ANNUAL STOCK ASSESSMENT AND FISHERY EVALUATION REPORT

HAWAII 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 HAWAII 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, and the 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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Hawaii Division of Aquatic Resources: Reginald Kokubun, Jo-Anne Kushima, Alton Miyasaka, and Hal Koike

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 and Sarah Ellgen

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 presents general descriptions of the local commercial fisheries including the deep-7 bottomfish, non deep-7 bottomfish, and coral reef, crustacean, mollusk and limu management unit species (MUS). The data collection systems for each fishery are then explained. The fishery statistics are organized into a summary dashboard tables showcasing the values for the most recent fishing year and the percent change between short-term (10 years) and long-term (20 years) averages. Time series for historical fishing parameters, top species catch by gear, and total catch parameters by gear are also provided. For 2016 catch in Hawaii, crustaceans and mollusks exceeded allowable biological catch (ABC), and annual catch limit (ACL) but remained below the overfishing limit (OFL). All other MUS catch for this year fell below these limits.

In 2016, the Main Hawaiian Island deep 7 bottomfish fishery is characterized by a decrease in fishing effort and participation. The number of fish caught and the weight showed an increase brought by an increase in CPUE. The deep 7 catch is mostly from the deep sea handline. The non-deep 7 bottomfish fishery is mostly dominated by uku (*Aprion virescens*). The fishery participation, effort, and number of fish caught are up in 2016 with a slight decrease in pounds caught. Non-deep 7 species are landed using the deap-sea handline, inshore-handline, and troll method. The deep-sea handline method exhibited a decrease in participation, effort, and catch. The inshore handline showed the same patter with a slight increase in effort. In contrast, troll with bait showed increase in participation, effort, and catch with a decrease in CPUE.

The CREMUS finfish fishery, in general, exhibited a decline in fishing participation, effort, and catch. The CREMUS fishery is dominated by inshore handline that lands coastal pelagic species, followed by purse seine, lay gill net, and seine net that lands schooling and coastal pelagic species. Inshore handline showed a slight increase in CPUE but a decline in participation, effort, and catch. Purse seine showed a general decrease in the indicators monitored. In contrast, lay gill net showed an increase in participation, effort, catch and CPUE. Seine net showed an increase in catch and CPUE. The last major fishery is the spear fishery that showed a general decline in 2016.

In 2016, the crustacean fishery showed an overall decline. Among the crustacean MUS, only deep water shrimp had shown an increase in catch and CPUE. Kona crab and lobsters statistics are all down in 2016.

The invertebrate fisheries for mollusks and limu are generally from hand harvest, spear, and inshore handline. Hand piking for invertebrates showed a general decline in 2016. Spearing for day octopus showed an increase in catch and CPUE last year. Other octopus landing using the inshore handline also showed an increase last year.

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 Main Hawaiian Islands (MHI), Northwest Hawaiian Islands (NWHI), American Samoa, Pacific Remote Island Area, Commonwealth of Northern Mariana Islands, and Guam. 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 MHI and NWHI are presented by sampling year and reef area. Finally, the reef fish population estimates for each study site within MHI and NWHI are provided for hardbottom habitat (0-30 m).

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 Hawaiian 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 Hawaii, followed by summaries of relevant studies and data for each fishery within Hawaii. 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 Hawaii FEP. These fisheries generally have limited impacts to protected species, and currently 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. 2014-2015 showed extreme high temperature anomalies, with values surpassing 12 degree heating weeks in 2015. 2016 returned within historical bounds. The year also saw an abundance of tropical cyclones including 21 named storms and 5 major hurricanes in the eastern Pacific. Eddy kinetic energy was unusually high in the last quarter in Hawaii.

The Hawaii 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 Hawaii 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. In the Hawaii Archipelago, alternative energy development and military activities take center stage as activities with potential fisheries impact. The Bureau of Ocean Energy Management received four nominations of commercial interest for its Call Areas northwest and south of Oahu, and is in the area identification stage of the leasing process. The Department of Defense is expected to release a draft environmental impact statement regarding training and testing activities in summer of 2017.

The Data Integration Chapter of this report is still under development. The Council hosted a Data Integration Workshop on November 30 - December 1, 2017 with participants from the NMFS Pacific Islands Regional Office and Pacific Islands Fisheries Science Center. The goal of the workshop was to identify policy-relevant fishery ecosystem relationships. The archipelagic data integration chapter will investigate 30 fishery dependent variable-ecological/environmental indicator combinations. A contractor is currently conducting the analysis and results will be included in the 2017 SAFE report.

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 Hawaiian archipelago precious corals fishery, the Plan Team recommends the Council:

- Review how the updated information in the precious corals species descriptions may affect the scientific justification of precious corals conservation and management measures, noting that the gold coral moratorium expires in June of 2018.

Regarding the evaluation of 2016 catch to the 2016 ACL and Hawaii catches, the Plan Team appoints the Archipelagic Plan Team Chair work with the agency and Council staff in conducting the evaluation and provide the rationale if there are any overage in ACLs for the Hawaii coral reef fisheries.

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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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
DLNR-DAR	Department of Land and Natural Resources-Division of Aquatic Resources
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

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1 FISHERY PERFORMANCE

1.1 DEEP-7 BMUS

1.1.1 Fishery Descriptions

The State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources manages the deep-sea bottomfish fishery in the Main Hawaiian Islands (MHI) under a joint management arrangement with the National Marine Fisheries Service (NMFS), Pacific Islands Regional Office (PIRO) and the Western Pacific Regional Fishery Management Council (WPRFMC).

The State collects the fishery information, the NMFS analyzes this information, the Council, working with the State, proposes the management scheme. Lastly, the NMFS implements the scheme into federal regulations and the State adopts the state regulations. These three agencies coordinate their management to simplify the regulations for the fishing public, to prevent overfishing, and manage the fishery for long-term sustainability. This shared management responsibility is necessary because the bottomfish complex of species occurs in both State and Federal waters. The information in this report is largely based on the State collected data.

1.1.2 Data Collection Systems

The collection of commercial main Hawaiian Islands Deep-7 bottomfish fishing reports comes from two sources: paper report received by mail or fax or pdf copy of it via e-mail; and report filed online through the Online Fishing Report system (OFR) at dlnr.ehawaii.gov/cmls-fr. Since the federal management of the Deep-7 bottomfish fishery began in 2007, the bottomfish landings have been collected on three types of fishing reports. Bottomfishers were required to use the Monthly Fishing Report and Deep-sea Handline Fishing Trip Report to report their Deep-7 landings within 10 days after the end of the month. These reports were replaced by the MHI Deep-7 Bottomfish Fishing Trip Report on September 2011, and bottomfish fishers were required to submit the trip report within five days after the trip end date. DLNR-DAR implemented the OFR online website on February 2010.

Paper fishing reports received through mail by DLNR-DAR are initially processed by an office assistant that date stamps the report, scans the report image and enters the report header as index information into an archival database application to store the report image and header index into database files. The report header index information is downloaded in a batch text file via FTP at 12:00 AM for transmission to the web portal vendor that maintains the Commercial Marine Licensing System (CMLS). This information updates the fisher's license report log in the CMLS to credit submission of the fishing report. The web portal vendor also exports a batch text file extract of the updated license profile and report log data file via FTP on a daily basis at 2:00 AM for transmission to DLNR-DAR. The office assistant checks reports for missing information, and then sorts by fishery form type (e.g. Deep-7 or monthly fishing report) and distributes it to the appropriate database assistant by the next business day. Database assistants and the data monitoring associate will enter the Deep-sea Handline Fishing Trip Report into the DLNR-DAR Fishing Report System (FRS) database, and the other report types through the Online Fishing Reporting System (OFR) within two business days.

The data records from fishing reports submitted online by fishers are automatically extracted and exported as daily batch text files from the OFR and uploaded by DLNR-DAR and imported into the FRS database on the following business day.

The FRS processes the data, and a general error report is run daily by the data supervisor. A database assistant will contact the fisher when clarification of the data is needed. Duplicate data checks are run weekly, and then researched by a database assistant. Discrepancies between dealer and catch data are checked monthly by a fisheries database assistant. The assistant will call the fisher or dealer to clarify any discrepancies. The data supervisor then transfers both fisheries and dealer data to WPACFIN daily; data trends are reported weekly to Deep-7 fishery managers and stake holders; and a Bottomfish newsletter is published for bottomfishers and fish dealers on a quarterly basis.

1.1.1.1 Historical Summary

Table 1. Annual fishing parameters for the Deep-7 bottomfish fishery comparing current values with short-term (10 years) and long-term (20 years) averages. Values are for the fishing year.

Fishery	**Parameters**	**2016 Values**	**2016 Comparative Trends**	
			Short Average (10 years)	Long Average (20 years)
BMUS Deep-7	No. License	372	↓ 12.7%	↓ 2.9%
	Trips	2,344	↓ 18.7%	↓ 0.6%
	No. Caught	76,831	↑ 11.1%	↑ 0.02%
	Lbs. Caught	277,454	↑ 10.9%	↑ 0.004%

1.1.1.2 Species Summary

Table 2. . Annual indicators for the Deep-7 bottomfish fishery comparing current estimates with the short-term (10 years) and the long-term (20 years) average. Values are for the fishing year.

Methods	Fishery indicators	2016 values	2016 Comparative Trends	
			Short Average (10 years)	Long Average (20 years)
Deep-Sea Handline	Opakapaka	136,357 lbs	↑ 12.2%	↑ 0.01%
	Onaga	73,792 lbs	↑ 10%	↑ 0.01%
	Ehu	32,050 lbs	↑ 22.3%	↑ 0.1%
	Hapuupuu	10,010 lbs	↑ 14.5%	↑ 0.1%
	No. Lic.	353	↓ 12.5	↓ 3.1
	No. Trips	2,245	↓ 18.9	↓ 0.62
	Lbs Caught	275,016 lbs	↑ 11.4	↑ 0.005
	CPUE	122.5 lbs/trip	↑ 36.2	↑ 44.4
Inshore Handline	Opakapaka Ehu Lehi Onaga	Insufficient data to report trends		
	No. Lic. No. Trips Lbs Caught CPUE	Insufficient data to report trends		
Palu-ahi	Opakapaka	698 lbs	↑ 12.2%	↑ 0.01%

	Ehu	Insufficient data to report trends		
	Lehi	598 lbs	↑ 22.3%	↑ 0.1%
	Hapuupuu	Insufficient data to report trends		
	No. Lic.	18	↓ 23.1	↓ 121.5
	No. Trips	73	↓ 10.5	↓ 18.5
	Lbs Caught	1,366 lbs	↓ 34.2	↓ 2.6
	CPUE	18.7 lbs/trip	↓ 23.1	↓ 101.8

1.1.3 Time Series Statistics

1.1.3.1 Commercial Fishing Parameters

The time series format for the Deep-7 bottomfish fishery begins with an arrangement by the state fiscal year period (July – June) until June 1993. Prior to July 1993, the state issued and renewed the Commercial Marine License (CML) on a fiscal year basis and all licenses expired on June 30, regardless of when it was issued. During that period, the fisher received a different CML number. This will allow the reporting of un-duplicated count of licensees until June 1993. The state issued and renewed permanent CML numbers effective July 1993. The federal Deep-7 bottomfish fishing year - which is defined from September through August of the following year - was established in 2007. In order to evaluate Deep-7 bottomfish fishing trends, the time series format was re-arranged with the September through August period beginning with September 1993 until August 2015. This arrangement provides a 22-year time series trend for the Deep-7 bottomfish fishery. There is a two-month segment including July 1993 through August 1993 that is defined as a separate period.

Early in the time series, this artisan fishery is dominated by highliners with large landings. Beginning in Fiscal 1966, less than 100 fishers made just over 1,000 trips, but attained the highest CPUE at 178 pounds per trip. With the expansion of the small vessel fleet during the 70’s and 80’s, effort and landings increased until it peaked in the late-80’s at 6,253 trips and 559,293 lbs. In June 1993, the state established bottomfish fish regulation including bottomfish restricted fishing areas, vessel registration identification, and non-commercial bag limit. Fishing effort and landings further declined from that time. Since the implementation of the federal Deep-7 bottomfish management, the landings has been under the control of the former total annual catch (TAC) and now annual catch limit (ACL) fishing quotas.

Table 3. Time series of commercial fishermen reports for Deep-7 BMUS fishery (1966-2016). Historical record reported in fiscal year from 1966-1993 and switches to fishing year from 1994-2016. July and August 1993 omitted to allow for this change.

Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1966	92	1055	413	11018	181629
1967	110	1469	550	16005	231315
1968	121	1193	524	12906	194851
1969	132	1216	532	11409	177381
1970	139	1150	528	8482	158195
1971	167	1254	606	10203	135156
1972	218	1929	831	19833	228375
1973	210	1574	732	16747	169273
1974	264	2161	938	23976	225561
1975	247	2094	903	24052	221385
1976	303	2265	995	23896	250270
1977	338	2722	1173	26872	274298
1978	434	2658	1540	41381	307672
1979	447	2255	1517	32312	273846
1980	461	2853	1435	35096	244219
1981	486	3769	1636	45085	308296
1982	451	3917	1634	46873	329436
1983	539	4875	1890	61857	409241
1984	553	4462	1799	55532	340790
1985	551	5752	2043	88679	484042
1986	605	5748	2256	99886	509121

Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1987	581	5572	2178	132498	579170
1988	550	6033	2122	136728	566724
1989	564	6253	2231	117599	559293
1990	531	5249	1944	90353	455802
1991	499	4223	1773	68411	334673
1992	488	4508	1846	85693	371245
1993	450	3550	1497	63668	265287
1993	121	374	168	7356	28826
1994	518	3886	1698	84875	318461
1995	525	3921	1706	78159	320940
1996	519	3999	1755	84096	295881
1997	500	4189	1762	83893	307615
1998	520	4119	1733	83781	290083
1999	430	3007	1428	56682	214004
2000	497	3929	1697	84064	311611
2001	457	3572	1550	71433	265755
2002	388	2856	1334	54520	209351
2003	364	2936	1248	62891	246814
2004	331	2649	1138	57386	208743
2005	351	2702	1198	61410	241660
2006	352	2266	1051	45427	189550
2007	356	2548	1144	49953	204792
2008	353	2345	1023	49423	196889

Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
2009	476	3266	1473	66836	258335
2010	460	2787	1224	56645	207978
2011	472	3423	1408	74412	273053
2012	479	3079	1520	67956	226704
2013	458	2977	1497	68445	239063
2014	423	3172	1492	90291	311179
2015	410	2886	1413	90793	307075
2016	372	2344	1194	76831	277454
10 yr ave	**426**	**2,883**	**1,339**	**69,159**	**250,252**
20 yr ave	**422**	**3,053**	**1,376**	**67,654**	**249,385**

1.1.4 Top 4 Species Per Gear Type

1.1.4.1 Deep-sea Handline

The heavy tackle, deep-sea handline gear is the dominant method for this fishery. The opakapaka and onaga are the primary target species, with the latter requiring much more fishing skill. In recent years, bottomfishers have remarked that opakapaka is the preferred target due to less fishing grounds and because it is easier to land for what is now a one-day fishery.

Table 4. HDAR MHI Fiscal Annual Deep-7 Catch (Lbs. caught) Summary (1966-2016) by Species and top Gear: Deep-sea handline. Historical record reported in fiscal year from 1966-93 and switches to fishing year from 1994-2016. July and August 1993 omitted to allow for this change.

Yr	Opakapaka		Onaga		Ehu		Hapuupuu	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	76	70651	34	63965	47	17587	49	11644
1967	96	120888	43	68442	62	18350	60	10624
1968	97	83983	62	69504	68	19864	58	11304

1969	115	85663	48	53839	68	16088	60	10881
1970	114	69538	44	43540	62	15870	64	19842
1971	130	59002	53	39213	78	15255	81	14471
1972	184	117426	71	58673	105	21282	112	16659
1973	175	93197	68	35584	94	14524	117	14828
1974	220	134838	86	43607	113	21113	117	14444
1975	199	114571	94	45016	113	21136	108	23078
1976	224	101618	118	78684	105	21621	140	21236
1977	255	98398	100	82049	144	32530	130	26769
1978	345	149538	135	66124	191	34385	197	27366
1979	306	140303	133	51601	190	20859	184	28053
1980	344	147342	161	29889	183	15836	182	16984
1981	386	193944	153	42659	207	20754	188	16056
1982	370	173803	177	65235	233	24088	189	20854
1983	422	226589	240	71687	277	27450	209	31733
1984	394	153138	239	84602	281	35214	207	26286
1985	437	196016	296	162305	308	40325	250	30960
1986	475	171581	343	194172	368	59768	241	23593
1987	454	254234	287	173638	320	45258	175	27703
1988	445	299861	272	156077	296	41010	194	10039
1989	436	306607	302	142829	318	37110	184	13288
1990	419	209597	307	141419	312	37326	176	13488
1991	385	138285	276	104562	301	32397	169	17217
1992	375	174138	253	95363	308	33331	165	17915
1993	346	138439	194	52703	256	25588	167	15721
1993	85	14511	51	5707	61	3087	35	2120

1994	393	176118	241	71989	287	22658	190	11610
1995	427	179674	236	65906	289	26001	230	15564
1996	417	148425	245	68198	279	31371	223	12017
1997	380	160062	218	61209	266	28676	216	15796
1998	386	146576	250	68984	299	25402	215	12458
1999	325	101755	198	60605	233	19747	179	9908
2000	386	166796	251	72599	283	27600	209	13569
2001	340	127076	253	64661	273	25856	203	15845
2002	288	100796	194	59867	218	17149	165	8676
2003	256	127191	190	69473	214	15768	142	9442
2004	233	87126	185	76754	193	20557	131	8384
2005	249	102641	202	87588	208	21948	131	10548
2006	245	73282	202	74745	206	18327	122	7635
2007	270	82512	202	80629	223	17566	118	6155
2008	271	94145	197	55680	210	17910	133	6729
2009	361	132724	245	59827	295	24649	168	7808
2010	324	102000	251	56166	296	23718	165	8022
2011	367	146934	258	67375	304	24124	175	8002
2012	341	109265	261	55524	321	27276	157	9737
2013	326	98600	246	68383	306	31332	156	10342
2014	324	162369	233	75213	275	30408	161	10667
2015	308	150657	227	78044	269	33058	138	9930
2016	280	136357	201	73792	232	32050	120	10010
10 yr ave	**317**	**121,556**	**232**	**67,063**	**273**	**26,209**	**149**	**8,740**
20 yr ave	**313**	**120,443**	**223**	**68,356**	**256**	**24,156**	**160**	**9,983**

1.1.4.2 Inshore Handline

The inshore handline gear is supposed to be a lighter tackle than the deep-sea handline. The ehu and onaga landings were probably made with the heavier tackle gear, but were reported by fishers as inshore handline. For these cases, in recent years fishers were contacted to verify the gear reported. The fishing report was not amended if the fisher did not respond. The opakapaka and lehi landings were probably fished in shallow water habitat.

Table 5. HDAR MHI Fiscal Annual Deep-7 Catch (Lbs. caught) Summary (1966-2016) by Species and second Gear: Inshore handline. Historical record reported in fiscal year from 1966-93 and switches to fishing year from 1994-2016. July and August 1993 omitted to allow for this change.

Yr	**Opakapaka**		**Ehu**		**Lehi**		**Onaga**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	4	500	4	55	n.d.	n.d.	n.d.	n.d.
1967	n.d.	n.d.	NULL	NULL	n.d.	n.d.	NULL	NULL
1968	NULL	NULL	n.d.	n.d.	NULL	NULL	NULL	NULL
1969	n.d.	n.d.	4	80	NULL	NULL	n.d.	n.d.
1970	n.d.	n.d.	NULL	NULL	4	129	NULL	NULL
1971	4	56	5	26	n.d.	n.d.	6	57
1972	n.d.	n.d.	3	26	n.d.	n.d.	n.d.	n.d.
1973	n.d.	n.d.	3	37	3	32	n.d.	n.d.
1974	n.d.	n.d.	NULL	NULL	n.d.	n.d.	NULL	NULL
1975	12	1318	3	54	6	327	n.d.	n.d.
1976	21	975	9	398	10	387	11	857
1977	40	2552	27	1024	12	473	13	1572
1978	43	1735	28	415	36	943	5	84
1979	100	4644	60	1451	53	1934	19	1406
1980	13	113	9	40	21	712	3	14
1981	18	531	9	39	14	336	5	26
1982	15	111	16	129	19	296	6	84

Yr	**Opakapaka**		**Ehu**		**Lehi**		**Onaga**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1983	30	228	24	235	22	360	11	283
1984	16	668	16	154	29	274	14	883
1985	NULL	NULL	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1986	8	267	4	36	5	29	n.d.	n.d.
1987	13	647	n.d.	n.d.	3	16	NULL	NULL
1988	4	53	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1989	6	291	5	33	NULL	NULL	n.d.	n.d.
1990	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
1991	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1992	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1993	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1993	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1994	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1995	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1996	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1997	3	22	n.d.	n.d.	4	29	n.d.	n.d.
1998	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	NULL	NULL
1999	NULL	NULL	NULL	NULL	n.d.	n.d.	NULL	NULL
2000	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	NULL	NULL
2001	6	80	3	74	NULL	NULL	NULL	NULL
2002	5	51	n.d.	n.d.	NULL	NULL	n.d.	n.d.
2003	7	211	6	191	n.d.	n.d.	n.d.	n.d.
2004	15	824	6	51	3	7	5	90
2005	9	772	5	246	7	68	3	200

Yr	**Opakapaka**		**Ehu**		**Lehi**		**Onaga**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
2006	6	539	3	21	NULL	NULL	n.d.	n.d.
2007	9	1074	3	430	4	88	n.d.	n.d.
2008	5	268	n.d.	n.d.	3	24	n.d.	n.d.
2009	15	733	4	78	3	111	3	40
2010	14	250	8	172	3	33	4	63
2011	7	242	3	13	n.d.	n.d.	NULL	NULL
2012	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
2013	3	12	NULL	NULL	n.d.	n.d.	NULL	NULL
2014	NULL	NULL	n.d.	n.d.	n.d.	n.d.	NULL	NULL
2015	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2016	n.d.	n.d.	NULL	NULL	n.d.	n.d.	NULL	NULL
10 yr ave	**9**	**430**	**5**	**173**	**3**	**64**	**4**	**52**
20 yr ave	**8**	**391**	**5**	**142**	**4**	**51**	**4**	**98**

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.1.4.3 Palu ahi

The primary use of palu ahi gear as it is defined for the state database is a form of tuna handline. This is normally a handline gear used during the day with drop stone or weight and chum. The target species is usually pelagic such as yellowfin and bigeye tunas. The Deep-7 bottomfish landings taken by palu ahi are common bycatches for Big Island fishers. Some of the landings may have been taken by bottomfishers who used deep-sea handline tackle but reported it as palu ahi because of the gear definition, which involves weights and chum on a handline. For these cases, in recent years fishers were contacted to verify the gear reported. The fishing report was not amended if the fisher did not respond.

Table 6. HDAR MHI Fiscal Annual Deep-7 Catch (Lbs. caught) Summary (1983-2016) by Species and third Gear: Palu ahi. Historical record reported in fiscal year from 1983-93

and switches to fishing year from 1994-2016. July and August 1993 omitted to allow for this change.

Year	**Opakapaka**		**Ehu**		**Lehi**		**Hapuupuu**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1983	n.d.	n.d.	NULL	NULL	3	50	NULL	NULL
1984	3	629	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1985	NULL	NULL	NULL	NULL	n.d.	n.d.	NULL	NULL
1986	10	275	n.d.	n.d.	9	1087	NULL	NULL
1987	6	112	n.d.	n.d.	9	331	NULL	NULL
1988	n.d.	n.d.	n.d.	n.d.	9	165	n.d.	n.d.
1989	3	110	NULL	NULL	4	91	NULL	NULL
1990	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1991	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1992	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1993	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1993	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1994	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1995	n.d.	n.d.	NULL	NULL	6	92	NULL	NULL
1996	4	15	NULL	NULL	12	228	NULL	NULL
1997	3	64	n.d.	n.d.	14	226	NULL	NULL
1998	n.d.	n.d.	NULL	NULL	11	291	NULL	NULL
1999	5	86	NULL	NULL	13	410	NULL	NULL
2000	8	133	NULL	NULL	11	302	NULL	NULL
2001	4	30	NULL	NULL	4	34	NULL	NULL
2002	NULL	NULL	n.d.	n.d.	4	135	n.d.	n.d.
2003	10	298	n.d.	n.d.	12	450	n.d.	n.d.

Year	**Opakapaka**		**Ehu**		**Lehi**		**Hapuupuu**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
2004	13	436	n.d.	n.d.	15	717	3	68
2005	11	134	n.d.	n.d.	16	551	n.d.	n.d.
2006	8	680	NULL	NULL	18	782	NULL	NULL
2007	9	340	n.d.	n.d.	12	539	NULL	NULL
2008	12	1754	3	8	16	1238	3	39
2009	8	1731	5	97	26	1613	n.d.	n.d.
2010	14	272	4	73	20	683	n.d.	n.d.
2011	4	168	n.d.	n.d.	9	218	n.d.	n.d.
2012	18	400	n.d.	n.d.	18	1029	n.d.	n.d.
2013	21	1174	n.d.	n.d.	21	1505	n.d.	n.d.
2014	24	1217	4	24	25	1322	NULL	NULL
2015	16	1491	n.d.	n.d.	19	938	n.d.	n.d.
2016	14	698	n.d.	n.d.	11	598	n.d.	n.d.
10 yr ave	**13**	**923**	**3**	**46**	**18**	**987**	**n.d.**	**n.d.**
20 yr ave	**10**	**549**	**n.d.**	**n.d.**	**15**	**661**	**n.d.**	**n.d.**

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.1.5 Catch Parameters by Gear

The CPUE (lbs. per trip) for the dominant method, deep-sea handline, peaked at the beginning of the time series, and leveled off since the early 1990's and through 2012. Most of the flat CPUE ranging between 71 - 92 lbs. per trip is attributed to state and federal regulations that removed fishing areas, interim closed season, and quotas on the landings. Recently, CPUE is trending up since 2014; last year it was 112 lbs. per trip. Fishers are making fewer trips, but landings are larger because the size weight of the Deep-7 bottomfish is increasing.

Table 7. HDAR MHI Fiscal Annual Deep-7 CPUE by dominant fishing methods (1966-2016). Historical record reported in fiscal year from 1966-93 and switches to fishing year from 1994-2016. July and August 1993 omitted to allow for this change.

Year	**Deep-sea handline**				**Inshore handline**				**Palu ahi**			
	No Lic	No trips	Lbs Caught	CPUE	No. Lic	No trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE
1966	86	1012	180165	178.03	10	16	711	44.44	NULL	NULL	NULL	0
1967	107	1449	231014	159.43	4	5	45	9	NULL	NULL	NULL	0
1968	118	1164	194494	167.09	n.d.	n.d.	n.d.	n.d.	NULL	NULL	NULL	0
1969	128	1175	176874	150.53	8	14	234	16.71	NULL	NULL	NULL	0
1970	135	1118	157853	141.19	5	6	161	26.83	NULL	NULL	NULL	0
1971	163	1219	134916	110.68	14	24	185	7.71	NULL	NULL	NULL	0
1972	214	1896	227744	120.12	15	22	182	8.27	NULL	NULL	NULL	0
1973	201	1537	168976	109.94	13	16	117	7.31	NULL	NULL	NULL	0
1974	258	2126	225181	105.92	4	6	61	10.17	NULL	NULL	NULL	0
1975	238	2038	219094	107.5	21	39	1864	47.79	NULL	NULL	NULL	0
1976	270	2028	241655	119.16	50	103	3134	30.43	NULL	NULL	NULL	0
1977	290	2263	255125	112.74	61	195	7428	38.09	NULL	NULL	NULL	0
1978	392	2365	297167	125.65	103	209	3866	18.5	NULL	NULL	NULL	0
1979	379	1901	259999	136.77	171	327	11685	35.73	NULL	NULL	NULL	0
1980	412	2591	235253	90.8	49	92	1038	11.28	NULL	NULL	NULL	0
1981	456	3458	301716	87.25	48	79	1114	14.1	NULL	NULL	NULL	0
1982	429	3688	322688	87.5	58	103	742	7.2	n.d.	n.d.	n.d.	n.d.
1983	501	4571	401606	87.86	90	166	1482	8.93	3	8	64	8
1984	503	4157	330294	79.45	82	148	2535	17.13	5	22	930	42.27

1985	533	5623	481308	85.6	10	13	1024	78.77	n.d.	n.d.	n.d.	n.d.
1986	582	5563	503729	90.55	27	42	790	18.81	12	63	1403	22.27
1987	562	5412	569395	105.21	21	39	887	22.74	13	35	484	13.83
1988	534	5955	564910	94.86	11	15	141	9.4	9	17	262	15.41
1989	536	6155	556924	90.48	20	27	629	23.3	5	12	201	16.75
1990	526	5230	454948	86.99	n.d.	n.d.	n.d.	n.d.	NULL	NULL	NULL	0
1991	492	4205	334546	79.56	4	4	55	13.75	NULL	NULL	NULL	0
1992	483	4485	371088	82.74	n.d.	n.d.	n.d.	n.d.	NULL	NULL	NULL	0
1993	445	3537	265195	74.98	n.d.	n.d.	n.d.	n.d.	NULL	NULL	NULL	0
1993	120	372	28773	77.35	NULL	NULL	NULL	0	NULL	NULL	NULL	0
1994	511	3864	318157	82.34	6	7	64	9.14	NULL	NULL	NULL	0
1995	516	3897	320634	82.28	n.d.	n.d.	n.d.	n.d.	6	6	105	17.5
1996	507	3952	295248	74.71	5	6	28	4.67	13	21	243	11.57
1997	484	4129	306177	74.15	13	16	128	8	16	23	301	13.09
1998	506	4056	288890	71.23	7	7	69	9.86	11	30	301	10.03
1999	415	2920	213039	72.96	4	4	38	9.5	14	48	496	10.33
2000	492	3885	311032	80.06	6	8	59	7.38	13	30	435	14.5
2001	447	3536	265437	75.07	9	19	178	9.37	6	9	79	8.78
2002	381	2826	208840	73.9	9	14	93	6.64	5	14	199	14.21
2003	345	2844	244718	86.05	14	26	543	20.88	16	49	850	17.35
2004	301	2530	206293	81.54	19	40	1117	27.93	21	72	1271	17.65
2005	319	2596	239409	92.22	21	50	1389	27.78	22	49	803	16.39
2006	323	2155	186274	86.44	11	27	673	24.93	19	61	1464	24
2007	334	2433	201381	82.77	14	46	2291	49.8	16	56	902	16.11
2008	331	2241	192029	85.69	8	15	1494	99.6	20	78	3119	39.99
2009	448	3117	252861	81.12	18	29	1078	37.17	31	105	3943	37.55

2010	421	2660	205699	77.33	25	41	616	15.02	28	67	1352	20.18
2011	449	3330	270282	81.17	9	18	284	15.78	11	33	542	16.42
2012	464	2979	224953	75.51	3	3	19	6.33	23	90	1512	16.8
2013	439	2847	235651	82.77	5	5	21	4.2	32	119	2785	23.4
2014	404	3061	308472	100.77	3	3	26	8.67	31	106	2638	24.89
2015	392	2765	303255	109.68	3	9	156	17.33	24	89	2599	29.2
2016	353	2245	275016	122.5	n.d.	n.d.	n.d.	n.d.	18	73	1366	18.71
10 yr ave	**404**	**2,768**	**246,960**	**90**	**10**	**19**	**665**	**28**	**23**	**82**	**2,076**	**24**
20 yr ave	**402**	**2,958**	**246,985**	**85**	**11**	**20**	**541**	**21**	**19**	**60**	**1,348**	**19**

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.2 NON DEEP-7 BMUS

1.2.1 Fishery Descriptions

This species group category is characterized by three jacks: the White or Giant ulua (*Caranx ignobilis*), Gunkan or Black ulua (*Caranx lugubris*), and Butaguchi or Pig-lip ulua (*Pseudocaranx dentex*); and two snappers, the Uku (*Aprion virescens*) and Yellowtail kalekale (*Pristipomoides auricilla*). All three jack species have been identified as specific species in the catch records since 1981. Before then, landings for these jacks were reported under the jack miscellaneous category, which is summarized in the CREMUS group category. The Yellowtail kalekale was identified as a specific species in the catch records in 1996. Previously, this species may have been reported with the Kalekale (*Pristipomoides sieboldii*), which is summarized in the Deep-7 BMUS group category.

The jacks are predators and found throughout the MHI, although the Black ulua and Butaguchi are more abundant in the NWHI. In terms of habitat, White ulua prefer nearshore with rocky shores, embayments, reefs, shallow and deep waters. Butaguchi forage in deeper waters near the bottom, and Gunkan also prefer deeper waters off reef slopes. The peak spawning period for White ulua is during new and full moon between May and August.

Citation: Hawaii's Comprehensive Wildlife Conservation Strategy. 9/6/2005

1.2.2 Dashboard Statistics

The collection of commercial non-Deep-7 BMUS fishing reports comes from two sources: paper report received by mail or fax or pdf copy of it via e-mail; and report filed online through the Online Fishing Report system (OFR). The non-Deep7 BMUS are reported by commercial fishers on the Monthly Fishing Report or the Net, Trap, Dive Activity Report or the MHI Deep-7 Bottomfish Fishing Trip Report.

Refer to data processing procedures documented in the Deep-7 BMUS section for paper fishing reports and fishing reports filed online. Database assistants and data monitoring associate will enter the paper Monthly Fishing Report information within 4 weeks, and the Net, Trap, Dive Activity Report and the MHI Deep-7 Bottomfish Fishing Trip Report within 2 business days.

1.2.2.1 Historical Summary

Table 8. Annual fishing parameters for the non Deep-7 Bottomfish fishery comparing current values with short-term (10 years) and long-term (20 years) averages. Values are for the fiscal year.

Fishery	Parameters	2016 Values	2016 Comparative Trends	
			Short Average (10 years)	Long Average (20 years)
BMUS Non	No. License	457	↑ 3.8	↑ 0.8

Deep-7	Trips	2,174	↑ 8.6	↑ 0.5
	No. Caught	14,931	↑ 8.4	↑ 0.08
	Lbs. Caught	118,960	↓ 1.3	↓ 0.001

1.2.2.2 Species Summary

Table 9. Annual indicators for the non-Deep-7 bottomfish fishery comparing current estimates with the short-term (10 years) and the long-term (20 years) average. Values are for the fiscal year.

Methods	Fishery indicators	2016 values	2016 Comparative Trends	
			Short Average (10 years)	Long Average (20 years)
Deep-Sea Handline	Uku	64,206 lbs	↓ 5.6%	↓ 0.01%
	White ulua	2,603 lbs	↓ 54.8%	↓ 2.1%
	No. Lic.	353	↓ 10.4%	↓ 3.1
	No. Trips	2,245	↓ 9.9%	↓ 0.62
	Lbs Caught	275,016 lbs	↓ 9.3%	↑ 0.01%
	CPUE	122.5 lbs/trip	↑ 0.7%	↑ 0.9%
Inshore Handline	Uku	12,188 lbs	↓ 15.9%	↓ 0.1%
	White ulua	1,581 lbs	↓ 39.3%	↓ 2.1%
	No. Lic.	72	↓ 21.9%	↓ 20.1%
	No. Trips	380	↑ 1.8%	↑ 0.5%
	Lbs Caught	13,833 lbs	↓ 19.6%	↓ 0.1%
	CPUE	36.4 lbs/trip	↓ 19.8%	↓ 53.3%
Troll with bait	White ulua	1,095 lbs	↓ 37.8%	↓ 2.3%

	Uku	10287 lbs	↑ 51.4%	↑ 0.8%
	No. Lic.	52	↑ 43.3%	N/A
	No. Trips	255	↑ 45.6%	N/A
	Lbs Caught	11,383 lbs	↑ 32.8%	N/A
	CPUE	44.64 lbs/trip	↓ 7.9%	N/A

*N/A = no data available to make a 20 year trend

1.2.3 Time Series Statistics

1.2.3.1 Commercial Fishing Parameters

The most important species in this group category is the uku. Because of the wide habitat range where this species is found it is commonly taken by heavy (deep-sea handline) and light (inshore handline) tackles and troll gear. The white ulua, gunkan ulua, and butaguchi ulua, and yellowtail kalekale were not established as specific species during the entire time series. Refer to discussion in the previous section. Early in the time series up until 1982, the effort and catch trends reflect only uku landings. The White ulua was not widely accepted by markets during the 1990's because of the ciguatera toxin. Since the implementation of the federal bottomfish fishing year, uku landings have trended upwards. During the first four federal fishing years, the Deep-7 bottomfish fishery was closed because the TAC or ACL was attained. Bottomfish fishers shifted target to uku during the closures, and in recent years this effort is rewarding because of decent market prices.

Table 10. HDAR MHI Fiscal Annual non Deep-7 Bottomfish commercial fishermen reports (1966-2016).

