795	Wine-Mth Frog Shell	Bursa rhodostoma	Mollusks
50790	Frog Shells	Bursidae	Mollusks
50751	Umbilicate Ovula	Calpurnus verrucosus	Mollusks
50878	File Miter	Cancilla filaris	Mollusks
50842	Smoky Goblet	Cantharus fumosus	Mollusks
50841	Waved Goblet	Cantharus undosus	Mollusks
56721	Varitated Cardita	Cardita variegata	Mollusks
56720	Carditid Clams	Carditidae	Mollusks
50767	Vibex Bonnet	Casmaria erinaceus	Mollusks
50768	Heavy Bonnet	Casmaria ponderosa	Mollusks
50765	Helmet Shells	Cassidae	Mollusks
50766	Horned Helmet	Cassius cornuta	Mollusks
55022	3-Toothed Cavoline	Cavolina tridentata	Mollusks
55023	Unicate Cavoline	Cavolina uncinata	Mollusks
55021	Sea Butterfly	Cavolinia cf globulosa	Mollusks
55020	Sea Butterflies	Cavolinidae	Mollusks
50650	Turret,Worm-Shells	Cerithiidae	Mollusks
50654	Column Certh	Cerithium columna	Mollusks

50651	Giant Knobbed Certh	Cerithium nodulosum	Mollusks
56711	Lazarus Jewel Box	Chama lazarus	Mollusks
56710	Jewel Boxes	Chamidae	Mollusks
50781	Triton Trumpet	Charonia tritonis	Mollusks
50812	Ramose Murex	Chicoreus ramosus	Mollusks
54500	Chitons	Chitonidae	Mollusks
56623	Cook'S Scallop	Chlamys cooki	Mollusks
56621	Squamose Scallop	Chlamys squamosa	Mollusks
56500	Bivalves	Class Bivalvia	Mollusks
55027	Pyramid Clio	Clio cuspidata	Mollusks
55026	Irregular Urchins	Clio pyramidata	Mollusks
50652	Morus Certh	Clypeomorus concisus	Mollusks
56706	Punctate Lucina	Codakia punctata	Mollusks
50847	Maculated Dwarf Triton	Columbraria muricata	Mollusks
50845	Shiny Dwarf Triton	Columbraria nitidula	Mollusks
50846	Twisted Dwarf Triton	Columbraria tortuosa	Mollusks
50920	Cone Shells	Conidae	Mollusks
50952	Sand-Dusted Cone	Conus arenatus	Mollusks
50963	Princely Cone	Conus aulicus	Mollusks
50968	Aureus Cone	Conus aureus	Mollusks
50969	Gold-Leaf Cone	Conus auricomus	Mollusks
50947	Banded Marble-Cone	Conus bandanus	Mollusks
50971	Bubble Cone	Conus bullatus	Mollusks
50942	Captain Cone	Conus capitaneus	Mollusks

50932	Cat Cone	Conus catus	Mollusks
50924	Chaldean Cone	Conus chaldeus	Mollusks
50972	Comma Cone	Conus connectens	Mollusks
50922	Crowned Cone	Conus coronatus	Mollusks
50970	Cylindrical Cone	Conus cylandraceus	Mollusks
50926	Distantly-Lined Cone	Conus distans	Mollusks
50923	Hebrew Cone	Conus ebraeus	Mollusks
50936	Ivory Cone	Conus eburneus	Mollusks
50965	Episcopus Cone	Conus episcopus	Mollusks
50927	Pacific Yellow Cone	Conus flavidus	Mollusks
50928	Frigid Cone	Conus frigidus	Mollusks
50945	General Cone	Conus generalis	Mollusks
50961	Geography Cone	Conus geographus	Mollusks
50955	Acorn Cone	Conus glans	Mollusks
50946	Imperial Cone	Conus imperialis	Mollusks
50964	Ambassador Cone	Conus legatus	Mollusks
50938	Leopard Cone	Conus leopardus	Mollusks
50951	Lithography Cone	Conus lithoglyphus	Mollusks
50937	Lettered Cone	Conus litteratus	Mollusks
50929	Livid Cone	Conus lividus	Mollusks
50958	Luteus Cone	Conus luteus	Mollusks
50966	Dignified Cone	Conus magnificus	Mollusks
50930	Soldier Cone	Conus miles	Mollusks
50939	1000-Spot Cone	Conus miliaris	Mollusks

50935	Morelet'S Cone	Conus moreleti	Mollusks
50934	Muricate Cone	Conus muriculatus	Mollusks
50940	Music Cone	Conus musicus	Mollusks
50943	Weasel Cone	Conus mustelinus	Mollusks
50954	Obscure Cone	Conus obscurus	Mollusks
50959	Pertusus Cone	Conus pertusus	Mollusks
50921	Flea-Bite Cone	Conus pulicarius	Mollusks
50931	Rat Cone	Conus rattus	Mollusks
50967	Netted Cone	Conus retifer	Mollusks
50933	Blood-Stained Cone	Conus sanguinolentus	Mollusks
50957	Leaden Cone	Conus scabriusculus	Mollusks
50925	Marriage Cone	Conus sponsalis	Mollusks
50950	Striatellus Cone	Conus striatellus	Mollusks
50948	Striated Cone	Conus striatus	Mollusks
50956	Terebra Cone	Conus terebra	Mollusks
50944	Checkered Cone	Conus tesselatus	Mollusks
50953	Textile Cone	Conus textile	Mollusks
50962	Tulip Cone	Conus tulipa	Mollusks
50960	Varius Cone	Conus varius	Mollusks
50941	Flag Cone	Conus vexillum	Mollusks
50949	Calf Cone	Conus vitulinus	Mollusks
50832	Eroded Coral Shell	Coralliophila erosa	Mollusks
50831	Violet Coral Shell	Coralliophila neritodidea	Mollusks
50830	Coral Shells	Coralliophilidae	Mollusks

56662	Giant Oyster	Crassostrea gigas	Mollusks
56661	Mangrove Oyster	Crassostrea mordax	Mollusks
50813	Bionic Rock Shell	Cronia biconica	Mollusks
56624	Speciosus Scallop	Cryptopecten speciosum	Mollusks
55025	Cigar Pteropod	Cuvierina columnella	Mollusks
50770	Tritons	Cymatiidae	Mollusks
50784	Clandestine Triton	Cymatium clandestinium	Mollusks
50773	Jeweled Triton	Cymatium gemmatum	Mollusks
50776	Liver Triton	Cymatium hepaticum	Mollusks
50786	Wide-Lipped Triton	Cymatium labiosum	Mollusks
50782	Black-Spotted Triton	Cymatium lotorium	Mollusks
50774	Short-Neck Triton	Cymatium muricinum	Mollusks
50772	Nicobar Hairy Triton	Cymatium nicobaricum	Mollusks
50779	Common Hairy Triton	Cymatium pileare	Mollusks
50771	Aquatile Hairy Triton	Cymatium pilere aquatile	Mollusks
50783	Pear Triton	Cymatium pyrum	Mollusks
50775	Red Triton	Cymatium rubeculum	Mollusks
50785	Dwarf Hairy Triton	Cymatium vespaceum	Mollusks
50703	Gold-Ringer Cowry	Cypraea annulus	Mollusks
50726	Arabian Cowry	Cypraea arabica	Mollusks
50734	Eyed Cowry	Cypraea argus	Mollusks
50739	Golden Cowry	Cypraea aurantium	Mollusks
50738	Beck'S Cowry	Cypraea beckii	Mollusks
50733	Bistro Cowry	Cypraea bistronatata	Mollusks

50702	Snake'S Head Cowry	Cypraea caputserpentis	Mollusks
50710	Carnelian Cowry	Cypraea carneola	Mollusks
50740	Chinese Cowry	Cypraea chinensis	Mollusks
50732	Chick-Pea Cowry	Cypraea cicercula	Mollusks
50721	Clandestine Cowry	Cypraea clandestina	Mollusks
50715	Sieve Cowry	Cypraea cribaria	Mollusks
50713	Sowerby'S Cowry	Cypraea cylindrica	Mollusks
50717	Depressed Cowry	Cypraea depressa	Mollusks
50743	Dillwyn'S Cowry	Cypraea dillywini	Mollusks
50706	Eglantine Cowry	Cypraea eglantina	Mollusks
50708	Eroded Cowry	Cypraea erosa	Mollusks
50736	Globular Cowry	Cypraea globulus	Mollusks
50711	Honey Cowry	Cypraea helvola	Mollusks
50730	Swallow Cowry	Cypraea hirundo	Mollusks
50742	Humphrey'S Cowry	Cypraea humphreysi	Mollusks
50707	Isabelle Cowry	Cypraea isabella	Mollusks
50731	Lined-Lip Cowry	Cypraea labrolineata	Mollusks
50741	Limacina Cowry	Cypraea limicina	Mollusks
50704	Lynx Cowry	Cypraea lynx	Mollusks
50716	Reticulated Cowry	Cypraea maculifera	Mollusks
50705	Map Cowry	Cypraea mappa	Mollusks
50737	Marie'S Cowry	Cypraea mariae	Mollusks
50725	Humpback Cowry	Cypraea mauritiana	Mollusks
50723	Microdon Cowry	Cypraea microdon	Mollusks

50701	Money Cowry	Cypraea moneta	Mollusks
50722	Nuclear Cowry	Cypraea nucleus	Mollusks
50709	Porus Cowry	Cypraea poraria	Mollusks
50714	Punctata Cowry	Cypraea punctata	Mollusks
50729	Jester Cowry	Cypraea scurra	Mollusks
50712	Grape Cowry	Cypraea staphlea	Mollusks
50724	Stolid Cowry	Cypraea stolida	Mollusks
50720	Mole Cowry	Cypraea talpa	Mollusks
50728	Teres Cowry	Cypraea teres	Mollusks
50718	Tiger Cowry	Cypraea tigris	Mollusks
50727	Ventral Cowry	Cypraea ventriculus	Mollusks
50719	Pacific Deer Cowry	Cypraea vitellus	Mollusks
50735	Undulating Cowry	Cypraea ziczac	Mollusks
50700	Cowrys	Cypraeidae	Mollusks
55024	3-Spined Cavoline	Diacria trispinosa	Mollusks
50778	Anal Triton	Distorso anus	Mollusks
55100	Dorid Nudibranchs	Doridae	Mollusks
50823	Clatherate Drupe	Drupa clathrata	Mollusks
50821	Elegant Pacific Drupe	Drupa elegans	Mollusks
50820	Digitate Pacific Drupe	Drupa grossularia	Mollusks
50819	Purple Pacific Drupe	Drupa morum	Mollusks
50818	Prickley Pacific Drupe	Drupa ricinus	Mollusks
50822	Strawberry Drupe	Drupa rubusidacaeus	Mollusks
56622	Spectacular Scallop	Excellichlamys spectiablis	Mollusks

50850	Spindles	Fasciolariidae	Mollusks
56722	Pac Strawberry Cockle	Fragum fragum	Mollusks
56908	Tumid Venus	Gafrarium tumidum	Mollusks
50777	Rosy Gyre Triton	Gyrineum roseum	Mollusks
50780	Purple Gyre Triton	Gyrinium pusillum	Mollusks
50911	Little Love Harp	Harpa amouretta	Mollusks
50913	True Harp	Harpa harpa	Mollusks
50912	Major Harp	Harpa major	Mollusks
50910	Harp Shells	Harpidae	Mollusks
50989	Lance Auger	Hastula lanceata	Mollusks
50988	Pencil Auger	Hastula penicillata	Mollusks
55101	Spanish Dancer	Hexabranchus sanguineus	Mollusks
56881	Giant Clam	Hippopus hippopus	Mollusks
50806	Anatomical Murex	Homalocanthia anatomica	Mollusks
54423	Gr-Lined Paber Bubble	Hydratina physis	Mollusks
50875	Cone-Like Miter	Imbricaria conularis	Mollusks
50873	Olive-Shaped Miter	Imbricaria olivaeformis	Mollusks
50874	Bonelike Miter	Imbricaria punctata	Mollusks
56611	Saddle Tree Oyster	Isognomon ephippium	Mollusks
56610	Tree Oysters	Isognomonidae	Mollusks
54351	Janthina Snail	Janthina janthina	Mollusks
54350	Pelagic Snails	Janthinidae	Mollusks
50682	Chiragra Spider Conch	Lambis chiragra	Mollusks

50685	Ormouth Spider Conch	Lambis crocota	Mollusks
50681	Common Spider Conch	Lambis lambis	Mollusks
50684	Scorpio Conch	Lambis scorpius scorpius	Mollusks
50680	Spider Conch	Lambis sp.	Mollusks
50683	Giant Spider Conch	Lambis truncata	Mollusks
50851	Nobby Spindle	Latirus nodatus	Mollusks
50852	Spindle	Latirus rudis	Mollusks
56681	Fragile Lima	Lima fragilis	Mollusks
56682	Indo-Pac Spiny Lima	Lima vulgaris	Mollusks
56680	Limas	Limidae	Mollusks
56904	Camp Pitar Venus	Lioconcha castrensis	Mollusks
56906	Hieroglyphic Venus	Lioconcha hieroglyphica	Mollusks
56905	Ornate Pitar Venus	Lioconcha ornata	Mollusks
50642	Scabra Periwinkle	Littorina scabra	Mollusks
50641	Undulate Periwinkle	Littorina undulata	Mollusks
50640	Periwinkles	Littorinidae	Mollusks
56705	Lucinas	Lucinidae	Mollusks
50762	Apple Tun	Malea pomum	Mollusks
50811	Pinnacle Murex	Marchia bipinnatus	Mollusks
50809	Fenestrate Murex	Marchia martinetana	Mollusks
54430	Melampus Shells	Melampidae	Mollusks
54431	Yellow Melampus	Melampus luteus	Mollusks
57401	Flamboyant Cuttlefish	Metasepia pfefferi	Mollusks
54425	Mini Lined-Bubble	Micromelo undatus	Mollusks

54411	Ventricose Milda	Milda ventricosa	Mollusks
56626	Miraculous Scallop	Mirapecten mirificus	Mollusks
50897	Imperial Miter	Miter imperalis	Mollusks
50899	Acuminate Miter	Mitra acuminata	Mollusks
50890	Cardinal Miter	Mitra cardinalis	Mollusks
50893	Chrysalis Miter	Mitra chrysalis	Mollusks
50895	Gold-Mth Miter	Mitra chrysostoma	Mollusks
50889	Coffee Miter	Mitra coffea	Mollusks
50898	Contracted Miter	Mitra contracta	Mollusks
50892	Kettle Miter	Mitra cucumaria	Mollusks
50876	Rusty Miter	Mitra ferruginea	Mollusks
50891	Strawberry Miter	Mitra fraga	Mollusks
50888	Tesselate Miter	Mitra incompta	Mollusks
50872	Episcopal Miter	Mitra mitra	Mollusks
50883	Papal Miter	Mitra papalis	Mollusks
50894	Red-Painted Miter	Mitra rubitincta	Mollusks
50871	Pontifical Miter	Mitra stictica	Mollusks
50870	Miter Shells	Mitridae	Mollusks
50000	Mollusca	MOLLUSCA	Mollusks
50801	Burnt Murex	Murex burneus	Mollusks
50800	Murex Shells	Muricidae	Mollusks
56505	Mussels	Mytilidae	Mollusks
50804	Tragonula Murex	Naquetia trigonulus	Mollusks
50803	Triquetra Murex	Naquetia triquetra	Mollusks

50817	Francolina Jopas	Nassa francolina	Mollusks
50855	Nassa Mud Snails	Nassariidae	Mollusks
50858	Granulated Nassa	Nassarius graniferus	Mollusks
50857	Margarite Nassa	Nassarius margaritiferus	Mollusks
50856	Pimpled Basket	Nassarius papillosus	Mollusks
50755	Moon Shells	Naticidae	Mollusks
57300	Nautilus	Nautilidae	Mollusks
57301	Chambered Nautilus	Nautilus ponpilius	Mollusks
50884	Clathrus Miter	Neocancilla clathrus	Mollusks
50896	Flecked Miter	Neocancilla granitina	Mollusks
50901	Butterfly Miter	Neocancilla papilio	Mollusks
50633	Ox-Palate Nerite	Nerita albicilla	Mollusks
50631	Plicate Nerite	Nerita plicata	Mollusks
50632	Polished Nerite	Nerita polita	Mollusks
50634	Reticulate Nerite	Nerita signata	Mollusks
50630	Nerites	Neritidae	Mollusks
50600	Diotocardia	O Archaeogastropoda	Mollusks
57700	Octopus	Octopodidae	Mollusks
57735	Common Octopus	Octopus cyanea	Mollusks
57734	Red Octopus	Octopus luteus	Mollusks
57736	Ornate Octopus	Octopus ornatus	Mollusks
57730	Octopus	Octopus sp	Mollusks
57732	Pelagic Octopus	Octopus sp 1	Mollusks
57733	Long-Armed Octopus	Octopus sp 2	Mollusks

57731	Elongate Octopus	Octopus teuthoides	Mollusks
50861	Amethyst Olive	Oliva annulata	Mollusks
50863	Carnelian Olive	Oliva carneola	Mollusks
50862	Red-Mth Olive	Oliva miniacea	Mollusks
50864	Peg Olive	Oliva paxillus	Mollusks
50860	Olive Shells	Olividae	Mollusks
57500	Squids	Order Teuthoidea	Mollusks
56660	True Oysters	Ostreidae	Mollusks
54412	Cat'S Ear Otopleura	Otopleura auriscati	Mollusks
50753	Common Egg Cowry	Ovula ovum	Mollusks
50750	Egg Shells	Ovulidae	Mollusks
56620	Scallops	Pectinidae	Mollusks
56902	Crispate Venus	Periglypta crispata	Mollusks
56903	Youthful Venus	Periglypta puerpera	Mollusks
56901	Reticulate Venus	Periglypta reticulata	Mollusks
56601	Pearl Oyster	Pinctada margaritfera	Mollusks
56531	Bicolor Pen Shell	Pinna bicolor	Mollusks
56530	Pen Shells	Pinnidae	Mollusks
50756	Breast-Shaped Moon	Polinices mamatus	Mollusks
50757	Pear-Shaped Moon	Polinices tumidus	Mollusks
50844	Strawberry Goblet	Pollia fragaria	Mollusks
50843	Beautiful Goblet	Pollia pulchra	Mollusks
50752	Fruit Ovula	Prionovula fruticum	Mollusks
56600	Pearl Oysters	Pteriidae	Mollusks

50904	Crenulate Miter	Pterygia crenulata	Mollusks
50907	Fenestrate Miter	Pterygia fenestrata	Mollusks
50905	Nut Miter	Pterygia nucea	Mollusks
50902	Rough Miter	Pterygia scabricula	Mollusks
50810	Club Murex	Pterynotus elongatus	Mollusks
50807	Fluted Murex	Pterynotus laqueatus	Mollusks
50808	3-Winged Murex	Pterynotus tripterus	Mollusks
54413	Solid Pupa	Pupa solidula	Mollusks
50816	Perssian Purpura	Purpura persica	Mollusks
54401	Sulcate Pyram	Pyramidella sulcata	Mollusks
54400	Pyram Shells	Pyramidellidae	Mollusks
50833	Quoy'S Coral Shell	Quoyula madreporarum	Mollusks
50834	Rapa Snail	Rapa rapa	Mollusks
50653	Rough Vertigus	Rhinoclavis aspera	Mollusks
50655	Obelisk Vertigus	Rhinoclavis sinensis	Mollusks
50900	Chaste Miter	Sabricola casta	Mollusks
56625	Tiger Scallop	Semipallium tigris	Mollusks
57403	Broadclub Cuttlefish	Sepia latimanus	Mollusks
57402	Cuttlefish	Sepia sp.	Mollusks
57594	Bigfin Reef Squid	Sepioteuthis lessoniana	Mollusks
56511	Box Mussel	Septifer bilocularis	Mollusks
50805	Lacy Murex	Siratus laciniatus	Mollusks
56670	Thorny Oysters	Spondylidae	Mollusks
56671	Ducal Thorny Oyster	Spondyulus squamosus	Mollusks

56532	Baggy Pen Shell	Streptopinna saccata	Mollusks
50660	True Conchs	Strombidae	Mollusks
50665	Samar Conch	Strombus dentatus	Mollusks
50666	Fragile Conch	Strombus fragilis	Mollusks
50663	Gibbose Conch	Strombus gibberulus	Mollusks
50669	Lavender-Mouth Conch	Strombus haemastoma	Mollusks
50667	Silver-Lip Conch	Strombus lentigninosus	Mollusks
50662	Red-Lip Conch	Strombus luhuanus	Mollusks
50664	Micro Conch	Strombus microurceus	Mollusks
50661	Mutable Conch	Strombus mutabilis	Mollusks
50672	Pretty Conch	Strombus plicatus	Mollusks
50670	Laciniate Conch	Strombus sinuatus	Mollusks
50671	Bull Conch	Strombus taurus	Mollusks
50612	Pyramid Top	Tectus pyramis	Mollusks
56894	Box-Like Tellin	Tellina capsoides	Mollusks
56892	Cat'S Tongue Tellin	Tellina linguafelis	Mollusks
56895	Remie'S Tellin	Tellina remies	Mollusks
56893	Rasp Tellin	Tellina scobinata	Mollusks
56890	Tellin Clams	Tellinidae	Mollusks
50668	Terebellum Conch	Terebellum terebellum	Mollusks
50985	Similar Auger	Terebra affinis	Mollusks
50997	Fly-Spotted Auger	Terebra areolata	Mollusks
50996	Eyed Auger	Terebra argus	Mollusks
50987	Babylonian Auger	Terebra babylonia	Mollusks

50990	Certhlike Auger	Terebra cerithiana	Mollusks
50995	Short Auger	Terebra chlorata	Mollusks
50984	Crenulated Auger	Terebra crenulata	Mollusks
50982	Dimidiate Auger	Terebra dimidiata	Mollusks
50994	Tiger Auger	Terebra felina	Mollusks
50991	Funnel Auger	Terebra funiculata	Mollusks
50993	Spotted Auger	Terebra gutatta	Mollusks
50981	Marlinspike Auger	Terebra maculata	Mollusks
50986	Cloud Auger	Terebra nubulosa	Mollusks
50983	Subulate Auger	Terebra subulata	Mollusks
50992	Undulate Auger	Terebra undulata	Mollusks
50980	Auger Shells	Terebridae	Mollusks
50815	Belligerent Rock Shell	Thais armigera	Mollusks
50814	Tuberose Rock Shell	Thais tuberosa	Mollusks
50761	Partridge Tun	Tonna perdix	Mollusks
50760	Tun Shells	Tonnidae	Mollusks
56723	Angulate Cockle	Trachycardium angulatum	Mollusks
56882	Giant Clam	Tridacna crocea	Mollusks
56883	Lagoon Giant Clam	Tridacna derasa	Mollusks
56884	Giant Clam	Tridacna gigas	Mollusks
56885	Common Giant Clam	Tridacna maxima	Mollusks
56886	Fluted Giant Clam	Tridacna squamosa	Mollusks
56880	Giant Clams	Tridacnidae	Mollusks
50610	Top Shells	Trochidae	Mollusks

50611	Top Shell	Trochus niloticus	Mollusks
50613	Radiate Top	Trochus radiatus	Mollusks
50865	Vases	Turbinellidae	Mollusks
50620	Turban Shell	Turbinidae	Mollusks
50622	Silver-Mouth Turbin	Turbo argyrostoma	Mollusks
50623	Tapestry Turbin	Turbo petholatus	Mollusks
50621	Rough Turbin	Turbo setosus	Mollusks
50867	Ceramic Vase	Vasum ceramicum	Mollusks
50866	Common Pacific Vase	Vasum turbinellus	Mollusks
56900	Venus Shells	Veneridae	Mollusks
50887	Bernhard'S Miter	Vexillum bernhardiana	Mollusks
50882	Cancellaria Miter	Vexillum cancellarioides	Mollusks
50880	Saffron Miter	Vexillum crocatum	Mollusks
50879	Roughened Miter	Vexillum exasperatum	Mollusks
50885	Patriarchal Miter	Vexillum patriarchalis	Mollusks
50881	Half-Banded Miter	Vexillum semifasciatum	Mollusks
50903	Specious Miter	Vexillum speciosum	Mollusks
50886	Bumpy Miter	Vexillum tuberosum	Mollusks
50906	Turbin Miter	Vexillum turbin	Mollusks
50877	Decorated Miter	Vexillum unifasciatum	Mollusks
50802	Spotted Vitularia	Vitularia miliaris	Mollusks
41316	Manahak (Forktail Rabbitfish)	Manahak lesso'	Siganidae
41318	Manahak	Manahak sp	Siganidae
41300	Rabbitfish	Siganidae	Siganidae

41301	Fork-Tail Rabbitfish	Siganus argenteus	Siganidae
41307	Seagrass Rabbitfish	Siganus canaliculatus	Siganidae
41308	Coral Rabbitfish	Siganus corallinus	Siganidae
41302	Pencil-Streaked Rabbitfish	Siganus doliatus	Siganidae
41303	Fuscescens Rabbitfish	Siganus fuscescens	Siganidae
41309	Golden Rabbitfish	Siganus guttatus	Siganidae
41311	Lined Rabbitfish	Siganus lineatus	Siganidae
41313	White-Spotted Rabbitfish	Siganus oramin	Siganidae
41310	Masked Rabbitfish	Siganus puellus	Siganidae
41314	Peppered Rabbitfish	Siganus punctatissimus	Siganidae
41304	Gold-Spotted Rabbitfish	Siganus punctatus	Siganidae
41315	Randal'S Rabbitfish	Siganus randalli	Siganidae
41305	Scribbled Rabbitfish	Siganus spinus	Siganidae
41306	Vermiculated Rabbitfish	Siganus vermiculatus	Siganidae
41312	Rabbitfish	Siganus vulpinus	Siganidae
32301	Silvermouth/Jobfish	Aphareus furca	Lutjanidae
32300	Snappers	Lutjanidae	Lutjanidae
32306	River Snapper	Lutjanus argentimaculatus	Lutjanidae
32325	Two-Spot Snapper	Lutjanus biguttatus	Lutjanidae
32307	Red Snapper	Lutjanus bohar	Lutjanidae
32334	Snapper	Lutjanus boutton	Lutjanidae
32326	Checkered Snapper	Lutjanus decussatus	Lutjanidae
32327	Blackspot Snapper	Lutjanus ehrenbergi	Lutjanidae
32335	Snapper	Lutjanus fulviflamma	Lutjanidae

32308	Flametail Snapper	Lutjanus fulvus	Lutjanidae
32309	Humpback Snapper	Lutjanus gibbus	Lutjanidae
32328	Malabar Snapper	Lutjanus malabaricus	Lutjanidae
32312	Onespot Snapper	Lutjanus monostigma	Lutjanidae
32311	Scribbled Snapper	Lutjanus rivulatus	Lutjanidae
32333	Snapper	Lutjanus sebae	Lutjanidae
32329	1/2-Barred Snapper	Lutjanus semicinctus	Lutjanidae
32330	One-Lined Snapper	Lutjanus vitta	Lutjanidae
32332	Bl And Wh Snapper	Macolor macularis	Lutjanidae
32313	Black Snapper	Macolor niger	Lutjanidae
32314	Fusilier	Paracaesio sordidus	Lutjanidae
32315	Yellowtail Fusilier	Paracaesio xanthurus	Lutjanidae
32322	Deepwater Snapper	Randallichthys filamentosus	Lutjanidae
49130	Shallow Snappers	SHALLOW SNAPPERS	Lutjanidae
32331	Sailfin Snapper	Symphorichthys spilurus	Lutjanidae
28901	Red-Flushed Grouper	Aethaloperca rogaa	Serranidae
28956	Grouper	Anyperodon leucogrammicus	Serranidae
28908	Orange Grouper	Cephalopholis analis	Serranidae
28907	Peacock Grouper	Cephalopholis argus	Serranidae
28911	Brownbarred Grouper	Cephalopholis boenack	Serranidae
28909	Ybanded Grouper	Cephalopholis igarashiensis	Serranidae
28910	Leopard Grouper	Cephalopholis leopardus	Serranidae
28945	Coral Grouper	Cephalopholis miniata	Serranidae

28929	Harlequin Grouper	Cephalopholis polleni	Serranidae
28913	6-Banded Grouper	Cephalopholis sexmaculata	Serranidae
28912	Tomato Grouper	Cephalopholis sonnerati	Serranidae
28903	Grouper	Cephalopholis sp	Serranidae
28906	Pygmy Grouper	Cephalopholis spiloparaea	Serranidae
28914	Flag-Tailed Grouper	Cephalopholis urodeta	Serranidae
28915	Grouper	Cromileptes altivelis	Serranidae
28947	Orange Grouper	Epinephelus caeruleopunctatus	Serranidae
28948	Brown-Spotted Grouper	Epinephelus chlorostigma	Serranidae
28960	Orange Spot Grouper	Epinephelus coioides	Serranidae
28957	Grouper	Epinephelus corallicola	Serranidae
28946	Grouper	Epinephelus cyanopodus	Serranidae
28920	Blotchy Grouper	Epinephelus fuscoguttatus	Serranidae
28921	Hexagon Grouper	Epinephelus hexagonatus	Serranidae
28918	Grouper	Epinephelus howlandi	Serranidae
28922	Giant Grouper	Epinephelus lanceolatus	Serranidae
28958	Grouper	Epinephelus macrospilos	Serranidae
28923	Highfin Grouper	Epinephelus maculatus	Serranidae
28950	Malabar Grouper	Epinephelus malabaricus	Serranidae
28949	Bl-Spot Honeycomb Grouper	Epinephelus melanostigma	Serranidae

28925	Honeycomb Grouper	Epinephelus merra	Serranidae
28942	Grouper	Epinephelus miliaris	Serranidae
28916	Grouper	Epinephelus morrhua	Serranidae
28951	Wavy-Lined Grouper	Epinephelus ongus	Serranidae
28926	Marbled Grouper	Epinephelus polyphekadion	Serranidae
28953	Grouper	Epinephelus retouti	Serranidae
28930	7-Banded Grouper	Epinephelus septemfasciatus	Serranidae
28924	Tidepool Grouper	Epinephelus socialis	Serranidae
28952	4-Saddle Grouper	Epinephelus spilotoceps	Serranidae
28928	Greasy Grouper	Epinephelus tauvina	Serranidae
28902	Truncated Grouper	Epinephelus truncatus	Serranidae
28943	Wh-Margined Grouper	Gracila albomarginata	Serranidae
28938	Squaretail Grouper	Plectropomus areolatus	Serranidae
28937	Saddleback Grouper	Plectropomus laevis	Serranidae
28954	Leopard Coral Trout	Plectropomus leopardus	Serranidae
28955	Blue-Lined Coral Trout	Plectropomus oligacanthus	Serranidae
28940	Powell'S Grouper	Saloptia powelli	Serranidae
28900	Sea Basses,Groupers	Serranidae	Serranidae
28944	Whmargin Lyretail Grouper	Variola albimarginata	Serranidae
35902	Fringelip Mullet	Crenimugil crenilabis	Mugilidae
35903	Yellowtail Mullet	Ellochelon vaigiensis	Mugilidae
35901	Engel'S Mullet	Moolgarda engeli	Mugilidae
35906	Bluespot Mullet	Moolgarda seheli	Mugilidae

35904	Gray Mullet	Mugil cephalus	Mugilidae
35900	Mullets	Mugilidae	Mugilidae
35905	Acute-Jawed Mullet	Neomyxus leuciscus	Mugilidae
33900	Rudderfish	Kyphosidae	Kyphosidae
33901	Highfin Rudderfish	Kyphosus cinerascens	Kyphosidae
33902	Lowfin Rudderfish	Kyphosus vaigiensis	Kyphosidae
33903	Insular Rudderfish	Kyphosus bigibbus	Kyphosidae
69251	Spider Crab	Achaeus japonicus	CRE-Crustaceans
67500	Snapping Shrimp	Alphaeidae	CRE-Crustaceans
67501	Snapping Shrimp	Alpheus bellulus	CRE-Crustaceans
67502	Snapping Shrimp	Alpheus paracrinitus	CRE-Crustaceans
64999	Anchylomerids	Anchylomeridae	CRE-Crustaceans
67951	Slipper Lobster	Arctides regalis	CRE-Crustaceans
60101	Acorn Barnacle	Balanus sp	CRE-Crustaceans
62050	Mantis Shrimp	Bathysquillidae	CRE-Crustaceans
69201	Box Crab	Calappa bicornis	CRE-Crustaceans
69202	Box Crab	Calappa calappa	CRE-Crustaceans
69203	Box Crab	Calappa hepatica	CRE-Crustaceans
69200	Box Crabs	Calappidae	CRE-Crustaceans
69252	Decorator Crab	Camposcia retusa	CRE-Crustaceans
69350	Cancrids	Cancridae	CRE-Crustaceans
69501	7-11 Crab	Carpilius convexus	CRE-Crustaceans
69502	7-11 Crab	Carpilius maculatus	CRE-Crustaceans
69401	Red-Legged Sw Crab	Charybdis erythrodactyla	CRE-Crustaceans

69402	Red Sw Crab	Charybdis hawaiiensis	CRE-Crustaceans
69204	Box Crab	Cycloes granulosa	CRE-Crustaceans
69301	Elbow Crab	Daldorfia horrida	CRE-Crustaceans
68202	Marine Hermit Crab	Dardanus gemmatus	CRE-Crustaceans
68204	Marine Hermit Crab	Dardanus megistos	CRE-Crustaceans
68203	Marine Hermit Crab	Dardanus pendunculatus	CRE-Crustaceans
68201	Marine Hermit Crab	Dardanus sp	CRE-Crustaceans
67121	Commensal Shrimp	Dasycaris zanzibarica	CRE-Crustaceans
67000	Decapod Crustaceans	Decapoda	CRE-Crustaceans
68200	Marine Hermit Crabs	Diogenidae	CRE-Crustaceans
69161	Dorippid Crab	Dorippe frascone	CRE-Crustaceans
69171	Sponge Crab	Dromia dormia	CRE-Crustaceans
69170	Sponge Crabs	Dromiidae	CRE-Crustaceans
68701	Mole Crab	Emerita pacifica	CRE-Crustaceans
67851	Soft Lobster	Enoplometopus debelius	CRE-Crustaceans
67852	Hairy Lobster	Enoplometopus occidentalis	CRE-Crustaceans
69553	Redeye Crab	Eriphia sebana	CRE-Crustaceans
69554	Red-Reef Crab	Etisus dentatus	CRE-Crustaceans
69551	Red-Reef Crab	Etisus splendidus	CRE-Crustaceans
69555	Brown-Reef Crab	Etisus utilis	CRE-Crustaceans
62100	Mantis Shrimp	Eurysquillidae	CRE-Crustaceans
68500	Squat Lobsters	Galatheidae	CRE-Crustaceans
69850	Gecarcinids	Gecarcinidae	CRE-Crustaceans
67220	Bbee And Harlequin Shrimp	Gnathophyllidae	CRE-Crustaceans

67221	Bumblebee Shrimp	Gnathophylloides mineri	CRE-Crustaceans
67222	Bumblebee Shrimp	Gnathophyllum americanum	CRE-Crustaceans
62203	Mantis Shrimp	Gonodactylaceus mutatus	CRE-Crustaceans
62201	Mantis Shrimp	Gonodactylellus affinis	CRE-Crustaceans
62200	Mantis Shrimp	Gonodactylidae	CRE-Crustaceans
62202	Mantis Shrimp	Gonodactylus chiragra	CRE-Crustaceans
62204	Mantis Shrimp	Gonodactylus platysoma	CRE-Crustaceans
62205	Mantis Shrimp	Gonodactylus smithii	CRE-Crustaceans
69860	Shore Crabs	Grapsidae	CRE-Crustaceans
69861	Shore Crab	Grapsus albolineatus	CRE-Crustaceans
69862	Shore Crab	Grapsus grapsus tenuicrustat	CRE-Crustaceans
69950	Hapalocarcinids	Hapalocarcinidae	CRE-Crustaceans
62550	Mantis Shrimp	Harposquillidae	CRE-Crustaceans
62300	Mantis Shrimp	Hemisquillidae	CRE-Crustaceans
67104	Deepwater Shrimps	Heteropenaeus sp	CRE-Crustaceans
67210	Hump-Backed Shrimp	Hippolytidae	CRE-Crustaceans
69100	Homolids	Homolidae	CRE-Crustaceans
67853	Soft Lobster	Hoplometopus holthuisi	CRE-Crustaceans
67223	Harlequin Shrimp	Hymenocera picta	CRE-Crustaceans
64810	Hyperid Amphipods	Hyperiidae	CRE-Crustaceans
67921	Slipper Lobster	Ibacus sp	CRE-Crustaceans
69000	True Crabs	Io Brachyura	CRE-Crustaceans
67931	Long-Handed Lobster	Justitia longimanus	CRE-Crustaceans

67211	Hump-Backed Shrimp	Koror misticius	CRE-Crustaceans
69302	Elbow Crab	Lambrus longispinis	CRE-Crustaceans
67111	Palaemonid Shrimp	Leander plumosus	CRE-Crustaceans
68300	Lithodids	Lithodidae	CRE-Crustaceans
69421	Swimming Crab	Lupocyclus grimquedentatus	CRE-Crustaceans
64830	Lycaeids	Lycaeidae	CRE-Crustaceans
69151	3-Toothed Frog Crab	Lyreidus tridentatus	CRE-Crustaceans
62800	Mantis Shrimp	Lysiosquillidae	CRE-Crustaceans
60100	Barnacles	Lythoglyptidae	CRE-Crustaceans
69901	Telescope-Eye Crab	Macrophthalmus telescopicus	CRE-Crustaceans
69250	Spider Crabs	Majidae	CRE-Crustaceans
67101	Penaeid Prawn	Metapenaeopsis sp 1	CRE-Crustaceans
67102	Penaeid Prawn	Metapenaeopsis sp 2	CRE-Crustaceans
67103	Penaeid Prawn	Metapenaeopsis sp 3	CRE-Crustaceans
69205	Box Crab	Mursia spinimanus	CRE-Crustaceans
62900	Mantis Shrimp	Nannosquillidae	CRE-Crustaceans
67850	Soft Lobsters	Nephropidae	CRE-Crustaceans
69902	Large Ghost Crab	Ocypode ceratopthalma	CRE-Crustaceans
69903	Ghost Crab	Ocypode cordimana	CRE-Crustaceans
69904	Ghost Crab	Ocypode saratum	CRE-Crustaceans
69900	Ocypodids	Ocypodidae	CRE-Crustaceans
62350	Mantis Shrimp	Odontodactylidae	CRE-Crustaceans
62351	Mantis Shrimp	Odontodactylus brevirostris	CRE-Crustaceans

62352	Mantis Shrimp	Odontodactylus scyallarus	CRE-Crustaceans
62701	Mantis Shrimp	Oratosquilla oratoria	CRE-Crustaceans
62700	Mantis Shrimp	Oratosquillidae	CRE-Crustaceans
68400	Soldier Hermit Crab	Paguridae	CRE-Crustaceans
68401	Coral Hermit Crab	Paguritta gracilipes	CRE-Crustaceans
68402	Coral Hermit Crab	Paguritta harmsi	CRE-Crustaceans
67110	Palaemonid Shrimp	Palaemonidae	CRE-Crustaceans
67917	Mole Lobster	Palinurellus wieneckii	CRE-Crustaceans
67918	Painted Crayfish	Panulirus albiflagellum	CRE-Crustaceans
67911	Painted Crayfish	Panulirus homarus	CRE-Crustaceans
67912	Painted Crayfish	Panulirus longipes	CRE-Crustaceans
67914	Painted Crayfish	Panulirus ornatus	CRE-Crustaceans
67910	Painted Crayfish	Panulirus sp	CRE-Crustaceans
67916	Painted Crayfish	Panulirus versicolor	CRE-Crustaceans
69300	Elbow Crabs	Parthenopidae	CRE-Crustaceans
67100	Panaeid Prawns	Penaeidae	CRE-Crustaceans
67106	Penaeid Prawn	Penaeus latisulcatus	CRE-Crustaceans
67105	Penaeid Prawn	Penaeus monodon	CRE-Crustaceans
69864	Flat Rock Crab	Percnon planissimum	CRE-Crustaceans
67122	Commensal Shrimp	Periclimenes amboinensis	CRE-Crustaceans
67123	Commensal Shrimp	Periclimenes brevicarpalis	CRE-Crustaceans
67124	Commensal Shrimp	Periclimenes cf ceratophthalmus	CRE-Crustaceans

67125	Commensal Shrimp	Periclimenes holthuisi	CRE-Crustaceans
67126	Commensal Shrimp	Periclimenes imperator	CRE-Crustaceans
67127	Commensal Shrimp	Periclimenes inornatus	CRE-Crustaceans
67128	Commensal Shrimp	Periclimenes kororensis	CRE-Crustaceans
67129	Commensal Shrimp	Periclimenes ornatus	CRE-Crustaceans
67130	Commensal Shrimp	Periclimenes psamathe	CRE-Crustaceans
67131	Commensal Shrimp	Periclimenes soror	CRE-Crustaceans
67132	Commensal Shrimp	Periclimenes tenuipes	CRE-Crustaceans
67133	Commensal Shrimp	Periclimenes venustus	CRE-Crustaceans
68601	Porcelain Crab	Petrolisthes lamarkii	CRE-Crustaceans
64820	Phronimids	Phronimidae	CRE-Crustaceans
69863	Shore Crab	Plagusia depressa tuberculata	CRE-Crustaceans
64840	Platyscelids	Platyscelidae	CRE-Crustaceans
67134	Commensal Shrimp	Pliopotonia furtiva	CRE-Crustaceans
69461	Long-Eyed Swimming Crab	Podophthalmus vigil	CRE-Crustaceans
67135	Commensal Shrimp	Pontonides uncigar	CRE-Crustaceans
67120	Commensal Shrimp	Pontoniidae	CRE-Crustaceans
68600	Porcellanid Crabs	Porcellanidae	CRE-Crustaceans
69400	Swimming Crabs	Portunidae	CRE-Crustaceans
69432	Blue Swimming Crab	Portunus pelagicus	CRE-Crustaceans
69431	Swimming Crab	Portunus sanguinolentus	CRE-Crustaceans
62400	Mantis Shrimp	Protosquillidae	CRE-Crustaceans
62501	Mantis Shrimp	Pseudosquilla ciliata	CRE-Crustaceans
62500	Mantis Shrimp	Pseudosquillidae	CRE-Crustaceans

67231	Hingebeak Prawn	Rhinchocinetes hiatti	CRE-Crustaceans
67230	Hinge-Beaked Prawns	Rhynchocinetidae	CRE-Crustaceans
69471	Mangrove Crab	Scylla serrata	CRE-Crustaceans
67604	Solenocerids	Solenoceridae	CRE-Crustaceans
62600	Mantis Shrimp	Squillidae	CRE-Crustaceans
67136	Commensal Shrimp	Stegopontonia commensalis	CRE-Crustaceans
67200	Cleaner Shrimp	Stenopodidae	CRE-Crustaceans
67201	Banded Coral Shrimp	Stenopus hispidus	CRE-Crustaceans
62000	Mantis Shrimps	Stomatopoda	CRE-Crustaceans
67503	Snapping Shrimp	Synalpheus carinatus	CRE-Crustaceans
60102	Acorn Barnacle	Tetraclitella divisa	CRE-Crustaceans
69481	Swimming Crab	Thalamita crenata	CRE-Crustaceans
67212	Ambonian Shrimp	Thor amboinensis	CRE-Crustaceans
69598	Xanthid Crab	Unid Megalops	CRE-Crustaceans
69499	Portunid Crab	Unid sp 1	CRE-Crustaceans
69599	Xanthid Crab	Unid sp 1	CRE-Crustaceans
69498	Portunid Crab	Unid sp 2	CRE-Crustaceans
69597	Xanthid Crab	Unid sp 2	CRE-Crustaceans
67112	Palaemonid Shrimp	Urocaridella antonbruunii	CRE-Crustaceans
69500	Dark-Finger Coral Crabs	Xanthidae	CRE-Crustaceans
69870	Urchin Crab	Zebrida adamsii	CRE-Crustaceans
69552	Shallow Reef Crab	Zosymus aeneus	CRE-Crustaceans
24300	Squirrel,Soldierfishes	Holocentridae	Holocentridae

24398	Squirrelfishes	Holocentrinae	Holocentridae
24399	Soldierfishes	Myripristinae	Holocentridae
24313	Bronze Soldierfish	Myripristis adusta	Holocentridae
24314	Brick Soilderfish	Myripristis amaena	Holocentridae
24331	Doubletooth Soldierfish	Myripristis amaena	Holocentridae
24315	Bigscale Soldierfish	Myripristis berndti	Holocentridae
24324	Yellowfin Soldierfish	Myripristis chryseres	Holocentridae
24317	Pearly Soldierfish	Myripristis kuntee	Holocentridae
24318	Red Soldierfish	Myripristis murdjan	Holocentridae
24322	Scarlet Soldierfish	Myripristis pralinia	Holocentridae
24319	Violet Soldierfish	Myripristis violacea	Holocentridae
24320	White-Tipped Soldierfish	Myripristis vittata	Holocentridae
24326	White-Spot Soldierfish	Myripristis woodsi	Holocentridae
24309	Clearfin Squirrelfish	Neoniphon argenteus	Holocentridae
24312	Yellowstriped Squirrelfish	Neoniphon aurolineatus	Holocentridae
24310	Blackfin Squirrlefish	Neoniphon opercularis	Holocentridae
24311	Bloodspot Squirrelfish	Neoniphon sammara	Holocentridae
24340	Deepwater Soldierfish	Ostichthys brachygnathus	Holocentridae
24323	Deepwater Soldierfish	Ostichthys kaianus	Holocentridae
24321	Cardinal Squirrelfish	Plectrypops lima	Holocentridae
24301	Tailspot Squirrelfish	Sargocentron caudimaculatum	Holocentridae
24332	3-Spot Squirrelfish	Sargocentron cornutum	Holocentridae
24302	Crown Squirrelfish	Sargocentron diadema	Holocentridae

24330	Spotfin Squirrelfish	Sargocentron dorsomaculatum	Holocentridae
24334	Furcate Squirrelfish	Sargocentron furcatum	Holocentridae
24327	Samurai Squirrelfish	Sargocentron ittodai	Holocentridae
24333	Squirrelfish	Sargocentron lepros	Holocentridae
24328	Blackspot Squirrelfish	Sargocentron melanospilos	Holocentridae
24304	Finelined Squirrelfish	Sargocentron microstoma	Holocentridae
24305	Dark-Striped Squirrelfish	Sargocentron praslin	Holocentridae
24303	Speckled Squirrelfish	Sargocentron punctatissimum	Holocentridae
24306	Long-Jawed Squirrelfish	Sargocentron spiniferum	Holocentridae
24307	Blue-Lined Squirrelfish	Sargocentron tiere	Holocentridae
24308	Pink Squirrelfish	Sargocentron tieroides	Holocentridae
24329	Violet Squirrelfish	Sargocentron violaceum	Holocentridae
92102	Algae	Enteromorpha clathrata	Algae
92200	Algae	Caulerpaceae	Algae
92217	Algae	Caulerpa racemosa	Algae
93602	Algae	Sargassum polycystum	Algae
93604	Algae	Turbinaria ornata	Algae
95000	Algae	Div Anthophyta	Algae
95003	Algae	Halodule uninervis	Algae
36201	Chiseltooth Wrasse	Anampses caeruleopunctatus	Labridae
36297	Geographic Wrasse	Anampses geographicus	Labridae

36268	Wrasse	Anampses melanurus	Labridae
36202	Yellowtail Wrasse	Anampses meleagrides	Labridae
36203	Yellowbreasted Wrasse	Anampses twisti	Labridae
36205	Lyretail Hogfish	Bodianus anthioides	Labridae
36206	Axilspot Hogfish	Bodianus axillaris	Labridae
36288	2-Spot Slender Hogfish	Bodianus bimaculatus	Labridae
36269	Diana'S Hogfish	Bodianus diana	Labridae
36270	Blackfin Hogfish	Bodianus loxozonus	Labridae
36271	Mesothorax Hogfish	Bodianus mesothorax	Labridae
36243	Hogfish	Bodianus tanyokidus	Labridae
36209	Floral Wrasse	Cheilinus chlorourus	Labridae
36210	Red-Breasted Wrasse	Cheilinus fasciatus	Labridae
36211	Snooty Wrasse	Cheilinus oxycephalus	Labridae
36213	Tripletail Wrasse	Cheilinus trilobatus	Labridae
36216	Cigar Wrasse	Cheilio inermis	Labridae
36217	Yel-Cheeked Tuskfish	Choerodon anchorago	Labridae
36313	Harlequin Tuskfish	Choerodon fasciatus	Labridae
36305	Wrasse	Cirrhilabrus balteatus	Labridae
36272	Wrasse	Cirrhilabrus cyanopleura	Labridae
36273	Exquisite Wrasse	Cirrhilabrus exquisitus	Labridae
36306	Johnson'S Wrasse	Cirrhilabrus johnsoni	Labridae
36218	Wrasse	Cirrhilabrus katherinae	Labridae
36274	Yellowband Wrasse	Cirrhilabrus luteovittatus	Labridae
36307	Rhomboid Wrasse	Cirrhilabrus rhomboidalis	Labridae

36309	Red-Margined Wrasse	Cirrhilabrus rubrimarginatus	Labridae
36219	Clown Coris	Coris aygula	Labridae
36275	Dapple Coris	Coris batuensis	Labridae
36314	Pale-Barred Coris	Coris dorsomacula	Labridae
36220	Yellowtailed Coris	Coris gaimardi	Labridae
36221	Knife Razorfish	Cymolutes praetextatus	Labridae
36291	Finescale Razorfish	Cymolutes torquatus	Labridae
36300	Wandering Cleaner Wrasse	Diproctacanthus xanthurus	Labridae
36222	Sling-Jawed Wrasse	Epibulus insidiator	Labridae
36276	Sling-Jawed Wrasse	Epibulus n sp	Labridae
36223	Bird Wrasse	Gomphosus varius	Labridae
36224	2-Spotted Wrasse	Halichoeres biocellatus	Labridae
36277	Drab Wrasse	Halichoeres chloropterus	Labridae
36278	Canary Wrasse	Halichoeres chrysus	Labridae
36318	Wrasse	Halichoeres dussumieri	Labridae
36226	Checkerboard Wrasse	Halichoeres hortulanus	Labridae
36227	Weedy Surge Wrasse	Halichoeres margaritaceus	Labridae
36228	Dusky Wrasse	Halichoeres marginatus	Labridae
36279	Pinstriped Wrasse	Halichoeres melanurus	Labridae
36229	Black-Ear Wrasse	Halichoeres melasmapomus	Labridae
36311	Ornate Wrasse	Halichoeres ornatissimus	Labridae
36315	Seagrass Wrasse	Halichoeres	Labridae

		papilionaceus	
36298	Wrasse	Halichoeres prosopeion	Labridae
36304	Wrasse	Halichoeres purpurascens	Labridae
36280	Richmond'S Wrasse	Halichoeres richmondi	Labridae
36281	Zigzag Wrasse	Halichoeres scapularis	Labridae
36312	Shwartz Wrasse	Halichoeres shwartzi	Labridae
36282	Wrasse	Halichoeres sp	Labridae
36230	3-Spot Wrasse	Halichoeres trimaculatus	Labridae
36225	Wrasse	Halichoeres zeylonicus	Labridae
36231	Striped Clown Wrasse	Hemigymnus fasciatus	Labridae
36232	1/2 &1/2 Wrasse	Hemigymnus melapterus	Labridae
36303	Wrasse	Hologymnosus annulatus	Labridae
36233	Ring Wrasse	Hologymnosus doliatus	Labridae
36234	Tubelip Wrasse	Labrichthys unilineatus	Labridae
36200	Wrasse	Labridae	Labridae
36235	Bicolor Cleaner Wrasse	Labroides bicolor	Labridae
36266	Bluestreak Cleaner Wrasse	Labroides dimidiatus	Labridae
36237	Black-Spot Cleaner Wrasse	Labroides pectoralis	Labridae
36283	Allen'S Wrasse	Labropsis alleni	Labridae
36238	Micronesian Wrasse	Labropsis micronesica	Labridae
36239	Wedge-Tailed Wrasse	Labropsis xanthonota	Labridae
36240	Leopard Wrasse	Macropharyngodon meleagris	Labridae
36284	Negros Wrasse	Macropharyngodon	Labridae

		negrosensis	
36241	Seagrass Razorfish	Novaculichthys macrolepidotus	Labridae
36242	Dragon Wrasse	Novaculichthys taeniourus	Labridae
36207	Arenatus Wrasse	Oxycheilinus arenatus	Labridae
36264	2-Spot Wrasse	Oxycheilinus bimaculatus	Labridae
36208	Celebes Wrasse	Oxycheilinus celebecus	Labridae
36263	Bandcheek Wrasse	Oxycheilinus digrammus	Labridae
36215	Oriental Wrasse	Oxycheilinus orientalis	Labridae
36212	Ringtail Wrasse	Oxycheilinus unifasciatus	Labridae
36292	Wrasse	Paracheilinus bellae	Labridae
36293	Wrasse	Paracheilinus sp	Labridae
36265	Wrasse	Polylepion russelli	Labridae
36294	Wrasse	Pseudocheilinops ataenia	Labridae
36244	Striated Wrasse	Pseudocheilinus evanidus	Labridae
36245	6 Line Wrasse	Pseudocheilinus hexataenia	Labridae
36246	8 Line Wrasse	Pseudocheilinus octotaenia	Labridae
36285	Line Wrasse	Pseudocheilinus sp	Labridae
36247	4 Line Wrasse	Pseudocheilinus tetrataenia	Labridae
36316	Rust-Banded Wrasse	Pseudocoris aurantiofasciata	Labridae

36317	Torpedo Wrasse	Pseudocoris heteroptera	Labridae
36286	Yamashiro'S Wrasse	Pseudocoris yamashiroi	Labridae
36267	Chiseltooth Wrasse	Pseudodax moluccanus	Labridae
36248	Polynesian Wrasse	Pseudojuloides atavai	Labridae
36249	Smalltail Wrasse	Pseudojuloides cerasinus	Labridae
36250	Wrasse	Pterogogus cryptus	Labridae
36296	Wrasse	Pterogogus guttatus	Labridae
36251	Red-Shoulder Wrasse	Stethojulis bandanensis	Labridae
36252	Wrasse	Stethojulis strigiventor	Labridae
36299	Wrasse	Stethojulis trilineata	Labridae
36253	2 Tone Wrasse	Thalassoma amblycephalum	Labridae
36255	6 Bar Wrasse	Thalassoma hardwickii	Labridae
36262	Jansen'S Wrasse	Thalassoma janseni	Labridae
36287	Crescent Wrasse	Thalassoma lunare	Labridae
36256	Sunset Wrasse	Thalassoma lutescens	Labridae
36257	Surge Wrasse	Thalassoma purpureum	Labridae
36258	5-Stripe Surge Wrasse	Thalassoma quinquevittatum	Labridae
36254	Xmas Wrasse	Thalassoma trilobatum	Labridae
36289	Wh-Barred Pygmy Wrasse	Wetmorella albofasciata	Labridae
36259	Bl-Spot Pygmy Wrasse	Wetmorella nigropinnata	Labridae
36290	Wrasse	Xiphocheilus sp	Labridae
36261	Yblotch Razorfish	Xyrichtys aneitensis	Labridae
36301	Celebe'S Razorfish	Xyrichtys celebecus	Labridae

36302	Razorfish	Xyrichtys geisha	Labridae
36308	Yellowpatch Razorfish	Xyrichtys melanopus	Labridae
36260	Blue Razorfish	Xyrichtys pavo	Labridae
36401	Bolbometopon muricatum	Bumphead parrotfish	
36214	Cheilius undulatus	Napoleon wrasse	
1101	Carcharhinus albimarginatus	Carcharhinidae	Carcharhinidae
1102	Carcharhinus amblyrhynchos	Carcharhinidae	Carcharhinidae
1104	Carcharhinus galapagensis	Carcharhinidae	Carcharhinidae
1106	Carcharhinus melanopterus	Carcharhinidae	Carcharhinidae
1201	Sphyrna lewini	Hammerhead	Carcharhinidae
1202	Sphyrna mokorran	Hammerhead	Carcharhinidae
1200	Sphyrnidae	Hammerhead	Carcharhinidae
44518	Starry Triggerfish	*Abalistes stellatus*	Other
20701	Barred Needlefish	*Ablennes hians*	Other
35050	Blackspot Sergeant	*Abudefduf lorenzi*	Other
35051	Yellowtail Sergeant	*Abudefduf notatus*	Other
35001	Banded Sergeant	*Abudefduf septemfasciatus*	Other
35002	Scis-Tail Sgt Major	*Abudefduf sexfasciatus*	Other
35003	Black Spot Sergeant	*Abudefduf sordidus*	Other
35004	Sergeant-Major	*Abudefduf vaigiensis*	Other
29150	Spiney Basslets	Acanthoclinidae	Other
29151	Hiatt'S Basslet	*Acathoplesiops hiatti*	Other
40537	Goby	*Acentrogobius bonti*	Other
44566	Seagrass Filefish	*Acreichthys tomentosus*	Other

25601	Shrimpfish	*Aeoliscus strigatus*	Other
2201	Spotted Eagle Ray	*Aetobatis narinari*	Other
2202	Eagle Ray	*Aetomyleaus maculatus*	Other
4801	Indo-Pacific Bonefish	*Albula glossodonta*	Other
4802	Bonefish	*Albula neoguinaica*	Other
4800	Bonefish	Albulidae	Other
17100	Lancetfishes	Alepisauidae	Other
17101	Lancetfish	*Alepisaurus ferox*	Other
40711	Dorothea'S Wriggler	*Allomicrodesmis dorotheae*	Other
39202	Blenny	*Alticus arnoldorum*	Other
44558	Unicorn Filefish	*Aluterus monoceros*	Other
44551	Filefish	*Aluterus scriptus*	Other
44552	Filefish	*Amanses scopas*	Other
28700	Glass Perch	Ambassidae	Other
28701	Glassie	*Ambassis buruensis*	Other
28702	Glassie	*Ambassis interrupta*	Other
35201	2-Spot Hawkfish	*Amblycirrhitus bimacula*	Other
40501	Goby	*Amblyeleotris faciata*	Other
40502	Goby	*Amblyeleotris fontaseni*	Other
40503	Goby	*Amblyeleotris guttata*	Other
40506	Goby	*Amblyeleotris randalli*	Other
40505	Brown-Barred Goby	*Amblyeleotris steinitzi*	Other
40507	Bluespotted Goby	*Amblyeleotris wheeleri*	Other
4306	Blue Pilchard	*Amblygaster clupeoides*	Other

4307	Spotted Pilchard	*Amblygaster sirm*	Other
35005	Damselfish	*Amblygliphidodon aureus*	Other
35006	Staghorn Damsel	*Amblygliphidodon curacao*	Other
35052	White-Belly Damsel	*Amblygliphidodon leucogaster*	Other
35053	Ternate Damsel	*Amblygliphidodon ternatensis*	Other
40523	Goby	*Amblygobius decussatus*	Other
40524	Goby	*Amblygobius hectori*	Other
40670		*Amblygobius linki*	Other
40525	Goby	*Amblygobius nocturnus*	Other
40526	Goby	*Amblygobius phalaena*	Other
40527	Goby	*Amblygobius rainfordi*	Other
40662	Goby	*Amblygobius sp*	Other
44816	Evileye Puffer	*Amblyrhinchotus honckenii*	Other
40504	Prawn Goby	*Amlbyeleotris periophthalma*	Other
35007	Org-Fin Anemonefish	*Amphiprion chrysopterus*	Other
35008	Clark'S Anemonefish	*Amphiprion clarkii*	Other
35095	Tomato Anemonefish	*Amphiprion frenatus*	Other
35009	Dusky Anemonefish	*Amphiprion melanopus*	Other
35096	False Clown Anemonefish	*Amphiprion ocellaris*	Other
35010	Pink Anemonfish	*Amphiprion peridaeraion*	Other

35097	3-Banded Anemonefish	*Amphiprion tricinctus*	Other
43507	Dragonet	*Anaora tentaculata*	Other
5601	Allardice'S Moray	*Anarchias allardicei*	Other
5646	Canton Island Moray	*Anarchias cantonensis*	Other
5602	Seychelles Moray	*Anarchias seychellensis*	Other
4901	Freshwater Eel	*Anguilla bicolor*	Other
4902	Freshwater Eel	*Anguilla marmorata*	Other
4900	Freshwater Eel	Anguillidae	Other
24250	Flashlightfish	Anomalopidae	Other
24251	Flashlightfish	*Anomalops katoptron*	Other
19200	Anglerfish	*Antenariidae*	Other
19201	Pigmy Frogfish	*Antennarius analis*	Other
19202	Frogfish	*Antennarius biocellatus*	Other
19203	Freckled Frogfish	*Antennarius coccineus*	Other
19204	Giant Frogfish	*Antennarius commersonii*	Other
19205	Bandtail Frogfish	*Antennarius dorehensis*	Other
19206	Sargassumfish	*Antennarius maculatus*	Other
19207	Spotfin Frogfish	*Antennarius nummifer*	Other
19208	Painted Frogfish	*Antennarius pictus*	Other
19209	Randall'S Frogfish	*Antennarius randalli*	Other
19210	Spiney-Tufted Frogfish	*Antennarius rosaceus*	Other
19211	Bandfin Frogfish	*Antennatus tuberosus*	Other
25201	Boarfish	*Antigonia malayana*	Other
26460	Velvetfishes	*Aploactinidae*	Other