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1966	84	571	278	1297	46816
1967	108	733	366	1911	64215
1968	110	570	317	1222	52352
1969	116	716	377	1554	54139
1970	125	731	394	1576	49794
1971	137	608	356	1712	48418
1972	161	761	441	1369	54139

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1973	169	767	472	1897	46578
1974	235	1039	632	3768	72953
1975	213	1041	580	2709	75490
1976	213	934	518	2388	69009
1977	245	1093	612	2643	47094
1978	376	1569	1038	4460	94798
1979	381	1346	1037	4832	82747
1980	361	1483	902	5140	63980
1981	392	2117	1107	7950	95027
1982	389	2021	1120	7945	96144
1983	431	2769	1366	10880	123244
1984	469	2631	1312	14199	164464
1985	467	2112	1157	8905	101889
1986	363	1566	859	6064	83164
1987	366	1586	887	10700	117959
1988	461	2713	1260	15511	201383
1989	509	3317	1621	31063	347700
1990	488	2522	1391	12746	150809
1991	454	2189	1258	12183	144940
1992	409	1812	1072	9399	101683
1993	365	1498	897	6811	76343
1994	386	1515	919	6981	89516
1995	395	1710	954	7961	85106

Fiscal Year	**No. License**	**Trips**	**No. Reports**	**No. Caught**	**Lbs. Caught**
1996	340	1248	830	7085	73067
1997	448	1901	1144	10147	93482
1998	418	1696	1011	6883	63243
1999	366	1458	916	9639	84116
2000	418	1791	1048	12550	103673
2001	374	1520	924	9392	78113
2002	313	1190	779	8733	82572
2003	329	1223	780	7064	66225
2004	355	1436	898	7822	76849
2005	381	1557	946	10587	95028
2006	382	1478	912	8926	80867
2007	357	1706	958	9832	96223
2008	384	1815	980	12438	107483
2009	411	1725	1018	11399	97130
2010	457	2019	1167	15007	125417
2011	494	2374	1325	16402	149144
2012	455	2009	1181	13690	124217
2013	493	2113	1274	17378	157798
2014	461	1997	1201	12050	104390
2015	460	2092	1236	14631	123931
2016	457	2174	1238	14931	118960
10 yr ave	**443**	**2,002**	**1,158**	**13,776**	**120,469**
20 yr ave	**411**	**1,764**	**1,047**	**11,475**	**101,443**

1.2.4 Top Two Species Per Gear Type

1.2.4.1 Deep-sea Handline

Table 11. HDAR MHI Fiscal Annual non Deep-7 Bottomfish Catch (Lbs. caught) Summary (1966-2016) by Species and top Gear: Deep-sea handline.

Fiscal year	**Uku**		**White ulua**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	78	46358	NULL	NULL
1967	101	63303	NULL	NULL
1968	104	51705	NULL	NULL
1969	107	52824	NULL	NULL
1970	115	48645	NULL	NULL
1971	133	48038	NULL	NULL
1972	154	53336	NULL	NULL
1973	161	45817	NULL	NULL
1974	216	72130	NULL	NULL
1975	191	74325	NULL	NULL
1976	166	63048	NULL	NULL
1977	187	36177	NULL	NULL
1978	303	75501	NULL	NULL
1979	248	67218	NULL	NULL
1980	290	57725	NULL	NULL
1981	338	90177	NULL	NULL
1982	355	88334	15	426
1983	368	109638	31	5284
1984	381	134395	49	8369

Fiscal year	**Uku**		**White ulua**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1985	360	84510	37	3789
1986	267	62839	20	1253
1987	246	61087	15	4466
1988	347	166300	29	3193
1989	422	297514	67	15715
1990	374	121439	63	10686
1991	322	104580	58	7316
1992	281	68668	13	1368
1993	221	54888	9	712
1994	270	69806	12	1333
1995	275	61449	13	501
1996	224	51617	19	2037
1997	250	56910	12	923
1998	228	37599	5	416
1999	215	64511	8	466
2000	252	78851	8	403
2001	205	50998	10	608
2002	176	58177	7	1313
2003	153	41730	28	2120
2004	133	47695	29	1966
2005	160	55707	33	1519
2006	167	46767	29	1415

Fiscal year	**Uku**		**White ulua**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2007	162	51603	34	4052
2008	167	53056	35	4405
2009	183	65897	40	3462
2010	200	75714	51	4113
2011	234	88939	57	7033
2012	206	65393	42	4319
2013	203	89061	40	5475
2014	174	57181	35	3104
2015	174	69025	30	2603
2016	173	64206	28	1826
10 yr ave	**188**	**68,008**	**39**	**4,039**
20 yr ave	**191**	**60,951**	**28**	**2,577**

NULL = no data available

1.2.4.2 Inshore Handline

Table 12. HDAR MHI Fiscal Annual non Deep-7 Bottomfish (Lbs. caught) Summary (1966-2016) by Species and second Gear: Inshore handline.

Fiscal year	**Uku**		**White Ulua**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	4	50	NULL	NULL
1967	4	554	NULL	NULL
1968	8	345	NULL	NULL
1969	3	24	NULL	NULL
1970	3	20	NULL	NULL
1971	3	25	NULL	NULL
1972	3	12	NULL	NULL
1973	8	47	NULL	NULL
1974	7	158	NULL	NULL
1975	16	331	NULL	NULL
1976	42	2453	NULL	NULL
1977	60	7792	NULL	NULL
1978	134	14348	NULL	NULL
1979	211	12673	NULL	NULL
1980	71	1825	NULL	NULL
1981	67	1198	NULL	NULL
1982	43	582	n.d.	n.d.
1983	45	560	6	182
1984	53	1169	8	1062
1985	4	207	3	91

Fiscal year	**Uku**		**White Ulua**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1986	22	2323	4	147
1987	91	11687	14	537
1988	91	10401	14	661
1989	75	4532	10	415
1990	78	2653	10	297
1991	106	4675	23	973
1992	127	17553	12	864
1993	114	8222	13	552
1994	83	8333	7	169
1995	98	8413	11	436
1996	85	4668	10	926
1997	175	14612	14	1206
1998	173	17614	14	1427
1999	134	10050	12	930
2000	152	14423	11	609
2001	142	14844	17	827
2002	94	12229	18	1291
2003	70	6748	24	1458
2004	68	5063	31	1431
2005	80	6980	24	1856
2006	64	9098	20	1275
2007	64	10452	21	1642

Fiscal year	Uku		White Ulua	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2008	67	13079	33	2619
2009	91	9148	36	2446
2010	86	15368	40	3039
2011	102	17679	47	5070
2012	89	20860	31	4594
2013	88	21188	37	2174
2014	78	12968	29	1549
2015	63	11917	23	1353
2016	64	12188	21	1581
10 yr ave	**79**	**14,485**	**32**	**2,607**
20 yr ave	**97**	**12,825**	**25**	**1,919**

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.2.4.3 Troll with Bait

The gear code for troll with bait was established in October 2002 when the revised commercial fishing reports were implemented. Previously all troll activities were reported as troll miscellaneous gear.

Table 13. HDAR MHI Fiscal Annual non Deep-7 Bottomfish Catch (Lbs. caught) Summary (2003 - 2016) by Species and third Gear: Troll with Bait.

Fiscal year	White Ulua		Uku	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2003	11	1034	19	2270
2004	8	1365	17	5664

Fiscal year	**White Ulua**		**Uku**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2005	6	1036	21	9041
2006	8	994	17	6361
2007	16	1837	12	4842
2008	14	2090	13	13599
2009	14	1292	15	2470
2010	12	1493	26	5813
2011	17	2075	31	3679
2012	13	1885	26	5315
2013	16	2370	40	6615
2014	18	2177	45	6334
2015	12	1294	45	9004
2016	15	1095	47	10287
10 yr ave	**15**	**1,761**	**30**	**6,796**
20 yr ave	**13**	**1,574**	**27**	**6,521**

1.2.4.4 Troll (Misc.)

The troll gear was standardized and reported under specific methods including troll with lure or bait or green stick in October 2002 when the revised commercial fishing reports were implemented. Since then fishers were contacted to verify miscellaneous troll activities on their fishing reports. The fishing report was not amended if the fisher did not respond.

Table 14. HDAR MHI Fiscal Annual non Deep-7 Bottomfish Catch (Lbs. caught) Summary (1972 - 2004) by Species and fourth Gear: Troll (misc.). Recent data restricted by confidentiality protocol.

Fiscal year	Uku		White Ulua	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	NULL	NULL	NULL	NULL

Fiscal year	Uku		White Ulua	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1967	n.d.	n.d.	NULL	NULL
1968	n.d.	n.d.	NULL	NULL
1969	n.d.	n.d.	NULL	NULL
1970	NULL	NULL	NULL	NULL
1971	NULL	NULL	NULL	NULL
1972	5	142	NULL	NULL
1973	5	204	NULL	NULL
1974	12	326	NULL	NULL
1975	16	283	NULL	NULL
1976	20	2206	NULL	NULL
1977	26	955	NULL	NULL
1978	20	1374	NULL	NULL
1979	n.d.	n.d.	NULL	NULL
1980	51	1748	NULL	NULL
1981	29	1125	NULL	NULL
1982	27	1329	6	470
1983	29	1429	7	185
1984	42	2563	34	1689
1985	9	380	83	4568
1986	23	634	48	2616
1987	24	1777	15	3731
1988	29	2877	15	852
1989	49	6196	18	1389
1990	52	3063	17	1978
1991	41	5991	27	2007
1992	38	3867	13	339
1993	24	932	10	872
1994	34	1155	7	553
1995	37	1028	4	261
1996	33	1562	6	327
1997	47	2411	6	556
1998	33	675	5	257
1999	23	1724	4	369
2000	31	1359	7	184
2001	40	2340	9	1129
2002	37	2040	6	476
2003	10	373	3	115
2004	3	43	NULL	NULL
2005	NULL	NULL	n.d.	n.d.

Fiscal year	Uku		White Ulua	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2006	NULL	NULL	NULL	NULL
2007	NULL	NULL	NULL	NULL
2008	NULL	NULL	NULL	NULL
2009	NULL	NULL	NULL	NULL
2010	NULL	NULL	NULL	NULL
2011	NULL	NULL	NULL	NULL
2012	NULL	NULL	NULL	NULL
2013	NULL	NULL	n.d.	n.d.
2014	NULL	NULL	NULL	NULL
2015	NULL	NULL	NULL	NULL
2016	NULL	NULL	NULL	NULL

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.2.5 Catch Parameters by Gear

With uku being the driver species in this group category, it is commonly caught by the following top dominant gears: deep-sea handline, inshore handline, troll with bait and troll miscellaneous. Landings of uku along with the Deep-7 bottomfish species peaked in 1989 with deep-sea handline gear. A second peak for this dominant gear occurred in 2013 because of bottomfishers shifting their fishing target to uku during the summer months.

Table 15. Time series of CPUE by dominant fishing methods from non Deep-7 BMUS (1966-2016).

	Deep-sea handline				Inshore handline				Troll with Bait				Troll (misc.)			
Fiscal year	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE
1966	78	514	46358	90.19	4	4	50	12.5	NULL	NULL	NULL	0	NULL	NULL	NULL	0
1967	101	683	63303	92.68	4	5	554	110.8	NULL	NULL	NULL	0	n.d.	n.d.	n.d.	n.d.
1968	104	509	51705	101.58	8	13	345	26.54	NULL	NULL	NULL	0	n.d.	n.d.	n.d.	n.d.
1969	107	615	52824	85.89	3	3	24	8	NULL	NULL	NULL	0	n.d.	n.d.	n.d.	n.d.
1970	115	633	48645	76.85	3	4	20	5	NULL	NULL	NULL	0	NULL	NULL	NULL	0
1971	133	548	48038	87.66	3	4	25	6.25	NULL	NULL	NULL	0	NULL	NULL	NULL	0
1972	154	663	53336	80.45	3	3	12	4	NULL	NULL	NULL	0	5	10	142	14.2
1973	161	675	45817	67.88	8	9	47	5.22	NULL	NULL	NULL	0	5	7	204	29.14
1974	216	968	72130	74.51	7	10	158	15.8	NULL	NULL	NULL	0	12	13	326	25.08
1975	191	947	74325	78.48	16	23	331	14.39	NULL	NULL	NULL	0	16	19	283	14.89
1976	166	732	63048	86.13	42	97	2453	25.29	NULL	NULL	NULL	0	20	52	2206	42.42
1977	187	716	36177	50.53	60	211	7792	36.93	NULL	NULL	NULL	0	26	41	955	23.29
1978	303	1097	75501	68.82	134	298	14348	48.15	NULL	NULL	NULL	0	20	41	1374	33.51
1979	248	857	67218	78.43	211	431	12673	29.4	NULL	NULL	NULL	0	n.d.	n.d.	n.d.	n.d.
1980	290	1196	57725	48.27	71	110	1825	16.59	NULL	NULL	NULL	0	51	82	1748	21.32
1981	338	1763	90177	51.15	67	110	1198	10.89	NULL	NULL	NULL	0	29	44	1125	25.57
1982	355	1760	90223	51.26	45	66	603	9.14	NULL	NULL	NULL	0	30	40	1799	44.98
1983	374	2506	115980	46.28	51	74	748	10.11	NULL	NULL	NULL	0	36	46	1614	35.09
1984	397	2246	144502	64.34	58	95	2239	23.57	NULL	NULL	NULL	0	73	108	4252	39.37
1985	378	1853	92057	49.68	8	8	306	38.25	NULL	NULL	NULL	0	91	133	4948	37.2
1986	282	1271	70271	55.29	28	60	2540	42.33	NULL	NULL	NULL	0	63	92	3250	35.33
1987	262	1084	82513	76.12	100	264	12376	46.88	NULL	NULL	NULL	0	35	75	5555	74.07
1988	365	2270	174945	77.07	101	218	11132	51.06	NULL	NULL	NULL	0	43	78	3837	49.19
1989	441	2867	320763	111.88	83	174	4955	28.48	NULL	NULL	NULL	0	62	116	7585	65.39

Fiscal year	Deep-sea handline				Inshore handline				Troll with Bait				Troll (misc.)			
	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE
1990	395	2053	139989	68.19	83	232	3136	13.52	NULL	NULL	NULL	0	67	113	5041	44.61
1991	346	1680	125306	74.59	120	259	5679	21.93	NULL	NULL	NULL	0	64	126	7998	63.48
1992	289	1169	72393	61.93	130	445	18434	41.42	NULL	NULL	NULL	0	48	79	4206	53.24
1993	237	911	62746	68.88	122	372	8790	23.63	NULL	NULL	NULL	0	31	68	1804	26.53
1994	282	1086	76244	70.21	85	218	8502	39	NULL	NULL	NULL	0	39	63	1708	27.11
1995	291	1230	72242	58.73	105	298	8886	29.82	NULL	NULL	NULL	0	40	63	1289	20.46
1996	234	811	61442	75.76	92	250	5668	22.67	NULL	NULL	NULL	0	39	67	1889	28.19
1997	268	1033	71884	69.59	179	655	15868	24.23	NULL	NULL	NULL	0	51	91	2966	32.59
1998	238	905	40551	44.81	183	619	19302	31.18	NULL	NULL	NULL	0	39	59	978	16.58
1999	222	782	67218	85.96	140	473	11029	23.32	NULL	NULL	NULL	0	27	44	2093	47.57
2000	258	996	83039	83.37	158	567	15049	26.54	NULL	NULL	NULL	0	36	47	1543	32.83
2001	212	850	55632	65.45	152	464	15707	33.85	NULL	NULL	NULL	0	50	84	3481	41.44
2002	187	697	62685	89.94	106	335	13562	40.48	NULL	NULL	NULL	0	43	71	2536	35.72
2003	173	674	46791	69.42	80	238	8390	35.25	23	65	3333	51.28	13	18	488	27.11
2004	150	644	51079	79.32	85	275	6614	24.05	21	118	7075	59.96	3	3	43	14.33
2005	175	761	60698	79.76	89	313	8904	28.45	22	127	10077	79.35	n.d.	n.d.	n.d.	n.d.
2006	173	691	50233	72.7	71	246	10481	42.61	24	108	7385	68.38	NULL	NULL	NULL	0
2007	169	813	56300	69.25	73	313	12115	38.71	25	137	6719	49.04	NULL	NULL	NULL	0
2008	189	840	60670	72.23	83	334	15869	47.51	21	199	15689	78.84	NULL	NULL	NULL	0
2009	201	899	70006	77.87	109	329	11678	35.5	21	104	3792	36.46	NULL	NULL	NULL	0
2010	217	911	81054	88.97	99	388	18439	47.52	32	142	7306	51.45	NULL	NULL	NULL	0
2011	257	1200	97542	81.29	121	443	22881	51.65	37	136	5827	42.85	NULL	NULL	NULL	0
2012	223	807	70811	87.75	100	465	25724	55.32	29	157	7199	45.85	NULL	NULL	NULL	0
2013	217	861	96085	111.6	105	404	23407	57.94	47	175	8985	51.34	n.d.	n.d.	n.d.	n.d.
2014	184	807	60699	75.22	88	341	14787	43.36	51	222	8511	38.34	NULL	NULL	NULL	0
2015	181	826	72040	87.22	72	335	13328	39.79	48	224	10300	45.98	NULL	NULL	NULL	0

	Deep-sea handline				Inshore handline				Troll with Bait				Troll (misc.)			
Fiscal year	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE	No. License	No. trips	Lbs. Caught	CPUE
2016	181	789	66362	84.11	72	380	13833	36.4	52	255	11383	44.64	NULL	NULL	NULL	0
10 yr ave	**202**	**875**	**73,157**	**84**	**92**	**373**	**17,206**	**45**	**36**	**175**	**8,571**	**48**				
20 yr ave	**204**	**839**	**66,069**	**79**	**108**	**396**	**14,848**	**38**					**33**	**52**	**1,766**	**31**

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.3 CREMUS FINFISH

1.3.1 Fishery Descriptions

There are 66 different specific finfish species in this group category. These species represent a total of 12 species families including surgeonfish (*Acanthuridae*), jacks (*Carangidae*), squirrelfish (*Holocentridae*), rudderfish (*Kyphosidae*), wrasses (*Labridae*), emperor (*Lethrinidae*), snappers (*Lutjanidae*), mullet (*Mugilidae*), goatfish (*Mullidae*), parrotfish (*Scaridae*), grouper (*Serranidae*), and shark (*Carcharhinidae).*

Overall, the key driver species in this group category is the akule, halalu (juvenile akule) and opelu from the Carangidae family; taape from the Lutjanidae family, amama from the Mugilidae family, and weke miscellaneous from the Mullidae family. The dominant gear types are inshore handline, purse seine net (pelagic), lay gill net, and seine net.

1.3.2 Dashboard Statistics

The collection of commercial CREMUS finfish fishing reports comes from two sources: paper report received by mail or fax or pdf copy of it via e-mail; and report filed online through the Online Fishing Report system (OFR). The CREMUS finfish are reported by commercial fishers on the Monthly Fishing Report or the Net, Trap, Dive Activity Report or the MHI Deep-7 Bottomfish Fishing Trip Report.

Refer to data processing procedures documented in the Deep-7 BMUS section for paper fishing reports and fishing reports filed online. Database assistants and data monitoring associate will enter the paper Monthly Fishing Report information within four weeks, and the Net, Trap, Dive Activity Report and the MHI Deep-7 Bottomfish Fishing Trip Report within two business days.

1.3.2.1 Historical Summary

Table 16. Annual fishing parameters for the CREMUS finfish fishery comparing current values with short-term (10 years) and long-term (20 years) averages.

Fishery	Parameters	2016 Values	2016 Comparative Trends	
			Short Average (last 10 years)	Long Average (last 20 years)
CREMUS Finfish	No. License	699	↓ 7.6%	↓ 0.9%
	Trips	7,316	↓ 13.2%	↓ 0.1%
	No. Caught	1,345,114	↓ 3.3%	↓ 0.0004%
	Lbs. Caught	923,042	↓ 9%	↓ 0.0007%

1.3.2.2 Species Summary

Table 17. Annual indicators for the CREMUS finfish fishery comparing current estimates with the short-term (10 years) and the long-term (20 years) average.

Methods	Fishery indicators	2016 values	2016 Comparative Trends	
			Short Average (10 years)	Long Average (20 years)
Inshore Handline	Opelu	61,494 lbs	↓ 52.6%	↓ 0.03%
	Akule	100,223 lbs	↑ 10.5%	↑ 0.01%
	Taape	3,058 lbs	↓ 51.0%	↓ 0.5%
	Ulua	63 lbs	↓ 57.1%	↓ 1.0%
	No. Lic.	210	↓ 33.3%	↓ 7.9%
	No. Trips	2,522	↓ 28.2%	↓ 0.6%
	Lbs Caught	180,318 lbs	↓ 26%	↓ 0.1%
	CPUE	71.5 lbs/trip	↑ 2.7%	↑ 4.1%
Purse Seine Net	Akule Ulua Kala Taape	Insufficient data for species level trends		
	No. Lic.	3	↓ 48.6%	↓ 809%
	No. Trips	15	↓ 52.4%	↓ 163%
	Lbs Caught	16,974 lbs	↓ 87.8%	↓ 0.1%
	CPUE	1,131 lbs/trip	↓ 81.4%	↓ 1.7%
Lay Gill Net	Akule	187,154 lbs	↑ 33.4%	↑ 0.02%
	Weke	N/A	N/A	N/A

	Amaama	3,601 lbs	↓ 51.9%	↓ 0.8%
	Kala	12,364 lbs	↑ 15.2%	↑ 0.2%
	No. Lic.	37	↑ 3.6	↑ 8.7
	No. Trips	452	↑ 18.5	↑ 3.7
	Lbs Caught	231,673 lbs	↑ 28.7	↑ 0.02
	CPUE	512 lbs/trip	↑ 8.6	↑ 2.3
Seine Net	Akule	102,076 lbs	↑ 91.1	↑ 0.05
	Weke	N/A	N/A	N/A
	Taape	12,144 lbs	↑ 7.2	↑ 0.05
	Opelu	N/A	N/A	N/A
	No. Lic.	20	↓ 15.6%	↓ 78.1%
	No. Trips	178	↓ 19.6%	↓ 10.1%
	Lbs Caught	167,564 lbs	↑ 16.7	↑ 0.01
	CPUE	941 lbs/trip	↑ 42	↑ 3.1
Spear	Uhu	23,749 lbs	↓ 43.6%	↓ 0.1%
	Palani	10,110 lbs	↓ 26.4%	↓ 0.3%
	Kala	5,368 lbs	↓ 49%	↓ 0.7%
	Manini	5,950 lbs	↓ 21.7%	↓ 0.4%
	No. Lic.	63	↓ 36.8%	↓ 34.4%
	No. Trips	675	↓ 42.7%	↓ 4.3%
	Lbs Caught	66,797 lbs	↓ 41.6%	↓ 4.3%
	CPUE	98 lbs/trip	↑ 3.4%	↑ 4.8%

1.3.3 Time Series Statistics

1.3.3.1 Commercial Fishing Parameters

Table 18. Time series of commercial fishermen reports for CREMUS finfish fishery (1966-2016).

Fiscal year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1966	261	6387	1482	329614	1114853
1967	302	7324	1731	325083	1328133
1968	294	6463	1634	302805	1512844
1969	362	7038	1802	411936	1628970
1970	417	7870	2113	371275	1469487
1971	478	7671	2171	304742	1332051
1972	488	8288	2369	318812	1287455
1973	538	7488	2328	352780	1269877
1974	646	8290	2684	353026	1115435
1975	648	8872	2657	427742	1159570
1976	684	9047	2839	353277	1378855
1977	772	10321	3172	423391	1577768
1978	942	8739	3928	461673	1315632
1979	955	6460	4072	462099	1171970
1980	954	9315	3771	536639	1410824
1981	989	11968	3967	495199	1350879
1982	868	10477	3602	269481	1075781
1983	956	12482	4017	339593	1493283
1984	1037	12511	4145	269324	1475465
1985	925	11057	3757	297806	921552
1986	996	11149	3984	272007	848528
1987	1010	11758	3973	350436	994022
1988	1029	11671	4034	268120	960842
1989	1090	12125	4370	336536	1222961
1990	1051	12046	4183	450386	1477667
1991	1059	12079	4151	348003	1341206
1992	1055	12513	4122	443298	1547351
1993	987	10497	3551	208924	1396986
1994	1036	10522	3688	162596	1152157
1995	1038	10543	3626	148510	1397121
1996	1058	11514	3818	178477	1382267
1997	1110	12081	4172	194210	1243396
1998	1097	12313	4111	346507	1953487
1999	1015	10881	3701	251043	1861426
2000	953	11067	3552	353755	1795017

Fiscal year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
2001	889	9845	3292	290579	1516577
2002	808	8378	2972	221654	1064347
2003	736	8347	2700	1181409	1268654
2004	687	8224	2612	1155922	1231904
2005	648	7023	2349	890187	1210960
2006	634	6500	2178	956258	1095354
2007	641	7678	2416	1648856	1301579
2008	646	7534	2438	1664832	1071304
2009	806	8798	3018	1642692	908931
2010	824	9983	3276	1391746	1074816
2011	851	9789	3312	1303543	1187856
2012	779	8972	3031	1324037	947831
2013	793	8515	3011	1204777	932060
2014	761	8083	2920	1195820	883302
2015	761	7655	2877	1181857	912322
2016	699	7316	2730	1345114	923042
10 yr ave	**756**	**8,432**	**2,903**	**1,390,327**	**1,014,304**
20 yr ave	**807**	**8,949**	**3,033**	**987,240**	**1,219,208**

1.3.4 Top 4 Species Per Gear Type

1.3.4.1 Inshore Handline

Table 19. HDAR MHI Fiscal Annual CREMUS finfish Catch (Lbs. caught) Summary (1966 - 2016) by Species and top Gear: Inshore handline.

	Opelu		Akule		Taape		Ulua	
Fiscal year	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	88	89408	110	160301	NULL	NULL	57	4879
1967	109	136450	118	155720	NULL	NULL	64	4863
1968	87	104308	111	174282	NULL	NULL	59	5076
1969	89	128720	134	188541	NULL	NULL	83	5988
1970	100	114741	141	164990	5	534	76	5921
1971	111	97302	158	150492	25	1546	73	3832
1972	140	120995	190	174260	40	1602	104	4957
1973	137	92282	182	147072	48	1822	96	4202
1974	139	89675	202	142495	54	2065	107	4517
1975	143	164833	201	159815	66	3262	91	5461
1976	123	152760	166	126854	58	2844	96	6351
1977	119	122355	138	52421	77	2298	93	4617
1978	156	186552	194	97186	232	18596	182	11917
1979	138	172771	238	109071	244	20643	251	20628
1980	180	246393	226	94969	209	11943	156	9651
1981	195	217082	237	109449	200	13603	180	11898
1982	173	133747	235	97257	242	14386	172	8576
1983	164	114400	322	162519	246	16390	167	6885
1984	207	235467	295	150735	272	17387	215	8003
1985	182	151699	214	101670	191	14188	142	8507
1986	250	193535	224	73529	257	19526	137	6838
1987	289	252473	222	78773	197	16682	159	10156
1988	227	148241	211	82828	226	20170	151	6489
1989	228	142750	207	90862	173	7112	163	10831
1990	227	156300	309	141707	183	8412	118	3820
1991	212	184668	310	203420	250	13989	155	6751
1992	323	227866	372	207980	219	14286	154	16812
1993	243	205254	322	154577	194	12284	121	12166
1994	299	211838	266	133564	204	14430	107	7811
1995	222	176137	245	103124	201	19664	132	12875
1996	344	276576	295	148925	207	14429	103	7196
1997	327	230136	361	179306	255	16995	182	13587

	Opelu		Akule		Taape		Ulua	
Fiscal year	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1998	241	159954	350	203059	277	21573	177	22456
1999	208	170547	293	195973	212	17345	142	16322
2000	225	185713	284	185869	193	21144	117	7575
2001	214	185394	239	140482	176	20370	123	14019
2002	194	152356	200	108446	145	11760	112	9591
2003	209	214377	151	107384	115	6835	44	2661
2004	176	163963	145	100022	97	5770	5	171
2005	141	100965	103	83258	89	5212	14	369
2006	140	117589	98	69912	84	4747	n.d	n.d.
2007	187	172586	117	87912	87	4846	n.d	n.d.
2008	140	143692	105	65024	100	6282	3	100
2009	213	178821	154	80157	124	8158	n.d	n.d.
2010	197	159413	171	121585	124	8975	6	195
2011	188	168377	150	90770	114	8368	NULL	NULL
2012	166	117301	162	91604	116	9003	NULL	NULL
2013	172	119257	153	92126	110	6238	NULL	NULL
2014	161	96798	129	79606	88	3612	n.d	n.d.
2015	102	80284	128	98014	73	3819	9	230
2016	86	61494	119	100223	57	3058	4	63
10 yr ave	**161**	**129,802**	**139**	**90,702**	**99**	**6,236**	**6**	**147**
20 yr ave	**184**	**148,951**	**181**	**114,037**	**132**	**9,706**	**72**	**6,718**

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.3.4.2 Purse Seine Net (Pelagic)

The purse seine net (pelagic) gear was standardized in October 2002 when the revised fishing reports were implemented. This gear was formerly called the akule or bag net by surrounding a school of fish with a net and drawing the bottom of the net closed to form a bag. In recent years this method was used by a few highliners to land large volumes of akule. The largest operation ended a few years ago and the vessel was converted to the longline fleet. Recent annual landings may not be available due to data confidentiality. Fishers who use this type of operation where the fish end up being entangled in the mesh will opt to report the method as gill net.

Table 20. HDAR MHI Fiscal Annual CREMUS Finfish Catch (Lbs. caught) Summary (1966 - 2016) by Species and 2nd Gear: Purse seine net (pelagic).

Fiscal Year	**Akule**		**Ulua (misc.)**		**Kala**		**Taape**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	9	430069	n.d.	n.d.	NULL	NULL	NULL	NULL
1967	8	541816	3	10163	n.d.	n.d.	NULL	NULL
1968	19	802810	4	6860	3	5214	NULL	NULL
1969	22	575744	5	14359	5	3822	NULL	NULL
1970	32	764641	n.d.	n.d.	5	3168	NULL	NULL
1971	14	604113	3	1332	3	4500	NULL	NULL
1972	19	527806	n.d.	n.d.	4	335	NULL	NULL
1973	27	563319	4	1919	n.d.	n.d.	NULL	NULL
1974	25	331655	n.d.	n.d.	n.d.	n.d.	NULL	NULL
1975	21	233349	4	341	n.d.	n.d.	n.d.	n.d.
1976	37	136603	3	4607	n.d.	n.d.	n.d.	n.d.
1977	24	369813	NULL	NULL	n.d.	n.d.	NULL	NULL
1978	15	235862	n.d.	n.d.	n.d.	n.d.	NULL	NULL
1979	27	198657	NULL	NULL	n.d.	n.d.	NULL	NULL
1980	25	271103	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1981	24	100923	NULL	NULL	NULL	NULL	NULL	NULL
1982	18	159716	NULL	NULL	NULL	NULL	NULL	NULL
1983	26	152571	NULL	NULL	NULL	NULL	n.d.	n.d.
1984	31	322873	n.d.	n.d.	3	1028	NULL	NULL

Fiscal Year	**Akule**		**Ulua (misc.)**		**Kala**		**Taape**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1985	13	46523	n.d.	n.d.	NULL	NULL	NULL	NULL
1986	6	53683	n.d.	n.d.	NULL	NULL	n.d.	n.d.
1987	13	19779	n.d.	n.d.	NULL	NULL	NULL	NULL
1988	12	10660	NULL	NULL	NULL	NULL	NULL	NULL
1989	25	262304	NULL	NULL	NULL	NULL	NULL	NULL
1990	21	105824	n.d.	n.d.	NULL	NULL	NULL	NULL
1991	26	102669	NULL	NULL	NULL	NULL	NULL	NULL
1992	16	47720	NULL	NULL	NULL	NULL	NULL	NULL
1993	8	23160	NULL	NULL	NULL	NULL	NULL	NULL
1994	12	29766	NULL	NULL	NULL	NULL	NULL	NULL
1995	18	294130	NULL	NULL	NULL	NULL	NULL	NULL
1996	14	276916	NULL	NULL	NULL	NULL	NULL	NULL
1997	9	50949	NULL	NULL	NULL	NULL	NULL	NULL
1998	7	27496	n.d.	n.d.	NULL	NULL	n.d.	n.d.
1999	5	55633	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2000	6	105037	NULL	NULL	NULL	NULL	NULL	NULL
2001	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
2002	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2003	3	286796	NULL	NULL	n.d.	n.d.	n.d.	n.d.
2004	6	276164	NULL	NULL	NULL	NULL	n.d.	n.d.
2005	5	427938	NULL	NULL	n.d.	n.d.	n.d.	n.d.
2006	4	356297	NULL	NULL	NULL	NULL	NULL	NULL

Fiscal Year	**Akule**		**Ulua (misc.)**		**Kala**		**Taape**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
2007	3	374871	NULL	NULL	NULL	NULL	NULL	NULL
2008	n.d.	n.d.	NULL	NULL	NULL	NULL	n.d.	n.d.
2009	4	98213	NULL	NULL	n.d.	n.d.	n.d.	n.d.
2010	8	52604	NULL	NULL	NULL	NULL	NULL	NULL
2011	n.d.	n.d.	NULL	NULL	n.d.	n.d.	n.d.	n.d.
2012	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
2013	n.d.	n.d.	NULL	NULL	NULL	NULL	n.d.	n.d.
2014	NULL	NULL	NULL	NULL	NULL	NULL	n.d.	n.d.
2015	4	23735	NULL	NULL	NULL	NULL	n.d.	n.d.
2016	n.d.	n.d.	NULL	NULL	NULL	NULL	n.d.	n.d.
10 yr ave	**3**	**143223**	**NULL**	**NULL**	**n.d.**	**n.d.**	**n.d.**	**n.d.**
20 yr ave	**5**	**155377**	**n.d.**	**n.d.**	**n.d.**	**n.d.**	**n.d.**	**n.d.**

n.d. = non-disclosure due to data confidentiality

NULL = no available data

1.3.4.3 Lay Gill Net

The lay gill net gear was standardized in October 2002 when the revised fishing reports were implemented. This gear is defined more like a method in that it is net that captures fish by entangling the fish head in the mesh. Subsequently, most fishers who use mesh net and entangle the fish will report this method.

Table 21. HDAR MHI Fiscal Annual CREMUS Finfish Catch (Lbs. caught) Summary (1966 - 2016) by Species and 3rd Gear: Lay gill net.

Fiscal Year	**Akule**		**Weke (misc.)**		**Amaama**		**Kala**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	9	22711	23	6421	25	14090	9	777
1967	6	14380	26	10865	25	19491	12	2789
1968	13	48949	29	12389	19	16964	9	633
1969	17	37858	43	11405	30	22603	11	2709
1970	17	35368	56	24342	35	14449	19	7326
1971	22	86067	54	16467	36	17357	23	6038
1972	27	104361	49	15346	34	15600	29	10785
1973	35	94435	68	21882	42	13898	24	7127
1974	53	148772	71	23164	41	15358	40	18656
1975	53	188093	61	27097	44	12100	51	15742
1976	35	139046	66	27985	28	11021	46	10705
1977	47	208639	79	24005	35	13304	51	10827
1978	51	144587	87	31425	46	13230	58	16611
1979	33	92734	84	15208	38	15676	45	8606
1980	32	170266	70	37174	39	8369	47	8049
1981	31	173429	73	55584	36	8031	42	6728
1982	22	80563	62	36216	40	6900	39	5362
1983	29	166452	58	32332	33	5723	36	6678
1984	36	142881	62	28323	35	3998	31	2622
1985	22	109702	31	8541	16	2581	19	1383

Fiscal Year	**Akule**		**Weke (misc.)**		**Amaama**		**Kala**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1986	19	61882	22	6857	17	1773	14	2622
1987	13	26469	22	9146	22	3721	13	7782
1988	19	21536	30	8386	17	1296	15	8313
1989	22	33648	43	11727	13	1427	28	4542
1990	26	223344	23	7052	15	2046	11	326
1991	27	114547	30	6467	12	276	21	2481
1992	33	155760	36	8836	14	7820	21	2086
1993	35	158397	34	11727	14	8500	15	2726
1994	30	131655	35	5767	14	5636	26	2396
1995	28	99625	36	10008	16	4658	17	1747
1996	25	109947	36	19069	14	6026	31	7245
1997	27	182017	29	11848	16	4904	25	3779
1998	23	205954	24	6283	10	5469	17	3986
1999	25	198943	22	6960	13	3537	12	1130
2000	23	217039	18	2851	14	2862	15	4291
2001	27	140410	20	2448	11	5759	15	9788
2002	20	42247	14	3875	9	5423	13	8110
2003	20	97978	12	4592	12	7054	15	11198
2004	19	114786	8	2021	11	7089	12	4918
2005	25	135373	7	450	11	8214	14	7841
2006	17	74215	n.d.	n.d.	11	6116	15	7357
2007	15	128642	NULL	NULL	6	8515	11	8193

Fiscal Year	**Akule**		**Weke (misc.)**		**Amaama**		**Kala**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
2008	16	112086	NULL	NULL	10	11905	5	6109
2009	16	59712	3	206	10	8102	9	6123
2010	19	112663	4	1152	12	6038	10	11105
2011	21	169952	n.d.	n.d.	8	6177	12	12392
2012	19	153280	n.d.	n.d.	4	14111	12	10453
2013	23	128601	NULL	NULL	12	5400	10	16716
2014	14	144310	NULL	NULL	11	5802	12	10367
2015	23	206132	NULL	NULL	8	5141	11	13473
2016	19	187154	NULL	NULL	6	3601	6	12364
10 yr ave	**19**	**140,253**	**4**	**679**	**9**	**7,479**	**10**	**10,730**
20 yr ave	**21**	**140,575**	**15**	**3,881**	**10**	**6,561**	**13**	**8,485**

n.d. = non-disclosure due to data confidentiality

NULL = no data available

1.3.4.4 Seine Net

The seine net gear was standardized in October 2002 when the revised fishing reports were implemented. This gear is defined as using a net by moving it through the water to surround a school of fish and corralling and trapping them within the walls of the net. Fishers who use this type of operation where the fish end up being entangled in the mesh will opt to report the method as gill net.

Table 22. HDAR MHI Fiscal Annual CREMUS Finfish Catch (Lbs. caught) Summary (1977 - 2016) by Species and fourth Gear: Seine net.