30435	Cardinalfish	*Apogon amboinensis*	Other
30401	Broad-Striped Cardinalfish	*Apogon angustatus*	Other
30402	Bigeye Cardinalfish	*Apogon bandanensis*	Other
30403	Cryptic Cardinalfish	*Apogon coccineus*	Other
30436	Ohcre-Striped Cardinalfish	*Apogon compressus*	Other
30437	Redspot Cardinalfish	*Apogon dispar*	Other
30438	Longspine Cardinalfish	*Apogon doryssa*	Other
30455	Elliot'S Cardinalfish	*Apogon ellioiti*	Other
30462	Cardinalfish	*Apogon eremeia*	Other
30439	Evermann'S Cardinalfish	*Apogon evermanni*	Other
30404	Eyeshadow Cardinalfish	*Apogon exostigma*	Other
30405	Bridled Cardinalfish	*Apogon fraenatus*	Other
30441	Cardinalfish	*Apogon fragilis*	Other
30440	Gilbert'S Cardinalfish	*Apogon gilberti*	Other
30406	Guam Cardinalfish	*Apogon guamensis*	Other
30468		*Apogon hartzfeldii*	Other
30407	Iridescent Cardinalfish	*Apogon kallopterus*	Other
30408	Inshore Cardinalfish	*Apogon lateralis*	Other
30409	Bluestreak Cardinalfish	*Apogon leptacanthus*	Other
30457	Black Cardinalfish	*Apogon melas*	Other
30463	Cardinalfish	*Apogon nigripinnis*	Other
30412	Black-Striped Cardinalfish	*Apogon nigrofasciatus*	Other
30464	Cardinalfish	*Apogon notatus*	Other
30413	7-Lined Cardinalfish	*Apogon novemfasciatus*	Other

30442	Pearly Cardinalfish	*Apogon perlitus*	Other
30465	Cardinalfish	*Apogon rhodopterus*	Other
30443	Sangi Cardinalfish	*Apogon sangiensis*	Other
30415	Gray Cardinalfish	*Apogon savayensis*	Other
30456	Seale'S Cardinalfish	*Apogon sealei*	Other
30417	Cardinalfish	*Apogon sp*	Other
30414	Bandfin Cardinalfish	*Apogon taeniophorus*	Other
30410	Bandfin Cardinalfish	*Apogon taeniopterus*	Other
30416	3-Spot Cardinalfish	*Apogon trimaculatus*	Other
30418	Ocellated Cardinalfish	*Apogonichthys ocellatus*	Other
30444	Perdix Cardinalfish	*Apogonichthys perdix*	Other
30400	Cardinalfishes	Apogonidae	Other
34377	Angelfish	*Apolemichthys griffisi*	Other
34351	Flagfin Anglefish	*Apolemichthys trimaculatus*	Other
34376	Angelfish	*Apolemichthys xanthopunctatus*	Other
29201	2-Lined Soapfish	*Aporops bilinearis*	Other
6619	Snake Eel	*Apterichtus klazingai*	Other
30419	Twinspot Cardinalfish	*Archamia biguttata*	Other
30420	Orange-Lined Cardinalfish	*Archamia fucata*	Other
30445	Blackbelted Cardinalfish	*Archamia zosterophora*	Other
6206	Scheele'S Conger	*Ariosoma scheelei*	Other
43903	Flounder	*Arnoglossus intermedius*	Other
44801	Brown Puffer	*Arothron hispidus*	Other

44802	Puffer	*Arothron manilensis*	Other
44803	Puffer	*Arothron mappa*	Other
44804	White-Spot Puffer	*Arothron meleagris*	Other
44805	Black-Spotted Puffer	*Arothron nigropunctatus*	Other
44806	Star Puffer	*Arothron stellatus*	Other
44102	Black Spotted Sole	*Aseraggodes melanostictus*	Other
44103	Smith'S Sole	*Aseraggodes smithi*	Other
44104	Whitaker'S Sole	*Aseraggodes whitakeri*	Other
39257	Lance Blenny	*Aspidontus dussumieri*	Other
39203	Cleaner Mimic	*Aspidontus taeniatus*	Other
40539		*Asteropteryx semipunctatus*	Other
43905	Intermediate Flounder	*Asterorhombus intermedius*	Other
40538	Goby	*Asterropteryx ensiferus*	Other
21800	Silverside	Atherinidae	Other
21805	Tropical Silverside	*Atherinomorus duodecimalis*	Other
21806	Striped Silverside	*Atherinomorus endrachtensis*	Other
21803	Silverside	*Atherinomorus lacunosus*	Other
21804	Hardyhead Silverside	*Atherinomorus lacunosus*	Other
21801	Bearded Silverside	*Atherion elymus*	Other
39240	Blenny	*Atrosalarius fuscus holomelas*	Other

25300	Trumpetfish	Aulostomidae	Other
25301	Trumpetfish	*Aulostomus chinensis*	Other
40540	Goby	*Austrolethops wardi*	Other
40541	Goby	*Awaous grammepomus*	Other
40542	Goby	*Awaous guamensis*	Other
44501	Undulate Triggerfish	*Balistapus undulatus*	Other
44500	Triggerfishes	Balistidae	Other
44502	Clown Triggerfish	*Balistoides conspicillum*	Other
44503	Titan Triggerfish	*Balistoides viridescens*	Other
40543	Goby	*Bathygobius cocosensis*	Other
40544	Goby	*Bathygobius cotticeps*	Other
40545	Goby	*Bathygobius fuscus*	Other
20700	Needlefish	Belonidae	Other
29001	Soapfish	*Belonoperca chaubanaudi*	Other
24200	Lantern-Eye Fish	Berycidae	Other
24201	Flashlightfish	*Beryx decadactylus*	Other
25818	Pipefish	*Bhanotia nuda*	Other
6205	Conger Eel	*Blachea xenobranchialis*	Other
39218	Blenny	*Blenniella cyanostigma*	Other
39222	Blenny	*Blenniella gibbifrons*	Other
39239		*Blenniella paula*	Other
39221	Blenny	*Blenniella periophthalmus*	Other
39200	Blennies	Blenniidae	Other

43900	Flounders	Bothidae	Other
43901	Peacock Flounder	*Bothus mancus*	Other
43902	Leopard Flounder	*Bothus pantherinus*	Other
44559	Taylor'S Inflator Filefish	*Brachaluteres taylori*	Other
6601	Snake Eel	*Brachysomophis sauropsis*	Other
18201	Codlet	*Bregmaceros nectabanus*	Other
18200	Codlets	*Bregmacerotidae*	Other
18651	Free-Tailed Brotula	*Brosmophyciops pautzkei*	Other
18601	Reef Cusk Eel	*Brotula multibarbata*	Other
18602	Townsend'S Cusk Eel	*Brotula townsendi*	Other
40546	Goby	*Bryaninops amplus*	Other
40547	Goby	*Bryaninops erythrops*	Other
40548	Goby	*Bryaninops natans*	Other
40549	Goby	*Bryaninops ridens*	Other
40550	Goby	*Bryaninops youngei*	Other
25819	Pipefish	*Bulbonaricus brauni*	Other
40402	Gudgeon	*Butis amboinensis*	Other
18650	Livebearing Brotulas	Bythitidae	Other
40551	Goby	*Cabillus tongarevae*	Other
6602	Snake Eel	*Caecula polyophthalma*	Other
32351	Scissor-Tailed Fusilier	*Caesio caerulaurea*	Other
32355	Fusilier	*Caesio cuning*	Other
32356	Lunar Fusilier	*Caesio lunaris*	Other

32352	Yellowback Caesio	*Caesio teres*	Other
32350	Fusilier	*Caesionidae*	Other
29050	Goldies	*Callanthiidae*	Other
6603	Snake Eel	*Callechelys marmorata*	Other
6604	Snake Eel	*Callechelys melanotaenia*	Other
43500	Dragonets	Callionymidae	Other
43508	Delicate Dragonet	*Callionymus delicatulus*	Other
43501	Mangrove Dragonet	*Callionymus enneactis*	Other
43502	Simple-Spined Dragonet	*Callionymus simplicicornis*	Other
40559	Goby	*Callogobious sp*	Other
40552	Goby	*Callogobius bauchotae*	Other
40553	Goby	*Callogobius centrolepis*	Other
40554	Goby	*Callogobius hasselti*	Other
40555	Goby	*Callogobius maculipinnis*	Other
40556	Goby	*Callogobius okinawae*	Other
40557	Goby	*Callogobius plumatus*	Other
40558	Goby	*Callogobius sclateri*	Other
29401	Longfin	*Calloplesiops altivelis*	Other
40403	Sleeper	*Calumia godeffroyi*	Other
44553	Gray Leatherjacket	*Cantherhines dumerilii*	Other
44565	Specktacled Filefish	*Cantherhines fronticinctus*	Other
44554	Honeycomb Filefish	*Cantherhines pardalis*	Other

44504	Rough Triggerfish	*Canthidermis maculatus*	Other
44807	Puffer	*Canthigaster amboinensis*	Other
44808	Puffer	*Canthigaster bennetti*	Other
44815	Puffer	*Canthigaster compressa*	Other
44809	Sharp Back Puffer	*Canthigaster coronata*	Other
44810	Puffer	*Canthigaster epilampra*	Other
44811	Puffer	*Canthigaster janthinoptera*	Other
44812	Puffer	*Canthigaster leoparda*	Other
44819	Circle-Barred Toby	*Canthigaster ocellicincta*	Other
44820	Papuan Toby	*Canthigaster papua*	Other
44813	Sharpnose Puffer	*Canthigaster solandri*	Other
44814	Saddle Shpns Puffer	*Canthigaster valentini*	Other
25200	Boarfishes	Caproidae	Other
26700	Coral Crouchers	*Caracanthidae*	Other
26701	Velvetfish	*Caracanthus maculatus*	Other
26702	Velvetfish	*Caracanthus unipinna*	Other
18700	Pearlfish	*Carapodidae*	Other
18702	Pearlfish	*Carapus mourlani*	Other
1109	Blackfin Shark	*Carcharhinus limbatus*	Other
902	Great White Shark	*Carcharodon carcharius*	Other
25600	Shrimpfishes	*Centriscidae*	Other
34379	Golden Angelfish	*Centropyge aurantia*	Other
34352	Bicolor Angelfish	*Centropyge bicolor*	Other

34353	Dusky Angelfish	*Centropyge bispinosus*	Other
34354	Colin'S Angelfish	*Centropyge colini*	Other
34367	White-Tail Angelfish	*Centropyge flavicauda*	Other
34355	Lemonpeel Anglefish	*Centropyge flavissimus*	Other
34356	Herald'S Anglefish	*Centropyge heraldi*	Other
34357	Flame Anglefish	*Centropyge loriculus*	Other
34368	Multicolor Angelfish	*Centropyge multicolor*	Other
34358	Multibarred Angelfish	*Centropyge multifasciatus*	Other
34359	Black-Spot Anglefish	*Centropyge nigriocellus*	Other
34378	Midnight Angelfish	*Centropyge nox*	Other
34360	Shepard'S Anglefish	*Centropyge shepardi*	Other
34369	Keyhole Angelfish	*Centropyge tibicen*	Other
34361	Pearlscale Anglefish	*Centropyge vrolicki*	Other
28959	Grouper	*Cephalopholis cyanostigma*	Other
39008	Triplefin	*Ceratobregma helenae*	Other
34301	Threadfin Butterflyfish	*Chaetodon auriga*	Other
34330	E Triangular Butterflyfish	*Chaetodon barronessa*	Other
34302	Bennetts Butterflyfish	*Chaetodon bennetti*	Other
34331	Burgess' Butterflyfish	*Chaetodon burgessi*	Other
34303	Speckled Butterflyfish	*Chaetodon citrinellus*	Other
34304	Saddleback Butterflyfish	*Chaetodon ephippium*	Other
34305	Ylw-Crn Butterflyfish	*Chaetodon flavocoronatus*	Other
34306	Kleins Butterflyfish	*Chaetodon kleinii*	Other

34307	Lined Butterflyfish	*Chaetodon lineolatus*	Other
34308	Racoon Butterflyfish	*Chaetodon lunula*	Other
34316	Redfinned Butterflyfish	*Chaetodon lunulatus*	Other
34309	Black-Back Butterflyfish	*Chaetodon melannotus*	Other
34310	Mertens Butterflyfish	*Chaetodon mertensii*	Other
34332	Meyer'S Butterflyfish	*Chaetodon meyeri*	Other
34311	Butterflyfish	*Chaetodon modestus*	Other
34333	Spot-Tail Butterflyfish	*Chaetodon ocellicaudus*	Other
34334	8-Banded Butterflyfish	*Chaetodon octofasciatus*	Other
34312	Ornate Butterflyfish	*Chaetodon ornatissimus*	Other
34335	Spot-Nape Butterflyfish	*Chaetodon oxycephalus*	Other
34313	Spotbnded Butterflyfish	*Chaetodon punctatofasciatus*	Other
34314	4-Spotted Butterflyfish	*Chaetodon quadrimaculatus*	Other
34336	Latticed Butterflyfish	*Chaetodon rafflesii*	Other
34315	Retculted Butterflyfish	*Chaetodon reticulatus*	Other
34337	Dotted Butterflyfish	*Chaetodon semeion*	Other
34338	Oval-Spot Butterflyfish	*Chaetodon speculum*	Other
34340	Tinker'S Butterflyfish	*Chaetodon tinkeri*	Other
34329	Chevron Butterflyfish	*Chaetodon trifascialis*	Other
34317	Pac Dblsddl Butterflyfish	*Chaetodon ulietensis*	Other
34318	Teardrop Butterflyfish	*Chaetodon unimaculatus*	Other
34319	Vagabond Butterflyfish	*Chaetodon vagabundus*	Other
34300	Butterflyfish	*Chaetodontidae*	Other

34370	Vermiculated Angelfish	*Chaetodontoplus mesoleucus*	Other
37401	Saddled Sandburrower	*Chalixodytes tauensis*	Other
36701	Gaper	*Champsodon vorax*	Other
36700	Gapers	*Champsodontidae*	Other
9800	Milkfish	*Chanidae*	Other
5647	Long-Jawed Moray	*Channomuraena vittata*	Other
9801	Milkfish	*Chanos chanos*	Other
30458	Lined Cardinalfish	*Cheilodipterus artus*	Other
30466	Intermediate Cardinalfish	*Cheilodipterus intermedius*	Other
30446	Cardinalfish	*Cheilodipterus isostigma*	Other
30422	Lg-Toothed Cardinalfish	*Cheilodipterus macrodon*	Other
30423	5-Lined Cardinalfish	*Cheilodipterus quinquelineata*	Other
30421	Truncate Cardinalfish	*Cheilodipterus singapurensis*	Other
20601	Flying Fish	*Cheilopogon spilonopterus*	Other
20602	Flying Fish	*Cheilopogon spilopterus*	Other
20603	Flying Fish	*Cheilopogon unicolor*	Other
35089	Minstrel Fish	*Cheiloprion labiatus*	Other
35907	Ceram Mullet	*Chelon macrolepis*	Other
5400	False Moray Eel	Chlopsidae	Other
25802	Pipefish	*Choeroichthys brachysoma*	Other

25801	Pipefish	*Choeroichthys sculptus*	Other
37001	Duckbill	*Chrionema squamiceps*	Other
35011	Midget Chromis	*Chromis acares*	Other
35012	Bronze Reef Chromis	*Chromis agilis*	Other
35022	Yel-Speckled Chromis	*Chromis alpha*	Other
35013	Ambon Chromis	*Chromis amboinensis*	Other
35014	Yellow Chromis	*Chromis analis*	Other
35015	Black-Axil Chromis	*Chromis atripectoralis*	Other
35054	Dark-Fin Chromis	*Chromis atripes*	Other
35059	Blue-Axil Chromis	*Chromis caudalis*	Other
35060	Deep Reef Chromis	*Chromis delta*	Other
35017	Twin-Spot Chromis	*Chromis elerae*	Other
35018	Scaly Chromis	*Chromis lepidolepis*	Other
35055	Lined Chromis	*Chromis lineata*	Other
35019	Bicolor Chromis	*Chromis margaritifer*	Other
35056	Black-Bar Chromis	*Chromis retrofasciata*	Other
35049	Ternate Chromis	*Chromis ternatensis*	Other
35020	Vanderbilt'S Chromis	*Chromis vanderbilti*	Other
35016	Blue-Green Chromis	*Chromis viridis*	Other
35057	Weber'S Chromis	*Chromis weberi*	Other
35058	Yel-Axil Chromis	*Chromis xanthochir*	Other
35021	Black Chromis	*Chromis xanthura*	Other
35024	2-Spot Demoiselle	*Chrysiptera biocellata*	Other
35027	Surge Demoiselle	*Chrysiptera brownriggii*	Other

35025	Blue-Line Demoiselle	*Chrysiptera caeruleolineata*	Other
35062	Blue Devil	*Chrysiptera cyanea*	Other
35026	Gray Demoiselle	*Chrysiptera glauca*	Other
35090	Blue-Spot Demoiselle	*Chrysiptera oxycephala*	Other
35064	King Demoiselle	*Chrysiptera rex*	Other
35065	Talbot'S Demoiselle	*Chrysiptera talboti*	Other
35028	Tracey'S Demoiselle	*Chrysiptera traceyi*	Other
35091	1-Spot Demoiselle	*Chrysiptera unimaculata*	Other
34610	Peacock Bass	*Cichla ocellaris*	Other
34600	Cichlids	Cichlidae	Other
35211	Threadfin Hawkfish	*Cirrhitichthys aprinus*	Other
35202	Falco'S Hawkfish	*Cirrhitichthys falco*	Other
35203	Pixy Hawkfish	*Cirrhitichthys oxycephalus*	Other
35200	Hawkfish	Cirrhitidae	Other
35204	Stocky Hawkfish	*Cirrhitus pinnulatus*	Other
6620	Fringelip Snake Eel	*Cirricaecula johnsoni*	Other
39242	Chestnut Blenny	*Cirripectes castaneus*	Other
39204	Spotted Blenny	*Cirripectes fuscoguttatus*	Other
39243	Blenny	*Cirripectes perustus*	Other
39206	Barred Blenny	*Cirripectes polyzona*	Other
39205	Squiggly Blenny	*Cirripectes quagga*	Other
39244	Red-Streaked Blenny	*Cirripectes stigmaticus*	Other
39207	Red-Speckled Blenny	*Cirripectes variolosus*	Other

14802	Air-Breath Catfish	*Clarias batrachus*	Other
14801	Air-Breath Catfish	*Clarias macrocephalus*	Other
14800	Air-Breath Catfish	Clariidae	Other
4300	Herring,Sprat,Sardines	Clupeidae	Other
26461	Velvetfish	*Cocotropis larvatus*	Other
6201	White Eel	*Conger cinereus cinereus*	Other
6202	Conger Eel	*Conger oligoporus*	Other
6208	Conger Eel	*Conger sp*	Other
6200	White,Conger,Garden Eel	Congridae	Other
30306	Deepwater Glasseye	*Cookeolus boops*	Other
30304	Bulleye	*Cookeolus japonicus*	Other
34339	Orangebanded Coralfish	*Coradion chrysozonus*	Other
40590	Goby	*Coryphopterus signipinnis*	Other
25803	Network Pipefish	*Corythoichthys flavofasciatus*	Other
25820	Pipefish	*Corythoichthys haematopterus*	Other
25804	Reef Pipefish	*Corythoichthys intestinalis*	Other
25805	Bl-Breasted Pipefish	*Corythoichthys nigripectus*	Other
25821	Ocellated Pipefish	*Corythoichthys ocellatus*	Other
25822	Many-Spotted Pipefish	*Corythoichthys polynotatus*	Other
25823	Guilded Pipefish	*Corythoichthys schultzi*	Other

25824	Roughridge Pipefish	*Cosmocampus banneri*	Other
25806	D'Arros Pipefish	*Cosmocampus darrosanus*	Other
25825	Maxweber'S Pipefish	*Cosmocampus maxweberi*	Other
37400	Sand Burrowers	Creedidae	Other
35911	Mullet	*Crenimugil heterochilos*	Other
40560	Goby	*Cristagobius sp*	Other
40508	Goby	*Cryptocentroides insignis*	Other
40511	Goby	*Cryptocentrus cauruleomaculatus*	Other
40509	Goby	*Cryptocentrus cinctus*	Other
40510	Goby	*Cryptocentrus koumansi*	Other
40512	Goby	*Cryptocentrus leptocephalus*	Other
40514	Goby	*Cryptocentrus sp A*	Other
40513	Goby	*Cryptocentrus strigilliceps*	Other
40515	Goby	*Ctenogobiops aurocingulus*	Other
40516	Goby	*Ctenogobiops feroculus*	Other
40517	Goby	*Ctenogobiops pomastictus*	Other
40518	Long-Finned Prwn Goby	*Ctenogobiops tangarorai*	Other
27304	Flathead	*Cymbacephalus beauforti*	Other
35212	Swallowtail Hawkfish	*Cyprinocirrhites*	Other

		polyactis	
20604	Flying Fish	*Cypselurus angusticeps*	Other
20605	Flying Fish	*Cypselurus poecilopterus*	Other
20606	Flying Fish	*Cypselurus speculiger*	Other
28501	Flying Gurnard	*Dactyloptena orientalis*	Other
28502	Flying Gurnard	*Dactyloptena petersoni*	Other
28500	Flying Gurnard	*Dactylopteridae*	Other
35029	Humbug Dascyllus	*Dascyllus aruanus*	Other
35066	Black-Tail Dascyllus	*Dascyllus melanurus*	Other
35030	Reticulated Dascyllus	*Dascyllus reticulatus*	Other
35031	3-Spot Dascyllus	*Dascyllus trimaculatus*	Other
2000	Stingray	Dasyatididae	Other
2001	Blue-Spotted Sting Ray	*Dasyatis kuhlii*	Other
26401	Scorpionfish	*Dendrochirus biocellatus*	Other
26402	Scorpionfish	*Dendrochirus brachypterus*	Other
26427	Zebra Lionfish	*Dendrochirus zebra*	Other
32701	Slatey Sweetlips	*Diagramma pictum*	Other
16701	Lanternfish	*Diaphus schmidti*	Other
18652	Bythitid	*Dinematichthys iluocoetenoides*	Other
44903	Porcupinefish	*Diodon eydouxi*	Other
44901	Porcupinefish	*Diodon hystrix*	Other
44902	Porcupinefish	*Diodon liturosus*	Other

44900	Porcupinefish	Diodontidae	Other
43503	Dragonet	*Diplogrammus goramensis*	Other
8801	Bristlemouth	*Diplophos sp*	Other
35067	White-Spot Damsel	*Dischistodus chrysopoecilus*	Other
35068	Black-Vent Damsel	*Dischistodus melanotus*	Other
35032	White Damsel	*Dischistodus perspicillatus*	Other
25808	Banded Pipefish	*Doryramphus dactyliophorus*	Other
25807	Bluestripe Pipefish	*Doryramphus excisus*	Other
25826	Janss' Pipefish	*Doryramphus janssi*	Other
25827	Negros Pipefish	*Doryramphus negrosensis negrsensi*	Other
4303	Sprat	*Dussumieria elopsoides*	Other
4302	Sprats	*Dussumieria sp B*	Other
31300	Diskfishes	Echeneidae	Other
31304	Remora	*Echeneis naucrates*	Other
5603	Whiteface Moray	*Echidna leucotaenia*	Other
5604	Snowflake Moray	*Echidna nebulosa*	Other
5605	Girdled Moray Eel	*Echidna polyzona*	Other
5606	Unicolor Moray	*Echidna unicolor*	Other
1350	Bramble Shark	*Echinorhinidae*	Other
1351	Bramble Shark	*Echinorhinus brucus*	Other
1352	Bramble Shark	*Echinorhinus cookei*	Other

39264	Banda Clown Blenny	*Ecsenius bandanus*	Other
39208	Blenny	*Ecsenius bicolor*	Other
39209	Blenny	*Ecsenius opsifrontalis*	Other
39245	Blenny	*Ecsenius sellifer*	Other
39246	Blenny	*Ecsenius yaeyamaensis*	Other
6621	Snake Eel	*Elapsopsis versicolor*	Other
40400	Sleepers	Eleotrididae	Other
40401	Gudgeon	*Eleotris fusca*	Other
32201	Bonnetmouth	*Emmelichthys karnellai*	Other
32200	Bonnet Mouths	*Emmelichtyidae*	Other
18703	Pearlfish	*Encheliophis boraboraensis*	Other
18705	Pearlfish	*Encheliophis gracilis*	Other
18701	Pearlfish	*Encheliophis homei*	Other
18704	Pearlfish	*Encheliophis vermicularis*	Other
5607	Bayer'S Moray	*Enchelycore bayeri*	Other
5608	Bikini Atoll Moray	*Enchelycore bikiniensis*	Other
5655	Dark-Spotted Moray	*Enchelycore kamara*	Other
5609	White-Margined Moray	*Enchelycore schismatorhynchus*	Other
5610	Viper Moray	*Enchelynassa canina*	Other
39210	Blenny	*Enchelyurus kraussi*	Other
4406	Gold Anchovy	*Enchrasicholina devisi*	Other
4405	Blue Anchovy	*Enchrasicholina heterolobus*	Other

4401	Oceanic Anchovy	*Enchrasicholina punctifer*	Other
4400	Anchovies	Engraulidae	Other
43904	Flounder	*Engyprosopon sp*	Other
39001	Triplefin	*Enneapterygius hemimelas*	Other
39002	Triplefin	*Enneapterygius minutus*	Other
39003	Triplefin	*Enneapterygius nanus*	Other
39247	Blenny	*Entomacrodus caudofasciatus*	Other
39248	Blenny	*Entomacrodus cymatobiotus*	Other
39211	Blenny	*Entomacrodus decussatus*	Other
39212	Blenny	*Entomacrodus niuafooensis*	Other
39213	Blenny	*Entomacrodus sealei*	Other
39241	Blenny	*Entomacrodus stellifer*	Other
39214	Blenny	*Entomacrodus striatus*	Other
39215	Blenny	*Entomacrodus thalassinus thalassin*	Other
34000	Batfish	Ephippidae	Other
32202	Bonnetmouth	*Erythrocles scintillans*	Other
1301	Spiny Dogfish	*Etmopterus pusillus*	Other
20757	Ribbon Halfbeak	*Euleptorhamphus viridis*	Other
28601	Dragon Fish	*Eurypegasus draconis*	Other
4304	Mantis Shrimp	*Eutremus teres*	Other

40561	Kawakawa	*Eviota afelei*	Other
40562	Herring	*Eviota albolineata*	Other
40563	Goby	*Eviota bifasciata*	Other
40564	Goby	*Eviota cometa*	Other
40565	Goby	*Eviota distigma*	Other
40566	Goby	*Eviota fasciola*	Other
40567	Goby	*Eviota herrei*	Other
40568	Goby	*Eviota infulata*	Other
40569	Goby	*Eviota lachdebrerei*	Other
40570	Goby	*Eviota latifasciata*	Other
40571	Goby	*Eviota melasma*	Other
40572	Goby	*Eviota nebulosa*	Other
40573	Goby	*Eviota pellucida*	Other
40574	Goby	*Eviota prasina*	Other
40575	Goby	*Eviota prasites*	Other
40576	Goby	*Eviota punctulata*	Other
40577	Goby	*Eviota queenslandica*	Other
40579	Goby	*Eviota saipanensis*	Other
40578	Goby	*Eviota sebreei*	Other
40580	Goby	*Eviota sigillata*	Other
40581	Goby	*Eviota smaragdus*	Other
40585	Goby	*Eviota sp*	Other
40582	Goby	*Eviota sparsa*	Other
40583	Goby	*Eviota storthynx*	Other

40584	Goby	*Eviota zonura*	Other
6622	Snake Eel	*Evipes percinctus*	Other
39216	Blenny	*Exalias brevis*	Other
20600	Flying Fish	*Exocoetidae*	Other
20611	Flying Fish	*Exocoetus volitans*	Other
40586	Goby	*Exyrias belissimus*	Other
40587	Goby	*Exyrias puntang*	Other
25401	Cornetfish	*Fistularia commersoni*	Other
25400	Cornetfish	Fistulariidae	Other
30453	Bay Cardinalfish	*Foa brachygramma*	Other
30454	Cardinalfish	*Foa sp*	Other
34320	Longnosed Butterflyfish	*Forcipiger flavissimus*	Other
34321	Big Longnose Butterflyfish	*Forcipiger longirostris*	Other
30467	Cardinalfish	*Fowleria abocellata*	Other
30426	Marbled Cardinalfish	*Fowleria marmorata*	Other
30425	Spotcheek Cardinalfish	*Fowleria punctulata*	Other
30427	Variegated Cardinalfish	*Fowleria variegatus*	Other
40588	Goby	*Fusigobius longispinus*	Other
40589	Goby	*Fusigobius neophytus*	Other
1107	Tiger Shark	*Galeocerdo cuvier*	Other
31802	Lg-Toothed Ponyfish	*Gazza achlamys*	Other
31808	Toothed Ponyfish	*Gazza minuta*	Other
34362	Ornate Angelfish	*Genicanthus bellus*	Other
34371	Black-Spot Angelfish	*Genicanthus melanospilos*	Other

34364	Watanabe'S Angelfish	*Genicanthus watanabei*	Other
32600	Mojarras	Gerreidae	Other
32602	Deep-Bodied Mojarra	*Gerres abbreviatus*	Other
32601	Common Mojarra	*Gerres acinaces*	Other
32604	Filamentous Mojarra	*Gerres filamentosus*	Other
32603	Oblong Mojarra	*Gerres oblongus*	Other
32605	Oyena Mojarra	*Gerres oyena*	Other
32606	Mojarra	*Gerres punctatus*	Other
9200	Telescopefish	*Giganturidae*	Other
40591	Goby	*Gladigobius ensifera*	Other
40592	Goby	*Glossogobius biocellatus*	Other
40593	Goby	*Glossogobius celebius*	Other
40594	Goby	*Glossogobius guirus*	Other
39249	Blenny	*Glyptoparus delicatulus*	Other
40595	Goby	*Gnatholepis anjerensis*	Other
40601		*Gnatholepis caurensis*	Other
40596	Goby	*Gnatholepis scapulostigma*	Other
40597	Goby	*Gnatholepis sp A*	Other
43400	Clingfish	Gobiesocidae	Other
40500	Goby	Gobiidae	Other
40598	Goby	*Gobiodon albofasciatus*	Other
40599	Goby	*Gobiodon citrinus*	Other
40602	Goby	*Gobiodon okinawae*	Other
40603	Goby	*Gobiodon*	Other

		quinquestrigatus	
40604	Goby	*Gobiodon rivulatus*	Other
40605	Goby	*Gobiopsis bravoi*	Other
8802	Bristlemouth	*Gonostoma atlanticum*	Other
8803	Bristlemouth	*Gonostoma ebelingi*	Other
8800	Bristlemouths	*Gonostomatidae*	Other
6209	Orange-Barred Garden Eel	*Gorgasia preclara*	Other
6203	Conger Eel	*Gorgasia sp*	Other
29051	Goldies	*Grammatonotus sp 1*	Other
29052	Goldies	*Grammatonotus sp 2*	Other
41604	2-Lined Mackerel	*Grammatorcynos bilineatus*	Other
29002	Yellowstripe Soapfish	*Grammistes sexlineatus*	Other
29000	Soapfish	Grammistidae	Other
29003	Ocellate Soapfish	*Grammistops ocellatus*	Other
41001	Wormfish	*Gunnellichthys monostigma*	Other
41002	Onestripe Wormfish	*Gunnellichthys pleurotaenia*	Other
41011	Wormfish	*Gunnellichthys viridescens*	Other
30460	Philippine Cardinalfish	*Gymnapogon philippinus*	Other
30447	Cardinalfish	*Gymnapogon urospilotus*	Other
32361	Fusilier	*Gymnocaesio gymnopterus*	Other

5611	Zebra Moray	*Gymnomuraena zebra*	Other
5619	Moray Eel	*Gymnothorax berndti*	Other
5620	Buro Moray	*Gymnothorax buroensis*	Other
5624	Moray Eel	*Gymnothorax elegans*	Other
5635	Enigmatic Moray	*Gymnothorax enigmaticus*	Other
5621	Fimbriated Moray	*Gymnothorax fimbriatus*	Other
5622	Yellow-Margined Moray	*Gymnothorax flavimarginatus*	Other
5612	Brown Spotted Moray	*Gymnothorax fuscomaculatus*	Other
5623	Graceful-Tailed Moray	*Gymnothorax gracilicaudus*	Other
5625	Moray Eel	*Gymnothorax hepaticus*	Other
5626	Giant Moray	*Gymnothorax javanicus*	Other
5627	Blotch-Necked Moray	*Gymnothorax margaritophorus*	Other
5613	Marshall Isles Moray	*Gymnothorax marshallensis*	Other
5614	Dirty Yellow Moray	*Gymnothorax melatremus*	Other
5628	Whitemouth Moray	*Gymnothorax meleagris*	Other
5648	Monochrome Moray	*Gymnothorax monochrous*	Other
5629	1-Spot Moray	*Gymnothorax monostigmus*	Other
5630	Moray Eel	*Gymnothorax neglectus*	Other
5645	Yellowmouth Moray	*Gymnothorax nudivomer*	Other

5616	Pinda Moray	*Gymnothorax pindae*	Other
5649	Moray Eel	*Gymnothorax polyuranodon*	Other
5631	Richardson'S Moray	*Gymnothorax richardsoni*	Other
5632	Yellow-Headed Moray	*Gymnothorax rueppelliae*	Other
5618	Moray Eel	*Gymnothorax sp cf Melatremus*	Other
5633	Undulated Moray	*Gymnothorax undulatus*	Other
5634	Zonipectis Moray	*Gymnothorax zonipectus*	Other
32700	Sweetlips	*Haemulidae*	Other
25811	Brock'S Pipefish	*Halicampus brocki*	Other
25828	Duncker'S Pipefish	*Halicampus dunckeri*	Other
25812	Samoan Pipefish	*Halicampus mataafae*	Other
25829	Glittering Pipefish	*Halicampus nitidus*	Other
44301	Spikefish	*Halimochirurgus alcocki*	Other
39004	Triplefin	*Helcogramma capidata*	Other
39005	Triplefin	*Helcogramma chica*	Other
39006	Triplefin	*Helcogramma hudsoni*	Other
35069	Damselfish	*Hemiglyphidodon plagiometopon*	Other
20751	Halfbeak	*Hemiramphus archipelagicus*	Other
20758	Halfbeak	*Hemiramphus far*	Other
20760	Halfbeak	*Hemiramphus lutkei*	Other
20750	Halfbeak	*Hemirhamphidae*	Other

34322	Pyrimid Butterflyfish	*Hemitaurichthys polylepis*	Other
34323	Butterflyfish	*Hemitaurichthys thompsoni*	Other
34324	Longfinned Bannerfish	*Heniochus acuminatus*	Other
34325	Pennant Bannerfish	*Heniochus chrysostomus*	Other
34341	Bannerfish	*Heniochus diphreutes*	Other
34326	Masked Bannerfish	*Heniochus monoceros*	Other
34327	Singular Butterflyfish	*Heniochus singularis*	Other
34328	Humphead Bannerfish	*Heniochus varius*	Other
4308	Gold Spot Herring	*Herklotsichthys quadrimaculatus*	Other
6204	Conger Eel	*Heteroconger hassi*	Other
40606	Goby	*Heteroeleotris sp*	Other
30301	Glasseye	*Heteropriacanthus cruentatus*	Other
2006	Whipray	*Himantura fai*	Other
2005	Wh Tail Whipray	*Himantura granulata*	Other
2003	Leopard Ray	*Himantura uarnak*	Other
25830	Pipefish	*Hippichthys cyanospilos*	Other
25831	Pipefish	*Hippichthys spicifer*	Other
25809	Pipefish	*Hippocampus histrix*	Other
25832	Pipefish	*Hippocampus kuda*	Other
19212	Sargassum Fish	*Histrio histrio*	Other
28965	Fairy Basslet	*Holanthias borbonius*	Other
28966	Fairy Basslet	*Holanthias katayamai*	Other

30801	Tilefish	*Hoplolatilus cuniculus*	Other
30802	Tilefish	*Hoplolatilus fronticinctus*	Other
30803	Tilefish	*Hoplolatilus starcki*	Other
21807	Silverside	*Hypoatherina barnesi*	Other
21808	Silverside	*Hypoatherina cylindrica*	Other
21802	Silverside	*Hypoatherina ovalaua*	Other
20753	Halfbeak	*Hyporhamphus acutus acutus*	Other
20754	Halfbeak	*Hyporhamphus affinis*	Other
20755	Halfbeak	*Hyporhamphus dussumieri*	Other
6623	Snake Eel	*Ichthyapus vulturus*	Other
26430	Spiny Devilfish	*Inimicus didactylus*	Other
21901	Keeled Silverside	*Iso hawaiiensis*	Other
35210	6-Band Hawkfish	*Isocirrhitus sexfasciatus*	Other
21900	Keeled Silversides	Isonidae	Other
39265	Beautiful Rockskipper	*Istiblennius bellus*	Other
39217	Blenny	*Istiblennius chrysospilos*	Other
39266	Streaky Rockskipper	*Istiblennius dussumieri*	Other
39219	Blenny	*Istiblennius edentulus*	Other
39267	Interrupted Rockskipper	*Istiblennius interruptus*	Other
39220	Blenny	*Istiblennius lineatus*	Other
40607	Goby	*Istigobius decoratus*	Other
40608	Goby	*Istigobius ornatus*	Other
40609	Goby	*Istigobius rigilius*	Other

40610	Goby	*Istigobius spence*	Other
41900	Billfishes	Istiophoridae	Other
901	Mackerel Shark	*Isurus oxyrhinchus*	Other
5402	Bl-Nostril False Moray	*Kaupichthys atronasus*	Other
5403	Shortfin False Moray	*Kaupichthys brachychirus*	Other
5401	Common False Moray	*Kaupichthys hyoproroides*	Other
40612	Goby	*Kellogella quindecimfasciata*	Other
40611	Goby	*Kelloggella cardinalis*	Other
40701	Sand Dart	*Kraemeria bryani*	Other
40702	Sand Dart	*Kraemeria cunicularia*	Other
40703	Sand Dart	*Kraemeria samoensis*	Other
40700	Sand Darts	Kraemeriidae	Other
30103	Dark-Margined Flagtail	*Kuhlia marginata*	Other
30101	Barred Flagtail	*Kuhlia mugil*	Other
30102	River Flagtail	*Kuhlia rupestris*	Other
30100	Flagtails	*Kuhliidae*	Other
44601	Longhorn Cowfish	*Lactoria cornuta*	Other
44602	Spiny Cowfish	*Lactoria diaphana*	Other
44605	Thornback Cowfish	*Lactoria fornasini*	Other
44817	Oceanic Blaasop	*Lagocephalus lagocephalus*	Other
44818	Silverstripe Blaasop	*Lagocephalus sceleratus*	Other
900			

6627	Oriental Snake Eel	*Lamnostoma orientalis*	Other
31800	Ponyfishes	Leiognathidae	Other
31806	Slipmouth	*Leiognathus bindus*	Other
31804	Slipmouth	*Leiognathus elongatus*	Other
31801	Common Slipmouth	*Leiognathus equulus*	Other
31805	Slipmouth	*Leiognathus smithursti*	Other
31803	Oblong Slipmouth	*Leiognathus stercorarius*	Other
6605	Saddled Snake Eel	*Leiuranus semicinctus*	Other
43401	Clingfish	*Lepadichthys caritus*	Other
43402	Clingfish	*Lepadichthys minor*	Other
35048	Fusilier Damsel	*Lepidozygus tapienosoma*	Other
16901	Barracudina	*Lestidium nudun*	Other
37402	Sand Burrower	*Limnichthys donaldsoni*	Other
43403	Clingfish	*Liobranchia stria*	Other
28991	Swissguard Basslet	*Liopropoma lunulatum*	Other
28997	Swissguard Basslet	*Liopropoma maculatum*	Other
28992	Swissguard Basslet	*Liopropoma mitratum*	Other
28993	Swissguard Basslet	*Liopropoma multilineatum*	Other
28994	Pallid Basslet	*Liopropoma pallidum*	Other
28995	Pinstripe Basslet	*Liopropoma susumi*	Other
28996	Redstripe Basslet	*Liopropoma tonstrinum*	Other
39251	Blenny	*Litobranchus fowleri*	Other
35908	Giantscale Mullet	*Liza melinoptera*	Other

32501	Triplefin	*Lobotes surinamensis*	Other
32500	Tripletails	Lobotidae	Other
40519	Goby	*Lotilia graciliosa*	Other
28981	Magenta Slender Basslet	*Luzonichthys waitei*	Other
28982	Whitley'S Slender Basslet	*Luzonichthys whitleyi*	Other
40613	Goby	*Macrodontogobius wilburi*	Other
40520	Goby	*Mahidolia mystacina*	Other
30800	Tilefishes	Malacanthidae	Other
30851	Quakerfish	*Malacanthus brevirostris*	Other
30852	Striped Blanquillo	*Malacanthus latovittatus*	Other
2301	Manta Ray	*Manta birostris*	Other
45001	Sharptail Sunfish	*Masturus lanceolatus*	Other
4700	Tarpons	*Megalopidae*	Other
4701	Indo-Pacific Tarpon	*Megalops cyprinoides*	Other
39233	Poison-Fang Blenny	*Meiacanthus anema*	Other
39223	Poison-Fang Blenny	*Meiacanthus atrodorsalis*	Other
39258	1-Stripe Poison-Fang Blenny	*Meiacanthus ditrema*	Other
39259	Striped Poison-Fang Blenny	*Meiacanthus grammistes*	Other
44505	Black Triggerfish	*Melichthys niger*	Other
44506	Pinktail Triggerfish	*Melichthys vidua*	Other
18653	Brotula	*Microbrotula sp*	Other
41000	Wormfish	*Microdesmidae*	Other
25817	Anderson'S Shrt-Nosed	*Micrognathus*	Other

	Pipefish	*andersonii*	
25810	Pygmy Short-Nosed Pipefish	*Micrognathus brevirostris pygmaeus*	Other
25833	Pipefish	*Microphis brachyurus brachyurus*	Other
25834	Pipefish	*Microphis brevidorsalis*	Other
25835	Pipefish	*Microphis leiaspis*	Other
25836	Pipefish	*Microphis manadensis*	Other
25837	Pipefish	*Microphis retzii*	Other
25813	Ventricose Milda	*Minyichthys myersi*	Other
2300	Myer'S Pipefish	*Mobulidae*	Other
45000	Ocean Sunfishes	*Molidae*	Other
44550	Filefishes	*Monacanthidae*	Other
33300	Monos	*Monodactylidae*	Other
33301	Mono	*Monodactylus argenteus*	Other
18000	Codlings	*Moridae*	Other
5103	Rusty Spaghetti Eel	*Moringua ferruginea*	Other
5102	Java Spaghetti Eel	*Moringua javanica*	Other
5101	Spaghetti Eel	*Moringua microchir*	Other
5100	Worm Eel	*Moringuidae*	Other
40614	Goby	*Mugilogobius tagala*	Other
40615	Goby	*Mugilogobius villa*	Other
6300	Pike Eels	*Muraenesocidae*	Other
6301	Pike Conger	*Muraenesox cinereus*	Other
6612	Snake Eel	*Muraenichthys gymnotus*	Other

6606	Snake Eel	*Muraenichthys laticaudata*	Other
6607	Snake Eel	*Muraenichthys macropterus*	Other
6613	Snake Eel	*Muraenichthys schultzi*	Other
6614	Snake Eel	*Muraenichthys sibogae*	Other
5600	Morays	*Muraenidae*	Other
16700	Lanternfishes	*Myctophidae*	Other
16702	Laternfish	*Myctophum brachygnathos*	Other
2200	Eagle Ray	*Myliobatidae*	Other
6624	Snake Eel	*Myrichthys bleekeri*	Other
6608	Banded Snake Eel	*Myrichthys colubrinus*	Other
6610	Spotted Snake Eel	*Myrichthys maculosus*	Other
6615	Snake Eel	*Myrophis uropterus*	Other
200	Hagfish	*Myxinidae*	Other
201	Hagfish	*Eptaptretus carlhubbsi*	Other
39252	Combtooth Blenny	*Nannosalarius nativitatus*	Other
701	Nurse Shark	*Nebrius ferrugineus*	Other
1110	Lemon Shark	*Negaprion acutidens*	Other
41010	Decorated Dartfish	*Nemateleotris decora*	Other
41003	Helfrichs' Dartfish	*Nemateleotris helfrichi*	Other
41004	Fire Dartfish	*Nemateleotris magnifica*	Other
32400	Threadfin Breams	*Nemipteridae*	Other
32900	Breams	*Nemipteridae*	Other

32412	Forktail Bream	*Nemipterus furcosus*	Other
32409	Butterfly Bream	*Nemipterus hexadon*	Other
32410	Notched Butterfly Bream	*Nemipterus peronii*	Other
32411	Butterfly Bream	*Nemipterus tolu*	Other
35205	Flame Hawkfish	*Neocirrhitus armatus*	Other
35072	Royal Damsel	*Neoglyphidodon melas*	Other
35073	Yellowfin Damsel	*Neoglyphidodon nigroris*	Other
35070	Coral Demoiselle	*Neopomacentrus nemurus*	Other
35071	Freshwater Demoiselle	*Neopomacentrus taeniurus*	Other
35047	Violet Demoiselle	*Neopomacentrus violascens*	Other
42200	Man-Of-War Fish	*Nomeidae*	Other
39007	Triplefin	*Norfolkia brachylepis*	Other
44507	Redtooth Triggerfish	*Odonus niger*	Other
35909	Foldlip Mullet	*Oedalechilus labiosus*	Other
39263	Mangrove Blenny	*Omobranchus obliquus*	Other
39224	Blenny	*Omobranchus rotundiceps*	Other
39256	Blenny	*Omox biporos*	Other
18706	Bivalve Pearlfish	*Onuxodon fowleri*	Other
6600	Snake Eel	*Ophichthidae*	Other
6611	Dark-Shouldered Snake Eel	*Ophichthus cephalozona*	Other
18600	Cusk Eel	*Ophidiidae*	Other
40405	Sleeper	*Ophieleotris aporos*	Other

40406	Sleeper	*Ophiocara porocephala*	Other
36600	Jawfishes	*Opisthognathidae*	Other
36601	Variable Jawfish	*Opisthognathus sp A*	Other
36602	Wass' Jawfish	*Opisthognathus sp B*	Other
34700	Knifejaws	Oplegnathidae	Other
34701	Spotted Knifejaw	*Oplegnathus punctatus*	Other
40528	Goby	*Oplopomops diacanthus*	Other
40529	Goby	*Oplopomus oplopomus*	Other
40616	Goby	*Opua nephodes*	Other
700	Nurse,Zebra,Carpet Sharks	Orectolobidae	Other
34601	Tilapia	*Oreochromis mossambicus*	Other
44600	Boxfish, Cowfish	Ostraciidae	Other
44603	Cube Trunkfish	*Ostracion cubicus*	Other
44604	Spotted Trunkfish	*Ostracion meleagris meleagris*	Other
44606	Reticulate Boxfish	*Ostracion solorensis*	Other
35206	Longnose Hawkfish	*Oxycirrhitus typus*	Other
40407	Sleeper	*Oxyleotris lineolatus*	Other
44555	Longnose Filefish	*Oxymonacanthus longirostris*	Other
20759	Smallwing Flying Fish	*Oxyporhamphus micropterus micropter*	Other
40617	Goby	*Oxyurichthys guibei*	Other
40618	Goby	*Oxyurichthys microlepis*	Other
40619	Goby	*Oxyurichthys*	Other

		ophthalmonema	
40620	Goby	*Oxyurichthys papuensis*	Other
40621	Goby	*Oxyurichthys tentacularis*	Other
40622	Goby	*Padanka sp*	Other
40623	Goby	*Palutris pruinosa*	Other
40624	Goby	*Palutris reticularis*	Other
35207	Arc-Eyed Hawkfish	*Paracirrhitus arcatus*	Other
35208	Freckeled Hawkfish	*Paracirrhitus forsteri*	Other
35209	Whitespot Hawkfish	*Paracirrhitus hemistictus*	Other
40625	Goby	*Paragobiodon echinocephalus*	Other
40626	Goby	*Paragobiodon lacunicolus*	Other
40627	Goby	*Paragobiodon melanosoma*	Other
40628	Goby	*Paragobiodon modestus*	Other
40629	Goby	*Paragobiodon xanthosoma*	Other
41012	Seychelle'S Wormfish	*Paragunnellichthy seychellensis*	Other
16900	Barracudinas	Paralepididae	Other
44556	Blacksaddle Mimic	*Paraluteres prionurus*	Other
44560	Filefish	*Paramonacanthus cryptodon*	Other
44561	Filefish	*Paramonacanthus japonicus*	Other

37102	Latticed Sandperch	*Parapercis clathrata*	Other
37103	Cylindrical Sandperch	*Parapercis cylindrica*	Other
37101	Blk-Dotted Sandperch	*Parapercis millipunctata*	Other
37105	Red-Barred Sandperch	*Parapercis multiplicata*	Other
37106	Black-Banded Sandperch	*Parapercis tetracantha*	Other
37104	Blotchlip Sandperch	*Parapercis xanthozona*	Other
33402	Sandperch	*Parapriacanthus ransonneti*	Other
26433	Mcadam'S Scorpionfish	*Parascorpaena mcadamsi*	Other
26426	Mozambique Scorpionfish	*Parascorpaena mossambica*	Other
44105	Peacock Sole	*Pardachirus pavoninus*	Other
39225	Blenny	*Parenchelyurus hepburni*	Other
20607	Flying Fish	*Parexocoetus brachypterus*	Other
20608	Flying Fish	*Parexocoetus mento*	Other
41013	Beautiful Hover Goby	*Parioglossus formosus*	Other
41014	Lined Hover Goby	*Parioglossus lineatus*	Other
41015	Naked Hover Goby	*Parioglossus nudus*	Other
41016	Palustris Hover Goby	*Parioglossus palustris*	Other
41017	Rainford'S Hover Goby	*Parioglossus rainfordi*	Other
41018	Rao'S Hover Goby	*Parioglossus raoi*	Other
41019	Taeniatus Hover Goby	*Parioglossus taeniatus*	Other
41020	Vertical Hover Goby	*Parioglossus verticalis*	Other

2007	Shortsnouted Ray	*Pasinachus sephen*	Other
28600	Dragonfish	Pegasidae	Other
33400	Sweepers	*Pempherididae*	Other
33401	Bronze Sweeper	*Pempheris oualensis*	Other
34500	Armourheads	*Pentacerotidae*	Other
32901	Smalltooth Whiptail	*Pentapodus caninus*	Other
32902	3-Striped Whiptail	*Pentapodus trivittatus*	Other
37000	Duckbills	Percophidae	Other
40630	Goby	*Periophthalmus argentilineatus*	Other
40631	Goby	*Periophthalmus kalolo*	Other
44567	Yelloweye Filefish	*Pervagor alternans*	Other
44562	Orangetail Filefish	*Pervagor aspricaudatus*	Other
44557	Blackbar Filefish	*Pervagor janthinosoma*	Other
44563	Blackheaded Filefish	*Pervagor melanocephalus*	Other
44564	Blacklined Filefish	*Pervagor nigrolineatus*	Other
39260	Blenny	*Petroscirtes breviceps*	Other
39226	Blenny	*Petroscirtes mitratus*	Other
39261	Blenny	*Petroscirtes thepassi*	Other
39262	Blenny	*Petroscirtes variabilis*	Other
39227	Blenny	*Petroscirtes xestus*	Other
6625	Snake Eel	*Phenamonas cooperi*	Other
24202	Flashlightfish	*Photoblepheron palpebratus*	Other
25814	Pipefish	*Phoxocampus*	Other

		diacanthus	
6626	Snake Eel	*Phyllophichthus xenodontus*	Other
18001	Codling	*Physiculus sp*	Other
37100	Sand Perch	Pinguipedidae	Other
39228	Blenny	*Plagiotremus laudandus*	Other
39229	Red Sabbertooth Blenny	*Plagiotremus rhynorhynchus*	Other
39230	Blenny	*Plagiotremus tapienosoma*	Other
34001	Batfish	*Platax orbicularis*	Other
34002	Pinnate Spadefish	*Platax pinnatus*	Other
34003	Longfin Spadefish	*Platax teira*	Other
20702	Keeled Needlefish	*Platybelone argalus platyura*	Other
27300	Flathead	Platycephalidae	Other
32710	2-Lined Sweetlips	*Plectorhinchus albovittatus*	Other
32706	Celebes Sweetlips	*Plectorhinchus celebecus*	Other
32707	Harlequin Sweetlips	*Plectorhinchus chaetodonoides*	Other
32712	Sweetlip	*Plectorhinchus flavomaculatus*	Other
32703	Gibbus Sweetlips	*Plectorhinchus gibbosus*	Other
32708	Lined Sweetlips	*Plectorhinchus lessonii*	Other
32709	Goldman'S Sweetlips	*Plectorhinchus lineatus*	Other
32705	Giant Sweetlips	*Plectorhinchus obscurus*	Other

32704	Spotted Sweetlips	*Plectorhinchus picus*	Other
32713	Sweetlip	*Plectorhinchus sp*	Other
32702	Oriental Sweetlips	*Plectorhinchus vittatus*	Other
28987	Fourmanoir'S Basslet	*Plectranthias fourmanoiri*	Other
28968	Basslet	*Plectranthias kamii*	Other
28985	Long-Finned Basslet	*Plectranthias longimanus*	Other
28969	Pygmy Basslet	*Plectranthias nanus*	Other
28990	Basslet	*Plectranthias rubrifasciatus*	Other
28986	Basslet	*Plectranthias winniensis*	Other
35033	Dick'S Damsel	*Plectroglyphidodo dickii*	Other
35034	Bright-Eye Damsel	*Plectroglyphidodo imparipennis*	Other
35035	Johnston Isle Damsel	*Plectroglyphidodo johnstonianus*	Other
35036	Jewel Damsel	*Plectroglyphidodo lacrymatus*	Other
35037	White-Band Damsel	*Plectroglyphidodo leucozonus*	Other
35038	Phoenix Isle Damsel	*Plectroglyphidodo phoenixensis*	Other
29400	Longfins	Plesiopidae	Other
29402	Red-Tipped Longfin	*Plesiops caeruleolineatus*	Other
29403	Bluegill Longfin	*Plesiops corallicola*	Other
29405	Sharp-Nosed Longfin	*Plesiops oxycephalus*	Other

40632	Goby	*Pleurosicya bilobatus*	Other
40664	Caroline Ghost Goby	*Pleurosicya carolinensis*	Other
40665	Blue Coral Ghost Goby	*Pleurosicya coerulea*	Other
40666	Fringed Ghost Goby	*Pleurosicya fringella*	Other
40667	Michael'S Ghost Goby	*Pleurosicya micheli*	Other
40668	Common Ghost Goby	*Pleurosicya mossambica*	Other
40633	Goby	*Pleurosicya muscarum*	Other
40669	Plicata Ghost Goby	*Pleurosicya plicata*	Other
14900	Eel Catfishes	Plotosidae	Other
14901	Striped Eel Catfish	*Plotosus lineatus*	Other
6207	Barred Sand Conger	*Poeciloconger fasciatus*	Other
29004	Spotted Soapfish	*Pogonoperca punctata*	Other
36101	6 Feeler Threadfin	*Polydactylus sexfilis*	Other
17501	Beardfish	*Polymixia japonica*	Other
17500	Beardfish	Polymixiidae	Other
36100	Threadfins	Polynemidae	Other
34350	Angelfishes	Pomacanthidae	Other
34365	Emperor Anglefish	*Pomacanthus imperator*	Other
34372	Blue-Girdled Angelfish	*Pomacanthus navarchus*	Other
34375	Semicircle Angelfish	*Pomacanthus semicirculatus*	Other
34373	6-Banded Angelfish	*Pomacanthus sexstriatus*	Other
34374	Blue-Faced Angelfish	*Pomacanthus xanthometopon*	Other
35000	Damselfishes	Pomacentridae	Other

35087	Damselfish	*Pomacentrus adelus*	Other
35039	Ambon Damsel	*Pomacentrus amboinensis*	Other
35094	Goldbelly Damsel	*Pomacentrus auriventris*	Other
35074	Speckled Damsel	*Pomacentrus bankanensis*	Other
35081	Charcoal Damsel	*Pomacentrus brachialis*	Other
35075	Burrough'S Damsel	*Pomacentrus burroughi*	Other
35084	White-Tail Damsel	*Pomacentrus chrysurus*	Other
35076	Neon Damsel	*Pomacentrus coelestis*	Other
35077	Outer Reef Damsel	*Pomacentrus emarginatus*	Other
35078	Blue-Spot Damsel	*Pomacentrus grammorhynchus*	Other
35092	Lemon Damsel	*Pomacentrus moluccensis*	Other
35086	Nagasaki Damsel	*Pomacentrus nagasakiensis*	Other
35093	Black-Axil Damsel	*Pomacentrus nigromanus*	Other
35040	Sapphire Damsel	*Pomacentrus pavo*	Other
35082	Philappine Damsel	*Pomacentrus philippinus*	Other
35083	Reid'S Damsel	*Pomacentrus reidi*	Other
35085	Blueback Damsel	*Pomacentrus simsiang*	Other
35041	Princess Damsel	*Pomacentrus vaiuli*	Other
35088	Slender Reef-Damsel	*Pomachromis exilis*	Other
35042	Guam Damsel	*Pomachromis guamensis*	Other

32711	Common Javelinefish	*Pomadasyus kaakan*	Other
26404	Lg-Headed Scorpionfish	*Pontinus macrocephalus*	Other
26431	Scorpionfish	*Pontinus sp*	Other
26452	Scopionfish	*Pontinus tentacularis*	Other
39231	Blenny	*Prealticus amboinensis*	Other
39232	Blenny	*Prealticus natalis*	Other
30300	Bigeyes	Priacanthidae	Other
30305	Bigeye	*Priacanthus alalaua*	Other
30302	Goggle-Eye	*Priacanthus hamrur*	Other
40634	Goby	*Priolepis cincta*	Other
40635	Goby	*Priolepis farcimen*	Other
40636	Goby	*Priolepis inhaca*	Other
40637	Goby	*Priolepis semidoliatus*	Other
30303	Bigeye	*Pristigenys meyeri*	Other
20609	Flying Fish	*Prognichthys albimaculatus*	Other
20610	Flying Fish	*Prognichthys sealei*	Other
42201	Freckeled Driftfish	*Psenes cyanophrys*	Other
44568	Rhino Leatherjacket	*Pseudalutarias nasicornis*	Other
30448	Cardinalfish	*Pseudamia amblyuroptera*	Other
30449	Cardinalfish	*Pseudamia gelatinosa*	Other
30450	Cardinalfish	*Pseudamia hayashii*	Other
30461	Cardinalfish	*Pseudamia zonata*	Other
30428	Cardinalfish	*Pseudamiops*	Other

		gracilicauda	
28971	Bartlet'S Fairy Basslet	*Pseudanthias bartlettorum*	Other
28972	Bicolor Fairy Basslet	*Pseudanthias bicolor*	Other
28961	Red-Bar Fairy Basslet	*Pseudanthias cooperi*	Other
28973	Peach Fairy Basslet	*Pseudanthias dispar*	Other
28979	Fairy Basslet	*Pseudanthias huchtii*	Other
28974	Lori'S Anthias	*Pseudanthias lori*	Other
28962	Purple Queen	*Pseudanthias pascalus*	Other
28963	Sq-Spot Fairy Basslet	*Pseudanthias pleurotaenia*	Other
28975	Randall'S Fairy Basslet	*Pseudanthias randalli*	Other
28977	Smithvaniz' Fairy Basslet	*Pseudanthias smithvanizi*	Other
28964	Fairy Basslet	*Pseudanthias sp*	Other
28980	Fairy Basslet	*Pseudanthias squammipinnis*	Other
28976	Y Striped Fairy Basslet	*Pseudanthias tuka*	Other
28978	L-Finned Fairy Basslet	*Pseudanthias ventralis*	Other
5637	White Ribbon Eel	*Pseudechidna brummeri*	Other
44508	Ymargin Triggerfish	*Pseudobalistes flavimarginatus*	Other
44509	Blue Triggerfish	*Pseudobalistes fuscus*	Other
29100	Dottybacks	*Pseudochromidae*	Other
29101	Surge Dottyback	*Pseudochromis cyanotaenia*	Other
29102	Dusky Dottyback	*Pseudochromis fuscus*	Other

29103	Marshall Is Dottyback	*Pseudochromis marshallensis*	Other
29404	Dottyback	*Pseudochromis melanotaenia*	Other
29105	Long-Finned Dottyback	*Pseudochromis polynemus*	Other
29106	Magenta Dottyback	*Pseudochromis porphyreus*	Other
40638	Goby	*Pseudogobius javanicus*	Other
29202	Soapfish	*Pseudogramma polyacantha*	Other
29203	Soapfish	*Pseudogramma sp*	Other
29200	Soapfishes	*Pseudogrammidae*	Other
34501	Amourhead	*Pseudopentaceros pectoralis*	Other
29111	Robust Dottyback	*Pseudoplesiops multisquamatus*	Other
29107	Revelle'S Basslet	*Pseudoplesiops revellei*	Other
29108	Rose Island Basslet	*Pseudoplesiops rosae*	Other
29110	Basslet	*Pseudoplesiops sp*	Other
29109	Hidden Basslet	*Pseudoplesiops typus*	Other
41005	Blackfin Dartfish	*Ptereleotris evides*	Other
41021	Filament Dartfish	*Ptereleotris hanae*	Other
41006	Spot-Tail Dartfish	*Ptereleotris heteroptera*	Other
41009	Dartfish	*Ptereleotris lineopinnis*	Other
41007	Pearly Dartfish	*Ptereleotris microlepis*	Other
41008	Zebra Dartfish	*Ptereleotris zebra*	Other

32357	Yellowstreak Fusilier	*Pterocaesio lativittata*	Other
32353	Twinstripe Fusilier	*Pterocaesio marri*	Other
32360	Ruddy Fusilier	*Pterocaesio pisang*	Other
32362	Mosaic Fusilier	*Pterocaesio tesselatata*	Other
32354	Bluestreak Fusilier	*Pterocaesio tile*	Other
32358	3-Striped Fusilier	*Pterocaesio trilineata*	Other
26405	Spotfin Lionfish	*Pterois antennata*	Other
26406	Clearfin Lionfish	*Pterois radiata*	Other
26407	Turkeyfish	*Pterois volitans*	Other
26602	Ocellated Gurnard	*Pterygiotrigla multiocellata*	Other
26601	Gurnard	*Pterygiotrigla sp*	Other
31301	Slender Suckerfish	*Ptheirichthys lineatus*	Other
34366	Regal Anglefish	*Pygoplites diacanthus*	Other
28989	Fairy Basslet	*Rabaulichthys sp*	Other
45003	Trunkfish	*Ranzania laevis*	Other
41612	Mackerel	*Rastrelliger brachysoma*	Other
41610	Striped Mackerel	*Rastrelliger kanagurta*	Other
40639	Goby	*Redigobius bikolanus*	Other
40640	Goby	*Redigobius horiae*	Other
40641	Goby	*Redigobius sapangus*	Other
31302	Remora	*Remora remora*	Other
30451	Cardinalfish	*Rhabdamia cypselurus*	Other
30452	Cardinalfish	*Rhabdamia gracilis*	Other

39234	Blenny	*Rhabdoblenius rhabdotrachelus*	Other
39250		*Rhabdoblennius ellipes*	Other
39235	Blenny	*Rhabdoblennius snowi*	Other
1701	Guitarfish	*Rhinchobatus djiddensis*	Other
44510	Picassofish	*Rhinecanthus aculeatus*	Other
44511	Wedge Picassofish	*Rhinecanthus rectangulus*	Other
44520	Blackbelly Picassofish	*Rhinecanthus verrucosa*	Other
1700	Guitarfish	Rhinobatidae	Other
5636	Ribbon Eel	*Rhinomuraena quaesita*	Other
26428	Weedy Scorpionfish	*Rhinopias frondosa*	Other
31303	Remora	*Rhombochirus osteochir*	Other
44607	Smallnose Boxfish	*Rhynchostracion nasus*	Other
44608	Largenose Boxfish	*Rhynchostracion rhynorhynchus*	Other
9201	Telescopefish	*Rosaura indica*	Other
44569	Minute Filefish	*Rudarius minutus*	Other
39253		*Salarius alboguttatus*	Other
39236	Spotted Rock Blenny	*Salarius fasciatus*	Other
39255	Blenny	*Salarius luctuosus*	Other
39254	Blenny	*Salarius segmentatus*	Other
44000	Righteye Flounders	Samaridae	Other
44001	3 Spot Flounder	*Samariscus triocellatus*	Other
16001	Graceful Lizardfish	*Saurida gracilis*	Other
16002	Nebulous Lizardfish	*Saurida nebulosa*	Other

34100	Scats	*Scatophagidae*	Other
34101	Scat	*Scatophagus argus*	Other
40101	Schindleriid	*Schindleria praematurus*	Other
40100	Shindleriid	*Schindleriidae*	Other
6616	Snake Eel	*Schismorhinchus labialis*	Other
6617	Snake Eel	*Schultzidia johnstonensis*	Other
6618	Snake Eel	*Schultzidia retropinnis*	Other
32404	Spinecheek	*Scolopsis affinis*	Other
32402	2 Line Spinecheek	*Scolopsis bilineatus*	Other
32406	Ciliate Spinecheek	*Scolopsis ciliatus*	Other
32401	Bl And Wh Spinecheek	*Scolopsis lineatus*	Other
32403	Margarite'S Spinecheek	*Scolopsis margaritifer*	Other
32407	Spinecheek	*Scolopsis taeniopterus*	Other
32405	3 Line Spinecheek	*Scolopsis trilineatus*	Other
32408	Spinecheek	*Scolopsis xenochrous*	Other
41611	Narrow-Barred King Mackerel	*Scomberomorus commerson*	Other
26400	Scorpionfish	Scorpaenidae	Other
26413	Guam Scorpionfish	*Scorpaenodes guamensis*	Other
26429	Hairy Scorpionfish	*Scorpaenodes hirsutus*	Other
26414	Kellogg'S Scorpionfish	*Scorpaenodes kelloggi*	Other
26412	Minor Scorpionfish	*Scorpaenodes minor*	Other
26415	Coral Scorpionfish	*Scorpaenodes parvipinnis*	Other
26420	Blotchfin Scorpionfish	*Scorpaenodes varipinis*	Other

26417	Devil Scorpionfish	*Scorpaenopsis diabolus*	Other
26421	Pygmy Scorpionfish	*Scorpaenopsis fowleri*	Other
26422	Flasher Scorpionfish	*Scorpaenopsis macrochir*	Other
26416	Tassled Scorpionfish	*Scorpaenopsis oxycephala*	Other
26434	Papuan Scorpionfish	*Scorpaenopsis papuensis*	Other
26432	Scorpionfish	*Scorpaenopsis sp*	Other
5654	Tiger Snake Moray	*Scuticaria tigrinis*	Other
26408	Yellowspotted Scorpionfish	*Sebastapistes cyanostigma*	Other
26409	Galactacma Scorpionfish	*Sebastapistes galactacma*	Other
26410	Mauritius Scorpionfish	*Sebastapistes mauritiana*	Other
26425	Barchin Scorpionfish	*Sebastapistes strongia*	Other
31807	Pugnose Soapy	*Secutor ruconius*	Other
28970	Basslet	*Selenanthias myersi*	Other
28988	Hawkfish Anthias	*Serranocirrhitus latus*	Other
40645	Goby	*Sicyopterus macrostetholepis*	Other
40646	Goby	*Sicyopterus micrurus*	Other
40647	Goby	*Sicyopterus sp*	Other
40642	Goby	*Sicyopus leprurus*	Other
40644	Goby	*Sicyopus sp*	Other
40643	Goby	*Sicyopus zosterophorum*	Other
5615	Peppered Moray	*Sideria picta*	Other

5617	White-Eyed Moray	*Sideria prosopeion*	Other
40530	Goby	*Signigobius biocellatus*	Other
40531	Goby	*Silhouettea sp*	Other
30700	Sillagos	*Sillaginidae*	Other
30701	Cardinalfish	*Sillago sihama*	Other
30431	Cardinalfish	*Siphamia fistulosa*	Other
30459	Cardinalfish	*Siphamia fuscolineata*	Other
30430	Cardinalfish	*Siphamia versicolor*	Other
44101	Banded Sole	*Soleichthys heterohinos*	Other
44100	Soles	Soleidae	Other
25700	Ghost Pipefish	*Solenostomidae*	Other
25701	Ghost Pipefish	*Solenostomus cyanopterus*	Other
25702	Ornate Ghost Pipefish	*Solenostomus paradoxus*	Other
27305	Flathead	*Sorsogona welanderi*	Other
30434	Cardinalfish	*Sphaeramia nematoptera*	Other
30432	Cardinalfish	*Sphaeramia orbicularis*	Other
36004	Sharpfin Barracuda	*Sphyraena acutipinnis*	Other
36001	Great Barracuda	*Sphyraena barracuda*	Other
36008	Yellowtail Barracuda	*Sphyraena flavicauda*	Other
36003	Blackspot Barracuda	*Sphyraena forsteri*	Other
36007	Arrow Barracuda	*Sphyraena novaehollandiae*	Other
36002	Pygmy Barracuda	*Sphyraena obtusata*	Other
36006	Slender Barracuda	*Sphyraena putnamiae*	Other

36005	Blackfin Barracuda	*Sphyraena qenie*	Other
36000	Barracudas	Sphyraenidae	Other
4301	Blue Sprat	*Spratelloides delicatulus*	Other
4305	Silver Sprat	*Spratelloides gracilis*	Other
39237	Blenny	*Stanulus seychellensis*	Other
35043	White-Bar Gregory	*Stegastes albifasciatus*	Other
35044	Pacific Gregory	*Stegastes fasciolatus*	Other
35045	Farmerfish	*Stegastes lividus*	Other
35046	Dusky Farmerfish	*Stegastes nigricans*	Other
702	Leopard Shark	*Stegastoma varium*	Other
21809	Panatella Silverside	*Stenatherina panatella*	Other
40648	Goby	*Stenogobius genivittatus*	Other
40649	Goby	*Stenogobius sp*	Other
8900	Hatchetfishes	*Sternoptichidae*	Other
40650	Goby	*Stiphodon elegans*	Other
40651	Goby	*Stiphodon sp*	Other
4408	Samoan Anchovy	*Stolephorus apiensis*	Other
4404	Indian Anchovy	*Stolephorus indicus*	Other
4407	Gold Esurine Anchovy	*Stolephorus insularis*	Other
4409	Caroline Islands Anchovy	*Stolephorus multibranchus*	Other
4403	West Pacific Anchovy	*Stolephorus pacificus*	Other
4499	Anchovy	*Stolephorus sp*	Other
20703	Reef Needlefish	*Strongylura incisa*	Other
20705	Littoral Needlefish	*Strongylura leiura leiura*	Other

5638	Giant Esturine Moray	*Strophidon sathete*	Other
44512	Scythe Triggerfish	*Sufflamen bursa*	Other
44513	Halfmoon Triggerfish	*Sufflamen chrysoptera*	Other
44514	Bridle Triggerfish	*Sufflamen freanatus*	Other
32371	Symphysanid	*Symphysanodon typus*	Other
32370	Sympysanodon	*Symphysanodontidae*	Other
26418	Stonefish	*Synanceia verrucosa*	Other
5700	Cutthroat Eel	*Synaphobranchidae*	Other
5701	Cutthroat Eel	*Synaphobranchus sp*	Other
43504	Cirlcled Dragonet	*Synchiropus circularis*	Other
43511	Ladd'S Dragonet	*Synchiropus laddi*	Other
45308	Morrison'S Dragonet	*Synchiropus morrisoni*	Other
43505	Ocellated Dragonet	*Synchiropus ocellatus*	Other
43510	Dragonet	*Synchiropus sp*	Other
43506	Mandarin Fish	*Synchiropus splendidus*	Other
43509	Pipefish, Seahorse	*Syngnathidae*	Other
25800	Alligator Pipefish	*Syngnathoides biaculeatus*	Other
25815	Lizardfish	Synodontidae	Other
16000	2-Spot Lizardfish	*Synodus binotatus*	Other
16003	Clearfin Lizardfish	*Synodus dermatogenys*	Other
16007	Reef Lizardfish	*Synodus englemanni*	Other
16004	Blackblotch Lizardfish	*Synodus jaculum*	Other
16005	Variegatus Lizardfish	*Synodus variegatus*	Other
16006	Leaf Fish	*Taenianotus triacanthus*	Other

26419	Goby	*Taenioides limicola*	Other
40652	Giant Reef Ray	*Taeniura meyeni*	Other
2002	Crescent-Banded Grunter	*Terapon jarbua*	Other
29901	Thornfishes	*Teraponidae*	Other
29900	Smooth Puffers	*Tetraodontidae*	Other
26451	Mangrove Waspfish	*Tetraroge barbata*	Other
26450	Waspfishes	*Tetrarogidae*	Other
4402	Little Priest	*Thryssa baelama*	Other
27302	Broadhead Flathead	*Thysanophrys arenicola*	Other
27303	Longsnout Flathead	*Thysanophrys chiltonae*	Other
27301	Fringlip Flathead	*Thysanophrys otaitensis*	Other
34602	Tilapia	*Tilapia zillii*	Other
33701	Banded Archerfish	*Toxotes jaculator*	Other
33700	Archerfishes	Toxotidae	Other
25816	Double-Ended Pipefish	*Trachyramphus bicoarctata*	Other
44300	Spikefishes	*Triacanthodidae*	Other
1108	Reef Whitetip Shark	*Triaenodon obesus*	Other
37200	Sand Divers	Trichonotidae	Other
37201	Micronesian Sand-Diver	*Trichonotus sp*	Other
26600	Gurnards	Triglidae	Other
40653	Goby	*Trimma caesiura*	Other
40654	Goby	*Trimma naudei*	Other
40655	Goby	*Trimma okinawae*	Other
40658	Goby	*Trimma sp A*	Other

40659	Goby	*Trimma sp B*	Other
40656	Goby	*Trimma taylori*	Other
40657	Goby	*Trimma tevegae*	Other
40660	Goby	*Trimmatom eviotops*	Other
44702	3 Tooth Puffer	*Triodon bursarius*	Other
44701	3 Tooth Puffer	*Triodon macropterus*	Other
44700	Tripletooth Puffers	*Triodontidae*	Other
39000	Triplefins	*Tripterygiidae*	Other
20706	Keeled Houndfish	*Tylosurus acus melanotus*	Other
20704	Houndfish	*Tylosurus crocodilis crocodilis*	Other
39009	Longjaw Triplefin	*Ucla xenogrammus*	Other
37800	Stargazers	*Uranoscopidae*	Other
37801	Stargazer	*Uranoscopus sp*	Other
2004	Porcupine Ray	*Urogymnus africanus*	Other
5639	Unicolor Snake Moray	*Uropterygius concolor*	Other
5660	Fiji Moray Eel	*Uropterygius fijiensis*	Other
5650	Brown-Spotted Snake Eel	*Uropterygius fuscoguttatus*	Other
5651	Gosline'S Snake Moray	*Uropterygius goslinei*	Other
5652	Moon Moray	*Uropterygius kamar*	Other
5642	Lg-Headed Snake Moray	*Uropterygius macrocephalus*	Other
5640	Marbled Snake Moray	*Uropterygius marmoratus*	Other

5641	Tidepool Snake Moray	*Uropterygius micropterus*	Other
5653	Lg-Spotted Snake Moray	*Uropterygius polyspilus*	Other
5643	Moray Eel	*Uropterygius supraforatus*	Other
5644	Moray Eel	*Uropterygius xanthopterus*	Other
2008	Roundray	*Urotrygon daviesi*	Other
40532	Glass Goby	*Valenciennea muralis*	Other
40663	Parva Goby	*Valenciennea parva*	Other
40533	Goby	*Valenciennea puellaris*	Other
40534	Goby	*Valenciennea sexguttatus*	Other
40536	Goby	*Valenciennea sp*	Other
40535	Goby	*Valenciennea strigatus*	Other
40521	Goby	*Vanderhorstia ambanoro*	Other
40661	Goby	*Vanderhorstia lanceolata*	Other
40522	Goby	*Vanderhorstia ornatissima*	Other
44515	Guilded Triggerfish	*Xanthichthys auromarginatus*	Other
44516	Bluelined Triggerfish	*Xanthichthys careuleolineatus*	Other
44521	Crosshatch Triggerfish	*Xanthichthys mento*	Other
40713	Wriggler	*Xenishthmus sp*	Other
40710	Flathead Wriggler	Xenisthmidae	Other

40712	Barred Wriggler	*Xenisthmus polyzonatus*	Other
44517	Triggerfish	*Xenobalistes tumidipectoris*	Other
39238	Blenny	*Xiphasia matsubarai*	Other
41250	Moorish Idols	*Zanclidae*	Other
41251	Moorish Idol	*Zanclus cornutus*	Other
20756	Esturine Halfbeak	*Zenarchopterus dispar*	Other
49400	ASSORTED REEF FISH	Misc. Reeffish	Misc. Reeffish
49110	SHALLOW BOTTOMFISH	Misc. Shallow bottomfish	Misc. Shallow bottomfish
49100	ASSORTED BOTTOMFISH	Misc. Bottomfish	Misc. Bottomfish
72600	Acanthaster planci	Crown-Of-Thorns	Other Invertebrates
79301	Actinopyga lecanora	Stonefish	Other Invertebrates
79302	Actinopyga miliaris	Blackfish	Other Invertebrates
79303	Actinopyga obesa	Sea Cucumber	Other Invertebrates
79304	Actinopyga sp	Sea Cucumber	Other Invertebrates
72500	Asterinidae	Starfish	Other Invertebrates
72400	Asteropidae	Starfish	Other Invertebrates
72100	Astropectinidae	Starfish	Other Invertebrates
79801	Bohadschia argus	Sea Cucumber	Other Invertebrates
79802	Bohadschia graeffei	Sea Cucumber	Other Invertebrates
79803	Bohadschia marmorata	Brown Sandfish	Other Invertebrates
79804	Bohadschia paradoxa	Sea Cucumber	Other Invertebrates
79805	Bohadschia sp	Sea Cucumber	Other Invertebrates
78900	Brissidae	Irregular Urchins	Other Invertebrates

97100	Cephea sp	Jellyfish	Other Invertebrates
78100	Cidaridae	Cidarians	Other Invertebrates
71000	Class Crinoidea	Crinoids	Other Invertebrates
78000	Class Echinoidea	Sea Urchins	Other Invertebrates
78800	Clypeasteridae		Other Invertebrates
79400	Cucumariidae	Sea Cucumbers	Other Invertebrates
78301	Diadema savignyi	Longspine Urchin	Other Invertebrates
78302	Diadema setosum	Longspine Urchin	Other Invertebrates
78300	Diadematidae	Sea Urchins	Other Invertebrates
78700	Echinoidea	Sea Urchins	Other Invertebrates
78600	Echinometridae	Sea Urchins	Other Invertebrates
72800	Echinosteridae	Reef Starfish	Other Invertebrates
78304	Echinothrix calamaris	Longspine Urchin	Other Invertebrates
78303	Echinothrix diadema	Longspine Urchin	Other Invertebrates
78200	Echinothuriidae	Sea Urchins	Other Invertebrates
78605	Heterocentrotus mammillatus	Slate Pencil Urchin	Other Invertebrates
79201	Holothuria atra	Lollyfish	Other Invertebrates
79202	Holothuria edulis	Pinkfish	Other Invertebrates
79203	Holothuria fuscogilva	White Teatfish	Other Invertebrates
79204	Holothuria fuscopunctata	Elephant'S Trunkfish	Other Invertebrates
79205	Holothuria hilla	Sea Cucumber	Other Invertebrates
79206	Holothuria impatiens	Sea Cucumber	Other Invertebrates
79207	Holothuria leucospilota	Sea Cucumber	Other Invertebrates
79208	Holothuria sp	Sea Cucumber	Other Invertebrates

79200	Holothuriidae	Sea Cucumber	Other Invertebrates
79000	Holothuroidea	Sea Cucumbers	Other Invertebrates
72700	Mithrodia bradleyi	Spiney-Armed Starfish	Other Invertebrates
72300	Ophidiaster confertus	Orange Starfish	Other Invertebrates
72200	Oreasteridae	Starfish	Other Invertebrates
79500	Phyllophoridae	Sea Cucumbers	Other Invertebrates
78503	Pseudoboletia maculata	Common Urchin	Other Invertebrates
72000	Sc Asteroidea	Starfish	Other Invertebrates
75000	Sc Ophiuroidea	Basket,Brittle, Serpentstars	Other Invertebrates
72900	Sphaerasteridae	Starfish	Other Invertebrates
79100	Stichopodidae	Sea Cucumbers	Other Invertebrates
79101	Stichopus chloronotus	Greenfish	Other Invertebrates
79102	Stichopus horrens	Sea Cucumber	Other Invertebrates
79103	Stichopus noctivatus	Sea Cucumber	Other Invertebrates
79105	Stichopus sp	Sea Cucumber	Other Invertebrates
79104	Stichopus variegatus	Curryfish	Other Invertebrates
79601	Synapta maculata	Sea Cucumber	Other Invertebrates
79602	Synapta media	Sea Cucumber	Other Invertebrates
79603	Synapta sp	Sea Cucumber	Other Invertebrates
79600	Synaptidae	Sea Cucumbers	Other Invertebrates
78400	Temnopleuridae	Sea Urchins	Other Invertebrates
79901	Thelenota ananas	Prickly Redfish	Other Invertebrates
79902	Thelenota anax	Amberfish	Other Invertebrates
79903	Thelenota sp	Sea Cucumber	Other Invertebrates

78502	Toxopneustes pileolus	Flower Urchin	Other Invertebrates
78500	Toxopneustidae	Shortspine Urchins	Other Invertebrates
78501	Tripneustes gratilla	Shortspine Urchin	Other Invertebrates

Appendix B. List of Protected Species and Designated Critical Habitat.

Table B1. Protected species found or reasonably believed to be found in or near Mariana Archipealgo waters.

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	Guam/ CNMI	References
Seabirds						
Wedge-Tailed Shearwater	*Ardenna pacifica*	Not Listed	N/A	Uncommon visitor	Both	Wiles 2003
Streaked Shearwater	*Calonectris leucomelas*	Not Listed	N/A	Rare visitor	Guam	Wiles 2003
Short-Tailed Shearwater	*Ardenna tenuirostris*	Not Listed	N/A	Common visitor	Both	Wiles 2003
Newell's Shearwater[a]	*Puffinus newelli (Puffinus auricularis newelli)*	Endangered	N/A	Rare visitor	Both	40 FR 44149, Wiles 2003
Audubon's Shearwater	*Puffinus lherminieri*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Matsudaira's Storm-Petrel	*Oceanodroma matsudairae*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
White-Tailed Tropicbird	*Phaethon lepturus*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Red-Tailed Tropicbird	*Phaethon rubricauda*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Masked Booby	*Sula dactylatra*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Brown Booby	*Sula leucogaster*	Not Listed	N/A	Uncommon visitor	Both	Wiles 2003
Red-Footed Booby	*Sula sula*	Not Listed	N/A	Uncommon visitor	Both	Wiles 2003
Great Frigatebird	*Fregata minor*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Lesser Frigatebird	*Fregata ariel*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Black-Headed Gull	*Chroicocephalus ridibundus*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Gull-Billed Tern	*Gelochelidon nilotica*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Great Crested Tern	*Thalasseus bergii*	Not Listed	N/A	Uncommon visitor	Both	Wiles 2003
Common Tern	*Sterna hirundo*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Black-Naped Tern	*Sterna sumatrana*	Not Listed	N/A	Rare visitor	Guam	Wiles 2003
Little Tern	*Sternula albifrons*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Sooty Tern	*Onychoprion fuscatus*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
White-Winged Tern	*Chlidonias leucopterus*	Not Listed	N/A	Rare visitor	Both	Wiles 2003
Brown Noddy	*Anous stolidus*	Not Listed	N/A	Common resident	Both	Wiles 2003

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	Guam/ CNMI	References
Black Noddy	*Anous minutus*	Not Listed	N/A	Common visitor	Both	Wiles 2003
White Tern	*Gygis alba*	Not Listed	N/A	Common resident	Both	Wiles 2003
Short-Tailed Albatross	*Phoebastria albatrus*	Endangered	N/A	Breed in Japan and NWHI, and range across the North Pacific Ocean. Potential range includes the Marianas archipelago.	N/A	35 FR 8495, 65 FR 46643, BirdLife International 2017
Laysan Albatross	*Phoebastria immutabilis*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Black-Footed Albatross	*Phoebastria nigripes*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
White-Necked Petrel	*Pterodroma cervicalis*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Bonin Petrel	*Pterodroma hypoleuca*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Black-Winged Petrel	*Pterodroma nigripennis*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Bulwer's Petrel	*Bulweria bulwerii*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Christmas Shearwater	*Puffinus nativitatis*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Band-Rumped Storm-Petrel	*Oceanodroma castro*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Long-Tailed Jaeger	*Stercorarius longicaudus*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Laughing Gull	*Leucophaeus atricilla*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Herring Gull	*Larus argentatus*	Not Listed	N/A	Rare visitor	CNMI	Wiles 2003
Gray-Backed Tern	*Onychoprion lunatus*	Not Listed	N/A	Uncommon resident	CNMI	Wiles 2003
Sea Turtles						
Green Sea Turtle	*Chelonia mydas*	Endangered (Central West Pacific DPS)	N/A	An estimated 1000-2000 turtles forage in Guam/CNMI waters. Particularly common in winter and late spring.	Both	43 FR 32800, 81 FR 20057, Kolinski et al. 2000, Pritchard 1982, Honigman 1994
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered[b]	N/A	Small population nesting and foraging around Guam. Occur worldwide in tropical and subtropical waters.	Both	35 FR 8491, NMFS & USFWS 2007, Baillie & Groombridge 1996
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered[b]	N/A	Occasional sightings. Occur worldwide in tropical, subtropical, and subpolar waters.	Guam	35 FR 8491, Eldredge 2003, Eckert et al. 2012

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	Guam/ CNMI	References
Loggerhead Sea Turtle	*Caretta caretta*	Endangered (North Pacific DPS)	N/A	No known sightings. Found worldwide along continental shelves, bays, estuaries and lagoons of tropical, subtropical, and temperate waters.	N/A	43 FR 32800, 76 FR 58868, Dodd 1990, USFWS 2005
Olive Ridley Sea Turtle	*Lepidochelys olivacea*	Threatened (Entire species, except for the breeding population on the Pacific coast of Mexico, which is listed as endangered)	N/A	Believed to occasionally transit through area.	N/A	43 FR 32800, Starmer et al. 2005
Marine mammals						
Blainville's Beaked Whale	*Mesoplodon densirostris*	Not Listed	Non-strategic	Found worldwide in tropical and temperate waters.	CNMI	Mead 1989
Blue Whale	*Balaenoptera musculus*	Endangered	Strategic	No known sightings in CNMI but occur worldwide in tropical and warm-temperate waters. Known to occur in the western North Pacific.	N/A	35 FR 18319, McDonald et al. 2006, Stafford et al. 2001
Bottlenose Dolphin	*Tursiops truncatus*	Not Listed	Non-strategic	Distributed worldwide in tropical and warm-temperate waters	Both	Perrin et al. 2009
Bryde's Whale	*Balaenoptera edeni*	Not Listed	Non-strategic	Distributed widely across tropical and warm-temperate Pacific Ocean.	CNMI	Leatherwood et al. 1982
Cuvier's Beaked Whale	*Ziphius cavirostris*	Not Listed	Non-strategic	Occur worldwide.	CNMI	Heyning 1989
Dugong	*Dugong dugong*	Endangered	N/A (managed by USFWS)	Extremely rare. One confirmed sighting in Guam in 1975, and multiple anecdotal reports in Guam in 1985.	Guam	Randall et al. 1975, Eldredge 2003
Dwarf Sperm Whale	*Kogia sima*	Not Listed	Non-strategic	Found worldwide in tropical and warm-temperate waters.	Both	Nagorsen 1985
False Killer Whale	*Pseudorca crassidens*	Not Listed	Non-strategic	Found worldwide in tropical and warm-temperate waters.	CNMI	Stacey et al. 1994
Fin Whale	*Balaenoptera physalus*	Endangered	Strategic	Infrequent sightings, occur throughout the North Pacific Ocean.	N/A	35 FR 18319, Oleson et al. 2015, Mizroch et al. 2009
Fraser's Dolphin	*Lagenodelphis hosei*	Not Listed	Non-strategic	Found worldwide in tropical waters.	CNMI	Perrin et al. 2009

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	Guam/ CNMI	References
Humpback Whale	*Megaptera novaeangliae*	Delisted Due to Recovery (Oceania DPS)	Strategic	Breed in Oceania waters during the winter.	Both	35 FR 18319, 81 FR 62259, Guarrige et al. 2007, SPWRC 2008
Killer Whale	*Orcinus orca*	Not Listed	Non-strategic	Found worldwide. Prefer colder waters within 800 km of continents.	Guam	Leatherwood & Dalheim 1978, Mitchell 1975, Baird et al. 2006
Longman's Beaked Whale	*Indopacetus pacificus*	Not Listed	Non-strategic	Found in tropical waters from the eastern Pacific westward through the Indian Ocean to the eastern coast of Africa.	CNMI	Dalebout 2003
Melon-Headed Whale	*Peponocephala electra*	Not Listed	Non-strategic	Found in tropical and warm-temperate waters worldwide, primarily found in equatorial waters.	Both	Perryman et al. 1994
Minke Whale	*Balaenoptera acutorostrata*	Not Listed	Non-strategic	Uncommon in this region, usually seen over continental shelves in the Pacific Ocean.	CNMI	Brueggeman et al. 1990
Northern Elephant Seal	*Mirounga angustirostris*	Not Listed	Non-strategic	Females migrate to central North Pacific to feed on pelagic prey	N/A	Le Beouf et al. 2000
Pantropical Spotted Dolphin	*Stenella attenuata attenuata*	Not Listed	Non-strategic	Found in tropical and subtropical waters worldwide.	Both	Perrin et al. 2009
Pygmy Killer Whale	*Feresa attenuata*	Not Listed	Non-strategic	Found in tropical and subtropical waters worldwide.	CNMI	Ross & Leatherwood 1994
Pygmy Sperm Whale	*Kogia breviceps*	Not Listed	Non-strategic	Found worldwide in tropical and warm-temperate waters.	Guam	Caldwell & Caldwell 1989
Risso's Dolphin	*Grampus griseus*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide.	Both	Perrin et al. 2009
Rough-Toothed Dolphin	*Steno bredanensis*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide.	CNMI	Perrin et al. 2009
Sei Whale	*Balaenoptera borealis*	Endangered	Strategic	Extremely rare. Generally found in offshore temperate waters.	CNMI	35 FR 18319, Barlow 2003, Bradford et al. 2013
Short-Finned Pilot Whale	*Globicephala macrorhynchus*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide.	Both	Shallenberger 1981, Baird et al. 2013, Bradford et al. 2013
Sperm Whale	*Physeter macrocephalus*	Endangered	Strategic	Found in tropical to polar waters worldwide, most abundant cetaceans in the	Both	35 FR 18319, Rice 1960, Barlow 2006,

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	Guam/ CNMI	References
				region. Regularly sighted in waters around CNMI.		Lee 1993, Mobley et al. 2000, Shallenberger 1981
Spinner Dolphin	*Stenella longirostris*	Not Listed	Non-strategic	Found worldwide in tropical and warm-temperate waters. Occur in shallow protected bays during the day, feed offshore at night.	Both	Norris and Dohl 1980, Norris et al. 1994, Hill et al. 2010, Andews et al. 2010, Karczmarski 2005, Perrin et al. 2009
Striped Dolphin	*Stenella coeruleoalba*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters throughout the world	Both	Perrin et al. 2009
Sharks						
Scalloped hammerhead	*Sphyrna lewini*	Threatened (Indo-West Pacific DPS)	N/A	Occur over continental and insular shelves, and adjacent deep waters, but rarely found in waters < 22°C. Range from the intertidal and surface to depths up to 450–512 m. Guam's inner Apra Harbor is a nursery habitat.	Both	Compagno 1984, Schulze-Haugen & Kohler 2003, Sanches 1991, Klimley 1993
Corals						
N/A	*Acropora globiceps*	Threatened	N/A	Occur on upper reef slopes, reef flats, and adjacent habitats in depths ranging from 0 to 8 m.	Both	Veron 2014
N/A	*Acropora retusa*	Threatened	N/A	Occur in shallow reef slope and back-reef areas, such as upper reef slopes, reef flats, and shallow lagoons, and depth range is 1 to 5 m.	Both	Veron 2014
N/A	*Seriatopora aculeata*	Threatened	N/A	Found in broad range of habitats including, but not limited to, upper reef slopes, mid-slope terraces, lower reef slopes, reef flats, and lagoons, and depth ranges from 3 to 40 m.	Both	Veron 2014

[a] Birds recorded in CNMI (including Guam) as Townsend's or Manx Shearwaters prior to the resolution of the Manx Shearwater complex were probably Newell's Shearwaters based on morphology and distribution (Drahos 1977, Wiles 2003).
[b] These species have critical habitat designated under the ESA. See Table B2.

Table B2. ESA-listed species' critical habitat in the Pacific Ocean[a].

Common name	Scientific name	ESA listing status	Critical habitat	References
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered	None in the Pacific Ocean.	63 FR 46693
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered	Approximately 16,910 square miles (43,798 square km) stretching along the California coast from Point Arena to Point Arguello east of the 3,000 meter depth contour; and 25,004 square miles (64,760 square km) stretching from Cape Flattery, Washington to Cape Blanco, Oregon east of the 2,000 meter depth contour.	77 FR 4170
Hawaiian Monk Seal	*Neomonachus schauinslandi*	Endangered	Ten areas in the Northwestern Hawaiian Islands (NWHI) and six in the main Hawaiian Islands (MHI). These areas contain one or a combination of habitat types: Preferred pupping and nursing areas, significant haul-out areas, and/or marine foraging areas, that will support conservation for the species.	53 FR 18988, 51 FR 16047, 80 FR 50925
North Pacific Right Whale	*Eubalaena japonica*	Endangered	Two specific areas are designated, one in the Gulf of Alaska and another in the Bering Sea, comprising a total of approximately 95,200 square kilometers (36,750 square miles) of marine habitat.	73 FR 19000, 71 FR 38277

[a] For maps of critical habitat, see http://www.nmfs.noaa.gov/pr/species/criticalhabitat.htm.

Appendix C: Precious Corals Species Descriptions

1 PRECIOUS CORAL SPECIES

This section is an update of Appendix 1 to the Western Pacific FEPs, "Essential Fish Habitat Species Descriptions for Western Pacific Archipelagic, and Remote Island Areas Fishery Ecosystem Plan Management Unit Species" for precious corals. Important new references and data points have been added to the original documentation. Many older observations continue to be cited because no newer studies have been completed, with a few notable exceptions. While the original sources are still relevant, new research has revealed important distribution, life history, growth rate, age, and abundance information that is relevant to precious coral management. Some progress has also been made toward clarifying some of the vexing taxonomic challenges presented by these organisms. First, the name of the most important species of gold coral, *Gerardia* sp., has been updated to *Kulamanamana haumeaae* by Sinniger, *et al.* (2013). Second, two of the most important species in the family Coralliidae, *Corallium secundum* (pink coral) and *Corallium regale* (red coral) have been placed into separate genera, the latter also becoming a different species (Figueroa & Baco, 2014). Their new names are now *Pleurocorallium secundum* and *Hemicorallium laauense*, respectively. Third, two changes have taken place in the black corals. *Antipathes dichotoma* is now *Antipathes griggi* and *Antipathes ulex* has been moved to a different genus and is now *Myriopathes ulex* (Opresko, 2009). These changes are shown in Table 1.

1.1 General Distribution of Precious Corals

Most research related to precious corals has been limited to the Hawaiian archipelago, and the majority of the more recent efforts have been directed at taxonomy or simply documenting species distributions, with a few works on growth and life history (*Parrish et al.*, 2015). However, significant new insights have been gained into the genetics (Baco and Cairns, 2012; Sinniger, *et al.*, 2013; Figueroa and Baco, 2014), reproductive biology (Waller and Baco, 2007; Wagner, *et al.*, 2011; Wagner *et al.*, 2012; Wagner *et al.*, 2015), growth and age (Parrish and Roark 2009; Roark *et al.*, 2009; Putts, *pers. comm.*, 2017), and community structure (Kahng *et al.*, 2010; Long and Baco, 2014; Parrish, 2015; Wagner, *et al.*, 2015; Putts, *pers. comm.*, 2017) of precious coral and black coral species.

The U.S. Pacific Islands Region under jurisdiction of the Western Pacific Regional Fisheries Management Council consists of more than 50 oceanic islands, including the Hawaiian and Marianas archipelagos, American Samoa, Johnston, Wake, Palmyra, Kingman, Jarvis, Baker and Howland, and numerous seamounts in proximity to each of these groups. These islands fall under a variety of political jurisdictions, and include the State of Hawaii, the Commonwealth of the Northern Mariana Islands (CNMI), and the territories of Guam and American Samoa, as well as nine sovereign Federal territories—Midway Atoll, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Howland Island, Baker Island, Rose Atoll, and Wake Island. Precious corals (with currently accepted species names) are known to exist in American Samoa, Guam, Hawaii and the Northern Mariana Islands, as well as throughout the other US islands in the Pacific (Tables 1 and 2), but the only detailed assessments of precious corals have been in Hawaii (Parrish and Baco, 2007, Parrish *et al.*, 2015; Wagner, *et al.*, 2015). Over the last 10 years, we have begun to better understand the distribution and abundance of these corals, but many areas remain unexplored,

Table 1. Precious coral management unit species with updated species names

Species	Common name
Pleurocorallium secundum (prev. *Corallium secundum*)	Pink coral
Hemicorallium laauense (prev. *C. regale*)	Red coral
Kulamanamana haumeaae (prev. *Gerardia* sp.)	Gold coral
Narella sp.	Gold coral
Calyptrophora sp.	Gold coral
Callogorgia gilberti	Gold coral
Lepidisis olapa	Bamboo coral
Acanella sp.	Bamboo coral
*Antipathes griggi (*prev. *A. dichotoma)*	Black coral
Antipathes grandis	Black coral
*Myriopathes ulex (*prev. *Antipathes ulex*)	Black coral

and conditions which lead to their settlement, growth and distribution are still uncertain. Modelling efforts have provided some insight into the global distribution and habitat requirements of deep-water corals (Rogers *et al.*, 2007; Tittensor *et al.*, 2009, Clark *et al.*, 2011, Yesson *et al.*, 2012, Schlacher *et al.*, 2013), but have provided little certainty regarding localized distribution or the specific conditions required for growth of precious corals. Antipatharians, commonly known as black corals, have been exploited for years, but are still among the taxonomic groups containing precious corals that have been inadequately surveyed, as evidenced by the high rates of species discoveries from deep-water surveys around the Hawaiian Islands (Opresko 2003b; Opresko 2005a; Baco 2007; Parrish & Baco 2007; Parrish *et al.*, 2015; Roark, 2009; Wagner *et al.*, 2011, 2015; Wagner, 2011, 2013). Despite this ongoing research, only a few places are known to have dense agglomerations of precious corals. A summary of the known distribution and abundance of precious corals in the central and western Pacific Islands region follows.

American Samoa

There is little information available for the deepwater species of precious corals in American Samoa. Much of the information available comes from the personal accounts of fishermen. In the South Pacific there are no known commercial beds of pink coral (Carleton and Philipson 1987). Survey work begun in 1975 by the Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC) identified three areas of *Corallium* off Western Samoa: off eastern Upolu, off Falealupo and at Tupuola Bank (Carleton and Philipson 1987). Pink coral has been reported off Cape Taputapu, but no information concerning the quality or quantity of these corals or the depths where they occur is available. Unidentified precious corals have also been reported in the past off Fanuatapu at depths of around 90 m. Precious corals are known to occur at an uncharted seamount, about three-fourths of a mile off the northwest tip of Falealupo Bank at depths of around 300 m.

Commercial quantities of one or more species of black coral are known to exist at depths of 40 m and deeper within the territorial waters of American Samoa. Wagner (*pers. comm.*, 2015) has tentatively identified as many as 12 species (not previously catalogued in Am. Samoa) of black corals in depths between 50m and 90m, with 6 of these potential new species exhibiting growth forms that could lead to harvestable sizes. However, Wagner did not find any locations with the types of densities and sizes that would support any commercial harvest of these corals.

Guam and the Commonwealth of the Northern Marianas

There are no known commercial quantities of precious corals in the Northern Mariana Islands archipelago (Grigg and Eldredge 1975). In the past, Japanese fishermen claimed to have taken some *Corallium* north of Pagan Island and off Rota and Saipan. Preliminary results from surveys conducted throughout the Marianas Islands in 2016 indicate a scattered distribution with no areas of large agglomerations of precious corals found in waters deeper than 250 m.

U.S. Pacific Island Remote Areas

There are no known commercial quantities of precious corals in the remote Pacific Island areas, though individual colonies of precious corals have been seen at Jarvis, Palmyra, Kingman (Parrish and Baco, 2007) and Johnston Atoll, and planned surveys in 2017 may provide more information about abundance and distribution of precious corals found in waters deeper than 250 meters in these areas.

Hawaii

In the Hawaiian Archipelago there are seven legally-defined beds of pink, gold and bamboo corals, which are shown in Table 2. It is difficult to determine from the publication record exactly why these particular areas were singled out for legal recognition, other than the fact that they contain some unspecified densities of precious corals within their geographic boundaries. In the MHI, the Makapuu bed is located off Makapuu, Oahu, at depths of between 250 and 575 meters. Discovered in 1966, it the precious coral bed that has been most extensively surveyed in the Hawaiian chain. Its total area is about 4.5 km^2. Its substrate consists largely of hard limestone

(Grigg, 1988). Careful examination during numerous dives with submersibles has determined that about 20% of the total area of the Makapuu bed is comprised of irregular lenses of thin sand,

Table 2. Location of Hawaii FEP precious coral beds

Area Name	Description
Makapu'u (Oahu)	**includes the area within a radius of 2.0 nm of a point at 21°18.0′ N. lat., 157°32.5′ W. long.**
Auau Channel, Maui	**includes the area west and south of a point at 21°10′ N. lat., 156°40′ W. long., and east of a point at 21° N. lat., 157° W. long., and west and north of a point at 20°45′ N. lat., 156°40′ W. long.**
Keahole Point, Hawaii	**includes the area within a radius of 0.5 nm of a point at 19°46.0′ N. lat., 156°06.0′ W. long.**
Kaena Point, Oahu	**includes the area within a radius of 0.5 nm of a point at 21°35.4′ N. lat., 158°22.9′ W. long.**
Brooks Banks	**includes the area within a radius of 2.0 nm of a point at 24°06.0′ N. lat., 166°48.0′ W. long.**
180 Fathom Bank, north of Kure Island	**N.W. of Kure Atoll, includes the area within a radius of 2.0 nm of a point at 28°50.2′ N. lat., 178°53.4′ W. long.**
WesPac Bed, between Nihoa and Necker Islands	**includes the area within a radius of 2.0 nm of a point at 23°18′ N. lat., 162°35′ W. long.**

sediments and barren patches (WPRFMC, 1979). These sediment deposits are found primarily in low lying areas and depressions (Grigg, 1988). Thus, the total area used for extrapolating coral density is 3.6 km^2, or 80% of 4.5 km^2 (WPRFMC, 1979).

Precious coral beds have also been found in the deep inter-island channels such as Auau, Alalakeiki, and Kolohi channels off of Maui, around the edges of Penguin Banks, off promontories such as Keahole Point, on older lava flows south from Keahole to Ka Lae, and off of Hilo Harbor, and off of Cape Kumukahi on the Big Island of Hawaii (Oishi, 1990; Grigg, 2001, 2002; Putts, *pers. comm*., 2017). On Oahu, there is a bed off Kaena Point, and multiple precious coral observations have been made from offshore Barber’s Point extending to offshore

Pearl Harbor, Oahu. On Kauai, a bed of black corals has been identified offshore of Poipu (WPRFMC, 1979).

A dense bed has been located on the summit of Cross Seamount, southwest of the island of Hawaii. This bed covers a pinnacle feature on the top of the summit, but does not contain numbers of corals large enough to sustain commercial harvests (Kelley, pers. comm., 2015).

In the NWHI, a small bed of deepwater precious corals have been found on WestPac bed, between Nihoa and Necker Islands and east of French Frigate Shoals. This bed is not large enough to sustain commercial harvests. Precious coral beds have also been discovered at Brooks Banks, Pioneer Bank, Bank 8, Seamount 11, Laysan, and French Frigate Shoals (Parrish and Baco, 2007; Parrish *et al*., 2015). ROV surveys conducted throughout the NWHI by the Okeanos Explorer during 2015 discovered multiple places that had dense colonies of deep-sea corals. Few of these colonies were precious corals, but these dives were mostly conducted in waters deeper than normal distributions of precious corals (>1500 meters). However, large areas of potential habitat exist in the NWHI on seamounts and banks near 400 m depth. Based on the abundance of potential habitat, it is thought that stocks of precious corals may be more abundant in the northwestern end of the island chain. All precious coral stocks within the boundaries of the Papahānaumokuākea National Marine Monument or Coral Reef Ecosystem Reserve are reserved from harvest, and most habitat suitable for precious corals growth falls within the boundaries of the monument.

Precious corals have also been discovered at the 180 Fathom Bank, north of Kure Island. The extent of this bed is not known. Precious corals have been observed during submersible and ROV dives throughout the Northwestern Hawaiian Islands, and in EEZ waters surrounding Johnston, Jarvis, Palmyra, and Kingman atolls, but little can be definitively said about the overall distribution and abundance of precious corals in the central Pacific region.

In addition to these legally defined areas of precious corals, many other sites have been discovered that sustain populations of precious corals (Parrish and Baco, 2007; Parrish *et al*., 2015; Wagner *et al*., 2015). The map below (Figure 1) provides a color-coded illustration of some of these 8600 observations (Kelley and Drysdale, 2012, *unpublished data*). Given the number of observations and the wide distribution of precious corals in the main Hawaiian Islands, it is almost certain that undiscovered beds of precious corals exist in the EEZ waters of the region managed by the WPRFMC. Whether these beds would contain organisms at sufficient densities and size distributions to support commercial harvests is yet to be determined.

1.2 Systematics of the Deepwater Coral Species

Published records of deep corals from the Hawaiian Archipelago include more than 137 species of gorgonian octocorals and 63 species of azooxanthellate scleractinians (Parrish and Baco, 2007). A total of 6 new genera and 20 new species of octocorals, antipatharians, and zoanthids have been discovered in Hawaii since the 2007 report (Parrish *et al*., 2015). These are either new to science, or new records for the Hawaiian Archipelago (Cairns & Bayer 2008, Cairns 2009, Opresko 2009, Cairns 2010, Wagner *et al.,* 2011a, Opresko *et al.,* 2012, Sinniger *et al.,* 2013).

Taxonomic revisions currently underway for several groups of corals, e.g., isidids, coralliids, plexaurids and paragorgiids, are also likely to yield additional species new to science and new records for Hawaii (Parrish *et al.,* 2015). Only a handful of these deep coral species are considered economically *precious* and have any history of exploitation.

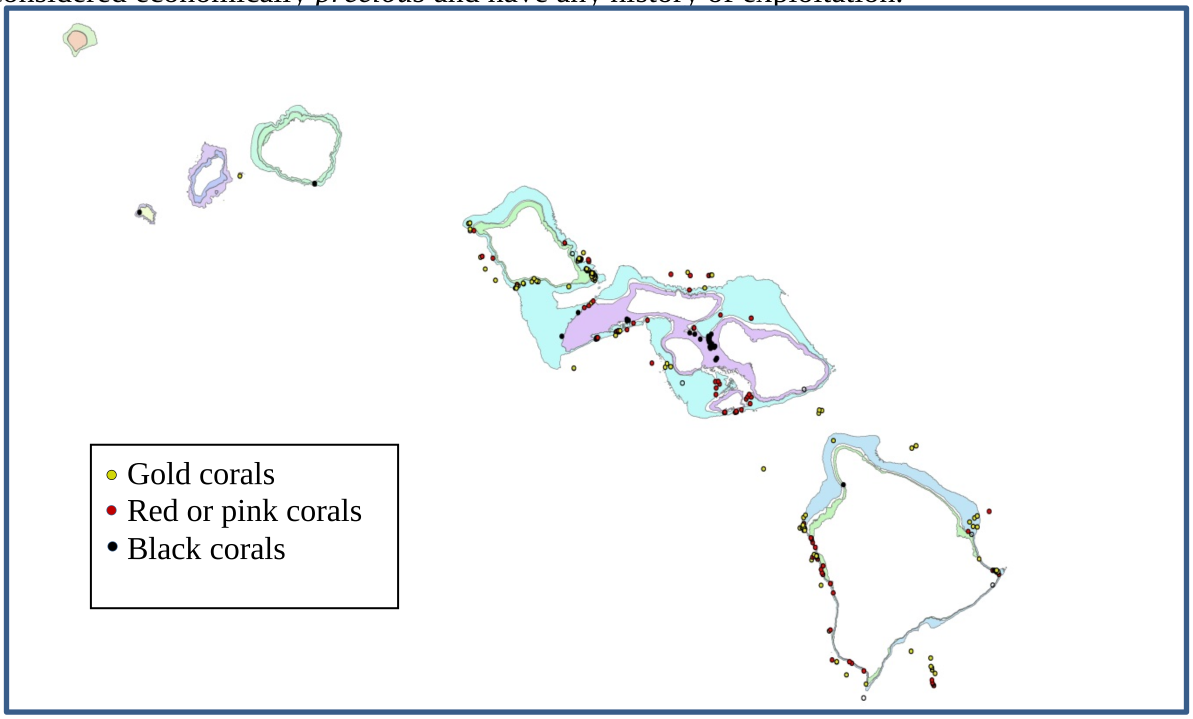

Figure 1. Observations of precious corals in the main Hawaiian islands

Recent molecular phylogenetic and morphologic studies of the family Coralliidae, including Hawaiian precious corals, have illuminated taxonomic relationships. These studies synonymized *Paracorallium* into the genus *Corallium*, and resurrected the genera *Hemicorallium* (Ardila *et al*., 2012; Figueroa & Baco, 2014; Tu *et al*., 2015) and *Pleurocorallium* (Figueroa & Baco, 2014; Tu *et al*., 2015) for several species, including several species in the precious coral trade. A molecular and morphological analysis of octocoral-associated zoanthids collected from the deep slopes in the Hawaiian Archipelago revealed the presence of at least five different genera including the gold coral (Sinniger *et al*., 2013). This study describes the five new genera and species and proposes a new genus and species for the Hawaiian gold coral, *Kulamanamana haumeaae*, an historically important species harvested for the jewelry trade and the only Hawaiian zoanthid that appears to create its own skeleton.

Precious corals are found principally in three orders of the class Anthozoa: Gorgonacea, Antipatharia, and Zoanthiae (Grigg, 1984). In the western Pacific region, pink coral (*Pleurocorallium secundum*), red coral (*Hemicorallium laauense*), gold coral (*Kulamanamana haumeaae*), black coral (*Antipathes* sp.) and bamboo coral (*Lepidisis olapa*) are the primary species/genera of commercial importance. Of these, the most valuable precious corals are species of the genera *Pleurorallium* and *Hemicorallium*, the pink and red corals (Grigg, 1984). Pink coral (*P. secundum*) and Midway deep-sea coral (*Corallium* sp. nov,) are two of the principal species of commercial importance in the Hawaiian and Emperor Seamount chain (Grigg, 1984). *P. secundum* is found in the Hawaiian archipelago from Milwaukee Banks in the Emperor

Seamounts (36°N) to the Island of Hawaii (18°N); *Corallium* sp. nov. is found between 28°–36°N, from Midway to the Emperor Seamounts (Grigg, 1984). In addition to the pink corals, the bamboo corals, *Lepidistis olapa* and *Acanella* sp., are commercially important precious corals in the western Pacific region (Grigg, 1984). Pink coral and bamboo coral are found in the order Gorgonacea in the subclass Octocorallia of the class Anthozoa, in the Phylum Coelenterata (Grigg, 1984).

The final two major groups of commercially important precious corals, gold coral and black coral, are found in separate orders, Zoanthidea and Antipatharia, in the subclass Hexacorallia, in the class Anthozoa and the phylum Coelenterata. The gold coral, *Kulamanamana haumeaae* (prev. *Gerardia* sp.) (Sinneger, *et.al.*, 2013), is endemic to the Hawaiian and Emperor Seamount chain (Grigg 1984). It inhabits depths ranging from 300–400 m (Grigg 1974, 1984). In Hawaii, gold coral, *Kulamanamana haumeaae,* grows mostly on bamboo hosts (e.g. *Acanella, Keratoisis*) as a parasitic overgrowth (Brown, 1976; Grigg, 1984; Parrish, 2015). Gold coral is, therefore, only found growing in areas that were previously inhabited by colonies of *Acanella* (Grigg, 1993) and possibly other bamboo corals (Parrish, 2015). Despite its ecological significance and long history of exploitation, the Hawaiian gold coral has never been subject to taxonomic studies or a formal species description. As a result of this, the nomenclature concerning the Hawaiian gold coral has been relatively confused. Symptomatic of the order, a suite of other zoanthids, besides the Hawaiian gold coral, have been observed and collected in Hawaii, but far less is known of their biology and ecology and they have not been described taxonomically (Sinnegar *et al.*, 2013).

Grigg (1984) classified black corals in the order *Antipatharia*, and identified fourteen genera of black corals reported from the Hawaii-Pacific region with species found in both shallow and deep habitats Grigg, 1965). Wagner (2015) noted that there are over 235 known species of black coral that occur in the oceans of the world, and of this total, only about 10 species are of commercial importance (Grigg, 1984). Wagner (2011) confirmed 8 species of black corals in Hawaii, including (1) *Antipathes griggi* Opresko, 2009, (2) *Antipathes grandis* Verrill, 1928, (3) *Stichopathes echinulata* Brook, 1889, (4) an undescribed *Stichopathes* sp., (5) *Cirrhipathes* cf. *anguina* Dana, 1846, (6) *Aphanipathes verticillata* Brook, 1889, (7) *Acanthopathes undulata* (Van Pesch, 1914), and (8) *Myriopathes* cf. *ulex* Ellis & Solander, 1786. A new name for the Hawaiian species of antipatharian coral previously identified as *Antipathes dichotoma* (Grigg and Opresko, 1977) is described as *Antipathes griggi* (Opresko, 2009).

Many species of gorgonian corals are known to occur within the habitat of pink, gold and bamboo corals in the Hawaiian Islands. At least 37 species of precious corals in the order Gorgonacea have been identified from the Makapuu bed (Grigg and Bayer, 1976). In addition, 18 species of black coral (order Antipatharia) have been reported to occur in Hawaiian waters (Grigg and Opresko, 1977; Oishi, 1990; Wagner, 2011.), but only 3 of these species have been subject to commercial harvest (Oishi, 1990; Wagner *et al.*, 2015).

1.3 Biology and Life History

The management and conservation of deep-sea coral communities is challenged by international harvest with non-selective gear types for the jewelry trade and the paucity of information to inform management strategies. In light of their unusual vulnerability, a better understanding of deep-sea coral ecology and their interrelationships with associated benthic communities is needed to inform coherent international conservation strategies for these important deep-sea habitat-forming species (Bruckner, 2013). Millennia are probably required for a precious coral community to form with full diversity, high evenness, and mature size structure (Putts, *pers. comm*., 2017). Most of the interior of the global ocean remains unobserved. This leaves questions of trophic connectivity, longevity, and population dynamics of many deep-sea communities unanswered. Deep-sea megafauna provide a complex, rich, and varied habitat that promotes high biodiversity and provides congregation points for juvenile and adult fish (Freiwald *et al.*, 2004; Husebo *et al.*, 2002; Smith *et al.*, 2008).

Precious corals may be divided primarily into two groups of species based on their depth ranges: the deepwater species (200-600m) and the shallow water species (20-120m). Other precious corals can be found in depths down to 2000 m, but these species are not exploited in the United States for commercial purposes. Deep-sea corals are found on hard substrates on seamounts and continental margins worldwide at depths of 300 to 3,000 m.

Deep Corals

The Pacific Islands deepwater precious coral species include pink coral, *Pleurocorallium secundum* (prev. *Corallium secundum*), red coral, *Hemicorallium laauense* (prev. *C. regale or C. laauense*), gold coral, *Kulamanamana haumeaae (*prev. *Gerardia sp*.) and bamboo coral, *Lepidistis olapa*. As previously discussed, the most valuable precious corals are gorgonian octocorals (Grigg, 1984). There are seven varieties of pink and red precious corals in the western Pacific region, six of which used to be recognized as distinct species of *Corallium* (Grigg, 1981), but have been reclassified (Parrish *et al.*, 2015). The two species of commercial importance in the EEZ around the Hawaiian Islands are the pink coral *Pleurocorallium secundum* (prev. *Corallium secundum*), and the red coral, *Hemicorallium laauense* (prev. *C. laauense*). The Gorgonian octocorals are by far the most abundant and diverse corals in the Hawaiian Archipelago. Two species, *Pleurocorallium secundum* and *Hemicorallium laauense* are known to occur at depths of 300-600 m on islands and seamounts throughout the Hawaiian Archipelago (Grigg 1974, 1993; Parrish *et al.*, 2015; Parrish and Baco, 2007). Parrish (2007) surveyed *Pleurocorallium secundum* and *Hemicorallium laauense* at 6 precious coral beds in the lower Hawaiian chain, from Brooks Bank to Keahole Point, Hawaii, in depths ranging from 350m to 500m. He found corals on summits, flanks, and shallow banks, with bottom substrate and relief at these sites ranging from a homogenous continuum of one type to a combination of many types at a single site. The survey results show that all three coral taxa colonize both carbonate and basalt/manganese substrates, and the corals favor areas where bottom relief enhances or modifies flow characteristics that may improve the colony's feeding success.

These corals can grow to more than 30 cm in height, and are often found in large beds with other octocorals, zoanthids, and sometimes scleractinians (Parrish *et al.*, 2015; Parrish and Baco, 2007). These species are relatively long lived, with some of the oldest colonies observed within Makapuu Bed about 0.7 m in height and at least 80 years old (Grigg, 1988b, Roark, 2006). Populations of *P. secundum* appear to be recruitment limited, although in favorable environments (e.g., Makapuu Bed) populations are relatively stable, suggesting that recruitment and mortality are in a steady state (Grigg, 1993). During surveys of lava flows off the western flanks of Hawaii

Island, Putts (*pers. comm*., 2017) found that Coralliidae dominated the early successional stages, and using dates established for those flows, determined that a mature Corallidae community can be established within 150 years. A study by Roark *et al.* (2006) showed that the radial growth rate for specimens of *P. secundum* in the Hawaiian Islands is ~170 µm yr^{-1} and average age is 67 to 71 years, older than previously calculated. Individual colonies have been measured as tall as 28 cm. Bruckner (2009) suggested that the minimum allowable size for genus *Corallium* for harvest should be increased, and supported a potential listing for *Corallium* within the Appendices of the Convention on International Trade in Endangered Species (CITES). The current size restriction in the 2010 Code of Federal Regulations for Pacific Islands Region is 10 in (25.4 cm).

In Cairn's reviews (2008; 2009; 2010), he summarized the research conducted on Hawaiian Octocorallia taxa, including three gold coral PCMUS genuses, *Narella*, *Calyptrophora* and *Callogorgia*. Octocorallia are distributed over all ocean basins, found in depths ranging from shallow (~ 50m) to deep (~ 4,600) in Alaska. All gold PCMUS in Hawaii were collected in deep water (> 270m), throughout the Hawaiian archipelago and adjacent seamounts. Although these octocorals are managed as PCMUS, the only commercially exploited gold coral is the zoantharian, *Kulamanamana haumeaae* (prev. *Gerardia* sp.). It is probably the most common and largest of the zoanthids in Hawaii, and is widely distributed throughout the Hawaiian Archipelago and into the Emperor Seamount Chain at depths of 350–600 meters (Parrish *et al.,* 2015; Parrish and Baco, 2007). While subject to commercial exploitation from the 1970's until 2001 with an interruption between 1979 and 1999 (Grigg, 2001), the gold coral is not currently exploited in Hawaii due to a moratorium on the fishery. The Hawaiian gold coral is one of the largest and numerically dominant benthic macro-invertebrates in its depth range on hard substrate habitats of the Hawaiian Archipelago, and plays an important ecological role in Hawaiian seamount benthic assemblage (Parrish, 2006; Parrish and Baco, 2007; Parrish, *et al.,* 2015). The Hawaiian gold coral has also been found to be one of the longest-lived species on earth. Earlier ageing attempts on the gold coral focused on ring counts (Grigg, 1974; Grigg, 2002) and led to a maximal estimated age of 70 years and a radial growth rate (increase in branch diameter) of 1 mm/year. Recent studies using radiometric data suggest colonies of Hawaiian gold coral are as old as 2740 year with a radial growth rate of only 15 to 45 µm/year (Roark *et al.,* 2006; Roark *et.al.,* 2009; Parrish and Roark, 2009).

Parrish (2015) has found the host of the parasitic *Kulamanamana haumeaae* to be primarily the bamboo corals (e.g. Acanella, Keratoisis). *K. haumeaae* secretes a protein skeleton that over millennia can grow and more than double the original mean size of the host colony. It is relatively common and even dominant at geologically older sample sites, but recruitment is probably infrequent (Parrish, 2015). Although it can be relatively common compared to some other deep corals, it grows very slowly. Parrish and Roark (2009) determined that the Hawaiian gold coral *Kulamanamana haumeaae* has a mean life span of 950 yrs with an overall radial growth of ~41 µm yr^{-1}, and a gross radiocarbon linear growth rate of 2.2 ± 0.2 mm yr^{-1}. This is a much slower growth rate and longer life span than given in previous studies. Grigg (2002) reported a 1 mm yr^{-1} radial growth rate, equivalent to a 6.6 cm yr^{-1} linear growth for a maximum life span of roughly 70 yrs. This means these corals are growing much slower than previously thought, and have much longer life spans if undisturbed. Newly applied radiocarbon age dates from the deep water proteinaceous corals *Gerardia* and *Leiopathes* show that radial growth rates are as low as 4 to 35 micometers per year and that individual colony longevities are on the order of thousands of years (Roark *et al.*, 2009, 2006). The longest-lived *Gerardia* sp. and *Leiopathes* specimens were estimated to be 2,742 years old and 4,265 years old, respectively. *Gerardia* sp. is a colonial zoanthid with a hard skeleton of hard proteinaceous matter that forms tree-like structures with heights of several meters and basal diameters up to 10s of a centimeter. Black corals of *Leiopathes sp*. also has a hard proteinaceous skeleton and grows to heights in excess of 2 m. In Hawai'ian waters, these corals are found at depths of 300 to 500 m on hard substrates, such as seamounts and ledges.