Fiscal Year	Akule		Weke (misc.)		Taape		Opelu	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	n.d.	n.d.	3	5214	NULL	NULL	n.d.	n.d.
1967	n.d.	n.d.	4	4654	NULL	NULL	n.d.	n.d.
1968	n.d.	n.d.	3	683	NULL	NULL	n.d.	n.d.
1969	3	17337	5	3339	NULL	NULL	n.d.	n.d.
1970	n.d.	n.d.	3	1179	NULL	NULL	n.d.	n.d.
1971	n.d.	n.d.	3	1519	NULL	NULL	n.d.	n.d.
1972	n.d.	n.d.	3	383	NULL	NULL	n.d.	n.d.
1973	n.d.	n.d.	3	336	NULL	NULL	n.d.	n.d.
1974	3	14740	n.d.	n.d.	NULL	NULL	n.d.	n.d.
1975	n.d.	n.d.	NULL	NULL	NULL	NULL	n.d.	n.d.
1976	n.d.	n.d.	n.d.	n.d.	NULL	NULL	n.d.	n.d.
1977	5	74825	4	1800	n.d.	n.d.	n.d.	n.d.
1978	n.d.	n.d.	10	21233	4	12207	NULL	NULL
1979	n.d.	n.d.	19	30891	15	17900	n.d.	n.d.
1980	n.d.	n.d.	12	17748	6	7372	n.d.	n.d.
1981	NULL	NULL	8	7508	n.d.	n.d.	NULL	NULL
1982	5	21701	9	14804	6	14106	n.d.	n.d.
1983	6	48543	11	14865	6	14837	n.d.	n.d.
1984	6	41584	5	7539	3	1355	NULL	NULL
1985	4	7548	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Fiscal Year	**Akule**		**Weke (misc.)**		**Taape**		**Opelu**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1986	n.d.	n.d.	3	8168	n.d.	n.d.	n.d.	n.d.
1987	4	68407	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1988	3	79020	6	8426	3	1165	n.d.	n.d.
1989	n.d.	n.d.	5	2033	n.d.	n.d.	NULL	NULL
1990	10	274936	4	2123	3	451	n.d.	n.d.
1991	12	222235	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1992	13	247721	9	6998	8	14558	NULL	NULL
1993	8	394896	10	12045	5	22492	n.d.	n.d.
1994	7	198718	9	5130	8	12948	NULL	NULL
1995	8	252684	6	6072	6	15149	n.d.	n.d.
1996	5	44863	8	9763	6	9248	n.d.	n.d.
1997	9	97418	6	12556	6	6169	n.d.	n.d.
1998	10	698010	6	12103	6	19641	n.d.	n.d.
1999	7	589149	12	13361	8	18275	n.d.	n.d.
2000	9	636089	5	6236	5	13654	NULL	NULL
2001	10	579500	7	8844	6	12386	n.d.	n.d.
2002	4	330385	6	4579	3	4978	n.d.	n.d.
2003	3	53492	6	1670	7	10507	n.d.	n.d.
2004	5	92423	7	1747	13	11169	3	364
2005	4	80927	n.d.	n.d.	9	28648	n.d.	n.d.
2006	6	44799	n.d.	n.d.	13	22816	NULL	NULL
2007	5	75070	NULL	NULL	13	16953	NULL	NULL

Fiscal Year	**Akule**		**Weke (misc.)**		**Taape**		**Opelu**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
2008	6	53194	n.d.	n.d.	11	19307	3	2512
2009	8	71279	NULL	NULL	15	20945	n.d.	n.d.
2010	11	86288	n.d.	n.d.	17	15492	3	1811
2011	8	29822	n.d.	n.d.	13	29445	n.d.	n.d.
2012	9	42285	n.d.	n.d.	12	12186	3	1064
2013	4	19837	n.d.	n.d.	10	18030	n.d.	n.d.
2014	4	18147	NULL	NULL	14	10728	n.d.	n.d.
2015	5	36252	NULL	NULL	11	16408	n.d.	n.d.
2016	10	102076	NULL	NULL	9	19144	NULL	NULL
10 yr ave	**7**	**53,425**			**13**	**17,864**		
20 yr ave	**7**	**186,822**	**7**	**7,637**	**10**	**16,344**		

n.d. = non-disclosure due to data confidentiality

NULL = no data available

Table 23. HDAR MHI Fiscal Annual CREMUS Finfish Catch (Lbs. Caught) Summary (1966-2016) by Species and fifth Gear: Spear.

Fiscal Year	**Uhu (misc.)**		**Palani**		**Kala**		**Manini**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1967	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
1968	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

1969	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1970	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1971	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1972	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1973	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1974	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1975	n.d.	n.d.	n.d.	n.d.	NULL	NULL	NULL	NULL
1976	6	350	4	96	NULL	NULL	4	23
1977	12	419	3	100	n.d.	n.d.	n.d.	n.d.
1978	47	8843	5	220	n.d.	n.d.	n.d.	n.d.
1979	58	11970	7	241	n.d.	n.d.	3	50
1980	56	12564	25	568	7	169	19	362
1981	50	11173	26	891	10	153	17	340
1982	45	10491	22	885	11	241	17	397
1983	42	16284	23	2992	10	1407	16	979
1984	50	15855	28	3014	13	161	20	563
1985	57	17152	28	1709	24	1259	28	1435
1986	70	23967	36	2026	14	1167	32	1225
1987	69	24905	31	3141	14	792	29	1531
1988	68	35479	30	3366	16	963	30	1595
1989	64	42786	34	6223	25	1016	34	2135
1990	50	20253	24	2133	12	294	27	1292
1991	74	19331	41	3151	26	832	27	582
1992	67	27060	32	2624	22	638	35	771

1993	72	20251	41	4673	26	1059	35	1103
1994	78	31501	44	4665	33	2271	43	1661
1995	94	32250	50	7972	49	5106	51	6281
1996	102	25995	57	7940	46	2925	52	3175
1997	99	20990	45	2094	38	1686	44	2772
1998	90	25193	51	4035	34	2565	47	1873
1999	85	23518	45	3220	37	2357	48	1406
2000	88	22984	45	4530	39	2083	43	2134
2001	78	13914	40	4630	33	2152	41	2847
2002	78	14865	39	3327	43	3502	39	1128
2003	81	14980	43	7605	38	5106	34	6466
2004	63	14265	41	7077	30	6915	30	4949
2005	57	15965	37	13607	26	10391	31	3701
2006	58	16426	37	6952	23	7072	39	4235
2007	64	18122	46	6915	32	5624	45	5827
2008	65	23266	39	9178	26	6347	42	5554
2009	93	31139	63	10792	52	6101	55	5635
2010	77	43112	49	12165	42	7833	42	9714
2011	81	62728	46	19114	38	15299	47	9982
2012	79	66193	44	21736	45	19742	52	11454
2013	84	69873	53	20516	45	18659	45	10532
2014	67	51217	38	14558	32	10619	38	7024
2015	56	31992	33	12320	26	9690	32	4283
2016	42	23749	23	10110	21	5368	26	5950

10 yr ave	**71**	**42,139**	**43**	**13,740**	**36**	**10,528**	**42**	**7,596**
20 yr ave	**74**	**30,225**	**43**	**9,724**	**35**	**7,456**	**41**	**5,373**

1.3.5 Catch Parameters by Gear

The top gear in this group category is inshore handline where the driver species landed are opelu and akule. The CPUE is basically flat throughout the time series at about 68 lbs. per trip. In the most recent years, the number of fishers and trips are about half the levels observed in the first 25 years of the time series. The driver species are landed by the more efficient net methods with higher CPUEs.

Table 24. . Time series of CPUE by dominant fishing methods from CREMUS Finfish (1966-2016).

Fiscal Year	**Inshore Handline**				**Purse Seine Net (Pelagic)**				**Lay Gill Net**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
1966	150	3774	266302	70.56	9	147	430497	2928.55	45	419	49542	118.24
1967	182	4008	309477	77.21	8	146	553059	3788.08	50	458	57619	125.81
1968	158	3793	297015	78.31	20	262	821723	3136.35	44	538	91095	169.32
1969	188	3978	339863	85.44	22	265	598758	2259.46	73	570	84914	148.97
1970	215	4191	300057	71.6	32	312	778068	2493.81	88	701	94010	134.11
1971	266	4082	269197	65.95	14	251	619914	2469.78	100	708	137975	194.88
1972	292	4898	318019	64.93	19	220	531166	2414.39	97	723	158686	219.48
1973	300	4009	262107	65.38	27	249	578496	2323.28	122	850	167162	196.66
1974	347	4125	255203	61.87	25	202	336492	1665.8	151	1140	239854	210.4
1975	344	4498	352409	78.35	22	215	238058	1107.25	144	1230	288651	234.68
1976	312	3993	305383	76.48	38	182	144679	794.94	137	1182	277074	234.41
1977	299	3340	201757	60.41	25	138	370673	2686.04	170	1481	351439	237.3
1978	522	4331	360820	83.31	16	97	237134	2444.68	190	1205	258359	214.41
1979	557	3074	363052	118.1	27	104	198671	1910.3	162	705	161428	228.98
1980	495	4126	385421	93.41	27	228	271488	1190.74	147	1110	280779	252.95

Fiscal Year	**Inshore Handline**				**Purse Seine Net (Pelagic)**				**Lay Gill Net**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
1981	539	5442	371769	68.31	25	208	104009	500.04	140	1345	352970	262.43
1982	512	4526	273897	60.52	18	230	159754	694.58	115	1248	199378	159.76
1983	550	5628	316215	56.19	27	241	153022	634.95	121	1271	279881	220.21
1984	640	6638	438069	65.99	32	251	334178	1331.39	125	1025	225017	219.53
1985	593	5655	306035	54.12	13	56	46551	831.27	57	638	141943	222.48
1986	594	5997	315878	52.67	6	48	54278	1130.79	50	454	84349	185.79
1987	567	6230	385860	61.94	13	36	20258	562.72	47	486	60314	124.1
1988	557	5373	286062	53.24	14	32	11308	353.38	51	454	57236	126.07
1989	546	4890	279454	57.15	26	113	263017	2327.58	73	595	79365	133.39
1990	617	5718	340318	59.52	21	91	105841	1163.09	58	577	245178	424.92
1991	612	6414	440419	68.67	26	121	102669	848.5	55	532	145638	273.76
1992	663	7115	493187	69.32	16	73	47720	653.7	67	700	192317	274.74
1993	587	6044	403974	66.84	8	27	23160	857.78	71	922	198350	215.13
1994	605	6023	389643	64.69	12	35	29766	850.46	67	747	174593	233.73
1995	589	5626	335008	59.55	18	54	294130	5446.85	72	717	147546	205.78
1996	641	6813	466273	68.44	14	88	276929	3146.92	66	747	201023	269.11
1997	705	7550	472493	62.58	9	27	50949	1887	64	747	237614	318.09

Fiscal Year	**Inshore Handline**				**Purse Seine Net (Pelagic)**				**Lay Gill Net**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
1998	706	7630	444827	58.3	8	35	28328	809.37	52	712	245845	345.29
1999	583	6419	430366	67.05	6	73	62049	849.99	52	674	247793	367.65
2000	571	6891	424637	61.62	7	48	105931	2206.9	42	680	254315	373.99
2001	546	6259	387024	61.83	3	22	4397	199.86	37	616	179294	291.06
2002	477	5270	302263	57.36	NULL	NULL	NULL	0	37	467	92792	198.7
2003	389	4596	348882	75.91	8	22	290257	13193.5	47	551	182279	330.81
2004	326	4006	285912	71.37	12	57	291421	5112.65	43	488	168519	345.33
2005	267	3291	207344	63	8	28	429217	15329.18	49	447	174188	389.68
2006	266	2733	203102	74.31	5	23	356478	15499.04	38	384	110986	289.03
2007	314	3620	277141	76.56	4	16	375211	23450.69	28	327	156379	478.22
2008	284	3306	226571	68.53	6	84	262029	3119.39	31	287	150939	525.92
2009	390	4251	285604	67.19	7	18	101714	5650.78	36	203	86770	427.44
2010	382	4487	308256	68.7	8	22	52804	2400.18	39	328	145384	443.24
2011	365	4099	287173	70.06	n.d.	n.d.	n.d.	n.d.	39	407	217742	534.99
2012	336	3788	237462	62.69	n.d.	n.d.	n.d.	n.d.	33	398	201600	506.53
2013	345	3415	236692	69.31	n.d.	n.d.	n.d.	n.d.	41	441	178374	404.48
2014	283	2923	197882	67.7	n.d.	n.d.	n.d.	n.d.	34	461	186918	405.46

Fiscal Year	**Inshore Handline**				**Purse Seine Net (Pelagic)**				**Lay Gill Net**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
2015	238	2693	198906	73.86	7	34	27818	818.18	39	511	244790	479.04
2016	210	2522	180318	71.5	3	15	16974	1131.6	37	452	231673	512.55
10 yr ave	315	3,510	243,601	70	6	32	139,425	6,095	36	382	180,057	472
20 yr ave	399	4,487	297,143	67	7	35	163,705	5,729	41	479	184,710	398

Fiscal Year	**Seine Net**				**Spear**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
1966	5	31	18394	593.35	NULL	NULL	NULL	0
1967	4	91	74956	823.69	n.d.	n.d.	n.d.	n.d.
1968	6	83	30244	364.39	NULL	NULL	NULL	0
1969	7	119	89370	751.01	NULL	NULL	NULL	0
1970	5	81	36905	455.62	NULL	NULL	NULL	0
1971	3	74	29123	393.55	NULL	NULL	NULL	0
1972	3	64	6789	106.08	NULL	NULL	NULL	0
1973	4	35	20873	596.37	n.d.	n.d.	n.d.	n.d.
1974	4	32	19948	623.38	NULL	NULL	NULL	0

Fiscal Year	**Seine Net**				**Spear**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
1975	3	4	5246	1311.5	n.d.	n.d.	n.d.	n.d.
1976	3	36	358799	9966.64	15	39	1287	33
1977	11	65	89655	1379.31	23	51	1319	25.86
1978	11	97	63475	654.38	70	318	16631	52.3
1979	30	162	91355	563.92	74	327	19001	58.11
1980	13	52	37893	728.71	78	394	26011	66.02
1981	10	54	15921	294.83	72	552	28336	51.33
1982	18	116	82967	715.23	57	495	27562	55.68
1983	21	116	290269	2502.32	62	455	34102	74.95
1984	14	75	62692	835.89	71	491	30171	61.45
1985	8	21	15389	732.81	82	800	45158	56.45
1986	6	64	37930	592.66	90	716	48877	68.26
1987	6	110	112255	1020.5	92	770	53505	69.49
1988	11	101	100070	990.79	92	833	69271	83.16
1989	9	63	35218	559.02	92	792	78910	99.63
1990	15	118	283108	2399.22	82	628	44447	70.78
1991	13	94	240900	2562.77	99	749	47338	63.2

Fiscal Year	**Seine Net**				**Spear**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
1992	20	186	298547	1605.09	96	895	54082	60.43
1993	20	277	464809	1678.01	96	751	49072	65.34
1994	15	109	238403	2187.18	115	875	61625	70.43
1995	14	129	300961	2333.03	132	1094	75764	69.25
1996	15	162	99743	615.7	143	1047	58782	56.14
1997	17	146	139146	953.05	140	802	40931	51.04
1998	17	198	755425	3815.28	128	912	50731	55.63
1999	20	188	643390	3422.29	119	861	47853	55.58
2000	13	130	667234	5132.57	115	822	50685	61.66
2001	18	116	613925	5292.46	110	673	38805	57.66
2002	10	65	361127	5555.8	108	637	35665	55.99
2003	15	166	138804	836.17	105	672	47636	70.89
2004	23	229	195862	855.29	80	696	47247	67.88
2005	17	238	200324	841.7	78	752	57827	76.9
2006	21	219	151261	690.69	82	729	51233	70.28
2007	24	215	187849	873.72	96	882	57313	64.98
2008	23	209	144626	691.99	81	989	64845	65.57

Fiscal Year	**Seine Net**				**Spear**			
	No. License	No. Trips	Lbs. Caught	CPUE	No. License	No. Trips	Lbs. Caught	CPUE
2009	28	276	164758	596.95	128	1332	82441	61.89
2010	33	335	190900	569.85	110	1505	119727	79.55
2011	23	294	149084	507.09	109	1522	169297	111.23
2012	24	177	109493	618.6	109	1458	185632	127.32
2013	18	173	98394	568.75	114	1417	187608	132.4
2014	23	193	105467	546.46	101	1026	123958	120.82
2015	21	165	117859	714.3	86	966	86790	89.84
2016	20	178	167564	941.37	63	675	66797	98.96
10 yr ave	24	222	143,599	663	100	1,177	114,441	95
20 yr ave	20	196	265,125	1,701	103	966	80,651	79

n.d. = non-disclosure due to data confidentiality

1.4 CRUSTACEAN

1.4.1 Fishery Descriptions

This species group category is comprised of the *Heterocarpus* deep water shrimps (*H. laevigatus* and *H. ensifer*), spiny (*Panulirus marginatus* and *P. Penicillatus*) and slipper lobsters (*S. haanii* and *S. squammosus*), kona crab (*R. ranina*), kuahonu crab (*P. Sanguinolentus*), Hawaiian crab (*P. vigil*), Opaelolo (*Penaeus marginatus*), and aama crab (*G. tenuicrustatus*). The main gear types are shrimp trap, loop net, trap miscellaneous, and crab trap.

1.4.2 Dashboard Statistics

The collection of commercial Crustacean fishing reports comes from two sources: paper report received by mail or fax or pdf copy of it via e-mail; and report filed online through the Online Fishing Report system (OFR). The Crustacean landings are reported by commercial fishers on the Monthly Fishing Report or the Net, Trap, Dive Activity Report or the MHI Deep-7 Bottomfish Fishing Trip Report.

Refer to data processing procedures documented in the Deep-7 BMUS section for paper fishing reports and fishing reports filed online. Database assistants and data monitoring associates will enter the paper Monthly Fishing Report information within 4 weeks, and the Net, Trap, Dive Activity Report and the MHI Deep-7 Bottomfish Fishing Trip Report within 2 business days.

1.4.2.1 Historical Summary

Table 25. Annual fishing parameters for the Crustacean fishery comparing current values with short-term (10 years) and long-term (20 years) averages.

Fishery	Parameters	2016 Values	2016 Comparative Trends	
			Short Average (last 10 years)	**Long Average (last 20 years)**
Crustacean	No. License	56	↓ 19.8%	↓ 19.6%
	Trips	604	↓ 17%	↓ 2.3%
	No. Caught	147,281	↓ 26.8%	↓ 0.02%
	Lbs. Caught	52,866	↓ 15.9%	↓ 0.02%

1.4.2.2 Species Summary

Table 26. Annual indicators for the Crustacean fishery comparing current estimates with the short-term (10 years) and the long-term (20 years) average.

Methods	Fishery indicators	2016 values	2016 Comparative Trends	
			Short Average (10 years)	Long Average (20 years)
Shrimp trap	H. laevigatus	27,009 lbs	↑ 11.1%	↑ 0.04%
	No. Lic.	5	↓ 19.4%	↓ 483.9%
	No. Trips	171	↓ 10.9%	↓ 11.2%
	Lbs Caught	27,041 lbs	↑ 9.9%	↑ 0.03%
	CPUE	158.13 lbs/trip	↑ 33.3%	↑ 10.5%
Loop net	Kona crab	2,512 lbs	↓ 66%	↓ 0.5%
	No. Lic.	23	↓ 33.1%	↓ 62.5%
	No. Trips	49	↓ 63.1%	↓ 34.8%
	Lbs Caught	2,525 lbs	↓ 65.9%	↓ 0.5%
	CPUE	51.53 lbs/trip	↓ 6.4%	↓ 8.6%
Hand grab	Green spiny lobster	4,739 lbs	↓ 44.8%	N/A
	Red spiny lobster	5,250 lbs	↓ 46.4%	N/A
	No. Lic.	12	↓ 38.1%	↓ 131.5%
	No. Trips	158	↓ 35.5%	↓ 14.5%
	Lbs Caught	5,499 lbs	↓ 44.9%	↓ 0.5%
	CPUE	34.8 lbs/trip	↓ 14.9%	↓ 39.9%

1.4.3 Time Series Statistics

1.4.3.1 Commercial Fishing Parameters

Table 27. Time series of commercial fishermen reports for Crustacean fishery (1966-2016).

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1966	64	805	234	12042	33264
1967	74	759	259	3814	38359
1968	56	592	205	2313	40873
1969	84	817	268	4580	56873
1970	75	886	269	13514	82730
1971	94	1248	352	67103	104014
1972	92	1070	319	3479	119988
1973	77	942	293	2485	107373
1974	113	911	321	14124	80283
1975	109	1123	320	10047	89689
1976	125	1041	337	9784	74056
1977	125	1199	381	10999	64335
1978	138	781	403	10678	68289
1979	115	472	309	7596	42366
1980	111	487	257	5216	24689
1981	117	631	290	6480	27641
1982	111	740	325	4370	30683
1983	121	865	354	12732	38359
1984	170	1251	436	12867	238819

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1985	160	1357	440	14086	110456
1986	160	1000	431	9078	53374
1987	173	1048	422	12804	51870
1988	124	806	300	7807	48713
1989	106	596	249	3984	74013
1990	122	747	278	7526	377734
1991	132	845	324	10311	123992
1992	148	935	339	13526	77038
1993	129	831	319	7729	86093
1994	130	821	323	6627	100993
1995	140	856	383	6715	117203
1996	172	1016	405	8980	119882
1997	159	785	365	11909	79349
1998	157	945	388	13987	80900
1999	157	802	365	14865	242736
2000	149	782	345	18691	53546
2001	128	615	280	14616	34803
2002	113	576	275	14717	32919
2003	96	495	221	48737	35703
2004	85	499	195	49743	36308
2005	82	737	188	75462	97915
2006	74	789	193	83508	146245
2007	59	577	174	92091	41580

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
2008	67	726	200	159436	67057
2009	83	761	212	160505	59563
2010	78	872	235	169993	70786
2011	93	766	246	141811	60222
2012	73	667	212	145928	40785
2013	64	756	213	253927	69657
2014	66	870	206	534365	100880
2015	59	677	176	205648	65576
2016	56	604	188	147281	52866
10 yr ave	72	746	207	194721	72235
20 yr ave	101	736	255	110946	76821

1.4.4 Top 4 Species Per Gear Type

1.4.4.1 Shrimp Trap

This gear code was established in 1985. Prior to 1985 all trap activities were reported under trap miscellaneous gear. The principal species taken by shrimp trap or shrimp pot are the deep water heterocarpus shrimp. There are only a hand-full of resident fishers in the state who actively fish for heterocarpus. This fishery pulses every 5 to 7 years when large vessels from the mainland return to the islands to harvest the heterocarpus, then land it in the state for export to external markets.

Table 28. HDAR MHI Fiscal Annual Crustacean Catch (Lbs. caught) Summary (1987 - 2016) by species and Top Gear: Shrimp trap.

Fiscal Year	**Laevigatus**		**Ensifer**		**Opaelolo**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught

Fiscal Year	Laevigatus		Ensifer		Opaelolo	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	NULL	NULL	NULL	NULL	NULL	NULL
1967	NULL	NULL	NULL	NULL	NULL	NULL
1968	NULL	NULL	NULL	NULL	NULL	NULL
1969	NULL	NULL	NULL	NULL	NULL	NULL
1970	NULL	NULL	NULL	NULL	NULL	NULL
1971	NULL	NULL	NULL	NULL	NULL	NULL
1972	NULL	NULL	NULL	NULL	NULL	NULL
1973	NULL	NULL	NULL	NULL	NULL	NULL
1974	NULL	NULL	NULL	NULL	NULL	NULL
1975	NULL	NULL	NULL	NULL	NULL	NULL
1976	NULL	NULL	NULL	NULL	NULL	NULL
1977	NULL	NULL	NULL	NULL	NULL	NULL
1978	NULL	NULL	NULL	NULL	NULL	NULL
1979	NULL	NULL	NULL	NULL	NULL	NULL
1980	NULL	NULL	NULL	NULL	NULL	NULL
1981	NULL	NULL	NULL	NULL	NULL	NULL
1982	NULL	NULL	NULL	NULL	NULL	NULL
1983	NULL	NULL	NULL	NULL	NULL	NULL
1984	NULL	NULL	NULL	NULL	NULL	NULL
1985	NULL	NULL	NULL	NULL	NULL	NULL
1986	NULL	NULL	NULL	NULL	NULL	NULL
1987	3	1796	n.d.	n.d.	n.d.	n.d.

Fiscal Year	**Laevigatus**		**Ensifer**		**Opaelolo**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1988	n.d.	n.d.	3	1568	NULL	NULL
1989	n.d.	n.d.	n.d.	n.d.	NULL	NULL
1990	5	341780	n.d.	n.d.	NULL	NULL
1991	n.d.	n.d.	NULL	NULL	NULL	NULL
1992	n.d.	n.d.	NULL	NULL	n.d.	n.d.
1993	n.d.	n.d.	NULL	NULL	NULL	NULL
1994	4	47737	n.d.	n.d.	NULL	NULL
1995	6	69962	n.d.	n.d.	n.d.	n.d.
1996	4	67077	n.d.	n.d.	n.d.	n.d.
1997	8	32564	n.d.	n.d.	n.d.	n.d.
1998	7	21157	n.d.	n.d.	n.d.	n.d.
1999	5	185139	n.d.	n.d.	NULL	NULL
2000	3	11770	n.d.	n.d.	NULL	NULL
2001	4	6307	n.d.	n.d.	n.d.	n.d.
2002	n.d.	n.d.	NULL	NULL	NULL	NULL
2003	3	4284	n.d.	n.d.	NULL	NULL
2004	n.d.	n.d.	NULL	NULL	NULL	NULL
2005	4	51996	n.d.	n.d.	NULL	NULL
2006	5	99718	n.d.	n.d.	NULL	NULL
2007	n.d.	n.d.	n.d.	n.d.	NULL	NULL
2008	n.d.	n.d.	n.d.	n.d.	NULL	NULL
2009	n.d.	n.d.	n.d.	n.d.	NULL	NULL

Fiscal Year	**Laevigatus**		**Ensifer**		**Opaelolo**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
2010	n.d.	n.d.	n.d.	n.d.	NULL	NULL
2011	n.d.	n.d.	n.d.	n.d.	NULL	NULL
2012	4	6854	n.d.	n.d.	NULL	NULL
2013	5	12759	n.d.	n.d.	NULL	NULL
2014	10	47764	5	927	NULL	NULL
2015	7	27163	3	21	NULL	NULL
2016	5	27009	n.d.	n.d.	NULL	NULL
10 yr ave	4	21113	n.d.	n.d.	NULL	NULL
20 yr ave	4	29966	n.d.	n.d.	n.d.	n.d.

n.d. = non-disclosure due to data confidentiality

NULL = no available data

1.4.4.2 Loop Net

The driver species for this gear is the kona crab with the kuahonu or white crab making up the bycatch. The level of fishing effort and landings has gradually declined since 2000. The state established or amended several regulations on the taking and sale of kona crab. Besides longstanding restrictions for minimum size, berried females and closed season, the added prohibition of taking females hampered the fishing effort of fishers and may have discouraged them from further participation in the fishery. Another factor that impacted the decline in kona crab landings was the retirement of a longtime highline fisher from this fishery a few years ago.

Table 29. HDAR MHI Fiscal Annual Crustacean Catch (Lbs. caught) Summary (1966 - 2016) by species and 2nd Gear: Loop net.

Fiscal Year	**Kona Crab**		**Kuahonu Crab**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	21	10029	NULL	NULL

Fiscal Year	**Kona Crab**		**Kuahonu Crab**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1967	30	17444	NULL	NULL
1968	25	26419	NULL	NULL
1969	28	35939	NULL	NULL
1970	29	35033	NULL	NULL
1971	38	42977	NULL	NULL
1972	40	69328	NULL	NULL
1973	32	62455	NULL	NULL
1974	49	39121	NULL	NULL
1975	58	23996	NULL	NULL
1976	50	23195	n.d.	n.d.
1977	33	15966	NULL	NULL
1978	60	28582	NULL	NULL
1979	51	24674	NULL	NULL
1980	39	8162	NULL	NULL
1981	47	12102	NULL	NULL
1982	48	8291	NULL	NULL
1983	48	9009	NULL	NULL
1984	58	12904	NULL	NULL
1985	71	20846	NULL	NULL
1986	80	27200	NULL	NULL
1987	62	16310	NULL	NULL
1988	47	12475	NULL	NULL

Fiscal Year	**Kona Crab**		**Kuahonu Crab**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1989	32	11790	4	668
1990	32	16118	NULL	NULL
1991	44	22789	NULL	NULL
1992	71	34291	NULL	NULL
1993	66	25305	n.d.	n.d.
1994	70	23770	NULL	NULL
1995	77	22763	NULL	NULL
1996	88	30581	NULL	NULL
1997	86	28893	n.d.	n.d.
1998	82	28611	n.d.	n.d.
1999	90	25417	n.d.	n.d.
2000	84	16908	n.d.	n.d.
2001	61	10035	n.d.	n.d.
2002	64	11372	n.d.	n.d.
2003	51	11755	3	17
2004	49	12685	n.d.	n.d.
2005	51	11750	n.d.	n.d.
2006	38	9143	3	58
2007	33	5653	n.d.	n.d.
2008	35	13136	3	14
2009	43	7519	3	15
2010	39	11449	3	12

Fiscal Year	**Kona Crab**		**Kuahonu Crab**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2011	49	10609	n.d.	n.d.
2012	41	8149	n.d.	n.d.
2013	28	9551	n.d.	n.d.
2014	29	2999	3	19
2015	24	2293	n.d.	n.d.
2016	23	2512	n.d.	n.d.
10 yr ave	36	8050	n.d.	n.d.
20 yr ave	53	13425	n.d.	n.d.

n.d. = non-disclosure due to data confidentiality

NULL = no available data

1.4.4.3 Crab Trap

The gear code for crab trap was established in 1985. Prior to 1985 all trap activities were reported under trap miscellaneous gear. The driver species for this gear is the kuahonu or white crab. Throughout the time series, there is a small group of fishers participating in this fishery numbering no more than eight (8) in a year. There is a market demand for kuahonu crab and the landings are trending upwards for the past eight (8) years, except for 2015 (undisclosed because of data confidentiality.)

Table 30. HDAR MHI Fiscal Annual Crustacean Catch (Lbs. caught) Summary (1986 - 2016) by species and 4th Gear: Crab trap.

Fiscal Year	**Kuahonu Crab**		**Kona Crab**		**Samoan Crab**		**Spiny Lobster**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	3	5399	NULL	NULL	n.d.	n.d.	12	2683
1967	5	4070	NULL	NULL	NULL	NULL	9	2180
1968	4	2757	NULL	NULL	n.d.	n.d.	9	1714

1969	8	2488	n.d.	n.d.	4	305	14	4142
1970	7	19012	n.d.	n.d.	n.d.	n.d.	8	1983
1971	11	42507	n.d.	n.d.	NULL	NULL	11	1878
1972	8	39091	n.d.	n.d.	n.d.	n.d.	12	2886
1973	8	34095	NULL	NULL	n.d.	n.d.	10	3945
1974	11	28858	n.d.	n.d.	NULL	NULL	14	3969
1975	11	52730	n.d.	n.d.	NULL	NULL	13	2599
1976	11	29457	n.d.	n.d.	NULL	NULL	10	1619
1977	10	10024	n.d.	n.d.	n.d.	n.d.	14	4382
1978	7	17015	n.d.	n.d.	n.d.	n.d.	14	5383
1979	3	3409	NULL	NULL	NULL	NULL	12	2139
1980	5	1590	3	2099	n.d.	n.d.	15	4303
1981	5	2054	NULL	NULL	n.d.	n.d.	11	2372
1982	5	2693	n.d.	n.d.	NULL	NULL	12	4937
1983	3	2832	n.d.	n.d.	NULL	NULL	16	4639
1984	5	3167	n.d.	n.d.	NULL	NULL	19	11279
1985	6	7437	n.d.	n.d.	n.d.	n.d.	22	9347
1986	n.d.	n.d.	NULL	NULL	NULL	NULL	3	465
1987	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3	179
1988	n.d.	n.d.	n.d.	n.d.	NULL	NULL	n.d.	n.d.
1989	NULL	NULL	NULL	NULL	NULL	NULL	n.d.	n.d.
1990	NULL	NULL	NULL	NULL	NULL	NULL	n.d.	n.d.
1991	n.d.	n.d.	NULL	NULL	n.d.	n.d.	n.d.	n.d.
1992	n.d.	n.d.	n.d.	n.d.	NULL	NULL	NULL	NULL

1993	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1994	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
1995	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
1996	n.d.	n.d.	n.d.	n.d.	NULL	NULL	NULL	NULL
1997	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
1998	n.d.	n.d.	NULL	NULL	n.d.	n.d.	3	95
1999	n.d.	n.d.	NULL	NULL	NULL	NULL	3	20
2000	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2001	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2002	n.d.	n.d.	NULL	NULL	NULL	NULL	n.d.	n.d.
2003	n.d.	n.d.	NULL	NULL	n.d.	n.d.	NULL	NULL
2004	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2005	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2006	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2007	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2008	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2009	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2010	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2011	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2012	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2013	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2014	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2015	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
2016	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

n.d. = non-disclosure due to data confidentiality

1.4.4.4 Hand/grab for crustaceans

DLNR-DAR standardized the gear/method definitions in October 2002. For the harvesting of crustacean – lobster by hand, the 'Diving' gear code is used. It is defined as "Fishing while swimming free dive (skin diving) or swimming with the assistance of compressed gases (SCUBA, rebreathers, etc.). Examples are lobster or namako diving. Does not include diving with a spear (see spearfishing), a net (see various nets), or for limu or opihi (see handpicking). Typical species: various marine species."

Table 31. HDAR MHI Fiscal Annual Crustacean Catch (Lbs. caught) Summary (1966-2016) by species and Fourth Gear: Hand/Grab.

Fiscal Year	**Green Spiny Lobster**		**Spiny Lobster**		**Red Spiny Lobster**		**A'ama / Black Crab**		**Slipper Lobster**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	NULL	NULL	4	177	NULL	NULL	NULL	NULL	NULL	NULL
1967	NULL	NULL	3	179	NULL	NULL	NULL	NULL	NULL	NULL
1968	NULL	NULL	n.d.	n.d.	NULL	NULL	NULL	NULL	NULL	NULL
1969	NULL	NULL	5	261	NULL	NULL	NULL	NULL	NULL	NULL
1970	NULL	NULL	7	1062	NULL	NULL	NULL	NULL	n.d.	n.d.
1971	NULL	NULL	7	264	NULL	NULL	NULL	NULL	n.d.	n.d.
1972	NULL	NULL	10	505	NULL	NULL	NULL	NULL	NULL	NULL
1973	NULL	NULL	7	267	NULL	NULL	NULL	NULL	NULL	NULL
1974	NULL	NULL	18	767	NULL	NULL	NULL	NULL	n.d.	n.d.
1975	NULL	NULL	6	252	NULL	NULL	NULL	NULL	NULL	NULL
1976	NULL	NULL	7	617	NULL	NULL	NULL	NULL	NULL	NULL
1977	NULL	NULL	11	657	NULL	NULL	NULL	NULL	n.d.	n.d.
1978	NULL	NULL	19	630	NULL	NULL	NULL	NULL	3	111
1979	NULL	NULL	19	764	NULL	NULL	NULL	NULL	4	73
1980	NULL	NULL	14	708	NULL	NULL	NULL	NULL	n.d.	n.d.
1981	NULL	NULL	11	160	NULL	NULL	NULL	NULL	NULL	NULL
1982	NULL	NULL	4	264	NULL	NULL	NULL	NULL	NULL	NULL

1983	NULL	NULL	6	484	NULL	NULL	NULL	NULL	NULL	NULL
1984	NULL	NULL	7	344	NULL	NULL	NULL	NULL	NULL	NULL
1985	NULL	NULL	11	487	NULL	NULL	NULL	NULL	NULL	NULL
1986	NULL	NULL	25	2877	NULL	NULL	n.d.	n.d.	n.d.	n.d.
1987	NULL	NULL	35	3208	NULL	NULL	9	385	3	54
1988	NULL	NULL	33	4369	NULL	NULL	8	840	3	66
1989	NULL	NULL	24	3084	NULL	NULL	5	226	n.d.	n.d.
1990	NULL	NULL	36	3997	NULL	NULL	NULL	NULL	NULL	NULL
1991	NULL	NULL	39	2904	NULL	NULL	NULL	NULL	6	31
1992	NULL	NULL	33	3543	NULL	NULL	NULL	NULL	n.d.	n.d.
1993	NULL	NULL	23	1268	NULL	NULL	NULL	NULL	n.d.	n.d.
1994	NULL	NULL	24	799	NULL	NULL	NULL	NULL	n.d.	n.d.
1995	NULL	NULL	27	2359	NULL	NULL	NULL	NULL	3	26
1996	NULL	NULL	51	6504	NULL	NULL	NULL	NULL	5	81
1997	NULL	NULL	39	5119	NULL	NULL	NULL	NULL	5	58
1998	NULL	NULL	37	8878	NULL	NULL	NULL	NULL	3	25
1999	NULL	NULL	39	6596	NULL	NULL	NULL	NULL	n.d.	n.d.
2000	NULL	NULL	44	8480	NULL	NULL	NULL	NULL	8	83
2001	NULL	NULL	41	7212	NULL	NULL	NULL	NULL	n.d.	n.d.
2002	NULL	NULL	36	9998	NULL	NULL	NULL	NULL	6	38
2003	12	4667	15	1036	24	5396	n.d.	n.d.	n.d.	n.d.
2004	15	4577	n.d.	n.d.	24	6782	3	146	NULL	NULL
2005	14	10023	4	167	19	10263	n.d.	n.d.	NULL	NULL
2006	17	9381	5	387	22	9647	n.d.	n.d.	n.d.	n.d.
2007	12	8645	n.d.	n.d.	15	8990	n.d.	n.d.	n.d.	n.d.
2008	15	7657	n.d.	n.d.	15	7834	NULL	NULL	n.d.	n.d.

2009	18	10695	n.d.	n.d.	21	11149	n.d.	n.d.	n.d.	n.d.
2010	18	10302	n.d.	n.d.	21	14088	n.d.	n.d.	n.d.	n.d.
2011	21	9702	NULL	NULL	26	11479	n.d.	n.d.	NULL	NULL
2012	15	8176	NULL	NULL	20	10350	NULL	NULL	n.d.	n.d.
2013	16	8843	NULL	NULL	18	10429	NULL	NULL	NULL	NULL
2014	10	6594	n.d.	n.d.	12	9329	NULL	NULL	n.d.	n.d.
2015	12	7983	NULL	NULL	15	8971	n.d.	n.d.	NULL	NULL
2016	8	4739	NULL	NULL	9	5250	n.d.	n.d.	NULL	NULL

1.4.5 Catch Parameters by Gear

Table 32. Time series of CPUE by dominant fishing methods from Crustaceans (1966-2016).

Fiscal Year	**Shrimp Trap**				**Kona Crab Net (Loop)**				**Hand/Grab**				**Crab Trap**			
	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE
1966	NULL	NULL	NULL	0	21	178	10029	56.34	4	8	177	22.13	n.d.	n.d.	n.d.	n.d.
1967	NULL	NULL	NULL	0	30	185	17444	94.29	3	4	179	44.75	6	76	2758	36.29
1968	NULL	NULL	NULL	0	25	167	26419	158.2	n.d.	n.d.	n.d.	n.d.	4	96	2624	27.33
1969	NULL	NULL	NULL	0	28	232	35939	154.91	5	16	261	16.31	11	132	4095	31.02
1970	NULL	NULL	NULL	0	29	195	35033	179.66	7	31	1075	34.68	11	73	2384	32.66
1971	NULL	NULL	NULL	0	38	241	42977	178.33	7	16	265	16.56	6	133	3211	24.14
1972	NULL	NULL	NULL	0	40	259	69328	267.68	10	35	505	14.43	9	120	3560	29.67
1973	NULL	NULL	NULL	0	32	230	62455	271.54	7	13	267	20.54	9	66	1354	20.52
1974	NULL	NULL	NULL	0	49	199	39121	196.59	18	49	772	15.76	7	83	2130	25.66
1975	NULL	NULL	NULL	0	58	233	23996	102.99	6	12	252	21	11	141	2694	19.11
1976	NULL	NULL	NULL	0	50	205	23256	113.44	7	22	617	28.05	30	159	5047	31.74
1977	NULL	NULL	NULL	0	33	133	15966	120.05	12	33	723	21.91	43	383	16237	42.39
1978	NULL	NULL	NULL	0	60	227	28582	125.91	22	39	741	19	16	120	3799	31.66
1979	NULL	NULL	NULL	0	51	188	24674	131.24	20	34	837	24.62	21	102	6396	62.71
1980	NULL	NULL	NULL	0	40	101	8192	81.11	15	21	732	34.86	21	98	2779	28.36

Fiscal Year	**Shrimp Trap**				**Kona Crab Net (Loop)**				**Hand/Grab**				**Crab Trap**			
	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE
1981	NULL	NULL	NULL	0	47	143	12102	84.63	11	20	160	8	15	73	2419	33.14
1982	NULL	NULL	NULL	0	48	163	8291	50.87	4	7	264	37.71	16	54	1534	28.41
1983	NULL	NULL	NULL	0	48	148	9305	62.87	6	18	496	27.56	22	93	3730	40.11
1984	NULL	NULL	NULL	0	58	178	12904	72.49	7	17	344	20.24	29	81	2182	26.94
1985	NULL	NULL	NULL	0	71	309	20846	67.46	11	19	487	25.63	16	69	1149	16.65
1986	NULL	NULL	NULL	0	80	302	27200	90.07	29	122	2976	24.39	13	56	755	13.48
1987	5	26	3481	133.88	62	158	16310	103.23	48	219	3774	17.23	9	20	358	17.9
1988	3	44	12934	293.95	47	179	12475	69.69	41	247	5518	22.34	6	7	352	50.29
1989	n.d.	n.d.	n.d.	n.d.	33	140	12458	88.99	29	160	3338	20.86	7	14	312	22.29
1990	5	87	343102	3943.7	32	130	16118	123.98	36	142	3997	28.15	18	78	1233	15.81
1991	n.d.	n.d.	n.d.	n.d.	44	161	22789	141.55	40	179	2935	16.4	12	77	1785	23.18
1992	n.d.	n.d.	n.d.	n.d.	71	316	34291	108.52	33	141	3556	25.22	11	23	524	22.78
1993	n.d.	n.d.	n.d.	n.d.	66	309	25306	81.9	23	80	1277	15.96	12	14	269	19.21
1994	4	75	49505	660.07	70	245	23770	97.02	25	68	824	12.12	9	31	446	14.39
1995	7	103	74697	725.21	77	296	22763	76.9	28	148	2415	16.32	7	26	412	15.85
1996	5	190	70386	370.45	88	329	30581	92.95	52	289	6586	22.79	5	13	114	8.77
1997	9	99	34009	343.53	86	278	28895	103.94	39	200	5184	25.92	n.d.	n.d.	n.d.	n.d.

Fiscal Year	**Shrimp Trap**				**Kona Crab Net (Loop)**				**Hand/Grab**				**Crab Trap**			
	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE
1998	8	82	21537	262.65	82	307	28632	93.26	38	272	8903	32.73	4	7	173	24.71
1999	5	111	186400	1679.2	90	258	25425	98.55	39	186	6604	35.51	5	9	50	5.56
2000	3	72	11798	163.86	84	195	16914	86.74	45	264	8573	32.47	n.d.	n.d.	n.d.	n.d.
2001	6	64	6436	100.56	61	151	10067	66.67	43	193	7273	37.68	n.d.	n.d.	n.d.	n.d.
2002	n.d.	n.d.	n.d.	n.d.	64	179	11382	63.59	37	194	10036	51.73	5	12	53	4.42
2003	3	50	4748	94.96	51	165	11772	71.35	33	175	6600	37.71	3	4	65	16.25
2004	n.d.	n.d.	n.d.	n.d.	49	158	12690	80.32	28	234	7001	29.92	n.d.	n.d.	n.d.	n.d.
2005	4	67	54379	811.63	51	170	11815	69.5	24	300	10512	35.04	NULL	NULL	NULL	0
2006	5	163	103857	637.16	38	160	9201	57.51	23	274	10095	36.84	n.d.	n.d.	n.d.	n.d.
2007	n.d.	n.d.	n.d.	n.d.	33	133	5657	42.53	16	275	9128	33.19	3	20	177	8.85
2008	n.d.	n.d.	n.d.	n.d.	35	221	13150	59.5	16	191	8354	43.74	9	94	1356	14.43
2009	n.d.	n.d.	n.d.	n.d.	43	168	7534	44.85	24	271	11329	41.8	5	109	1475	13.53
2010	n.d.	n.d.	n.d.	n.d.	39	209	11461	54.84	24	361	14422	39.95	4	60	1756	29.27
2011	n.d.	n.d.	n.d.	n.d.	49	190	10622	55.91	30	268	11539	43.06	5	82	1300	15.85
2012	4	95	7140	75.16	41	128	8154	63.7	21	267	10421	39.03	5	57	906	15.89
2013	5	150	12972	86.48	28	106	9554	90.13	19	233	10452	44.86	5	61	1309	21.46
2014	10	316	48691	154.09	29	59	3017	51.14	14	234	9350	39.96	n.d.	n.d.	n.d.	n.d.

Fiscal Year	**Shrimp Trap**				**Kona Crab Net (Loop)**				**Hand/Grab**				**Crab Trap**			
	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE	No Lic	No. Trips	Lbs. Caught	CPUE
2015	7	228	27184	119.23	24	64	2319	36.23	18	191	9230	48.32	5	31	493	15.9
2016	5	171	27041	158.13	23	49	2525	51.53	12	158	5499	34.8	7	36	811	22.53
10 yr ave	NULL	NULL	NULL	0	NULL	NULL	NULL	0	NULL	NULL	NULL	0	NULL	NULL	NULL	0
20 yr ave	4	98	31121	317.56	53	181	13442	74.27	29	244	9080	37.21	4	32	523	16.34

1.5 MOLLUSK AND LIMU

1.5.1 Fishery Descriptions

This species group category is comprised of seaweed or algae including miscellaneous *Gracilaria spp*., limu kohu (*A. taxiformis*), limu manauea (*G. coronopifolia*), ogo (*G. parvispora*), and limu wawaeiole (*U. fasciata*), and mollusks including clam (*T. phililippinarum*), he'e (*O. cyanea*), he'e pu loa (*O. ornatus*), octopus (*Octopus spp*.), hihiwai (*Theodoxus spp*.), opihi ‘alina (yellowfoot, *C. sandwicensis*), opihi makaiauli (black foot, *C. exarata*), opihi (*Cellana spp*.), pupu (top shell).

The top gears for this species group category are handpicked, spear and inshore handline.

1.5.2 Dashboard Statistics

The collection of commercial Mollusk and limu fishing reports comes from two sources: paper report received by mail or fax or pdf copy of it via e-mail; and report filed online through the Online Fishing Report system (OFR). The Mollusk and limu landings are reported by commercial fishers on the Monthly Fishing Report or the Net, Trap, Dive Activity Report.

Refer to data processing procedures documented in the Deep-7 BMUS section for paper fishing reports and fishing reports filed online. Database assistants and data monitoring associate will enter the paper Monthly Fishing Report information within fourweeks, and the Net, Trap, Dive Activity Report within two business days.

1.5.2.1 Historical Summary

Table 33. Annual fishing parameters for the Mollusk and Limu fishery comparing current values with short-term (10 years) and long-term (20 years) averages.

Fishery	Parameters	2016 Values	2016 Comparative Trends	
			Short Average (last 10 years)	Long Average (last 20 years)
Mollusk and Limu	No. License	81	↓ 37.6%	↓ 23.9%
	Trips	1,101	↓ 34.7%	↓ 1.8%
	No. Caught	31,643	↑ 34.8%	↑ 0.2%
	Lbs. Caught	51,315	↓ 13.3%	↓ 0.03%

1.5.2.2 Species Summary

Table 34. Annual indicators for the Mollusk and Limu fishery comparing current values with the short-term (10 years) and the long-term (20 years) average.

Methods	Fishery indicators	2016 values	2016 Comparative Trends	
			Short Average (10 years)	Long Average (20 years)
Hand pick	Opihi	2,180 lbs	↓ 20.6%	↓ 0.4%
	Opihi’alina	9,722 lbs	↓ 32.1%	↓ 0.3%
	Wawaaeiole	No data	↓ 100%	↓ 2.4%
	Limu kohu	3,492 lbs	↓ 12.9%	↓ 0.4%
	No. Lic.	21	↓ 52.8%	↓ 91%
	No. Trips	336	↓ 51.5%	↓ 5.5%
	Lbs Caught	15,431 lbs	↓ 44.9%	↓ 0.2%
	CPUE	45.9 lbs/trip	↑ 13.7%	↑ 52.3%
Spear	Octopus (misc)	251 lbs	↓ 8.4%	↓ 0.1%
	He’e day tako	30,688 lbs	↑ 24.5%	N/A
	No. Lic.	36	↓ 42.4%	↓ 59.7%
	No. Trips	735	↓ 15.9%	↓ 2.1%
	Lbs Caught	22,985 lbs	↑ 24.4%	↑ 0.1%
	CPUE	31.3 lbs/trip	↑ 48%	↑ 185.5%
Inshore handline	Octopus (misc)	297 lbs	↑ 19.5%	↑ 0.6%
	He’e day tako	4,259 lbs	↓ 18.2%	↓ 0.4%
	No. Lic.	16	↓ 23.4%	↓ 80.8%
	No. Trips	87	↓ 53.3%	↓ 23.9%

	Lbs Caught	4,556 lbs	↓ 14.2%	↓ 0.2%
	CPUE	52.4 lbs/trip	↑ 73.7%	↑ 272.8%

1.5.3 Time Series Statistics

1.5.3.1 Commercial Fishing Parameters

Table 35. Time series of commercial fishermen reports for Mollusk and Limu fishery (1966-2016).

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1966	43	435	195	2070	23044
1967	75	996	293	2764	44221
1968	52	651	220	2177	33000
1969	71	831	257	1797	72176
1970	98	1075	338	3683	83503
1971	103	1133	374	3321	85479
1972	111	1265	406	1491	129860
1973	119	1363	429	2499	125317
1974	145	1400	484	67955	103763
1975	136	1292	452	2588	91532
1976	127	1234	423	16005	90835
1977	169	1632	595	5053	133804
1978	180	1119	577	20070	89918
1979	186	738	598	4563	58359
1980	195	1135	562	4730	48302
1981	153	1376	479	3554	36955
1982	128	972	371	1954	26604

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
1983	138	867	386	3036	24502
1984	194	1688	607	7895	57637
1985	160	1837	501	4761	50425
1986	204	2022	670	7001	57333
1987	247	2526	785	8153	71628
1988	211	2106	596	8489	58079
1989	208	2134	610	6494	47015
1990	165	1649	510	3424	29992
1991	175	1551	535	3966	30730
1992	206	1796	613	4775	38103
1993	195	1887	564	5575	41109
1994	192	1866	602	5524	41601
1995	186	2033	600	4536	55517
1996	212	2136	632	5745	41700
1997	207	1832	606	5407	38267
1998	224	2253	718	8324	43896
1999	214	1972	714	5625	35968
2000	190	2306	722	8036	44732
2001	185	2384	685	6534	52219
2002	183	2308	682	6252	48262
2003	150	2264	606	21658	46540
2004	131	2092	544	15049	44820
2005	103	2185	448	8585	46550

Fiscal Year	No. License	Trips	No. Reports	No. Caught	Lbs. Caught
2006	124	1702	447	10301	37217
2007	112	1485	432	15036	33332
2008	126	1451	460	10510	37506
2009	135	1737	500	18247	57779
2010	151	1945	576	16664	66268
2011	149	2150	617	29644	67042
2012	147	1945	587	50022	70837
2013	144	1951	624	21237	78325
2014	132	1748	564	19182	72963
2015	121	1335	452	22631	56162
2016	81	1101	352	31643	51315
10 yr ave	130	1,685	516	23,482	59,153
20 yr ave	150	1,907	567	16,529	51,500

1.5.4 Top Four Species Per Gear Type

1.5.4.1 Handpick

The top gear for this group category is handpick or gleaning. Fishers typically use their hands to gather seaweed or an instrument such as a knife to harvest opihi from the shoreline. Two specific species codes were established in 2002 for opihi. They are the yellow foot and black foot species. Prior to 2002, all opihi species were reported under opihi (misc.). The specific limu species were established in 1985. Prior to 1985, all seaweed species were reported under limu miscellaneous. When the revised fishing reports were implemented in October 2002, DAR launched an outreach campaign to inform fishers to report specific opihi and limu species.

Table 36. HDAR MHI Fiscal Annual Mollusk & Limu Catch (Lbs. caught) Summary (1966 – 2016) by Species and top Gear: Handpick.

Fiscal	**Opihi**	**Opihi'alina**	**Wawaeiole**	**Limu kohu**

Year	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	13	13989	NULL	NULL	NULL	NULL	NULL	NULL
1967	40	36000	NULL	NULL	NULL	NULL	NULL	NULL
1968	26	22994	NULL	NULL	NULL	NULL	NULL	NULL
1969	36	23818	NULL	NULL	NULL	NULL	NULL	NULL
1970	41	20446	NULL	NULL	NULL	NULL	NULL	NULL
1971	46	17229	NULL	NULL	NULL	NULL	NULL	NULL
1972	44	16689	NULL	NULL	NULL	NULL	NULL	NULL
1973	46	17169	NULL	NULL	NULL	NULL	NULL	NULL
1974	51	19558	NULL	NULL	NULL	NULL	NULL	NULL
1975	46	14277	NULL	NULL	NULL	NULL	NULL	NULL
1976	47	18090	NULL	NULL	NULL	NULL	NULL	NULL
1977	54	10494	NULL	NULL	NULL	NULL	NULL	NULL
1978	51	14267	NULL	NULL	NULL	NULL	NULL	NULL
1979	51	14146	NULL	NULL	NULL	NULL	NULL	NULL
1980	48	8435	NULL	NULL	NULL	NULL	NULL	NULL
1981	33	7231	NULL	NULL	NULL	NULL	NULL	NULL
1982	28	6050	NULL	NULL	NULL	NULL	NULL	NULL
1983	32	4765	NULL	NULL	NULL	NULL	NULL	NULL
1984	28	5708	NULL	NULL	NULL	NULL	NULL	NULL
1985	27	4850	NULL	NULL	n.d.	n.d.	n.d.	n.d.
1986	61	10607	NULL	NULL	6	4238	9	2119
1987	88	16748	NULL	NULL	12	5661	23	5373
1988	70	11989	NULL	NULL	6	6254	14	2313

Fiscal Year	**Opihi**		**Opihi'alina**		**Wawaeiole**		**Limu kohu**	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
1989	67	11914	NULL	NULL	3	1260	13	2600
1990	56	7848	NULL	NULL	4	1441	12	3319
1991	55	7618	NULL	NULL	4	1954	24	3180
1992	55	9271	NULL	NULL	9	1982	13	1354
1993	38	5587	NULL	NULL	6	2529	14	1709
1994	40	9879	NULL	NULL	5	820	21	3101
1995	50	13462	NULL	NULL	7	1086	19	2868
1996	52	14012	NULL	NULL	6	1879	14	2592
1997	45	10291	NULL	NULL	6	2346	17	3547
1998	55	11886	NULL	NULL	n.d.	n.d.	23	2999
1999	43	12028	NULL	NULL	n.d.	n.d.	9	1832
2000	35	10338	NULL	NULL	5	3129	16	1608
2001	31	12385	NULL	NULL	5	7328	15	1941
2002	28	12847	NULL	NULL	6	3550	10	2351
2003	21	5145	15	7300	4	2694	10	2606
2004	14	1709	15	8685	n.d.	n.d.	12	3179
2005	5	278	10	8240	n.d.	n.d.	7	1728
2006	7	403	11	8364	n.d.	n.d.	7	2163
2007	11	939	14	6487	5	2158	12	1480
2008	12	372	25	6993	5	4834	9	3061
2009	12	2782	19	14866	9	4013	12	3120
2010	22	5348	28	19521	7	5317	14	4243

Fiscal Year	Opihi		Opihi'alina		Wawaeiole		Limu kohu	
	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught	No. License	Lbs. Caught
2011	14	2984	18	16183	5	5458	10	4643
2012	12	3418	30	15129	6	10643	10	5454
2013	6	1958	18	16475	8	18864	9	4895
2014	7	4902	19	23479	5	2058	9	4659
2015	11	2574	19	14390	3	348	12	5065
2016	5	2180	15	9722	n.d.	n.d.	7	3492
10 yr ave	11	2,746	21	14,325	6	5,966	10	4,011
20 yr ave	20	5,238	18	12,560	6	5,196	12	3,203

n.d. = non-disclosure due to data confidentiality

NULL = no available data

1.5.4.2 Spear

For the secondary gear, spear, the driver species is octopus. Two specific species for octopus to distinguish the day species (*O. cyanea*) from night (*O. ornatus*) were established in 2002. Prior to 2002, all octopus species were reported under octopus (misc.). When the revised fishing reports were implemented in October 2002, DAR launched an outreach campaign to inform fishers to report specific octopus species. The use of spear may or may not include SCUBA apparatus. It is possible that the introduction of SCUBA may have increased fishing power and attributed to the overall increasing octopus landing trends. It should be noted that opihi and limu (misc.) species taken by this gear type are probably reporting discrepancies. Since 2002, fishers were contacted to verify the report discrepancy. The fish report remains unchanged if there is no response from fishers.

Table 37. HDAR MHI Fiscal Annual Mollusk & Limu Catch (Lbs. caught) Summary (1966 - 2016) by Species and 2nd Gear: Spear.

Fiscal	Octopus (misc.)	He'e (Day tako)

Year	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	15	4704	NULL	NULL
1967	20	6573	NULL	NULL
1968	15	5622	NULL	NULL
1969	18	4809	NULL	NULL
1970	27	4609	NULL	NULL
1971	30	5548	NULL	NULL
1972	38	9003	NULL	NULL
1973	41	7358	NULL	NULL
1974	54	9234	NULL	NULL
1975	59	9637	NULL	NULL
1976	51	7237	NULL	NULL
1977	58	12594	NULL	NULL
1978	81	14793	NULL	NULL
1979	81	13712	NULL	NULL
1980	74	16100	NULL	NULL
1981	54	11130	NULL	NULL
1982	45	7131	NULL	NULL
1983	44	6605	NULL	NULL
1984	66	13298	NULL	NULL
1985	63	10544	NULL	NULL
1986	89	14814	NULL	NULL
1987	73	20881	NULL	NULL
1988	68	13547	NULL	NULL

Fiscal Year	**Octopus (misc.)**		**He'e (Day tako)**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1989	71	15351	NULL	NULL
1990	52	6881	NULL	NULL
1991	58	7293	NULL	NULL
1992	71	9354	NULL	NULL
1993	71	10973	NULL	NULL
1994	75	12252	NULL	NULL
1995	74	11505	NULL	NULL
1996	94	11663	NULL	NULL
1997	89	14233	NULL	NULL
1998	100	17594	NULL	NULL
1999	94	11668	NULL	NULL
2000	84	18924	NULL	NULL
2001	80	18857	NULL	NULL
2002	73	15002	NULL	NULL
2003	48	11536	33	5340
2004	17	1012	51	12592
2005	20	2144	45	13028
2006	4	630	56	11489
2007	n.d.	n.d.	47	12472
2008	NULL	NULL	62	14420
2009	5	133	68	21865
2010	8	141	63	22351

Fiscal Year	**Octopus (misc.)**		**He'e (Day tako)**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2011	n.d.	n.d.	75	27910
2012	4	74	66	29521
2013	13	678	69	28045
2014	4	468	61	29875
2015	6	173	55	29358
2016	5	251	33	30688
10 yr ave	6	274	60	24,651
20 yr ave	38	6,678	56	20,640

n.d. = non-disclosure due to data confidentiality

NULL = no available data

1.5.4.3 Inshore Handline

Another popular method to take octopus, especially for the day species, is using a cowrie shell dragged by handline along the bottom. This gear also reported under inshore handline. It should be noted that hihiwai and limu (misc.) species taken by this gear type are probably reporting discrepancies. Since 2002, fishers were contacted to verify the report discrepancy. The fish report remains unchanged if there is no response from fishers.

Table 38. HDAR MHI Fiscal Annual Mollusk & Limu Catch (Lbs. caught) Summary (1966 - 2016) by Species and 3rd Gear: Inshore handline.

Fiscal Year	**Octopus (misc.)**		**He'e (day tako)**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1966	6	139	NULL	NULL
1967	7	117	NULL	NULL
1968	4	83	NULL	NULL

Fiscal Year	**Octopus (misc.)**		**He'e (day tako)**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1969	5	43	NULL	NULL
1970	6	423	NULL	NULL
1971	6	69	NULL	NULL
1972	8	249	NULL	NULL
1973	12	482	NULL	NULL
1974	15	400	NULL	NULL
1975	12	254	NULL	NULL
1976	9	459	NULL	NULL
1977	13	340	NULL	NULL
1978	29	1920	NULL	NULL
1979	43	3927	NULL	NULL
1980	47	5377	NULL	NULL
1981	49	5003	NULL	NULL
1982	35	2914	NULL	NULL
1983	39	6090	NULL	NULL
1984	56	14503	NULL	NULL
1985	46	7914	NULL	NULL
1986	43	10429	NULL	NULL
1987	44	12402	NULL	NULL
1988	46	17047	NULL	NULL
1989	33	5390	NULL	NULL
1990	30	3893	NULL	NULL

Fiscal Year	**Octopus (misc.)**		**He'e (day tako)**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
1991	25	5635	NULL	NULL
1992	45	6322	NULL	NULL
1993	44	8729	NULL	NULL
1994	41	5333	NULL	NULL
1995	30	4566	NULL	NULL
1996	37	7315	NULL	NULL
1997	40	4468	NULL	NULL
1998	46	6874	NULL	NULL
1999	46	5798	NULL	NULL
2000	41	6264	NULL	NULL
2001	40	5966	NULL	NULL
2002	42	7653	NULL	NULL
2003	31	6442	7	735
2004	12	1021	22	5994
2005	12	1099	14	4832
2006	n.d.	n.d.	23	7416
2007	NULL	NULL	15	7156
2008	NULL	NULL	13	3960
2009	NULL	NULL	19	7399
2010	n.d.	n.d.	16	4622
2011	NULL	NULL	27	5427
2012	n.d.	n.d.	19	4500

Fiscal Year	**Octopus (misc.)**		**He'e (day tako)**	
	No. License	Lbs. Caught	No. License	Lbs. Caught
2013	7	312	25	5476
2014	6	153	19	5903
2015	5	232	24	3341
2016	3	297	14	4259
10 yr ave	5	249	19	5,204
20 yr ave	25	3,583	18	5,073

n.d. = non-disclosure due to data confidentiality

1.5.5 Catch Parameters by Gear

Table 39. Time series of CPUE by dominant fishing methods from Mollusk and Limu (1966-2016).

Fiscal Year	**Handpicked**				**Spear**				**Inshore Handline**			
	No. Lic	No. Trips	Lbs. Caught	CPUE	No. Lic	No. Trips	Lbs. Caught	CPUE	No. Lic	No. Trips	Lbs. Caught	CPUE
1966	13	172	14584	84.79	15	131	4704	35.91	6	16	139	8.69
1967	41	783	36210	46.25	20	128	6573	51.35	7	15	117	7.8
1968	26	454	23766	52.35	16	120	5813	48.44	4	6	83	13.83
1969	37	415	23968	57.75	18	101	4809	47.61	5	8	43	5.38
1970	43	401	21089	52.59	27	126	4609	36.58	6	21	423	20.14
1971	48	372	17980	48.33	30	196	5548	28.31	6	9	69	7.67
1972	45	273	18519	67.84	38	209	9003	43.08	8	15	249	16.6
1973	47	275	19462	70.77	41	235	7358	31.31	12	37	482	13.03
1974	54	389	24946	64.13	54	302	9234	30.58	15	28	400	14.29

Fiscal Year	Handpicked				Spear				Inshore Handline			
	No. Lic	No. Trips	Lbs. Caught	CPUE	No. Lic	No. Trips	Lbs. Caught	CPUE	No. Lic	No. Trips	Lbs. Caught	CPUE
1975	49	363	17553	48.36	60	322	9709	30.15	12	18	254	14.11
1976	47	304	18283	60.14	51	287	7237	25.22	9	25	459	18.36
1977	54	247	10518	42.58	58	450	12854	28.56	13	20	340	17
1978	52	222	14375	64.75	82	430	14803	34.43	29	77	1920	24.94
1979	51	183	14174	77.45	81	335	13712	40.93	43	83	3927	47.31
1980	48	199	8435	42.39	77	415	16860	40.63	47	139	5377	38.68
1981	33	199	7231	36.34	54	394	11130	28.25	49	187	5003	26.75
1982	28	156	6054	38.81	45	284	7154	25.19	35	156	2914	18.68
1983	33	154	4871	31.63	47	298	6891	23.12	39	210	6090	29
1984	29	135	5760	42.67	66	478	13543	28.33	60	409	15484	37.86
1985	27	170	5600	32.94	63	494	10607	21.47	46	296	7914	26.74
1986	82	891	25441	28.55	89	582	14879	25.57	43	392	10429	26.6
1987	126	1373	32771	23.87	74	694	21164	30.5	44	387	12402	32.05
1988	95	1113	25112	22.56	68	482	13547	28.11	46	463	17047	36.82
1989	100	1414	24568	17.37	72	530	15565	29.37	33	175	5390	30.8
1990	95	1212	18718	15.44	52	279	6881	24.66	30	143	3893	27.22
1991	102	1108	17336	15.65	58	307	7293	23.76	25	123	5635	45.81
1992	101	1068	17354	16.25	71	496	9354	18.86	45	201	6322	31.45
1993	86	1056	14088	13.34	71	451	10973	24.33	44	323	8729	27.02
1994	90	1115	17676	15.85	75	537	12252	22.82	41	185	5333	28.83
1995	91	1293	20693	16	74	526	11505	21.87	30	170	4566	26.86
1996	87	991	21487	21.68	94	850	11663	13.72	37	251	7315	29.14
1997	85	921	18884	20.5	89	660	14268	21.62	40	215	4468	20.78
1998	90	1046	17975	17.18	100	920	17594	19.12	46	242	6874	28.4

Fiscal Year	Handpicked				Spear				Inshore Handline			
	No. Lic	No. Trips	Lbs. Caught	CPUE	No. Lic	No. Trips	Lbs. Caught	CPUE	No. Lic	No. Trips	Lbs. Caught	CPUE
1999	82	952	17610	18.5	94	738	11668	15.81	46	245	5798	23.67
2000	80	1054	18559	17.61	84	986	18924	19.19	41	229	6264	27.35
2001	74	1276	27040	21.19	80	863	18857	21.85	40	211	5966	28.27
2002	68	1354	24731	18.27	73	698	15002	21.49	43	210	7665	36.5
2003	55	1298	22055	16.99	60	686	16876	24.6	33	248	7176	28.94
2004	45	1299	23713	18.25	54	496	13633	27.49	23	264	7015	26.57
2005	33	1294	21018	16.24	49	572	15171	26.52	20	275	5931	21.57
2006	39	742	16279	21.94	57	604	12119	20.06	23	300	7434	24.78
2007	43	540	12479	23.11	49	627	12505	19.94	15	250	7156	28.62
2008	50	640	17369	27.14	62	561	14453	25.76	13	169	3960	23.43
2009	49	723	27177	37.59	70	725	21998	30.34	19	233	7399	31.76
2010	64	923	36790	39.86	65	698	22641	32.44	17	216	4655	21.55
2011	45	973	32765	33.67	75	880	27918	31.73	27	208	5427	26.09
2012	57	795	36136	45.45	69	907	29616	32.65	20	193	4533	23.49
2013	43	824	43556	52.86	77	871	28723	32.98	30	219	5788	26.43
2014	39	683	35643	52.19	63	800	30343	37.93	25	183	6056	33.09
2015	34	487	22463	46.13	59	680	29531	43.43	27	103	3572	34.68
2016	21	336	15431	45.93	36	620	30939	49.9	16	87	4556	52.37
10 yr ave	45	692	27,981	40	63	737	24,867	34	21	186	5,310	30
20 yr ave	55	908	24,384	30	68	730	20,139	28	28	215	5,885	28

1.6 PRECIOUS CORALS FISHERY

1.6.1 Fishery Descriptions

This species group category is comprised of any coral of the genus *Corallium* in addition to pink coral (also known as red coral, *Corallium secundum, C. regale, C. laauense)*; gold coral (*Gerardia* spp., *Callogorgia gilberti, Narella* spp., *Calyptrophora* spp.); bamboo coral (*Lepidisis olapa, Acanella* spp.); and black coral (*Antipathes griggi, A. grandis, A. ulex)*.

Only selective gear may be used to harvest corals in federal waters. The top gear for this species group category is submersible.

1.6.2 Dashboard Statistics

Future reports will include data as resources allow.

1.6.3 Other Statistics

Future reports will include data as resources allow.

1.7 HAWAII MARINE RECREATIONAL FISHING SURVEY

1.7.1 Fishery Descriptions

The State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources (DAR) manages the fishery resources within state waters of the Main Hawaiian Islands (MHI). Fishery resources in federal waters are collaboratively managed by DAR, the National Marine Fisheries Service's (NMFS) Pacific Islands Regional Office (PIRO) and Pacific Islands Fisheries Science Center (PIFSC), and the Western Pacific Regional Fishery Management Council (WPRFMC).

DAR manages the collection of both commercial and non-commercial fishery dependent information in both state and federal waters. Regulatory actions in federal waters are typically proposed by NMFS based largely on stock assessments produced by PIFSC staff. Proposed regulations in federal waters are then generally agreed upon by NMFS, DAR, and WPRFMC. These three agencies coordinate management in federal waters to simplify the regulations for the fishing public, prevent overfishing, and manage the fisheries for long-term sustainability. This shared management responsibility is necessary due to the overlap of various fisheries in both state and federal waters. The information in this report is largely based on the data collected by DAR.

1.7.2 Non-commercial Data Collection Systems

Two independent and complementary surveys were re-initiated in Hawaii in collaboration with NOAA Fisheries' Marine Recreational Fishery Statistics Survey's (MRFSS) since 2001. The Hawaii Marine Recreational Fishing Survey (HMRFS) follows the traditional MRFSS on-site Access Point Angler Intercept Survey (APAIS) used to collect non-commercial finfish catch information for shore and private boat fishing modes (Figure 1). The charter boat mode is covered by the State of Hawaii's Commercial Marine License (CML) system whereby all crew members working on charter boats are lawfully required to annually purchase a CML and report catch and trip statistics on a monthly basis to DAR. A local contractor currently conducts the Coastal Household Telephone Survey (CHTS) which utilizes a random-digit-dial sampling method of landline telephones to collect non-commercial effort information for both shore and private boat fishing modes. As of 2017, HMRFS consists of 13 field surveyors (one on Kauai, one on Maui, one on Molokai, six on Oahu, and four on Hawaii), one data manager, and one project manager. Ma and Ogawa (2016) provide a more detailed description of the current sampling and estimation procedures.

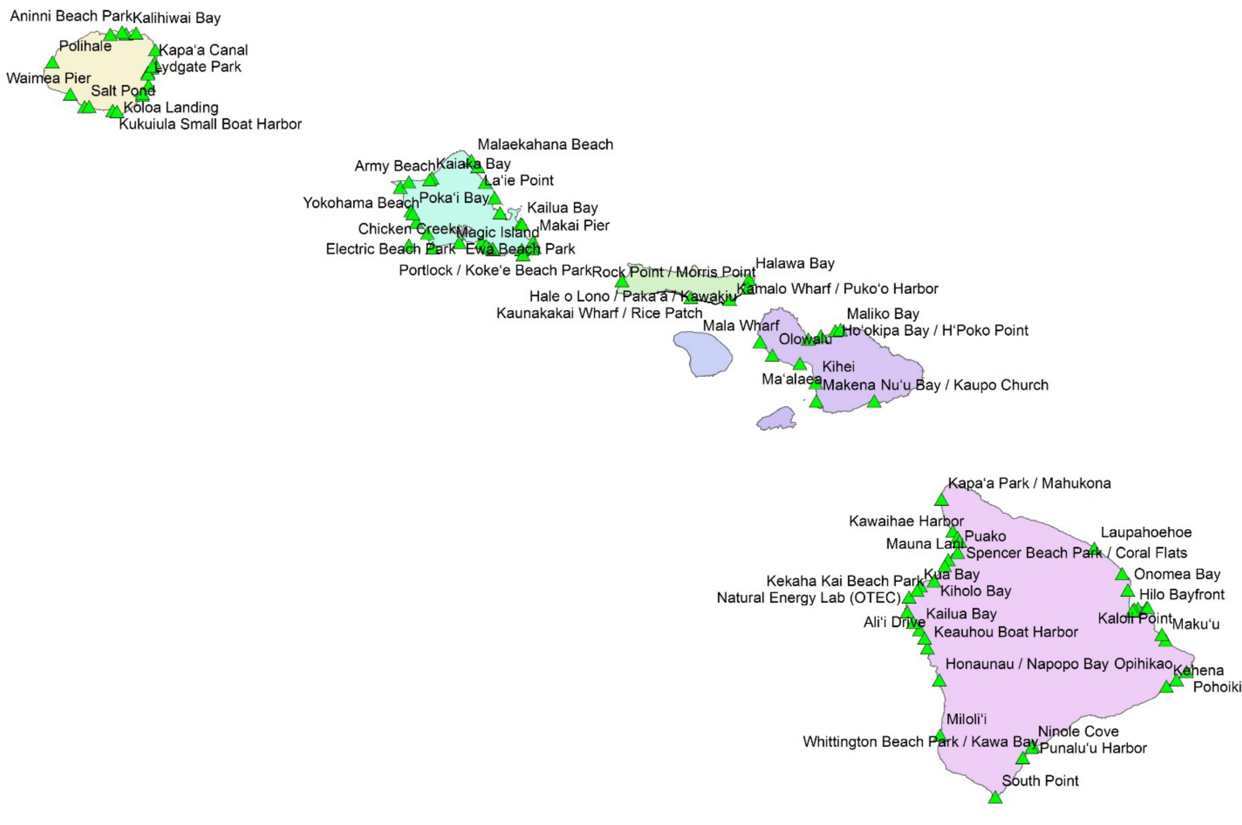

Figure 1. Access point angler intercept survey sites for the main Hawaiian islands.

1.7.2.1 Shore-based Fishing Effort Summary

The number of angler trips shows a decline since 2010 for shore-based fishing in state waters (Figure 2). However, the distribution of the fishing effort differed greatly among survey sites (Figure 3). Furthermore, each gear type also showed different fishing patterns among survey sites (Figure 4). These differences could be related to variations in local fisheries, shore line characteristics, habitat, and other environmental factors.

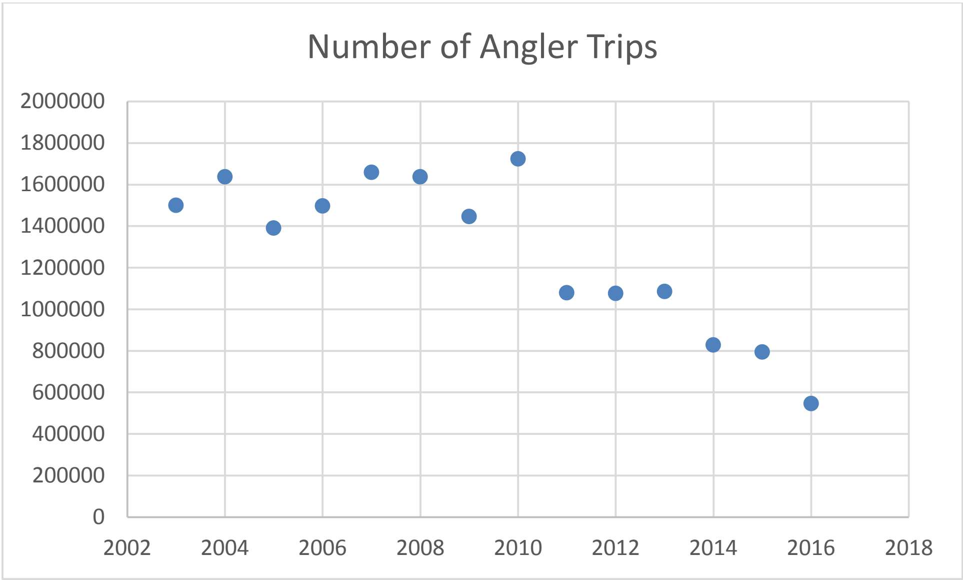

Figure 2. Annual shore-based fishing effort (in angler trips) within state waters (Marine Recreational Information Program).