The two bamboo coral PCMUS in the Pacific Islands Region are classified under two genera, *Acanella* and *Lepidistis*. Not much work has been done specifically on these genera, but Parrish (2015) identified branched bamboo colonies such as *Acanella* as a preferred host for *Kulamanamana haumeaae*. Because of the long colony life span of >3000 yrs and the bony hard bodied calcareous internodes of bamboo corals (family Isididae), geochemists are interested in using them to analyze paleo-oceanographic events and long-term climate change (Hill *et al*. 2011), while biologists use them to size and age deep-sea coral populations. Recent studies show that the subfamily Keratoisidinae (family Isididae) consists of four genera (*Acanella*, *Isidella*, *Lepidistis*, and *Keratoisis*), with two genera (*Tenuisis* and *Australisis*) perhaps belonging elsewhere in the Isididae family (Etnoyer 2008; France 2007). Bamboo corals commonly colonize intermediate to deep water depths (400m to >3000m) of continental slopes and seamounts in the Pacific Ocean.

Shallow Corals

The second group of precious coral species is found in shallow water between 20 and 120 m (Grigg, 1993 and Drysdale, *unpublished data*, 2012; Wagner *et al.*, 2015). The shallow water fishery is comprised of three species of black coral, *Antipathes griggi*, *A. grandis* and *Myriopathes ulex,* which have historically been harvested in Hawaii (Oishi 1990), but over 90% of the coral harvested by the fishery consists of *A. griggi* (Oishi 1990; Parrish *et al.*, 2015; Wagner *et al.*, 2015). Other black coral species are found in the NWHI in a wider depth range (20m to 1,400m), but with lower colony density (Wagner *et al*., 2011). Surveys performed in depths of 40-110 meters in the Au'au Channel in 1975 and 1998, suggested stability in both recruitment and growth of commercially valuable black coral populations, and thus indicated that the fishery had been sustainable over this time period (Grigg, 2001). Subsequent surveys performed in the channel in 2001 indicated a substantial decline in the abundance of black coral colonies, with likely causes including increases in harvesting pressure and overgrowth of black coral colonies by the invasive octocoral *Carijoa sp.* and the red alga, *Acanthophora spicifera*, especially on reproductively mature colonies at mesophotic depths (Grigg 2003; Grigg 2004; Kahng & Grigg 2005; Kahng, 2006). Together, these factors renewed scrutiny on the black coral fishery and raised questions about whether regulations need to be redefined in order to maintain a sustainable harvest (Grigg, 2004). In addition to these challenges, Wagner has suggested that taxonomic misidentification has led to the mistaken belief that there is a depth refuge that exists for certain harvested species (Wagner *et al.,* 2012; Wagner, 2011). All of these uncertainties and lack of basic life history information regarding black corals complicates effective management of the resource (Grigg, 2004).

In Hawaii, *A. griggi* accounts for around 90% of the commercial harvest of black coral (Oishi

1990). *A. grandis* accounts for 9% and *M. ulex* 1% of the total black corals harvested. In Hawaii, roughly 85% of all black coral harvested are taken from within state waters. Black corals are managed jointly by the State of Hawaii and the Council. Within state waters (0–3 nmi), black corals are managed by the State of Hawaii (Grigg, 1993).

A new name for the Hawaiian species of antipatharian coral previously identified as *Antipathes dichotoma* (Grigg and Opresko, 1977) is described as *Antipathes griggi* Opresko, n. sp. (Opresko, 2009). The shallow water black coral *A. dichotoma* (*A. griggi)* collected at 50 m exhibited growth rates of 6.42 cm yr^{-1} over a 3.5 yrs study.

Table 3: Depth zonation of precious corals in the Western Pacific. (Source: Grigg 1993, Baco-Taylor, 2007, HURL and Drysdale, 2012)

Species and Common Name	Depth Range (m)
Paracorallium secundum Angle skin coral	250–575
Hemicorallium laauense Red coral	250–575
Corallium sp nov. Midway deepsea coral	1,000–1,500
Kulamanamana haumeaae (prev. *Gerardia* sp.) Hawaiian gold coral	350–575
Lepidisis olapa, *Acanella* spp. bamboo coral	250–1800
Antipathes griggi (prev. *A. dichotoma*), black coral	20–120
Antipathes grandis, pine black coral	20–120
Cirrhipathes cf. *anguina* (prev. *Antipathes anguina*), wire black coral	20–120
Myriopathes ulex (prev. *Antipathes ulex*), fern black coral	20–220

1.4 Growth and Reproduction

There is very limited published literature regarding coral spawning of the PCMUS in the Pacific Islands Region. However, studies by Gleason, *et al*. (2006) and Waller and Baco (2007) indicate that the gold coral *Kulamanamana haumaae* may have seasonal reproduction, and that two pink coral species have a periodic or quasi-continuous reproductive periodicity. Although limited studies about growth rates and life spans of adult PCMUS in the Pacific Islands Region are available, early life history data on larvae, polyps, and juvenile colonies of the PCMUS are unavailable. Many other questions related to genetic connectivity and spatial distribution across the Pacific also remain unanswered. Recent mesophotic coral reef ecosystem studies provide an outline of essential knowledge for the limited deep water coral ecosystem (Kahng, *et al*. 2010). Slow-growing deep-water coral ecosystems are sensitive to many disturbances, such as temperature change, invasive species and destructive fishing techniques.

While different species of precious corals inhabit distinct depth zones, their habitat requirements are strikingly similar. Grigg (1984) noted that these corals are non-reef building and inhabit depth zones below the euphotic zone. In an earlier study, Grigg (1974) determined that precious corals are found in deep water on solid substrate in areas that are swept relatively clean by moderate to strong bottom currents (>25 cm/sec). Strong currents help prevent the accumulation of sediments, which would smother young coral colonies and prevent settlement of new larvae. Grigg (1984) notes that, in Hawaii, large stands of *Corralium* are only found in areas where sediments almost never accumulate, and *P. secundum* appears in large numbers in areas of high flow over carbonate pavement (Parrish *et al.,* 2015; Parrish and Baco, 2007). *Hemicorallium laauense* grows in an intermediate relief of outcrops; and *Kulamanamana haumaae* is most commonly seen growing in high relief areas on pinnacles, walls, and cliffs. These habitat differences may reflect preferred flow regimes for the different corals (e.g., laminar flow for *P. secundum*, alternating flow for *Kulamanamana haumaae*) (Parrish *et al.,* 2015).

Surveys of all potential sites for precious corals in the MHI conducted using a manned submersible show that most shelf areas in the MHI near 400 m are periodically covered with a thin layer of silt and sand (Grigg, 1984). Precious corals are known to grow on a variety of bottom substrate types. Precious coral yields, however, tend to be higher in areas of shell sandstone, limestone and basaltic or metamorphic rock with a limestone veneer. Grigg (1988) concludes that the concurrence of oceanographic features (strong currents, hard substrate, low sediments) necessary to create suitable precious coral habitat are rare in the MHI. Depth clearly influences the distribution of different coral taxa and certainly there is patchiness associated with the presence of premium substrate and environmental conditions (flow, particulate load, etc.). The environmental suitability for colonization and growth is likely to differ among coral taxa.

The habitat sustaining precious corals is generally in pristine condition. There are no known areas that have sustained damage due to resource exploitation, notwithstanding the alleged heavy foreign fishing for corals in the Hancock Seamounts area. Although unlikely, if future development projects are planned in the proximity of precious coral beds, care should be taken to prevent damage to the beds. Projects of particular concern would be those that suspend sediments or modify water-movement patterns, such as deep-sea mining or energy-related operations.

There has been very little research conducted concerning the food habits of precious corals. Precious corals are filter feeders (Grigg, 1984; 1993). The sparse research available suggests that particulate organic matter and microzooplankton are important in the diets of pink and bamboo coral (Grigg, 1970). Many species of pink coral, gold coral (*Kulamanamana haumeaae (*prev. *Gerardia* sp.*)* and black coral (*Antipathes*) form fan shaped colonies (Grigg, 1984; 1993). This type of morphological adaption maximizes the total area of water that is filtered by the polyps (Grigg, 1984; 1993). Bamboo coral (*Lepidisis olapa*), unlike other species of precious corals, is unbranched (Grigg, 1984). Long coils that trail in the prevailing currents maximize the total amount of seawater that is filtered by the polyps (Grigg, 1984). While clearly, the presence of strong currents is a vital factor determining habitat suitability for precious coral colonies, their role to date is not fully understood.

Light is one of the most important determining factors of the upper depth limit of many species of precious corals (Grigg, 1984).The larvae of two species of black coral, *Antipathes grandis* and *A. griggi,* are negatively phototaxic**.**

Grigg (1984) states that temperature does not appear to be a significant factor in delimiting suitable habitat for precious corals. In the Pacific Ocean, species of *Corallium* are found in temperature ranges of 8^{o} to 20^{o}C, he observes. Temperature may determine the lower depth limits of some species of precious coral, including two species of black corals in the MHI. In the MHI, the lower depth range of two species of black corals (*A.griggi* and *A. grandis*) coincides with the top of the thermocline (about 100 m). Although, *A. griggi* can be found to depths of 100 m, it is rare below the 75 m depth limit at which commercial harvest occurs in Hawai‘i. Thus, the supposed depth refuge from harvest does not really exist, and was probably based on taxonomic misidentification, thereby calling into question population models used for the management of the Hawaiian black coral fishery (Wagner *et al.*, 2012; Wagner, 2011).

In pink coral (*P. secundum*), the sexes are separate (Grigg, 1993). Based on the best available data, it is believed that *P. secundum* becomes sexually mature at a height of approximately 12 cm (13 years) (Grigg, 1976). Pink coral reproduce annually, with spawning occurring during the summer, during the months of June and July. Coral polyps produce eggs and sperm. Fertilization of the oocytes is completed externally in the water column (Grigg, 1976; 1993). The resulting larvae, called planulae, drift with the prevailing currents until finding a suitable site for settlement.

Pink, bamboo and gold corals all have planktonic larval stages and sessile adult stages. Larvae settle on solid substrate where they form colonial branching colonies. Grigg (1993) notes that the lengths of the larval stage of all deepwater species of precious corals is unknown. Clean swept areas exposed to strong currents provide important sites for settlement of the larvae, Grigg adds. The larvae of several species of black coral (*Antipathes*) are negatively photoactic, he notes. They are most abundant in dimly lit areas, such as beneath overhangs in waters deeper than 30 m. In an earlier study, Grigg (1976) found that “within their depth ranges, both species are highly aggregated and are most frequently found under vertical dropoffs. Such features are commonly associated with terraces and undercut notches relict of ancient sea level still stands. Such features are common off Kauai and Maui in the MHI. Both species are particularly abundant off of Maui and Kauai, suggesting that their abundance is related to suitable habitat.” Off of Oahu, many submarine terraces that otherwise would be suitable habitat for black corals are covered with sediments (Grigg, 1976).

A variety of invertebrates and fish are known to utilize the same habitat as precious corals. These species of fish include onaga (*Etelis coruscans*), kahala (*Seriola dumerili*) and deepwater shrimp (*Heterocarpus ensifer*). These species do not seem to depend on the coral for shelter or food.

Densities of pink, gold and bamboo coral have been estimated for an unexploited section of the Makapuu bed (Grigg, 1976). As noted in the FMP for precious corals, the average density of pink coral in the Makapuu bed is 0.022 colonies/m^2. This figure was extrapolated to the entire bed (3.6 million m^2), giving an estimated standing crop of 79,200 colonies. At the 95% confidence limit, the standing crop is 47,500 to 111,700 colonies. The standing crop of colonies was converted to biomass ($3N_iW_i$), resulting in an estimate of 43,500 kg of pink coral in the Makapuu bed.

In addition to coral densities, Grigg (1976) determined the age-frequency distribution of pink coral colonies in Makapuu bed. He applied annual growth rates to the size frequency to calculate the age structure of pink coral at Makapuu Bed (Table 4). More recent work by Roark *et al.* (2006) suggests that annual growth ring dating may underestimate the ages of many species of deep water corals, and that most of the colonies that have been dated using the ring method are probably older and slower growing than first estimated.

Estimates of density were also made for bamboo (*Lepidisis olapa*) and gold coral (*Kulamanamana haumeaae (*prev. *Gerardia* sp.*)* for Makapuu bed. The distributions of both these species are patchy. As noted in the FMP, the area where they occur comprises only half of that occupied by pink coral (1.8 km^2). Estimates of the unexploited abundance of bamboo and gold coral were 18,000 and 5,400 colonies, respectively. Estimates of density for the unexploited bamboo coral and gold coral in the Makapuu bed are 0.01 colonies/m^2 and 0.003 colonies/m^2. Using a rough estimate for the mean weights of gold and bamboo coral colonies (2.2 kg and 0.6 kg), a standing crop of about 11,880 kg of gold coral and 10,800 kg for bamboo for Makapuu bed was obtained.

Growth rates for several species of precious corals found in the western Pacific region have been estimated. Grigg (1976) stated that the height of pink coral (*P. secundum*) colonies increases about 0.9 cm/yr up to about 30 years of age. These growth rates are probably overestimated, and should be revisited using modern methodologies, such as radiometric dating (Roark *et al.*, 2006). As noted in the FMP for precious corals, the height of the largest colonies of *Pleurocorallium secundum* at Makapuu bed rarely exceed 60 cm. Colonies of gold coral are known to grow up to 250 cm tall while bamboo corals may reach 300 cm. The natural mortality rate of pink coral at Makapuu bed is believed to be 0.066, equivalent to an annual survival rate of about 93%.

Table 4: Age-Frequency Distribution of *Pleurocorallium secundum* (Source: Grigg, 1973)

Age Group (years)	Number of Colonies
0–10	44
10–20	73
0–30	22
30–40	12
40–50	7
50–60	0

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Non-fishing effects that may adversely affect essential fish habitat in the Pacific Islands region

FINAL REPORT

Prepared by

Dwayne Minton, Ph.D.

Prepared for

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Pacific Islands Regional Office
1845 Wasp Blvd., Building 176
Honolulu, HI 96818

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List of Acronyms

AS	American Samoa
ATON	Aids to Navigation
BMP	Best management practice
CCA	Crustose coralline algae
CLB	Continuous-line bucket system
CNMI	Commonwealth of the Northern Mariana Islands
DSHMRA	Deep Seabed Hard Mineral Resources Act
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
ENSO	El Niño-Southern Oscillation
EPAP	Ecosystem Principles Advisory Panel
FEP	Fishery Ecosystem Plan
FMP	Fishery Management Plan
HI	State of Hawai‘i
ISA	International Seabed Authority
MCE	Mesophotic coral ecosystems
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MUS	Management Unit Species
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OTEC	Ocean Thermal Energy Conversion
PAR	Photosynthetically Active Radiation
PCB	Polychlorinated biphenyls
PDO	Pacific Decadal Oscillation
POM	Particulate organic matter
PPM	Parts per million
PRIA	U.S. Pacific Remote Island Areas
REE	Rare earth elements
TBT	Tri-butyl tin
UV	Ultraviolet radiation
UXO	Unexploded ordnance
WPWP	Western Pacific Warm Pool
WPRFMC	Western Pacific Regional Fishery Management Council

Table of Contents

Executive Summary ... 2
1.0 Background ... 6
1.1 Magnuson-Stevens Fishery Conservation and Management Act ... 6
1.2 Fishery Ecosystem Plans ... 6
1.2.1 Effects of Non-fishing Activities ... 7
1.2.2 Cumulative Effects ... 7
1.3 Purpose of this Report ... 8
2.0 EFH in the Western Pacific Region ... 9
2.1 Benthic Ecosystems ... 9
2.1.1 Intertidal ... 10
2.1.2 Mangrove Forests (Mangal) ... 12
2.1.3 Seagrass Beds ... 13
2.1.4 Coral Reefs ... 14
2.1.5 Deep Reef Slopes ... 15
2.1.6 Banks and Seamounts ... 16
2.1.7 Deep Ocean Floor ... 17
2.2 Pelagic Environment ... 18
3.0 Non-fishing Activities and Other Sources of Stress ... 19
3.1 Climate Change ... 19
3.2 Energy Production ... 22
3.3 Mining ... 23
3.4 Land-based Aquaculture ... 25
3.5 Development/Construction ... 26
3.6 Shipping/Boating ... 27
3.7 Marine Debris ... 30
3.8 Other Human non-fishing Use ... 31
3.9 Wastewater Discharge ... 32
4.0 Ecological Stressors in the Marine Environment ... 35
4.1 Environmental Stresses ... 38
4.1.1 Ocean Acidification ... 38
4.1.2 Shifts in Productivity ... 44
4.1.3 Thermal ... 47
4.1.4 Salinity ... 52
4.1.5 Irradiance ... 57
4.1.6 Noise ... 58
4.1.7 Hypoxia ... 62
4.2 Biological Stresses ... 64
4.2.1 Invasive Species ... 64
4.2.2 Disease ... 68
4.2.3 Fish Aggregating Device (FAD) Effect ... 71

4.3 Physical Stress 73
4.3.1 Physical Damage 73
4.4 Pollution Stress 76
4.4.1 Sediment 76
4.4.2 Nutrient Enrichment 81
4.4.3 Chemicals 83
4.5 Sea level Rise 96
5.0 Cumulative Effects 100
6.0 Conservation and Enhancement Recommendation 105
7.0 Acknowledgements 120
8.0 References 121

List of Tables

Table 1. The marine and estuarine ecosystems comprising the EFH.......... 9
Table 2. The potential stressors associated with non-fishing activities 36
Summary Table: Climage Change.......... 22
Summary Table: Energy Production 23
Summary Table: Mining.......... 25
Summary Table: Aquaculture.......... 26
Summary Table: Development/Construction 28
Summary Table: Shipping/Boating 30
Summary Table: Marine Debris 31
Summary Table: Other Human Non-fishing Use 32
Summary Table: Wastewater Discharge 34
Summary Stressor Table: Potential effects of ocean acidification 45
Summary Stressor Table: Potential effects of shifting productivity.......... 48
Summary Stressor Table: Potential effects of thermal stress. 53
Summary Stressor Table: Potential effects of salinity.......... 56
Summary Stressor Table: Potential effects of irradiance 59
Summary Stressor Table: Potential effects of noise 62
Summary Stressor Table: Potential effects of hypoxia 65
Summary Stressor Table: Potential effects of invasive species 69
Summary Stressor Table: Potential effects of disease.......... 72
Summary Stressor Table: Potential effects of fish aggregating 74
Summary Stressor Table: Potential effects of physical damage.......... 77
Summary Stressor Table: Potential effects of sedimenton.......... 80
Summary Stressor Table: Potential effects of nutrient enrichment 84
Summary Stressor Table: Potential effects of chemical pollutants 97
Summary Stressor Table: Potential effects of sea level rise.......... 98
Summary BMP Table: BMPs by activity category.......... 108
Summary BMP Table: BMPs by stressor type.......... 114

List of Figures

Figure 1. Schematic of the marine ecosystems that comprise the EFH 11
Figure 2. Conceptual flow diagram of linkages of human activities to an ecosystem.......... 20
Figure 3. Conceptual model for pollutant pathways in marine ecosystems.......... 86
Figure 4. Conceptual flow diagram showing the linkage of activities.......... 100
Figure 5. Frequency distribution of interaction types across stressor pairs 103
Figure 6. Interaction matrix for pairs of stressors acting on the marine ecosystems.......... 104
Figure 7. Schematic of BMP activity.......... 106
Figure 8. Examples of inappropriately-selected and improperly-implemented BMPs.......... 107

Executive Summary

Originally enacted in 1976, the Magnuson-Stevens Fishery Conservation and Management Act (MSA) established a federal system to conserve fishery resources and promote a sustainable commercial and recreational fishing industry within the United States of America. To achieve this in the Western Pacific Region, the Western Pacific Regional Fishery Management Council (WPRFMC) was tasked with making management recommendations to the National Marine Fisheries Service for review and implementation through the regulatory process. Recognizing that both the loss and degradation of important habitat were significant, long-term threats to fisheries, the MSA required Essential Fish Habitat (EFH) be described and identified, that adverse effects on EFH be minimized to the extent practicable, and that actions be implemented to encourage habitat conservation and enhancement.

The MSA requires fishery management plans (FMPs) to identify non-fishing activities that may adversely affect EFH, and to provide conservation and enhancement measures that avoid, minimize, mitigate, or otherwise offset adverse effects for federal activities. The WPRFMC uses fishery ecosystem plans (FEPs) to meet the requirements of FMPs under the MSA. A review of information available on EFH must be completed at least once every five years, and EFH provisions of FMPs must be revised or amended, as warranted.

This report reviews the potential effects (including potential cumulative effects) resulting from a range of non-fishing activities and other potential sources of stress. The purpose of this review is to gather new information on: 1) non-fishing activities that may adversely affect EFH, 2) known and potential adverse effects of these activities on EFH, and 3) options to avoid, minimize, or offset those adverse effects. This information will assist the WPRFMC in determining whether modifications to the existing non-fishing effects sections of the five Western Pacific Region FEPs are warranted.

Due to a lack of specific habitat information for many of the management unit species (MUS), the WPRFMC has broadly defined EFH to include nearly all waters and benthos within the Exclusive Economic Zone (EEZ) and encompass all marine and estuarine ecosystems within the marine waters of the Western Pacific jurisdictions. In this report, effects to EFH are evaluated from the context of individual ecosystem function within a designated EFH because identified EFHs are often comprised of multiple marine and estuarine ecosystems. Additionally, most ecological studies assessing the effects of non-fishing activities are conducted at the organismal and ecosystem scales, and each ecosystem may display a different response to a given activity.

Consistent with the ecosystems included in the Western Pacific Region FEPs, this report examines the effect of non-fishing-related activities on eight marine ecosystems: (1) intertidal, (2) mangrove forests or mangals, (3) seagrasses, (4) coral reefs, (5) deep reef slopes, (6) banks and seamounts, (7) deep-ocean floor, and (8) pelagic.

The implementing regulations of the Sustainable Fisheries Act, which amended the MSA in 1996, focused on a diverse array of human activities that could adversely affect EFH, but failed to distinguish between human actions and ecological processes/stressors that can cause

ecosystem change in a meaningful way. This report attempts to clearly delineate human activities and sources of stress from the stressors themselves. Doing so allows for a clearer understanding of potential effects of an activity because different activities often alter the intensity, duration, frequency, timing, and/or scale of the same stressor, which results in similar effects on an ecosystem regardless of the original activity (*e.g.*, reduced light affects seagrass growth in the same way regardless of whether the reduction in light results from a dredging project or a permanent structure). Nine categories of non-fishing activities are identified: (1) climate change, (2) energy production, (3) mining, (4) land-based aquaculture, (5) development/ construction, (6) shipping, (7) marine debris, (8) non-fishing human uses, and (9) wastewater discharge.

EFH is subjected to a range of non-fishing human activities and other sources of stress. These activities can affect EFH by altering the magnitude and direction of potential ecological stressors, which in turn may either: a) directly affect organisms and/or the biological processes that control their population dynamics, or b) indirectly affect organisms by altering interspecies interactions or by affecting the quality or quantity of their environment.

Ecological stressors are factors that alter the productivity, fitness, and the survival of organisms, and/or affect the long-term persistence and the functional and structural capacity of populations, biological assemblages, or ecosystems. Sources of ecological stress can come from natural environmental events (*e.g.*, storms), or may result directly or indirectly from human activities. Some ecological stressors act at a relatively small spatial scale, whereas others are regional or global in effect.

When exposure to environmental stressors changes in intensity, duration, frequency, timing, and/or scale, organisms and/or ecosystems will undergo an ecological response. Species and ecosystems have some inherent capacity to tolerate changes in the exposure to stressors, but there are limits to this ability, which are often represented as tolerance thresholds. When these thresholds are exceeded, substantial ecological change may occur.

Fifteen potential stressors on EFH have been identified for this report, and their effects on the ecosystems within the Western Pacific Region are discussed in detail. These stressors (in bold) have been grouped into the following broad categories:

1. *Environmental stressors* are associated with excessive or insufficient physical or chemical conditions within the marine environment, and in this report, include: **Ocean acidification, Shifts in productivity, Thermal, Salinity, Irradiance, Noise,** and **Hypoxia.**

2. *Biological stressors* are associated with interactions among organisms of the same or different species, and in this report, include: **Invasive species, Disease,** and **Fish aggregating device (FAD) effect.**

3. *Physical stressors* are associated with changes in exposure to kinetic energy, and in this report, include: **Physical damage.**

4. *Pollution stressors* occur when chemicals or other contaminants are present in concentrations large enough to affect organisms and thereby cause ecological change, and in this report, include: **Sediment, Chemicals,** and **Nutrient inputs.**

5. ***Sea level rise*** is a unique marine stressor with important implications in the Western Pacific Region. On casual examination, sea level rise alone might appear to be unimportant to subtidal marine ecosystems, but it is a substantial direct threat to intertidal and mangrove ecosystems, and acts indirectly on certain other ecosystems through often synergistic interactions with other stressors.

In any circumstance—meaning at a particular time and place—organisms are exposed to a complex regime of interacting ecological stressors. In some instances, the exposure to a given stressor is intense, but of short duration (*e.g.*, a storm-driven flood event). In other instances, exposure may be chronic and relatively unchanging over time (*e.g.*, sewage discharge). The complex interactions among stressors, and across their ranges of exposure, are what determine the potential effects on organisms and ecosystems.

The effects of these stressors on EFH will vary broadly by ecosystem type, the organisms affected, and their location, and are discussed in detail in the report. In some cases, little-to-no effect may be observed (*e.g.*, changes in irradiance levels will likely have minor, if any, effects on deep ocean floor ecosystems). However, the effects of other stressors on EFH can be significant, resulting in increased mortality, altered abundances and assemblage composition, and disrupted trophic dynamics. Sub-lethal effects would result in reduced individual fitness, affecting calcification, photosynthesis, growth and metabolism, gene expression, behavior, and interspecific interactions. In many cases, adverse effects will be most pronounced on microscopic organisms and planktonic life history stages of macro-fauna, leading to reproductive failure and shifts in primary productivity leading to significant, and likely adverse, effects cascading through food webs.

Cumulative effects are impacts on the environment that result from the incremental effect of an action when added to other past, present, and reasonably foreseeable future actions, regardless of who undertakes such actions. Cumulative effects can result from individually minor, but collectively significant actions taking place over a period of time, or from the cumulative and interactive effects of multiple actions. The cumulative effect from two or more actions is the result of additive (no interaction), synergistic (increased adverse effect), or antagonistic (decreased adverse effect) interactions.

Crain *et al.* (2008) reviewed over 200 studies examining cumulative effects for multiple stressors in intertidal and nearshore marine ecosystems to elucidate general patterns in cumulative stressor effects. In 62% of all cases, interactions between two stressors resulted in an adverse effect on the species or ecosystem that was at least additive (26%) or synergistic (36%). In cases where a third stressor was considered, over two-thirds of the interaction became more negative, and the number of synergistic interactions increased to 66% of the three-stressor cases. Thus, any activity or set of activities that significantly increases the negative effects of three or more stressors is likely to result in synergistic interactions that increase the likelihood of adverse effects on EFH.

The WPRFMC is tasked with describing ways to avoid, minimize, mitigate, or otherwise offset adverse effects of non-fishing activities to EFH, and for promoting the conservation and enhancement of EFH. Best management practices (BMPs), due to their generalized applicability, are the focus of this report.

To be effective, a BMP must: (1) provide meaningful and measureable minimization of impacts, (2) be properly selected and implemented, (3) be regularly inspected to insure its integrity, and (4) be monitored to assess effectiveness. Failure to meet all four requirements may result in a BMP that is ineffective for its intended purpose.

BMPs that can reduce the potential adverse effects of non-fishing activities on EFH are identified from the scientific literature, recommendations made by federal and state/territorial/ commonwealth agencies, and environmental review documents such as environmental impact statements. BMPs have been recommended for specific activity categories and stressor types. The BMPs recommended by activity category generally contain recommendations on the design, placement and execution of activities with the intention of avoiding and minimizing potential adverse effects on EFH at the development and implementation stage of an activity. The BMPs recommended by stressor type contain recommendations intended to reduce the effect of a specific stressor on EFH, either through reduction of the activities' effect on the stressor or by reducing the effect of the stressor on the ecosystem. As such, these BMPs tend to address temporary issues (*e.g.*, construction-related runoff). The BMPs by stressor are not necessarily specific recommendations for a single category of non-fishing activity, and often can be broadly applied across a range of activities. The resulting list of BMPs is not exhaustive, but represents commonly-employed, proven approaches as well as some common-sense recommendations to reduce adverse environmental effects.

1.0 Background

1.1 Magnuson-Stevens Fishery Conservation and Management Act

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) is the primary federal statute for management of U.S. marine fisheries. Originally enacted in 1976, it established a federal system to govern fishing within the 3- to 200-nautical-mile Exclusive Economic Zone (EEZ). MSA's fishery management system was established to meet the goals of conserving fishery resources and promoting a sustainable commercial and recreational fishing industry in the United States (U.S.).

The MSA established eight Regional Fishery Management Councils that were charged with developing fishery management plans (FMPs) designed to foster long-term biological and economic sustainability of the nation's marine fisheries, with several key objectives, including preventing the overfishing of stocks, rebuilding overfished stocks, increasing long-term economic and social benefits, and ensuring a safe and sustainable supply of seafood. Recognizing the loss of important habitat was a significant, long-term threat to fisheries, in 1996 the Sustainable Fisheries Act amended the MSA to require that Essential Fish Habitat (EFH) be described and identified. The MSA defines EFH as "waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." Furthermore, the MSA requires that adverse effects on EFH be minimized to the extent practicable, and that federal actions be implemented to encourage habitat conservation and enhancement.

The MSA mandates Regional Fishery Management Councils with making fishery management recommendations to the National Marine Fisheries Service (NMFS) for consideration and incorporation into the regulatory process. These recommendations could include the size of the allowable catch, the length of the fishing season, the allocation of any quotas to states and fishers, provisions for permitting and licensing or other fishery management measures suitable for achieving the management objectives of the FMPs. The Western Pacific Regional Fishery Management Council (WPRFMC) has authority over the fisheries in the Western Pacific Region, including EEZ waters surrounding the State of Hawai'i (HI), the Territory of American Samoa (AS), the Territory of Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and the U.S. Pacific Remote Island Areas (PRIA).

1.2 Fishery Ecosystem Plans

In 1996, the MSA was reauthorized and called for the creation of an Ecosystem Principles Advisory Panel (EPAP) to develop recommendations to expand the application of ecosystem principles in fisheries management. Fishery ecosystem plans (FEPs) were identified as an important mechanism for implementing ecosystem-based fisheries management (EPAP 1999), and could be used to complement the MSA's existing fishery management framework, which requires Regional Fishery Management Councils to develop FMPs that contain conservation and management measures. Per the EPAP, FEPs should contain a management framework to control the harvest of marine resources based on available information regarding the structure and function of the ecosystem in which the harvests occur.

Between 2005 and 2009, the WPRFMC replaced their FMPs with five FEPs for the Western Pacific Region containing fishery conservation and management measures in accordance with provisions as stipulated in Section 303(a) of the MSA. FEPs were developed for each of the geographical/ jurisdictional areas of the Western Pacific Region (State of Hawai‘i, the Territory of American Samoa, the Mariana Islands, PRIA) and for Pacific-wide pelagic fisheries. These FEPs include the required provisions of an FMP and support the ecosystem-based management of the fisheries.

1.2.1 Effects of Non-fishing Activities

Fishery species and their habitats are subjected to a range of non-fishing human activities and other sources of stress. These activities can affect EFH by altering the magnitude and direction of potential stressors, which in turn may either: 1) directly affect organisms (*e.g.*, injury, mortality, etc.) and/or the biological processes that control their population dynamics (*e.g.*, reproduction, behavior), or 2) indirectly affect organisms by altering interspecies interactions or by affecting the quality or quantity of their environment through alteration of physical, chemical or ecological processes that ensure ecosystem condition, function, and persistence.

The EFH regulations require FMPs to identify non-fishing activities that may adversely affect EFH (50 CFR §600.815(4)), and to provide conservation and enhancement measures to avoid, minimize, mitigate, or otherwise offset adverse effects for federal activities, including (but not limited to): dredging; filling; excavating; mining; impounding, discharging or diverting water; discharging water with different thermal characteristics; conducting activities that contribute to non-point source pollution and sedimentation, introduce potentially hazardous materials, introduce exotic species; and converting aquatic habitat such that it eliminates, diminishes, or disrupts the functions of EFH. Any federal agency undertaking an activity that may adversely affect EFH is required to consult with the NMFS, who is responsible for issuing appropriate recommendations.

In addition to specific human activities, other “natural” stressors can exert considerable force on EFH, and in this report, are important sources of stress. These include events such as weather cycles, hurricanes/typhoons, and natural climatic variability such as the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), and other stressors arising from human activities that have global scale effects, such as climate change and ocean acidification from greenhouse gas emissions. While managers cannot regulate or otherwise control these types of events, their occurrence can often be predicted and appropriate management responses can lessen the adverse effects that do and are reasonably expected to occur.

1.2.2 Cumulative Effects

Cumulative effects are effects on the environment that result from the incremental impact of an action when added to other past, present, and reasonably foreseeable future actions, regardless of who undertakes such actions. Cumulative effects can result from individually minor, but collectively significant effects resulting from two or more actions taking place over a period of time. The EFH regulations require FMPs, to the extent feasible and practicable, to analyze how the cumulative effects of fishing and non-fishing activities influence the function of EFH on an ecosystem scale (50 CFR §600.815(5)).

1.3 Purpose of this Report

Under the MSA, a review of information available on EFH must be completed at least once every five years, and EFH provisions of FMPs must be revised or amended, as warranted (50 CFR §600.815(10)). This five-year review should evaluate published scientific literature, unpublished scientific reports, information solicited from interested parties, and previously unavailable or inaccessible data. The WPRFMC reviews and updates the EFH section of the Western Pacific Region FEPs based on a five-year schedule of rotating reviews through its annual Stock Assessment and Fishery Evaluation report process.

This report is intended to review the potential effects (including potential cumulative effects) resulting from a range of non-fishing activities and other potential sources of stress. This review is intended to gather new information on: (1) non-fishing activities that may adversely affect EFH, (2) known and potential adverse effects of these activities on EFH, and (3) options to avoid, minimize, mitigate, or otherwise offset adverse effects on EFH. This information will assist the WPRFMC in determining whether modifications to the existing non-fishing effects sections of the five Western Pacific Region FEPs are warranted. While this information is highly valuable to inform impacts-analyses, the goal was not to address the approach to EFH consultations.

This review includes the following sections:

1) A brief description of the marine and estuarine ecosystems that comprise EFH in the Western Pacific Region (Section 2.0).
2) A discussion, by broad categories, of the non-fishing activities and other sources of stress that could affect EFH in the Western Pacific Region, (Section 3.0).
3) An assessment of potential effects of stressors on the marine and estuarine ecosystem that comprise the region's EFH (Section 4.0).
4) A discussion of cumulative effects with specific guidance for assessing the effects of multiple stressors (Section 5.0).
5) A list of conservation measures to avoid, minimize, mitigate, or otherwise offset adverse effects (Section 6.0).
6) A comprehensive bibliography of relevant references reviewed and cited in this report (Section 8.0).

2.0 EFH in the Western Pacific Region

Regional Fishery Management Councils, with assistance from the NMFS, must identify and describe EFH for all Management Unit Species (MUS). EFH is defined as the waters and substrate necessary to a fishery species (*e.g.*, finfish, mollusks, crustaceans and all other forms of marine animal and plant life other than marine reptiles, marine mammals and birds) for spawning, breeding, feeding, or growth to maturity. EFH for managed fishery resources in the Western Pacific Region has been designated in the FEPs prepared by the WPRFMC and includes designations for five MUS: Bottomfish and Seamount Groundfish, Crustaceans, Precious Corals, Coral Reef Ecosystems, and Pelagic species.

For this report, an ecosystem refers to any taxonomically-diverse assemblage of species and the non-living components of their environment that interact with the unit or system (*e.g.*, a coral reef ecosystem). In contrast, habitat is the physical surroundings that influence and is used by a species (*e.g.*, sandflats are feeding habitat for many goatfishes). Due to a lack of habitat-related data for most MUS, the WPRFMC has broadly defined EFH to include all waters to a depth of 1,000 meters (m) and benthos to a depth of 700 m within the EEZ and encompassing all marine and estuarine ecosystems of the Western Pacific jurisdictions. In this report, effects to EFH are evaluated from the context of individual ecosystem function within a designated EFH because the EFH identified for all MUS are often comprised of multiple marine and estuarine ecosystems (Table 1). In addition, most ecological studies assessing the ecological effects of non-fishing activities are conducted at the organismal and ecosystem scales, and each ecosystem may display a different response to a given activity. As such, the broad definition of EFH in the five FEPs creates management and regulatory challenges due to the range and diversity of non-fishing activities (see Section 3.0) that occurs within these numerous and diverse marine ecosystems, and the potential effects of those activities on the stressors that impact these ecosystems. Additional refinement of the effects of non-fishing activities on EFH, and subsequent management of them, would benefit from a narrowing of the EFH designation to better describe the habitat of species within each MUS group.

Ecosystem structure and function varies over time due to a suite of dynamic and interacting processes (Christensen *et al.* 1996, Kay and Schneider 1994, EPAP 1999). Boundaries of marine ecosystems are often difficult to clearly and unambiguously delineate because most are interlinked by population- and ecosystem-level processes critical to each ecosystems' proper function and persistence. Although marine ecosystems are generally open systems, bathymetric and oceanographic features allow them to be reasonably identified (EPAP 1999), and for management purposes, WPRFMC has delineated them geographically, making them place-based. Each ecosystem type, as defined in the five Western Pacific Region FEPs, is discussed briefly below.

2.1 Benthic Ecosystems

Benthic ecosystems are those found on the bottom of the ocean, beginning at the shore line (*e.g.*, the intertidal, mangroves, etc.) and extending subtidally out to sea. Unlike continental coastal

Table 1. The marine and estuarine ecosystems comprising the EFH designations for the nine species complexes (comprising six MUS groups) in the Western Pacific Region.

MUS Group/Species Complex	**Ecosystems within the EFH**
Bottomfish and Seamount Groundfish	
Bottomfish	Deep reef slopes (<400 m), banks and seamounts, pelagic
Seamount Groundfish	Banks and seamounts at Hancock Seamounts (80-600 m), pelagic
Crustaceans	
Crustaceans: spiny and slipper lobsters, Kona crab	Coral reef, banks and seamounts, pelagic
Crustaceans: deepwater shrimp	Deep reef slopes, banks and seamounts, pelagic
Precious Coral	
Precious coral: deep-water complex	Deep-reef slopes, deep ocean floor, banks and seamounts, pelagic
Precious coral: shallow-water complex	Coral reef, deep reef slopes (to 100 m)
Currently-harvested Coral Reef Ecosystem	Coral reef, intertidal, seagrasses, mangroves, deep-slopes, banks and seamounts, pelagic
Potentially-harvested Coral Reef Ecosystem	Coral reef, intertidal, seagrasses, mangroves, deep-slopes, banks and seamounts, pelagic
Pelagic	Pelagic (<1,000 m), banks and seamounts

waters, islands within the Western Pacific Region tend to have narrow subtidal shelfs that support species-rich, nearshore marine ecosystems (*e.g.*, coral reefs, seagrass beds, etc.) that slope steeply into deep-water ecosystems (Figure 1). Consistent with those included in the Western Pacific Region FEPs, this section presents a brief description of the following benthic ecosystems: (a) intertidal, (b) mangrove forests or mangals, (c) seagrasses, (d) coral reefs, (e) deep reef slopes, (f) banks and seamounts, and (g) deep-ocean floor.

2.1.1 Intertidal

The intertidal zone exists between the highest and lowest extent of the tides and spends at least part of its time exposed to air. The duration and frequency of exposure is correlated with the vertical position on the shore; areas closer to the high tide mark are more frequently exposed and for longer durations than areas closer to the low tide mark. Intertidal areas can be comprised of hard (*e.g.*, basalt, limestone, etc.) or unconsolidated (*e.g.*, sand, cobble, etc.) substratum, which will dictate the types of associated fauna. Sandy shallows and tidal pools are important nursery areas for many subtidal invertebrate and fish species (Major 1978, Leber *et al.* 1998, Cox *et al.*

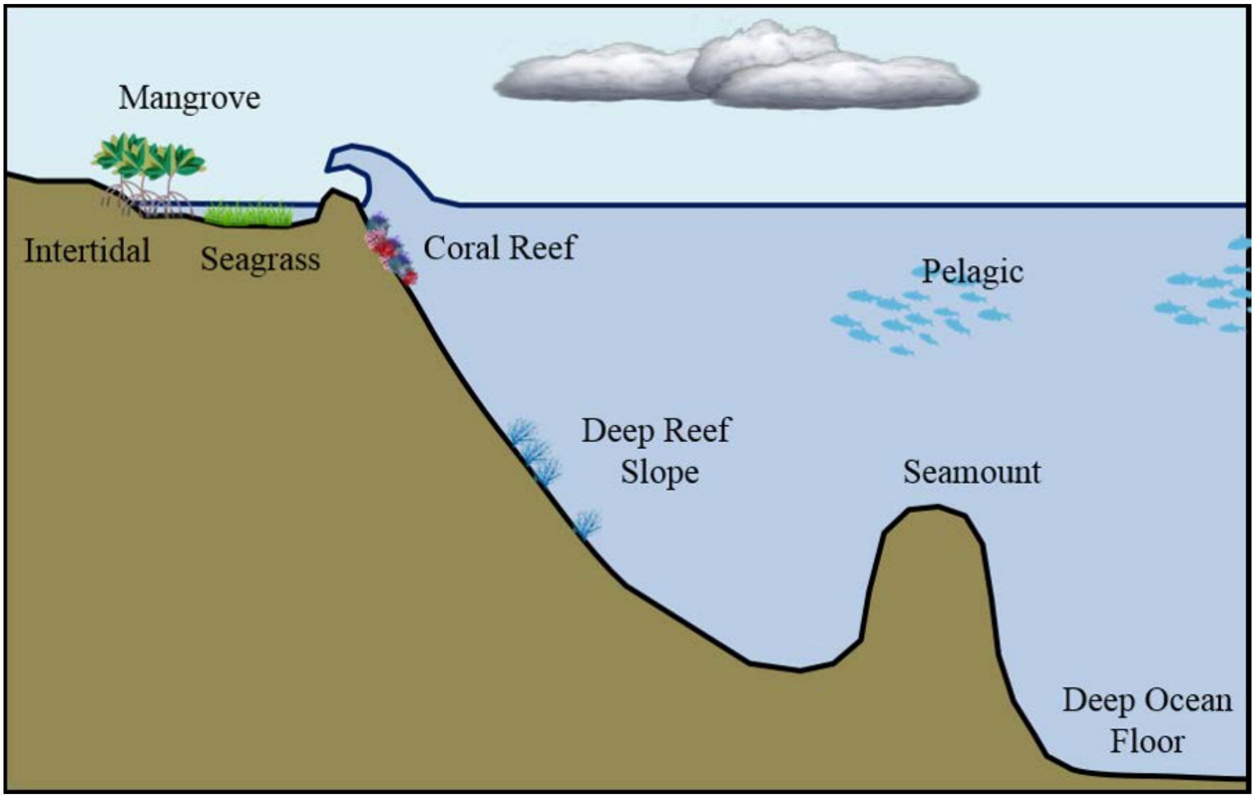

Figure 1. Schematic of the marine ecosystems that comprise the EFH of the Western Pacific Region.

2011, Iglesias 2012), including those that spend their adult life in other marine ecosystem such as coral reefs.

Intertidal organisms often display pronounced vertical zonation, where the lower limits of organisms are often determined by the presence of predators or competing species, and the upper limits are controlled by physiological limits and species' tolerance to temperature and drying (Garrity 1984, Levington 2001), although in the tropics, this may not always be the case (Minton and Gochfeld 2001). Due to challenging environmental conditions, intertidal areas generally have lower species richness and diversity than subtidal areas.

Along tropical rocky intertidal areas, marine algae and epilithic biofilms (comprised of cyanobacteria and diatoms) are the principle primary producers (Williams 1993, Williams *et al.* 2000, Macusi and Ashoka Deepananda 2013). Primary consumers such as snails and sea urchins graze on algae and biofilms, and support an array of secondary consumers that include a variety of invertebrates, sea birds and fish (Williams *et al.* 1993). Sandy intertidal areas usually support lower diversity than rocky intertidal areas, and may include a variety of burrowing mollusks, crustaceans, and worms, depending upon the amount of wave energy, which directly controls sediment grain size. Intertidal organisms are marine, and nearly all have a life history stage—usually a planktonic larval stage—that is dependent upon the ocean.

2.1.2 Mangrove Forests (Mangal)

Mangrove forests, or mangals, are tropical, coastal, forest ecosystems comprised of mangrove trees, which are adapted to grow in saline or brackish water. Mangrove forests are generally characterized as depositional coastal environments (Victor *et al.* 2004), where fine sediment, often high in organic content, collects in areas protected from high-energy wave action (Barbier *et al.* 2011). They help stabilize shorelines and reduce effects of natural disasters such as tsunamis and hurricanes (Scavia *et al.* 2002). Due to their high productivity and relatively sheltered environment, mangroves in some areas serve as important nursery habitat for many ecologically and commercially important coral reef fishery species, although research from several areas in the Pacific suggests that mangroves are less important than other coastal ecosystemns as nursery habitat for certain species (Laegdsgaard and Johnson 1995, Thollot 1992, Tupper 2007). Where mangroves have been found to be important as nurseries, they tend to have water quality conditions (*e.g.*, salinity, turbidity, etc.) similar to coral reefs (Cocheret de la Morinière *et al.* 2002), whereas in areas in which mangroves were not important reef fish nurseries, water tended to be less saline and more turbid. This is consistent with findings that juveniles of reef fishes inhabit the lower, more saline areas of mangals until migrating to the coral reef (Parrish 1989, Mumby *et al.* 2004, Abu El-Regal and Ibrahim 2014). Other fishes and crustaceans remain in the mangal throughout their adult lives, including mangrove crabs, which live in burrows among the mangrove roots. Mangals also provide food, medicine, fuel and building materials for certain local communities (Mumby *et al.* 2004 Gilman *et al.* 2006, Giri *et al.* 2011).

Mangrove trees possess an intricate salt filtration system (Lopez-Hoffman *et al.* 2007) and a complex root system to cope with salt water immersion, anoxic sediment, and wave action (Ball 1988). They can tolerate conditions ranging from brackish water to water with over twice the salinity of ocean water. Mangrove species zonation is generally correlated with soil water salinity (Ball 1988, Ukpong 1994), with less tolerant species located along the landward side of the forest or near freshwater inputs (*e.g.*, rivers). Some mangrove tree species have elaborate prop roots systems that form important substratum on which sessile organisms can settle and grow (MacDonald and Weis 2013), and which provide habitat for a variety of invertebrates and fish (Nagelkerken *et al.* 2010).

The natural eastern limit of mangroves in the Pacific is American Samoa (Ellison 1999), although three species (*Rhizophora mangle*, *Bruguiera gymnorrhiza*, and *Conocarpus erectus*) have become established in Hawai‘i since their introduction in the early 1900s, with *R. mangle* becoming the dominant plant in protected bays and along coastlines on all of the main islands (Allen 1998). While mangroves are highly regarded in most parts of the tropics for the ecosystem services they provide, in Hawai‘i they have significant negative ecological and economic effects, including reduction in habitat quality for native coastal wetland and mudflat species, displacement of native species in endemic ecosystems (*e.g.*, in anchialine pools), and overgrowth of native Hawaiian archaeological sites (Allen 1998, Chimner *et al.* 2006). Their values as nursery habitat for juvenile reef fish species is unclear, but generally they are considered detrimental.

Mangrove communities in American Samoa are composed of two species, *Bruguiera gymnorrhiza* and *Rhizophora mangle.* A majority of mangrove areas in American Samoa have been filled for residential and commercial development and roads since the early 1900s, and only five significant mangrove stands remain, covering approximately 52 hectares (ha) (Gillman *et al.* 2006). The role of mangroves in American Samoa as juvenile habitat for coral reef fish is unclear. Although numerous species are known to use areas fringed by mangal, the role of the forest themselves are unclear (Volk 1993).

In the Mariana Islands, mangroves cover an estimated 80 ha (Gillman *et al.* 2006) and comprise four species (*Rhizophora mucronata, R. apiculata, Bruguiera gymnorrhiza, Avicennia marina*). Only a single species is present in the CNMI (*Bruguiera gymnorrhiza*). Some mangrove areas on Guam (*e.g.*, Sasa Bay) have been identified as nursery habitat for jacks, barracudas, snappers, groupers, rabbitfish, mojarras, milkfish, and mullets (Wiles and Ritter 1993).

2.1.3 Seagrass Beds

Seagrasses are marine flowering plants widely distributed along tropical coastlines in the Western Pacific Region. Globally, seagrasses have an important role in fisheries production, and sediment accumulation and stabilization (, Jackson *et al.* 1989, Green and Short 2003, Dorenbosch *et al.* 2005, Larkum *et al.* 2006, Unsworth and Cullen 2008, Unsworth *et al.* 2010). Highly productive seagrass ecosystems have a relatively complex physical structure that provides a combination of food and shelter. This results in high biomass and secondary productivity, including for important fishery species in the Indo-Pacific (Parrish 1989, Beck *et al.* 2001, Honda *et al.* 2013, Nadiarti *et al.* 2015). In some area of the Pacific Ocean, seagrasses provide nursery area for species that support adjacent ecosystems, such as coral reefs and mangrove forests (Unsworth *et al.* 2010, Honda *et al.* 2013). While seagrasses may be less important in the Western Pacific Region as nursery habitat for fish and invertebrates, they are used in some jurisdictions by juvenile rabbitfish, goatfish, and snappers (Jones and Roberts 1975).

The role of seagrasses in binding sediment is important. Seagrass shoots baffle currents, thereby encouraging the settlement of sediment and inhibiting its resuspension (Short and Short 1984, Ward *et al.* 1984). By enhancing sediment retention, and through the relatively rapid uptake of nutrients both by seagrasses and their epiphytes, seagrass ecosystems can remove nutrients and other contaminants from the water column (Barbier *et al.* 2011). Once removed, these nutrients can be released more slowly through the eventual decomposition and consumption of leaf matter, thereby reducing problems of eutrophication and organic pollutants (Hemminga and Duarte 2000). Several studies that have documented the importance of seagrasses in reducing erosional forces during storm events (Koch *et al.* 2006, Barbier *et al.* 2011, Ganthy *et al.* 2014).

Seagrass diversity decreases from west to east across the Western Pacific Region. The Mariana Islands have three seagrass species (Lobban and Tsuda 2003), several of which form extensive and dense beds, especially on Saipan. American Samoa (Skelton 2003) and Hawaiʻi (McDermid *et al.* 2002) each have two species, both small in stature, which affects their functional ability to baffle currents and provide sediment stabilization and shoreline protection. However, they are still important sources of food for many species, including sea turtles (Russell *et al.* 2003).

2.1.4 Coral Reefs

Coral reefs are carbonate rock structures and associated unconsolidated substratum (*e.g.*, interspersed sand and rubble) that support viable populations of reef-building organisms, including scleractinian corals and coralline algae, and a variety of associated invertebrates and fish. Coral reef ecosystems are among the most abundant and diverse ecosystems on Earth, rivaling tropical rainforests in terms of biomass and species diversity (Roberts *et al.* 2002, Hughes *et al.* 2003). As such, coral reefs are also geologically, evolutionarily, and ecologically complex (Hatcher *et al.* 1989).

Due their reliance on light for photosynthesis, coral and other reef-building organisms are confined to the depths where light sufficient to conduct photosynthesis penetrates—known as the euphotic zone—although some predominately non-reef-building coral species can occur in the deeper ocean zones (see Section 2.1.5, Section 2.1.6, and Section 2.1.7). Maximum reef growth and productivity generally occurs between approximately five and 15 m (Hopley and Kinsey 1988), but the maximum depth at which reefs can grow depends on water clarity and photosynthetic capability, which is highly variable among species (Baker 2001, Yentsch *et al.* 2002, Baird *et al.* 2003). Maximum biodiversity of coral reef species usually occurs between 10-30 m (Huston 1985).

Four primary reef types are found in the Western Pacific Region. Fringing reefs grow directly along the shoreline of islands and often include a shallow (<2 m) reef flat before sloping into deeper water. Given their relatively shallow waters and proximity to the shoreline, fringing reefs are often exposed to more human activity than other reef types. Barrier reefs are shallow reef systems that are separated from the shore, generally by a relatively shallow (<10-20 m) lagoon system. Barrier reefs are relatively rare in the jurisdictions of the Western Pacific Region, with the barrier reefs in Kāneʻohe Bay, Hawaiʻi, Cocos Lagoon, Guam, and Saipan Lagoon, Saipan being the most prominent examples. Patch reefs are comparatively small, often circular reef outcroppings that rise up from the bottom of lagoons or other relatively shallow embayments to within a few meters of the surface (*e.g.*, Kāneʻohe Bay, Hawaiʻi and Apra Harbor, Guam). Atolls are continuous barrier reef-like structures that enclose a lagoon and have no central island. Most atolls have one or more channels through the reef that allows water exchange between the lagoon and the ocean. Patch reefs are commonly found within the atoll's lagoon. Atolls may or may not have one or more low-relief, coral and rubble islands atop the reef structure. Atolls are prominent in the Northwestern Hawaiian Islands and the PRIA.

Reef-building corals are the primary providers of physical structure upon which associated organisms depend for food and shelter (Alvarez-Filip *et al.* 2009), and loss of this structure is often referred to as "flattening" of the reef. The symbiotic relationship between coral and algal cells, known as zooxanthellae, is a key feature of reef-building corals (Roth 2014). Zooxanthellae provide much of the polyp's nutritional needs, and play a critical role in the coral's ability to accrete carbonate from the water column to construct its skeleton, a process called calcification (Colombo-Pallotta *et al.* 2010). The rate at which a reef can calcify is among its most important ecological functions because persistence of the coral reef ecosystem depends on rate of calcification exceeding the rate of erosion (Wilkinson and Buddemeier 1994).

A healthy, functioning coral reef ecosystem is comprised of more than corals. In addition to coral zooxanthellae, other important primary producers on coral reefs include phytoplankton, macro- and micro-algae, benthic bacteria, and seagrasses. Primary consumers include many species of mollusks, crustaceans, echinoderms, gastropods, sea turtles, and herbivorous fish. Secondary consumers include anemones, crustaceans, and fish, including several important fishery species. Tertiary consumers include eels, octopuses, barracudas, sharks (sometimes referred to as apex predators), and monk seals in Hawaiʻi. While many coral reef species rely on the hardbottom areas on which coral colonies grow, associated sand patches and algal and seagrass beds, often serve as important feeding or spawning habitat for many species (*e.g.*, goatfishes, some wrasses, squid, etc.). Some coral reef organisms also use mangroves, seagrass beds, and intertidal ecosystems for nursery areas (*e.g.*, jacks, barracudas, snappers, rabbitfish, etc.), and these coastal ecosystems also play important roles in ecosystem processes on coral reefs, such as nutrient cycling.

The diversity of nearly all coral reef organisms declines in an easterly direction across the Pacific Ocean (Stoddart 1992, Reaka *et al.* 2008). While taxonomy can vary among observers, ~375 species of reef-building corals have been identified from the Mariana Islands (Randall 2003), ~220 species from American Samoa (DiDonato *et al.* 2006), 59 species from Hawaiʻi (Maragos *et al.* 2004) and between 47 and 173 species on each of the PRIA (Kenyon 2010). As coral species richness declines, reefs tend to lose specific coral genera and families and their associated reef functions. For example, the genus *Acropora* is absent from the main Hawaiian Islands (with some rare exceptions, see Walsh *et al.* 2014, Kosaki *et al.* 2013). *Acropora* species, and especially tabular *Acropora*, provide a complex three-dimensional structure, a key ecological feature for coral reefs. Among mollusks, species with large larval forms and/or short planktonic durations are under-represented or absent from Hawaiian reefs (Paulay and Meyer 2006), and more prevalent Western Pacific Ocean reefs such as the Mariana Islands.

2.1.5 Deep Reef Slopes

Unlike continental areas, the jurisdictions in the Western Pacific Region lack extensive shallow water shelves around their perimeter; instead, relatively narrow fringing reefs generally slope steeply into deep water not far from shore. The benthic communities on these deep reef slopes are zoned in relation to light penetration. Where light is still sufficient for photosynthesis, deep-water reef-building corals will continue to grow where appropriate substratum is available. These mesophotic coral ecosystems (MCE), found at depths of nearly 200 m (Baker *et al.* 2016), have been hypothesized to serve as refugia for shallow reef species, especially those subject to significant fishing pressure and/or other non-fishing stresses (Glynn 1996, Blyth-skyrme *et al.* 2013, Lindfield *et al.* 2014, Muir *et al.* 2015). Deep reef slopes are also home to a diversity of marine organisms, including many important fishery species (Lindfield *et al.* 2014) and antipatharian coral, *i.e.*, precious corals.

Relatively little is known about deep reef slope ecosystems, but recent technological advances have made it possible to conduct scientific investigations of MCE, which inhabit the upper boundary of this area, where low levels of light still penetrate. Significant work to characterize these assemblages has recently been undertaken in several of the jurisdictions in the Western Pacific Region (*e.g.*, survey work by the NOAA Coral Reef Ecosystem Program).

At shallower depths (50 to 80 m) in Hawaiʻi, large *Halimeda* meadows and diverse macroalgal assemblages (*Lobophora variegata*, *Dictyota friabilis*, coralline algal rhodoliths, *Mesophyllum mesomorphum*, and *Peyssonnelia rubra*) have been observed covering both hard and soft substrata. These macroalgal communities generally do not comprise significant habitats for large-bodied fishes in the main Hawaiian Islands (Pyle *et al.* 2016), although endemic reef-associated fishes have been found in deep water *Microdicyton* (algae) beds in the Northwestern Hawaiian Islands (Kane *et al.* 2014). At greater depths, abundance of macroalgae declines and hard substratum is often dominated by monospecific stands of the hard coral *Leptoseris* spp. (Rooney *et al.* 2010, Pyle *et al.* 2016). Below approximately 100 m, live benthic cover was uniformly low, but on hardbottom features exposed to currents, precious black corals and the invasive octocoral *Carijoa* sp. could be locally abundant, with the latter often overgrowing large black coral colonies (Kahng and Grigg 2005).

Limited work in American Samoa has confirmed reef-building MCE at depths as great as 110 m. Encrusting corals belonging to the genus *Montipora* and massive corals in the genus *Porites* were most abundant at shallow depths with their cover gradually decreasing as depth increased. At depths of 60 to 70 m, plate corals in the genus *Acropora* dominated the MCE, giving way to species in the genera *Leptoseris*, *Pachyseris*, or *Montipora*. Branching coral cover was high in the 80 to 110 m depth range (Bare *et al.* 2010).

Extensive mesophotic reefs have been observed seaward of the Saipan Lagoon barrier reef, mainly on the Garapan Anchorage. Lindfield *et al.* (2016), using baited camera drops on Guam, Saipan, Tinian, and Rota, found high fish abundance on MCE (35-90 m) compared to inshore reefs (10-35 m), and suggest that MCE represent a depth refuge for many coral reef fish species. They also noted that coral structure disappeared at depths greater than 70 m and fish abundance decreased. At depths greater than 70 m, unconsolidated sediment was the primary bottom feature (Lindfield *et al.* 2016). In addition to hard scleractinian corals, sea fans, a type of soft coral, were a common feature on hard substrate at mesophotic depths in the Mariana Archipelago (Blythe-Skyrme *et al.* 2013).

Data are insufficient to identify the location or density of MCE in the PRIA, but the presence of deep-water corals (165 m) at Johnston Atoll (Kahng and Maragos 2006), along with the clear oligotrophic waters minimally influenced by terrigenous inputs, suggests that MCE are likely present at most or all islands within the PRIA (Blyth-Skyrme *et al*. 2013).

2.1.6 Banks and Seamounts

In the Western Pacific Region, banks and seamounts are submerged features formed by undersea volcanos. During the formation of seamounts, they never reached the surface of the ocean and thus maintain a generally "mountainous" shape, with steep slopes and relative little flat area on top of them. Banks are less specifically defined, but comprise shallow areas rising up from relatively deep waters that may have been formed by a submerged part of a larger landmass or a submerged atoll. Over 50,000 seamounts may exist in the Pacific Ocean (Rogers 2004), and banks and seamounts are found in all jurisdictions in the Western Pacific Region.

Seamounts can have a significant effect on the pelagic environment. They may deflect major ocean currents (*e.g.*, the Emperor Seamount Chain deflects the Kuroshio Current), and have the potential to form eddies, called Taylor Columns, that may become trapped or shed downstream (White and Mohn 2002, Rogers 2004). Taylor Columns are associated with the upwelling of nutrient-rich water from the deep ocean, and may lead to increased productivity in the upper waters above or downstream of seamounts (Brainard 1986, Rogers 2004), and may help retain pelagic larvae, although evidence for larval retention over seamounts, especially small ones, is sparse (Boehlert and Mundy 1993, Sponaugle *et al.* 2002).

In the Western Pacific Region, coral reef ecosystems tend to be found on the shallower parts of banks and seamounts, but can extend downslope into the mesophotic zone. Deeper parts of seamounts and banks may be composed of rock, coral rubble, sand, or shell deposits. Bank and seamount assemblages tend to be dominated by those found on nearby shallow areas and do not have unusual diversity or endemism (Howell *et al.* 2010). Seamounts and banks are important feeding and reproduction grounds for many deep water or pelagic species of fish. Plankton biomass may be increased over and around seamounts and form a source of prey for seamount-associated species (Rogers 2004). This forms the basis for the WPRFMC's designation of the water column down to 1,000 m above seamounts with summits shallower than 2,000 m as Habitat Areas of Particular Concern for the Pelagic MUS.