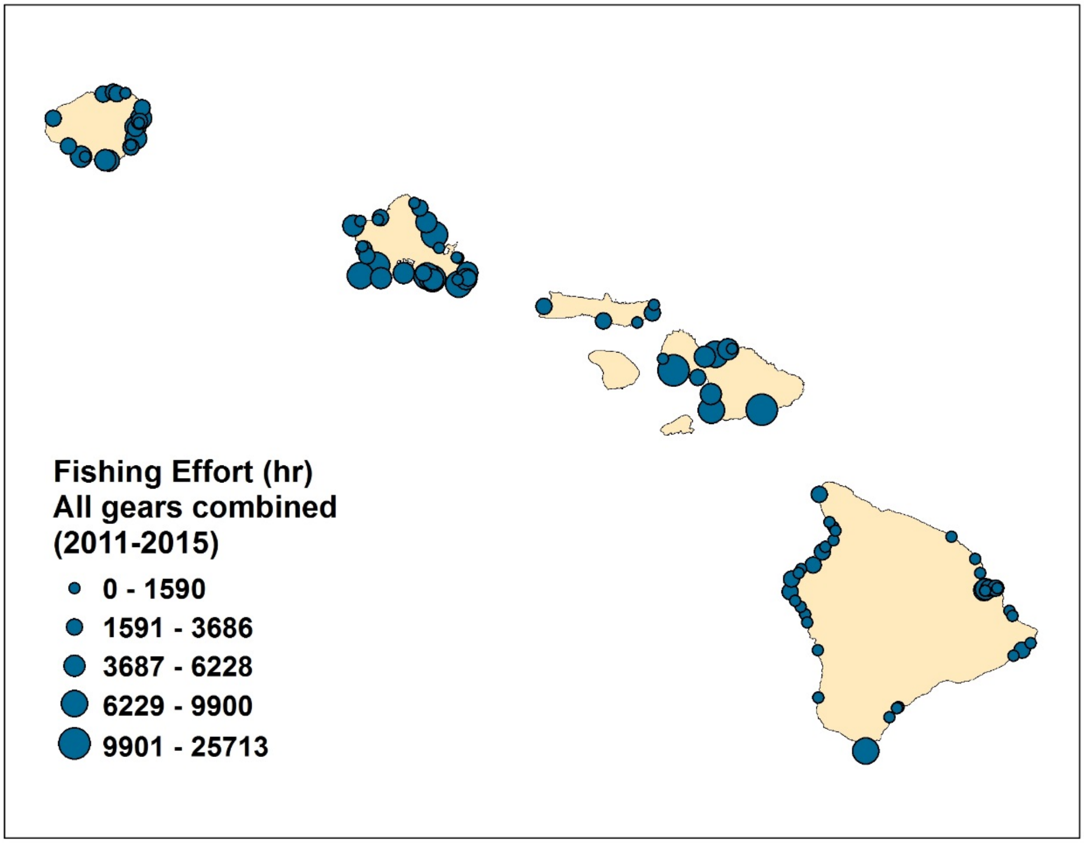

Figure 3. Map of overall shore-based annual fishing effort (in fisher-hour) for each angler intercept survey site averaged from 2011 to 2015.

ala

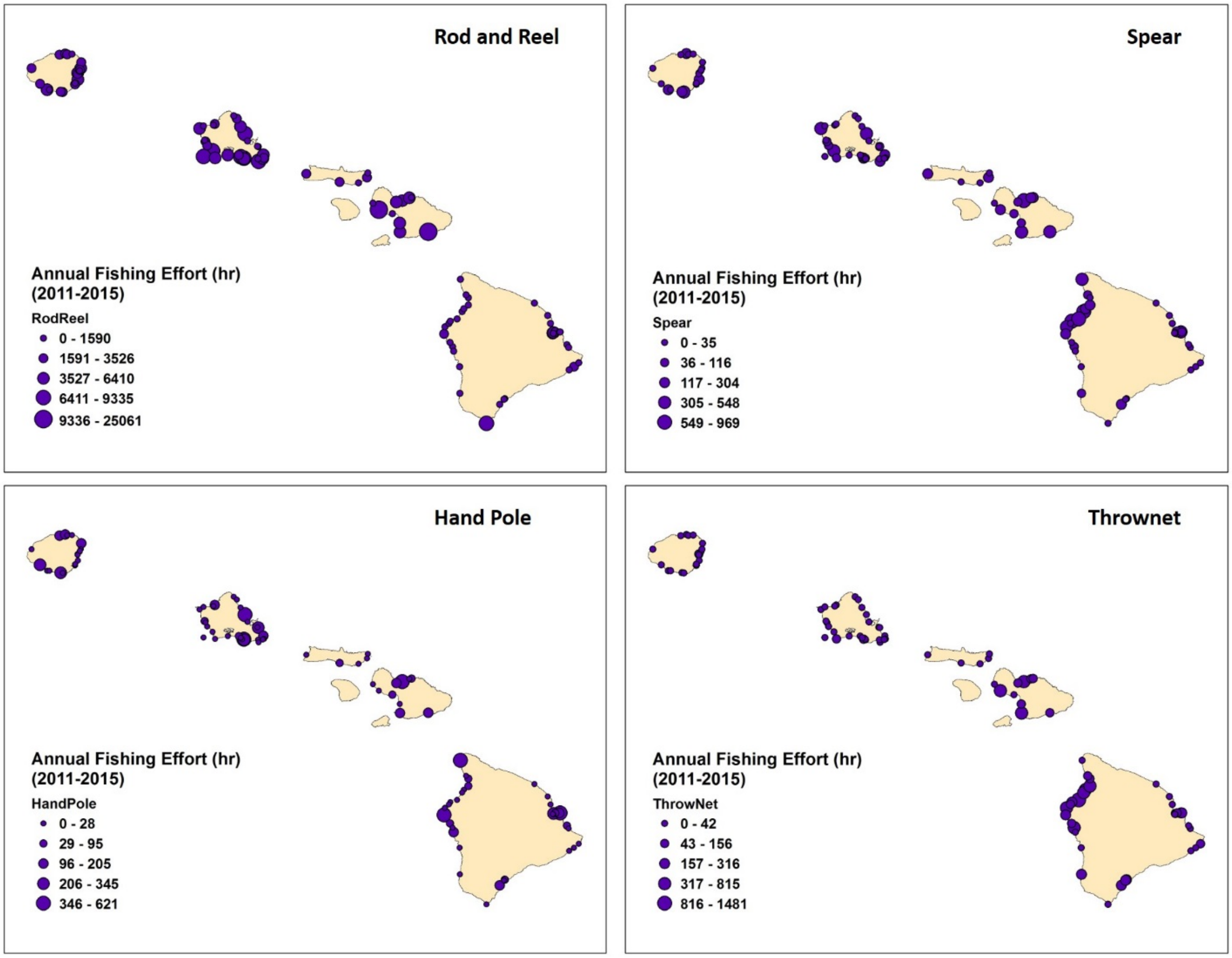

Figure 4. Map of shore-based annual fishing effort (in fisher-hour) for each angler intercept survey site for each gear type averaged from 2011 to 2015.

Various gear types are used for non-commercial fishing, though rod and reel was the most popular fishing method for shore-based fishing in state waters followed by spear fishing and throw netting (Figure 5). Hand pole was heavily used during the summer (quarter 3), likely due to seasonal fishing for halalu/akule (*Selar crumenophthalmus*) and oama (*Mulloidichthys* spp.). Rod and reel showed consistent use throughout the year for all islands. Throw netting was observed mostly on Maui and Hawaii without any seasonal differences. Fishing effort was highest on Maui for most gear types followed by Oahu though this may be the result of a survey site bias (i.e. sampling limited to relatively accessible areas only). Most of the Maui and Oahu sample sites are heavily used areas since most other sites are logistically difficult to survey. Overall, fishing effort was highest during the summer months (quarter 3).

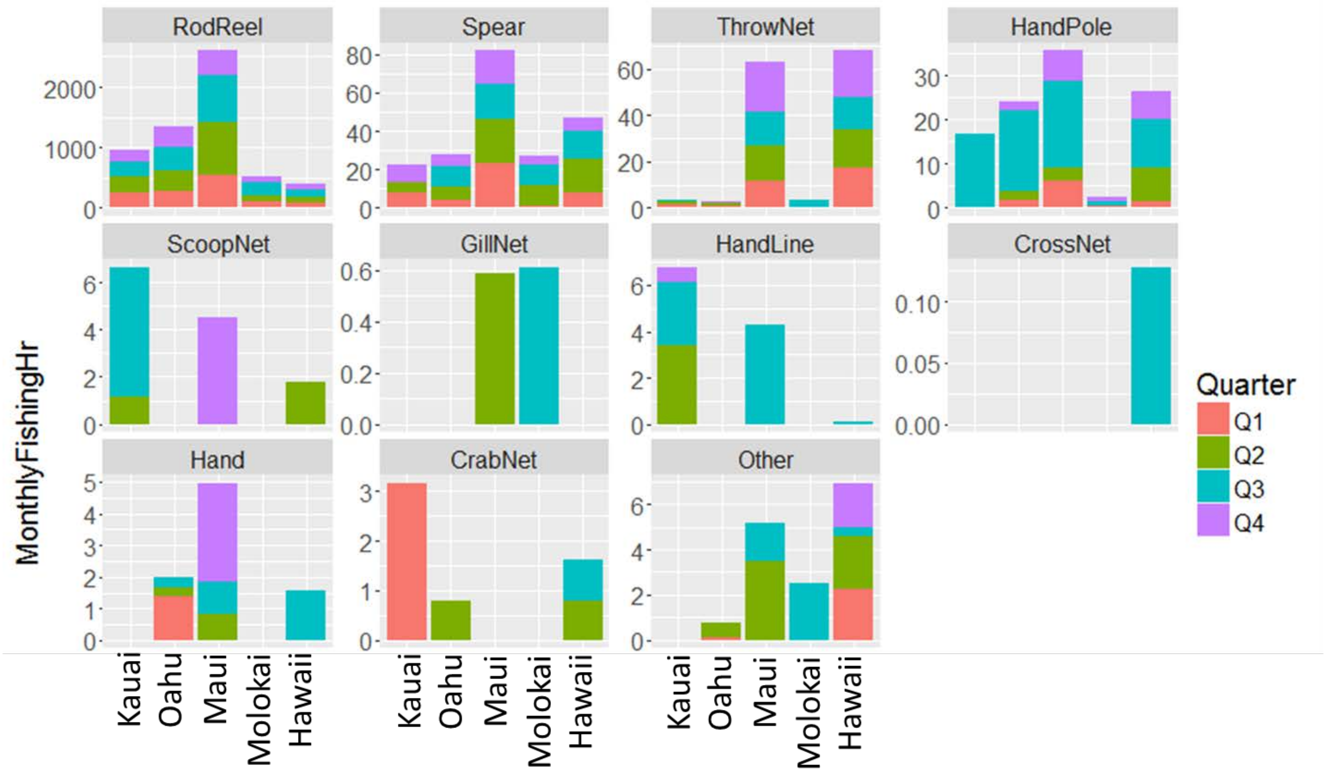

Figure 5. Monthly average fishing effort (in fishing-hour) for each quarter for each gear type and island averaged from 2011 to 2015..

1.7.2.2 Species Catch Summary

Among the reported catch, 188 species were identified (177 osteichthyes, 5 chondrichthyes, and 6 invertebrates). Species catch composition varied by gear types: surgeon fish, parrot fish (on Oahu), molluscs (*Octopus* spp.), and various pelagic species were mostly caught by spear fishing; ahole (*Kuhlia* spp.), goat fish (*Mulloidichthys* spp.) and akule (*S. crumenophthalmus)* were mostly caught by hand pole; ahole, goat fish, and invertebrates were mostly caught by scoop net; jacks (Caragidae), akule, goat fish, surgeonfish (*Acanthurus* spp.), and various pelagic species were mostly caught by rod and reel; and surgeon fish as well as some goat fish, ahole, and detritivores (Mugilidae) were mostly caught by throw net.

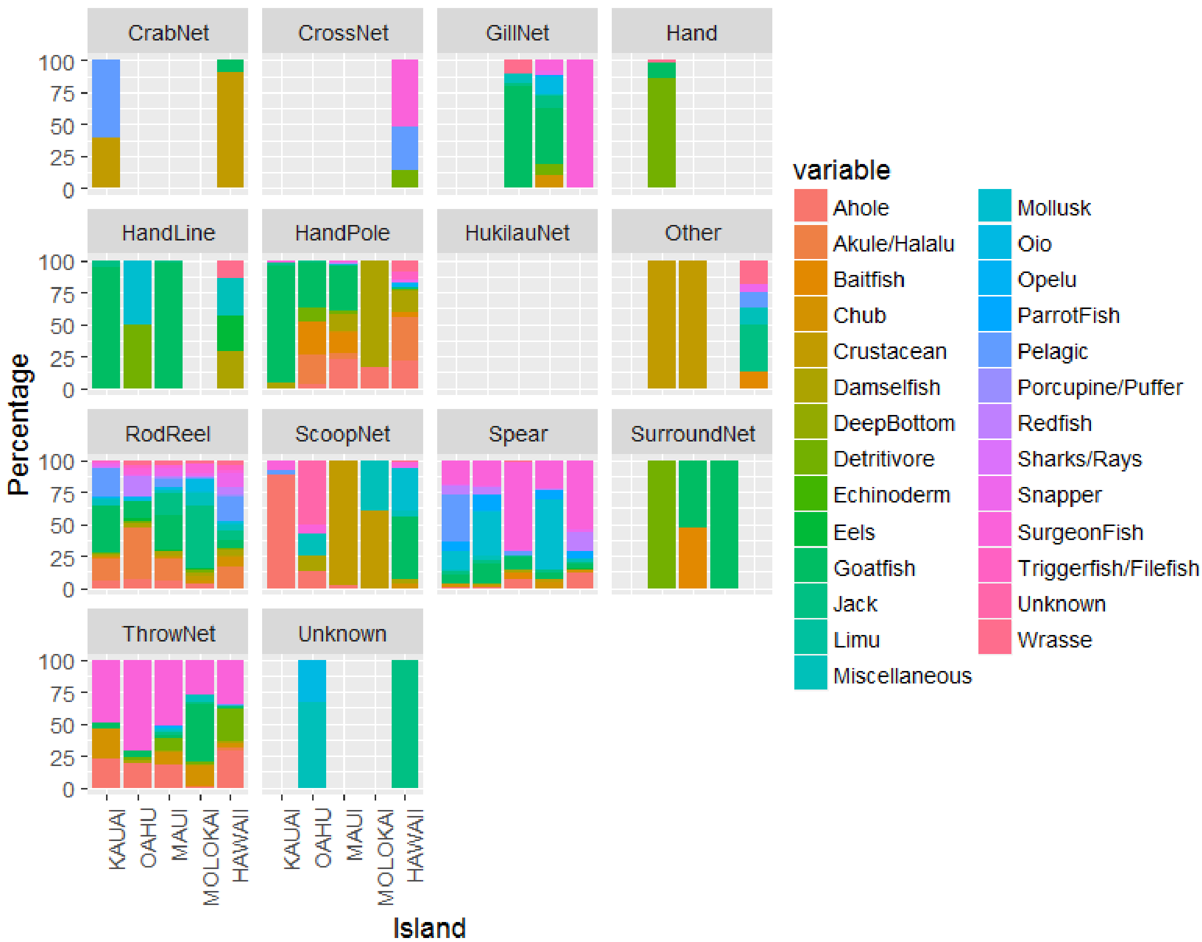

Figure 6. Averaged species catch composition for each gear type and island for shore-based fisheries in state waters from 2011 to 2015. Proportions based upon estimated number of species landed.

1.7.2.3 Catch Estimate

Average annual catch estimates for shore-based non-commercial fisheries within state waters were estimated using MRIP data and other creel survey data from 2004 to 2013 (Table 40, McCoy 2017). The most recreationally caught species were carangids (jacks), followed by acanthurids (surgeon fishes), mullids (goat fishes), mugilids (mullets), and scarids (parrot fishes). When compared with the reported commercial near-shore landing information, non-commercial catch is significantly higher for any species except for holocentridae (squirrel fish and soldier fish) and lethrinidae (emperors).

Table 40. Average annual landing estimates for commercial and shore-based non-commercial (MRIP) fisheries from 2004 to 2013 (McCoy 2017)..

Family	MRIP (kg)	Commercial (kg)	Grand Total (kg)
Carangidae	433,503	4,430	437,933
Acanthuridae	203,339	37,327	240,666

Mullidae	104,991	19,190	124,181
Mugilidae	92,455	2,796	95,251
Scaridae	84,252	20,501	104,752
Lutjanidae	61,726	13,197	74,923
Kyphosidae	60,203	10,394	70,597
Kuhliidae	44,604	754	45,358
Albulidae	42,486	3,536	46,022
Carcharhinidae	28,263		28,263
Labridae	22,788	1,845	24,634
Holocentridae	14,248	16,399	30,647
Chanidae	13,777	447	14,224
Pomacentridae	12,792	14	12,806
Sphyraenidae	9,328	557	9,885
Serranidae	8,050		8,050
Cirrhitidae	6,353	208	6,561
Balistidae	6,193	48	6,241
Priacanthidae	5,717	1,456	7,173
Polynemidae	3,996	153	4,148
Aulostomidae	3,833	16	3,850
Muraenidae	2,402	79	2,482
Scorpaenidae	2,278	501	2,779
Tetraodontidae	2,118		2,118
Diodontidae	1,649		1,649
Fistulariidae	1,284		1,284
Lethrinidae	919	1,404	2,323
Sphyrnidae	546		546
Congridae	405	5	410
Bothidae	402	2	404
Monacanthidae	371		371
Chaetodontidae	99		99
Apogonidae	78		78
Synodontidae	69		69
Gobiidae	3		3
Grand Total	1,275,520	135,260	1,410,780

1.7.3 References

McCoy K. (2017). Catch estimate improved upon the work of "McCoy, K. (2015). *Estimating nearshore fisheries catch for the main Hawaiian Islands*. Unpublished master's thesis, The University of Hawaii at Manoa, Honolulu, Hawaii."

1.8 NUMBER OF FEDERAL PERMIT HOLDERS

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

1.8.1 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.

1.8.2 Main Hawaiian Islands Non-commercial Bottomfish

This permit is required for any person, including vessel owners, fishing for bottomfish management unit species in the EEZ around the main Hawaiian Islands. If the participant possesses a current State of Hawaii Commercial Marine License, or is a charter fishing customer, he or she is not required to have this permit. The permit expires one year after the date of issuance. Permitted vessel operators or owners must submit a logbook to NMFS within 72 hours after landing. Vessel owners must mark their vessels according to State of Hawaii or Federal requirements.

1.8.3 Western Pacific Precious Coral

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. The Papahānaumokuākea Marine National Monument prohibits precious coral harvests in the monument (Federal Register notice of final rule, 71 FR 51134, August 29, 2006). Regulations governing this fishery are in the Code of Federal Regulations, Title 50, Part 665, Subpart F, and Title 50, Part 404 (Papahānaumokuākea Marine National Monument).

1.8.4 Western Pacific Crustaceans Permit

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).

Table 41 provides the number of permits issued to Hawaii FEP 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. 2017 Number of federal permits by Hawaii FEP Fishery between 2007 and 2017

Year	Special Coral reef ecosystem	MHI Non-commercial Bottomfish	Precious Coral	Crustacean Shrimp	Crustacean Lobster
2007			2		2
2008		76	1		2
2009		91	2		3
2010		28	2		3
2011	1	19	2		
2012	1	11	2	2	1
2013		3	1	5	2
2014		3	1	7	2
2015		2	1	5	2
2016	1	1	1	4	1
2017*	1		1	2	1

*As of February 3, 2017

1.9 STATUS DETERMINATION CRITERIA

1.9.1 Bottomfish and Crustacean 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 maximum sustainable yield (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_{FLAG} reaching the threshold. MFMT, MSST, and B_{FLAG} are specified as indicated in Table 42.

Table 42. Overfishing threshold specifications for the bottomfish and crustacean management unit species in Hawaii

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

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 for bottomfish stocks 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. Recruitment overfishing control rule specifications for the bottomfish management unit species in Hawaii

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

The Council adopted a rebuilding control rule for the NWHI lobster stock, which can be found in the supplemental overifrshing amendment to the Sustainable Fisheries Act omnibus amendment, on the Council's website.

1.9.2 Coral Reef Fishery

Available biological and fishery data are poor for all coral reef ecosystem management unit species in the Hawaiian 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 ($CPUE_{REF}$).

1.9.3 Current Stock Status

1.9.3.1 Deep-7 Bottomfish Management Unit Species Complex

Despite availability of catch and effort (from which CPUE is derived), some life history, and fishery independent information, the main Hawaiian island Deep-7 BMUS complex is still considered as data moderate. The stock assessment is conducted on a subset of the population that is being actively managed because of the closure of the Northwestern Hawaiian Islands to commercial fishing. The assessment is also conducted on the species complex because a typical bottom fishing trip is comprised primarily of these seven species.

Generally, data are only available on commercial landings by species and catch-per-unit-effort (CPUE) for the multi-species complexes as a whole. 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 main Hawaiian island Deep-7 bottomfish complex is not subject to overfishing and is not overfished (Table 45).

Table 45. Stock assessment parameters for the main Hawaiian island Deep-7 complex (Boggs memo 3/3/2015)

Parameter	**Value**	**Notes**	**Status**
MSY	0.404 ± 0.156	Expressed in million lbs (± std error)	
H_{2013}	3.8 ± 1.4	Expressed in percentage	
H_{MSY}	6 ± 2.1	Expressed in percentage (± std error)	
H/H_{MSY}	0.627		No overfishing occurring
B_{2013}	13.34 ± 5.397	Expressed in million pounds	
B_{MSY}	14.51 ± 4.267	Expressed in million lbs (± std error)	
B/ B_{MSY}	0.930		Not overfished

1.9.3.2 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 the Magnuson-Stevens Fishery Conservation and Management Act (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 Hawaii

Fishery	**Management Unit Species**	**MSY (lbs)**
Coral Reef Ecosystem	*Selar crumenopthalmus* – akule	1,150,800
	Decapterus macarellus – opelu	538,000
	Acanthuridae-surgeonfish	445,500
	Carangidae-jacks	185,100
	Carcharhinidae-reef sharks	12,400
	Crustaceans-crabs	43,100
	Holocentridae-squirrelfish	159,800
	Kyphosidae - rudderfish	122,800
	Labridae – wrasse	229,200
	Lethrinidae - emperors	39,600
	Lutjanidae-snappers	359,300
	Mollusk-turbo snails, octopus, giant clam	50,300
	Mugilidae-mullets	24,600
	Mullidae-goatfish	195,700
	Scaridae-parrotfish	271,500
	Serranidae - groupers	141,300
	All other CREMUS combined	540,800

1.9.3.3 Crustacean

The application of the SDCs for the crustacean MUS is limited to the NWHI lobster stock. Previous studies conducted in the main Hawaiian islands estimated the MSY for spiny lobsters at approximately 15,000 – 30,000 lobsters per year of 8.26 cm carapace length or longer (WPFMC 1983). There are insufficient data to estimate MSY values for MHI slipper lobsters. MSY for deepwater shrimp is estimated for the Hawaii Islands at 40 kg/nm2 (Tagami and Ralston, 1988 in King, 1993).

A stock assessment model was developed in 2014 in an attempt to understand and determine the status of the Kona crab stock in the main Hawaii islands (Thomas 2011). This assessment utilized a non-equilibrium generalized production model (using the Stock-Production Model Incorporating Covariate –ASPIC statistical routine) to estimate parameters needed to determine stock status. Based on this, the Kona crab stock is overfished (possibly rebuilding) but not experiencing overfishing (Table 47)

Table 47. Stock assessment parameters for the Kona crab stock (Thomas, Lee and Piner 2015)

Parameter	**Value**	**Notes**	**Status**
MSY	40,400	Expressed in lbs	
H_{2007}		Expressed in percentage	
H_{MSY}	0.2534	Expressed in percentage (± std error)	
H/H_{MSY}	0.9218		No overfishing occurring
B_{2007}		Expressed in million pounds	
B_{MSY}	159,500	Expressed in lbs	
B/ B_{MSY}	0.1810		Overfished

For ACL-specification purposes, MSY for spiny lobsters 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 48.

Table 48. Best available MSY estimates for the crustacean MUS in Hawaii

Fishery	**Management Unit Species**	**MSY (lbs)**
Crustacean	Deepwater shrimp	598,328
	Spiny lobsters	20,400

	Slipper lobsters	None
	Kona crab	40,400

SOURCE: Deepwater shrimp MSY – Tagami and Ralston 1988; Spiny lobster MSY – WPRFMC 2014; Kona crab – Thomas. 2011

1.10 OVERFISHING LIMIT, ACCEPTABLE BIOLOGICAL CATCH, AND ANNUAL CATCH LIMITS

1.10.1 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 and NMFS 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 over-fishing limit (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 Hawaii is an overage adjustment. The ACL is downward adjusted with the amount of overage from the ACL based on a three-year running average.

1.10.2 Current OFL, ABC, ACL, and recent catch

The most recent multiyear specification of OFL, ABC, and ACL for the coral reef, non-Deep-7, crustaceans, and precious coral fisheries was completed in the 160th Council meeting from June 25 to 27, 2014. The specification covers fishing years 2015, 2016, 2017, and 2018 for the coral reef MUS complexes. A P* and SEEM analysis was performed for this multiyear specification (NMFS 2015a).

The most recent multiyear specification of OFL, ABC and ACL for the main Hawaiian island Deep-7 bottomfish complex, was completed at the 163rd meeting in June of 2015. The specification covers fishing year 2015-2016, 2016-2017, and 2017-2018. This multi-year specification utilized a phased-in approach (Slow-up Fast-down) to alleviate the impact of a sudden drop of the new catch limit. A P* and SEEM analysis was also performed for this multiyear specification (NMFS 2015b).

Table 49. Hawaii Archipelago – Hawaii ACL table with 2016 catch (values are in pounds). Red font indicates overages.

Fishery	Management Unit Species	OFL	ABC	ACL	Catch
Bottomfish	MHI Deep-7 stock complex	352,000	326,000	326,000	309,127
	Non Deep-7 stock complex	265,000	187,100	178,000	115,760
Crustaceans	Deepwater shrimp	N.A.	250,773	250,773	30,771
	Spiny lobster	20,400	15,800	15,000	6,617
	Slipper lobster	N.A.	280	280	0
	Kona crab	N.A.	27,600	27,600	2,002
Precious coral	Auau channel black coral	8,250	7,500	5,512	
	Makapuu bed-pink coral	3,307	3,009	2,205	
	Makapuu bed-bamboo coral	628	571	551	
	180 fathom bank-pink coral	734	668	489	
	180 fathom bank-bamboo coral	139	126	123	
	Brooks bank-pink coral	1,470	1,338	979	
	Brooks bank-bamboo coral	280	256	245	
	Kaena point bed-pink coral	220	201	148	
	Kaena point bed-bamboo coral	42	37	37	
	Keahole bed-pink coral	220	201	148	
	Keahole bed-bamboo coral	42	37	37	
	Precious coral in HI exploratory area	N.A.	2,205	2,205	
Coral Reef Ecosystem	S. crumenopthalmus-akule	1,150,800	1,025,000	988,000	359,024
	D. macarellus-opelu	538,000	459,800	428,000	229,738
	Acanthuridae-surgeonfish	445,500	367,900	342,000	90,066

	Carangidae-jacks	185,100	168,100	161,200	39,642
	Carcharhinidae-reef sharks	12,400	9,800	9,310	1,948
	Crustaceans-crabs	43,100	35,400	**26,637**	28,140
	Holocentridae-squirrelfish	159,800	150,000	148,000	52,630
	Kyphosidae - rudderfish	122,800	108,600	105,000	17,353
	Labridae - wrasse	229,200	211,000	205,000	7,197
	Lethrinidae - emperors	39,600	36,600	35,500	3,295
	Lutjanidae-snappers	359,300	338,200	330,300	36,333
	Mollusk-turbo snails, octopus, giant clam	50,300	38,200	**31,163**	38,889
	Mugilidae-mullets	24,600	20,100	19,200	6,691
	Mullidae-goatfish	195,700	173,100	165,000	63,752
	Scaridae-parrotfish	271,500	251,700	239,000	50,206
	Serranidae - groupers	141,300	132,200	128,400	1,632
	All other CREMUS combined	540,800	496,500	485,000	64,438

NOTE:

* The MHI Deep-7 bottomfish is still ongoing; data as of 04/22/2016

***Cheilinus undulatus* and *Bolbometopon muricatum* are species not present in Hawaii

The catch shown in Table 49 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.

1.11 BEST SCIENTIFIC INFORMATION AVAILABLE

1.11.1 Main Hawaiian Island Deep-7 Bottomfish Fishery

1.11.1.1 Stock assessment benchmark

In 2011, NOAA's Pacific Islands Fisheries Science Center (PIFSC) completed a stock assessment for the MHI Deep-7 bottomfish fishery (2011 stock assessment) using data through 2010 (Brodziak et al. 2011). The 2011 stock assessment used similar commercial fishery data as in a 2008 assessment update (Brodziak et al. 2009), but includes a modified treatment of unreported catch and catch per unit effort (CPUE) standardization, as well as new research information on the likely life history characteristics of bottomfish (A. Andrews, PIFSC, unpublished 2010 research) in response to recommendations from the Western Pacific Stock Assessment Review (WPSAR) of the 2008 update (Stokes, 2009). Additionally, while the 2008 assessment considered the entire assemblage of Hawaii BMUS on an archipelagic basis (NWHI and MHI), the 2010 assessment focused solely on the Deep-7 bottomfish stock complex in the MHI.

To address the unreported catch issue, the 2011 assessment included four scenarios of unreported catch developed from available information. The four scenarios are labeled in order of magnitude from the highest (Scenario 1) to the lowest (Scenario 4) estimates of unreported catch.

- Catch Scenario 1: Unreported catch is two times commercial reported catch
- Catch Scenario 2: Unreported catch equals the commercial reported catch
- Catch Scenario 3: Unreported catch is one-fifth the commercial reported catch
- Catch Scenario 4: There is no unreported catch

According to the 2011 assessment the Catch Scenario 2 is the baseline (i.e., most plausible scenario) because it used the best available information on unreported to reported catch ratios estimated for individual MHI Deep-7 bottomfish species.

To determine the appropriate CPUE, the 2011 assessment included three scenarios to represent changes in fishing power of the fleet that targets Deep-7 bottomfish for commercial catch. CPUE is used in stock assessments as an index of relative stock abundance. Standardizing CPUE from different anglers over different areas and over many years helps to minimize the effects that could bias CPUE as an index of stock abundance.

- CPUE Scenario 1: Negligible change in bottomfish fishing power through time.
- CPUE Scenario 2: Moderate change in bottomfish fishing power through time. Specifically, this scenario assumed that: (i) there was no change in fishing power during 1949-1970; (ii) fishing power increased at a rate of 0.25 percent per year during 1971-1980; fishing power increased at a rate of 0.5 percent per year during 1981-1990; (iii) fishing power increased at a rate of 0.25 percent per year during 1991-2000; and (iv) fishing power did not change during 2001-2010.
- CPUE Scenario 3: Substantial change in bottomfish fishing power through time. Specifically, this scenario assumed that a substantial change in fishing power scenario had occurred since the 1950s with an average increase in fishing power of roughly 1.2 percent per year.

According to the 2011 assessment, CPUE Scenario 1 is the baseline (i.e., most plausible scenario) because it represented the best scientific information about the efficiency of the Deep-7 bottomfish fishing fleet through time, and because it did not include ad hoc assumptions about changes in fishing power for the deep handline fishery that has traditionally harvested the Deep-7 bottomfish complex.

Based on the Catch 2/CPUE 1 scenario combination, the 2011 assessment estimates a maximum sustainable yield (MSY) of 417,000 lb for the MHI Deep-7 bottomfish stock complex. The 2011 stock assessment also included projection results of a range of commercial catches of Deep-7 bottomfish that would produce probabilities of overfishing ranging from 0 percent to 100 percent and at five percent intervals (Table 19.1 in Brodziak et al., 2011). Under the Catch 2/CPUE 1 scenario combination, the catch limit associated with a 50 percent probability of overfishing is 383,000 lb of MHI Deep-7 bottomfish. Therefore, while the long-term MSY for the fishery is 417,000 lb, the OFL for fishery is 383,000 lb.

Findings of an Independent Peer Review
In January 2011, PIFSC contracted the Center for Independent Experts (CIE) to provide three independent experts to review a draft of the 2011 stock assessment and prepare a report of their independent findings and recommendations, and whether the 2011 stock assessment is the best scientific information available for management purposes. In general, the CIE review panel found that the 2011 stock assessment was scientifically sound, and applied appropriate modeling approaches and methods given data limitations. In addition, each reviewer provided recommendations on how to improve the next assessment particularly with respect to providing credible CPUE standardization. The reports of the CIE reviewers are available on the PIFSC website at http://www.pifsc.noaa.gov/do/peer_reviews/.

1.11.1.2 Stock assessment updates

In 2014, the PIFSC completed a draft 2014 stock assessment update for the MHI Deep-7 bottomfish fishery (2014 stock assessment), using data through fishing year 2013 (Brodziak et al. 2014). The 2014 stock assessment update uses the previous 2011 stock assessment's methods for data analysis, modeling, and stock projections, with one improvement--it included the State of Hawaii's CML data as a variable to standardize CPUE over time. The State began issuing CMLs uniquely and consistently to individuals through time starting in 1994. Therefore, beginning in 1994 the CML number assigned to an individual has remained the same. The 2014 stock assessment included individual CMLs in the CPUE standardization for that year onward. This improvement is highly significant, resulting in a two-fold increase in the explanatory power (R-squared) of the CPUE standardization and a substantial decrease in the Akaike information criterion value of the CPUE standardization, which now explains over 50% of the variation in observed CPUE over time. Additionally, in the three additional years (2011-13) covered by the 2014 assessment, the biomass of the Deep-7 species and the exploitation rate were about the same as in the preceding three years. Therefore, the updated estimates of the values for management (i.e., MSY, OFL, probability of overfishing etc.) are not a result of any significant change in biomass or exploitation rate, but are due to better estimation of the values provided by the previous assessment.

Based on the revised CPUE standardization method and three years of additional catch data, the 2014 stock assessment update re-estimates MSY to be 415,000 lb, which is similar to the previous MSY estimate of 417,000 lb reported in the 2011 stock assessment. The 2014 stock assessment also included projection results of a range of commercial catches of Deep-7 bottomfish that would produce probabilities of overfishing ranging from 0 percent to 100 percent and at five percent intervals (Table 15 in Brodziak et al., 2014). Based on a maximum potential harvest of 325,000 lb of MHI Deep-7 bottomfish in the then-ongoing 2013-14 fishing year, the

2014 stock assessment estimated an OFL of 316,000 lb, which is 67,000 lb less than the OFL estimate in the 2011 stock assessment. These updated estimates of MSY and OFL are not the result of any significant change in biomass or exploitation rate, but are due to better estimations resulting from the revised CPUE standardization method.

Findings of an Independent Peer Review
In December 2014, PIFSC again contracted the CIE to provide three independent experts to review the 2014 stock assessment and prepare a report of their independent findings and recommendations, and to assist NMFS in determining whether the 2014 stock assessment is the best scientific information available for management purposes. In summary, the CIE panel found that including individual CML data as a variable to standardize CPUE over time was an improvement over the method used in the 2011 stock assessment. However, the CIE panel had strong reservations regarding the quality of input catch data and CPUE index of abundance used in both the 2011 and 2014 stock assessments. Specifically, the panel raised concern about the historical pre-1990 data for CPUE calculation and estimates of unreported catch. Given the concerns with the incomplete effort information, the CIE panel concluded that the 2014 stock assessment had serious flaws that compromised its utility for management. In particular, the CIE panel noted that because the 2014 stock assessment was an update only, and required improvements in the index and the population model, the science reviewed in the 2014 stock assessment is not considered the best available. The reports of the CIE reviewers are available on NMFS website at http://www.st.nmfs.noaa.gov/science-quality-assurance/cie-peer-reviews/cie-review-2015

1.11.1.3 Current best available scientific information

National Standard 2 requires that conservation and management measures be based on the best scientific information available, and be founded on comprehensive analyses. National Standard 2 guidelines (78 FR 43087, July 19, 2013) state that scientific information that is used to inform decision making should include an evaluation of its uncertainty and identify gaps in the information (50 CFR 600.315(a)(1). The guidelines also recommend scientific information used to support conservation and management be peer reviewed (50 CFR 600.315(a)(6)(vii)). However, the guidelines also state that mandatory management actions should not be delayed due to limitations in the scientific information or the promise of future data collection or analysis (50 CFR 600.315(a)(6)(v)).

On March 3, 2015, PIFSC outlined reasons why the fisheries data in the 2014 assessment produced results that the CIE panel advised was not ready for management application, and identified two ways in which the fisheries data can be improved for future application in the new CPUE standardization method.

1. Although catch per day fished is the best available CPUE that is available continuously over the whole time series, it may not be the best available over the most recent time series. If the time series is to be split with CPUE issues addressed differently before and after the split, one could also analyze and include detailed effort data that has been collected only for the last dozen years. This data could strongly influence recent trends. This was not seen by PIFSC as work that could be done as a simple update in 2014, because it is a complex undertaking.

The use of CPUE defined as catch per day fished is subject to great criticism, and one way to address this is by using details on hours and numbers of lines and hooks used by fishermen over the last dozen years. Only inexplicit, undescribed differences among fishermen linked through time were applied to the recent stanza in the 2014 CPUE standardization. Using the recent effort detail would still allow differences between individual fishermen to be standardized, and also allow changes in effort details through time to be addressed. Both were factors of great concern to the reviewers. Differences among areas and seasons and other such factors that can be applied throughout the whole time series have remained part of the CPUE standardization in both 2011 and 2014.