2.1.7 Deep Ocean Floor

The deep ocean (waters and seafloor deeper than ~200 m), supports a high diversity of ecosystems and species (Hessler and Sanders 1967, Grassle and Maciolek 1992, Sogin *et al.* 2006, Ramirez-Llodra *et al.* 2010, Mora *et al.* 2011), as well as abundant mineral resources (Herzig and Hannington 1995, Kato *et al.* 2011). Relatively little is known about this region due to the challenges associated with studying this environment, limiting our understanding of the resilience of this ecosystem to and its recovery from adverse effects. The deep ocean has a role in nutrient regeneration and global biogeochemical cycling that is essential for sustaining primary and secondary productivity in the oceans, and adverse effects that decrease the biodiversity of the deep ocean could affect this important ecosystem function (Danovaro *et al.* 2008). Pressure to extract deep ocean resources is increasing (Mengerink *et al.* 2014), including fishing, drilling for hydrocarbon extraction, and mining of rare earth elements (*e.g.*, Morato *et al.* 2006, Benn *et al.* 2010).

The deep ocean floor is generally comprised of soft-sediment, but biologically created "hardbottom" can cover tens of square kilometers and provide extensive three-dimension relief (Thurber *et al.* 2014). Probably the best-known example of biogenic habitat in the deep ocean is created by “cold-water” corals. Submersible explorations in Hawaiʻi have revealed that gorgonian-like corals (*e.g.*, "bamboo corals") and other antipatharian corals (*e.g.*, "precious" corals) can form complex hard structures with their skeletons (NOAA 2009). These areas often have high species diversities because of increased access to dietary resources and refuge from predators or physical disturbance, and may provide a nursery habitat for deep-ocean species including fish (Miller *et al.* 2012).

2.2 Pelagic Environment

The entirety of the water column overlying the benthos is the pelagic zone of the ocean, although the description of EFH for the pelagic MUS includes only the uppermost 1000 m. It comprises the largest ecosystem in the Western Pacific Region, and is the primary connection between all benthic marine ecosystems. Nearly all marine organisms spend all or part of their life in the pelagic environment.

Average primary productivity in the tropical open ocean is among the lowest of all marine ecosystems, typically around 40 grams (g) of carbon/m^2/year (Carpenter 1998). Warm conditions in the tropics promote thermal stratification in the upper layer of the ocean and prevent mixing with lower, cooler, nutrient-rich water (Carpenter 1998). However, in upwelling areas, including waters near oceanic islands and some seamounts (from Taylor Columns), nutrients are brought from the deep ocean into the sunlit upper layers, where phytoplankton can access it, thus increasing primary productivity.

Along the equator in the Central Pacific (near several of the PRIA) is an upwelling area caused by the diverging flow of the North Equatorial Current and the Equatorial Countercurrent (Chavez and Barber 1987). Additionally, the Western Pacific Warm Pool (WPWP) is an area of water with surface temperatures consistently above 28°C (Yan *et al.* 1992), creating a highly stratified water column and little vertical mixing. The waters within the WPWP are nutrient poor, and productivity is low. However, along the edge of the WPWP are convergence zones that upwell nutrient-rich waters from depth (Helber and Weisberg 2001), promoting high primary productivity. This edge area has high densities of tuna and is commercially important. In coastal waters (especially around high islands), productivity is greater than the open ocean, primarily because of land-derived nutrient inputs, including from groundwater discharge (Knee 2010).

Phytoplankton represent several different types of microscopic photosynthetic organisms and occur primarily in the upper 100 m of the water column. Phytoplankton includes organisms such as diatoms, dinoflagellates, coccolithophores, and cyanobacteria. Many of these organisms deposit skeletons by precipitating dissolved minerals (primarily silicates and carbonates) from the water column. Although some phytoplankton such as dinoflagellates have structures that allow them to move (especially vertically through the water column), the distribution of many phytoplankton is controlled by oceanic currents.

The secondary productivity from zooplankton in the Western Central Pacific Ocean roughly mirrors the pattern of primary productivity (Carpenter 1998). Highest zooplankton production is found in upwelling areas, but is generally lower than that found in most coastal areas (Carpenter 1998). Zooplankton include organisms such as copepods, cheatognaths, euphasids, ostracods, amphipods, and many other microscopic invertebrates. Larvae and gametes of marine macro-organisms, including pelagic fish and coral reef-associated fish and invertebrates, are also an important component of the zooplankton (King and Demond 1953).

Large-scale oceanographic events (*e.g.*, ENSO, PDO, etc.) change the characteristics of water temperature and productivity across the Pacific, and have a significant effect on open ocean productivity.

3.0 Non-fishing Activities and Other Sources of Stress

Numerous types of non-fishing activities and other sources of stress occur in the Western Pacific Region. These activities affect EFH by altering the magnitude and direction of potential stressors (see Section 4.0 for discussion of specific stressors) directly affecting organisms or changing the quality or quantity of their environment (Figure 2). The potential effects of a specific activity on a marine ecosystem are dependent on the location, size, timing, duration, method, etc. of the specific activity. It would be impossible to list and discuss every non-fishing activity in detail; however, many specific activities have sufficient similarities among the stressors they affect to allow them to be grouped into generalized categories to more easily examine their potential effects on EFH.

The implementing regulations for the Sustainable Fisheries Act, which amended the MSA and created the provision for EFH, focused on a diverse array of human activities and stressors (*e.g.*, coastal development projects, mining, sedimentation, nutrient loading, etc.) that could adversely affect EFH, but in doing so created a confusing mixture of human activities and ecological processes that can cause ecosystem change. Additionally, some potentially significant, non-fishing sources of stress were not adequately considered and analyzed in the subsequent FEPs developed by the WPRFMC, including the potential effect of climate change, which the WPRFMC has subsequently required for consideration in its management decisions through its Marine Planning and Climate Change Policy. Climate change is likely to be the most significant source of stress on EFH in the Western Pacific Region in the coming decades.

This report attempts to clearly delineate human activities and sources of stress from the stressors themselves. Doing so allows for a clearer understanding of potential effects because different activities often alter the intensity, duration, frequency, timing, and/or scale of the same stressor, which results in similar effects on a marine or estuarine ecosystem (Figure 2). For example, physical damage to a coral from the anchor chain of a large vessel dragging on the bottom would likely have similar effects to the damage caused from the underwater detonation of ordnance. The human activities and other sources of stress are discussed in subsections, and concluded with a summary table listing the stressors associated with the activity. Detailed information on the stressors themselves is the subject of Section 4.0.

3.1 Climate Change

Climate is the long-term (usually decades or longer) average weather pattern in a specific place or region. These average patterns are subject to natural cycles that contribute to short-term (annual or decadal) variability (*e.g.*, ENSO, PDO), but which do not result in long-term changes in average condition. **Climate change** is a long-term change in the state of climate that may encompass a change in average weather conditions and/or a change in the variability of that average condition, for example, more or fewer extreme weather events (IPCC 2007). The primary source of climate change – atmospheric accumulation of CO_2 – will also directly affect the acidity of the ocean, and thus ocean acidification is often considered a part of climate change

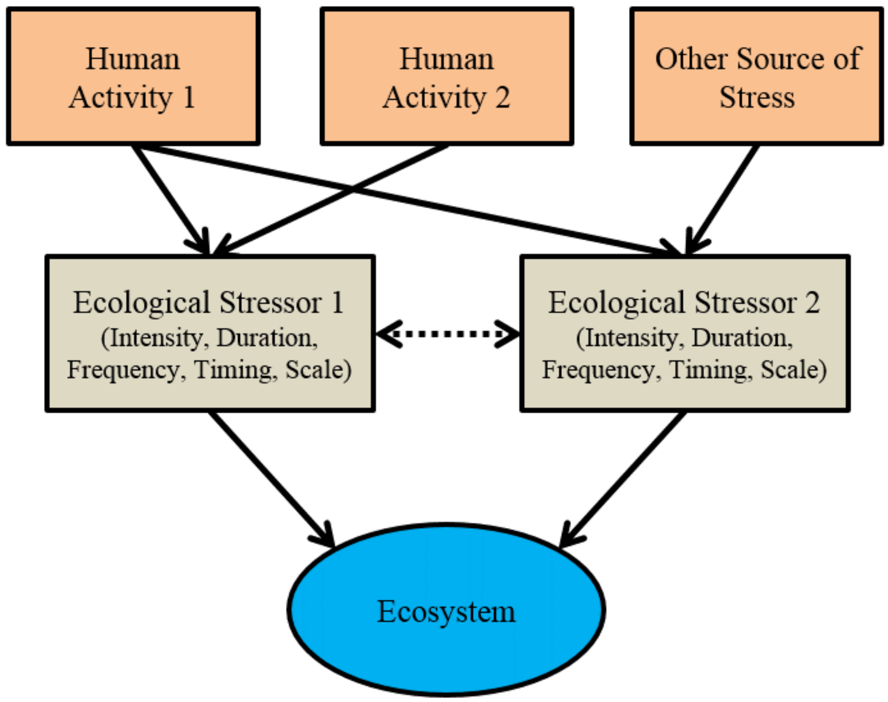

Figure 2. Conceptual flow diagram showing the linkage of human activities and other sources of stress on an ecosystem. Activities and sources of stress alter the intensity, duration, frequency, timing and/or scale of potential ecological stressors, which act directly on species or ecological processes in the ecosystem. Different activities often affect the same ecological stressor(s), and stressors often interact with each other (dotted arrow), resulting in a variety of potential responses (see Section 5.0).

even though it is not actually a climatological feature. The WPRFMC has “adopted the definition of climate change used by the Intergovernmental Panel on Climate Change (IPCC) to include natural climate variability such as ENSO and other patterns of natural variability as well as long-term changes in climate associated with anthropogenic (human) influence on greenhouse gases and other aspects of the Earth's climate system. The definition of climate change in this policy also includes ocean acidification” (WPRFMC 2015). Numerous factors contribute to climate change, including biological processes, variations in solar radiation, geological processes, and some human activities (National Academy of Science 2010).

Climate change is predicted to affect the jurisdictions in the Western Pacific Region in the following ways:

- American Samoa is expected to experience increased surface air temperature and sea-surface temperature, and the intensity and frequency of extreme heat events are expected to increase. Rainfall is expected to stay approximately the same, but the frequency of extreme rain events is expected to increase under current climate change scenarios (PCEP 2016). The number of hurricanes are expected to decline in the south-east Pacific Ocean Basin (Lagomauitumua *et al.* 2010), likely causing a decrease in hurricanes affecting American Samoa. Ocean acidification is expected to increase, and sea level is expected to rise.

- The Hawaiian Archipelago extends across a wide latitudinal range and is comprised of high and low islands. Thus, climate change effects such as rainfall and ocean acidification will likely vary across the archipelago, but to what degree is uncertain. To date research has focused on the southerly high islands, where the archipelago's human population lives. The Hawaiian Islands are expected to experience increased air and sea surface temperatures (Giambelluca *et al.* 2008, Sea Grant 2014). Anticipated decreases in prevailing northeasterly trade winds are expected to result in an overall decline in annual rainfall, which is consistent with observations over the past 40 years (Chu and Chen 2005). Extreme rainfall events and occurrences of drought are also expected to increase (Chu *et al.* 2010), resulting in extended dry periods and more flash flooding. Changes in rainfall patterns will potentially affect aquifer recharge and ground water flow into the coastal marine environment. Ocean acidification is expected to increase across the archipelago, and sea level is expected to rise from 0.3-1 m (1-3 feet (ft)) by the end of the century (Sea Grant 2014).

- The Mariana Islands are expected to experience higher air and sea surface temperatures. It is currently unclear how rainfall in the Mariana Islands will be affected. Guam may experience fewer, but more intense, storms (Lander 2004), but Saipan may see only a small increase in average rainfall and extreme rainfall events, but may experience "wetter" wet and "drier" dry seasons, *i.e.*, increased variability in rainfall (Greene and Skeele 2014). Ocean acidification is expected to increase, and sea level is expected to rise >1 m (>3 ft) by the end of the century (PREL 2014).

- The PRIA are spread across the Pacific Ocean, from south of the equator to the northern extent of coral reef distributions, and from the western to central Pacific. Therefore, the effects of climate change are expected to vary across these geographically dispersed islands, but it may be possible to predict the broader effects based on predicted changes in nearby jurisdictions for which information is currently available. A common feature of most of these island areas is their relatively low topographic relief and extensive coral reef structure. As such, increases in sea surface temperature and ocean acidification (Royal Society 2005, IPCC 2014), and a rise in sea level will affect all island areas within the PRIA, and are expected to be the most serious stressors associated with climate change.

- The open ocean, home to important pelagic fisheries species, is expected to experience warmer surface water temperatures, increased acidification, and increased variability in ENSO events, all of which will have direct effects on current patterns, ocean stratification, seawater chemistry, and productivity (Johnson *et al.* 2013).

Summary Table: Climate Change. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors: Direct	Stressors: Indirect
Climate change	● HI ● AS ● MI ● PRIA ● Pelagic	● Acidification ● Shift in productivity ● Thermal ● Sea level rise	● Salinity ● Irradiance ● Invasive species ● Disease ● Physical damage ● Sediment ● Nutrient inputs ● Hydrocarbons ● Herbicide/Pesticide ● Metals ● PCBs ● Ordnance[†] ● Endocrine disruptors

[†] Mariana Islands and Hawaii

3.2 Energy Production

With the desire to reduce fossil fuel usage and obtain energy independence, a considerable investment has been made to develop and assess the feasibility of alternative energy in the Pacific Islands. The jurisdictions in the Western Pacific Region have no fossil fuel resources, but energy can be obtained from wind, solar, ocean currents (hydrokinetic), ocean thermal, and geothermal means. It is no longer a question of whether alternative energy production will be implemented, but when. In the past decade, numerous utility-scale alternative energy projects have been proposed in the Hawaiian Islands, but only a handful have reached the construction stage. Hawaiʻi has committed to a long-term plan to convert entirely to renewable energy sources by 2050 (DOE 2015); the current proposal, called the Hawaiʻi Clean Energy Initiative, includes 31 types of activities whose specific projects could affect EFH. In American Samoa, an Energy Action Plan (Ness *et al.* 2016) proposes an array of renewable energy projects to be completed by 2020. One of those projects, converting the Island of Ta'u to 100% solar power generation (1.4 megawatts), was completed in 2016 (Heathman 2016). Both Guam (Conrad and Ness 2013a) and the CNMI (Conrad and Ness 2013b) have Energy Action Plans, but have yet to make significant progress in their implementation. Palmyra Atoll currently has a small research station (operated by The Nature Conservancy and the Palmyra Atoll Research Consortium) on its largest island that is powered by a combination of solar and wind power arrays, supported by a diesel generator. When assessing the potential effects on EFH, these renewable energy activities can be divided into two sub-categories: land-based and ocean-based energy activities.

Land-based energy projects include wind turbines, solar, geothermal facilities, and land-based Ocean Thermal Energy Conversion (OTEC). The stressors affected by the land-based portions of these projects would be similar to those found under land-based development/construction category. Some facilities, such as OTEC, require inwater intake and discharge structures which can contribute to direct effects on coastal and nearshore ecosystems. If energy produced through these projects remains on the island where it is generated, likely no additional effects to EFH would be expected, except for OTEC, which is discussed in more detail below. If energy is to be transferred to neighboring islands within an archipelago, the most practical transmission method would use submerged cables, either in surface or (more likely) buried conduits. Buried conduits would likely require removal or disturbance of the substratum, including coral reef, either through mechanical trenching, directional drilling, or a combination of the two.

Ocean-based energy projects include wind turbines and solar facilities placed on platforms in the ocean, and alternative energy approaches that use the physical (*e.g.*, wave or tidal energy) or thermal (*e.g.*, OTEC) properties of the ocean to generate power. Ocean-based energy projects require infrastructure, but it can be free floating or anchored to the bottom. Essential infrastructure feetures include power generating infrastructure and a means to transfer the generated energy to land. Proposals that have been considered in the Western Pacific Region include platform wind turbine farms, hydrokinetic generators (several designs are currently under testing off O‘ahu, Hawai‘i), and ocean-based OTEC. As with land-based projects, energy would be transferred to consumers via either surface or buried conduits.

The energy production potential for OTEC is considered to be much greater than for other ocean energy forms (Arvizu *et al.* 2011), and pilot projects have already been conducted in Hawai‘i. OTEC is considered an attractive and viable energy production method in the Pacific, but it presents specific challenges to EFH that do not occur with other alternative energy production methods. OTEC uses the temperature differential between cold deep and warmer surface waters to generate electricity. OTEC systems may be either closed-cycle or open-cycle. Closed-cycle OTEC uses refrigerants such as ammonia for powering the system’s generators, while open-cycle designs vaporize warm surface seawater in a low-pressure chamber and use it as the working fluid. As a by-product, OTEC produces cold, nutrient-rich water that is generally discharged back into the ocean.

3.3 Mining

Quarries are land-based mining locations that are present in most of the jurisdictions in the Western Pacific Region. Most quarry activity is dedicated to mining limestone for construction material, and likely has little effect on marine ecosystems, although they can potentially contribute to runoff. Unlike some other Pacific Islands (*e.g.*, Yap, Pohnpei, etc.), no direct mining of coral block/aggregate directly from living reefs occurs in the Western Pacific Region.

Currently, **deep ocean mining** is not economically viable on a large-scale, but continued advances in deep ocean mining technology and an increasing demand for rare earth elements (REE), will make it a realistic endeavor across the Pacific in the foreseeable future. Current deep ocean mining practices involve deploying remotely operated vehicles to locate prospective mine sites at depths between 1,400-3,700 m (4,200-8,100 ft) (Ahnert and Borowski 2000). Once a suitable site has been located, a mining ship or station is set up to mine the area (The Economist 2006) and one of two mineral extraction techniques are employed: 1) a continuous-line bucket system (CLB) and/or 2) a hydraulic suction system. The CLB system is the preferred technique and operates much like a conveyor-belt, running from the sea floor to the surface of the ocean

Summary Table: Energy Production. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors: Direct	Stressors: Indirect
Land-based Energy	● HI ● AS ● MI ● PRIA†	● Thermal ● Salinity ● FAD effect ● Physical damage ● Sediment	● Irradiance ● Noise ● Invasive species ● Sediment ● Nutrient inputs ● Hydrocarbons ● Herbicide/Pesticide ● Metals ● PCBs ● Ordnance†† ● Endocrine disruptors
Ocean-based Energy	● HI ● AS ● MI ● Pelagic	● Thermal ● Salinity ● Irradiance ● Invasive species ● FAD effect ● Physical damage ● Sediment ● Nutrient inputs ● Hydrocarbons ● Metals ● Ordnance†† ● Endocrine disruptors	● Noise

† Palmyra
†† Mariana Islands and Hawaii

where a ship or mining platform extracts the desired minerals from material collected by automated harvesters on the bottom, and discharges the tailings and deep ocean water back into the ocean (Nath and Sharma 2000). Hydraulic suction mining lowers a pipe to the seafloor and suction dredges material to the surface where it is processed to extract the desired minerals before a second pipe returns the tailings to the area of the mining site (Nath and Sharma 2000).

The International Seabed Authority (ISA), established as part of the United Nations Conventions on the Law of the Sea, regulates seabed mining in waters outside national jurisdictions, and grants exploration permits for projects. The U.S. is not a signatory to the Law of the Sea and not a party to the ISA. In 1980, Congress enacted the Deep Seabed Hard Mineral Resources Act (DSHMRA) under which U.S. citizens and corporations may apply to the Administrator of the National Oceanic and Atmospheric Administration (NOAA) for 10-year licenses to explore and 20-year permits to mine the deep seabed for hard mineral resources, and specifically REE (DSHMRA 1980). Within the EEZ of Hawaiʻi, commercial mining interests are subject to the Bureau of Ocean Energy Management's regulations governing non-energy mineral prospecting, leasing, and production. It is currently unclear under what authority deep ocean mining would be regulated in the territories, commonwealth or other administered areas outside of a designated Marine National Monument, National Wildlife Refuge, National Park or other such protected area, where mineral resource extraction is already prohibited.

Currently, U.S. mining licenses have been assigned in the mineral-rich Clarion-Clipperton Zone, roughly halfway between Hawai‘i and Mexico. Additional licenses could be assigned to other mineral rich areas, which are often associated with natural hydrothermal vents. These vents regularly deposit rich concentrations of metals and minerals from the Earth’s core to the ocean bottom. Hydrothermal regions are common off the Mariana Islands, and have been found off Hawai‘i, which present potential opportunities for mineral extraction.

3.4 Land-based Aquaculture

An increasing world population requires a sustainable source of protein, and for many cultures, this has traditionally been derived through the direct harvest of marine organisms. To meet future protein needs, freshwater aquaculture and marine aquaculture (sometimes refer to as aquaculture and mariculture, respectively) will likely continue to expand and become important farming practices throughout the Pacific. In Hawai‘i, aquaculture production has increased by more than 150% between 2011 and 2015 (DBEDT 2016). Likewise, increasing production has been seen in American Samoa and Guam since 2000 (Knomea 2016). "Fish farming" has a long cultural tradition in many parts of the Pacific (Keala *et al.* 2007), including Hawai‘i where native

Summary Table: Mining. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors: Direct	Stressors: Indirect
Quarries	• HI • AS • MI		• Irradiance • Sediment • Nutrient inputs • Hydrocarbons • Metals • PCBs • Ordnance[††] • Endocrine disruptors
Deep Ocean	• HI • AS • MI • PRIA[†] • Pelagic	• Irradiance • Noise • Physical damage • Sediment • Nutrient inputs • Hydrocarbons • Metals	

[†] Outside protected areas
[††] Mariana Islands and Hawai‘i

Hawaiians developed extensive coastal fishponds to grow species such as moi (*Polydactylus sexfilis*), āholehole (*Kuhlia sandvicensis*), and ʻamaʻama (*Mugil cephalus*).

Until recently, land-based aquaculture was the primary commercial approach used to rear fish and shellfish, wherein tanks or ponds were placed directly on shore and stocked with desired species[1]. Water (fresh or salt) is pumped into the ponds, and wastewater effluent, is often returned to the nearshore waters, either passively via channels or actively via pumps. Alternative disposal methods, such as ground injection (HDOA 2011), or treatment using reverse osmosis (Qin *et al.* 2005) have been employed in the Western Pacific Region. Cultured organisms were fed to maximize their growth rate, and any excess feed, combined with excretory products would be flushed from the ponds, resulting in elevated nutrient levels in the receiving waters.

3.5 Development/Construction

Given the relatively small size of the islands in the Western Pacific Region, nearly all human development and construction occurs close enough to the coast to potentially affect EFH. Of particular concern are development projects that move earth, alter surface condition (*e.g.*, change ground permeability, erosion rates, etc.), or introduce potential contaminants. Many of these projects require local and/or federal permits and are likely to be subject to environmental review

Summary Table: Land-based Aquaculture. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors: Direct	Stressors: Indirect
Land-based aquaculture	• HI • AS • MI	• Thermal • Salinity • Irradiance • Invasive Species • Disease • FAD effect • Sediment • Nutrient inputs • Herbicide/Pesticide • Metals • PCBs • Ordnance[†] • Endocrine disruptors	• Hypoxia

[†] Mariana Islands

[1] In some cases, fish ponds and other support structures such as oyster racks, were placed in coastal waters. In addition, new approaches use anchored and free floating cages. These aquaculture practices and associated facilities will not be covered in this review; the WPRFMC is examining their effects elsewhere.

or other forms of disclosure that involve public and expert review (*e.g.*, NEPA, coastal zone management program, Clean Water Act, and/or the local equivalent).

Land-based development/construction activities include the majority of development projects in the Western Pacific Region, and are projects that have no direct connection with coastal waters, *i.e.*, are not water dependent. This includes the construction of most buildings and associated infrastructure, other structures (*e.g.*, energy production and transmission structures), and most roads, although see coastal roads below for a special case.

Coastal roads are a special case of land-based road construction in which part of the construction requires activities to occur in coastal waters and usually require some placement of fill. This may include construction of bridges, but also include coastal stabilization or hardening structures intended to fortify roads from erosion and/or inundation. In addition, other coastal hardening conducted independent of road construction (*e.g.*, shoreline stabilization, channelizing waterways, etc.) will have similar effects. With rising seas and other anticipated climate change effects, an increase in the number of construction and refurbishments of existing roads using coastal fortifications is expected, as well as an increase in other coastal hardening projects intended to protect shorelines from erosion and infrastructure from inundation.

Unlike land-based projects, waterbased development/construction has a direct connection or nexus with estuarine or marine ecosystems. These structures or projects are "water dependent" and thus cannot be built elsewhere. **Waterbased (dredging)** projects require the removal or addition of material into the waters of the U.S., and may include activities such as dredging to create or maintain navigational channels; trenching, blasting, pile driving, or drilling to install pilings, anchorings or other structures, or to bury conduits, pipelines, or other features; or the release of fill material to create breakwaters and other in-water stabilization/fortification structures. In contrast, **waterbased (non-dredging)** projects do not require dredging or filling, and may include installation of floating structures (*e.g.*, wave or wind turbines, etc.), and possibly construction of harbors or marinas, depending on their size and location.

Artificial reefs are a special case of waterbased construction and are highlighted separately from other waterbased activities due primarily to their designed purpose. These structures are specifically designed and constructed to enhance one or more marine services, and are generally considered to have net positive effects on the marine environment (although this is not always the case). Artificial reefs are often proposed as mitigation for adverse effects on marine ecosystems under federal permitting requirements such as the Clean Water Act. Regardless of their intended purpose and benefits, the placement and design of these features must be individually assessed for their effectiveness to enhance ecosystem services, as well as their potential to adversely affect EFH.

3.6 Shipping/Boating

Beyond the operation of a vessel itself, shipping/boating encompasses a wide variety of activities that could adversely affect marine ecosystems. Many of these activities and sources of stress are covered elsewhere in this report (*e.g.*, dredging and construction projects associated with harbors and safe navigation, marine debris, etc.). Not covered elsewhere are activities including the

installation and maintenance of aids-to-navigation and large-scale anchorages, specifically the anchoring of prepositioning ships off the west coast of Saipan, CNMI.
Summary Table: Development/Construction. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors Direct	Stressors Indirect
Land-based	• HI • AS • MI		• Thermal • Salinity • Irradiance • Hypoxia • Invasive Species • Disease • Sediment • Nutrient inputs • Hydrocarbons • Herbicide/Pesticide • Metals • PCBs • Ordnance[††] • Endocrine disruptors
Coastal Roads	• HI • AS • MI	• Irradiance • Noise • Invasive species • Disease • FAD effect • Physical damage • Sediment • Nutrient inputs • Hydrocarbons • Herbicide/Pesticide • Metals • PCBs • Ordnance[††] • Endocrine disruptors	• Irradiance • Hypoxia • Sediment • Nutrient inputs • PCBs • Ordnance[††]
Waterbased (dredging)	• HI • AS • MI • PRIA[†]	• Irradiance • Noise • Invasive species • Disease • FAD effect • Physical damage • Sediment • Nutrient inputs • Hydrocarbons • Herbicide/Pesticide	• Hypoxia

Activity/Source	Potential Jurisdictions	Stressors Direct	Stressors Indirect
		• Metals • PCBs • Ordnance†† • Endocrine disruptors	
Waterbased (non-dredging)	• HI • AS • MI • PRIA† • Pelagic	• Noise • Invasive species • FAD effect • Physical damage • Hydrocarbons • Herbicide/Pesticide • Metals • PCBs • Ordnance†† • Endocrine disruptors	
Artificial reefs	• HI • AS • MI	• Invasive species • FAD effect • Physical damage • Hydrocarbons	• Noise

† Palmyra
†† Mariana Islands and Hawai‘i

Shipping is an essential activity in the Western Pacific Region, and is responsible for the transportation of nearly all imported goods. Maritime-based activities such as boat-based fishing and ocean tourism, are critical to island economies. Hawai‘i and Guam possess large U.S. military bases, from which naval activity and training are regularly conducted. Even for the PRIA, ships are the primary means for accessing the remote islands to conduct research and management activities.

Aids-to-navigation (ATONS) are "road signs" for ship crews and generally include a variety of buoys and beacons, each of which has a purpose to aid boaters in determining location, getting from one place to another, and staying out of danger. As such, ATONS are expected to have a net beneficial effect on EFH. These aids are securely anchored in the nearshore waters of all U.S. jurisdictions where shipping/boating occurs, although the PRIA are a notable exception (except for Palmyra, Wake Islands, and Johnston Islands which have ATONS).

Large-scale **anchorage** sites are rare in the jurisdictions of the Western Pacific Region, although the anchoring of military prepositioning ships off Saipan and military vessels in Apra Harbor are notable exceptions. The mission of these vessels is to quickly and efficiently deliver military cargo and supplies to a designated area in support of two Marine Expeditionary Brigades for up to 30 days and in response to a crisis or humanitarian disaster. Three to five vessels occupy the Garapan Anchorage as part of Maritime Prepositioning Ships Squadron-3 (MPSRON-3), and use large anchors with a considerable scope of heavy chain to hold their position. The vessels use pre-designated anchoring spots identified on NOAA nautical charts. Vessels have been observed to swing in an approximately 60-degree arc depending on the state of the winds and currents, dragging chain along the bottom (Rooney *et al.* 2005).

Summary Table: Shipping/Boating. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors Direct	Stressors Indirect
Shipping	• HI • AS • MI • PRIA	• Noise • Invasive species • Disease • FAD effect • Physical damage • Sediment • Nutrient inputs • Hydrocarbons • Metals • Endocrine disruptors	
ATONS	• HI • AS • MI • PRIA†	• FAD effect • Physical damage • Hydrocarbons • Metals • Endocrine disruptors	
Anchorage	• MI††	• Noise • Invasive species • FAD effect • Physical damage • Hydrocarbons • Metals • Endocrine disruptors	

† Wake and Palmyra
†† Saipan and Guam

3.7 Marine Debris

Marine debris is comprised of any persistent solid material that has been manufactured by humans and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the ocean. It can originate from land and be blown or transported via water into coastal waters or it can be directly disposed of into the ocean, generally from ships. Marine debris can include, but is not restricted to, derelict fishing gear, manufactured household and industrial items, metals, plastics, and microplastics. An estimated 4.8 to 12.7 million metric tons of marine debris entered the ocean in 2010 (Jambeck *et al.* 2015).

Once in the ocean, floating debris can be transported by wind and ocean currents thousands of kilometers (Erickson *et al.* 2014) before degrading, sinking, or washing up onto beaches. Due to the configuration of currents, marine debris often collects in specific regions of the ocean, usually referred to as “garbage patches” (NOAA 2011). Marine debris most often approaches islands from the windward side (Tetra Tech 2010), presenting added risk to marine ecosystems along those shores.

Floating debris poses a threat to pelagic animals and once it sinks, it can become entangled around benthic organisms. While ingestion rates may be high among sea turtles and marine mammals, it is considerably lower among fish, with documented ingestion limited to approximately 40 species worldwide, or less than one percent of all species (CBD 2012). Marine debris can serve as floatation and aid species dispersal (Gregory 2009, Donohoue *et al.* 2001). Recently, debris washed into the ocean from the 2011 tsunami in northern Japan has raised concerns for its potential to transport invasive species and contaminants (initial concerns associated with radioactivity have been found to be unwarranted [Smith *et al.* 2015]).

3.8 Other Human non-fishing Use

Humans use the marine environment in a variety of ways and for many purposes. Many of these activities have direct effects on EFH that are not included under other activities in this report. **Military training**, both land-based and ocean-based, is commonly conducted by all branches of the U.S. military throughout the jurisdictions of the Western Pacific Region. Troop and ship maneuvers, amphibious landings, weapons training, active use of sonar, missile launches, underwater demolitions, and coordinated maneuvers with multinational task forces are all important features of military training in the Pacific.

A wide range of civilian, non-fishing activities occur in the Pacific Islands, mostly involving **recreational use**, and including but not limited to scuba diving (and other similar activities), swimming, surfing, boating, and jet skiing. These activities are popular among local island residents and are an important part of the local tourist-based economies of most Wester Pacific jurisdictions.

Scientific research is actively conducted in most jurisdictions in the Western Pacific Region. Within the PRIA, it is likely the most prominent and common human use. Most scientific research has very low impact on the environment relative to the other activities included in this report, and the beneficial effects of scientific research likely outweigh these minimal effects.

Summary Table: Marine Debris. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors: Direct	Stressors: Indirect
Marine debris	● HI ● AS ● MI ● PRIA ● Pelagic	● Invasive species ● FAD effect ● Physical damage ● Hydrocarbons ● Herbicide/Pesticide ● Metals ● PCBs	

		● Endocrine disruptors

However, sample collection and the installation of instrumentation has the potential to produce cumulative effects, especially if numerous research efforts are spatially and/or temporally concentrated.

3.9 Wastewater Discharge

Most terrestrial-derived "pollutants" are transported to and enter the nearshore ocean via water, whether it is the intentional disposal or through natural processes. For the purposes of this report, wastewater is defined as any water entering the ocean, via point source, groundwater, river system, or runoff that carries some pollutant (*e.g.*, sediment, chemicals, biological contaminants/ organisms) or has different physical properties (*e.g.*, different temperature or salinity) than the receiving body.

Summary Table: Other Human Non-fishing Use. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors	
		Direct	Indirect
Military training	● HI ● AS ● MI ● Pelagic	● Noise ● Invasive species ● Physical damage ● Nutrient inputs ● Hydrocarbons ● Metals ● PCBs ● Ordnance ● Endocrine disruptors	● Salinity ● Irradiance ● Sediment ● Nutrient inputs ● PCBs ● Ordnance ● Endocrine disruptors
Recreational use	● HI ● AS ● MI	● Noise ● Invasive species ● FAD effect ● Physical damage ● Nutrient inputs ● Hydrocarbons ● Herbicide/Pesticide ● Metals ● Endocrine disruptors	● Sediment ● Endocrine disruptors
Scientific research	● HI ● AS ● MI ● PRIA ● Pelagic	● Invasive species ● Disease ● FAD effect ● Physical damage ● Hydrocarbons ● Metals	

In the jurisdictions of the Western Pacific Region, effluent from primary and secondary **sewage** treatment plants often discharge directly into the nearshore waters via outfalls. Discharges may be in relatively shallow (~30 m) to deep (>80 m) water. Alternatively, treated effluent can be discharged into upland injection wells, where there is the potential for it to migrate into the groundwater and eventually find its way to the ocean through submarine groundwater discharge. Following large rainfall events, high volumes of stormwater can overburden treatment facilities and result in the discharge of untreated human sewage. Many island communities around the Pacific are not connected to municipal sewage treatment facilities, and rely on cesspools or septic tanks. Cesspools and septic systems are common in many rural and coastal areas of Hawai‘i, American Samoa and the Mariana Islands (Southwest States and Pacific Islands Regional Water Program 2005). These are prone to leaking, allowing poorly or untreated human sewage to infiltrate into the groundwater, and in some locations, to enter coastal waters. Coastal septic and cesspool systems are particularly susceptible to sea level rise.

Intense or sustained rainfall can result in large discharges of **stormwater**, either through point sources such as stormwater pipes or via non-point sources such as runoff. High sheetwater flow rates can increase erosion and reduce the effectiveness of natural processes that filter pollutants from the stormwater prior to ocean entry. The volume and severity of stormwater discharges are directly related to the intensity, duration, frequency, timing, and/or scale of the rainfall event and the permeability of the surface. Low permeability, such as that associated with many land-based development/construction projects, often results in an increase in sheetwater flow.

Numerous **other activities** are responsible for discharges directly or indirectly into the nearshore marine waters. With some exceptions, agricultural fields (*e.g.*, sugar cane and other agriculture), taro lo‘i, and animal lots (*e.g.*, piggeries in American Samoa) produce discharges that are currently excluded from U.S. Clean Water Act regulation, but can be significant sources of pollutants to coastal waters. Fish canning facilities, present in American Samoa, produce nutrient-rich effluent high in suspended solids and oils, whereas other large, managed landscapes, including golf course and residential developments, can be significant sources of nutrients and chemical contaminants, via non-point source runoff. While their point source discharges are regulated, sugar mills, power plants, and OTEC facilities dispose of wastewater from processing or cooling generators into the nearshore marine environment.

Summary Table: Wastewater Discharge. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors: Direct	Stressors: Indirect
Sewage	• HI • AS • MI	• Thermal • Salinity • Irradiance • Disease • Sediment • Nutrient inputs • Hydrocarbons • Herbicide/Pesticide • Metals • Endocrine disruptors	• Hypoxia
Stormwater	• HI • AS • MI	• Thermal • Salinity • Irradiance • Disease • Sediment • Nutrient inputs • Hydrocarbons • Herbicide/Pesticide • Metals • PCBs • Endocrine disruptors	• Hypoxia
Other discharges	• HI • AS • MI	• Thermal • Salinity • Irradiance • Disease • Sediment • Nutrient inputs • Hydrocarbons • Herbicide/Pesticide • Metals • Endocrine disruptors	• Hypoxia

4.0 Ecological Stressors in the Marine Environment

Ecological stressors are factors that alter the productivity, fitness, and the survival of organisms, and/or affect the long-term persistence and the functional and structural capacity of populations, biological assemblages, or ecosystems. Sources of ecological stress can come from natural environmental events such as storms, or may result directly or indirectly from human activities (Table 2). Some ecological stressors act at a relatively small spatial scale, whereas others are regional or global in effect.

At any particular time and place, organisms are exposed to a complex regime of interacting ecological stressors. In some instances, the exposure to a given stressor is intense, but of short duration (*e.g.*, a storm-driven flood event, a ship grounding). In other instances, exposure may be chronic and relatively unchanging over time (*e.g.*, sewage discharge, nutrient input via groundwater). The complex interactions among stressors, and across their ranges of exposure, are what determine the potential effects on organisms and ecosystems.

Stressors create challenges to the integrity and quality of ecosystems, and by extension, the EFH to which those ecosystems are a component. When exposure to environmental stressors changes in intensity, duration, frequency, timing, and/or scale, organisms and/or ecosystems will undergo an ecological response. For example, disruption of an ecosystem by an intense disturbance could cause the mortality of specific organisms and other ecological damage, followed by a gradual recovery driven by natural processes (*e.g.*, succession). Species and ecosystems have some inherent capacity to tolerate changes to the intensity of stressors, but there are limits to this ability, which are often represented as tolerance thresholds. When these thresholds are exceeded, substantial ecological change may occur, often causing adverse effect to EFH.

Fifteen potential stressors on EFH (Table 2) have been identified for this report, and their effects on the ecosystems within the Western Pacific Region are discussed in greater detail below. These stressors (in bold) have been grouped into the following broad categories:

1. *Environmental stressors* are associated with excessive or insufficient physical or chemical conditions within the marine environment. Environmental stressors can be associated with water temperature, solar radiation, salinity, pH, dissolved oxygen, and any combinations of these, and in this report, include: **Ocean acidification, Shifts in productivity, Thermal, Salinity, Irradiance, Noise,** and **Hypoxia.**

2. *Biological stressors* are associated with interactions among organisms of the same or different species. Biological stressors can result from competition, herbivory, predation, parasitism, and disease, and in this report, include: **Invasive species, Disease,** and **Fish Aggregating Device (FAD) effect.**

Table 2. The potential stressors associated with non-fishing activities and sources of stress. Activity categories (rows) are discussed in detail in the text. Stressors are groups into five general types: environmental (blue), biological (red), physical (green), chemical (purple), and sea level rise (orange). D=activity directly affects the stressor, i=activity indirectly affect the stressor, *=may be a problem in some jurisdictions.

													Chemicals						
	Ocean Acidification	Shift in Productivity	Thermal	Salinity	Irradiance	Noise	Hypoxia	Invasive Species	Disease	FAD Effect	Physical Damage	Sediment	Nutrient Inputs	Hydrocarbons	Herbicide/Pesticide	Metals	PCBs	Ordnance	Endocrine Disruptors	Sea Level Rise
Climate Change	D	D	D	i	i			i	i		i	i	i	i	i	i	i	*	i	D
Energy Production																				
Landbased			D	D	i	i		i		D	D	iD	i	i	i	i	i	*	i	
Waterbased			D	D	D	i		D		D	D	D	D	D		D		*	D	
Mining																				
Quarries					i							i	i	i		i	i	*	i	
Deep Ocean					D	D					D	D		D		D				
Land-based Aquaculture			D	D	D		i	D	D	D		D	D		D	D	D	D	D	
Development/Construction																				

Landbased			i	i	i		i	i	i			i	i	i	i	i	i	*	i	
Coastal roads					iD	D	i	D	D	D	D	iD	iD	D	D	D	iD	*	D	
Waterbased-Dredging					D	D	i	D	D	D	D	D	D	D	D	D	D	*	D	
Waterbased-Non-dredging						D		D		D	D			D	D	D	D	*	D	
Artificial reefs						i		D		D	D			D						
Shipping/Boating																				
Shipping						D		D	D	D	D	D	D	D		D			D	
ATONs										D	D			D		D			D	
Anchorages						D				D	D			D		D			D	
Marine Debris								D		D	D			D	D	D	D		D	
Non-fishing Human Uses																				
Military training				i	i	D		D			D	i	iD	D		D	iD	*	iD	
Recreational use						D		D		D	D	i	D	D	D				iD	
Research								D	D	D	D			D		D				
Wastewater Discharge																				
Sewage			D	D	D		i		D			D	D	D	D	D			D	
Stormwater			D	D	D		i		D			D	D	D	D	D	D		D	
Other activities			D	D	D		i		D			D	D	D	D	D			D	

3. *Physical stressors* are associated with changes in exposure to kinetic energy. This type of ecological disturbance is often acute and episodic, and in this report, include: **Physical damage.**

4. *Pollution stressors* occur when chemicals or other contaminants are present in concentrations large enough to affect organisms and thereby cause ecological change. Pollution can include anthropogenic inputs of pesticides/herbicides, hydrocarbons, metals, and other toxic chemicals, but also can include inputs of sediment and nutrients. This report includes: **Sediment, Chemicals,** and **Nutrient inputs.**

5. ***Sea level rise*** is a unique marine stressor with important implications in the Western Pacific Region. On casual examination, sea level rise alone might appear to be unimportant to subtidal marine ecosystems, but it is a significant direct threat to intertidal and mangrove ecosystems. Additionally, it acts indirectly on other ecosystems through often synergistic interactions with other stressors (see Section 5.0).

4.1 Environmental Stresses

4.1.1 Ocean Acidification

Ocean acidification is the decrease in the pH of the oceans caused by the uptake of atmospheric carbon dioxide (CO_2) (Caldiera and Wickett 2003). Seawater is slightly basic (pH ~8.2) and acidification shifts it towards a less basic condition, *i.e.*, lower pH. Equally important, acidification decreases the carbonate concentration in seawater, and thus decreases the saturation state of calcium carbonate ($CaCO_3$) (Orr *et al.* 2005, Kleypas *et al.* 2006, Cooley and Doney 2009). This change in the chemical make-up of seawater can directly affect the biological process of calcification, essential for reef-building organisms, mollusks, echinoderms, and many types of plankton.

Over the past two centuries, atmospheric CO_2 has increased by over 43%, from pre-industrial levels of approximately 280 parts per million (ppm) (IPCC2007) to over 400 ppm in 2016 (NOAA 2016), and under "business-as-usual" models which assume continued greenhouse gas emissions at or exceeding current rates, atmospheric CO_2 could exceed 1,000 ppm by the end of the century (Kiehl 2011). This rate of CO_2 increase is driven primarily by human burning of fossil fuels and deforestation (Doney & Schimel 2007), and the current concentration of CO_2 is higher than that experienced on Earth for at least the past 800,000 years (Lüthi *et al.* 2008). Rising atmospheric CO_2 is tempered by oceanic uptake, which can absorb up nearly a third of the anthropogenic carbon added to the atmosphere (Sabine and Feely 2007, Sabine *et al.* 2004).

At the Hawaiʻi Ocean Time-Series (HOT) station ALOHA, the rate of increase of surface water CO_2 and atmospheric CO_2 are strongly correlated (Takahashi *et al.* 2006, Dore *et al.* 2009), indicating uptake of anthropogenic CO_2 is the primary cause of long-term decreases in pH and $CaCO_3$ saturation state. Since preindustrial times, the average ocean surface water (the ocean layer down to approximately 100 m) pH has fallen by approximately 0.1 pH units, from approximately 8.21 to 8.10 (Royal Society 2005) which is due to the logarithmic nature of the pH scale represents about a 30% increase in acidity (Caldiera and Wickett 2003). Buoy data from the equatorial Pacific (covering years 1997-2011) show pH ranged from 7.91-8.12 (Sutton *et al.* 2014), which is consistent with what has been observed in subtropical waters (pH = 8.06-8.14) via the HOT station ALOHA time series (Dore *et al.* 2009). Acidity is expected to decrease to7.88 pH units if the atmospheric CO_2 concentration reaches 1,000 ppm (IPCC 2007), although more current projections suggest pH might be lower under this business-as-usual model (IPCC 2014). Even under modest, likely-to-be-obtained climate change predictions (CO_2 = 560 ppm), oceanic pH is expected to be 7.92 pH units (IPCC 2014), and deep ocean waters and arctic surface waters are expected to be undersaturated ($CaCO_3$ saturation state <1). At pH 7.8, major ecological changes will occur because of the impairment of invertebrate reproduction (Wood *et al.* 2008, Wang *et al.* 2016) and recruitment (Nakamura *et al.* 2011), and shell dissolution of many benthic and planktonic invertebrate taxa (Smith & Buddemeier 1992, Kleypas *et al.* 1999, Hall-Spencer *et al.* 2008, Cooley and Doney 2009). Additionally, acidification will affect biological processes beyond calcification, including gene expression, metabolism, and cell death/regeneration (Kleypas *et al.* 2006, Todgham and Hoffman 2009). Already seasonal acidification events are appearing in upwelled waters along the California coastline in summer, decades earlier than models predict (Feely *et al.* 2008, Gruber *et al.* 2012).

However, the effect of ocean acidification on calcification is complicated by the fact that enhanced levels of CO_2 can increase photosynthetic rates (Behrenfeld *et al.* 2006, Kranz *et al.* 2009), which will affect net primary productivity (Hein and Sand-Jensen 1997, Behrenfeld *et al.* 2006, Jiao *et al.* 2010). In corals, much evidence suggests that under normal conditions, calcification rates generally rise proportionally with increases in rates of primary production, both at the colony and assemblage scale (Gattuso *et al.* 1999), yet in virtually all studies that have measured both photosynthesis and calcification in corals, any stimulation of photosynthesis by increased CO_2 was accompanied by a decrease, rather than an increase, in calcification (Reynaud *et al.* 2003). In Hawai‘i, Langdon and Atkinson (2005) exposed an assemblage of corals (*Porites compressa* and *Montipora capitata*) to two levels of CO_2, and at the higher CO_2 level, observed a 22–26% increase in the rate of net primary production but a 44–80% decrease in calcification, depending on the species and the time of year.

Furthermore, calcification rates in the wild are affected by other stressors such as temperature, light levels, and the availability of trace minerals and nutrients, and several studies have illustrated a complicated relationship between calcification (which affects photosynthesis), and the interactions among ocean acidification and these other stressors. For example, light intensity was shown to be an important factor in laboratory experiments with marine foraminifera, where calcification rates decreased with increasing CO_2 concentrations only under saturating light intensities (Zondervan *et al.* 2002). Trace metal limitation has been shown to affect marine foraminifera calcification and growth (Schulz *et al.* 2004), and iron limitation affected both calcification and productivity, while zinc was limiting to productivity, but not calcification.

Under the “business-as-usual” climate change scenarios, temperate and colder oceans are expected to become undersaturated in both calcite and the more bio-available aragonite (Orr *et al.* 2005), but the warm surface waters of the tropics and subtropics are not expected to become undersaturated over the range of these projected conditions (Fabry *et al.* 2008), except perhaps in some upwelling regions. In these areas aragonite undersaturated waters are pushed upward from the deep ocean into shallower water—a phenomenon frequently referred to as the "shoaling of aragonite saturation horizons"—where it would now impinge on the depth ranges of pelagic animals (Feely *et al.* 2004). Even though tropical surface waters are not expected to become undersaturated, the average aragonite saturation state under "business-as-usual" climate models is expected to be about half its current state in the tropical Pacific (Fabry *et al.* 2008), leading to significantly lower calcification rates.

Reduced calcification rates have been observed following acidification for a variety of calcareous organisms even when aragonite or calcite saturation state is > 1 (Royal Society 2005, Kleypas *et al.* 2006, Fabry *et al.* 2008). Some reef-building corals appear to cease calcification at aragonite saturation state as high as two, but the degree of sensitivity varies among species, and some marine taxa may even show enhanced calcification at elevated CO_2 levels (Iglesias-Rodríguez *et al.* 2008, Ries *et al.* 2009). However, studies of ocean acidification on calcification rates of marine organisms exist for a limited number of species, and we lack sufficient understanding of calcification mechanisms to explain species-specific differences (Doney *et al.* 2009). Regardless, the evidence suggests calcification rates will be significantly reduced for most marine organisms.

Currently, most studies examining the effect of ocean acidification on marine organisms have been of short duration, ranging from hours to weeks. Chronic exposure to increased acidification may have complex effects on the growth and reproductive success of calcifying organisms, and could induce adaptations that are not observed in short-term experiments (Kleypas *et al.* 2006, Doney *et al.* 2009).

Almost every study published to date confirms that calcification rates will decrease in response to decreasing aragonite saturation state and decreasing pH for corals (Gattuso *et al.* 1998, Langdon *et al.* 2000, Marubini & Atkinson 1999, Marubini & Davies 1996), coral reef communities (Langdon *et al.* 2000, 2005, Leclercq *et al.* 2000), and planktonic organisms (Bijma 1991, Riebesell *et al.* 2000). Additionally, in coral reef ecosystems, many other benthic calcifying taxa are ecologically important. Crustose coralline algae (CCA) are a widespread, globally-significant, but often undervalued, benthic marine organism (Foster 2001). CCA have shown declines in both calcification rates and recruitment rates at lower carbonate saturation state (Doropoulos *et al.* 2012), including in Hawai'i (Kuffner *et al.* 2008). This could have significant cascading effect through the coral reef ecosystem because CCA is an important structure-consolidating organism and a key settlement substratum for many corals. Under lower pH conditions, changes in CCA structure has significantly lowered the settlement density of coral larvae (Doropoulos *et al.* 2012).

Coral reef ecosystems are defined by their ability to produce a net surplus of $CaCO_3$ that produces the topographically complex reef structure necessary to support high marine biodiversity and biomass. Coral reef ecosystems have survived around many Pacific Islands because of their rapid accretion rates, giving them the ability to migrate upward and maintain themselves at a depth that has at least the minimum light levels required for continued growth. Under increasing ocean acidification, coral calcification rates will decrease, and dissolution rates will increase (Langdon *et al.* 2000, Yates and Halley 2006), particularly for those reefs at higher latitudes where seawater saturation state is expected to be closer to an undersaturated state. These reefs are already near the limit for reef growth, and will be further challenged by undersaturated seawater conditions. Interestingly, even though global warming may extend ocean water temperatures conducive to coral survival to higher latitudes, the decrease in reef $CaCO_3$ accretion expected at higher latitudes may restrict reef development to lower latitudes where aragonite saturation levels can support carbonate accumulation (Guinotte *et al.* 2003, Kleypas *et al.* 2001).

Even if calcification continues, reduced rates may impair the ability of calcifying organisms to compete with non-calcifying ones. Such a decrease has been observed in CCA assemblages when exposed to high-CO_2 conditions (Kuffner *et al.* 2008). Given that many taxa appear to exhibit species-specific responses (Fabry 2008, Ries *et al.* 2009, Doropoulos *et al.* 2012), assemblage- and ecosystem-level effects are likely to be complicated and difficult to predict, but are likely to result in major reorganizations of benthic and planktonic assemblages. These alterations will likely affect the physical and chemical structure of reefs. Topographical structure is a key ecological function strongly correlated with biodiversity, abundance, and biomass (Alvarez-Filip *et al.* 2009), and has direct implications on food webs dynamics.

Calcareous skeletal parts are widespread among many groups of benthic invertebrates and studies have reported drops in calcification rates at CO_2 levels below those expected under the current "business-as-usual" models for common species of mussels (*Mytilus edulis*) and oysters (*Crassostrea gigas*), a Pacific conch (*Strombus luhuanus*) and numerous species of sea urchin (Shirayama and Thorton 2005, Dupont *et al.* 2010), many of which occur in the Western Pacific Region. However, these findings cannot be easily generalized across taxa (Kroeker *et al.* 2014); many urchins and crustaceans show surprising resistance to low pH (Hendricks and Duarte 2010, Dupont *et al.* 2010, Kroeker *et al.* 2014), and calcification rates in the arms of a burrowing brittle star increased when they were grown in low pH water (Wood *et al.* 2008), but this finding is complicated in that while brittle stars experienced increased calcification, they also experienced decreased muscle mass in the arms, which would reduce arm movement and likely decrease respiration and feeding, suggesting that over the long-term, the organism would experience a reduction in fitness, highlighting the potential sub-lethal effects that can occur in seemingly resistant taxa (Dupont and Thorndyke 2013).

The effects of acidification may be exacerbated by certain developmental bottlenecks that are affected by low pH, and thus may have a disproportionately large influence on population dynamics that are missed by most experimental investigation (Dupont *et al.* 2010, although see Hendricks and Duarte 2010). The response of early developmental stages of invertebrates to ocean acidification has been investigated across a range of species, including bivalves and sea urchins. Under increasing acidification, sea urchins show reduced fertilization success, developmental rates, larval size, metamorphosis, spicule formation, and in their ability to settle (Kurihara and Shirayama 2004, Dupont *et al.* 2010; Evans and Watson-Wynn 2014). Likewise, developmental abnormalities have been observed in the oyster *C. gigas*, after 24 hours of exposure to high CO_2 levels (>2,000 ppm) and 80% of the larvae displayed malformed shells or remained unmineralized (Kurihara *et al.* 2007). Less dramatic, but still significant, effects have been observed at lower CO_2 levels, and even short exposure at the fertilization stage can carry over into later stage larvae, affecting growth rates and calcification (Barton *et al.* 2012). Greater susceptibility to increased acidification of larval and juvenile compared to adult mollusks is a pattern observed across a range of mollusks that have been studied (Kroeker *et al.* 2013).

In general, marine fish appear to be relatively tolerant to mild increases in CO_2 (Munday 2011a, Kroeker *et al.* 2014). Otolith development is unaffected by moderate increases in acidity (Munday *et al.* 2011b), although sublethal metabolic effects have been identified for some reef fish species (Munday *et al.* 2009). The most significant effects may occur through cellular changes that block olfactory senses, and consequently the ability of adults and juveniles to detect predators (Dixson *et al.* 2010; Munday *et al.* 2013; Heuer and Grosell 2014), and possibly to locate suitable settlement habitat (Dixson *et al.* 2008), which under some ecological conditions could have significant adverse effects on a population.

Deepwater corals in the Western Pacific Region are slow growing and long lived (Roark *et al.* 2006). Their carbonate structure serves as important habitat for many deep sea species and support high biodiversity of invertebrates (Parrish and Baco 2007). The maximum depth of deep water corals and their associated species appears to coincide with the depth of the aragonite saturation state horizon (Guinotte *et al.* 2006), which under the “business-as-usual” climate models is expected to shoal. As such, these deepwater coral systems are expected to be the first to experience a shift to an undersaturated seawater condition (Doney *et al.* 2009). This will likely lead to range/depth contractions, and could force slow-growing deepwater corals into direct competition with shallow water coral species, which are likely superior competitors.

The effects of elevated CO_2 and ocean acidification on primary productivity are complicated by the relationship between carbon uptake (as part of the photosynthetic process), temperature, calcification (where relevant), and nutrient availability. A potentially major consequence of ocean acidification will be significant changes in the inorganic and organic chemistry of seawater. Affected chemical species include biologically important elements such as boron, phosphorus, silicon, and nitrogen, as well as trace elements such as iron, zinc, vanadium, arsenic, and chromium (Doney *et al.* 2009). Concentrations of phosphate, silicate, fluoride, and ammonia species will decrease with increasing acidification (Zeebe and Wolf-Gladrow 2001), and will have far-reaching implications for phytoplankton and other ecological processes. Additionally, many trace elements (*e.g.*, aluminum, iron, chromium, etc.) show reduced bioavailability to organisms as result of hydrolyzation under increasing acidification. The overall effect of ocean acidification on the structure and function of these biologically important compounds is largely unknown, making predicting organismal and ecosystem effects difficult.

Seagrasses show a consistent and dramatic increase in light-saturated photosynthetic rates with increasing acidification (Zimmerman *et al.* 1997, Short and Neckles 1999, Invers *et al.* 2001), although it is possible these benefits could be offset by the negative effects of increased temperature on vegetative growth (Ehlers *et al.* 2008). Interestingly, regions near natural subsurface volcanic CO_2 vents in the Mediterranean Sea showed a marked absence of reef-building corals and reduced abundance of sea urchins, coralline algae, foraminifera, and gastropods. Instead, the benthos was dominated by sea grass, anemones, and non-native invasive algal species (Hall-Spencer *et al.* 2008), consistent with expectations from laboratory experiments.

The mangrove trees *Rhizophora mangle* showed increase photosynthesis under elevated CO_2 levels (Farnsworth *et al.* 1996), but this appears to be mediated by salinity. Trees grown under elevated CO_2 experienced little growth enhancement in high-salinity conditions, but more growth enhancement under low-salinity conditions (Ball *et al.* 1997), an effect that was magnified for less-tolerant species (Ball *et al.* 1997). Likewise, little effect on mangrove seedling growth or survival was found for three species in different mangrove genera when grown under highly acidic conditions (pH=5.0) (Rozainah *et al.* 2016), suggesting that mangrove trees will experience few adverse effects from CO_2 condition expected under "business-as-usual" climate models.

Most studies on the effect of ocean acidification on the calcification rates of non-larval planktonic organisms have focused on coccolithophores (a common tropical planktonic group), and have found inconsistent responses to acidified seawater. The bloom-forming coccolithophore species, *Emiliania huxleyi* and *Gephyrocapsa oceanica*, showed a 25-66% decrease in calcification rate when CO_2 was increased to 560–840 ppm (Riebesell *et al.* 2000, Zondervan *et al.* 2001, Zondervan *et al.* 2002, Sciandra *et al.* 2003, Delille *et al.* 2005, Engel *et al.* 2005). In contrast, other coccolithophore species have exhibited no significant change in calcification or malformations from being cultured in acidified seawater.

In laboratory experiments under conditions of 560 and 740 ppm CO_2, the shell mass of two foraminifera species (*Orbulina universa* and *Globigerinoides sacculifer*) decreased by four to 14% compared with preindustrial CO_2 controls. Finally, the sub-arctic pteropod *Clio pyramidata* showed net shell dissolution in the living organisms when the aragonite saturation state reached <1 (Orr *et al.* 2005, Fabry *et al.* 2008), a level expected to occur over the range of this species under the current "business-as-usual" models.

Most marine phytoplankton tested in single-species laboratory studies and field population experiments showed little change in photosynthetic rates under CO_2 conditions equivalent to ~760 ppm (Tortell *et al.* 1997, Hein and Sand-Jensen 1997, Burkhardt *et al.* 2001, Tortell and Morell 2002, Rost *et al.* 2003, Beardall and Raven 2004, Giordano *et al.* 2005, Martin and Tortell 2006). In contrast, a phytoplankton assemblage dominated by diatoms and coccolithophores showed nearly a 40% increase in carbon uptake at CO_2 levels consistent with the "business-as-usual" climate models (Riebesell *et al.* 2007) indicating increased photosynthesis. Whether species show increased rates of photosynthesis with progressive oceanic uptake of atmospheric CO_2 may depend on nutrient and trace metal availability, light conditions, and temperature. Extrapolating current experimental results to ocean regions presents significant challenges because the ocean warming that accompanies acidification increases stratification of the upper ocean, thereby reducing the upwelling of nutrients, which contributes to decreased phytoplankton biomass and productivity on a global scale (Behrenfeld *et al.* 2006). What is clear is that the species diversity and the composition of phytoplankton assemblages are likely to change, with some species facing a high probability of extinction. The potential for this change at the base of the food web to cascade upward through multiple trophic levels will directly depend on the dietary specialization of secondary and tertiary consumers. However, the potential for severe adverse effects throughout marine food webs is significant and particularly difficult to predict based on available information.

As with other plankton, the effect of ocean acidification on larval fishes appears to be highly variable. Potential effects include reduced growth and survival (Baumann *et al.* 2011), skeletal deformation (Pimentel *et al.* 2014), altered neurological function (Nilsson *et al.* 2012), altered otolith (ear stone) development (Checkley *et al.* 2009, Munday *et al.* 2011b, Hurst *et al.* 2012, Bignami *et al.* 2013), impaired tissue health (Frommel *et al.* 2011), and disrupted behavior (Munday *et al.* 2010, Ferrari *et al.* 2012, Hamilton *et al.* 2014). In contrast, several other studies reported no significant effects of ocean acidification on fish larvae (*e.g.*, Munday *et al.* 2011a, Frommel *et al.* 2013, Bignami *et al.* 2014), illustrating the variability in potential effects.

What is clear is that calcification in marine plankton will be adversely affected when surface waters become undersaturated. While the aragonite saturation state in tropical surface waters is not expected to drop below one under the current "business-as-usual" climate models, saturation state in deeper water layers is expected to be <1 and will likely affect the depth at which plankton can exist without experiencing shell demineralization (Orr *et al.* 2005). This will result in a contraction of marine phytoplankton ranges to shallower depths and lower latitudes. Unfortunately, predicting, and even detecting, such acidification-driven population shifts presents a significant challenge because of a lack of baseline data on the current distributions and abundances of most plankton species.

4.1.2 Shifts in Productivity

Open ocean productivity refers to the production of organic matter through the process of photosynthesis by phytoplankton (primary productivity) and the further production through the consumption and growth of non-photosynthetic heteroplankton (secondary productivity) suspended in the water column (Sigman and Hain 2012). Although productivity is the result of biological activity and the organisms responsible for it are subjected to many of the stressors described in this report, this report considers open ocean productivity as an environmental stressor because the location, diversity, abundance and biomass of pelagic assemblages, including important fishery species, are directly dependent on the amount of productivity in an area (Pauly and Christensen 1995, Chassot *et al.* 2010). Changes in the spatial distribution and amount of open ocean productivity are potentially among the most important non-fishing factors affecting all marine ecosystems, pelagic or benthic, and nearshore or open ocean.

In addition, this report treats open ocean productivity separately from nearshore productivity because the stressors affecting open ocean productivity tend to be regional, basin, or global in scale, all of which lack a strong local terrestrial component (although terrestrial inputs can be important via atmospheric deposition).

In addition to sunlight, phytoplankton require a suite of chemicals with which to grow and conduct photosynthesis, including nitrogen, phosphorous, iron, silicate, $CaCO_3$, and a variety of trace metals (Sigman and Hain 2012). Limitations in the availability of these requirements limit the amount of primary, and by extension secondary, productivity in a region of the ocean.

Open ocean productivity in the tropical Pacific is primarily associated with regions of upwelling, where nutrient-rich, deep-ocean water is brought to the surface. In regions without upwelling, thermal stratification creates a warm, nutrient-poor, or oligotrophic, surface layer (due to a lack

Summary Stressor Table: Potential effects of ocean acidification
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Decreased diversity • Decreased survival of planktonic larval stages of important herbivorous and sessile invertebrates (*e.g.*, urchins, nerites) • Increased algal photosynthetic activity, potential for a phase shift toward algal-dominated shoreline
Mangrove Forests	• Increased photosynthetic and growth rates for mangroves and other primary producers, but may depend on salinity • Decreased abundance of calcifying organism • Decreased survival of planktonic larval stages
Seagrass Beds	• Increased photosynthetic rates and primary productivity • Denser seagrass beds, although vegetative growth may be tempered by increasing seawater temperature • Decreased abundance of calcifying organism • Decreased survival of planktonic larval stage
Coral Reefs	• Reduced calcification rates in reef-building organisms, including corals and coralline algae. • Increased algal photosynthesis and growth • Reduced calcification and survival of potentially important invertebrate grazers (*e.g.*, urchins) • "Flattening" of reef structure leading to loss of species diversity, including important fishery species • Potential for a phase-shift toward algal-dominated assemblage
Deep Reef Slopes	• Drop in aragonite saturation state <1 under "business-as-usual" climate change predictions • Dissolution of calcifying organisms • "Shoaling" of range distributions, potentially leading to increased competitive interactions with shallow-water species • Extirpation of species likely • Decreased diversity (including fishery species) associated with loss of structure-producing organisms • Decreased survival of planktonic larval stages
Banks and Seamounts	See *Coral Reefs* and *Deep Reef Slopes*

Ecosystem	Potential Effects
Deep Ocean Floor	• Drop in aragonite saturation state <1 under "business-as-usual" climate change predictions • Dissolution of calcifying organisms • Extirpation of species is likely • Decreased diversity (including fishery species) associated with loss of structure-producing organisms
Pelagic Environment	• Increased photosynthesis in phytoplankton, but mediated by nutrients and trace minerals • Decreased abundance of calcifying organism • Decreased survival of planktonic larval stages • Shifts in species composition, which has potential to disrupt food web dynamics

of mixing with deeper layers) where both primary and secondary productivity are limited. Therefore, regions of productivity are strongly affected by oceanographic processes that alter the position and strength of upwelling. These oceanographic processes are usually the result of basin- or global-scale climatic events. Basin-scale events, including "short" duration ENSO events and longer duration PDO events, result in the shifting of surface water masses of differing temperature, which alters ocean stratification and moves the location of upwelling. At the global scale, climate change is expected to permanently change the amount, location, and quality of productivity.

In general, changing climate is likely to increase vertical stratification, reducing the upward flow of nutrients and lowering both primary (Falkowski *et al.* 1998, Behrenfeld *et al.* 2006, Toseland *et al.* 2013) and secondary (Roemmich and McGowan 1995) productivity. This effect is predicted to be most pronounced in the tropical oceans, including the Western Pacific Region. A six percent reduction in global oceanic primary production has already been observed between the early 1980s and the late 1990s (Gregg *et al.* 2003), and extrapolating into the future, suggests that marine biological productivity in the tropics and mid-latitudes will decline substantially (Cochrane *et al.* 2009). Both statistical and coupled biogeochemical models (Lehodey 2001, Lehodey *et al.*2003) have predicted the slowdown of Pacific meridional overturning circulation and a subsequent decrease of equatorial upwelling, which has been attributed as the cause of the primary production and biomass decrease over the past 40 years (McPhaden and Zhang 2002).

Changes in secondary productivity are likely to be linked closely with changes in primary productivity in the Western Pacific Region, and effects on tropical zooplankton are likely to be more pronounced than those already being observed at higher latitudes. The more heat-tolerant, low-latitude species might be more vulnerable to climate change stressors than less heat-tolerant species because they may live closer to their physiological limits (Tomanek and Somero 1999, Stillman 2002).

An increased in primary productivity has the potential to increase particulate organic matter (POM). Zooplankton, which consume phytoplankton, usually experience a time lag before they can respond to the increase in primary productivity. During this time lag, POM will be exported from the surface waters to the deep waters, where microbial assemblages will recycle it. This process consumes oxygen and can result in hypoxia in deep waters (see Section 4.1.7), creating what have been called "dead zones."

Currently, it is unclear how climate change will affect ENSO and PDO events in the Western Pacific Region (IPCC 2013). Climate change is expected to weaken tropical easterly trade winds, warm the surface ocean, and intensify the subsurface thermocline. ENSO variability is controlled by a delicate balance of competing feedbacks, and it is likely that one or more of the major physical processes that are responsible for determining the characteristics of ENSO will be modified by climate change (Collins *et al.* 2010). Unfortunately, our current understanding of ENSO variability does not make it possible to predict the potential changes that could occur (IPCC 2013). The WPWP, an immense region of warm water along whose eastern edge strong upwelling occurs, is likewise affected by ENSO events. The upwelling region is important to several species of tuna. During ENSO events, the eastern edge, and thus the region of high productivity can shift as much as 4,000 kilometers (km) eastward as a result of weakened easterly trade winds (Lehodey *et al.* 1997). Likewise, it is not clear how climate change stressors will affect the WPWP, but an effect is expected to cause a significant shift in both the amount and location of high productivity areas, which will result in concomitant shifts in pelagic assemblages, including important fishery species.

4.1.3 Thermal

Thermal stress occurs when the temperature of the environment changes such that it can disrupt the normal biological activity of an organism or the processes and/or function of an ecosystem. In the ocean, thermal stress is often associated with increased temperature of the water, but does not necessarily need to be the result of warming; a decrease in water temperature can be a source of thermal stress. Likewise, most current discussion and research of thermal stress has been focused around regional or global processes (*e.g.*, climate change, ENSO events, etc.), but thermal stress can occur at smaller scales (*e.g.*, a discharge for a power plant or OTEC facility). Regardless of the scale, the results of "climate change studies" that examine thermal effects are still relevant when assessing the potential adverse effects of a small-scale thermal stress event.

In the marine environment, much focus has been placed on the large-scale or global effect of climate change on sea surface water temperature, with a significant focus on both organismal response and potential ecosystem level changes. Corals and coral reef ecosystems have received the majority of the attention, as the potential thermal stress responses in these organisms are expected to have far-reaching and dire implications for coral colonies, associated species, and ecosystem level processes. To a lesser extent, thermal stress response has been investigated in other marine organisms.

Summary Stressor Table: Potential effects of shifting productivity
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Altered survival rates for planktonic larvae, especially those with a long larval duration • Reduced connectivity among insular populations, likely reducing recovery potential
Mangrove Forests	See *intertidal*
Seagrass Beds	See *intertidal*
Coral Reefs	See *intertidal*
Deep Reef Slopes	See *intertidal*
Banks and Seamounts	See *intertidal*
Deep Ocean Floor	• Altered transport of particulate organic material into the deep ocean, which could result in increased hypoxia (in areas with >POM) or fewer nutrient resources (in areas with <POM) • Decreased diversity and altered assemblage structure • Altered biochemical cycling, affecting nutrient and chemical composition of upwelled water • Reduced connectivity among insular populations, likely reducing recovery potential
Pelagic Environment	• Altered survival rates for planktonic larvae, especially those that have a long larval duration • Altered assemblage composition; likely resulting in a loss of biodiversity • Altered trophic structure and food web dynamics • Shifts in species composition, which has potential to disrupt food web dynamics. • Shift in location and position of pelagic assemblages

The relative thermal tolerance of many marine organisms is roughly correlated with the temperature variability occurring in the organism's natural climate regime (Pörtner *et al.* 2014). The highest temperature tolerances are generally found in species at temperate latitudes, where seasonally-driven temperature changes are often large. In contrast, polar and tropical species have relatively narrow natural thermal ranges and for many of these species, they inhabit waters near their physiological temperature tolerance limits (Storch *et al.* 2014), making even small changes in water temperature problematic. Additionally, the thermal range tolerated by a species can vary among its life history stages, with early stages (*e.g.*, eggs and larvae) generally more sensitive than later ones (Pörtner and Peck 2010). Temperature tolerance can also be affected by the presence of other environmental stressors, such as reduced oxygen or ocean acidification (Pörtner and Peck 2010, Deutsch *et al.* 2015).

The effects of elevated ocean temperature are perhaps best studied in reef-building corals. Elevated water temperatures can cause the symbiotic algae, called zooxanthellae, that are found in coral tissues to leave or be expelled, resulting in coral “bleaching.” The loss of zooxanthellae directly affects the coral's energy production, but this loss can be offset to a limited extent by heterotrophic feeding by the coral polyps. If bleaching is prolonged, however, a coral colony will suffer partial or total mortality because of starvation.

Many reef-building corals live close to their upper thermal tolerance and are thus extremely vulnerable to warming (Hughes *et al.* 2003, McWilliams *et al.* 2005). Numerous reports of coral bleaching due to recent warming have been reported (*e.g.*, Hoegh-Guldberg 1999, Sheppard 2003, Reaser *et al.* 2000), including in the Mariana Islands, Hawai‘i, and Jarvis Island in the PRIA. Bleaching usually occurs when temperatures exceed a “threshold” of about 0.8 to 1 °C above mean summer maximum levels for at least four to six weeks (Hoegh-Guldberg 1999, Pandolfi *et al.* 2011).

Bleaching susceptibility shows high inter- (McClanahan *et al.* 2004, Yee *et al.* 2008) and intra-specific variability (Baird and Marshall 2002) and varies as a consequence of the magnitude of the thermal stress (Kleypas *et al.* 2008), irradiance levels (Mumby *et al.* 2001, Dunne *et al.* 2001), zooxanthellae symbiont types (Berkelmans 2006, Baker *et al.* 2008), species identity (Loya *et al.* 2001), and the thermal history of the organism (Thompson and van Woesik 2009, Oliver and Palumbi 2011). Species identity is one of the best predictors of thermal tolerance due to a predictable hierarchy of susceptibility among coral taxa. Fast growing branching taxa, such as *Acropora* and *Pocillopora*, normally bleach rapidly and experience high rates of whole colony mortality (Baird and Marshall 2002). In contrast, massive taxa such as *Porites* and some faviids take longer to bleach, and often show lower colony mortality (Baird and Marshall 2002). Ultimately, variability in bleaching susceptibility may be driven by the predominant type of zooxanthellae hosted by corals (Glynn *et al.* 2001, Baker *et al.* 2008). For example, increasing thermal tolerance of *Pocillopora* at some locations in the eastern Pacific has been linked to increased prevalence of colonies that host a thermally tolerant clade D symbiont (Glynn *et al.* 2001). Similarly, *Pocillopora* in French Polynesia host a diversity of symbiont types, including clade D (Magalon *et al.* 2007), which may explain their low level of bleaching susceptibility during recent bleaching events compared with many other geographic locations (Pratchett *et al.* 2013).

Corals also show significant variation in their ability to recover following a bleaching event (Baird and Marshall 2002). If sufficient colony tissue survives, recovery can occur within a few years (Diaz-Pulido *et al.* 2009), but recovery often requires a decade or more (Glynn *et al.* 2001, Baker *et al.* 2008, Sheppard *et al.* 2008). In other cases, no appreciable recovery of coral cover has been observed up to a decade following a bleaching event (Graham *et al.* 2007, Somerfield *et al.* 2008). For coral species hosting multiple symbiont strains, shifts to thermally resistant strains are sometimes observed after bleaching events (Thonhill *et al.* 2006, Cunning *et al.* 2016), although reversion to domination by thermally sensitive strains may occur over several years, probably because of a trade-off between bleaching resistance and photosynthetic rate (Jones and Berklmans 2010).

Mass bleaching events, when most of the coral assemblage bleaches, have become more frequent and widespread in the past few decades (Baker *et al.* 2008). These events are often associated with high mortality (Baird and Marshall 2002) and decreased colony growth and reproduction among survivors (Mendes and Woodley 2002). The consistency of the species hierarchy to bleaching susceptibility has led to the prediction that hardier, slow-growing massive species will replace less hardy, fast-growing, branching species on reefs in the future (Loya *et al.* 2001, Hughes *et al.* 2003). Changes in the morphological composition of the coral assemblage (*e.g.*, loss of fast-growing branching and tabular species) would likely result in a loss, or "flattening," of three-dimensional topographic structure (Alvarez-Filip *et al.* 2009), an ecological function that forms a critical part of reef fish habitat. Mass bleaching can be followed by increases in macroalgae, especially when herbivores are absent or avoid consuming macroalgal species (Ledlie *et al.* 2007). Loss of coral diversity and physical structure usually leads to declines in reef community biodiversity (Jones *et al.* 2004, Alvarez-Filip 2009). Fishes and invertebrates that consume or inhabit corals during some part of their life cycle will also likely decline in abundance, although such effects may likely be accompanied by a time lag (Graham *et al.* 2007, Grandcourt and Cesar 2003).

In addition to reef-building corals, zooxanthellae are also found in species of soft-corals, sea anemones, gorgonians, giant clams (*Tridacna* spp.), and some nudibranchs, all of which have the potential to bleach under exposure to stress (Lesser *et al.* 1990, Norton *et al.* 1995, Ishikura *et al.* 1999, Buck *et al.* 2002, Leggat *et al.* 2003, Neo and Todd 2013). As in corals, bleaching reduces photosynthetic rates, alters the metabolism, and affects their growth, ultimately lowering fitness, although the magnitude of the effects varies among species. Following the 1998 mass bleaching event, survival rates of bleached clams were >95% (Leggat *et al.* 2003), compared to some species of coral which experience mortality as great as 99% (Mumby *et al.* 2001). This suggests that *Tridacna* spp. may be better able to cope with bleaching events significantly better than corals.

For non-photosynthetic marine organisms, research is more limited, but the most apparent effects of sub-lethal temperature stress are associated with altered metabolic processes such as growth, changes in the timing and success of reproduction (Walther *et al.* 2002, Walther *et al.* 2005, Parmesan and Yohe 2003), and shifts in the distribution of species (*e.g.*, Thomas *et al.* 2004, Perry *et al.* 2005, Poloczanska *et al.* 2007). For example, laboratory experiments on coral reef fishes have shown that elevated sea water temperatures lead to reductions in critical swimming speeds (Johansen and Jones 2011) and growth (Munday *et al.* 2008), as well as altering the timing of reproduction, reproductive output, and the condition of juveniles and larvae (Munday *et al.* 2008, Donelson *et al.* 2010). Juveniles of many marine fishes are particularly susceptible to changes in temperature, and larvae may succumb to elevated temperatures that their adult stages can survive (Gagliano *et al.* 2007). Shifts in the hatching times of eggs may affect the survival chances of larvae if hatching becomes asynchronous with food availability (Brierley and Kingsford 2009).

Changes in temperature may also change fish behavior, specifically their catchability in the fishery. Increased temperatures are likely to increase metabolic and consumption rates in fish and invertebrates (Kennedy *et al.* 2002), which could lead to higher catch rates using baits and potentially increase the diversity of catch, including unwanted bycatch (Cheung *et al.* 2012). In contrast, increased temperature could also result in increased fish swimming speeds (Peck *et al.* 2006), which could alter the efficiency of towed fishing devices, such as trawl nets (Rijnsdorp *et al.* 2009).

Intertidal species may already exist close to their tolerance limits, and further thermal stress may cause range shifts along continental coastlines (Stillman 2003, Sorte *et al.* 2010), but similar distributional shifts will not be possible on insular shorelines, and may lead to local extirpation of intertidal organisms that cannot adapt to changing conditions. This will result in substantial changes to intertidal assemblages, especially for species that occupy lower vertical positions on the shore because they tend to show lower thermal thresholds (Williams and Morritt 1995, Marshall *et al.* 2015).

The direct effect of increased temperature on seagrasses and macroalgae depends on species-specific thermal tolerances, and the seagrasses' optimal temperature for photosynthesis, respiration, and growth. Warm water species can often increase their photosynthetic rate and respiration over a wide range of temperatures (Perez and Romero 1992, Terrados and Ros 1995). Both respiration and photosynthesis are positively correlated with sea water temperature, but respiration usually increases at a greater rate than photosynthesis, especially at higher temperatures, thus leading to a reduction in net photosynthesis (Bulthuis 1983b; Dennison 1987, Marsh *et al.* 1986, Pérez and Romero 1992, Herzka and Dunton 1997, Masini and Manning 1997, Tait and Schiel 2013, Colvard *et al.* 2014). Thus, species growing near the upper limit of their thermal tolerance, will decrease in net productivity in warming water. Increased thermal stress may also affect flowering (de Cock 1981, McMillan 1982, Durako and Moffler 1987) and seed germination (Harrison 1982, Phillips *et al.* 1983), although the effect of temperature may be complicated by interactions with other stressors, for example, salinity (Caye and Meinesz 1986, Conacher *et al.* 1994). On intertidal shores, photosynthetic biofilms show increased productivity, but net productivity fell as herbivore grazing rates increased under elevated temperature conditions (Russell *et al.* 2013).

While the effects of rising sea temperature on individual species of plankton are not well understood and are likely variable (Huertas *et al.* 2011), rising sea surface temperatures will affect plankton assemblages by upsetting natural carbon dioxide, nitrogen and phosphorous cycling (Toseland *et al.* 2013) through reduced mixing and upwelling brought on by an increase in temperature-driven ocean stratification (see Section 4.1.2). This will result in lower primary productivity and decreased diversity, likely resulting in substantial adverse effects which cascade upward through the food chain. For example, increased thermal stress could lead to a decoupling in the timing of reproduction and the timing of plankton blooms (Platt *et al.* 2003), resulting in trophic instability through breaks in food chains (Hipfner 2009, Richardson and Schoeman 2004).

Even species with higher thermal tolerance could be affected by loss of prey species, including commercially important fish species (Beaurgrand *et al.* 2003). Some of these species will themselves shift ranges as a consequence of warming, but this will not necessarily lead to assemblage decline; for example, fish species richness in the North Sea has increased over the last two decades of the 20th century as the region has warmed, but species composition has been significantly altered (Hiddink and Hofstede 2008).

4.1.4 Salinity

Changes in water salinity will have different effects on marine organisms depending upon their ability to osmoregulate. Even minor osmoregulatory stress will result in increased energetic demands, possibly leading to a cascade of effects which are dependent upon the level of metabolic stress incurred. Like temperature tolerances, a species' tolerance, and thus its ability to cope with changes in salinity, is often associated with the natural variability within its habitat; species in estuarine and coastal ecosystems such as mangrove forests tend to display tolerance to a greater range of salinity than organisms found in the nearshore or open ocean ecosystems where salinity fluctuations tend to be small.

Salinity will directly affect estuarine (*e.g.*, mangroves, river mouths) organisms through osmoregulatory stress or indirectly by degrading their habitat, including breeding and nursery areas (Marshall and Elliot 1998). Mangrove trees are facultative halophytes, and tend to grow best when salinity is between five and 75 ppt, although many species can tolerate salinity up to 90 ppt (Krauss *et al.* 2008, Parida and Jha 2010). Mangrove trees do not have a salt resistant metabolism, but instead are equipped with physiological mechanisms that enable them to exclude or excrete salt (Drennan and Pammenter 1982). These mechanisms included one or more of the following (Mohammad and Uraguchi 2013): salt filtration at the root level (Takemura *et al.* 2000, Kahn *et al.* 2001), salt excretion via glands positioned on the undersides of the leaves, and/or salt disposal via accumulation of salt within leaf cells followed by defoliation (Popp *et al.* 1993).

Salinity is directly correlated with the standing crop of mangrove vegetation and productivity (Chen and Twilley 1998, Chen and Twilley 1999, Mall *et al.* 1987, Ukpong 1991), and under normal conditions, the distribution of mangrove species can be explained primarily by salinity gradients (Ball 1988, Ukpong 1994). Therefore, changes in salinity will likely influence the species richness of a mangal, and distributions of species within the forest. Deviations above or below a species' optimal salinity can reduce vegetative growth (Chodhury 2015), likely because of reduced photosynthesis, net photosynthetic rate, stomatal conductance, and transpiration rate (Noor *et al.* 2015). Additionally, changes to salinity can reduce seedling survival and establishment rates (Ye *et al.* 2004, Ye *et al.* 2005), and stunt tree height (Ball and Pidsley 1995, Hao *et al.* 2009).

Summary Stressor Table: Potential effects of thermal stress.
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Increased primary productivity associated with biofilms, but lower net productivity due to temperature-driven increases in grazing rates • Reduced growth due to increased metabolic demands for some animal species • Changed timing and lower success of reproduction for some species • Temperatures above thermal tolerance thresholds could result in extirpation of species unable to migrate due to insular habitat
Mangrove Forests	• Few effects on mangrove trees • Reduced growth due to increased metabolic demands for some animal species • Changed timing and lower success of reproduction for some species • Shifts in species distribution and assemblage composition • Change in behavior of fishes; potentially increased feeding
Seagrass Beds	• Increased photosynthesis and respiration; at higher temperatures a decrease in net productivity, which can alter nutrient cycling • Reduced growth due to increased metabolic demands for some animal species • Increased bleaching in zooxanthellae-bearing invertebrates • Changed timing and lowered success of reproduction for some species • Change in behavior of fishes; potentially increased feeding
Coral Reefs	• Increased bleaching in coral and other zooxanthellae-bearing organisms, resulting in some cases in organism death • Flattening of reef structure leading to loss of diversity, abundance and biomass, including important fishery species • Altered assemblage composition, including the potential for a phase-shift toward algal-dominated assemblage • Changed timing and lowered success of reproduction for some animal species • Reduced connectivity among populations, likely reducing recovery potential

Ecosystem	Potential Effects
Deep Reef Slopes	• Effects likely to be minor due to depth, water movement, and lack of dependency on particulate organic matter from surface waters
Banks and Seamounts	See *Coral Reefs* (shallow) and *Deep Reef Slopes* (deep)
Deep Ocean Floor	• Altered transport of POM into the deep ocean, which could result in increased hypoxia (if >POM) or fewer resources (if <POM) • Altered biochemical cycling, affecting nutrient and chemical composition of upwelled water
Pelagic Environment	• Decreased net primary productivity • Geographic shifts in productivity • Altered survival rates for planktonic larvae, especially those that have a long larval duration • Altered assemblage composition; likely resulting in a loss of biodiversity, leading to changed trophic structure and food web dynamics

While many seagrasses in the Western Pacific Region are primarily marine in nature, they often experience natural fluctuations in salinity because of their shallow, nearshore habitat.

Seagrasses show wide variability in salinity tolerance, which is correlated with the amount of natural variability in salinity found in their habitat. Changes in salinity have been associated with distributional shifts and changes in abundance of seagrasses (Young and Kirkman 1975, Dawes *et al.* 1989, Lazar and Dawes 1991, Quammen and Onuf 1993). For example, vegetative growth of *Zostera capensis*, a mid-saline seagrass in South Africa, is inhibited at high and low salinities, while *Ruppia cirrhosa*, a competing species adapted to fresher water, showed maximum growth near zero salinity (Adams and Bate 1994). Several studies of seagrass seedling survival conducted on a wide range of species have shown that seeds tend to germinate well at relatively low salinities, but optimal seedling growth and development often occur under higher salinity conditions (Caye and Meinesz 1986, Hootsmans *et al.* 1987, Loques *et al.* 1990). Although none of these studies examine species present in the Western Pacific Region, they suggest what may be a general pattern among seagrasses. Salinities that are above optimal can reduce biomass because adjusting osmotic regulation limits seagrass growth by competing for energy, carbohydrate, and nitrogen supplies (Stewart and Lee 1974, Cavalieri 1983, Yeo 1983). In contrast, low salinity has been shown to suppress protein metabolism and alter enzyme activity, again leading to reduced biomass (McGahee and Davis 1971, Haller *et al.* 1974, James and Hart 1993). In addition, salinity has been a major factor influencing the onset and severity of eelgrass diseases (Short *et al.* 1986, Muehlstein *et al.* 1991, Burdick *et al.* 1993), although little is known about tropical seagrass diseases.

Corals have few physiological mechanisms for osmoregulation (Muthiga and Szmant 1987, Mayfield and Gates 2007), so a change in salinity can directly alter metabolic processes and/or cause colony mortality. The effects of salinity changes on coral reefs have not been well-studied, likely because most reefs experience little fluctuation in natural salinity levels, but the response of corals to changing salinity appears to be related to the strength and duration of the exposure and the species affected. As with most other taxonomic groups, considerable inter-specific variation in salinity tolerance is present among coral species. For example, *Stylophora pistillata* is sensitive to small changes in salinity (Sakai *et al.* 1989) whereas *Porites compressa* is more tolerant (Coles 1992). *Platygyra sinensis*, *Acropora millepora*, and *Pocillopora damicornis* have also been found to be relatively tolerant to changes in salinity (Kuanui *et al.* 2015). All of these species are relatively common in the Western Pacific Region. Some coral species have shown evidence of an ability to acclimate to drops in salinity (Ferrier-Pages *et al.* 1999).

Regardless of individual tolerances, high coral mortality has been observed following intense rain events (Sakai *et al.* 1989), including in Hawai‘i (Jokiel *et al.* 1993 and references therein, Bahr *et al.* 2015). Where mortality did not occur, bleaching, and other metabolic (*e.g.*, increased respiration) and histopathological (swelling and lysis of cells) changes were noted (Glynn 1993, vanWoesik *et al.* 1995, Porter *et al.* 1999, Mayfield and Gates 2007). Severe tissue necrosis, followed by the death of the colonies, has been observed for corals incubated for extended periods in water with relatively small elevations in salinity (Ferrier-Pages *et al.* 1999). Changes in salinity can also adversely affect reproduction (Richmond 1993). Likewise, many coral reef-associated species show low tolerance to salinity changes. Mortality in a wide range of organisms (sea cucumbers, crabs and cryptic fish such as eels) has been observed following freshwater kill events in Hawai‘i (Jokiel *et al.* 1993, Bahr *et al.* 2015).

At large, oceanic scales, anticipated changes in the ocean's temperature and salinity as a result of climate change will affect circulation patterns. In general, the Pacific Ocean north of the equator is decreasing in salinity, which is expected to affect upwelling strength and location (Bindoff *et al.* 2007). Unfortunately, studies on the effects of salinity changes on non-estuarine phyto- and zooplankton are limited. Estuarine plankton are sensitive to salinity changes, but in many cases, effects associated with temperature, acidification, and nutrient availability are significantly larger. Open ocean plankton assemblages will likely show a similar pattern: the effects of salinity changes on the assemblage will be minor compared to the effects of other stressors. This is reinforced by climate change predictions which predict only small changes in salinity over much of the tropical ocean. Exceptions could include areas where deep ocean mining or OTEC energy production are being conducted, but even under these activities, temperature and nutrient differentials of deep ocean water compared to surface waters are likely to outweigh salinity-related effects. However, more research in this area would be beneficial given the importance of open ocean productivity to broader ecosystem processes.

Summary Stressor Table: Potential effects of salinity
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Organism tend to be extremely tolerant to changes in salinity
Mangrove Forests	• Reduced photosynthesis in mangrove trees and stunted growth at salinities higher or lower than that optimal for the species • Shifts in mangrove species distributions/zonation based on salinity • Reduced seedling survival • Other mangrove associated organisms tend to be salinity tolerant, but will experience sublethal metabolic stress
Seagrass Beds	• Reduced photosynthesis, growth, and biomass at salinities higher or lower than that optimal for the species • Reduce seedling germination at high salinity • Reduced seedling growth at low salinity • Other seagrass-associated organisms tend to be salinity tolerant, but will experience sublethal metabolic stress
Coral Reefs	• Many species have low tolerance to salinity changes • Increased coral mortality (partial and full) • Increase mortality among coral reef-associated species (sea cucumbers, crabs and cryptic fish such as eels) that also show low tolerance to salinity changes
Deep Reef Slopes	Unknown (no research available), but likely similar to *Coral Reefs*
Banks and Seamounts	See *Coral Reefs* (shallow) and *Deep Reef Slopes* (deep)
Deep Ocean Floor	Unknown; no research available
Pelagic Environment	• Decreased net primary productivity • Geographic shifts in productivity • Altered assemblage composition; likely resulting in a loss of biodiversity, leading to changed trophic structure and food web dynamics

4.1.5 Irradiance

Marine organisms are sensitive to changes in irradiance levels, both photosynthetically active radiation (PAR) and ultraviolet radiation (UV). Decreases in irradiance (often associated with decreased water clarity) generally results in lower photosynthetic rates. Increase irradiance, especially high UV exposure cause cellular damage.

Most research on corals has focused on increased irradiance, which has been linked to coral bleaching (Hoegh-Guldberg 1999, Jones *et al.* 1998) and damage to DNA. High irradiance can amplify the effect of thermal stress on corals (Coles and Jokiel 1978), whereas shading by high islands (Bruno *et al.* 2001), unusually cloudy conditions (Mumby *et al.* 2001), and even increased water turbidity (West and Salm 2003, Anthony *et al.* 2007), can ameliorate the effects of thermal stress on corals. Decreases in irradiance have been shown to affect settlement of coral larvae, and may account for depth zonation in at least five species of Indo-Pacific corals (Mundy and Babcock 1998).

Light limits the distribution and species composition of seagrass beds, and low irradiance levels reduce individual plant biomass and growth rates (Dennison 1987, Abal and Dennison 1996, Ralph *et al.* 2007, Campbell *et al.* 2007). Seagrasses have high respiratory (metabolic) demands needed to support and oxygenate their extensive root and rhizome biomass (Waycott *et al.* 2011), and they use only a limited range of the light spectrum. Seagrasses have a higher minimum light requirement than marine algae and phytoplankton (Dennison *et al.* 1993), making them competitively inferior under reduced light conditions. Thus, seagrasses are generally restricted to shallow coastal areas where ample sunlight can penetrate to the bottom, although considerable species variability exists (Dennison *et al.* 1993). For example, Indo-Pacific species of *Halophila* can grow at greater depth because of a lower minimum light requirement (Erftemeijer and Stapel 1999), a trait usually attributed to the morphology of *Halophila* (Middelboe and Markager 1997).

Seagrasses exhibit several physiological and morphological responses to reductions in irradiance. The magnitude and time required to initiate a response is species-specific, and depends on light intensity and duration, and interactions with other potential stressors, such as water temperature and nutrient availability (Bulthuis 1983a, Bulthuis 1983b, Gordon *et al.* 1994, van Lent *et al.* 1995, Abal 1996, Grice *et al.* 1996, Longstaff and Dennison 1999). Initial effects can include changes in amino acid content and chlorophyll levels (Longstaff and Dennison 1999). Later effects can include reduced biomass, shoot density, leaf production rates, and canopy height (Wiginton and McMillan 1979, Dennison and Alberte 1982, Dennison and Alberte 1985, Neverauskas 1988, Tomasko and Dawes 1989, Abal *et al.* 1994, Lee and Dunton 1997, Peralta *et al.* 2002).

Few studies have looked at the effects of irradiance on tropical Pacific macroalgae. While interspecific variation exists, the minimum light requirements of macroalgae (Sand-Jensen 1988, Duarte 1991, Markager and Sand-Jensen 1992, Dennison *et al.* 1993) and CCA (Littler *et al.* 1985) are lower than those of seagrasses. Thus, marine algae are generally able to survive and outcompete seagrasses under low light conditions, and their distribution (especially their maximum depth) is determined in part by their minimum light requirements for photosynthesis and growth.

Sun light is absorbed and scattered in the ocean, and irradiance decreases exponentially with depth. As with benthic primary producers, spatial and temporal variations in light affect the vertical distribution of phytoplankton. Under climate change forecasts, some areas of the Pacific Ocean are expected to experience increased cloud cover (*e.g.*, Western Pacific Warm Pool, Intertropical Convergence Zone, Pacific Equatorial Divergence), which will reduce irradiance and contribute to declines in primary productivity (Le Borgne *et al.* 2011). Other areas of the Pacific Ocean are expected to experience increased irradiation because of reduced cloud cover (*e.g.*, North and South Pacific Tropical Gyres). Primary productivity is sensitive to both too much and too little light. Photosynthesis can be reduced in the upper water column due to photo-inhibition. Alternatively, photosynthesis rates can drop three-fold if irradiance is reduced to 10% of that present on a sunny day (Le Borgne *et al.* 2011). The potential effects of these changes in irradiance on ocean productivity are unclear, but given that vertical mixing within the surface layer prevents planktonic organisms from staying in the upper photic zone for long, these changes in surface irradiation are expected to have a weak effect on ocean productivity (Le Borgne *et al.* 2011).

4.1.6 Noise

Sounds in the marine environment can originate from abiotic and biotic sources, including the movement of water, geologic events, and the noises generated by fish, marine mammals, and invertebrates. Organisms produce sounds to communicate over short and long distances with mates, offspring and other conspecifics, and/or to find prey or other objects of interest (Popper and Hastings 2009, Simpson *et al.* 2016).

Sources of anthropogenic sounds in the ocean are extensive and varied (Peng *et al.* 2015), and anthropogenic noise covers the full frequency bandwidth that marine animals use, from 1 hertz (Hz) – 200 kilohertz (kHz) (Stocker 2001). It also occurs throughout all ocean ecosystems, from shallow coral reef and seagrass beds down into the deep sea, including the deep ocean floor. Due to the efficiency of sound transmission in the ocean, noise travels great distances and containment is difficult.

Boats of all sizes are a significant source of noise. Pile driving is important in the construction of bridges, wind farms, and seaports. Sonar is used by military, the shipping and fishing industries, and in oceanographic research. Underwater explosions occasionally occur as part of military training, and, while seldom used in the Western Pacific Region, seismic devices such as air guns are used for oil exploration and for studies on undersea geology. Even bubble noise from scuba divers has been linked to altered fish behavior (Lobel 2005).

Noise in the marine environment has a broad range of potential effects, especially when it is very loud, *i.e.*, high amplitude (Casper *et al.* 2016), or when it is less intense but long-lasting (Popper and Hastings 2009). Intense, high amplitude sounds, such as pile driving, underwater explosions, and seismic air guns, can cause immediate death or tissue damage that might or might not directly result in the death of the organism (McCauley *et al.* 2003), but which might lower its fitness (Casper *et al.* 2016). Temporary hearing loss may also occur, which is likely to lower fitness until hearing recovers. Behavioral changes can occur, resulting in animals leaving

Summary Stressor Table: Potential effects of irradiance
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Organism tend to be tolerant to changes in irradiance
Mangrove Forests	• Few effects on mangrove trees unless extreme; leaves are above the water surface so unaffected by reduced water clarity
Seagrass Beds	• Reduced seagrass photosynthesis, biomass, shoot density, leaf production rates, and canopy height under reduced light conditions • Potential for a phase-shift toward algal-dominated assemblage under low light regimes
Coral Reefs	• Increased risk of coral bleaching at high irradiance; depth dependent sensitivity to UV • Reduced photosynthesis, calcification, and growth at low irradiance; potential for reduced fitness under prolonged shading • Potential for a phase-shift toward algal-dominated assemblage under low light regimes
Deep Reef Slopes	• Photosynthetic organisms highly adapted to low light conditions and could experience photo-inhibition under elevated irradiance • All photosynthetic organisms at the extreme lower irradiance threshold; further reductions would result in mortality, loss of diversity, abundance and biomass of the entire assemblage
Banks and Seamounts	See *Coral Reefs* (shallow) and *Deep Reef Slopes* (deep)
Deep Ocean Floor	Unknown, but the lack of photosynthetic organisms suggested minimal adverse effects would occur
Pelagic Environment	• Decreased primary productivity • Altered assemblage composition; likely resulting in a loss of biodiversity, leading to changed trophic structure and food web dynamics

feeding or reproduction grounds (Slabbekoorn *et al.* 2010) or becoming more susceptible to mortality through decrease predator-avoidance responses (Simpson *et al.* 2016). Less intense but chronic noise, such as that produced by continuous boating, can cause a general increase in background noise over a large area. Although not likely to kill organisms, chronic noise can mask biologically important sounds and alter the natural soundscape, cause hearing loss, and/or have an adverse effect on an organism's stress levels and immune system.

Little empirical research has been conducted on the effects of noise on tropical marine species, but most of that has focused on marine mammals. Research conducted on model fishes (*e.g.*, tilapia, goldfish, etc.) have shown a wide range of potential effects from excessive noise, most of which were sub-lethal (see Popper and Hastings 2009 for a review). Nichols *et al.* (2015) found that coastal marine fishes secreted stress hormones in the presence of shipping noise. Bluefin tuna showed a disruption in their schooling structure and swimming behavior when exposed to boat noise, as well as an increase in aggressive behavior (Sarà *et al.* 2007). Embryonic clownfish showed increased heart rate in the presence of elevated noise (Simpson *et al.* 2005). Chronic boat noise can reduce the startle response of coral reef fish, increasing their susceptibility to predation (Simpson *et al.* 2015). While it is often assumed that most motile animals will leave noisy areas, this is not always the case (Iafrate *et al.* 2016).

Reef fish use aspects of reef noise to select suitable settlement habitat, and anthropogenic noise that interferes with their "soundscape" could adversely affect their behavior. Simpson *et al.* (2008) found settlement-stage fish of six reef fish families (Pomacentridae, Apogonidae, Lethrinidae, Gobiidae, Syngnathidae, and Blenniidae) preferentially settled into light traps emitting high-frequency reef noised compared to low-frequency reef noise or silent traps. Only the Siganidae showed no preference between any of the sound treatments. High-frequency reef noise is produced mainly by marine invertebrates, and appears to be used by the fish as a means of selectively orienting towards suitable settlement habitats. Masking of natural reef soundscapes by anthropogenic noise could result in changes to the abundances of species and alterations to the structure of reef fish assemblages.

Prawns have been shown to be as sensitive to sound as fish (Lovell *et al.* 2005), and increased metabolic rates have been observed in brown shrimp exposed to elevated noise conditions, causing a reduction in growth and reproduction over three months (Lagardère 1982). Intense noise, such as pile driving and seismic surveying has been shown to reduce feeding rates in mussels (Spiga and Caldwell 2016) and cause larval malformations in scallops (Aguilar de Soto *et al.* 2013). Temperate lobster increased their food consumption for weeks to months after low-level exposure to seismic noise (Payne *et al.* 2007), suggesting increased metabolic demands. Similar effects have also been found in multiple crab species (Edmonds *et al.* 2016, Wale *et al.* 2013a, 2013b), suggesting sub-lethal stress effects in the presence of boat noise might be common in crustaceans.

Anthropogenic noise may mask deep-water invertebrate scavengers' sensitivity to 'micro-seismic' events in the frequency range of 30 Hz – 250 Hz, which they use to detect food-fall up to distances of 100 m (Klages and Muyakshin 1999). Some animals appear to adapt to "threat" sounds; recent anecdotal evidence suggests that schools of pelagic shrimp have adapted evasion strategies toward the sound of shrimp trawlers (Stocker 2001). When the trawlers circle in, the shrimp dive deep, below the nets. Similar behavior has been noted among carangid fish to boats on Midway Atoll, where a catch and release fishery operated for several years (Minton, pers. obs.). The flight response at Midway was opposite that observed at neighboring Pearl and Hermes, where carangids were frequently attracted to small vessel sound, sometimes forming schools of hundreds of individuals.

4.1.7 Hypoxia

In the marine environment, oxygen from the atmosphere and produced as a by-product of photosynthesis dissolves in the water and helps to meet the respiratory demand of all marineorganisms. When the supply of oxygen is diminished or it is removed, or the consumption rate exceeds the resupply rate, dissolved oxygen concentrations can decline below the point that sustains most marine life. This condition of low dissolved oxygen is known as hypoxia. The complete absence of oxygen is called anoxia.

Oxygen solubility in seawater is a function of water temperature, and as the oceans have warmed over the past half century, dissolved oxygen has declined (Garcia *et al.* 2005). By the end of the century, ongoing warming together with rising atmospheric CO_2 will likely result in an expansion of low oxygen zones, perhaps by more than 50% of their present volume (Diaz and Rosenberg 2008, Oschlies *et al.* 2008). This will result in adverse effects on some of the world's most productive fishery regions.

While temperature controls the amount of oxygen that can dissolve in seawater (fully-saturated seawater at 25 °C [77 °F] has an oxygen concentration of about 8.25 milligrams (mg)/liter (L), water column stratification and increased decomposition of organic matter are two processes that contribute to hypoxic regions in the ocean. Stratification of the water column reduces mixing of oxygen-rich surface layers with deep ocean waters, and microbial decomposition of POM increases respiration in deep ocean waters, resulting in a net decrease in dissolved oxygen at depth. Increased productivity in surface waters, especially in areas with anthropogenic inputs of coastal nutrients, increases the amount of POM that sinks into deep water layers, creating or exacerbating what have been called "dead zones" (Diaz and Rosenberg 2008). Therefore, increased productivity, coupled with increased oceanic stratification, has the potential to result in oxygenated surface waters and a hypoxic deep ocean, leading to the loss of biodiversity.

Most marine organisms experience a hypoxic response when the oxygen concentration falls below 2-3 mg/L (Gray *et al.* 2002, Stramma *et al.* 2008), but considerable interspecific variability exits (Vaquer-Sunyer and Duarte 2008, Seibel 2011). Vaquer-Sunyer and Duarte (2008) suggest this threshold is too low, and noted that many species experience lethal effects below 4.6 mg/L, and significant sublethal effects at oxygen concentrations below 5 mg/L. Crustaceans and fish appear to be particularly susceptible to hypoxic conditions, and mollusks and non-coral cnidarians appeared most tolerant (Vaquer-Sunyer and Duarte 2008). While there is considerable variability among species in a taxonomic group, motile organisms appear to be more sensitive to hypoxic conditions than sessile ones; many fish and motile organisms can detect, and actively avoid hypoxic areas (Pihl *et al.* 1991). Wannamaker and Rice (2000) studied the behavior of six species of fish and one species of shrimp, and all could detect and avoid hypoxic conditions.

Summary Stressor Table: Potential effects of noise
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Effects are expected to be minor for mid-to-high intertidal organisms due to lower exposure • For low intertidal organisms, high amplitude noise can cause mortality, hearing damage, and disrupted behavior which may reduce fitness • Chronic low amplitude noise may disrupt behavior • Individuals may relocate from area of the noise • Adverse effects generally resolve shortly after the cessation of the noise
Mangrove Forests	• High amplitude noise can cause mortality, hearing damage, and disrupted behavior which may reduce fitness • Chronic low amplitude noise may disrupt behavior • Individuals may relocate from area of the noise • Adverse effects generally resolve shortly after the cessation of the noise
Seagrass Beds	See *Mangrove Forests*
Coral Reefs	See *Mangrove Forests*
Deep Reef Slopes	See *Mangrove Forests*
Banks and Seamounts	See *Mangrove Forests*
Deep Ocean Floor	See *Mangrove Forests*
Pelagic Environment	See *Mangrove Forests*

While little research has been done on the effects of hypoxic conditions on tropical Pacific organisms, in general, marine animals respond to hypoxia by first attempting to maintain oxygen levels through increased respiration rate or increasing the number of oxygen-transporting cells, followed by conserving energy through metabolic depression and down-regulation of protein synthesis and other regulatory enzymes (Holeton and Randall 1967, Burggren and Randall 1978, van den Thillart and Smit 1984, Wu and Woo 1985, Dunn and Hochachka 1986, Boutilier *et al.* 1988, Chew and Ip 1992, Randall *et al.* 1992, Dalla Via *et al.* 1994). Reduction in movement is commonly employed by marine organisms to conserve energy and reduce metabolic demand under hypoxic conditions. For example, swimming of Atlantic cod (*Gadus morhua*) was reduced by ~60% under hypoxic conditions (Schurmann and Steffensen 1994), and digging activity in an Atlantic lobster ceased (Eriksson and Baden 1997).

Hypoxic conditions reduce growth and feeding, which may eventually affect individual fitness. Growth reductions have been shown in brittlestars, oysters (*Crassostrea virginica*), and mussels (*Mytilus edulis*) (Diaz and Rosenberg 1995), as well as in some polycheate worms (Forbes and Lopez 1990). Similarly, reduced growth has been demonstrated in fish subjected to hypoxia (Petersen and Phil 1995), likely a result of reduced feeding (Wu 2002). When subjected to hypoxic conditions, feeding rate was reduced in crabs, gastropods, annelid worms, and lobster, but this effect can vary with life history stage (Das and Stickle 1994, Baden *et al.* 1990a, Baden *et al.* 1990b, Llanso and Diaz 1994).

The effects of hypoxia on reproduction and development of marine animals remains poorly studied, but fish can suffer increased embryo and larval mortality when exposed to hypoxic conditions (Keckeis *et al.* 1996). High mortality and adverse effects on development and growth were found in oyster (*C. virginica*) larvae (Baker and Mann 1992), and mussel (*M. edulis*) embryos experienced delayed development (Wang and Widdows 1991). Hypoxia can also retard gonad development, fertilization success, reproductive output, larval hatching and larval success in the common carp (Wu *et al.* 2003).

Avoidance of hypoxic areas can make organisms more vulnerable to predation. Fish have been observed to change their feeding habits to prey upon hypoxia-stressed benthic invertebrates (Diaz *et al.* 1992). Hypoxia may also affect foraging of predators, reducing prey capture rates, (Sandberg *et al.* 1996, Abrahams *et al.* 2007, Altieri 2008, Johnson *et al.* 1984). Other important behaviors are also dependent upon oxygen concentrations. Fish schooling behavior responds to varying oxycline depth (Bertrand *et al.* 2008). Many benthic organisms such as sea anemones and polychaetes will leave their burrows, and bivalves will extend their siphons upward into the water column above the sediment–water interface, to gain access to more oxygenated water (Pihl *et al.* 1992, Nilsson and Rosenberg 1994, Hervant *et al.* 1996, Sandberg 1997).

Few studies have examined the effects of hypoxia on reef-building corals, even though oxygen concentrations can fluctuate widely on a diurnal cycle and be very low at night (Haas *et al.* 2010; Wild *et al.* 2010). Under low oxygen (2–4 mg/L) conditions, the Indo-Pacific coral *Acropora yongei* bleached, lost major portions of its tissue, and suffered mortality within three days. Its decline in health was accompanied by a significant decrease in photosynthetic performance (Haas *et al.* 2014). In Hawai‘i, a spill of 233,000 gallons of molasses in Honolulu Harbor resulted in hypoxia-related mortality in coral and fish (Basu 2013), although the extent of the kill is still unresolved. A wide range of Indo-Pacific reef fish have been shown to be more tolerant to hypoxia than expected; 31 species across seven families could tolerate oxygen concentrations as low as 1 mg/L (Nilsson and Ostlund-Nilsson 2004). However, their ability to tolerate hypoxic conditions decreased as water temperature increased (Nilsson *et al.* 2010).

Seagrasses tend to grow in hypoxic sediment and transport oxygen produced by photosynthesis to below-ground tissues (Sand-Jensen *et al.* 1982, Smith *et al.* 1984; Caffrey and Kemp 1991).

However, this photosynthetic oxygen pool can be depleted during the night, and insufficient oxygen supplied to the roots results in sulfide intrusions (Pedersen *et al.* 2004, Holmer *et al.* 2009), which has severe adverse effects growth and survival (Holmer and Bondgaard 2001, Koch *et al.* 2007, Mascaró *et al.* 2009, Borum *et al.* 2005, Frederiksen *et al.* 2007). Anoxia also impairs root growth, and nutrient uptake (Smith *et al.* 1988, Zimmerman and Alberte 1996). The depletion of oxygen reserves during night time respiration is exacerbated when water column oxygen concentration is lower (Holmer *et al.* 2009). Likewise, mangrove trees have special physiological adaptations to oxygenate roots and avoid sulphide intrusion, which have been demonstrated to depress normal growth and metabolism in *Rhizophora mangle* (Lin and Sternberg 1992).

At a population and ecosystem scale, sensitive species may be eliminated in hypoxic areas, thereby causing changes in species composition of benthic, fish, and phytoplankton assemblages. Decreases in species diversity and species richness are well documented in hypoxic areas, and changes to food web structure and functional groups have also been reported in areas with low oxygen availability (Wu 1982, Dauer 1993, Pihl 1994, Diaz and Rosenberg 1995, Altieri 2008). Under hypoxic conditions, there is a general tendency for suspension feeders to be replaced by deposit feeders (Levin 2000); demersal fish by pelagic fish; and macrobenthos by meiobenthos. Microflagellates and nanoplankton also tend to dominate phytoplankton assemblages in hypoxic environments (Josefson and Widbom 1988, Diaz and Rosenberg 1995, Qu *et al.* 2015, Rakocinski and Menke 2016, Briggs *et al.* 2017). A reduction in the biomass of fishes has been generally observed in hypoxic areas (Dyer *et al.* 1983, Rosenberg and Loo 1988, Pihl *et al.* 1992, Baden *et al.* 1990a, Baden *et al.* 1990b, Breitburg 1992, Petersen and Pihl 1995, Lekve *et al.* 1999), accompanied by shifts in species dominance, with less biomass of deep-dwelling species, but more biomass of opportunistic ones (Dauer 1993).

While data are limited, it appears recovery of benthic communities in temperate regions that have suffered hypoxic conditions can take several years (Diaz and Rosenberg 1995), but recovery may occur more quickly in subtropical environments (Wu 1982). Small-scale hypoxia associated with a point source discharge may recover more quickly because organisms can easily migrate from the surrounding, non-affected areas (Rosenberg 1976).

4.2 Biological Stresses

4.2.1 Invasive Species

Introduced species are organisms that have been moved, intentionally or unintentionally, into areas where they do not naturally occur. Many of them fail to establish persistent populations in their new environment; still others may establish breeding populations but do not experience rapid population growth or appear to cause adverse effects on the ecosystem (*e.g.*, they appear to "naturalize"). Other species, free of the ecological processes and interactions that controlled their population growth in their native range, rapidly increase in abundance to the point that they come to dominate their new environment, creating adverse ecological effects to other species of the ecosystem and the functions and services it may provide. These species are considered invasive (Goldberg and Wilkenson 2004).

Summary Stressor Table: Potential effects of hypoxia
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Hypoxia not a significant issue
Mangrove Forests	• Reduced mangrove tree growth and metabolism, contributing to lower productivity, altered nutrient cycling, reduced ability to filter contaminants • Changed organism behavior, likely exposing organisms to increased predation risk • Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality • Increased mortality, especially if oxygen concentrations drop below ~2-4 mg/L • Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure
Seagrass Beds	• Reduced seagrass growth and metabolism, contributing to lower productivity and altered nutrient cycling • Increased dominance of macroalgae, which are more tolerant to hypoxia; potential for a phase-shift toward algal-dominated assemblage under low light regimes • Changed organism behavior, likely exposing organisms to increased predation risk • Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality • Increased mortality, especially if oxygen concentrations drop below ~2-4 mg/L • Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure
Coral Reefs	• Increase coral mortality at oxygen concentrations between 2-4 mg/L, resulting in loss of topographic structure • Increased dominance of macroalgae, which are more tolerant to hypoxia; potential for a phase-shift toward algal-dominated assemblage under low light regimes • Changed organism behavior, likely exposing organisms to increased predation risk • Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality

Ecosystem	Potential Effects
	• Increased mortality, especially if oxygen concentrations drop below ~2-4 mg/L • Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	• Potential for severe hypoxia to result from increase transport of POM into the deep water • Changed organism behavior, likely exposing organisms to increased predation risk • Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality • Increased mortality, especially if oxygen concentrations is low • Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure • Disruption of ocean-wide nutrient cycling
Pelagic Environment	• Likely not a significant problem near the surface due to mixing • Displacement of mobile species to less hypoxic areas, potentially increasing predation- and fishing-related mortality • Increased mortality, especially among larval forms which appear less tolerant to hypoxia than adults • Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure • Mortality could increase export of particulate organic matter to deep ocean.

While most often invasive species are non-native, native species can also display invasive behaviors following a perturbation that disrupts the “normal” operation of their environment. For example, the native algae *Dictyosphaeria cavernosa*, became invasive in Kāne‘ohe Bay, Hawai‘i following decades of nutrient enrichment and decreased herbivory (Stimson *et al.* 2001) and was the dominant benthic organism in many areas of the bay until a dieback appeared to enable natural ecological process to reassert controls on its population (Stimson and Conklin 2008).

In a review of available data on invasive species, Molnar *et al.* (2008) found nearly three-quarters of marine invasive species were unintentionally introduced via shipping (*i.e.*, ballast water and/or hull fouling). Other significant pathways include agricultural imports, the aquarium trade, and the live fish trade.

While marine invasive species have received relatively little attention globally compared to their terrestrial counterparts, numerous species have become problematic in tropical marine ecosystems, especially on coral reefs. These invasive species have displaced native species, caused the loss of native genotypes, modified the physical environment, changed assemblage structures, affected food web dynamics and ecosystem processes, functions and service, impacted human health, and caused substantial economic losses (Grosholz 2002, Perrings 2002, Wallentinus and Nyberg 2007, Molnar *et al.* 2008, Vilà *et al.* 2010, Lapointe and Bedford 2010, Smith *et al.* 2002, Fernandez and Cortes 2005, Stimson *et al.* 2001, Conklin and Smith 2005 Andrefouet *et al.* 2004, Smith *et al.* 2004, Albins and Hixon 2008, Green *et al.* 2012). The growth and success of invasive species are often enhanced by other anthropogenic stressors, such as nutrient runoff (*e.g.*, promotes growth of algae) and overharvest of key herbivore species, although natural stressors, such as disease, can also contribute to their success.

Nearly 500 introduced species have been identified in Hawai‘i, but only a small number of them are invasive, including three species of algae, 19 invertebrates, and three fishes (Coles and Eldredge 2002, Carlton and Eldredge 2009, Randall 1987, Smith *et al.* 2002). Several of these invasive species are increasing in both abundance and spatial distribution, and threaten ecosystem function by outcompeting native species, especially native structure-forming organisms such as coral. This will contribute to decreased species diversity, changes in trophic structure, and loss of physical structure, but it is not clear exactly how this will affect individual species; effects will likely vary depending upon whether the species-specific interaction affected by invasive species is of a facultative or obligate nature, with the latter relationship likely more sensitive to effects.

On reefs subjected to nutrient enrichment or the removal of herbivores, invasive algae have overgrown corals and other benthic invertebrates; cover of invasive algae on some reefs in Hawai‘i has exceeded 50% (Smith *et al.* 2002, Concepcion *et al.* 2010). The snowflake coral *Carijoa riisei* has been observed overgrowing deep water black corals, causing the mortality of large, sexually mature colonies (Kahng and Grigg 2005). These same individuals provide important ecological functions to deep reef ecosystems. Invasive snappers have altered behavior and habitat use by some goatfish, potentially exposing them to higher mortality from fishing and possibly predation (Schumacher and Parrish 2005).

Fewer invasive species have been documented in other jurisdictions in the Western Pacific Region, but this is likely a result of inadequate survey effort. Given the correlation between shipping and harmful invasions (Seebens *et al.* 2014), regions with high port traffic but few reported invasions (*e.g.*, Guam and Saipan) probably contain more marine invaders than have been documented (Molnar *et al.* 2008), and may benefit from surveys targeted at identifying the presence of invasive species. A recent assessment of invasive species in the PRIA (Franklin and Mancini 2015) identified 15 non-native and potentially invasive species, including five species of bryozoan, two species of polychaete worms, three tunicate species, two sponge species, and one species each of macroalgae, fish, and hydroid. These species were identified from Palmyra Atoll and Johnston Island, both of which have a prior history of human and military activity, and have been the subject of comprehensive biological surveys over the past two decades. Other areas within the PRIA lack sufficient baseline biological information to make determinations (Franklin and Mancini 2015).

4.2.2 Disease

Diseases are a natural part of all ecosystems and play an important selective role in population dynamics. However, when disease outbreaks occur, mortalities can affect not only the host population, but have the potential to cascade through the ecosystem, leading to altered assemblage structure (Lessios 1988), including changes to benthic diversity, composition, and topographic structure, all of which have wide reaching implications on ecosystem function. However, despite decades of research, the ecological effect of diseases in the ocean remains relatively unknown, even when these diseases affect economically and ecologically important species (Ward and Lafferty 2004, Harvell *et al.* 2002). The lack of baseline data on historical disease levels in marine ecosystems is an impediment to determining diseases demographics, etiology, infectiousness, virulence, and spatial distribution.

Many marine organisms serve as potential hosts for a diversity of parasites and pathogens. Lafferty *et al.* (2015) identified 67 diseases with specific economic impacts. Most occurred in temperate waters, and while present in the wild, appeared to be problematic only under high-density aquaculture conditions. Marine disease outbreaks appear to be increasing over the past half century (Ward and Lafferty 2004), but not for all marine taxa. Turtles, corals, mammals, urchins, and mollusks have all shown significant increases in the rate of disease outbreaks, which cannot be attributed simply to increased vigilance or other reporting bias.

Over the past decade and a half, links between changing ocean temperatures and pathogens have been made (Porter *et al.* 2001, Harvell *et al.* 2002, Ward *et al.* 2007, Miller and Richardson 2014). Growth rates of marine bacteria (Shiah *et al.* 1994) and fungi (Holmquist *et al.* 1983) are positively correlated with temperature, and the optimum temperatures for fungal growth coincides with thresholds that trigger thermal stress and bleaching for many coral species (Holmquist *et al.* 1983, Coles *et al.* 1976), leading to the likely co-occurrence of bleaching and fungal infection. The 1998 mass bleaching of coral caused pronounced mortality worldwide, but the demise of some corals was accelerated by opportunistic infections (Harvell *et al.* 2001). Three coral pathogens grow well at temperatures close to or exceeding probable host optima, which suggests that they would increase in warmer seas (Harvell *et al.* 2002). Among marine invertebrates and seagrass, many disease outbreaks are also linked to temperature increases (Harvell *et al.* 2002), and increased ocean temperature has been linked to the northward expansion of oyster diseases in the mid-1980s (Ford 1996, Cook *et al.* 1998).

Additionally, stressors such as increasing water temperature and pollution, make hosts more susceptible to infection (Holmes 1996, Bruno *et al.* 2003, Trevathan-Tackett *et al.* 2013), although some stressors may affect parasites more than their hosts (Lafferty 1997). For example, stressors that decrease host population density may reduce density-dependent transmission of host-specific diseases by reducing contact rates between infected and uninfected individuals

Summary Stressor Table: Potential effects of invasive species
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Decreased species diversity, altered trophic structure • Disrupted behavior and interactions among and between species
Mangrove Forests	• Decreased species diversity, altered trophic structure, • Disrupted behavior and interactions among and between species • Decreased value as nursery habitat • Altered ecosystem functions to filter sediment, nutrients, and other pollutants
Seagrass Beds	• Decreased species diversity, altered trophic structure, and the potential for a phase-shift to an algal-dominated assemblage • Potential disruption of nutrient cycling and transport among nearshore marine ecosystems • Disrupted behavior and interactions among and between species
Coral Reefs	• Decreased species diversity, altered trophic structure and ecosystem function and services • Disrupted behavior and interactions among and between species • Increased potential for a phase-shift toward an algal-dominated assemblage
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	• Effects unclear due to a lack of research, but likely include decreased species diversity and altered trophic structure, and a potential disruption of nutrient cycling
Pelagic Environment	• Effects unclear due to a lack of research, but likely include decreased species diversity, altered trophic structure, and a potential decrease in productivity, alteration of food web dynamics, change in rate of POM export to deep ocean

(Lafferty and Holt 2003). However, any stressor that increases physiological stress in the host has the potential to increase the host's susceptibility to infection. For example, the bioaccumulation of toxins in marine mammals has been demonstrated to affect their immune system and increase susceptibility to disease (Lafferty and Gerber 2002).

Like many invertebrates, corals possess an innate immune system that is characterized by a series of mechanisms that defend the host from infection (Toledo-Hernández and Ruiz-Diaz 2014). In reef-building corals, mucus forms a physical barrier and acts as a first line of defense. Coral mucus is a viscous fluid made of a complex mixture of compounds secreted by the polyps, and which contains a variety of anti-bacterial compounds (Kvennefors *et al.* 2012, Krediet *et al.* 2013), including a variety of symbiotic microbes that prevent the settlement of potentially noxious bacteria (Brown and Bythell, 2005), and a range of viruses that also may play an important role in coral immunology (Nguyen-Kim *et al.* 2015). Factors that affect the mucus layer may have directly lower a coral's immunity to disease. While coral immune systems are generally considered rudimentary and simplistic (Pollock *et al.* 2011, Toledo-Hernández *et al.* 2013), recent research suggests they are surprisingly complex, with some components similar to those found in vertebrates (Reed *et al.* 2010, Palmer and Traylor-Knowles 2012).