2. Further efforts could be made to apply the CPUE standardization to account for differences among fishermen to more data using various exploratory methods and other data sets. The 2014 assessment overlooked a compilation of confidential non-electronic records held by the State of Hawaii that may help to link fisher's identities back through an earlier stanza of time.

Although the CIE panel noted the improvement in catch rate standardization in the 2014 stock assessment compared to 2011, it had strong reservations regarding the input catch data in both stock assessments, However, PIFSC cannot improve the assessment for MHI Deep-7 bottomfish in the ways described above in short order because it is a complex undertaking. Although catch per day fished may not be the best available CPUE data that can be used in the superior split-stanza CPUE standardization (i.e. after 1994), it is the best available CPUE data that is available over the entire time series, and thus appropriate for use in the 2011 assessment approach, which does not utilize a split-stanza CPUE standardization approach. Therefore, NMFS believes that a much simpler update of the 2011 assessment using data from the three most recent years available (i.e., 2011, 2012 and 2013) provides the best scientific information available for management. Applying this updated data, NMFS revised the MSY for MHI Deep-7 bottomfish from 417,000 lb to 404,000 lb and the OFL from 383,000 lb 352,000 lb. These values do not reflect a drastic change in stock status from the information considered by the Council, and the proposed ACL of 346,000 lb remains below the revised OFL of 352,000 lb.

1.11.2 Non-Deep-7 Bottomfish Fishery

1.11.2.1 Stock assessment benchmark

There is no benchmark stock assessment for the non-Deep-7 bottomfish. An attempt to determine sustainability of the non-Deep-7 bottomfish stock was done in conjunction with the assessment of the MHI Deep-7 bottomfish stocks. In 2011, NMFS Pacific Islands Fisheries Science Center completed a stock assessment for the Deep-7 bottomfish stock complex using data from 1949-2010 and produced stock projection results of a range of commercial catches of Deep-7 bottomfish that would produce probabilities of overfishing ranging from zero percent to 100 percent, and at five-percent intervals in fishing year 2011-12, and in 2012-13 (Brodziak et al., 2011, Table 19.1 and shown in Appendix C). The 2011 stock assessment used similar commercial fishery data as in the previous 2008 stock assessment that assessed the entire Hawaii multi-species bottomfish stock complex as a whole (Brodziak et al., 2009); however, the 2011 assessment includes a modified treatment of unreported catch and CPUE standardization, as well as new research information on the likely life history characteristics of Deep-7 bottomfish (A. Andrews, PIFSC, unpublished 2010 research).

According to the 2011 bottomfish stock assessment, the Catch 2/CPUE 1 scenario combination represents the best approximation (with a 40 percent probability) of the true state of the bottomfish fishery and Deep-7 bottomfish population dynamics. Under the Catch 2/CPUE 1 scenario combination, the long-term MSY of the MHI Deep-7 bottomfish stock complex is estimated to be 417,000 lb. The assessment model also estimates that the commercial catch associated with a 50 percent probability of overfishing the MHI Deep-7 bottomfish complex in fishing year 2011-12 and again in fishing year 2012-13 is 383,000 lb. Therefore, while the long-term MSY for the Deep-7 bottomfish fishery is 417,000 lb, the overfishing limit (OFL) for the 2011-12 and 2012-13 fishing years is estimated to be 383,000 lb.

The 2011 MHI Deep-7 bottomfish stock assessment does not include an evaluation of stock status or the risk of overfishing for any of the remaining BMUS in the MHI. Therefore, biological reference points, including estimates of MSY and OFL for the MHI non-Deep-7 bottomfish are unknown. However, the stock assessment projection results for the MHI Deep-7 bottomfish stock complex can be used to develop an OFL proxy for the MHI non-Deep-7 bottomfish stock complex, and a range of commercial non-Deep-7 bottomfish catches that would produce probabilities of overfishing ranging from zero percent to 100 percent. This approach relies on the assumption that population dynamics, catchability and other parameters of the non-Deep-7 bottomfish are similar in relative scale to the Deep-7 bottomfish (Brodziak, pers. com. March 31, 2011). In general, MHI non-Deep-7 bottomfish are coral reef associated species and are more productive compared to MHI Deep-7 bottomfish. However, non-Deep-7 bottomfish are also harvested by a greater range of gear methods, which results in levels, and rates of exploitation that have not been assessed quantitatively or qualitatively in any previous stock assessment.

While a separate stock assessment for MHI non-Deep-7 bottomfish is the preferred approach, until one is produced, estimating a proxy for OFL and probabilities of overfishing for this stock complex based on projection results for MHI Deep-7 bottomfish is an appropriate approach given the fact that only catch data are available for the non-Deep-7 stock complex. Additionally, this catch data indicate that reported commercial catches of MHI Deep-7 bottomfish in proportion to the total reported commercial catches of all MHI bottomfish (Deep-7 + non-Deep-7) are relatively stable over time as reported in Tables 5 (estimates of total Deep-7 catches) and Table 6 (estimates of total bottomfish catches) contained in Brodziak et al. (2011). Therefore, reported commercial catches of MHI non-Deep-7 bottomfish in proportion to total reported commercial catches of all MHI bottomfish are also stable over time.

Table 50 summarizes the average proportion of the reported commercial catches (C) of MHI Deep-7 bottomfish relative to the total reported commercial catches of all MHI bottomfish for three time periods: (1) 1949-2010; (2) 2000-2009; and 2008-2010 as presented in Tables 5 and 6 in Brodziak et al. (2011). The proportion of MHI Deep-7 catch (PDEEP7) to the total MHI bottomfish catch is also provided and is calculated using the following equation:

PDEEP7(t) = CDEEP7(t) / C Total BMUS(t)

These three time periods were chosen because they reflect the nature of the Hawaii bottomfish fishery over (1) the entire available catch history; (2) the recent decade; and (3) three recent years when the fishery operated under a catch limit system. The results summarized in Table 50 clearly demonstrate that the proportion of Deep-7 to the total reported commercial catches of all MHI bottomfish (Deep-7 + non-Deep-7) has been relatively stable over time with ranges from 67 percent to 72 percent. Conversely, this demonstrates the proportion of non-Deep-7 bottomfish to the total MHI bottomfish catch ranged from 33 percent to 28 percent.

Table 50. Proportion of reported commercial catches of MHI Deep-7 and total reported commercial MHI bottomfish catch over time under Catch 2/CPUE 1 scenario

	t = 1949-2010	t =2000-2009	t =2008-2010
Catch of Deep-7 bottomfish[1]	281.3	234.3	221.5
Catch of Total BMUS[2]	422.1	325.3	330.7
Proportion of Deep-7 (P_{DEEP7})	0.666	0.720	0.700

[1] Source: Table 5 in Brodziak et al., (2011)

[2] Source: Table 6 in Brodziak et al., (2011)

Because two Hawaii BMUS, taape *(Lutjanus kasmira)* and kahala (*Seriola dumerili),* are specifically excluded from the NMFS Hawaii bottomfish stock assessment parameters, their catch information is not included in the total bottomfish estimates used in Table 6 of Brodziak et al. (2011).

To estimate an OFL proxy for the MHI non-Deep-7 bottomfish stock complex and a range of commercial non-Deep-7 bottomfish catches that would produce probabilities of overfishing ranging from zero percent to 100 percent, the commercial catch values for MHI Deep-7 bottomfish associated with Catch 2/ CPUE Scenario 1 as presented in Table 19.1 of Brodziak et al., (2011), and shown in Appendix C can be divided by the P_{DEEP7} values in Table 50 above. The results of this calculation will derive the total commercial catch equivalent of all MHI bottomfish (Deep-7 + non-Deep-7) and the corresponding probabilities of overfishing all MHI bottomfish.

To derive the level of catch that would produce the corresponding probability of overfishing for MHI non-Deep-7 bottomfish (excluding taape and kahala), the level of catch for MHI Deep-7 bottomfish is simply subtracted from the level of catch for all MHI bottomfish.

Table 51 summarizes the results of this calculation for the time period 1949-2010. This time period is identical to the time period used to produce stock projection results for the Deep-7 stock complex and is the baseline for impact analyses.

Table 51. Commercial catch (in1000 pounds) of MHI Deep-7 BMUS, MHI non-Deep-7 BMUS and all MHI BMUS combined that would produce probabilities of overfishing from 0 through 99% based on 1949-2010 catch data (P_{DEEP7} = 0.666)

Probability of Overfishing[1]	**Catch of MHI Deep-7 BMUS**[1]	**Catch of All MHI BMUS** *(Deep-7 + non-Deep-7)*[2]	**Catch of MHI non-Deep-7 BMUS**[2]
0	11	17	6
5	147	221	74
10	197	296	99
15	229	344	115
20	255	386	131
25	277	415	138
30	299	449	150
35	319	479	160
40	341	512	171
45	361	542	181
50	383	575	192
55	407	611	204
60	429	644	215
65	455	683	228
70	481	722	241
75	513	779	266
80	549	824	275
85	597	896	299
90	665	998	333
95	783	1176	393
99	1001	1503	502

[1] Source: Table 19.1 in Brodziak et al., (2011)

[2] Excludes Hawaii BMUS taape *(Lutjanus kasmira)* and kahala (*Seriola dumerili)*

Based on Table 51 above, the catch limit associated with a 50 percent probability of overfishing the MHI Deep-7 bottomfish complex in fishing year 2011-12 and again in fishing year 2012-13 is 383,000 lb. The catch limit associated with a 50 percent probability of overfishing the MHI non-Deep-7 bottomfish complex in fishing year 2012 and again in 2013 is 192,000 lb and is the OFL proxy. These estimates will continue to apply in future fishing years until a new Deep-7 stock assessment update and associated stock projection analysis is conducted or a separate non-Deep-7 assessment is prepared.

1.11.2.2 Stock assessment updates

The initial method described above was abandoned in 2014. Estimates of MSY and OFL for non-Deep-7 bottomfish in the MHI are based on a modeling approach that uses catch data from local resource management agencies as described in section 1.2 ; together with a measure of population growth (r), carrying capacity (k), and biomass data from NMFS PIFSC underwater fish census surveys (Williams 2010). This model, termed the "Biomass Augmented Catch-MSY" model is described in detail in Sabater and Kleiber (2014). In summary, the model creates annual biomass projections from a set of r and k combinations that would not result in biomass that would exceed the carrying capacity or the stock being depleted. The assumption behind the biomass can be informed by augmenting the model with an independent source of biomass information.

The Biomass Augmented Catch-MSY model is based on the Catch-MSY model developed by Martell and Froese (2013), but differs in that it incorporates biomass data. Application of the model provides the very first model-based estimate of MSY for MHI non-Deep-7 bottomfish. In addition to estimates of MSY, the Biomass Augmented Catch-MSY model also generates a range of catches that if realized, would result in a probability of exceeding MSY ranging from five to 50 percent.

Because of the large number of possible combinations of r and k values available to estimate MSY using the Biomass Augmented Catch-MSY model, the model explored two methods to define the most meaningful and most likely (most plausible) range of r and k combinations. Method A allows for only a very narrow range of starting r and k values, while method B allows for a broad range of starting r and k values, with each method providing different MSY estimates and associated probability of overfishing projections. In reviewing the two methods, the SSC at its 114th meeting held March 11-13, 2014, determined the resulting MSY estimates from method B be used for management decisions because this method provides a more complete range of most likely r and k combinations compared to method A. The 114th SSC also found that method B also yielded r and k density plots that generally correspond better to the estimates of MSY than the method A approach.

Based on the method B approach, the Biomass Augmented Catch-MSY model estimates MSY for MHI non-Deep-7 bottomfish to be 265,000 lb. However, catch projection results generated from the model estimates the level of catch associated with a 50 percent probability of exceeding MSY to be 259,200 lb. Consistent with National Standard 1 guidelines (74 FR 3178, January 9, 2011), the Council at its 160th meeting, set OFL for MHI non-Deep-7 bottomfish equal to the level of catch associated with a 50 percent probability of exceeding MSY

1.11.3 Coral reef fishery

1.11.3.1 Stock assessment benchmark

Coral Reef Ecosystem Management Unit Species Complex-Level Assessment

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) for the purpose of improving the ACL specification for these stocks. 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 complex level coral reef stock assessment is as follows:

Input data: The catch data was derived commercial marine license reports.

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. This model was used for the multi-year specification for fishing year 2015 to 2018.

Coral Reef Ecosystem Management Unit Species Species-Level Assessment

In February 2017, PIFSC released the final species level assessment for the main Hawaiian islands (Nadon 2017). This assessment covers 27 species of reef fishes: *Acanthurus blochii*, *Acanthurus dussumieri*, *Naso brevirostris*, *Naso hexacanthus*, *Naso lituratus*, *Naso unicornis*, *Carangoides orthogrammus*, *Caranx ignobilis*, *Caranx melampygus*, *Aprion virescens*, *Lutjanus fulvus*, *Lutjanus kasmira*, *Mulloidichthys flavolineatus*, *Mulloidichthys pfluegeri*, *Mulloidichthys vanicolensis*, *Parupeneus cyclostomus*, *Parupeneus insularis*, *Parupeneus porphyreus*, *Calotomus carolinus*, *Chlorurus perspecillatus*, *Chlorurus spilurus*, *Scarus dubius*, *Scarus psittacus*, *Scarus rubroviolaceus*, *Cephalopholis argus*, *Monotaxis grandoculis*, and *Myripristis berndti*.

This assessment utilized a different approach compared to the existing model used for the FY2015-2018 specification. This approach used fishery independent size composition and abundance data from diver surveys combined with fishery dependent catch estimates to calculate current fishing mortality rates (F), spawning potential ratios (SPR), SPR-based sustainable fishing rates (F30: F resulting in SPR = 30%), and catch levels corresponding to these sustainable rates (C30). We used a length-based model to obtain mortality rates and a relatively simple age-structured population model to obtain the various stock status metrics. C30 were obtained by combining F30 estimates with current population biomass estimates derived directly from diver surveys or indirectly from the total catch. The overfishing limits (OFL) corresponding to a 50% risk of overfishing was defined as the median of the C30 distribution.

These assessments have undergone substantial peer review starting with the CIE review on September 8-11, 2015 (Stokes 2015; Dichmont 2015; Pilling 2015). The assessment author addressed the CIE review comments and recommendations and developed a stock assessment report that was reviewed by the WPSAR panel on August 29, 2016 to September 2, 2016 (Franklin 2016a; 2016b; Stokes 2016; Choat 2016). The assessment author revised the draft assessment addressing the WPSAR panel comments and recommendation and presented the final stock assessment document at the 125th and 169th meeting of the SSC and Council, respectively.

1.11.3.2 Stock assessment updates

No updates available for the coral reef MUS complex.

1.11.3.3 Other information available

Approximately every five years PIFSC administers a socioeconomic survey to small boat fishermen in Hawaii. 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 PIFSC internal report). This was the basis for the SEEM analysis that determined the risk levels to specify ACLs for all areas.

1.11.4 Crustacean fishery

1.11.4.1 Stock assessment benchmark

Spiny Lobsters: There is no benchmark stock assessment for any of the crustacean MUS. The first attempt to use a model-based approach in assessing the crustacean MUS complexes, particularly spiny lobsters, was done in 2014 using a biomass-based population dynamics model (Sabater and Kleiber 2014) for the purpose of improving the ACL specification for these stocks. 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 commercial marine license report.

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: There is no fishery independent data collection for crustaceans

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.

Slipper Lobsters: There has been no attempt to conduct an assessment of the slipper lobster stock. The best attempt to come up with a yield estimate was to use the 75^{th} percentile of the entire catch time series. This follows recommendations from the ORCS Working Group for data poor species (Berkson et al 2011).

Deep-water Shrimp: The deep water shrimp (*Heterocarpus laevigatus* and *H. ensifer*) initial resource assessment was conducted in the late 1980s by Ralston and Tagami (1988). This involved depletion experiments, stratified random sampling of different habitats, and calculation of exploitable biomass using the Ricker equation (Ricker 1975). Since then no new estimates were calculated for this stock.

Kona crab: A stock assessment model was developed in 2014 in an attempt to understand and determine the status of the Kona crab stock in the main Hawaii islands (Thomas, Lee, and Piner 2015). This assessment utilized a non-equilibrium generalized production model (using the Stock-Production Model Incorporating Covariate –ASPIC statistical routine) to estimate parameters needed to determine stock status. Based on this, the Kona crab stock is overfished (possibly rebuilding) but not experiencing overfishing.

This assessment had undergone a CIE desktop review in December 2015 (N.G. Hall 2015). The review concluded that the assessment had utilized the appropriate model and used the data and assumptions correctly making the assessment best available. However, the reviewer also cautioned that there are large uncertainties associated with the results which could change dramatically with the changes in the non-commercial catch assumptions and effects of the State of Hawaii's female release regulations. PIFSC agreed that further work is needed to provide advice on the current status of the population in more recent years. This was included in the list of stocks that PIFSC will conduct a benchmark assessment on in the future. To date, the best available information is based on the 75^{th} percentile of the entire catch time series as a proxy for sustainable yield levels.

1.11.4.2 Stock assessment updates

There were no stock assessment updates available for the crustacean MUS.

1.11.4.3 Best available scientific information

To date the best available scientific information for the crustacean MUS are as follows:

- Spiny lobsters – Sabater and Kleiber (2014)
- Slipper lobsters – WPRFMC (2011) – cite non-fin-fish EA
- Deepwater shrimp – Ralston and Tagami 1988
- Kona crab – WPRFMC (2011) – cite non-fin-fish EA

1.12 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. 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 52 summarizes the harvest extent and harvest capacity information for Hawaii in 2015

Table 52. Hawaii Archipelago – Main Hawaiian Island 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	Management Unit Species	ACL	Catch	Harvest extent (%)	Harvest capacity (%)
Bottomfish	MHI Deep-7 stock complex	326,000	309,127	97.2	2.8

	Non Deep 7 stock complex	178,000	115,760	65.0	35.0
Crustaceans	Deepwater shrimp	250,773	30,771	12.3	87.7
	Spiny lobster	15,000	6,617	44.1	55.9
	Slipper lobster	280	0	0.0	100.0
	Kona crab	27,600	2,002	7.3	92.7
Precious coral	Auau channel black coral	5,512		0.0	100.0
	Makapuu bed-pink coral	2,205		0.0	100.0
	Makapuu bed-bamboo coral	551		0.0	100.0
	180 fathom bank-pink coral	489		0.0	100.0
	180 fathom bank-bamboo coral	123		0.0	100.0
	Brooks bank-pink coral	979		0.0	100.0
	Brooks bank-bamboo coral	245		0.0	100.0
	Kaena point bed-pink coral	148		0.0	100.0
	Kaena point bed-bamboo coral	37		0.0	100.0
	Keahole bed-pink coral	148		0.0	100.0
	Keahole bed-bamboo coral	37		0.0	100.0
	Precious coral in HI exploratory area	2,205		0.0	100.0
Coral Reef Ecosystem	S. crumenopthalmus-akule	988,000	359,024	36.3	63.7
	D. macarellus-opelu	428,000	229,738	53.7	46.3
	Acanthuridae-surgeonfish	342,000	90,066	26.3	73.7
	Carangidae-jacks	161,200	39,642	24.6	75.4
	Carcharhinidae-reef sharks	9,310	1,948	20.9	79.1
	Crustaceans-crabs	**26,637**	28,140	105.6	-5.6
	Holocentridae-squirrelfish	148,000	52,630	35.6	64.4

	Kyphosidae - rudderfish	105,000	17,353	16.5	83.5
	Labridae - wrasse	205,000	7,197	3.5	96.5
	Lethrinidae - emperors	35,500	3,295	9.3	90.7
	Lutjanidae-snappers	330,300	36,333	11.0	89.0
	Mollusk-turbo snails, octopus, giant clam	**31,163**	38,889	124.8	-24.8
	Mugilidae-mullets	19,200	6,691	34.8	65.2
	Mullidae-goatfish	165,000	63,752	38.6	61.4
	Scaridae-parrotfish	239,000	50,206	21.0	79.0
	Serranidae - groupers	128,400	1,632	1.3	98.7
	All other CREMUS combined	485,000	64,438	13.3	86.7

1.13 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.

April 7, 2016. Final 2015-16 Annual Catch Limits and Accountability Measures for Main Hawaiian Islands Deep 7 Bottomfish. NMFS specified an annual catch limit (ACL) of 326,000 lb for Deep 7 bottomfish in the main Hawaiian Islands (MHI) for the 2015-16 fishing year. As an accountability measure (AM), if the ACL is projected to be reached, NMFS would close the commercial and non-commercial fisheries for MHI Deep 7 bottomfish for the remainder of the fishing year. The ACL and AM specifications support the long-term sustainability of Hawaii bottomfish. The specifications were effective May 9, 2016.

April 21, 2016. NMFS announced that the Secretary of Commerce approved Amendment 4 to the Fishery Ecosystem Plan for the Hawaiian Archipelago. In Amendment 4, the Council revised the essential fish habitat and habitat areas of particular concern for 14 species of bottomfish and three species of seamount groundfish in the Hawaiian Archipelago. The action considers the best available scientific, commercial, and other information about the fisheries, and supports the long-term sustainability of fishery resources.

January 18, 2017. Final 2016-17 Annual Catch Limit and Accountability Measures; **Main Hawaiian Islands (MHI) Deep 7 Bottomfish**. In this final rule, NMFS specifies an annual catch limit (ACL) of 318,000 lb of Deep 7 bottomfish in the MHI for the 2016-17 fishing year. As an accountability measure (AM), if the ACL is projected to be reached, NOAA Fisheries would close the commercial and non-commercial fisheries for MHI Deep 7 bottomfish for the remainder of the fishing year. The ACL and AM support the long-term sustainability of Hawaii bottomfish. The final specifications are effective from February 17, 2017, through August 31, 2017.

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.

January 23, 2017. **2017 NWHI lobster harvest guideline.** NMFS establishes the annual harvest guideline for the commercial lobster fishery in the Northwestern Hawaiian Islands for calendar year 2017 at zero lobsters.

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2 ECOSYSTEM CONSIDERATIONS

2.1 FISHERY ECOSYSTEM

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.

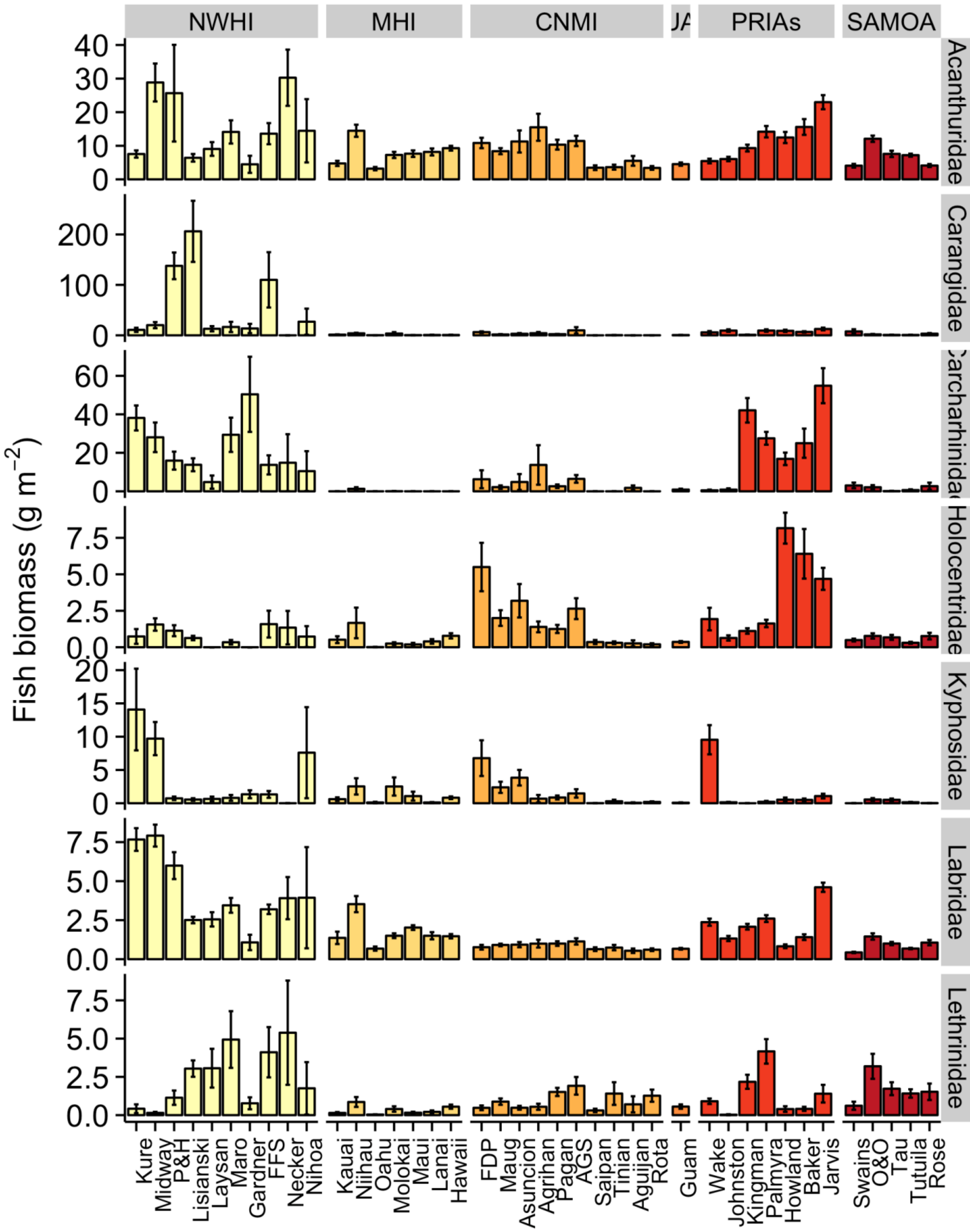
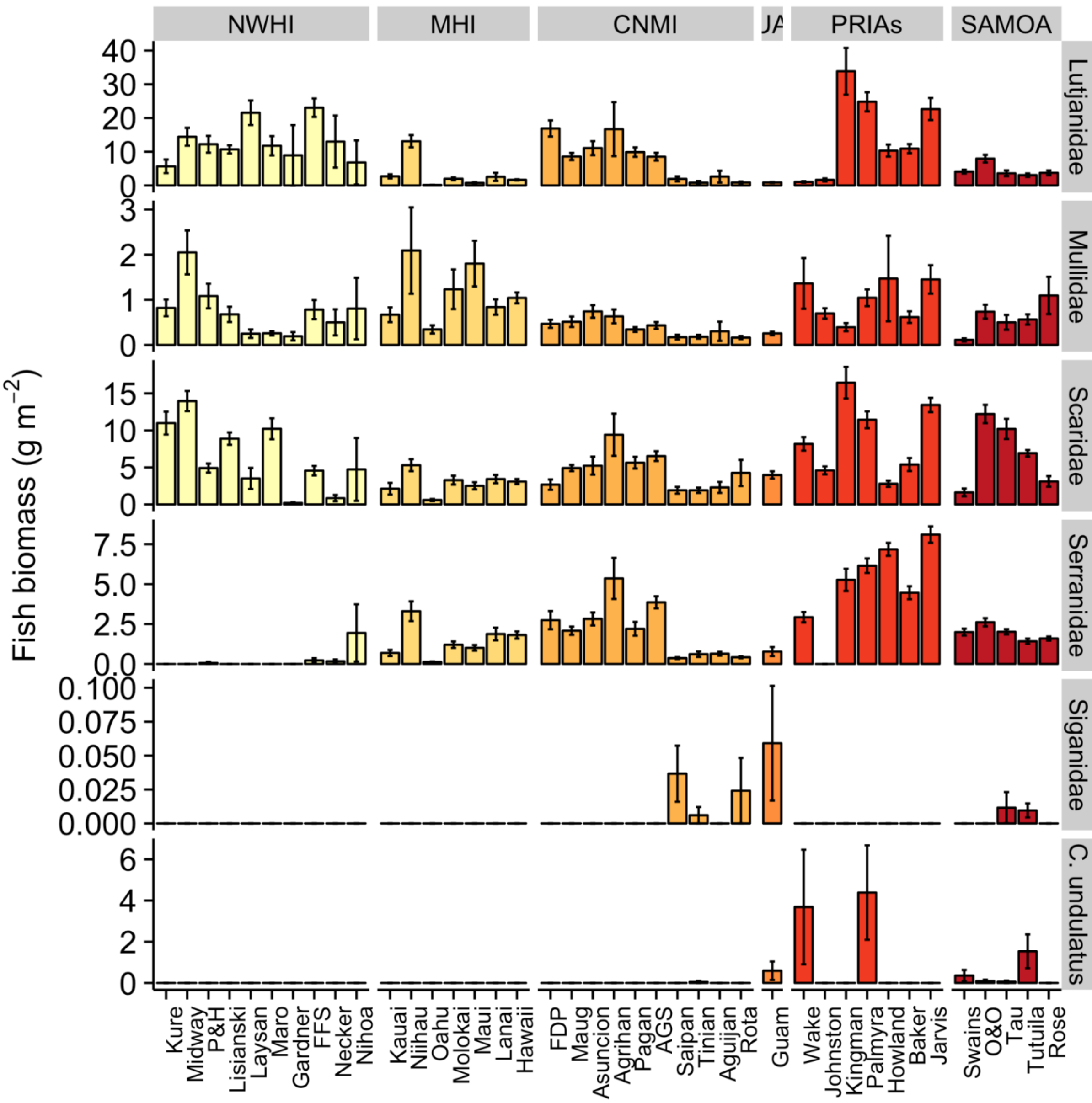


Figure 7. Mean fish biomass by Coral Reef Management Unit Species (CREMUS) grouping per US Pacific reef area. Mean fish biomass (± standard error) per CREMUS grouping per reef area pooled across survey years (2009-2015). Islands ordered within region by latitude. Continues on to next page.


NWHI
MHI
CNMI
JA
PRIAs
SAMOA
Lutjanidae
Mullidae
Scaridae
Serranidae
Siganidae
C. undulatus
Fish biomass (g m−2)
Kure
Midway
P&H
Lisianski
Laysan
Maro
Gardner
FFS
Necker
Nihoa
Kauai
Niihau
Oahu
Molokai
Maui
Lanai
Hawaii
FDP
Maug
Asuncion
Agrihan
Pagan
AGS
Saipan
Tinian
Aguijan
Rota
Guam
Wake
Johnston
Kingman
Palmyra
Howland
Baker
Jarvis
Swains
O&O
Tau
Tutuila
Rose

2.1.2 Main Hawaiian Islands 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.

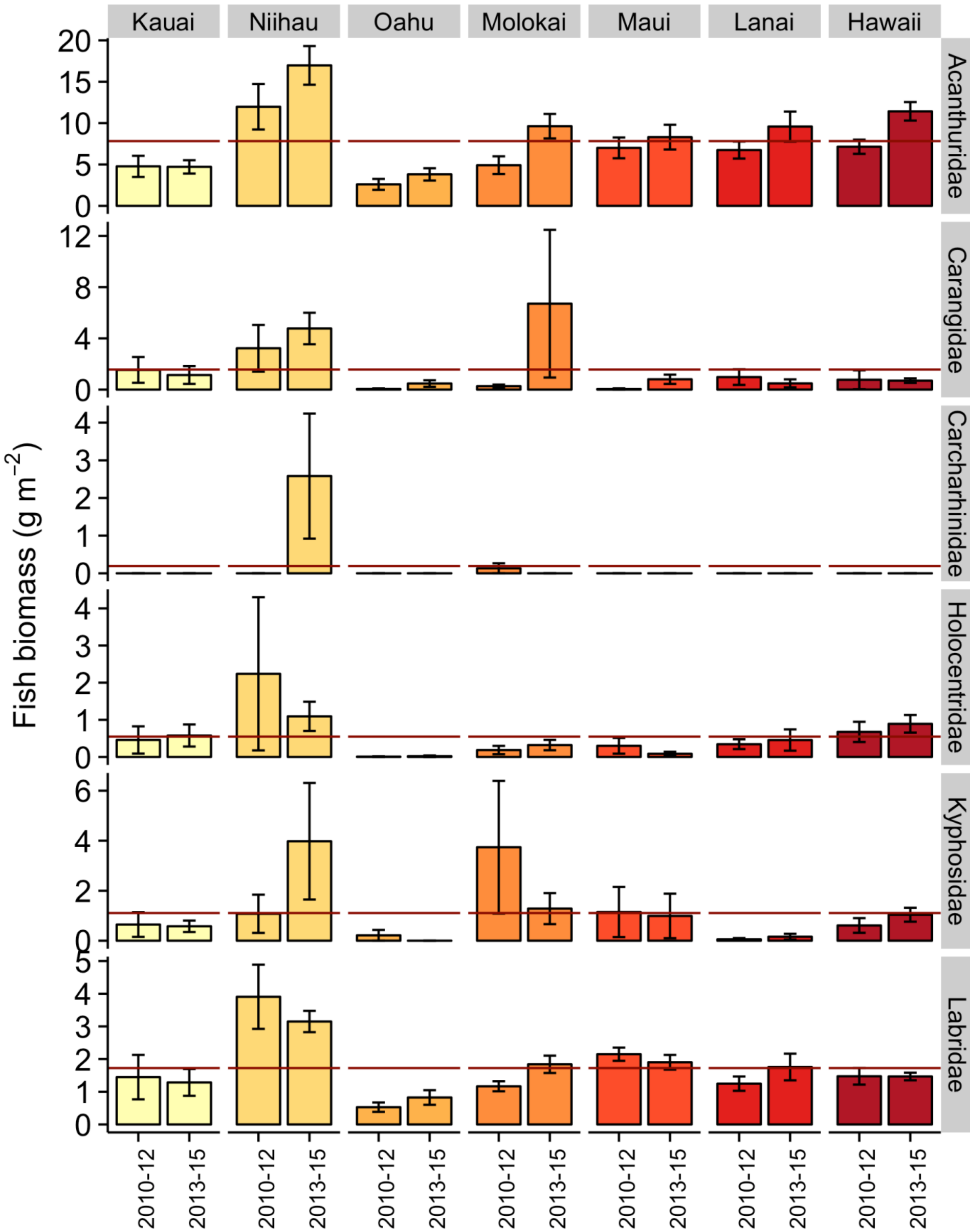
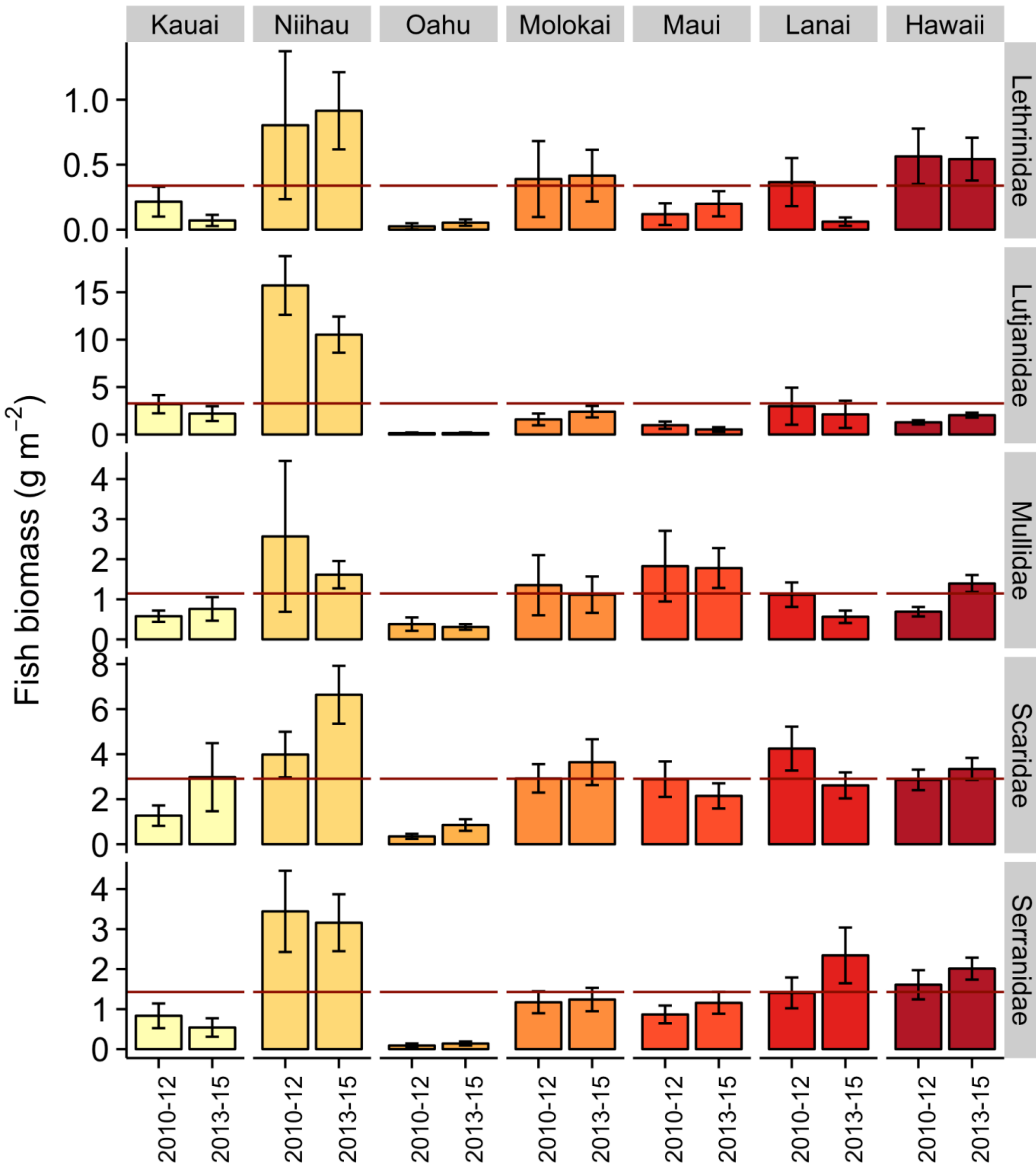


Figure 8. MHI showing the biomass of fish (g m-2 ± SE) per CREMUS grouping per year. The MHI mean estimates are plotted for reference (red line). Continues on to next page.


Kauai
Niihau
Oahu
Molokai
Maui
Lanai
Hawaii
Lethrinidae
Lutjanidae
Mullidae
Scaridae
Serranidae
Fish biomass (g m^{-2})
2010-12
2013-15

2.1.3 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.

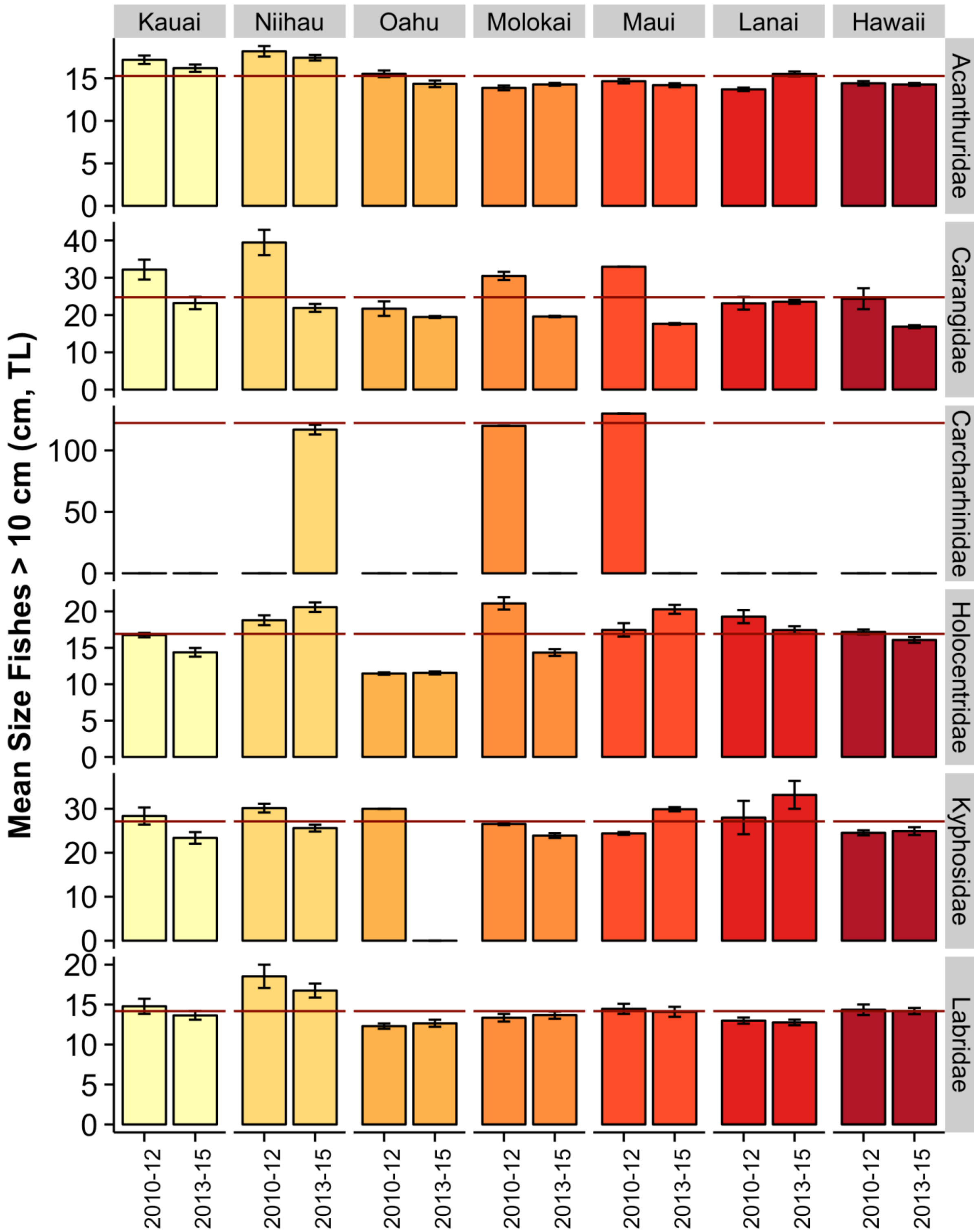
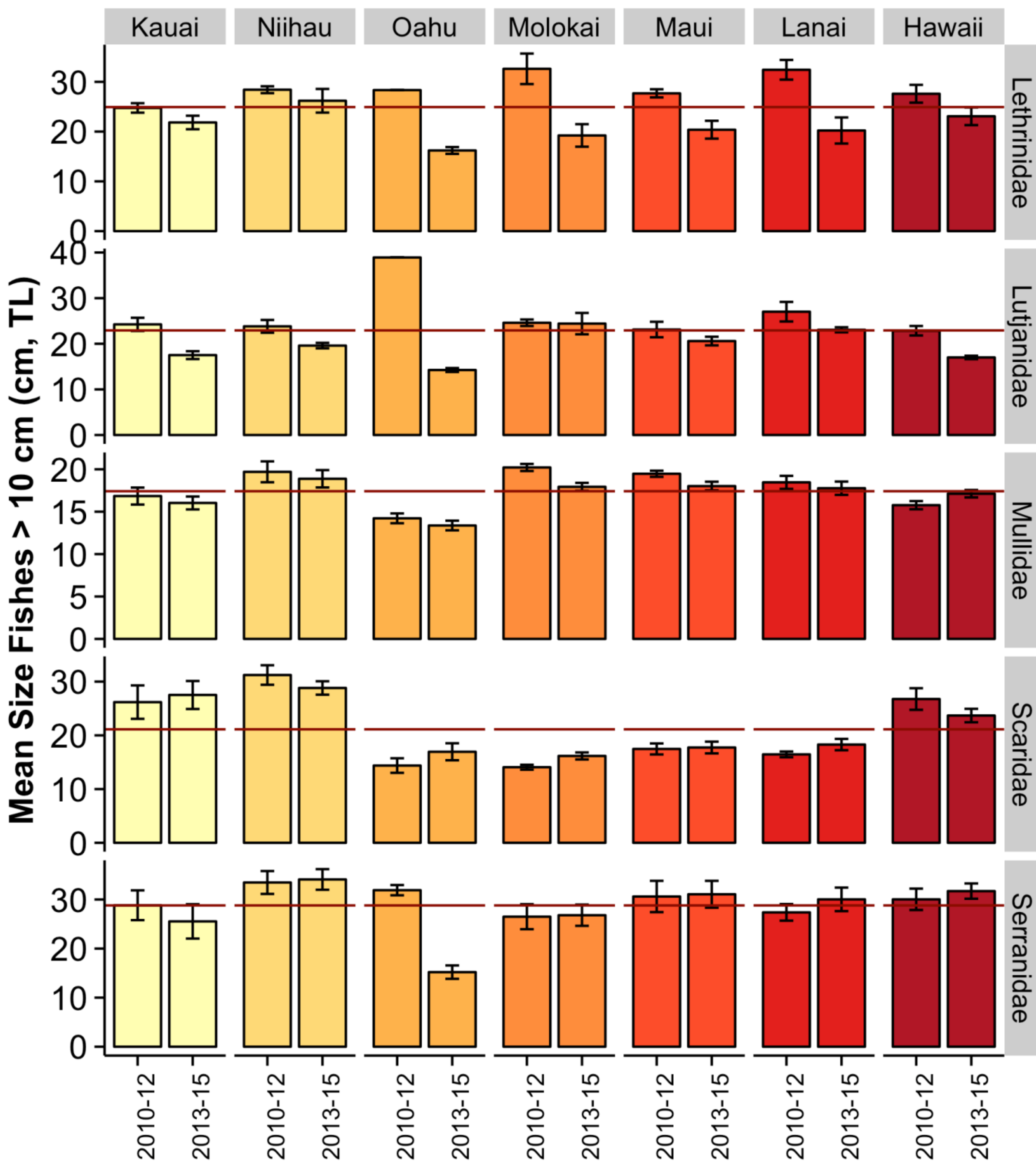


Figure 9. Figure 3. Main Hawaiian Islands mean reef fish size (cm ± SE) per CREMUS grouping per year. The Main Hawaiian Islands mean estimates are plotted for reference (red line). Continues to next page.


Kauai
Niihau
Oahu
Molokai
Maui
Lanai
Hawaii
Lethrinidae
Lutjanidae
Mullidae
Scaridae
Serranidae
Mean Size Fishes > 10 cm (cm, TL)
2010-12
2013-15

2.1.4 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 53. Reef fish population estimates for the Main Hawaiian Islands (MHI). 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 2-4 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.

Note (1): No Siganidae, *Bolbometopon muricatum* or *Cheilinus undulatus* were observed in MHI

			ESTIMATED POPULATION BIOMASS (metric Tonnes) in SURVEY DOMAIN OF <30m HARDBOTTOM					
ISLAND	Total Area of reef (Ha)	N	Acanthuridae	Carangidae	Carcharhinids	Holocentridae	Kyphosidae	Labridae
Kauai	18,127.1	82	859.6	242.3	-	94.0	111.0	247.7
Niihau	9,265.8	90	1,341.0	370.6	119.6	154.5	234.2	326.9
Oahu	25,118.8	171	804.5	67.1	-	3.8	27.3	170.0
Molokai	12,730.3	147	925.7	444.2	8.5	32.4	319.7	191.4
Maui	11,122.2	140	851.3	47.8	-	21.6	118.9	225.3
Lanai	3,003.7	88	245.3	22.0	-	12.0	3.3	45.1
Hawaii	16,839.8	198	1,563.1	123.6	-	132.0	139.0	247.7
TOTAL	**96,207.6**	**916**	**6,590.5**	**1,317.6**	**128.1**	**450.4**	**953.3**	**1,454.1**

ISLAND	Total Area of reef (Ha)	N	Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae
Kauai	18,127.1	82	25.9	489.0	121.3	385.2	124.6
Niihau	9,265.8	90	79.6	1,215.9	193.8	492.0	305.9
Oahu	25,118.8	171	9.9	36.9	86.5	151.3	29.0
Molokai	12,730.3	147	51.3	254.3	157.1	418.1	153.5
Maui	11,122.2	140	17.7	84.0	200.5	280.0	112.6
Lanai	3,003.7	88	6.4	76.7	25.2	103.0	56.3
Hawaii	16,839.8	198	93.2	279.9	175.5	522.2	305.0
TOTAL	**96,207.6**	**916**	**284.0**	**2,436.8**	**959.8**	**2,351.9**	**1,087.0**

2.1.5 Northwestern Hawaiian Islands 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.

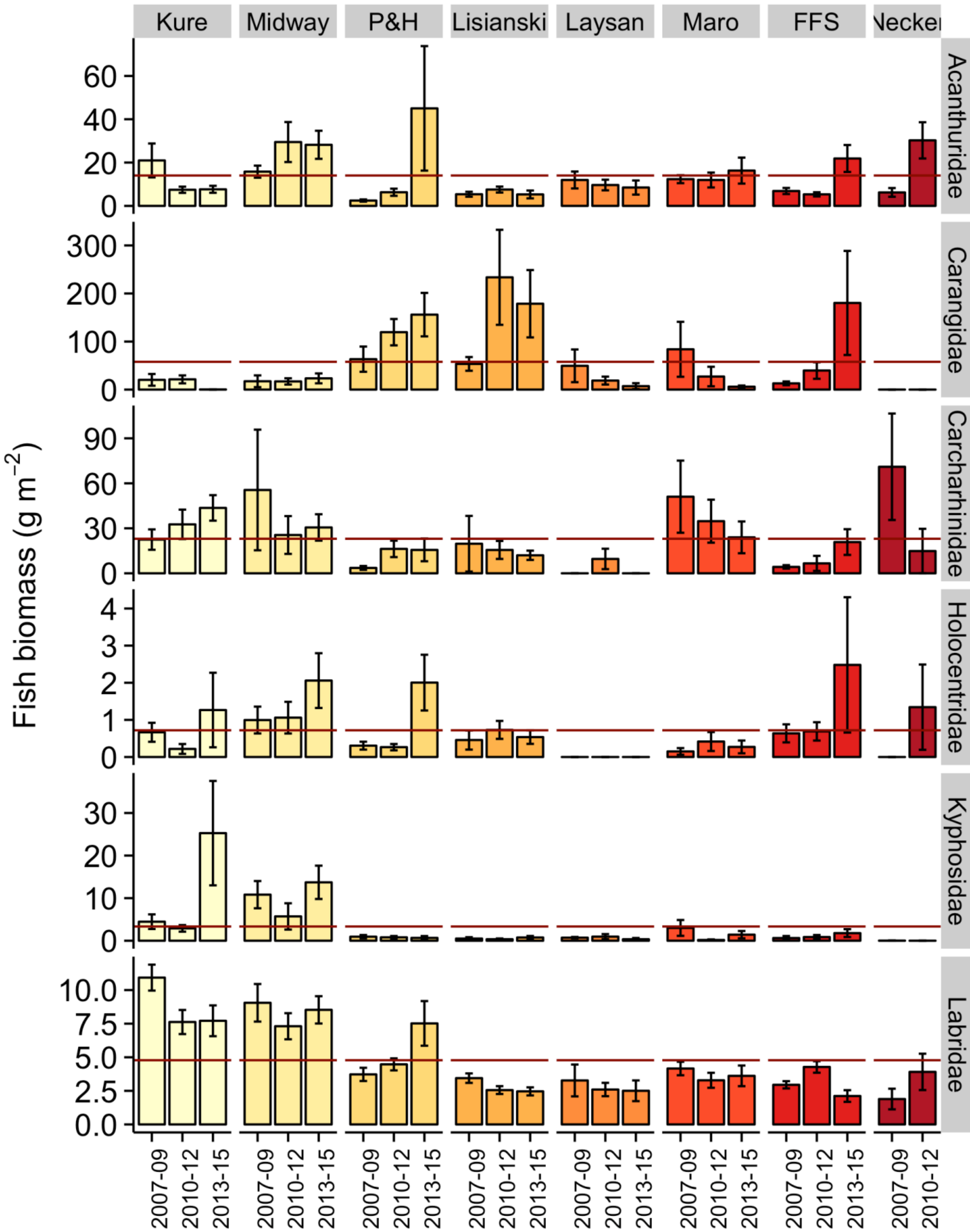
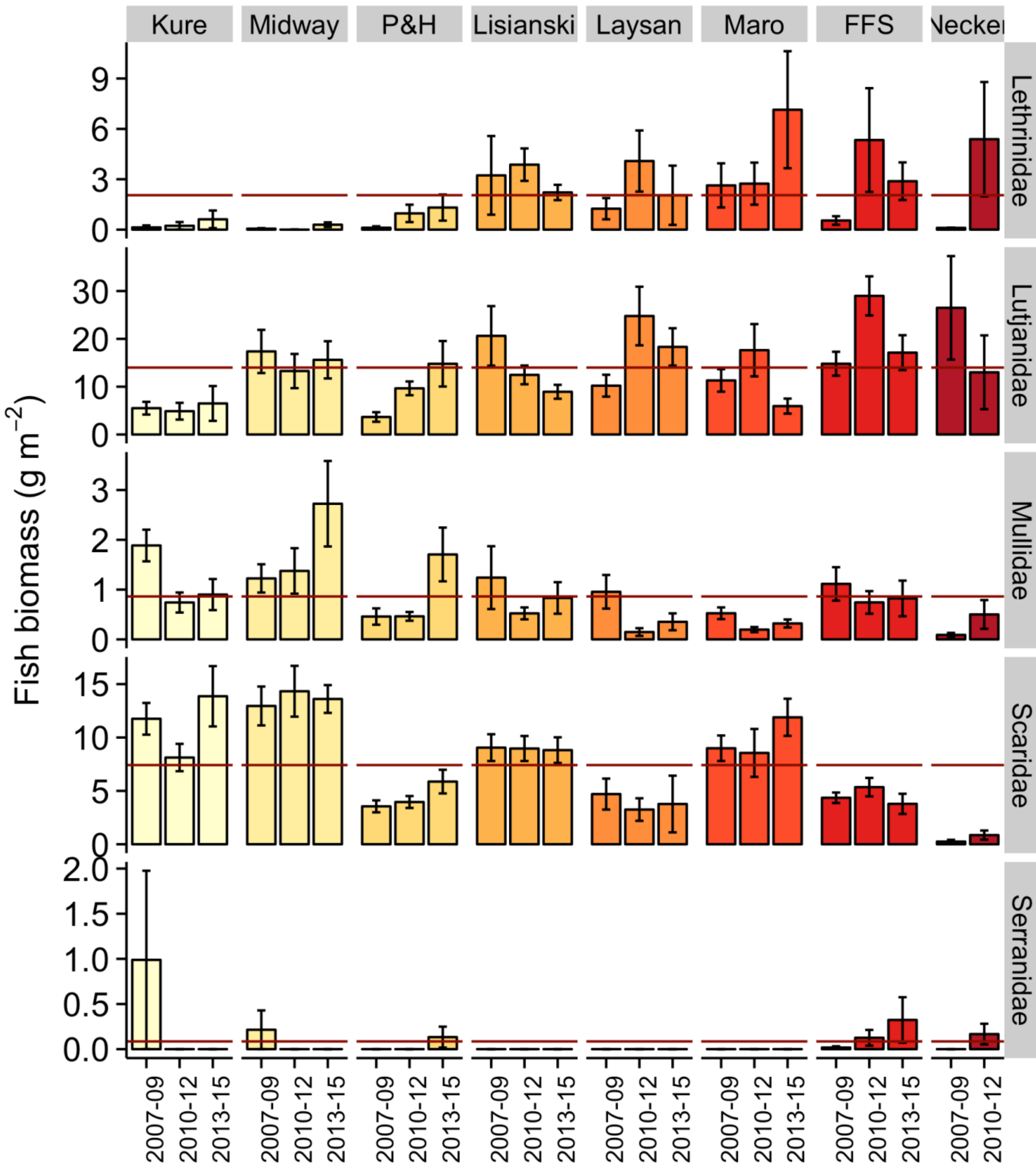


Figure 10. Mean fish biomass by Coral Reef Management Unit Species (CREMUS) grouping per Northwestern Hawaiian Island. Mean fish biomass (± standard error) per CREMUS grouping per reef area pooled across survey years (2009-2015). Islands ordered

within region by latitude. Data from Nihoa and Gardner Pinnacles are removed, as data are very limited. Continues to next page.



2.1.6 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.

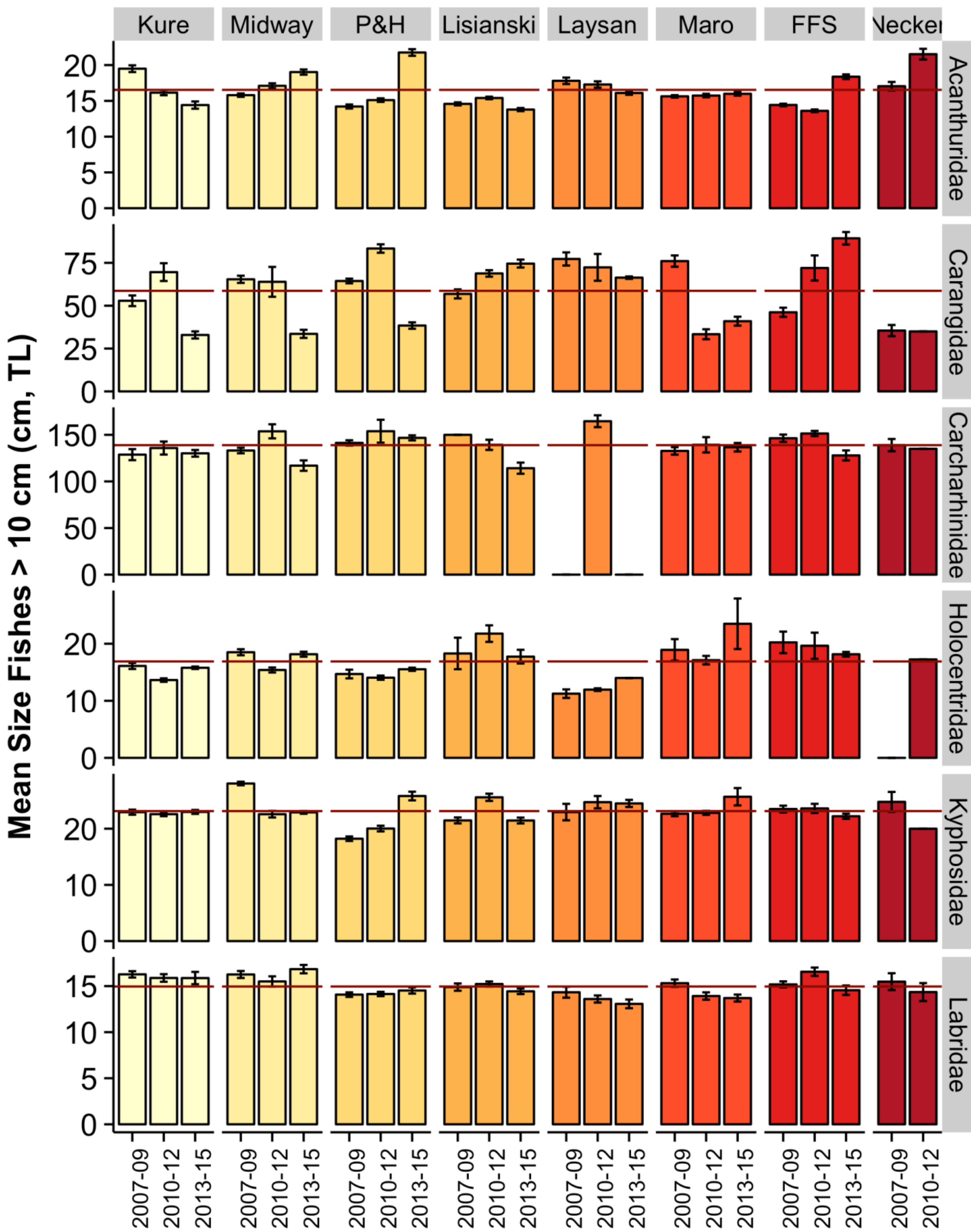
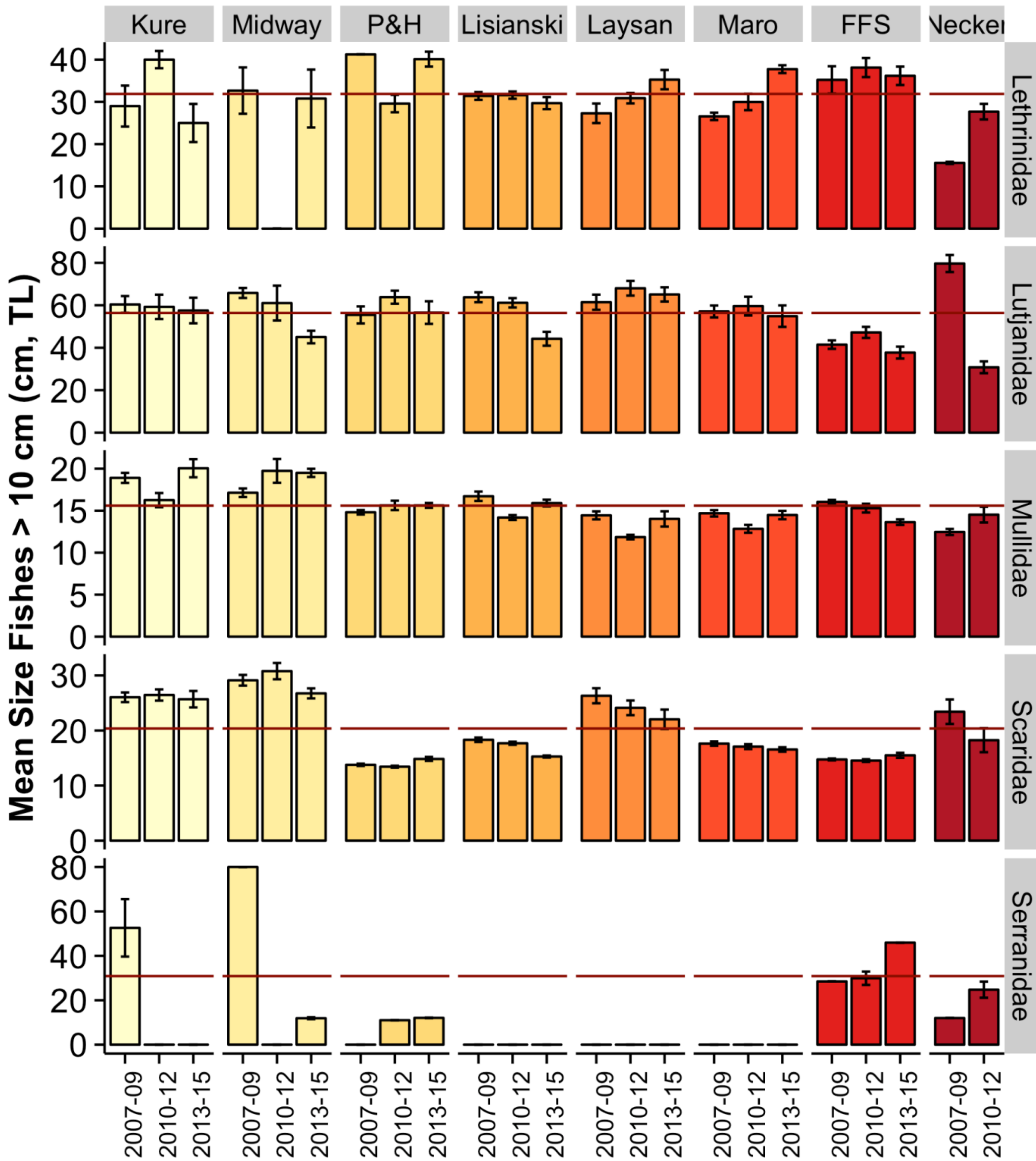


Figure 11. Northwestern Hawaiian Islands mean reef fish size (cm ± SE) per CREMUS grouping per year. The Northwestern Hawaiian Islands mean estimates are plotted for

reference (red line). Nihoa and Gardner Pinnacles are removed, as data are very limited. Continues to next page.



2.1.7 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 54. Reef fish population estimates for the Northwest Hawaiian Islands. 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 2-4 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.

			ESTIMATED POPULATION BIOMASS (metric Tonnes) in SURVEY DOMAIN OF <30m HARDBOTTOM					
ISLAND	Total Area of reef (Ha)	N	Acanthuridae	Carangidae	Carcharhinids	Holocentridae	Kyphosidae	Labridae
Kure	3,699.4	53	279.0	399.3	1,410.2	27.4	521.0	283.6
Midway	4,995.6	78	1,440.5	1,008.2	1,401.5	77.9	485.2	395.6
Pearl & Hermes	17,812.1	113	4,570.0	24,530.7	2,839.1	202.2	130.7	1,067.8
Lisianski	30,954.9	105	1,985.5	63,822.4	4,268.3	196.1	171.6	776.7
Laysan	3,399.6	31	307.8	441.5	162.9	-	22.0	86.7
Maro	34,192.6	42	4,827.9	5,676.8	10,040.6	117.7	274.1	1,179.6
Gardner	31,733.2	12	1,423.4	4,315.8	15,991.0	-	426.3	340.7
French Frigate	27,797.4	85	3,781.5	30,580.0	3,814.6	440.9	367.8	888.5
Necker	636.6	8	192.6	0.1	94.4	8.6	0.0	24.9
Nihoa	409.9	8	59.3	110.9	43.0	3.0	31.1	16.1
TOTAL	**155,631**	**535**	**21,137.0**	**146,910.5**	**35,152.7**	**1,262.1**	**2,597.5**	**5,499.4**

ISLAND	Total Area of reef (Ha)	N	Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae
Kure	3,699.4	53	15.5	210.2	30.4	406.7	-
Midway	4,995.6	78	7.3	721.3	102.4	697.8	-
Pearl & Hermes	17,812.1	113	203.1	2,176.3	193.1	875.3	11.9
Lisianski	30,954.9	105	941.3	3,311.5	209.6	2,752.9	-
Laysan	3,399.6	31	104.2	732.6	8.5	119.3	-
Maro	34,192.6	42	1,689.0	4,028.1	88.3	3,495.6	-
Gardner	31,733.2	12	245.6	2,839.8	61.5	64.4	1.3
French Frigate	27,797.4	85	1,142.2	6,407.8	217.5	1,269.8	62.5
Necker	636.6	8	34.3	82.8	3.2	5.5	1.1
Nihoa	409.9	8	7.2	27.9	3.3	19.4	8.0
TOTAL	**155,631**	**535**	**4,815.7**	**20,907.9**	**1,028.0**	**11,024.8**	**94.6**

Note (1): No Siganidae, *Bolbometopon muricatum* or *Cheilinus undulatus* were observed in NWHI

ISLAND	Total Area of reef (Ha)	N	ESTIMATED POPULATION BIOMASS (metric Tonnes) in SURVEY DOMAIN OF <30m HARDBOTTOM					
			Acanthuridae	Carangidae	Carcharhinids	Holocentridae	Kyphosidae	Labridae
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TOTAL	**155,631**	**535**	**21,137.0**	**146,910.5**	**35,152.7**	**1,262.1**	**2,597.5**	**5,499.4**

ISLAND	Total Area of reef (Ha)	N	Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae
Kure	3,699.4	53	15.5	210.2	30.4	406.7	-
Midway	4,995.6	78	7.3	721.3	102.4	697.8	-
Pearl & Hermes	17,812.1	113	203.1	2,176.3	193.1	875.3	11.9
Lisianski	30,954.9	105	941.3	3,311.5	209.6	2,752.9	-
Laysan	3,399.6	31	104.2	732.6	8.5	119.3	-
Maro	34,192.6	42	1,689.0	4,028.1	88.3	3,495.6	-
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Nihoa	409.9	8	7.2	27.9	3.3	19.4	8.0
TOTAL	**155,631**	**535**	**4,815.7**	**20,907.9**	**1,028.0**	**11,024.8**	**94.6**

Note (1): No Siganidae, *Bolbometopon muricatum* or *Cheilinus undulatus* were observed in NWHI

2.2 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 Fishery Ecosystem Plan for the Hawaii 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 Hawaii, followed by summaries of relevant studies and data for each fishery within the Hawaiian archipelago.

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 12), which is reflected in local culture, customs, and traditions.

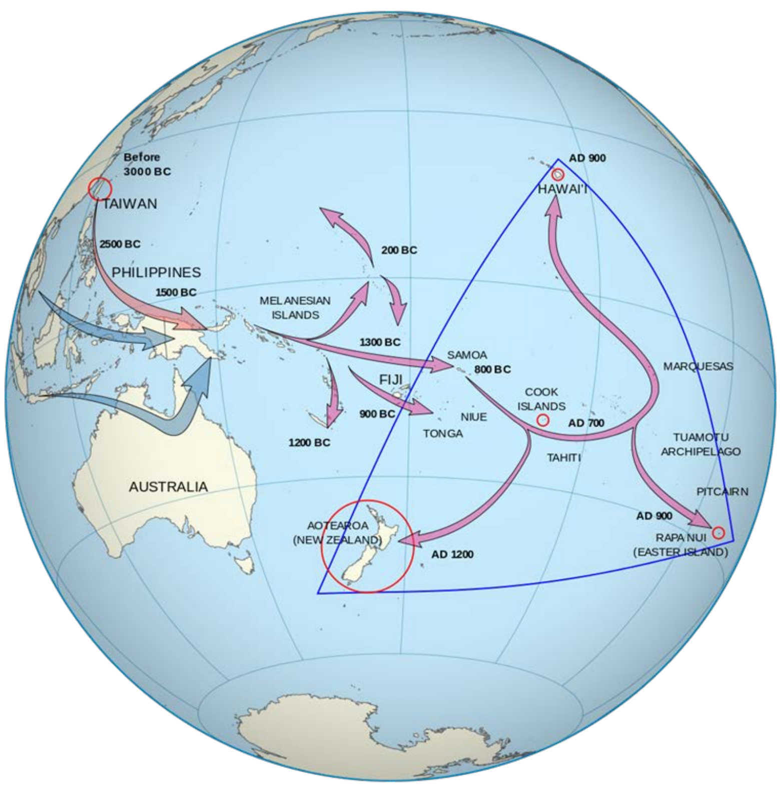

Figure 12. Settlement of the Pacific Islands, courtesy Wikimedia Commons https://commons.wikimedia.org/wiki/File:Polynesian_Migration.svg.

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.

2.2.1 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 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 with further input and guidance from the Council Social Science Planning Committee and Archipelagic Plan Team.

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 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).

2.2.2 Introduction

The geography and overall history of the Hawaiian Archipelago, including indigenous culture and current demographics and description of fishing communities is described in section 1.3 of the Fishery Ecosystem Plan for the Hawaii 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 the Hawaiian archipelago, as well as information about the people who engaging in the fisheries or use fishery resources.

As described in Chapter 1, a number of studies have outlined the importance of fishing for Hawaiian communities through history (e.g., see Geslani et al., 2012, and Richmond and Levine, 2012). Traditional Native Hawaiian subsistence relied heavily on fishing, trapping shellfish, and collecting seaweed to supplement land-based diets. Native Hawaiians also maintained fishponds, some of which date back thousands of years are still used today. The Native Hawaiian land and marine tenure system, known as ahupuaʻa-based management, divided the islands into large parcels called moku, which are reflected in modern political boundaries (Census County Districts).

Immigrants from many other countries with high seafood consumption and cultural ties to fishing and the ocean came to work on the plantations around the turn of the 20th Century, establishing in Hawaii large populations of Chinese, Japanese, Koreans, Filipinos, and Portugese, among others. In 1985, the Compact of Free Association also encouraged a large Micronesian population to migrate to Hawaii. According to the 2010 Census, the State of Hawaii's population is almost 1.4 million. Ethnically, it has the highest percentage of Asian Americans (38.6%) and Multiracial Americans (23.6%) and the lowest percentage of White Americans (24.7%) of all states. Approximately 21% of the population identifies as Native Hawaiian or part Native Hawaiian. Tourism from many of these Asian countries also increases the demand for fresh, high-quality seafood, especially sushi, sashimi, and related raw fish products such as poke.

Today, fishing continues to play a central role in the local Hawaiian culture, diet, and economy. In 2012, an estimated 486,000 people were employed in marine-related businesses in Hawaiʻi, with the level of commercial fishing-related employment well above the national average (Richmond et al., 2015). The Fisheries Economics of the United States 2014 report found that the seafood industry (including the commercial harvest sector, seafood processors and dealers, seafood wholesalers and distributors, importers, and seafood retailers) generated $743 million in sales impacts and approximately 10,000 full and part-time jobs that year (National Marine Fisheries Service, 2016). Recreational anglers took 1.4 million fishing trips, and 1,061 full- and part-time jobs were generated by recreational fishing activities in the state. Similarly, the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (U.S. Department of the Interior et al., 2011) estimated that 157 thousand people over 16 years old participated in saltwater angling in Hawai'i in 2011. They fished approximately 1.9 million days, with an average of 12 days per angler. This study estimated that fishing-related expenditures totaled $203 million, with each angler spending an average of $651 on trip-related costs. These numbers are not significantly different from those reported on the 2006 and 2001 national surveys.

Seafood consumption in Hawai'i is estimated at approximately two to three times higher than the entire U.S., and Hawai'i consumes more fresh and frozen finfish while shellfish and processed seafood is consumed more across the entire U.S. (see Geslani et al., 2010 and Davidson et al., 2012 for review). In addition, studies have shown that seafood is eaten frequently, at least once a week by most, and at least once a month by almost all respondents (National Coral Reef Monitoring Program, 2016). Fresh seafood is the most popular type of seafood purchased, and while most is purchased at markets or restaurants, a sizeable amount is reported as caught by friends, neighbors, or extended family (National Coral Reef Monitoring Program, 2016, Davidson et al., 2012).

At the same time, local supply is inadequate in meeting the high seafood demand. In 2010, 75% of all seafood consumed in the State of Hawaii was imported from either the U.S. mainland or foreign markets, and the rise in imported fish has influenced the price of local catch (Arita et al., 2011; Hospital et al., 2011). In addition, rising costs of fuel and other expenses have made it more difficult to recover trip costs (Hospital et al., 2011). A majority of commercial fishers report selling their fish simply to recover these costs, not necessarily to make income (Hospital et al., 2011). Many describe the importance of sharing fish as a part of maintaining relationships within family or other networks as being more important than earning income from fishing (personal communication, Bottomfish Oral History project, in progress).

Pelagic fish play a large role in seafood consumption, with Hawaii residents regularly consuming substantial amounts of fresh bigeye and yellowfin tuna as ‘ahi poke (bite-sized cubes of seasoned raw tuna) and ahi sashimi (sliced raw tuna). ‘Ahi is also a significant part of cultural celebrations, especially during the holiday period from late November (Thanksgiving) through late January to mid-February (Chinese New Year). Changes in bigeye regulations can have far-reaching effects not only on Hawai‘i's fishing community but also on the general population (Richmond et al., 2015). While most of the fresh tuna consumed in Hawaii is supplied by the local industry, market observations suggest that imported tuna is becoming more commonplace to meet local demands (Pan, 2014).

2.2.3 People who Fish

Hawaii includes a mix of commercial, non-commercial, and subsistence characteristics across fisheries. Archipelagic fisheries are primarily accessed via a small boat fleet and through shoreline fishing. Within the small boat fleet, there is a nearly continuous gradation from the full-time and part-time commercial fleet to the charter and personal recreation fleets. A single boat (and trip) will often utilize multiple gear types and target fish from multiple fisheries. Thus, other than the longline fishery, the other fisheries are typically not studied individually. Rather, studies have typically been conducted based on ability to reach potential respondents. Studies have targeted fishermen via State of Hawaii Commercial Marine Licenses (CMLs) (Chan and Pan, 2017, Madge et al., 2016), shoreline and boat ramp intercepts (Hospital et al., 2011, Madge et al., 2016), and vessel and angler registries (Madge et al, 2016). The number of participants involved in small boat fishing increased between 2003 and 2013 from 1,587 small boat-based commercial marine license holders to 1,843 (excluding charter, aquarium, and precious coral fisheries, Chan and Pan, 2017). Together, these small boat fishermen produced 6.2 million pounds of fish in 2013, with a commercial value amounted to $16 million.