The incidence of coral disease has been found to be positively correlated with increasing algal cover (Hayes and Goreau 1998, Harvell *et al.* 1999, Harvell *et al.* 2004), and a link between direct algal contact and coral disease has been established (Nugues *et al.* 2004, Bender *et al.* 2012). Macroalgae populations, including species of common Western Pacific Region genera *Halimeda*, *Hypnea* and *Chlorodesmia*, have been shown to harbor pathogens that have been directly linked to coral disease, although the specific mechanism of transfer between algae and coral is poorly understood (Sweet *et al.* 2013).

In general, Pacific reefs have been considered in good condition, with little concern given to coral and other diseases, but this may only reflect inadequate information for many geographic areas. As more studies are conducted on Pacific reefs, it is becoming clear that diseases exist and may be more widespread than originally believed (Ruiz-Moreno *et al.* 2012, Maynard *et al.* 2015), causing some experts to warn that Pacific coral reefs are on a trajectory of degradation similar to that experienced in the Caribbean where coral reefs have been decimated by disease (Galloway *et al.* 2009, Maynard *et al.* 2015).

Approximately 30 coral diseases are known from the Indo-Pacific region, affecting 97 species of coral (approximately 15% of all species) from 34 genera, and the identification of new diseases appears to be accelerating. Coral disease in the Western Pacific region is widespread with prevalence varying from a low of 0.14% in American Samoa to 0.5% in the Northwestern Hawaiian Islands, and up to ocean-wide highs of 10% along the Great Barrier Reef and 14% in the Philippines (Willis *et al.* 2009, Aeby 2009, Work *et al.* 2009). Disease progression can be variable, advancing across a few millimeters of tissue to >1 centimeter (cm) per day, and depending on the severity and length of the infection can cause partial or total colony mortality (Southerland *et al.* 2004).

Other coral reef organisms affected by identified diseases include coralline algae (Littler and Littler 1995, Aeby *et al.* 2005) and sea urchins, for which a massive die-off contributed to a regional phase-shift on Caribbean reefs (Mumby *et al.* 2006). Researchers believe an urchin disease outbreak may have responsible for a recent mass mortality of *Tripnuestes gratilla* (collector urchin) in Hawaiʻi (T. Work, pers. comm.).

No reports of seagrass disease have been located for the Western Pacific Region, but likely, seagrass diseases are present and their prevalence may increase in the Pacific in the future under warming seas. The limited information on seagrass disease comes from seagrass wasting diseases which has been reported in at least two Atlantic species: *Zostera marina* (eel grass) and *Thalassia testudinum* (turtle grass) (Loucks 2013). This disease was responsible for decimating *Z. marina* meadows in the 1930s with over 90% loss (Muehlstein 1989). The same micro-organism has been identified as the causative agent for both species, suggesting this disease has potential to affect numerous species in different genera. When not lethal, wasting disease has been shown to affect photosynthesis, growth, and leaf litter production (Ralph and Short 2002), which can affect nutrient transport and cycling.

Similarly, relatively few diseases of mangrove trees have been identified, and those that have been identified primarily affect *R. mangle* (Weir *et al.* 2000). Most are linked to a fungal causative agent, at least one of which has been identified in Hawaiian *R. mangle* populations (Kohlmeyer 1969), and which was responsible for rotting of woody tissue below the waterline.

4.2.3 Fish Aggregating Device (FAD) Effect

Nearly any floating object (anchored or unanchored) in the ocean will attract and aggregate organisms, mostly fish, underneath it. This behavioral response has led to the development of FADs as a fishery tool, but this report reviews the FAD effect from non-fishing activities including marine debris, anchored ships, navigational buoys, fixed structures, and floating platforms.

Unlike many of the other stressors discussed in this report, the FAD effect does not directly alter the condition of the physical or biological habitat. The only direct effect to the EFH is the deployment of the object into the environment, which then alters the behavior, and potentially the distribution and fitness of some species. Removal of the object would be expected to restore behavior to its pre-deployment condition. As such, the presence of the object itself is the primary effect on environment.

Fish aggregation has been best studied in relation to fishing FADs, which have been shown to have the potential to adversely affect fishery species and ecosystems (Wang *et al.* 2014), although considerable debate about their potential adverse effects exists (Dagorn *et al.* 2012). FADs have been shown to cause pelagic fishes to move away from their usual migration routes, which can lead them into regions with lower productivity (Fléchet 2008) and result in lower individual fitness and altered spatio-temporal dynamics of the population (Wang *et al.* 2014), but the converse has also been demonstrated (Dagorn *et al.* 2007, Dagorn *et al.* 2012). Compared to free-swimming tuna, tuna associated with FADs show significant differences in feeding patterns (Williams and Terawasi 2014, Fonteneau 2014, Wang *et al.* 2014), fish condition (Hallier and Gaertner 2008, Harley *et al.* 2014, Williams and Terawasi 2014), growth rates (Harley *et al.* 2014, Williams and Terawasi 2014), aggregation patterns (Fléchet 2008), and migratory

Summary Stressor Table: Potential effects of disease
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Species-specific disease may affect populations but not likely to significantly alter tropical intertidal assemblage • Depending on the species, could result in reduced species diversity, changes in trophic dynamics, and reduced resilience
Mangrove Forests	• Few diseases of mangrove trees have been identified and trees appear to be relatively resistant to disease. • For non-mangrove tree species, disease could result in reduced species diversity, and changes in trophic dynamics
Seagrass Beds	• Seagrass wasting disease has potential to eradicate seagrass beds, removing important nursery habitat • Reduced photosynthesis, growth, and leaf litter production • Altered nutrient transport processes • For non-coral species, disease could result in reduced species diversity, and changes in trophic dynamics
Coral Reefs	• Increased mortality in coral and important herbivores can lead to significant changes in assemblage diversity and composition, including the potential for a phase-shift toward an algal-dominated assemblage • “Flattening” of reef structure leading to loss of diversity, abundance and biomass, including important fishery species • Decreased coral recruitment if significant loss of CCA algae occurs • Sub-lethal effects reduce growth, reproduction and likely impair organism fitness
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	• Unknown, no research available
Pelagic Environment	• Depending on the species, could result in reduced species diversity, changes in trophic dynamics, and reduced resilience

direction and displacement rates (Hallier and Gaertner 2008, Williams and Terawasi 2014), although research conducted as part of the Hawai‘i FAD program suggest these effects are not universal (Grubbs *et al.* 2002, Holland *et al.* 2003, Dagorn *et al.* 2007).

FADs have also been implicated in increased bycatch and mortality of high-level, or apex, predators. An estimated 480,000 to 960,000 sharks per year are killed in the Indian Ocean when caught in drifting FADs (Filmater *et al.* 2013), although the design of these units may be directly responsible. “Smooth-bodies” FAD designs, such as those deployed in the Western Pacific Region have resulted in few adverse interactions with sharks, turtles and other protected species (Holland 2012). Juvenile bigeye tuna often gathers under FADs and are caught before they have a chance to reproduce. In 2013 more than 85% of bigeye tuna landed in the Western Pacific Region were small, and most of these were caught in association with purse seiners around FADs (Harley *et al.* 2014). Nevertheless, the potential to catch small FAD-associated individuals using other methods exists. While mortality from FADs is most likely associated with fishing (which is beyond the scope of this report), other potential ecological effects of fish aggregation should not be discounted. Fish will aggregate under and around any floating object in any shallow water marine ecosystem, not just the open ocean where traditional fishery-related FADs are generally deployed. Shifts in abundance of high-level predators from their natural habitat, can have significant ecosystem effects on the individuals and the population. Changes in the spatial distribution and density through the depletion or concentration of apex predators could induce ecological changes in marine assemblages (Stevens *et al.* 2000, Bascompte *et al.* 2005; Mumby *et al.* 2006), both near the aggregating structure and away from the structure. While potential ecosystem-level effects on the pelagic ecosystem are unclear, reef areas dominated by high-level predators often support greater biomass of herbivores (Stevenson *et al.* 2007), likely because of an indirect effect of predators preying upon intermediate consumers, thereby releasing herbivores from predatory control (Bascompte *et al.* 2005). The presence of herbivores has far reaching ramifications on ecosystem health, particularly on coral reefs, and particularly in combination with other stressors (*e.g.*, nutrients). However, to achieve a substantial adverse effect, structures that promote fish aggregation would need to be numerous and densely deployed in order exert sufficient attraction on many apex predators. Even so, the attractive capacity of a FAD array would be limited because FADs appear to have a limited range of attraction, approximately 10 km (Girard *et al.* 2004). Therefore, provided fishery related mortality is managed at any fish aggregating structure (*e.g.*, Cabral *et al.* 2014), ecosystem-level effects would likely be localized and small in magnitude.

4.3 Physical Stress

4.3.1 Physical Damage

Physical damage to an ecosystem can occur when sufficient mechanical force is generated either naturally through the movement of water (*e.g.*, by a storm, tsunami, etc.) or anthropogenically through contact with an object (*e.g.*, dredge, anchor, feet, groundings, etc.). Shallow water benthic organisms are most at risk to physical damage because they are unable to leave the area of impact or otherwise avoid being impacted. In Hawai‘i, reef fish have been observed to move into deeper water prior to large storm events (Walsh 1983), likely to escape the physical effects of the storm. Likewise, deep water ecosystems tended to be less affected by physical stress

Summary Stressor Table: Potential effects of fish aggregating
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Fish aggregating not a significant stressor
Mangrove Forests	• Fish aggregating likely not a significant stressor
Seagrass Beds	• Fish aggregating likely not a significant stressor
Coral Reefs	• Altered distribution of apex predators • Altered trophic dynamics, for example, change in fish herbivore abundance could alter herbivory rates
Deep Reef Slopes	• Fish aggregating like not a significant stressor
Banks and Seamounts	• Fish aggregating likely not a significant stressor
Deep Ocean Floor	• Fish aggregating not a significant stressor
Pelagic Environment	• Altered distribution apex predators • Altered fitness for aggregated species • Altered trophic dynamics

because storm-generated surge seldom extends deeper than ~50 m in the ocean (but see Smith *et al.* 2016), and human activity is generally restricted to shallow, coastal areas. Although storm damage has been observed as deep as 100 m (Harmelin-Vivien and Laboute 1986), activities such as deep-ocean mining (Sharma 2015) have the potential to cause substantial but localized physical damage to deep water ecosystems.

In tropical oceans, physical damage has been best studied in coral reef and seagrass ecosystems. Seagrasses are primarily affected through physical removal of plants, leaving bare patches (sometimes called "blowouts") that are subject to further erosion. Blowouts may lead to a decrease in topographical structure, and an increase in the abundance of early colonizing species, such as fast growing native and/or invasive algae (Short and Neckles 1999). Recolonization for many seagrass species occurs primarily through vegetative branching, and populations may take many years to recover (Williams 1990; van Tussenbroek 1994, Creed and Amado Filho 1999). However, deep water seagrass beds (30 m or more), such as those composed of *Halophila decipiens*, a common species seagrass in Hawaiʻi and elsewhere in the Western Pacific Region, show higher recovery rates due to the prolific sexual reproduction and high rhizome growth rates

(Williams 1988). This species (and similar ones) would be less likely to suffer long-term adverse effects from physical damage.

Physical damage on coral reefs is often associated with the breakage or dislodging of coral colonies, but can also manifest itself less severely (*e.g.*, tissue abrasion). Scleractinian corals, which are responsible for the structural complexity of coral reefs, are particularly vulnerable to physical damage because their slow-growing carbonate skeleton is relatively brittle and their polyps are easily damaged. A number of studies have reported coral damage from coastal development (Hawkins and Roberts 1994), boating and anchoring (Tilmant 1987, Rogers 1993), especially in large anchorages such as the Garapan Anchorage off Saipan (Rooney *et al.* 2005), derelict fishing gear and other marine debris (Edward 1999), as well as snorkeling (Rogers *et al.* 1988, Allison 1996), reef walking (Neil 1990, Hawkins and Roberts 1993, Rodgers and Cox 2003, Rodgers *et al.* 2003), and scuba diving (Tratalosa and Austin 2001, Zakai and Chadwick-Furman 2002, Hasler and Ott 2008). While nearly always very minor relative to the other activities mentioned above, scientific investigations have the potential, especially in pristine areas, to result in physical damage to coral colonies and other organisms.

The severity of the damage caused by physical stress to a coral colony is dependent on many factors, including the magnitude of the physical force and the skeletal strength of the organism, which for coral is dependent on skeletal density and colony morphology (Storlazzi *et al.* 2005, Shimabukuro 2014). In general, lobate, encrusting, and other massive colony morphologies tend to withstand breakage better than foliose, table, plating, and branching morphologies. However, these more fragile forms tend to have higher growth rates (Minton 2013), which would facilitate more rapid recovery following damage, provided the colony did not experience total mortality.

Recovery from physical damage can be slow, often on the order of years to decades (Rogers and Garrison 2001). Recovery can be hampered by loose rubble (Dollar 1982, Raymundo *et al.* 2007), which is often generated by the pulverizing of fragile coral morphologies, such as branching or foliose forms. The loose rubble rolls around on the bottom, causing secondary damage to small corals and other organisms, and impairs recruitment (Brown and Dunne 1988, Lindahl 1998, Fox and Caldwell 2006). Often, no recovery is observed until the rubble is washed from the area or solidified to the bottom (Fox and Caldwell 2006, Raymundo *et al.* 2007), usually by coralline algae (natural recovery) or human intervention. While rubble fields may inhibit coral settlement and regrowth, for some coral species fragmentation is a viable form of dispersal (Highsmith 1982), and if environmental conditions are suitable, coral fragments of these species can reattach to the bottom and continue to grow.

The abundances of fish and other coral-associated organisms depend on a reef's topographic complexity, and the flattening of reefs can lead to declines in biodiversity (Alvarez-Filip *et al.* 2009), including among fisheries species. When combined with other stressors, such as nutrient enrichment, large-scale physical damage can increase the probability of a shift in dominance from coral to algae, known as "phase-shifts." For example, Jameson *et al.* (2007) found that sites suffering from anchor and scuba diver damage, had a lower frequency of hard coral (especially *Acropora* coral), and higher percentage of algae, suggesting physical damage can contribute to a shift from coral- to algal-dominated assemblages.

The deep ocean floor is unlikely to experience a significant amount of physical damage from non-fishing effects. However, deep ocean mining has the potential to cause significant localized effects. While most studies that have examined the potential adverse effects of deep ocean mining have focused on adverse faunal effects without attempting to link the observed changes to a specific stressor (Ozturgut *et al.* 1980, Foell *et al.* 1990, Schriever *et al.* 1997, Tkachenko *et al.* 1996, Radziejewska 1997, Sharma *et al.* 2001), physical damage to the substratum is expected to be the primary mechanism causing damage. Most mining appears to be conducted in unconsolidated sediment, so breakage of structure-forming organisms is unlikely (Sharma 2015), and many effects are likely associated with sedimentation and smothering. Unfortunately, it's unknown how these changes may cascade through the deep sea food web.

4.4 Pollution Stress

4.4.1 Sediment

A large body of information exists examining the effects of sedimentation, nutrient enrichment and turbidity on marine ecosystems, especially coral reefs (see Rogers 1990, Fabricius 2005, Cabaçoa *et al.* 2008, Erftemeijer and Lewis 2006). Given the often confounding relationship between sediment, nutrients, turbidity, heavy metals, and other pollutants, it has often been difficult to assess the direct causal relationships between increasing sedimentation and ecosystem degradation (Fabricius 2005). Therefore, this section will focus primarily on the direct effects (*e.g.*, smothering, scouring, and burial) that can be attributed to sedimentation. Potential adverse effects associated with nutrients (4.4.3 Chemicals), metals, and other chemicals (4.4.2 Nutrient enrichment), and turbidity (4.1.5 Irradiance) are covered elsewhere in this report.

Suspended sediment can elicit short- and long-term responses from aquatic organisms depending on the quantity, quality, and duration of suspended sediment exposure (Kjelland *et al.* 2015). In general, high rates of sediment deposition contribute to reduced fitness or death in filter-feeding organisms such as mussels, oysters and other bivalves by clogging their feeding mechanisms (*i.e.*, cilia and siphons) and through direct smothering (Wilber and Clarke 2001, Nicholls *et al.* 2003). Fish are more likely to undergo sublethal stress from suspended sediment rather than mortality because of their ability to move out of an area with high suspended sediment load, although specific responses are not well-studied in coral reef fish or other tropical fish. Displacement can disrupt social interactions, increase intraspecific aggression, reduce reproductive success, increase predator–prey interactions, and alter food web dynamics, larvae disbursement, and settlement (Kjelland *et al.* 2015).

The transport of sediment from land into coastal marine ecosystems is a natural process that is important to mangrove forests and some seagrass ecosystems, but can be detrimental when its rate is changed and/or the physical or chemical composition of the sediment is altered by human activity. Coral reef assemblages change naturally along sediment gradients (McClannahan and Obura 1997, West and vanWoesik 2001, Fabricius 2005), and can flourish at relatively high levels of particulate matter and siltation (Anthony 1999). Sediment transport in the marine environment depends on two factors: the size of the particles, and the strength of water flow (either prevailing currents and/or tidal flux). Sediment composition and grain size are also important parameters when assessing the potential adverse effects on marine ecosystems. Fine

Summary Stressor Table: Potential effects of physical damage
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Organism tend to be resistant to physical damage
Mangrove Forests	• Organism tend to be resistant to physical damage • Increase mangrove tree mortality if significant damage occurs
Seagrass Beds	• Increased bed erosion in areas where seagrass is removed • Altered topographic structure could change assemblage structure • Decreased nursery habitat quality for coral reef fish species
Coral Reefs	• Increased partial or total coral colony mortality • Damage unlikely to affect all coral colonies, reducing overall threat to the ecosystem • If widespread damage occurs, shift in coral species composition to more breakage resistant colony morphologies could happen, with likely loss in topographic complexity; may contribute to a "flattening" of the reef and associated loss of biodiversity, abundance, and biomass of reef associated fish and invertebrates
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	• Physical damage likely not a significant stressor
Pelagic Environment	• Physical damage not a significant stressor

sediment has more potential for greater adverse effects due to their slow settlement rate, ability to re-suspend into the water column, thus prolonging periods of reduced water clarity, and the tendency to form microbial-rich organic flocs (Fabricius and Wolanski 2000). Finally, the composition of the sediment (*e.g.*, terrestrial vs. marine) affects the chemical properties of the particles, which can affect interactions with other pollutants and the availability and quality of light (Te 1997).

Mangrove trees require ~0.5 and 1 cm/yr of natural sediment input from which they extract nutrients. Rates above this threshold can lead to burial of mangrove roots, which is likely to result in tree mortality (Ellison 1998) due to reduced oxygenation of the roots resulting in hypoxia stress. Moreover, the accumulation of sediment can change bathymetry, altering current velocities and impeding the tidal system on which mangroves depend for vital nutrients (Armstrong *et al.* 2010), and reducing the flushing rate of excess sediment (Ellison 2000). Even if burial does not result in mangrove tree death, it can lead to reduced reproductive rates and increased mortality of seedlings (Terrados *et al.* 1997). Effects on mangrove-associated species are not as clear, but burial of soft sediment infauna is likely, and could result in a reduction of light reaching phototrophs and affecting primary productivity, especially in benthic bacteria and algae species.

Sedimentation in seagrass beds can result in burial and decreased photosynthesis due to higher turbidity (see Section 4.1.5). Sedimentation can also alter bathymetry by changing current velocities and wave conditions (Jensen and Mogensen 2000), which affect the natural deposition rates and cause erosion that can undercut seagrass beds (MacInnis-Ng 2003). The effect of burial by sediment on seagrass depends on several factors including the depth of burial and life history of the species involved (Duarte *et al.* 1997); for example, seagrass species with vertical shoots (*e.g.*, Western Pacific Region genera *Cymodocea*, *Thalassia*, *Thalassodendron*) can modify their vertical growth to keep their leaf-producing meristems close to the new sediment level provided sedimentation is not excessive (Marba and Duarte 1994). Response to burial is highly variable among species, although burial under ~5 cm of sediment often leads to substanital mortality in most species (Manzanera *et al.* 1995, Mills and Fonseca 2003, Erftemeijer and Lewis 2006). The adverse effects of sedimentation are often increased when blade epiphytes are abundant because leaf blades with high cover of epiphytes tend to collect a greater amount of sediment than those with fewer epiphytes, resulting in interference with photosynthesis (Shepherd *et al.* 1989) and causing the blades to sink to the bottom, thus increasing the probability of complete burial (Short *et al.* 1989). Sediment composition can be an important factor limiting seagrass distribution (Koch 2001), and incoming sediment can alter the silt and clay content and the amount of organic matter, leading to changes in species diversity, and/or shoot density and leaf biomass (Terrados *et al.* 1998).

Like seagrasses, potential sedimentation effects on coral reef ecosystems include burial and decreased water clarity from increased turbidity. Unlike seagrass beds, most coral reefs do not experience naturally high sedimentation rates, making them more susceptible to increased sediment loads. Coral reef benthic organisms are easily smothered by sediment (Golbuu *et al.* 2003), and rates >100 $mg/cm^2/day$ can kill exposed coral tissue within a few days (Riegl and Branch 1995), although corals show considerable interspecific variability. Sedimentation rates below a species mortality threshold can reduce photosynthesis rates (Philipp and Fabricius 2003), disrupt polyp gas exchange, inhibit nutrient acquisition (Rogers 1990, Richmond 1993), and increase metabolic costs (Telesnicki and Goldberg 1995) because a coral must increase mucus production to remove sediment from its surface. Sedimentation stress in corals increases linearly with the amount of sediment and the duration of exposure (Philipp and Fabricius 2003), and tissue damage is associated not only with amount and duration, but also with sediment type. Tissue damage is higher when exposed to sediment containing higher organic content and microbial activity, and small grain size (Hodgson 1990, Weber *et al.* 2004); mortality can occur quickly under these conditions, especially for newly settled coral recruits (Fabricius *et al.* 2003). High organic content in sediment promotes microbially induced anoxia and reduced pH, which can cause coral death within less than a day, depending on the concentration of organic matter in the sediments (Weber *et al.* 2004). Coral settlement can be inhibited by a layer of sediment covering otherwise suitable hardbottom (Hodgson 1990), and can disrupt larval attachment and metamorphosis (Gilmour 1999), leading to recruitment failure. Removing cohorts of young corals will impair reef recovery after a disturbance, leading to long-term, ecosystem-level effects.

Sedimentation has been shown to reduce biodiversity, alter coral colony size-frequencies of an assemblage, decrease mean colony sizes, alter growth forms, and reduce growth and survival (see Rogers 1990 for an extensive review). Large colonies, or species with branching growth forms and/or thick tissues tend to be more tolerant of sedimentation; whereas small colonies or species with thin tissues and flat surfaces are often more sensitive (Rogers 1990). Some species with thick tissues can remove particles from their surfaces by tissue extension, mucus production, or ciliary movement (Stafford-Smith and Ormond 1992).

Decreased light reduces photosynthesis (both through partial burial and increased turbidity), lowers calcification rates, and contributes to tissue thinning (Telesnicki and Goldberg 1995; Anthony and Hoegh-Guldberg 2003), but many corals can photo-acclimate to reduced light levels, provided the reduction is not too severe. In areas with chronic sediment issues, reduced irradiance can lead to compressed depth distributions, resulting in lower biodiversity at deeper depths, and will also result in a shallower lower depth limit for overall reef growth, leading to a decrease in the suitable substratum available across the entire coral reef ecosystem.

Natural sedimentation can affect MCE (Sherman *et al.* 2010), but overall, natural sedimentation rates are generally low (Smith *et al.* 2008) and lacks a significant terrestrial component (Weinstein 2014). Sediment effects in MCE tend to be associated with scour, especially in conjunction with intense storm events (Smith *et al.* 2016). The low exposure to natural sedimentation suggest deep reef slopes, particularly those with deep water corals may be sensitive to elevated inputs of terrestrial sediment. Appeldoorn *et al.* (2015), in an assessment of the effects on a MCE within a deep-water dredge disposal site, noted a heavy sediment coating on the substratum, and reduced fish abundance. They attributed the decrease fish abundance to an absence of herbivores, such as surgeonfishes and parrotfishes, and hypothesized this was the result of a decrease in algal cover from reduced light intensity attributable to high turbidity.

In most situations, non-fishing activities are unlikely to introduce significant sediment into pelagic and deep ocean ecosystems, but deep sea mining has the potential to introduce substantial sediment loads over a wide area of the pelagic and the deep ocean floor ecosystems via the dumping of sediment-rich effluent from surface processing vessels. Nutrient-rich bottom water filled with fine particulates has the potential to alter surface water column primary productivity and could result in bacterial flocculation (Wolanski and Fabricius 2000), which will quickly be exported to the deep ocean. Upon sinking, this POM will undergo microbial decomposition, which could increase the probability of hypoxic conditions. Additionally, nodule harvesters suspend fine sediment that settles back on the ocean bottom, burying infauna. This has been shown to alter the structure of benthic macro- and meiofaunal assemblages (Foell *et al.* 1990), and these disturbances can persist for a decade or more (Schriever *et al.* 1997, Sharma 2015).

Summary Stressor Table: Potential effects of sedimentation
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Sedimentation not a significant issue on most exposed shores • Reduce tide pool depth and area could affect nursery habitat
Mangrove Forests	• Increased mortality through root burial • Reduced mangrove reproduction success and increased seedling mortality • Altered oceanographic processes could affect nutrient cycling and transport to offshore ecosystems • Increased burial of benthic organisms, including photosynthetic algae • Reduced fitness/increased mortality of filter-feeding organisms (*e.g.*, mussels, oysters and other bivalves) through clogging of their feeding apparatus or smothering
Seagrass Beds	• Increased seagrass mortality from burial (>5 cm of sediment) • Altered silt and clay content and the amount of organic matter can result in long-term changes in species diversity, and/or shoot density and leaf biomass • Reduced fitness/increased mortality of filter-feeding organisms (*e.g.*, mussels, oysters and other bivalves) through clogging of their feeding apparatus or smothering • Altered behavior in fish, potentially causing decrease in fitness
Coral Reefs	• Increased coral mortality at rates >100 $mg/cm^2/d$, potentially significant assemblage-level effects at >50 $mg/cm^2/d$ • Decreased photosynthesis, calcification, and growth • Coral recruitment failure • Shift in coral species composition, with likely loss in topographic complexity; may contribute to a "flattening" of the reef and associated loss of biodiversity, abundance, and biomass • Altered assemblage composition, including loss of diversity of reef associated fish and invertebrates • Reduced fitness/increased mortality of filter-feeding organisms (*e.g.*, mussels, oysters and other bivalves) through clogging of their feeding apparatus or smothering • Altered behavior in fish, potentially causing decrease in fitness
Deep Reef Slopes	See *Coral Reefs*

Ecosystem	Potential Effects
Banks and Seamounts	• Banks and Seamounts tend to be isolated from sediment sources, so effects are expected to be minimal.
Deep Ocean Floor	• Increased risk of burial • Change in species composition, abundance of benthic macro- and meiofauna • Potential effects through food chain
Pelagic Environment	• Increased flocculation and export of particulate to the deep ocean

4.4.2 Nutrient Enrichment

Rapid population growth on small islands, the development of tourism-based economies, poorly developed and maintained infrastructure, poorly designed or insufficient sewage treatment systems (*e.g.,* coastal zone septic systems and cesspools), and generally poor land management have resulted in significant nutrient enrichment of nearshore marine ecosystems in the tropical Pacific (Adams 1996, Verhoeven *et al.* 2006, Honey *et al.* 2010, Spaulding *et al.* 2011). Coastal development, often immediately adjacent to the ocean, has occurred at a considerable pace and often without regard to its potential effects on the marine environment, although this appears to be changing. Residential and commercial landscaping and agricultural practices have contributed to nutrient-rich, non-point source runoff. In addition to often being a significant human health issue, nutrient enrichment adversely affects nearshore marine ecosystems (Bell 1992, Dubinsky and Stambler 1996, Lapointe 1997, Downing *et al.* 1999, Cloern 2001, Lovelock *et al.* 2009). The section will focus on nearshore nutrient enrichment; for information on changes to open ocean productivity see Section 4.1.2.

While mangroves are highly productive ecosystems and fix and store large amounts of carbon (Duarte and Cebrian 1996), they are often nutrient poor (Lovelock *et al.* 2005). Mangroves sustain high levels of productivity despite nutrient limitation through efficient nutrient cycling and nutrient conservation strategies (Reef *et al.* 2010). Nutrient additions can stimulate mangrove growth, and studies have found that small inputs over short time periods often result in no detectable effect on mangrove leaves, soils, or the assemblage structure (Wong *et al.* 1995, Trott and Alongi 2000), although prolonged eutrophication has been shown to have negative consequences on mangrove growth (Lovelock 2009). Under chronic nutrient enrichment, growth tends to favor shoots and canopy production over root structures (Lovelock 2009), resulting in stunted growth forms and a lack of pneumatophores, which eventually lead to plant mortality (Mandura 1997). Less root growth can also increase sensitivity to drought and hypersalinity, leading to increased mortality from water deficits. Nutrient enrichment has also been associated with increased densities of marine wood-borers (Kohlmeyer *et al.* 1995) and herbivory in some bark-mining moths (Feller and Chamberlain 2007). The rate of release of N_2O, a potent greenhouse gas, to the atmosphere can increase exponentially with external nitrogen inputs

(Corredor *et al.* 1999, Allen *et al.* 2007, Krithika *et al.* 2008). Nutrient enrichment favors growth of algae over other benthic organisms, resulting in an algal-dominated benthic assemblage (Lapointe *et al.* 1993).

Nutrient enrichment is considered a major threat to seagrasses worldwide (Short and Wyllie-Echeverria 1996, Ralph *et al.* 2006, Ralph *et al.* 2007, Waycott *et al.* 2009). Short-term additions of nutrients to seagrass beds generally stimulate plant growth resulting in increased biomass and shoot density (Hughes *et al.* 2004). However, if nutrient enrichment is sufficiently large or chronic, it can alter plant architecture, decrease shoot density, reduce biomass, and if persistent, result in seagrass death (Short 1983, van Katwijk *et al.* 1997, Brun *et al.* 2002, Hughes *et al.* 2004, Romero *et al.* 2006, Burkholder *et al.* 2007, Fertig *et al.* 2013). Elevated nutrients can contribute to the excessive growth of epiphytes, macroalgae and phytoplankton, all of which could decrease seagrass growth and survival (McGlathery 1995, Ralph *et al.* 2006, Lee *et al.* 2007, Schmidt *et al.* 2012). Extremely high nutrient regimes can also result in a build-up of organic matter in the sediment, increasing anoxia and creating unfavorable and sometimes toxic sediment conditions for seagrasses (Koch 2001, Koch *et al.* 2006, Ralph *et al.* 2006) and associated organisms. Nutrient enrichment promotes algal growth over seagrasses, potentially contributing to a phase shift from a seagrass- to an algal-dominated assemblage (Lapointe *et al.* 1993).

Coral reefs generally grow in oligotrophic, or nutrient-poor, waters (D’Elia and Wiebe 1990), and nutrient enrichment has been shown to negatively affect coral reef ecosystems (Pastorok and Bilyard 1985, Stambler *et al.* 1991; Dubinsky and Stambler 1996, Loya 2004). Reefs that have been exposed to chronic nutrient enrichment often show an increase in primary productivity, but this is mainly associated with algal growth (Smith *et al.* 1981, Hatcher *et al.* 1989, Bell 1992, Done 1992, Hughes 1994, Lapointe 1997, Schaffelke *et al.* 1998, Fabricius *et al.* 2010), which can quickly occupy hard substratum and potentially overgrow corals, smothering or otherwise outcompeting them (Smith *et al.* 1981, Nairn 1993, Genin *et al.* 1995). This could contribute to a shift to an assemblage dominated by algae (McManus and Polsenburg 2004, Dudgeon *et al.* 2010, Edinger *et al.* 2000, Lapointe 1997), although it is unlikely that nutrient enrichment alone is sufficient to cause such a change, and instead must occur in combination with other stresses (Szmant 2002).

The growth rates of reef algae are believed to be constrained by nutrient limitation and herbivore grazing, thereby preventing algae from overgrowing and killing corals under normal conditions (Carpenter 1986, Lewis 1986, Birkeland 1988, Hay 1991, Littler *et al.* 1991; Lapointe 1997). In the absence of grazing, a nutrient increase could shift the competitive balance in favor of algae. Nutrient enrichment also has the potential to increase water column productivity, resulting in plankton blooms that can reduce water clarity and light for benthic producers, and trigger an increase in the abundance of deposit and filter feeders (Grigg 1995). This shift away from coral dominance would likely result in a “flattening” of the reef (Alvarez-Filip 2009).

While research suggests the effects of nutrient enrichment vary by coral species, type of nutrient input, and the history of the exposed individuals or population, nutrient enrichment generally has an adverse effect on coral. Eutrophication has been reported to cause subtle physiological changes in parameters such as coral growth, skeletal tensile strength, reproduction (Stambler *et* *al.* 1991, Ferrier-Pages *et al.* 2000; Bucher and Harrison 2002; Cox and Ward 2003, Dunn *et al.* 2012), and suppressed calcification rates (Kinsey and Davies 1979; Marubini and Davies 1996; Ferrier-Pages *et al.* 2000). Corals exposed to elevated nutrients often show lower larvae and planula production, impaired planula settlement, decreased gonadal index and fertilization rates, and higher rates of irregular embryos and hermaphroditism (Tomascik and Sander 1987, Richmond 1997, Harrison and Ward 2001, Cox and Ward 2003, Bongiorni *et al.* 2003, Koop *et al.* 2001, Loya *et al.* 2004). Nutrient enrichment has been implicated in reduced ability to withstand disease (Bruno *et al.* 2003, Voss and Richardson 2006, Harvell *et al.* 2007) and may increase susceptibility to temperature stress, thereby increasing the chances of bleaching (Wiedenmann *et al.* 2013). However, responses vary considerably within and among species (Tomascik and Sander 1987; Ward and Harrison 2000; Harrison and Ward 2001; Bongiorni *et al.* 2003), making it difficult to identify generalize trends.

Nutrient additions to the open ocean are unlikely to occur at a large spatial scale, but small scale inputs from activities such as deep ocean mining or OTEC could create localized nutrient inputs. The effects of nutrient additions on primary productivity in the open ocean would be mediated by the availability of limiting elements, primarily iron, which enters the tropical Pacific via wind-blown, terrestrially-derived dust (Falkowski *et al.* 1998). The tropical Pacific, however, is predominately nutrient poor (except in upwelling areas) due to oceanic stratification (Sigman and Hain 2012), and thus may not be severely iron-limited. It could respond to additions of nitrogen, through rapid uptake by phytoplankton and cyanobacteria, potentially leading to phytoplankton blooms. These would then contribute to a zooplankton bloom that could be exploited up through the pelagic foodchain. Ultimately, the production of organic matter, especially POM, would sink and be exported out of the surface layer, into the deep ocean for nutrient recycling. Excess POM in the deep ocean could result in an increased of hypoxia because of microbial decomposition (see Section 4.1.7). While localized nutrient enrichment might be possible, humans appear incapable of fertilizing a large enough area of the ocean on a continuous basis to create significant basin-wide effects.

Coastal areas may be subjected to sufficient, chronic nutrient inputs derived from land-based activities to promote conditions that result in seasonal or even persistent phytoplankton blooms. This increased productivity can have numerous potentially adverse effects on nearshore waters, including increased turbidity which can reduce irradiance, altered trophic dynamics in which planktivores and filter feeding organisms are favored over other trophic groups, and an increased likelihood of seasonal dead zones resulting from microbial decomposition of POM, especially in areas were currents and flushing are low (*e.g.*, harbors, enclosed lagoons, etc.).

4.4.3 Chemicals

All marine ecosystems are under threat of contamination from toxic substances, including oil and oil dispersants, industrial chemicals from discharges, household and personal-use chemicals, pharmaceuticals, pesticides from run-off, and antifouling compounds (Spaulding *et al.* 2001). These chemical pollutants can have a variety of lethal and sub-lethal effects on marine organisms, including alteration of growth, interference with reproduction, disruption of metabolic processes, and changes in behavior. These adverse effects can cascade through

Summary Stressor Table: Potential effects of nutrient enrichment
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Increased algal growth in lower intertidal, with the potential to alter species composition • Likely little or no effect on upper intertidal
Mangrove Forests	• Chronic nutrient enrichment favors canopy growth over root growth, resulting in a lack of pneumatophores and increased tree mortality • Increased release of N_2O, a potent greenhouse gas • Short-term nutrient enrichment unlikely to have noticeable effect
Seagrass Beds	• Under high or chronic nutrient enrichment, altered plant architecture, decreased shoot density and biomass, increased hypoxia in sediment, contributing to increased mortality • Increased abundance of benthic deposit- and filter-feeders • Increased growth of seagrass epiphytes, macroalgae and phytoplankton, which compete with seagrasses for space and light • Potential for a phase-shift toward an algal-dominated assemblage
Coral Reefs	• Altered coral growth rates, decreased calcification and skeletal tensile strength (could increase physical damage) • Decrease coral reproductive output, increased rates of irregular embryos, decreased recruitment • Decreased coral disease resistance • Increase sensitivity to temperature stress in coral, increasing the risk of bleaching • Increased abundance of benthic deposit and filter feeders • Increased growth of macroalgae and phytoplankton, which compete for space and light • Potential for a phase-shift toward an algal-dominated assemblage
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	• Banks and Seamounts tend to be isolated from nutrient sources, so effects are expected to be minimal.

Ecosystem	Potential Effects
Deep Ocean Floor	Unknown; no research available.
Pelagic Environment	• Increased primary productivity until iron becomes limiting • Increased abundance of phytoplankton and cyanobacteria, leading to phytoplankton bloom • Formation of POM that eventually sinks into the deep ocean.

ecosystems, altering species composition, and ecosystem functions and services. Some pollutants are environmentally persistent and can take years or even decades to biodegrade, and others can bio-accumulate and biomagnify through the food chain, eventually posing a direct threat to human health.

Chemicals enter the marine environment through a variety point and non-point pathways (Figure 3), and may be transported great distances from their origin. In the marine environment, the transport, dispersion, and the biological effects of pollutants depend upon the environmental persistence of these chemicals under tropical conditions (*e.g.*, their biodegradation rates), and their propensity to bioaccumulate (van Dam *et al.* 2011). Many contaminants readily attach to sediment particles and are transported into the ocean where they become entrained in the bottom sediment of estuaries, reefs, and potentially deeper ocean ecosystems. Once trapped in sediment porewater, they can continue to flux into the overlying water column (Figure 3), creating a persistent source of contamination long after the initial input has ended. Contaminated organisms carrying accumulated loads of persistent chemicals in their tissues can transport pollutants between marine ecosystems and far from their application or deposition sites (*e.g.*, heavy metals in pelagic fish).

Hydrocarbons

The jurisdictions in the Western Pacific Region have no significant fossil fuel deposits or ongoing extraction activity, so the threat of oil and hydrocarbon pollution is likely low. Hydrocarbons will enter the ocean primarily through run-off from urban areas, and through activities associated with shipping (*e.g.*, spills, fueling, groundings, etc.).

Often, hydrocarbons entering the marine environment do not contact organisms because they stay near the surface where much of it evaporates within a few days (Neff *et al.* 2000), before the remaining non-volatile and semivolite components sink and become entrained in the benthic sediment, where they can potentially persist for years to decades (Owens *et al.* 2008, Bagby *et al.* 2016). However, organisms that use the surface (*e.g.*, marine mammals, some jellyfish, sea birds, etc.) or life history stages that are positively buoyant (*e.g.*, many benthic gametes, including coral spawn) are particularly susceptible to adverse effects from direct contact with hydrocarbons (Haapkylä *et al.* 2007). Rough sea surface conditions can mix hydrocarbons into the water column, and over time some types of crude oils will weather, sink, and adsorb to particulate material (before eventually becoming entrained in the bottom sediment (Fitzpatrick *et*

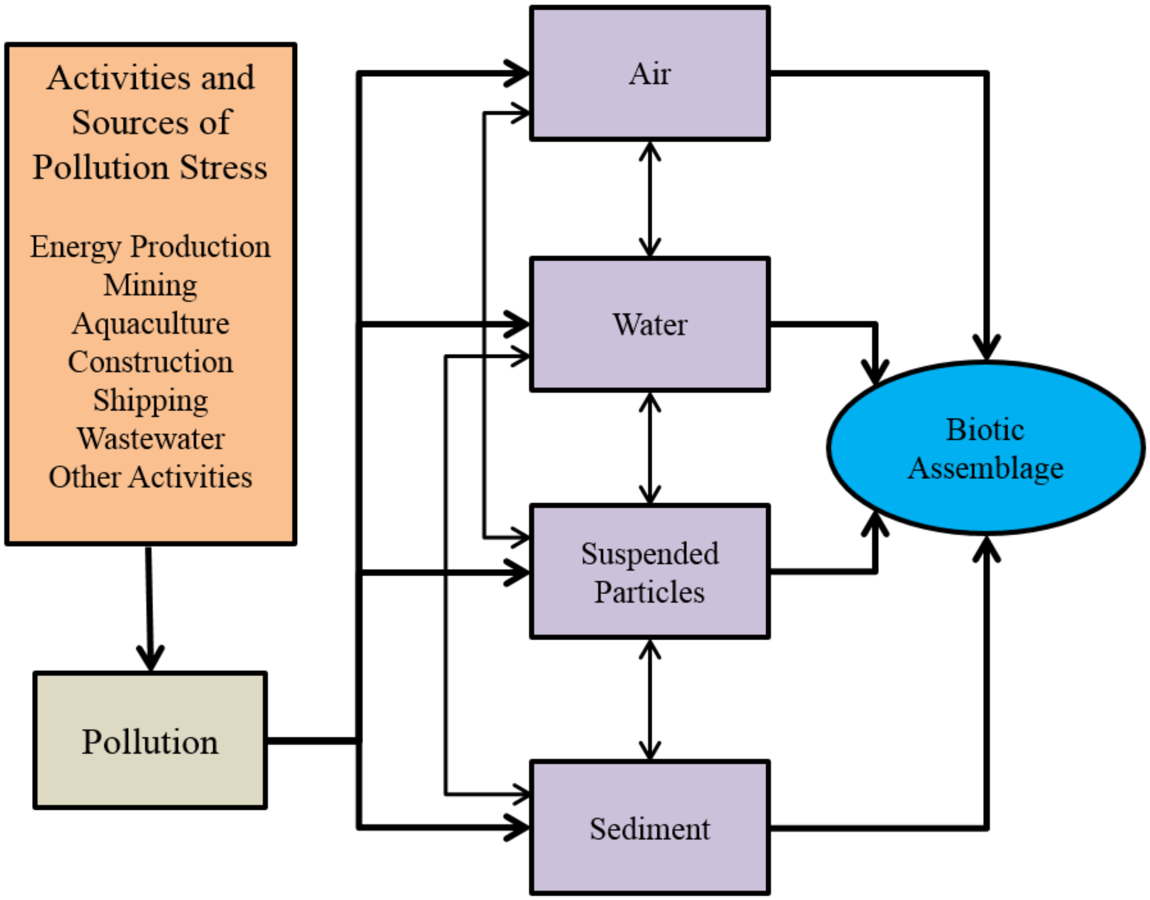

Figure 3. Conceptual model for pollutant pathways in marine ecosystems (modified from van Dam *et al.* 2011).

al. 2015, Gong *et al.* 2014). The sinking of the non-volatile component of the crude increases the chance for adverse effects on “sub-surface” organisms. Direct contact with hydrocarbon itself is not required for an adverse effect to occur because most oil products have a "water-accommodating fraction" that will dissolve into seawater and disperse throughout the water column (Neff *et al.* 2000, Beyer *et al.* 2016). Unfortunately, dispersing agents used to clean up oil spills are often more toxic than the oil itself, and have been demonstrated to cause larval deformities, loss of normal larval swimming behavior, and tissue damage in corals (Epstein *et al.* 2000, Lane and Harrison 2000, Shafir *et al.* 2007, DeLeo *et al.* 2015, Beyer *et al.* 2016).

Mangrove forest ecosystems are particularly sensitive to hydrocarbon pollution because they span the air/water interface and tend to have calm water conditions, which makes it difficult to flush contaminants (Moore 1972, Getter *et al.* 1981). Mangroves are especially sensitive to smothering when pneumatophores, which are responsible for aerating roots, become clogged with oil, causing roots to die from the lack of oxygen (Teas *et al.* 1987, Boer 1993). Both light and heavy crudes have been shown to be difficult to remove from clogged pneumatophores (Reilinger 1991), and recovery can take more than a year (Wardrop *et al.* 1987, Lugo *et al.* 1981, Snedecker *et al.* 1981). Oil can disrupt normal root growth, resulting in deformed aerial roots (Boer 1993, Snedecker *et al.* 1981, Lewis *et al.* 1979, Getter *et al.* 1980, Lewis 1980, Getter *et al.* 1982). The anaerobic soil conditions found in most mangals are not conducive to the biodegradation of oil, and hydrocarbons can persist in mangal soils for years (Page *et al.* 1979). Oiled mangrove trees show reduced productivity, lower rates of litter production and lower seedling survival (Saenger *et al.* 1983). While direct, immediate mortality of mangroves and associated organisms can be high (Nadeau and Berquist 1977, Ray 1981, Getter *et al.* 1981, Saenger *et al.* 1983, Jernelov and Linden 1983, Lewis 1983, Hoi-Chow 1984, Hoi-Chow *et al.* 1984, Teas *et al.* 1987, Garrity and Levins 1993). The added long-term stress on mangrove trees can lead to mortality that extends years into the future (Dodge *et al.* 1995). Recovery of severely damaged mangrove forests can take decades, and depending on the characteristics of the forest, a century or more may be required to replace the lost features, functions and services (Klekowski *et al.* 1994, Davis 1940, Noakes 1955, Tschirley 1969, Westing 1971, Lugo *et al.* 1975). Infaunal populations might recover rapidly, but shrimp, polychaetes, mollusks, and sipunculids may be affected for years (Krebs and Burns 1977, Gilfillian *et al.* 1981, Garrity and Levins 1993), and could experience increased mutations (Klekowski *et al.* 1994).

Damage to seagrass ecosystems includes direct mortality from smothering, fouling, asphyxiation, and chemical toxicity, as well as indirect effects associated with decreased irradiance, trophic disruption, habitat destruction, and loss of sensitive juvenile fish and invertebrates (Zieman *et al.* 1984). Oil in direct contact with seagrasses decreases growth rates, smothers or otherwise damages leaves, and decrease spatial coverage (Jacob 1988). Photosynthetic rates are often depressed, but the magnitude of the reduction varies considerably among species and exposure parameters (Thorhaug *et al.* 1986, Baca and Getter 1984, Thorhaug and Marcus 1985); for example, following spills in the Persian Gulf, seagrasses appeared to be unaffected (Kenworthy 1993). The level of exposure is particularly important for seagrasses because under light oiling, some seagrass species may actually experience enhanced growth for up to decade afterwards (Ballou *et al.* 1989, Dodge *et al.* 1995), a phenomenon in toxicology known as hormesis. Seagrass-associated organisms may or may not recolonize previously oiled beds, resulting in a potential loss of biodiversity (Marshall *et al.* 1993).

Coral reefs may be more susceptible to small, frequent spills than to large single-spill events (Bak 1987, Keller *et al.* 1993, Loya and Rinkevich 1980, Craik 1991). While the chemical composition of the oil can affect its dispersion, emulsification, and weathering, oil released over a reef will generally float above it and not come into direct contact with the corals or other benthic organisms (although reef flats are at risk to direct contact). Oil globules can adhere to the coral tissue (Jackson *et al.* 1989, Marumo and Kamada 1973, Knap *et al.* 1982), and soluble oil components can be adsorbed from the water column by polyps (Knap *et al.* 1982, Burns and Knap 1989, Peters *et al.* 1981), likely a result of the high lipid content of most corals. Effects on coral colonies include mortality, tissue death, reduced growth, impaired reproduction, bleaching, reduced photosynthetic rates, and decreased cellular lipid content, which is correlated with coral fitness (Fucik *et al.* 1984, Cook and Knap 1983, Neff and Anderson 1981, Burns and Knap 1989, Ballou *et al.* 1989, Guzman *et al.* 1993). Coral cover tends to decrease in oiled areas, with potential cascading effects throughout the coral reef ecosystem. Both brooding and broadcasting coral species that are oiled often experience impaired gonadal development (Peters *et al.* 1981, Guzman and Holst 1993). Oil-caused reductions in colony size can result in decreased egg size and fecundity that can persist for years after exposure (Guzman and Holst 1993). Spills occurring near or at peak reproductive season (*e.g.*, summer spawning months for most jurisdictions in the Western Pacific Region) could adversely affect an entire year of reproductive effort because coral gametes and eggs are buoyant, potentially bringing them into direct contact with floating oil. Finally, settlement and recruitment survival can be severely compromised by oil exposure (Loya and Rinkevich 1980, Guzman *et al.* 1993, Messiha-Hanna and Ormand 1982).

Few studies have been conducted on the adverse effects of oil on tropical fish, but decreased growth, altered behavioral responses, and changes in metabolic rate have been observed (Johnson *et al.* 1979, Kloth and Wohlschlag 1972). For several pelagic fish species, including yellowfin tuna, amberjack tuna, and mahi-mahi, exposure resulted in impaired larval swimming and cardiotoxicity (Icardona *et al.* 2014, Mager *et al.* 2014). The water-accommodating fraction can disrupt tropical invertebrate reproduction (Neff *et al.* 2000).

The Deepwater Horizon spill in 2010 produced an extensive hydrocarbon plume that affected deepwater corals up to 22 km away and at a depth of 1,950 m (Fisher *et al.* 2014), resulting in varying degrees of coral tissue loss, sclerite enlargement, excess mucous production, bleached commensal ophiuroids, and a covering of the benthos by brown flocculent material that contained traces of oil (potentially lengthening the exposure period). At sites closer to the wellheads, corals still exhibited significant colony damage at four months after the spill (White *et al.* 2012). Additionally, oil in combination with dispersants used in the clean-up effort proved markedly more toxic than the water-accommodating fraction of the oil alone (Goodbody-Gringley *et al.* 2013, DeLeo *et al.* 2015).

Pesticides/Herbicides

While run-off from Pacific Islands likely contains a range of pesticides and/or herbicides at low concentrations (Orazio *et al.* 2007, Burdick *et al.* 2008, Knee *et al.* 2010, Royer *et al.* 2014), levels below those that impact human health have been shown to adversely affect marine organisms (Richmond 1997, Peters *et al.* 1997, Downs *et al.* 2012). In general, pesticides can cause mortality, reduce growth and fecundity, inhibit fertilization and metamorphosis, alter behavior, and affect photosynthesis. While studies are limited, residual herbicides and breakdown products may not persist at high concentration in aquatic or marine sediment (Edwards 1970).

Unlike many other pollutants, the effects of herbicides on mangals and mangrove trees have received little attention in the scientific literature. Not surprisingly, the few studies available suggest mangals are particularly sensitive to herbicide exposure. Mangrove trees exposed to herbicides experience reduced photosynthesis, plant growth, and biomass production, often leading to mortality (Duke *et al.* 2005, Lovelock *et al.* 2009, Maiti and Chowdhury 2013). Declines in seedling health have been noted (Duke *et al.* 2005). Following extensive aerial herbicide spraying during the Vietnam War, over 40% of the total mangrove forest area of Vietnam experienced substantial mortality (Snedaker 1984, Westing 1984), a level greater than that observed in other vegetative ecosystems that received similar herbicide treatment (NAS 1974, Snedaker 1984, Westing 1984). The heightened sensitivity of mangroves relative to other types of vegetation, however, is poorly understood, but may be associated with its saline environment (Westing 1971), or an increased susceptibility to endocrine disrupting compounds (Snedaker 1984, Westing 1984), which interfere with meristematic tissue (Lugo and Snedaker 1974). In Australia in the 1990s, the herbicide Diuron was implicated in a massive dieback of mangal (Duke *et al.* 2005).

Larger ecosystem effects have also been observed, but direct causal links to herbicides have been difficult to clearly establish. In Vietnam, mangals affected by herbicides showed lower abundance and species richness of planktonic organisms and large fish, but more fish eggs and larvae (NAS 1974), possibly because of an absence of predators. After herbicide spraying marine fishery stocks declined, likely from loss of critical nursery habitat, and the local extirpation of some species occurred (DeSylva and Michel 1975). Not surprisingly, enormous reductions in the abundance of birds were noted in mangals that had been sprayed (Orians and Pfeiffer 1970), which can reduce important nutrient inputs via guano (Adame *et al.* 2015). Recovery of mangrove forest following herbicide exposure is uncertain; estimates vary from 20 years to more than 100 years (Tschirley 1969, NAS 1974, Snedaker 1984). Natural regeneration of mangroves has been minimal in coastal South Vietnam, even after half a century (Westing 1984, Hiep 1984, Marchand 2008). The restoration that has occurred, was the result of extensive human efforts and took over a quarter of a century to return small areas to pre-herbicide condition (Marchand 2008). Recovery in Vietnam has been impeded by the loss of mature seed- or propagule-bearing trees (NAS 1974, Snedaker 1984, Ross 1975), the susceptibility of seedlings to herbicide residuals (Walsh *et al.* 1973), a lack of vegetative cover (NAS 1974) and debris (Ross 1975), and increased erosion (Westing 1984, Ross 1975).

Pesticide applications have adverse effects on mangal species as well. At normal application rates, a mosquito larvicide reached concentrations that were toxic to mysids (Pierce *et al.* 1989), caused sub-lethal effects in fish (Sanders *et al.* 1985, Gehrke 1988), and had significant adverse effects on fiddler crabs (Ward and Howes 1974, Ward and Bush 1976, Ward *et al.* 1976).

Seagrasses appear to show considerable interspecific variability in sensitivity to herbicides, although studies are limited. Diuron has been identified as a significant threat to seagrasses (Haynes *et al.* 2000), and like other herbicides appears to primarily affect seagrasses by disrupting photosynthesis (Ralph 2000, Macinnis-ng and Ralph 2003, Schäfer *et al.* 2007). Diuron is heavily used in U.S. agriculture, including in Hawaiʻi (Royer *et al.* 2014), and has been detected in runoff from sugarcane fields on Maui. Other potential effects of herbicide exposure include mortality, decreases respiration, and decreased production of new shoots and above-sediment biomass (Walsh *et al.* 1982, Mitchell 1987, Grady 1981, Ramachandran *et al.* 1984, Johnson *et al.* 1995).

Pesticides may be more prevalent on coral reefs than suspected, and might merit more attention. For example, in Florida, pesticide residues have been found in samples of lobsters, sponges, crustaceans and fishes from numerous coral reef locations (Glynn *et al.* 1995), suggesting pesticides may be a widespread problem. While no obvious effects on organisms or reef ecosystem were observed in Glynn *et al.*'s study, low concentrations of pesticides, herbicide, and fungicides can inhibit fertilization and metamorphosis and to reduce photosynthesis in numerous species crossing multiple genera that occur in the Western Pacific Region (Markey *et al.* 2007, Jones *et al.* 2003). Pesticides associated with sugarcane production have been shown to reduce photosynthetic efficiency in *Pocillopora damicornis* recruits at low concentrations and short exposure times (Negri *et al.* 2005), cause bleaching in several coral species (Jones *et al.* 2003), and reduce fecundity or entirely inhibit planulae release under longer exposure times (Cantin and Negri 2007). Diuron has been detected at levels above those found to be lethal to corals in runoff adjacent to Maui sugarcane fields, but it is unclear if the runoff entered the nearshore marine waters from the drainage areas in which is was detected (Royer *et al.* 2014).

Metals

Metals can enter the marine environment via numerous pathways, including runoff from urban landscapes, spills, and lubricating muds used in drilling (including directional drilling) (Guzmán and Jiménez 1992, Marx and McGowan 2010, Denton *et al.* 2014, Denton *et al.* 2016). Atmospheric deposition is also a significant source, and is likely the primary source of iron, mercury and other metals to the open ocean (Mason and Sheu 2002, Jickells *et al.* 2005, Sunderland *et al.* 2009). Until the ban on the use of tri-butyl tin (TBT) in 2003, antifouling paints contained the compound as a biocidal component, and were a significant source of tin, copper and zinc. TBT is a persistent compound and is still present in the sediment of many harbors and waterways and around shipwrecks (Smith *et al.* 2003), where it is an important source of toxic substances, especially if the entraining sediment is disturbed.

Mangrove sediment is composed of fine particles with a high organic content and low pH, and are effective at sequestering potentially toxic metals as sulfides (Rand 1995, Harbison 1986, Riedel and Sanders 1988, Lacerda and Rezende 1987, Klerks and Bartholomew 1991). Thus, adverse effects from metal exposures on mangrove trees tend to be minor or nonexistent (Harbison 1986, Defew *et al.* 2005), but at sufficiently high concentrations can result in reduced leaf numbers and stem diameter (Yim and Tam 1999). While metal effects on mangrove trees are generally low, metals can be reintroduced to nearshore waters when they are taken up and concentrated in exported leaf detritus. Metal concentrations can be higher in leaves than in the underlying water or sediment (Peterson *et al.* 1979, Snedaker and Brown 1981, Lacerda *et al.* 1986), although this is not a universal pattern. Tam *et al.* (1995) did not detect lead, chromium, or cadmium in leaf samples from the mangroves in China, but found them in high concentrations in the sediment. Additionally, storms and human activities such as dredging or clearing of mangrove forests can remobilize metals and facilitate transport into coastal waters. Leaf litter is an important food source for many invertebrates (Heald and Odum 1970, Boto and Bunt 1981), and could serve as a pathway through which metals could be transported from mangrove forests to surrounding marine ecosystems. Mercury, a bioaccumulative metal, has been detected in mangrove leaf litter, as well as in a variety of invertebrates and fish trophically linked to the leaf debris (Reimold 1975). Metals have been shown to increase in concentration in mangrove leaf detritus as it ages (Rice and Windom 1982), possibly because of the loss of organic material. Zinc, cadmium, lead, manganese, and copper have all been detected in high concentrations in mangrove leaf debris (DeLaune *et al.* 1981, Nye 1990, Mackey and Hodgkinson 1995, Defew *et al.* 2005).

Many seagrasses directly incorporate metals from the water column into leaf tissue (Brinkhuis *et al.* 1980, Nienhuis 1986), making them a major transport pathway for copper, iron, manganese, and zinc (Drifmeyer *et al.* 1980) to easily pass into the food chain (Ward 1987), and bioaccumulate through higher trophic levels. Several seagrass species are capable of bioaccumulating a range of metals (Pulich 1980, Nienhuis 1986, Wolfe *et al.* 1976, Wahlbeh 1984), including nickel, copper, lead, and zinc (Nienhuis 1986). Seagrass ecosystems have been shown to rapidly uptake TBT, increasing the potential exposure to associated fauna (Levine *et al.* 1990), and potentially leading to decreased invertebrate abundance (Kelly *et al.* 1990). A range of drilling muds have been shown to adversely affect seagrass ecosystems, reducing invertebrate abundance and species richness (Morton *et al.* 1986, Kelly *et al.* 1987), and reducing photosynthetic rates and growth in both seagrasses and their epiphytes (Morton *et al.* 1986, Kelly *et al.* 1987).

Elevated concentrations of metals have been found in the tissues of reef invertebrates. Corals near populated areas have been found to have significantly higher concentrations of metals than those near less populated areas (Howard and Brown 1987, Harland and Brown 1989, Howard and Brown 1984, Howard and Brown 1986, Reichelt and Jones 1994**,** Reichelt-Brushett 2012, Tanaka *et al.* 2013). Metals can enter coral tissues or skeleton via numerous pathways, and evidence exists whereby corals might be able to regulate the concentrations of metals in their tissues (Leatherland and Burton 1974, Riley and Segar 1970, Klumpp and Peterson 1979, Bryan and Gibbs, Brown and Howard 1985, Harland *et al.* 1990). Coral tissue tends to retract in response to environmental stress, exposing skeletal spines, which can directly take up metals from the surrounding seawater (Brown *et al.* 1991). Coral mucus, which is produced in copious quantities in response to metal and chemical exposure (Thompson 1980, Thompson and Bright 1980, Thompson *et al.* 1980, Krone and Biggs 1980, Szmant-Froelich *et al.* 1981, Dodge and Szmant-Froelich 1985, Esquivel 1986), can effectively bind heavy metals (Howell 1982, Harland and Nganro 1990) and may be involved in metal regulation (Harland and Nganro 1990).

Coral branchlets exposed to sediment with a high concentration of anti-fouling compounds suffered significant mortality (Smith *et al.* 2003). Elevated levels of tin can affect the growth rates of coral, especially branching corals (Howard and Brown 1987), by lowering linear extension rates and carbonate accretion, and can affect key biological processes such as respiration (Howard *et al.* 1986), fertilization, metamorphosis (Reichelt-Brushett and Michalek-Wagner 2005; Reichelt-Brushett and Harrison 1999; Negri and Heyward 2001) and larval settlement (Goh 1991, Reichelt-Brushett and Harrison 2000). Even at low concentrations, TBT and copper inhibited fertilization and larval metamorphosis (Negri and Heyward 2001). Heyward (1988) detected the complete inhibition of fertilization in the Western Pacific Region corals *Goniastrea aspera*, *Favites chinensis* and *Platygyra ryukyuensis* gametes when exposed to copper sulphate solutions, and fertilization in the Hawaiian species *Montipora capitata* was adversely affected at low copper concentrations (Hedouin and Gates 2013). Copper has also been shown to impair larval motility (Reichelt-Brushett and Harrison 2004). At the coral assemblage level, metal pollution has been linked to decreased coral species abundance, diversity (Ramos *et al.* 2004), and cover, and more broadly can lead to a shift in the assemblage from one dominated by primary producers to one dominated by filter- and detritus-feeders (Scott 1990).

Zooxanthellae have been shown to accumulate higher concentrations of metals than do host tissues in corals (Buddemeier *et al.* 1981, Harland and Nganro 1990) and clams (Benson and Summons 1981). It has been suggested that sequestering metals in zooxanthellae might diminish possible toxic effects to the host (Harland and Nganro 1990), and that expulsion of algae, which has been reported as a stress response to heavy metals (Harland and Brown 1989, Esquivel 1986, Howard *et al.* 1986), may be a mechanism for metal excretion (Harland *et al.* 1990, Harland and Nganro 1990). Two common Pacific corals, *Porites lutea* and *Pocillopora damicornis*, expelled their symbiotic algae when exposed to elevated metal concentrations (Esquivel 1986; Harland and Brown 1989), a response that was more noticeable in corals obtained from pristine areas. This suggests that corals may be able to develop a tolerance to metal contamination (Harland and Brown 1989).

Like corals, giant clams collected from a populated atoll had significantly higher concentrations of iron, manganese, copper, zinc, and lead than clams from an unpopulated atoll (Khristoforova and Bogdanova 1981). Their symbiotic algae can also influence the uptake of metals by substituting potentially toxic metals for essential elements such as manganese (Hannan and Patouillet 1972, Pilson 1974, Harland and Nganro 1990). This may serve to concentrate metals in zooxanthellae, which can then be expelled to remove the toxic materials.

Metals, including zinc, copper, cadmium, chromium, lead, and mercury, have been detected in the tissue of 50 Indo-Pacific reef fish species from Australia (Denton and Burdon-Jones 1986a), in reef fish from the Gulf of Aqaba (Ismail and Abu-Hi1al 2008), and in a wide range of invertebrates and fish from Apra Harbor, Guam (Denton *et al.* 2006a), with mercury showing evidence of bioaccumulation. Changes in behavior, including erratic swimming, increased gill ventilation, and disrupted schooling ability have been noted in tropical fish exposed to heavy metals (Denton and Burdon-Jones 1986b), as has increased mucus production, fin erosion, and changes in color. While exposure to drilling muds in the Western Pacific Region is expected to be low compared to areas where active oil exploration and extraction are occurring, use of drilling muds in the region is increasing with the increased use of directional drilling technology. The effects of short-term, localized exposure to drilling muds are expected to be low, but considerable uncertainty about the environmental effects of many drilling muds exists due to lack of information on their specific composition. Short-term exposure to drilling muds can decrease coral calcification and growth rates (Hudson and Robin 1980, Kendall *et al.* 1983, Dodge and Szmant-Froelich 1985), including lowering calical relief which could impair sediment-shedding capabilities (Dodge and Szmant-Froelich 1985). Corals were not able to remove drilling muds from their surface under laboratory conditions (Thompson and Bright 1980), but may be successful with assistance from currents (Dodge and Szmant-Froelich 1985). Exposure can reduce photosynthesis, cause bleaching (Kendall *et al.* 1983), increase the likelihood of disease (Parker *et al.* 1984), and result in mortality for some species (Thompson *et al.* 1980). Long-term monitoring of reefs near drilling sites (within ~100 m) have documented large reductions in foliose, branching, and plating corals, although massive corals appeared relatively unaffected (Hudson *et al.* 1982).

Most studies examining the effects of deep ocean mining have focused on adverse faunal effects without attempting to link observed changes to a specific stressor (Ozturgut *et al.* 1980, Foell *et al.* 1990, Schriever *et al.* 1997, Tkachenko *et al.* 1996, Radziejewska 1997, Sharma *et al.* 2001). Deep ocean mining will result in increased sedimentation, physical damage, nutrient enrichment, and the release of trace metals, including nickel, cobalt, copper, manganese, and iron, into both the pelagic and deep ocean environment (Sharma 2015). While the effect of many of these metals on pelagic and deep ocean organisms is currently unclear, iron has the potential to increase primary productivity in surface waters, and in combination with high-nutrient deep ocean water could increase productivity in areas where mining effluent is discharged. Increased productivity could result in more export of POM from surface waters into the deep ocean, increasing the risk of hypoxia, and potentially alter nutrient cycling (see Section 4.1.7), depending on the size of the mining operation.

Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) are a class of persistent, synthetic chlorinated hydrocarbons manufactured and used in the U.S. beginning in 1929 with production peaking in the 1960s (Parnell *et al.* 2008). Although the U.S. banned their production in 1977 (Breivik *et al.* 2007), PCBs persist as legacy pollutants whose chronic toxicity represents a serious environmental risk (Pivnenko *et al.* 2016). The main bulk of PCBs produced were used in closed applications, especially electrical transformers, where they served as coolants and insulating fluids, and in old fluorescent light ballasts. Open application included uses in carbonless copy paper, plasticizers, flexible coatings for electrical cables, pesticides, flame retardants, caulking, adhesives, etc. Thus, many legacy landfills can have high levels of PCB contamination, both from civilian and military waste (Pivnenko *et al.* 2016). Two particularly relevant avenues for PCBs to enter the marine environment are via marine debris, especially through macro- and micro-plastics (UNEP 2016), and atmospheric deposition, although they can also enter through wastewater treatment facilities (Wang *et al.* 2007, Yao *et al.* 2014). PCBs have been identified from several areas in Mariana Islands (EPA 2000, Denton *et al.* 2006b, Haddock *et al.* 2011), including in marine sediment and organisms from several Guam harbors (Denton *et al.* 2006b), as well as American Samoa (EPA 2015), Hawaiʻi (HDOH 2011), and the PRIA (Kerr *et al.* 1997, APSNet 2005, Hathaway *et al.* 2011).

Given their extreme physical and chemical inertness (*e.g.*, thermal stability, low water solubility, etc.) and tendency to adhere to sediment particles, PCBs often accumulate and persist in the marine environment, especially in the sediment of many industrialized bays and watersheds. Offshore sewage discharge and disposal or suspension and transport by ocean currents of sediment dredged from harbors are also potential avenues for contamination of coastal areas with PCBs. PCBs have entered marine food chains through benthic feeding organisms and the ingestion of plastics by higher trophic-level organisms (Ryan *et al.* 1988; Bjorndal *et al.* 1994). Additionally, plankton near the surface can take up PCBs, allowing them to enter pelagic food chains and bioaccumulate in shellfish, and tuna (Soedergren *et al.* 1990).

While considerable research has focused on the human health effects associated with PCB ingestion (especially PCBs bioaccumulated in fish), little research has examined the effect of PCBs on marine organisms. Adverse effects from PCB exposure in adult fish and macroinvertebrates appear to be minor, although some evidence exists suggesting adverse effects may occur to the livers of fish (Rochman *et al.* 2013). Overall, considerably more research is needed. Evidence exists that phyto- and zooplankton are adversely affected through reduced photosynthesis and growth rates, and cell damage (Keil *et al.* 1971, Harding *et al.* 1978, Harding and Phillips 1978). Zooplankton were particularly sensitive to PCB exposure, entirely disappearing in some studies (Iseki *et al.* 1981), but overall, the effects of PCB exposure were variable among species. Widespread PCB contamination could lead to the alteration of the species composition of the plankton assemblage (Iseki *et al.* 1981, Zhao *et al.* 2013). Early larval stages of cod were also found to be sensitive (Foekema *et al.* 2008). Exposure of eggs to low concentrations of PCBs caused developmental abnormalities in subsequent life stages, leading Foekema *et al.* (2008) to postulate that accumulation of PCBs in adult females could have reproductive consequences that are difficult to detect, but may have long-term effects on the population. Fortunately, many PCBs can be metabolized, and rendered inert, although this can often be a slow process, especially for PCBs that are stored in fatty tissue.

Ordnance

Disposal of military munitions in the oceans has been practiced since World War II (Darrach *et al.* 1998, Denton *et al.* 2014), especially in and near historic battle fields in the Western Pacific Region (Minton *et al.* 2006). Additionally, multiple locations within the Western Pacific Region, including numerous small islands, have been employed as military training ranges (*e.g.*, Kahoʻolawe, Kaʻula Rock, Farallon de Medinilla) resulting in considerable unexploded ordnance (UXO) on the islands and in nearshore marine ecosystems.

The biological effects of UXO on marine organisms and ecosystems, including contamination levels and biological accumulation rates, are not well studied and therefore, poorly understood (Clausen *et al.* 2004, Rosen and Lotufo 2007, Lotufo *et al.* 2009). Two potential threats exist with UXO: detonation and leakage of toxic materials. Detonation risk for UXO in the marine environment appears relatively low. Concussive damage from an exploding ordnance could cause extensive physical damage (see Fox and Caldwell [2006] for a discussion of damage associated with dynamite fishing), but it would be spatially limited, and therefore do not pose a large threat to marine ecosystems.

Munitions are comprised of many potentially toxic compounds that over time will leak into the marine environment. However, their bioaccumulative potential is low because they are weakly hydrophobic (Lotufo and Lydy 2005, Lotufo *et al.* 2009). This has been demonstrated for some of the known UXO compounds in a variety of model test animals, including minnows, carp, goldfish, and marine worms (Lotufo and Lydy 2005, Lang *et al.* 1997, Wang *et al.* 1999, Condor *et al.* 2004). Dietary uptake has also been shown to be minimal relative to aqueous uptake through the gills in fish (Belden *et al.* 2005, Huston and Lotufo 2005), suggesting these compounds will have minor effects through food webs. However, even with low uptake, the transfer and bioaccumulation of many of these compounds in marine organisms have been not been adequately investigated. While no significant effects were found on a mussel or flounder species, low concentrations of chemicals from munitions have been linked to increased mortality in marine copepods, an important component of the zooplankton (Ek *et al.* 2006). Likewise, marine polychaetes and amphipods showed decreased growth, survival, and reproduction (Lotufo *et al.* 2001), and mortality in bivalve larvae (Pascoe *et al.* 2010) at low levels of exposure. Marine algae are also efficient at uptaking toxic compounds leaked from UXO, and can efficiently biotransform the compounds, rendering them inert, although exposure can reduce photosynthesis (Cruz-Uribe and Rorrer 2006).

Even in areas with high concentrations of UXO, most organisms are likely to receive only limited exposure to low chemical concentrations because the munition casings are slow to corrode and break, generally resulting in a slow release of the constituent compounds. Many of the compounds are also efficiently biotransformed and eliminated from organisms once the organisms are removed from the exposure, suggesting mobile organisms are unlikely to bioaccumulate toxic UXO compounds. The potential risk for deleterious biological effects is thus spatially-limited and minor compared to many other potential stressors.

Endocrine Disruptors

In addition to the pollutants described above, many other chemical compounds enter the marine environment because of human activity. While the effects of most chemicals on marine ecosystems are poorly known, endocrine disruptors are a group that has received considerable attention due to their potentially harmful effects. Endocrine disruptors are a diverse group of compounds that adversely affect organisms through deleterious interactions with the endocrine system (Colborn *et al.* 1993). A wide range of substances are thought to cause endocrine disruption, including pharmaceuticals, dioxin and dioxin-like compounds, PCBs, various organochlorine pesticides, plasticizers, and surfactants. These compounds can be found in many common products, including plastic bottles, metal food cans, detergents, flame retardants, food, toys, cosmetics, and pesticides (Porte *et al.* 2006). Many known endocrine disruptors are estrogenic (also known as estrogen mimics), and disrupt reproductive functions. Because of their persistent nature in organisms, many endocrine disruptors bioaccumulate and biomagnify in marine organisms (Colborn 1998, Arukwe *et al.* 1996, Matthiessen 2003, Langston *et al.* 2005, Lye 2000), including in corals (Tarrant *et al.* 2001, Stocker 2016). Similar to exposure to some metals (*e.g.*, TBT in gastropods), endocrine disruptors have been shown to affect hormone systems (Scott and Sloman 2004, Tierney *et al.* 2010).

The effects of endocrine disruptors have largely been studied in marine vertebrates. Fish are particularly vulnerable to exposure because uptake occurs through multiple routes including directly from the water via the gills, skin and gut, through the diet, and through contact with contaminated sediment (Weber and Goerke 2003, Kwong *et al.* 2008). Some endocrine disruptors have been shown to bioaccumulate and bioconcentrate in fish (Ferreira-Leach and Hill 2001, Barber *et al.* 2006, Smith and Hill 2004, Sharma *et al.* 2009).

Endocrine disruptors most commonly affect fish growth, development, reproduction (Hutchinson *et al.* 2006), and behavior (Jones and Reynolds 1997, Scott and Sloman 2004, Sloman and Wilson 2006), potentially affecting the fitness of individuals and adversely affecting the larger populations. Endocrine disruptors disrupt sex steroid activity, thereby affecting sexual development and reproduction. Sex steroid hormones play vital roles in almost all aspects of reproduction, including sexual differentiation, gonadal growth, and reproductive behaviors (Jobling *et al.* 1996, Kiparissis *et al.* 2003 van der Ven *et al.* 2003, Jensen *et al.* 2004, van den Belt *et al.* 2002, Weber *et al.* 2003, Örn *et al.* 2006). Their disruption can lead to high incidence of intersex, abnormal spawning behavior, skewed population sex ratios, and lessened reproductive success (Nimrod and Benson 1998, Parrott and Blunt 2005, Seki *et al.* 2005, Kang *et al.* 2006, Larsen *et al.* 2008, Örn *et al.* 2003, Hahlbeck *et al.* 2004, Örn *et al.* 2006, Iwanowicz and Blazer 2014).

Compared to vertebrates, relatively little is known about the effect of endocrine disruptors on marine invertebrates, mostly due to a poor understanding of invertebrate endocrine systems (Porte *et al.* 2006). In some mollusks and sponges, endocrine disruptors have been shown to interfere with key enzymatic pathways, leading to cellular damage (Wiens *et al.* 1999, Viarengo *et al.* 2000) and reproductive abnormalities (Sarojini *et al.* 1986, Wasson *et al.* 2000), including high incidence of imposex and blocked embryonic development. Diverse effects of estrogen mimics on invertebrates have been reported, including stimulated ovarian and/or oocyte development (Shoenmakers *et al.* 1981, Sarojini *et al.* 1986, Wasson *et al.* 2000), blocked embryonic development (Hathaway and Black 1969), altered enzymatic activities (Ghosh and Ray 1993a, 1993b), accumulation of proteins (Ghosh and Ray 1992, Wiens *et al.* 1999, Billinghurst *et al.* 2000), and cellular damage or cell death (Wiens *et al.* 1999, Viarengo *et al.* 2000). On the other hand, some studies have failed to detect effects of estrogen mimics on invertebrates (Hutchinson *et al.* 1999, Breitholtz and Bengtsson 2001, Pascoe *et al.* 2002). In one of the few studies on corals, two common Hawaiian coral species showed adverse effects from exposure to endocrine disruptors; *Montipora capitata* coral colonies showed reduced fecundity and *Porites compressa* displayed decreased skeletal growth rates (Tarrant *et al.* 2004).

4.5 Sea level Rise

Sea level rise is a unique marine stressor with important implications for the jurisdictions in the Western Pacific Region. Sea level rise alone might appear to be relatively unimportant to many marine ecosystems, but it has the potential to affect nearly all marine ecosystems through indirect effects and interactions with other stressors discussed in this report. Under current climate change predictions, sea level rise is expected to exacerbate many of the stressors described in this report.

Indirectly, sea level rise will displace large numbers of people and decrease food availability and security. Coastal inundation will destroy homes and other infrastructure, forcing many people to undertake coastal modifications or to relocate to higher ground or higher islands (for those living on atolls). These changing patterns in human density will alter patterns of marine resource use. Inundation and groundwater intrusions with salt water will degrade drinking water supplies and render low-lying agricultural lands unproductive (Rahman *et al.* 2009, Nicholls 2010, Chen *et al.* 2012), potentially increasing reliance and harvest pressure on fisheries (IPCC 2014).

Shallow water marine ecosystems will be directly affected through inundation with ocean water, altering salinities, depth, temperature, sedimentation, and nutrients. Sea level rise is expected to not only increase coastal erosion rates, but also nutrient loading (IPCC 2014), especially in areas where septic and cesspool systems are in use. In addition, municipal sewer systems that have aging infrastructure will become vulnerable to leaking.

Mangrove and seagrass ecosystems are expected to experience "coastal squeeze" (IPCC 2014) especially along urbanized coastlines. With little opportunity to migrate inland, mangrove trees will be inundated by rising seas and experience high mortality. Increased wave energy will result in less suitable habitat for seedling germination or sediment accretion, which is necessary to produce and/or maintain the substratum at the appropriate depth. Seagrass ecosystems are

Summary Stressor Table: Potential effects of chemical pollutants
Color reflects the relative severity of an adverse effect: green=mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Adverse effects vary by contaminant and by organism • Intertidal areas particularly sensitive to hydrocarbons • Potential to significantly alter species composition, abundance, and biomass of the assemblage
Mangrove Forests	• Adverse effects vary by contaminant and by organism • Mangrove trees particularly sensitivity to hydrocarbons and herbicides, and less sensitivity to heavy metal • Potential to significantly alter species composition, abundance, and biomass of the assemblage
Seagrass Beds	• Adverse effects vary by contaminant and by organism • Potential to significantly alter species composition, abundance, and biomass of the assemblage • Light oiling from hydrocarbons has potential "beneficial" effects on seagrass growth
Coral Reefs	• Adverse effects vary by contaminant and by organism • Potential to significantly alter species composition, abundance, and biomass of the assemblage
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	• Effects poorly studied in deep ocean floor ecosystems, but likely vary by contaminant and by organism • Increase atmospheric deposition associated with climate change and deep ocean mining are likely to be the primary source of future pollutants in the Western Pacific Region
Pelagic Environment	• Effects poorly studied in pelagic ecosystem, but likely vary by contaminant and by organism

expected to experience higher salinity and lower irradiance levels due to increase in turbidity because of coastal erosion (Scavia *et al.* 2002). For both mangroves and coastal seagrass beds, the rate of sea level rise, coupled with erosion, could outpace the ability of primary producers to maintain optimal depth for survival.

The direct effects of sea level rise on deeper marine ecosystems are expected to be smaller, although concern has been expressed about the ability of some coral and other slow growing organisms to maintain an optimal depth for photosynthesis. This concern is heightened when considering the effects of ocean acidification and temperature on calcification rates for many marine organisms, although most coral reefs seem to have kept pace with the recent sea level rise (Buddemeier and Smith 1988, Brown *et al.* 2011). Sea level rise is expected to exacerbate sedimentation rates, nutrient enrichment and pollution on coastal coral reefs.

Summary Stressor Table: Potential effects of sea level rise
Color reflects the relative severity of an adverse effect: green=mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Inundation and entire loss on low islands • Increased coastal fortification in inhabited areas leading to changes in shoreline process • Increase erosion, nutrient enrichment, influx of pollutants, etc., especially in urbanized areas
Mangrove Forests	• Inundation and entire loss on low islands and along urban/developed coastline on high island, where it is not possible for the mangrove to “retreat” • Increased salinity altering mangrove species composition, with cascading effects through the ecosystem • Increase erosion, nutrient enrichment, influx of pollutants, etc., especially in urbanized areas
Seagrass Beds	• Increased salinity and within bed erosion via increase water flow • Lower irradiance because of increased turbidity, leading to lower photosynthetic rates and growth in seagrasses • Altered water quality from coastal inundation • Potential for a phase-shift toward an algal-dominated assemblage
Coral Reefs	• Altered water flow could affect the distribution of species • Altered water quality from coastal inundation • Potential for a phase-shift to an algal-dominated assemblage

Ecosystem	Potential Effects
Deep Reef Slopes	• Affects likely to be small • Altered water quality from coastal inundation • Potential for change in distribution of species and shift in lower depth limit
Banks and Seamounts	See *Coral Reefs* (shallow) and *Deep Reef Slopes* (deep)
Deep Ocean Floor	• Likely little or no effect
Pelagic Environment	• Likely little or no effect

5.0 Cumulative Effects

Under the MSA implementing regulations, each FMP must contain an evaluation of the potential adverse effects, both individually and cumulatively, of non-fishing activities on the function of EFH at an ecosystem or watershed scale. Cumulative effects are impacts on the environment that result from the incremental effect of an action when added to other past, present, and reasonably foreseeable future actions, regardless of who undertakes such actions (Council on Environmental Quality 1997). Cumulative effects can result from individually minor, but collectively significant actions taking place over a period of time, or from the cumulative and interactive effects of multiple actions (Figure 4).

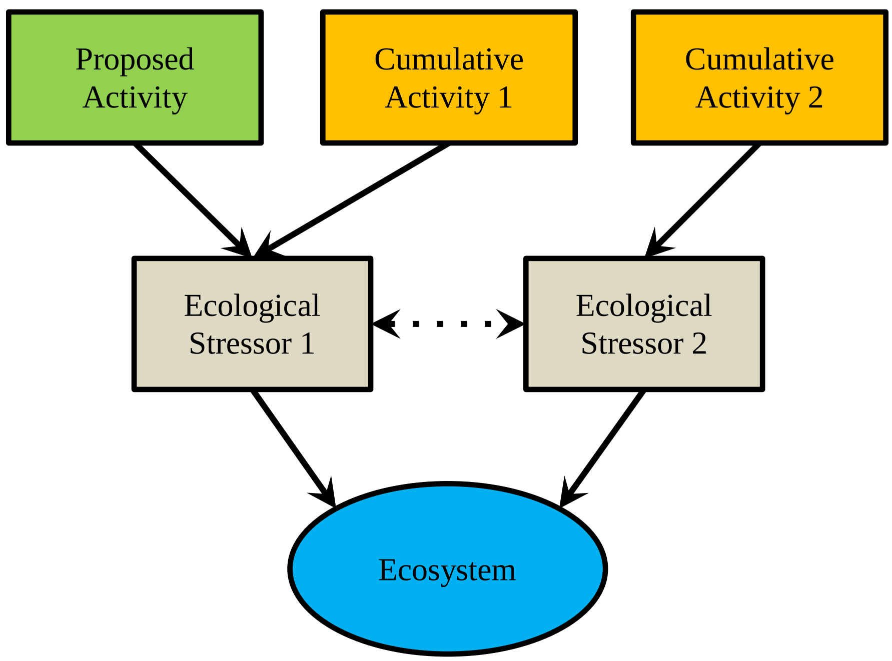

Figure 4. When assessing cumulative effects, the incremental effects of other past, present, and reasonably foreseeable future actions must be considered. In the flow diagram above, two types of cumulative effects are illustrated. In the first type, the Proposed Activity and Cumulative Activity 1 both act on Ecological Stressor 1, producing an additive effect on the ecosystem. While neither activity alone may have resulted in an adverse effect on the ecosystem, the two activities occurring together could. In the second type, Cumulative Activity 2 affects Ecological Stressor 2, which is known to interact with Ecological Stressor 1 (dotted arrow). This interaction, if synergistic in nature, would increase the total effect on the ecosystem beyond the additive effect of the two stressors, and thus heighten the adverse effects of the Proposed Activity beyond what would be expected if the Proposed Activity were implemented alone. However, if the interaction is antagonistic, it would produce a total effect on the ecosystem less than additive effect of the two stressors.

Evidence is increasing that the greatest environmental effects may result not from the direct effects of a particular activity, but from the combination of individually "minor" effects of multiple actions[2] concentrated in space ("space crowded") and/or time ("time crowded"). Assessing the cumulative environmental effects of an activity requires identifying from the complex networks of possible interactions those that substantially affect species and/or ecosystems, and then describing the response of the species and/or ecosystem to this environmental change. Predicting the effects of a stressor on an ecosystem is particularly difficult when many stressors of different types act in concert (NRC 1986).

Conceptually, cumulative effects involving multiple stresses can encompass three broad categories of interaction types (Crain *et al.* 2008). For the most common case involving two stressors, the resulting cumulative effect (CE_F) can be additive ($CE_F = E_A + E_B$), antagonistic ($CE_F < E_A + E_B$), or synergistic ($CE_F > E_A + E_B$). If two stressors show no interaction, their cumulative effects would be additive; that is, the effect of each stressor would act on the ecosystem in the same manner, as if the other stressor were not present. However, if two stressors interact, two scenarios are possible:

1) The stressors when co-occurring may produce a synergistic effect, whereby the presence of one stressor increases the effect of the other. This could result if a stressor acted on an organism to increase its susceptibility to the second stressor, thus producing a cumulative effect that is larger than what would be expected with no interaction.

2) The stressors when co-occurring produce an antagonistic effect, whereby the presence of one stressor reduces the effect of the other. For example, if a stressor acted on an organism to reduce susceptibility to the second stressor, thus producing a cumulative effect that is smaller than what would be expected with no interaction. An antagonistic interaction could be considered "beneficial" if the net effect of the two stressors together was smaller than the effect of the single stressor ($E_A + E_B < E_A$).

Given the complex interconnections among marine ecosystems, cumulative effects associated with human activities are expected to occur and to be potentially substantial and far-reaching. Thus, an assessment of cumulative effects must consider actions that may affect the ecosystem, regardless of where the action occurs and for a long enough period both into the past and into the future[3]. For example, actions potentially affecting a coastal coral reef should consider actions occurring in nearby seagrass, intertidal and mangal ecosystems that may also directly or indirectly affect the coral reef ecosystem when assessing the cumulative effects of an activity on the coastal reef. Selecting an appropriate time frame can be more challenging, but at minimum should attempt to include any projects previously conducted that have not recovered to their pre-activity condition and any future projects that would occur before the ecosystem has recovered

[2]This is sometimes referred to as "nibbling" in the literature.

[3]For practical guidance, Hegmann *et al.* (1999) is good source for using "Scoping" to set appropriate spatial and temporal boundaries. The practical guide is available online: https://www.canada.ca/en/environmental-assessment-agency/services/policy-guidance/cumulative-effects-assessment-practitioners-guide.html

from the effects of the proposed activity (Hegmann *et al.* 1999). Failure to do so could result in an incorrect assessment of all the potential effects of an action and could result in an adverse effect on EFH.

Climate change is a reality, and the ocean is rapidly changing. A cumulative effects analysis must consider the changes to the marine environment that are expected to occur under our current climate trajectory. This is especially critical for any activity that will result in long-term effects on any marine ecosystem (*e.g.*, a sewage outfall, coastal road, waterbased energy production facility). Activities that produce long-term effects that are at present not detrimental to EFH, may become detrimental in the coming decades. Considering that many effects in marine ecosystems have long durations due to slow ecosystem recovery (*e.g.*, coral reefs), many activities proposed today, could result in significant and irreversible damage to EFH in coming decades. Without immediate action at the global level, marine ecosystems will continue to decline over the next half century (Hoegh-Guldberg *et al.* 2007, Cheung *et al.* 2009) and maintaining fishery sustainability will require tough decisions be made about human activities today (Cheung *et al.* 2009, Sumaila *et al.* 2011).

Many of the stresses identified in this report have the potential to interact, and often in ways that increase adverse effects on one or more ecosystems (Brown 1997, Negri and Hoogenboom 2011). For example, elevated seawater temperatures can cause coral bleaching, but the temperature threshold at which coral bleaching occurs is lowered under elevated nutrient conditions (Wooldridge 2009, Wolldridge *et al.* 2012), leading to a higher probability of bleaching in the presence of both thermal and nutrient stressors compared to a temperature increase alone. A cumulative effects analysis should account for such potential interactive effects.

Unfortunately, predicting the cumulative effect of multiple stressors is challenging (NRC 1986, Cooper and Shaete 2002, Bérubé 2007). In addition to the stressors themselves interacting, a species may respond similarly or differently to sets of stressors due to evolutionarily- or ecologically-derived tolerances (*e.g.*, coral colonies that have been bleached often show increased tolerance to later potential bleaching events), such that the interaction also depends upon which species are present, and their relevant history. Additionally, the response of an assemblage can differ due to changing functional roles and interactions among species (Crain *et al.* 2008, Breitburg *et al.* 1999), its species composition (and associated issues of redundancy and resilience), its connectivity to other ecosystems, and its environmental stochasticity (Breitburg *et al.* 1999). Temporal patterns of stressor occurrence (simultaneous vs. consecutive, frequency of stressor occurrence, etc.) and the intensity of the stressor (Relyea and Hoverman 2006) also influence the strength of the cumulative effects.

Fortunately, interactions among stressors have received more attention over the past 15 years, and enough information on potential interactions between and among multiple stressors now exist to allow for some understanding of when and where interactions can be expected to occur. Crain *et al.* (2008) reviewed over 200 studies examining cumulative effects for multiple stressors in intertidal and nearshore marine ecosystems to elucidate general patterns in cumulative stressor effects. The cumulative effects of any two stressors were distributed among all interaction types with 26% being additive, *i.e.*, no interaction, 36% synergistic and 38% antagonistic, and with all interaction types found to some degree for all stressors pairs with >5 studies (Figure 5 and Figure 6). In 62% of all cases, interactions between stressors resulted in an adverse effect on the species or ecosystem that was at least additive (Crain *et al.* 2008). In cases where a third stressor was considered, over two-thirds of the interaction became more negative, and the number of synergistic interactions increased to 66% of the cases. Thus, any activity or set of activities that significantly increases the negative effects of three or more stressors should be closely examined for adverse effects on EFH.

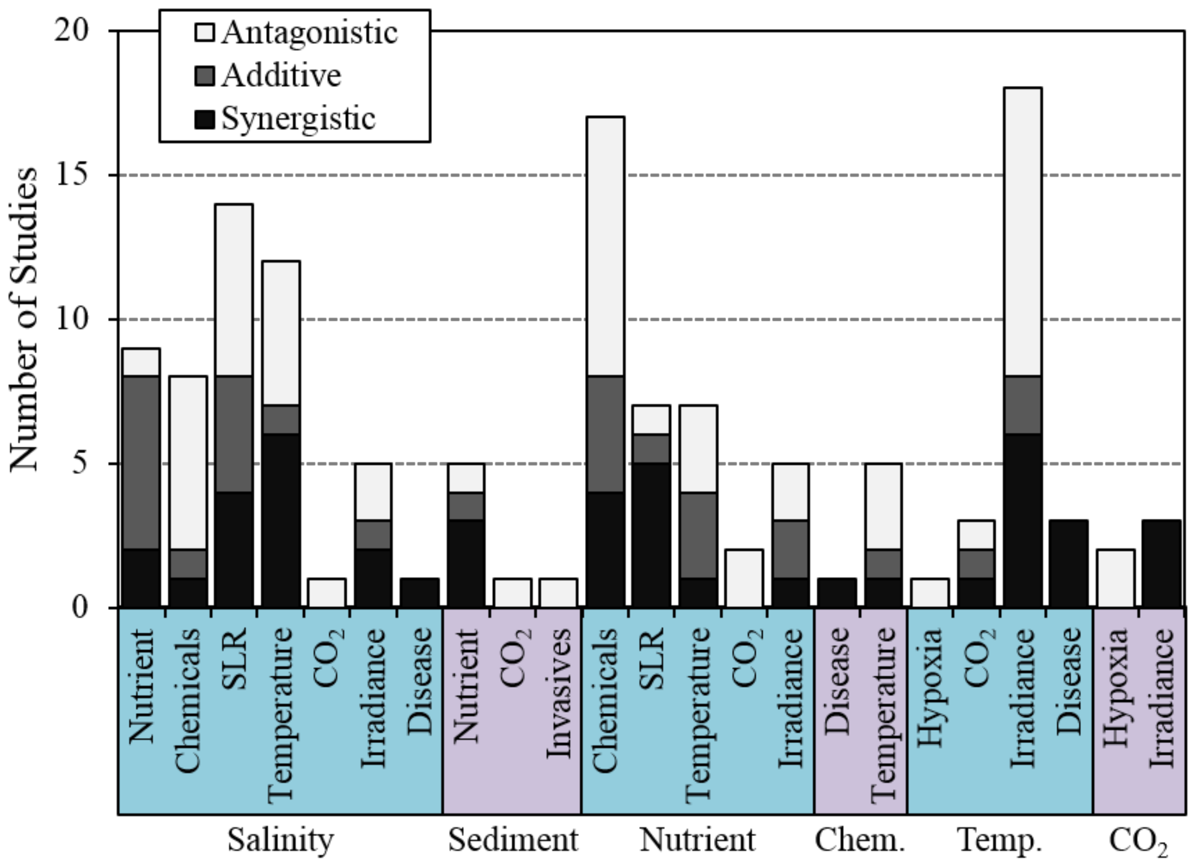

Figure 5. Frequency distribution of interaction types (additive, synergistic, and antagonistic) across stressor pairs. Stressor pairs are indicated within blocks on the x-axis that list one stressor horizontally (*e.g.*, salinity) with all stressor combinations listed vertically (*e.g.*, nutrient). See text for discussion of additive, synergistic, and antagonistic interactions. CO2=acidification, SLR=Sea Level Rise. Figure adapted from Crain *et al.* (2008).

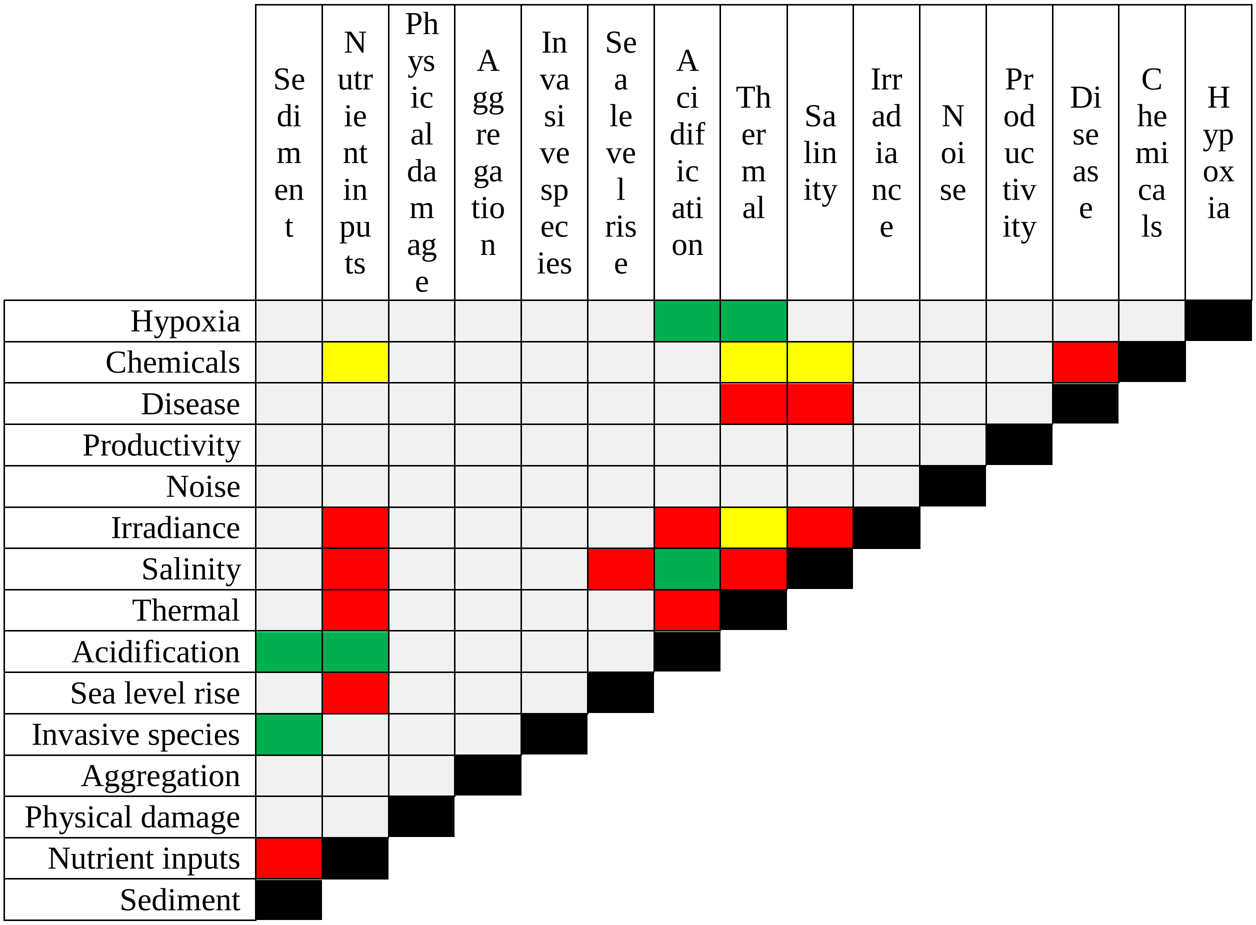

Figure 6. Interaction matrix for pairs of stressors acting on the marine ecosystems of the Western Pacific Region. Red = >50% of the studies show additive or synergistic interactions; yellow = <50% of the studies showed additive or synergistic interactions, green = studies showed only antagonistic interactions; gray = no data available; solid color = determination based on >5 studies; hatched color = determination based on <5 studies. Data from Crain *et al.* (2008).

6.0 Conservation and Enhancement Recommendation

The WPRFMC is tasked with describing ways to avoid, minimize, or compensate for the adverse effects to EFH and for promoting the conservation and enhancement of EFH. Activities that may result in significant adverse effects on EFH should be avoided when less environmentally harmful alternatives are available. If there are no alternatives, the adverse effects of these activities should be minimized to the extent practicable by employing conservation and enhancement recommendations.

For this report, a conservation and enhancement recommendation is a single practice or combination of practices that has been determined to be an effective and practicable means of preventing or reducing the effect of an activity on a stressor, or in reducing the magnitude of a stressor acting on an organism or the ecosystem. A best management practice (BMP) is a type of conservation and enhancement recommendation that includes generalized practices that can be employed across a range of activities with little modification. In contrast, some conservation and enhancement recommendations are specific to a project or location, and are not applicable across a range of activities. Due to the broad applicability of BMPs, they will be the focus of this report.

Non-fishing activities and other sources of stress act on organisms and ecosystems through stressors (see Section 3.0). BMPs can be applied at two different locations in the event chain (Figure 7):

- A BMP can reduce the effect of an activity on a stressor. For example, a road construction project may choose to narrow a road or re-route it around a hill, thus reducing the amount of earth moving that is required. A sewage treatment plant may choose to route grey water to agricultural fields instead of discharging it into the marine environment.

- Alternatively, a BMP can reduce the effect of the stressor on the organism or ecosystem. For example, a road construction project may erect sediment fencing along a stream bank to reduce the amount of sediment washing into the ocean. A sewage treatment plant may install a long diffuser system to promote dilution of nutrients over a wider area of the discharge site.

Ideally, BMPs that act at either position in the event chain can be recommended to avoid and minimize adverse effects to EFH. However, BMPs that act to reduce the effect of an activity on a stressor are preferable to those that reduce the effect of the stressor on an organism or ecosystem because the former addresses the root cause of the potential adverse effect. To be effective, a BMP must:

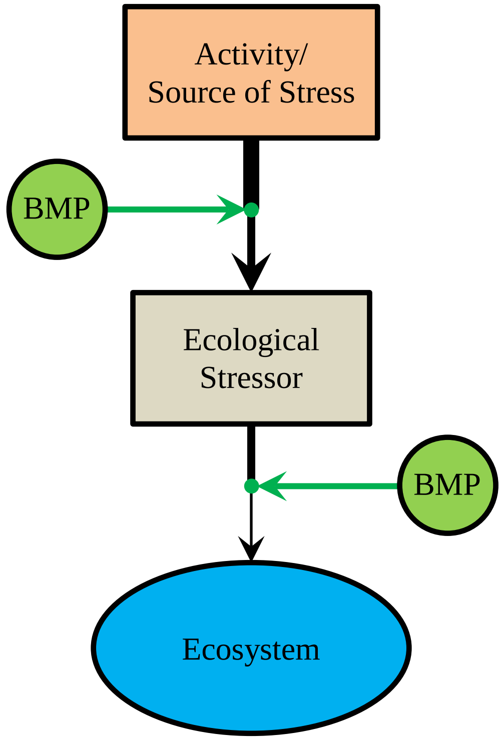

Figure 7. Conservation and enhancement recommendations, of which BMPs are common type, are practices intended to reduce the adverse effects of an activity on an ecosystem. BMPs can reduce the effect of an activity on the particular stressor (top) or reduce the effect of a stressor on an organism or ecosystem (bottom).

1) *Provide meaningful and measureable minimization of potential adverse effects.* BMPs are specifically developed to combat specific problems and often display a range of effectiveness associated with activity-specific factors. BMPs that have been demonstrated to be ineffective in providing meaning minimization of an adverse effects should not be recommended or implemented.

2) *Be properly selected and implemented.* BMPs are specifically developed to combat specific problems under certain conditions, and it is important that the correct BMP is selected for any given activity or stressor. Proper BMP selection and implementation is required or the BMP will be ineffective (Figure 8).

3) *Regularly inspected to insure its integrity.* Regular inspection of a BMP insures it is in proper working condition provides the opportunity to repair or adjust a BMP that has fallen into disrepair or is not working as effectively as it should. How frequently a BMP should be inspected depends on the specific conditions of the project and the BMP, but all BMPs should have a regular inspection schedule that is determined prior to implementation.

4) *Monitored to assess its effectiveness.* Few if any BMPs are 100% effective, but their effectiveness can vary considerably depending on the specifics of the project and the BMP. Monitoring the effectiveness of a BMP enables adaptive management to occur, and ineffective BMPs can either be reinstalled to improve performance or replaced with another BMP that may be better suited to the conditions and/or project.

The following BMPs can reduce the potential adverse effects of non-fishing activities on EFH. These BMPs have been identified from the scientific literature, recommendations made by federal and state/territorial/commonwealth agencies, and regulatory documents such as environmental impact statements. This list is not exhaustive, but represents commonly-employed, proven approaches as well as some common-sense recommendations to reduce adverse environmental effects. To facilitate selection, the BMPs have been organized into two tables: BMPs by activity category and BMPs by stressor. When recommending BMPs, BMPs from both tables should be considered, as appropriate.

The BMPs recommended by activity category generally contain recommendations on the design, placement and execution of activities with the intention of avoiding and minimizing potential adverse effects on EFH at the development stage of an activity.

The BMPs recommended by stressor type contain recommendations intended to reduce the effect of a specific stressor on EFH, either through reduction of the activities' effect on the stressor or

Figure 8. An inappropriately-selected BMP or one that is improperly-implemented is ineffective at reducing the adverse effect of a non-fishing activity on EFH: a) an inappropriately-selected oil control boom for the ocean conditions; b) an improperly-installed silt fence.

by reducing the effect of the stressor on the ecosystem. These BMPs are not necessarily specific recommendations for a single category of non-fishing activity, but could be broadly applied across a range of activities. These BMPs tend to address temporary issues (*e.g.*, construction-related runoff).

Summary BMP Table: BMPs by activity category

Activity Category	BMPs
General Considerations	• Areas of high diversity, abundance, and productivity or which serve as habitat for sensitive or important fishery species should be avoided to the maximum extent possible. • Environmental surveying/sampling/monitoring should be developed with input from federal and state/territorial/commonwealth resource agencies. • Biological surveys to determine species composition, abundance/biomass and productivity of an assemblage should be conducted using scientifically-rigorous survey designs and methods, and be completed prior to approval of any activity. • All activities should reference latitude–longitude coordinates of the site so that information can be incorporated into Geographic Information Systems (GIS). • All plans should have an adaptive management component, and a schedule for review and update.
Energy Production	• See BMPS for *Development/Construction (Land-based)* and *Development/Construction (Water-based)*
Mining	• Quarries should be placed outside the coastal zone where practicable and not adjacent to rivers. • Measures to reduce/avoid runoff should be implemented, including; minimizing hard surfaces, minimize runoff through installing/preserving existing natural (and native) vegetation and/or building of a retention pond, and attempting to restore disturbed lands to as close to natural conditions, as possible, after no longer being mined. (HDOT 2008) • Mining (coral and sand) should be avoided in coral reefs and other shallow water ecosystems (*i.e.*, those within the euphotic

Activity Category	BMPs
	zone). ● Deep ocean mining in areas of high biological diversity, abundance, and productivity (including the overlying surface waters) should be avoided. This is especially true if mining waste will be discharged into these waters due to the potential to expand the area of effect. ● For deep ocean mining, interaction of the collected with the seafloor should be kept to a minimum. Separation of the minerals from the sediment (and other debris) should occur as close as possible to the bottom to reduce water column discharge. (Sharma 2015) ● Deep ocean mining should be conducted in a "strip-wise" fashion, leaving alternate strips of undisturbed seafloor to promote recovery. (Sharma 2015) ● Surface discharge from deep ocean mining should be kept to a minimum and be dispersed across a wide area to dilute. Sufficient light should be allowed to penetrate the watercolumn for photosynthetic activity. Discharge of sediment at different levels in the water column should be encouraged. (Sharma 2015)
Land-based Aquaculture	● Facilities should be in upland areas and not in the coastal zone where practicable. (Howerton 2001) ● Tidally-influenced wetlands[4] should not be converted for aquaculture use. Wetland conversion reduces the functional value of the ecosystem, and potentially lacks a mechanism to control nutrient/waste exchange between the ponds and the coastal marine waters. (Howerton 2001) ● The siting of any aquaculture facility (regardless of type) should consider the size of the operation, the presence or

[4]In Hawai‘i, fishponds have been constructed in many estuarine and coastal areas, and are important native Hawaiian cultural and historical features. Where appropriate, existing fishponds should be restored, maintained, and managed for both their cultural and ecological value. This BMP is intended for non-historical/cultural activities or for activities that would represent a "new" structure/fishpond. In general, tidal wetlands should not be converted into ponds for aquaculture production when other viable alternatives exist.

Activity Category	BMPs
	absence of submerged vegetation and coral reef ecosystems, proximity of wild fish stocks, migratory patterns, competing uses, and hydrographic conditions. ● Operational plans should contain measures to prevent nutrient and waste disposal from reaching the marine environment without appropriate treatment. Where possible, water systems should recycle back into the pond or be used as grey water. (Ozbay *et al.* 2014, FDACS 2016) ● A plan to optimize feeding protocols to minimize nutrient accumulation at the site should be in place before operations start. Water quality thresholds should be established prior to the start of operations. (Ozbay *et al.* 2014) ● Chemical anti-foulants should not be used, instead, mechanical cleaning methods and air drying should be employed when practicable. (FDACS 2016) ● To the extent practicable, water intakes should be designed to avoid entrainment of flora and fauna. ● Non-native species that *could* adversely affect the ecological balance of an area (*i.e.*, have a reasonable probability of becoming invasive), should not be imported for aquaculture. A thorough scientific review and risk assessment should be undertaken by invasive species experts prior to any non-native species introduction. (FDACS 2016)
Development/Construction (Water-based)	● Dredging projects should be allowed only when water-dependent and when no other feasible and practicable alternative is available. ● Dredging activities should be sited in deep-water areas or designed in such a way as to minimize the amount of dredging and reduce the need for maintenance dredging. ● To the extent practicable, fill materials from dredging operations should be placed in an upland site. Unless unavoidable, fill should not be allowed in areas with mangal, subaquatic vegetation, coral reefs, or other areas of high productivity. (Johnson 2011) ● For clamshell dredges, a closed (environmental) bucket should be considered for use to reduce suspended sediment. Likewise, slower cycle times, single “bites” with the bucket, and no

Activity Category	BMPs
	bottom stockpiling should be implemented when practical. (Johnson 2011) ● If a hydraulic dredge (*e.g.*, cutterhead, suction, etc.) is to be used, selecting the appropriate type will minimize sediment loss. (Johnson 2011) ● The disposal of contaminated dredge material should not be allowed in EFH. ● Ocean disposal should be restricted to an approved, deep ocean disposal site. Currently, Hawai'i and Guam have EPA approved ocean disposal sites. ((Johnson 2011, EPA 2016a, EPA 2016b) ● If the need for dredging (especially maintenance dredging) has been caused by excessive sedimentation from a land-based source, the source should be identified, and appropriate management actions to remediate the source should be proposed as part of the pre-dredging planning activities. Where legal and practicable, actions to remediate the upland sediment source should be part of the dredging project. ● Where practicable, pipelines (*e.g.*, wastewater, cooling discharge, etc.) should be elevated off the bottom using pedestals. (PBS&J 2008) ● Where possible, use horizontal directional drilling technology to install pipes, conduits, etc. instead of trenching or surface installation. (PBS&J 2008)
Development/Construction (Land-based/Coastal roads)	● Coastal hardening should only occur after all other alternatives have been determined not to be feasible or practicable. Alternative should include re-alignment of any road/activity to a different, upland location. ● Where practicable, bioengineering approaches should be used to protect altered shorelines. The alteration of natural, stable shorelines should be avoided as much as is practicable. ● For roads, parking lots, and other applicable structures, considering using oil/water or oil/grit separators, swales, constructed wetlands, etc., as part of the stormwater management to remove pollutants such as oils, grease, sand,

Activity Category	**BMPs**
	and grit from runoff. (HDOT 2007) • Avoid upland and coastal earth-moving during the local rainy season. (USCRTF 2016) • For coastal directional drilling activities, the volume of drill mud and the drill pressure should be monitored constantly to detect potential leaks ("frac-outs"). For the last 15-20 m of bore, seawater should be used in place of drill mud to prevent drill mud from entering the water. Any free-flowing slurry at the upland site during pull back and drilling should be properly contained and disposed of so that it does not enter marine waters. (PBS&J 2008, CALTRANS 2015)
Shipping/Boating	• The siting of any anchorage should consider the size and number of the vessels, the presence or absence of submerged aquatic vegetation and coral reef ecosystems, proximity of wild fish stocks, migratory patterns, competing uses, and hydrographic conditions. • Where possible and practicable, permanent mooring facilities that reduce the activity's contact footprint with the bottom should be used. Contact footprint includes any anchors, chains, and/or lines that have the potential to adversely affect EFH. Potential adverse indirect effects associated with mooring buoys need to be considered. (Taratalos and Austin 2001, PADI 2005, USCRTF 2016)
Marine Debris	• No trash or other debris should be disposed of or otherwise allowed to enter the ocean. Ensure adequate trash receptacles with lids are available onsite or onboard vessels. • All debris that enters the water because of the activity should be removed using means that do not cause additional damage to organisms such as coral (*e.g.*, dip net, snorkel, SCUBA, etc.). • All loose articles (*e.g.*, clothing, towels on the deck, etc.) should be secured to prevent them blowing off or accidentally falling overboard.
Non-fishing, human activities (Military)	• A clear protocol to decrease sonar power when sensitive organisms are detected near a vessel should be in place. (USN 2008)

Activity Category	**BMPs**
	• No underwater detonations (training) should occur except within pre-approved areas designated for such activity. Detonations should be conducted using approved protocols, which should include protection measures for coral and other sensitive or important fishery species. (USN 2008)
"Waste" water discharge	• Where practicable, outfall structures should be placed sufficiently far offshore in areas of good mixing and use diffusers to promote dilution and reduce risk of discharged effluent from adversely affecting EFH. (Tate *et al.* 2016) • Where practicable, pipelines (*e.g.*, wastewater, cooling discharge, etc.) should be elevated off the bottom using pedestals. (PBS&J 2008) • Where possible, use horizontal directional drilling technology to install pipes, conduits, etc. instead of trenching or surface installation. (PBS&J 2008) • When practicable, wastewater effluent should be treated using the best available and practicable technology, including implementation of up-to-date methods to reduce discharges of biocides (*e.g.*, chlorine), endocrine disruptors, other toxic substances, and potential disease agents.

Summary BMP Table: BMPs by stressor type

Stressor	BMPs
Thermal	● Where practicable, discharges with different thermal or salinity characteristics than the receiving waters should be "treated" (*e.g.,* cooling or warming towers) prior to discharging, or should be discharged through means that will dilute the effluent to reduce the differential between it and the receiving body. (North Shore Consultants 2012, Tate *et al.* 2016) ● An effort should be made to ensure discharge temperatures (both heated and cooled effluent) do not exceed the thermal tolerance of the most sensitive organism[5] in the receiving waters.
Salinity	● Where practicable, discharges with different thermal or salinity characteristics than the receiving waters should be discharged through means that will dilute the effluent, reducing the differential between it and the receiving body. (Tate *et al.* 2016)
Irradiance	● Irradiance levels (PAR) should be monitored beneath any temporary structure that shades benthic, photosynthetic organisms. Prolonged exposure to levels below 35% of surface irradiance is likely to cause adverse effects on coral (see Erftemeijer *et al.* 2012 for more information). ● Temporary platforms or other structures that shade benthic photosynthetic organisms should be removed immediately upon completion of the activities that required them. ● Organisms, especially corals, beneath a temporary, shading structure should be monitored for condition, and if the organisms show signs of stress (*e.g.*, color change [especially paling], increased mucus production etc.), the temporary structure should be removed, if practicable and would not result in additional adverse effects. The structure can be returned once the organisms have sufficiently recovered.

[5]This will be site-specific, but in most shallow water ecosystems this will likely be coral, which have been shown can bleach when temperatures exceed the summer maximum temperature by only a few degrees for a prolonged period (Baker *et al.* 2009). Deep slope ecosystems, especially deep sea corals, might be more sensitive given the lower natural variability in temperature.

Stressor	**BMPs**
Noise	• High amplitude noise should not exceed 150 decibel (dB) in a single strike. Noise more than 150 dB has been found to cause adverse behavioral effects in fish. High amplitude noise exceeding 180 dB has been shown to cause injury in fish. (Hastings 2002, WSDOT 2015) • Where appropriate and practicable, bubble screens should be used to attenuate single strike noise. Curtains have been shown to reduce noise by 10-30 dB. (MacGillivray *et al.* 2007, WSDOT 2015)
Invasive species	• All vessels should undergo routine inspections for presence of non-native species growing on the hull of the vessel prior conducting work in a different area of operation. • Any equipment that has been previously used in an area known to contain invasive species should be sanitized prior to its use elsewhere[6]. • Any effluent from a facility containing non-native species (*e.g.*, aquaculture, aquarium, etc.) should be treated prior to discharge to ensure gametes/larvae[7] are not released into the marine environment. • All facilities that contain live non-native species should have a thorough biosecurity plan. Staff should be trained in the execution of the plan to decrease the potential for release of non-native species or propagules into the environment.
Disease	• Where practicable, discharges that have the potential to contain biological pathogens (*e.g.*, sewage, aquaculture waste, etc.) should treated to neutralize disease-causing agents.

[6]For more information on cleaning equipment, see NOAA's Preventing Invasive Species: Cleaning Watercraft and Equipment fact sheet available at: http://www.habitat.noaa.gov/pdf/best_management_practices/Cleaning%20of%20Watercraft%20and%20Equipment.pdf

[7]For example, see Tucker *et al.* (2012) for a discussion of using UV on non-native fish larvae to control invasive species.

Stressor	**BMPs**
FAD Effect	● Any structure using netting (*e.g.*, silt curtains, etc.) should have small enough webbing, and be installed to prevent entanglement by sensitive and fishery species. ● No marine life should be fed.
Physical damage	● No anchors, tools, or other equipment should be placed on any organism, especially coral. Preference should be to place anchors and spuds in soft-sediment only. ● No tools or materials should be dropped on the bottom during demolition and/or construction activities. ● Floating tow and anchoring lines should be used to prevent lines and cables from dragging in the water or on the bottom. All lines should be kept taut to reduce chance of entanglement of sensitive or fishery species. (Harnois *et al.* 2015) ● Where practicable, corals and other sensitive species that are likely to experience adverse effects, especially mortality, should be translocated/transplanted to a nearby, suitable location that is not likely to be impacted by the proposed or future projects. The condition of the relocated organisms should be monitored for at least two years[8]. (USCRTF 2016) ● All vessels should operate at "no wake/idle" speeds at all times while in water depths where the draft of the vessel provides less than a 2 m (6 ft.) clearance. All vessels should preferentially follow deep-water routes (*e.g.*, marked channels) whenever possible. If operating in shallow water, all vessels should employ a dedicated "lookout" to assist the pilot with avoiding large coral colonies and other benthic organisms that might extend up from the bottom.

[8]Effective evaluation of translocation/transplantation success for coral has been a problematic because few efforts have monitored the relocated coral colonies sufficiently to determine long-term success. Given limited data, 18-24 months appears to be a critical threshold point (see figure 2 in Okuba and Omori 2001, USCRTF 2016), but most monotirng efforts only continue for about 12 months. While interspefic variability exists, survival after one year is often high, but after 18 months, colonies appear to expierience more mortality. Success appears to be correlated with the quality of the habitat to which the corals are moved (USCRTF 2016).

Stressor	BMPs
Sediment	● Runoff control measures, including silt screens, retention basins, swales, etc., should be installed prior to any activity that could result in sediment entering any waterbody[9]. The best land management practices should be used to control soil erosion. (HDOT 2008) ● As appropriate and practicable, apply water and/or dust control measures to minimize wind transport of dust. (HDOT 2008) ● Avoid upland and coastal earth-moving during the local rainy season. (USCRTF 2016) ● All dredge/fill activities should be avoided to the extent possible during the coral broadcast spawning season (May-September in the northern hemisphere; Richmond and Hunter 1990). If dredge/fill window cannot be avoided, no activity should occur the 7 days before and 14 days after the full moon to avoid coral spawning[10]. This dredge/fill window may be narrowed based on site-specific spawning information. (PBS&J 2008) ● Dredging activities should be conducted only under calm sea state conditions and with a slack tide. Depending on project-specific conditions, an incoming or outgoing tide might also be suitable for dredging. (PBS&J 2008) ● Based on project-specific conditions, an appropriate turbidity

[9]A thorough assessment of the effectiveness of BMPs is beyond the scope of this review, but such an assessment is a critical need to assist NMFS in making conservation and enhancement recommendations that will have positive benefits on EFH. For example, while silt fences are nearly universally employed for erosion control during earth moving activities and are often an effective BMP, they have been shown to exacerbate sediment erosion in some situations (Wear *et al.* 2013).

[10]Little is known about larval competency for most coral species. *Pocillopora damicornis* (lace coral) can be competent within one day of spawning, and *Seriatopora caliendrum* (birdsnest coral) in as little as five hours (Cumbo *et al.* 2013, Edmunds *et al.* 2013). Both are brooding species that produce larger propagules than broadcast spawing species. Even broadcast spawners appear to have relatively short minimum compentency periods. Broadcaster *Favites chinensis* (larger star coral) and brooder *Coelastrea (=Goniastrea) aspera* (lesser star coral) are competent within one to three days after spawning, and possess a relatively long maximum settlement-competency period of nearly 70 days (Nozawa and Harrison 2002). Corals, while likely competent to settle quickly, can remain competent for as much as 2-3 months (Harrison 2011). Given this relatively sparse data, 7-14 days following the full moon appears to be a reasonably cautious period because spawning occurs for several days after the full moon, providing 7-10 days for coral larvae to move from the site. This window can be revised as more information becomes available.

Stressor	BMPs
	barrier (*e.g.*, turbidity curtains, turbidity screens, gunderbooms, pneumatic screens, etc.) should be considered as a potential approach to reduce the adverse effects of suspended sediment resulting from dredge/fill operations. However, due to highly variable, and often overstated effectiveness, this method should not be the sole approach to sediment management. (PBS&J 2008, Johnson 2011, Cutroneo *et al.* 2014, Radermacher *et al.* 2015) ● Where practicable, corals and other sensitive species that are likely to experience adverse effects, especially mortality, should be translocated/transplanted to a nearby, suitable location that is not likely to be impacted by the proposed or future projects. The condition of the relocated organisms should be monitored for at least two years[11]. (USCRTF 2016)
Nutrients	● For construction projects near or in marine waters, nutrient and water quality "stop work" thresholds should be established prior to implementing any activity. If the thresholds are exceeding, work should be suspended immediately until conditions improve. The water quality monitoring should be conducted to determine if the threshold criteria have been exceeded. (PBS&J 2008)
Chemicals	● A spill contingency plan should exist for both the construction and operation (as appropriate) of a facility, and all employees should be familiar with its contents and be trained in how to respond to a spill. (HDOT 2013) ● Containment equipment and sufficient supplies to combat spills should be on-site at all facilities that handle hydrocarbons, chemicals and/or other hazardous substances. (HDOT 2013) ● To the maximum extent practicable, storage of hydrocarbons,

[11]Effective evaluation of translocation/transplantation success for coral has been problematic because few efforts have monitored the relocated coral colonies sufficiently to determine long-term success. Given limited data, 18-24 months appears to be a critical threshold point (see figure 2 in Okuba and Omori 2001, USCRTF 2016), but most monitoring efforts only continue for about 12 months. While interspecific variability exists, survival after one year is often high, but after 18 months, colonies appear to experience more mortality. Success appears to be correlated with the quality of the habitat to which the corals are moved (USCRTF 2016).

Stressor	BMPs
	chemicals and/or hazardous substances should be in an area that would prevent spills from reaching marine environments. (HDOT 2013) ● All equipment should be properly maintained to prevent discharge of contaminants into marine waters. All equipment should be free of contaminants prior to use in or near the marine environment. ● Fueling of any equipment should be conducted in a dedicated area on land with control mechanisms to stop and spill from reaching the ocean. Seagoing vessels should be fueled at an approved location. (HDOT 2013) ● To the extent practicable, no heavy equipment should be driven or operated on reefs or tidal flats regardless of the tidal stage or exposure. ● Where practicable, an oil containment boom should be placed around mechanical equipment such as a dredge to contain any spilled oil or fuel. ● In the event of a spill, caution should be used when deploying and anchoring containment booms near reefs to prevent physical damage to corals and to prevent entangling marine species. ● The use of oil dispersants directly over shallow coral reefs and seagrass beds or near mangal and intertidal ecosystems should be avoided. ● The use of pesticides, herbicides, and fungicides in areas that would allow for their entry into marine environments should be avoided. ● Enzyme-based cleaners should be used instead of detergents, degreasers or chemicals.

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