The Hawaii small boat pelagic fleet was studied in 2007-2008 (hereafter, referred to as the 2008 study), following a design last used in 1997 (Hospital et al., 2011). Because respondents also targeted insular fish, the study is included in this report. Their work was updated in 2014 by Chan and Pan (2017) for the small boat fleet in general. Both studies found that the small boat fleet is predominantly owner-operated and a male dominated activity (98% of respondents were male in both studies). The ethnic composition was predominantly Asian (45% in 2008, 41% in 2014) and White (23% in 2008, 26% in 2014), which is similar to the state population as a whole. In 2014, proportionally more Native Hawaiians and Pacific Islanders responded to the survey than are represented in the general population (18% vs. 10%). In addition, the majority of respondents had a household income above $50,000 (75% in 2008, 69% in 2014).

These studies also asked respondents to classify themselves based on categories ranging from commercial to non-commercial. In 2014, 7% identified as full-time commercial, 51% identified as part-time commercial, 27% identified as recreational expense where they sold some catch to offset fishing expenses, 11% as purely recreational, 3% as subsistence, and 1% as cultural. Different activities were then compared based on self-classification.

As previously mentioned, the Hawaii small boat fishery is a mixed-gear fishery. In 2008, 47% of respondents reported using more than one gear type, predominantly trolling (for pelagic fish) and handline (for bottomfish). In 2014, 65% of respondents reported trolling as their most common gear, while 16% indicated bottomfish handline, and 12% stated pelagic handline was their most commonly used gear. Trolling was more commonly used by recreational fishermen whereas pelagic handline and bottomfish gears were more commonly used by commercial fishermen. The 2014 study also asked about species composition of catch. While 93% of the respondents reporting landing pelagic fish in the past 12 months, about half of respondents also reported they caught and landed bottomfish or reef fish. Thus, the small boat fleet includes not only a mixture of gear types, but also targets both pelagic and insular fish stocks.

Both studies also examined how fishermen self-identified vs. their commercial and non-commercial activities. In both cases, many people who considered themselves recreational, subsistence, or cultural fishers still sold fish. In 2008, 42% of fishermen self-classified as commercial fishermen, yet 60% of respondents reported selling fish in the past 12 months. In addition, just over 30% of fishermen who self-classified as recreational reported selling fish in the past year. Results for the 2014 study are shown in Table 55.

Table 55. Catch disposition by fisherman self-classification (Chan and Pan, 2017)

	Number of respondents (n)	Caught and released (%)	Given away (%)	Consumed at home (%)	Sold (%)
All Respondents	***738***	**5.6**	**13.9**	**15.4**	**65.0**
By Fisherman Classification					
Full-time commercial	*55*	6.2	9.4	11.6	72.8
Part-time commercial	*369*	5.2	12.9	14.4	67.5
Recreational expense	*200*	6.7	19.8	21.7	51.8
Purely recreational	*78*	5.4	37.3	29.6	27.6
Subsistence	*24*	1.9	20.7	31.0	46.5
Cultural	*8*	4.0	36.8	22.5	36.7

In 2014, the average value of fish sold by all respondents was approximately $8,500. Full-time commercial fishermen reported the highest value of fish sold ($35,528 annually and $558 per trip), part-time commercial fishermen reported $8,391 annually and $245 per trip, cultural fishermen $3,900 annually and $150 per trip, recreational expenses fishermen $2,690 annually and $95 per trip, subsistence fishermen $1,905 annually and $79 per trip, and purely recreational fishermen reported selling close to $1,000 annually ($58 per trip). While income from fish selling served as an important source of personal income for full-time commercial fishermen, the majority of fishermen reported selling fish to cover trip expenses, not necessarily to make a profit; few fishermen reported substantial, if any, profits from fishing. In the 2008 study, respondents expressed concern about their ability to cover trip costs, noting that trip costs continued to increase from year to year, but fish prices remained relatively flat.

The 2008 study was also the first attempt to quantify the scale of unsold fish that was shared within community networks. For commercial fishermen, trips where no fish are sold (30.5%) were nearly equal to trips where profit was made (30.9%). In addition, 97% of survey respondents indicated they participated in fish sharing networks with friends and relatives, and more than 62% considered the fish they catch as an important food source for their family. Community networks were also present in the outlets where fish were sold, which included the United Fishing Agency (UFA) auction in Honolulu, dealers/wholesalers, markets/stores, restaurants, roadside, but also sales to friends, neighbors, and coworkers. The 2014 study also documented 27% of sales to friends, neighbors, or coworkers and corroborated the importance of giving away fish for all self-classification categories (Table 55). In addition, 17% of respondents (who all held CMLs) sold no fish in the past 12 months.

Taken together, the results from these studies suggest a disconnect between Hawaii fishermen’s attitudes and perceptions of their fishing activity relative to current regulatory frameworks. The small boat fleet is extremely heterogeneous with respect to gear type, target species, and catch disposition, while regulations attempt to treat each separately with clear distinctions between commercial and recreational activities. In addition to providing income, the Hawaii small boat fleet serves many vital nonmarket functions, including building social and community networks, perpetuating fishing traditions, and providing fish to local communities.

A survey was also conducted on the attitudes and preferences of Hawaii non-commercial fishers (see Madge et al., 2016). Nearly all survey respondents were male (96%). Their average age was 53, and, on average, they had engaged in non-commercial saltwater fishing in Hawaii for 31 years. The majority had household income equal to or greater than $60,000, reported high levels of education, and reflected a large racial diversity (primarily various Asian ethnicities and White). They primarily fished via private motor boat (61%), followed by shore, including beach, pier, and bridge (38%). Offshore trolling and whipping/casting, and free-dive spearfishing were the most frequent gears reported as “always” used, and a majority of respondents reported using multiple gears on a single fishing trip.

As with the small boat fleet, even though this study targeted “non-commercial fishermen”, 9% reported that their primary motivation for fishing was to sell some catch to recover trip expenses. However, the primary motivation for the majority (51%) was purely for recreational purposes (only for sport or pleasure). A total of 78% of respondents indicated they “always” or “often” share catch with family and friends, and only 35% indicated they “never” supply fish for community/cultural events. Fishing for home/personal consumption was the most important trip catch outcome (36% rated it “extremely important”), followed by catching enough fish to be able to share with friends and family (20%). Thirty-six percent indicated that their catch was extremely or very important to their regular diet. Thus, similar to the small boat fleet, non-commercial fishermen demonstrate mixed motivations that include commercial activities. They also play an important role in providing fish via social and community networks, even though they report their primary motivation as fishing only for sport or pleasure.

The National Marine Fisheries Service (NMFS) and the Hawaiʻi Division of Aquatic Resources (DAR) have been collecting information on recreational fishing in Hawaiʻi, administered through the Hawaiʻi Marine Recreational Fishing Survey (HMRFS, see Allen and Bartlett, 2008, and Ma and Ogawa, 2016). The program collected data from 1979-1981, but not from 1982-2000, and then began annual data collection again in 2001. A dual survey approach is currently used. A telephone survey of a random sample of households determines how many have done any fishing in the ocean, their mode of fishing, methods used, and effort. The telephone survey component will be discontinued after 2017 due to declining land line coverage. Concurrently, surveyors conduct in-person intercept surveys at boat launch ramps, small boat harbors, and shoreline fishing sites. Fisher county of residence and zip code is regularly collected in the intercept surveys, but has not yet been compared to the composition of the general public. As with the other surveys, this program has documented a mix of gears used and pelagic and insular fish caught. The majority of trips from the onsite interviews were from "pure recreational fishermen" (defined as people who do not sell their catch), with an average of almost 60% to over 80%, depending on year and island. However, they also noted that in Hawaii the divisions between commercial, non-commercial or recreational are not clearly defined, and results suggested that the majority of catch for some categories of fishermen may be consumed by themselves or given away, further reinforcing common themes from other studies.

2.2.4 Costs of Fishing

Past research has documented the costs of fishing in Hawaii (Hamilton and Huffman, 1998; Hospital et al., 2011; Hospital and Beavers, 2012). This section presents the most recent estimates of trip-level costs of fishing for boat-based bottomfish and coral reef fishing trips in Hawaii. Fishing trip costs were collected from the 2014 Hawaii small boat survey (Chan and Pan, 2017). Fishermen were asked their fishing trip costs for the most common and second most common gear types they used in the past 12 months and the survey provides information on the variable costs incurred during the operation of vessel including; boat fuel, truck fuel, oil, ice, bait, food and beverage, daily maintenance and repair, and other. Table 56 provides estimates for the cost of an average boat-based bottomfish or reef fish-targeted trip during 2014. Estimates for annual fishing expenditures (fixed costs) and levels of investment in the fishery are also provided in the literature (Hamilton and Huffman, 1998; Hospital et al., 2011; Hospital and Beavers, 2012; Chan and Pan, 2017).

Table 56 Hawaii small boat trip costs: bottomfish and reef fish trips, 2014

Cost Category	Bottomfish handline		Reef Fish (spear)	
	$ per trip	% of total trip cost	$ per trip	% of total trip cost
Fuel	134.24	53%	86.26	54%
Non-fuel	118.34	47%	72.68	46%
Total cost	252.58	100%	158.94	100%

Source: PIFSC Socioeconomics Program: Hawaii small boat cost-earnings data: 2014. Pacific Islands Fisheries Science Center, https://inport.nmfs.noaa.gov/inport/item/29820

2.2.5 Bottomfish

This section reviews important community contributions of the MHI bottomfish fishery, as described in further detail in Hospital and Pan (2009), Hospital and Beavers (2011), and Hospital and Beavers (2012), and supplemented by recent data from Chan and Pan (2017). For studies that examined the small boat fishery in general (Hospital et al., 2011, and Chan and Pan, 2017), overall fisher demographics and catch disposition were summarized in section 2.2.3, as bottomfishing is only one of the gear types used by the small boat fleet.

Economically, the MHI bottomfish fishery is much smaller scale than the large pelagic fisheries in the region, but it is comparable in terms of rich tradition and cultural significance. Bottomfishing was part of the culture and economy of Native Hawaiians long before European explorers ever visited the region. Native Hawaiians harvested the same species as the modern fishery, and much of the gear and techniques used today are modeled after those used by Native Hawaiians. Most of the bottomfish harvested in Hawaii are red, which is considered an auspicious color in many Asian cultures, symbolic of good luck, happiness, and prosperity. Whole red fish are sought during the winter holiday season to bring good luck for the New Year from start to finish, and for other celebrations, such as birthdays, graduations, and weddings. Many restaurants across the State of Hawaii also serve fresh bottomfish, which are sought by tourists.

The bottomfish fishery grew steadily through the 1970s and into the 1980s but experienced steady declines in the following decades. Much of the decline in domestic production has been attributed to the limited-entry management regime introduced in the early 1990s in the NWHI and reductions in fishing vessels and trips fleet-wide. In the late 1990s, research identified overfishing as a contributor to the declines, which led to establishment of spatial closure areas (bottomfish restricted fishing areas [BRFAs]), a bottomfish boat registry, and a noncommercial bag limit for Deep 7 species. Emergency closures in 2007 also resulted in today's Total Allowable Catch (TAC) management regime, which sets a quota for the MHI Deep 7 bottomfish. Under this system, commercial catch reports are used to determine when the quota has been reached for the season, at which point both the commercial and non-commercial fisheries remain closed. This has implications for the ability of fishermen to build and maintain social and community networks throughout the year, given the cultural significance of this fishery.

In addition, in June 2006 the Northwestern Hawaiian Islands Marine National Monument was established in the NWHI, prohibiting all extractive activity and phasing out the active NWHI bottomfish fishery. This removed a source of approximately 35% of domestic bottomfish from Hawaii markets. The market has increasingly relied on imports to meet market demands, which may affect the fishery's traditional demand and supply relationships.

Overall, 45% of the MHI small boat fleet participated in the bottomfish fishery when last surveyed in 2014 (Chan and Pan 2017). The MHI bottomfish fleet is a complex mix of commercial, recreational, cultural, and subsistence fishing. The artisanal fishing behavior, cultural motivations for fishing, and relative ease of market access do not align well with mainland U.S. legal and regulatory frameworks.

In a 2010 survey, bottomfish fishermen were asked to define what commercial fishing meant to them (Hospital and Beavers 2012). The majority of respondents agreed that selling fish for profit, earning a majority of income from fishing, and relying solely on fishing to provide income all constituted commercial fishing. However, there was less agreement on other legally established definitions, such as selling one fish, selling a portion of fish to cover trip expenses, the trade and barter of fish, or selling fish to friends and neighbors. In the 2014 survey (Chan and Pan 2017), fishers whose most common gear was bottomfish handline identified themselves as primarily part-time commercial fishermen (53% selected this category) and recreational expense fishermen (21%). Only a few self-identified as full-time commercial (11%), purely recreational (9%), subsistence (6%) or cultural (1%) fishermen. Overall, bottomfish represented a lower percentage of total catch (11%) than total value (23%). While fishery highliners appear to be able to regularly recover trip expenditures and make a profit from bottomfish fishing trips, they represented only 8% of those surveyed in 2014. It is clear that for a large majority of fishery participants the social and cultural motivations for bottomfish fishing outweigh economic prospects.

2.2.5.1 Commercial Participation, Landings, Revenues, Prices

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

2.2.5.2 Economic Performance Metrics

NOAA Fisheries has established a national set of economic performance indicators to monitor the economic health of the nation’s fisheries (Brinson et al., 2015). The PIFSC Socioeconomics Program has used this framework to evaluate select regional fisheries; specifically, the Hawaii Longline, American Samoa Longline, and Main Hawaiian Islands (MHI) Deep 7 bottomfish fisheries. These indicators include metrics related to catch, effort, and revenues. This section will present revenue performance metrics of; (a) total fishery revenues, (b) fishery revenue per trip, (c) Gini coefficient, and (d) the share of annual revenues from the fishery for the MHI Deep 7 bottomfish fishery.

Revenue per trip, revenue per day-at-sea, and Gini coefficients for the MHI Deep 7 bottomfish fishery included any trip that catches one or more of the Deep 7 bottomfish species in main Hawaiian Islands including onaga, ehu, opakapaka, kalekale, gindai, lehi and hapuupuu. The Gini coefficient measures the equality of the distribution of revenue among active vessels in the fishery. A value of zero represents a perfectly equal distribution of revenue amongst these vessels, whereas, a value of one represents a perfectly unequal distribution, in the case that a single vessel earns all of the revenue.

The annual total revenue for the MHI Deep 7 bottomfish fishery was estimated based on:

1. The total number of fish kept by species from all MHI deep 7 fishing trips in a fishing year, as reported by fishermen (including deep 7 species, non-deep 7 Bottomfish-Management-Unit-Species (BMUS), and all other species (e.g. pelagic).
2. Since 2007, the fishing year for the MHI Deep 7 bottomfish fishery starts September 1 and ends August 31 of the following year, or earlier if the quota is reached before the end of the season. The 2013 fishing year is defined by September 1, 2013 through August 31, 2014.
3. The weight of the kept catch, estimated as the number of fish kept times the annual average whole weight per fish based on State of Hawaii marine dealer data.
4. The estimated value of the catch, estimated as the weight of the kept catch times the annual average price per pound.

For the Hawaii Deep 7 bottomfish fishery, revenue was calculated by license (CML) because individual revenues are monitored by CML. Multiple fishermen can fish in the same vessel but report their revenue separately, by individual CML. Additionally, a fisherman may fish in different vessels through the year, so revenue is more attached to CML than to vessel and the Gini coefficient essentially measures the equality of the distribution of revenue among active fishermen (CML holders). The high Gini coefficient in this fishery would imply that a small portion of fishermen account for a large share of fishery revenues. Past research demonstrates evidence of this as participants in this fishery reflect a wide range of motivations and avidity, and there is a relatively small segment of full-time commercial fishery highliners (Hospital and Beavers, 2012; Chan and Pan, 2017).

Trends in fishery revenues are shown Figure 13 while trends in revenue distribution are shown in Figure 14. In these figures "fishery" revenues refers only to Deep 7 bottomfish species catch and revenues and excludes other species (such as non-Deep 7 bottomfish, pelagic, and other species) caught on Deep 7 fishing trips. Supporting data are provided in Table 57, where the last column reflects the share of Deep 7 bottomfish in total fishing revenues (all species combined) for fishermen active in the MHI Deep 7 bottomfish fishery.

Figure 13 Trends in fishery revenues for the Hawaii Deep 7 Bottomfish fishery

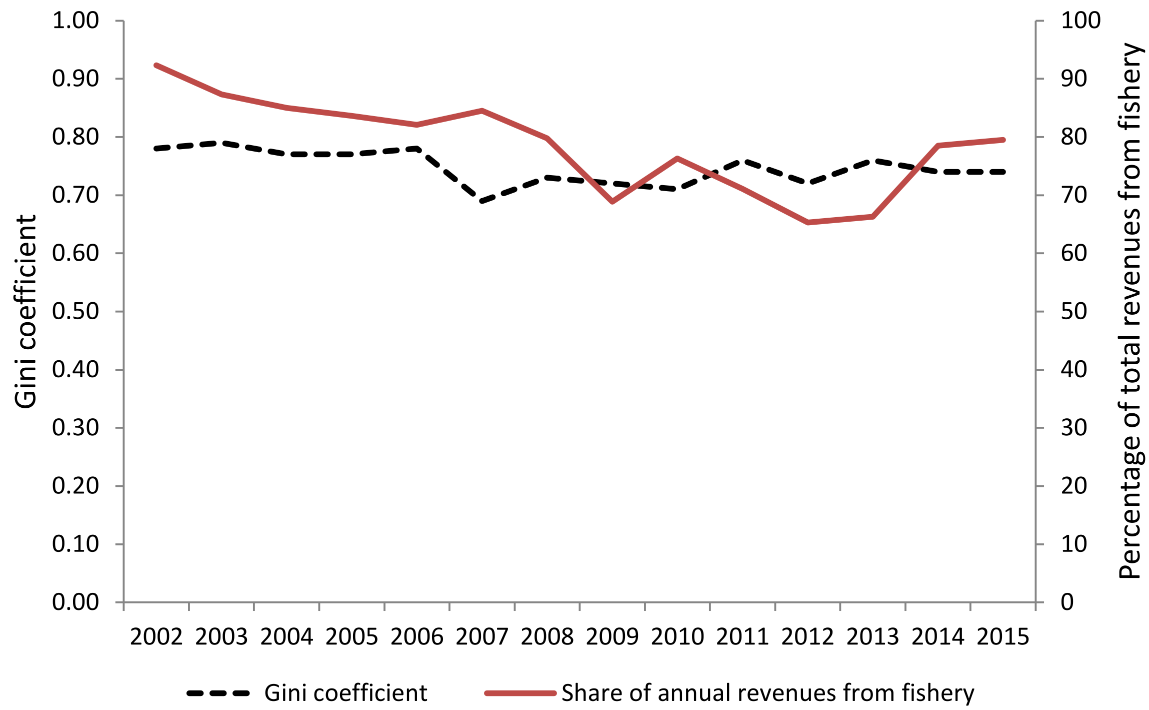

Figure 14 Trends in revenue distribution for the Hawaii Deep 7 Bottomfish fishery

Table 57 Hawaii bottomfish fishery economic performance measures

Year	Annual fishery revenues ($)[1], per vessel	Annual fishery revenues ($)[1], per trip	Gini coefficient	% Annual revenues ($)[1] from fishery
2002	3,032	558	0.78	92.3
2003	4,780	597	0.79	87.3
2004	4,462	635	0.77	85.0
2005	4,194	650	0.77	83.6
2006	3,840	605	0.78	82.1
2007	3,902	597	0.69	84.5
2008	3,356	502	0.73	79.8
2009	2,938	503	0.72	68.9
2010	3,549	505	0.71	76.3
2011	3,184	503	0.76	71.1
2012	3,679	572	0.72	65.3
2013	4,789	656	0.76	66.3
2014	5,083	727	0.74	78.5
2015	4,939	801	0.74	79.5

Source: PIFSC Socioeconomics Program: Fishery Economic Performance Measures. Pacific Islands Fisheries Science Center, https://inport.nmfs.noaa.gov/inport/item/46097

[1] Inflation-adjusted revenues (in 2015 dollars) use the Honolulu Consumer Price Index (CPI-U) https://www.bls.gov/regions/west/data/consumerpriceindex_honolulu_table.pdf

2.2.6 Reef Fish

As described in the reef fish fishery profile (Markrich and Hawkins, 2016), coral reef species have been shown by the archaeological record to be part of the customary diet of the earliest human inhabitants of the Hawaiian islands, including the NWHI. Coral reef species also played an important role in religious beliefs and practices, extending their cultural significance beyond their value as a dietary staple. For example, some coral reef species are venerated as personal, family or professional gods called ʻaumakua. While the majority of the commercial catch comes from nearshore reef areas around the MHI, harvests of some coral reef species also occur in federal waters (e.g., around Penguin Bank).

From 2014-2015, the National Coral Reef Monitoring Program conducted a household telephone survey of adult residents in the MHI to better understand demographics in coral reef areas, human use of coral reef resources, and knowledge, attitudes, and perceptions of coral reefs and coral reef management. This section summarizes results of the survey, which are available as an online presentation.[1]

Just over 40% of respondents participated in fishing, while almost 60% had never participated. However, almost all respondents reported recreational use of coral reef resources, including swimming or wading (80.9%), beach recreation (80.2%), snorkeling (just under 60%), waterside or beach camping (just over 50%), and wave riding (over 40%). Gathering of marine resources was the least frequently reported, with only about 25% participating in this specific activity.

Of those who fished or harvested marine resources, the reason with the highest level of participation was “to feed myself and my family/household” (80.2%). The reason with the lowest level of participation was “to sell” (82.5% never participate). Other reasons with over 60% each were: for fun, to give extended family members and/or friends, and for special occasions and cultural purposes/events. This indicates a substantial contribution from this fishery to local food security, as well as maintaining cultural connections.

The importance of culture was also evident in perceptions of value related to coral reefs. The statement that respondents agreed the most with was “Coral Reefs are important to Hawaiian culture” (93.8%). They also agreed strongly that healthy coral reefs attract tourists to the Hawaiian islands and that coral reefs protect the Hawaiian Islands from erosion and natural disasters. The statement that respondents disagreed the most with was “Coral reefs are only important to fisherman, divers, and snorkelers” (76.2%).

With respect to management strategies, at least half of respondents agreed with all the presented management strategies, which ranged from catch limits, to gear restrictions, to enforcement, and no take zones. Respondents disagreed most with “establishment of a non-commercial fishing license” (27.2%) and “limited use for recreational activities” (25.2%).

[1] Presentation is available at:
https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/monitoring/SocioEconomic/NCRMPSOCHawaiiReportOut2016_FINAL_061616_update.pdf

Just over half of the respondents (55%) perceive their local communities as at least moderately involved in protecting and managing coral reefs. However, only about a quarter (26%) of respondents indicated moderate or higher involvement themselves.

The importance of protecting and managing coral reefs was also identified in a 2007 study on spearfishing in Hawaii (see Stoffle and Allen, 2012). Spearfishing was not seen as just a sport but a vehicle for learning the appropriate ways to interact with and protect the environment, including how to carry oneself as a responsible fisherman. For many, learning to spearfish was an important part of "who you are" growing up near the ocean. Fishing also was discussed as a means of providing food or extra income during times of hardship, describing the ocean as a place that people turn to in times of economic crisis. Although there is a growing segment of people who spearfish for sport, with motivations focused more on the experience of the hunt, physical activity, and the sense of achievement. Like other methods of fishing, motivations for spearfishing often cross commercial, recreational, and subsistence lines, including sharing catch with family and among cultural networks.

Overall, coral reef fish not only have a long history of cultural significance in this archipelago, they also continue to play an important role in subsistence and in strengthening social networks and maintaining cultural ties.

2.2.6.1 Commercial Participation, Landings, Revenues, Prices

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

2.2.7 Crustaceans

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

2.2.7.1 Commercial Participation, Landings, Revenues, Prices

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

2.2.8 Precious Corals

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

2.2.8.1 Commercial Participation, Landings, Revenues, Prices

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

2.2.9 Ongoing Research and Information Collection

Social indicators are being compiled, 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.

2.2.10 Relevant PIFSC Economics and Human Dimensions Publications: 2016

Grace-McCaskey CA. 2016. Understanding Hawai'i resource users' knowledge, attitudes, and perceptions of coral reefs in South Kohala. Pacific Islands Fisheries Science Center administrative report H-16-02, 64 p. doi:10.7289/V5F769K5.

Madge L. 2016. Preliminary Assessment of Monk Seal-Fishery Interactions in the Main Hawaiian Islands. Pacific Islands Fisheries Science Center, Administrative Report H-16-07, 31 p. doi:10.7289/V5/AR-PIFSC-H-16-08.

Madge L. 2016. Exploratory study of interactions between cetaceans and small-boat fishing operations in the Main Hawaiian Islands (MHI). Pacific Islands Fisheries Science Center, Administrative Report H-16-07, 37 p. doi:10.7289/V5/AR-PIFSC-H-16-07.

Madge L, Hospital J, Williams ET. 2016. Attitudes and Preferences of Hawaii Non-commercial Fishermen: Report from the 2015 Hawaii Saltwater Recreational Fishing Survey, Volume 1. U.S. Dept. of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-58, 85 p. doi:10.7289/V5/TM-PIFSC-58.

Polovina J and Dreflak K (Chairs), Baker J, Bloom S, Brooke S, Chan V, Ellgen S, Golden D, Hospital J, Van Houtan K, Kolinski S, Lumsden B, Maison K, Mansker M, Oliver T, Spalding S, Woodworth-Jefcoats P. 2016. Pacific Islands Regional Action Plan: NOAA Fisheries climate science strategy. U.S. Dept. of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-59, 33 p. doi:10.7289/V5/TM-PIFSC-59.

2.2.11 References

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Brinson, A.A., E. M. Thunberg, and K. Farrow. 2015. The Economic Performance of U.S. NonCatch Share Programs. U.S. Dept. of Commer., NOAA Technical Memorandum NMFS-F/SPO-150, 191 p.

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2.3 PROTECTED SPECIES

This section of the report summarizes information on protected species interactions in fisheries managed under the Hawai`i 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 Hawai`i waters and a list of critical habitat designations in the Pacific Ocean are included in Appendix B.

2.3.1 Indicators for Monitoring Protected Species Interactions in the Hawai`i FEP Fisheries

This report monitors the status of protected species interactions in the Hawai`i 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 State waters.

2.3.1.1 FEP Conservation Measures

No specific regulations are in place to mitigate protected species interactions in the bottomfish, precious coral, coral reef ecosystem and crustacean fisheries currently active and managed under this FEP. 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.

The original Crustacean Fishery Management Plan (FMP) and subsequent amendments included measures to minimize potential impacts of the Northwestern Hawaiian Islands (NWHI) component of the spiny lobster fishery to Hawaiian monk seals, such as specification of trap gear design and prohibition of nets. The Bottomfish and Seamount Groundfish FMP began requiring protected species workshops for the NWHI bottomfish fishery participants in 1988. These fisheries are no longer active due to the issuance of Executive Orders 13178 and 13196 and the subsequent Presidential Proclamations 8031 and 8112, which closed the fisheries within 50 nm around the NWHI.

2.3.1.2 Endangered Species Act Consultations

Hawai`i FEP fisheries are covered under the following consultations under section 7 of the ESA, through which NMFS has determined that these fisheries are not likely to jeopardize or adversely affect any ESA-listed species or critical habitat in the Hawai`i Archipelago (Table 58).

Table 58. Summary of ESA consultations for Hawai`i FEP Fisheries

Fishery	**Consultation date**	**Consultation type[a]**	**Outcome[b]**	**Species**
Bottomfish	3/8/2002	BiOp	LAA, no adverse modification, non-jeopardy	Hawaiian monk seal
	3/18/2008	BiOp	NLAA	Loggerhead sea turtle, leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, northern right whale, sei whale, sperm whale, Hawaiian monk seal
	8/7/2013	BiOp modification	NLAA	False killer whale (MHI insular DPS)
Coral reef ecosystem	3/7/2002	LOC	NLAA	Hawaiian monk seal
	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
	9/25/2013	LOC	NLAA	Loggerhead sea turtle (North Pacific DPS), leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, North Pacific right whale, sei whale, sperm whale, Hawaiian monk seal, false killer whale (MHI insular DPS)
Coral reef ecosystem (Kona Kanpachi Special Coral Reef Ecosystem Fishing Permit only)	9/19/2013	LOC (USFWS)	NLAA	Short-tailed albatross, Hawaiian petrel, Newell's shearwater

Fishery	**Consultation date**	**Consultation type**[a]	**Outcome**[b]	**Species**
Crustacean	12/5/2013	LOC	NLAA	Loggerhead sea turtle (North Pacific DPS), leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, North Pacific right whale, sei whale, sperm whale, Hawaiian monk seal, false killer whale (MHI insular DPS)
Precious coral	12/5/2013	LOC	NLAA	Loggerhead sea turtle (North Pacific DPS), leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, North Pacific right whale, sei whale, sperm whale, Hawaiian monk seal, false killer whale (MHI insular DPS)
All fisheries	3/1/2016	LOC	NLAA	Hawaiian monk seal critical habitat

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

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

Bottomfish Fishery

In a Biological Opinion (BiOp) covering MHI bottomfish fishery, dated March 18, 2008, NMFS determined that the MHI bottomfish fishery is not likely to jeopardize the green turtle and included an incidental take statement (ITS) of two animals killed per year from collisions with bottomfish vessels. The 2008 BiOp also concluded that the fishery is not likely to adversely affect any four other sea turtle species (loggerhead, leatherback, olive ridley, and hawksbill turtles) and seven marine mammal species (humpback, blue, fin, Northern right whale, sei and sperm whales, and the Hawaiian monk seal).

In 2013, NMFS re-initiated consultation under ESA in response to listing of MHI insular false killer whale distinct population segment under the ESA. In a modification to the 2008 BiOp dated August 7, 2013, NMFS determined that commercial and non-commercial bottomfish fisheries in the MHI are not likely to adversely affect MHI insular false killer whale because of the spatial separation between the species and bottomfishing activities, the low likelihood of collisions, and the lack of observed or reported fishery interactions were among other reasons.

In August 2015, NMFS revised the Hawaiian monk seal critical habitat in the NWHI and designated new critical habitat in the main Hawaiian Islands (MHI). An informal consultation completed by NMFS on March 1, 2016 concluded that the Hawai`i bottomfish fishery is not likely to adversely affect monk seal critical habitat.

Crustacean Fishery

An informal consultation completed by NMFS on December 5, 2013 concluded that the Hawai`i crustacean fisheries are not likely to affect five sea turtle species (North Pacific loggerhead DPS, leatherback, olive ridley, green and hawksbill turtles) and eight marine mammal species (humpback, blue, fin, Northern right whale, sei and sperm whales, MHI insular DPS false killer whales and the Hawaiian monk seal). An informal consultation completed by NMFS on March 1, 2016 concluded that the Hawai`i crustacean fishery is not likely to adversely affect monk seal critical habitat.

Coral Reef Ecosystem 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 on September 25, 2013 concluded that the Hawai`i coral reef ecosystem fisheries are not likely to affect five sea turtle species (North Pacific loggerhead DPS, leatherback, olive ridley, green and hawksbill turtles) and eight marine mammal species (humpback, blue, fin, Northern right whale, sei and sperm whales, MHI insular DPS false killer whales and the Hawaiian monk seal). An informal consultation completed by NMFS on March 1, 2016 concluded that the Hawai`i coral reef ecosystem fishery is not likely to adversely affect monk seal critical habitat.

Precious Coral Fishery
An informal consultation completed by NMFS on December 5, 2013 concluded that the Hawai`i precious coral fisheries are not likely to affect five sea turtle species (North Pacific loggerhead DPS, leatherback, olive ridley, green and hawksbill turtles) and eight marine mammal species (humpback, blue, fin, Northern right whale, sei and sperm whales, MHI insular DPS false killer whales and the Hawaiian monk seal). An informal consultation completed by NMFS on March 1, 2016 concluded that the Hawai`i precious coral fishery is not likely to adversely affect monk seal critical habitat.

2.3.1.3 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 bottomfish (HI bottomfish handline), precious coral (HI black coral diving), coral fish (HI spearfishing), and crustacean (HI crab trap, lobster trap, shrimp trap, crab net, Kona crab loop net, lobster diving) fisheries are classified as Category III fisheries (i.e. a remote likelihood of or no known incidental mortality and serious injury of marine mammals).

2.3.2 Status of Protected Species Interactions in the Hawai`i FEP Fisheries

Bottomfish Fishery

Fisheries operating under the Hawai`i FEP currently do not have federal observers on board. The

NWHI component of the bottomfish fishery had observer coverage from 1990 to 1993 and 2003 to 2005.

The observer program for the NWHI bottomfish fishery between 1990-1993 reported a moderate level of depredation from non-endangered seabirds in the bottomfish fishery, with Laysan and black-footed albatrosses described as aggressively stealing bait from hooks during deployment and retrieval of bottomfish gear (Nitta 1999). However, no seabird injuries or mortalities were observed between 1990-1993 when fishermen were fishing for bottomfish. The 1990-1993 observer coverage also documented depredation by Hawaiian monk seals and bottlenose dolphins, but no injuries or mortalities were observed for either species.

During the 2003-2005 observer coverage in the NWHI bottomfish fishery, eight interactions with seabirds not listed under the ESA were observed across six trips (Table 59). Six of the interactions occurred during trolling operations and two during bottomfishing operations. Of the two interactions, one occurred with a black-footed albatross, and the other occurred with a brown booby. Hookings or entanglements with sea turtles and marine mammals were not observed during this period.

Table 59. Observed takes of protected species in the NWHI bottomfish fishery observer program, 2003-2005. Take data are based on vessel arrival dates.

Year	Vessels with Observers	Observer Coverage (%)	Seabirds						Sea turtles	Marine mammals
			Laysan albatross	Black-footed albatross	Brown booby	Red-footed booby	Unidentified booby	Short-tailed albatross		
2003[a]	4	33.3	0	0	0	0	0	0	0	0
2004	14	18.3	1[b]	1[c]	1[c]	0	2[b]	0	0	0
2005	13	25.0	1[b]	0	1[b]	1[b]	0	0	0	0

[a] The Hawai`i-based bottomfish fishery began monitoring under the observer program in October, 2003.

[b] Protected species interactions occurred during trolling operations.

[c] Protected species interactions occurred during bottomfish operations.

Source: 2003-2005 PIRO Observer Program Annual and Quarterly Status Reports Hawai`i Bottomfish Fishery

To date, there have been no reported interactions between MHI bottomfish fisheries and ESA-listed species of sea turtles, marine mammals, and seabirds. Furthermore, the commercial and non-commercial bottomfish fisheries in the MHI are not known to have the potential for a large and adverse effect on non ESA-listed marine mammals. Although these species of marine mammals occur in Exclusive Economic Zone (EEZ) waters where the fisheries operate and depredation of bait or catch by dolphins (primarily bottlenose dolphins) has been known to occur in the bottomfish fishery (Kobayashi and Kawamoto 1995), there have been no observed or reported takes between the fishery and marine mammals.

The 2008 BiOp included an ITS of two green turtle mortalities per year from collisions with bottomfish vessels. There have not been any reported or observed collisions of bottomfish vessels with green turtles, and data are not available to attribute stranded turtle mortality source to bottomfish vessels. However, the BiOp analysis to determine the estimated level of take from vessel collisions was based on an estimated 71,800 bottomfish fishing trips per year. The total annual number of commercial and non-commercial bottomfishing trips since 2008 has been less than 3,500 per year. Therefore, the potential for collisions with bottomfish vessels is substantially lower than was estimated in the 2008 BiOp.

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 no observer data available for the crustacean fisheries operating under the Hawai`i FEP. However based on current ESA consultations, these fisheries are not expected to interact with any ESA-listed species in Federal waters around the Hawai`i Archipelago. NMFS has also concluded that the Hawai`i crustacean commercial fisheries will not affect marine mammals in any manner not considered or authorized under the Marine Mammal Protection Act.

Since 1986, there have been no reports of direct interactions between the NWHI lobster fishery and Hawaiian monk seals. However, in 1986 near Necker Island, one Hawaiian monk seal died as a result of entanglement with a bridle rope from a lobster trap. Modifications to bridle ropes were subsequently made and the Council recommended regulations to improve the ability to respond to any future reports of interactions between monk seals and lobster fishing gear. There have been no other reports of Hawaiian monk seal entanglements or other interactions since 1987 (WPRFMC 2009).

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.

Coral Reef Fishery

There are no observer data available for the coral reef fisheries operating under the Hawai`i FEP. However based on current ESA consultations, these fisheries are not expected to interact with any ESA-listed species in Federal waters around the Hawai`i Archipelago. NMFS has also concluded that the Hawai`i 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 no observer data available for the precious coral fisheries operating under the Hawai`i FEP. However based on current ESA consultations, these fisheries are not expected to interact with any ESA-listed species in Federal waters around the Hawai`i Archipelago. NMFS has also concluded that the Hawai`i crustacean 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.

2.3.3 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

Species		**Listing process**			**Post-listing activity**	
Common name	**Scientific name**	**90-day finding**	**12-month finding / Proposed rule**	**Final rule**	**Critical Habitat**	**Recovery Plan**
False killer whale (MHI Insular DPS)	*Pseudorca crassidens*	Positive (75 FR 316, 1/5/2010)	Positive, endangered (75 FR 70169, 11/17/2010)	Listed as endangered (77 FR 70915, 11/28/2012)	In development, proposal expected fall 2017	In development, public comment expected 2017
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

2.3.4 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.
- Update analysis of fishing-gear related strandings of Hawai`i green turtles.

2.3.5 References

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WPRFMC (Western Pacific Regional Fishery Management Council). 2009. Fishery Ecosystem Plan for the Hawai`i Archipelago. September 24, 2009.

2.4 CLIMATE AND OCEANIC INDICATORS

2.4.1 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.

2.4.2 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:

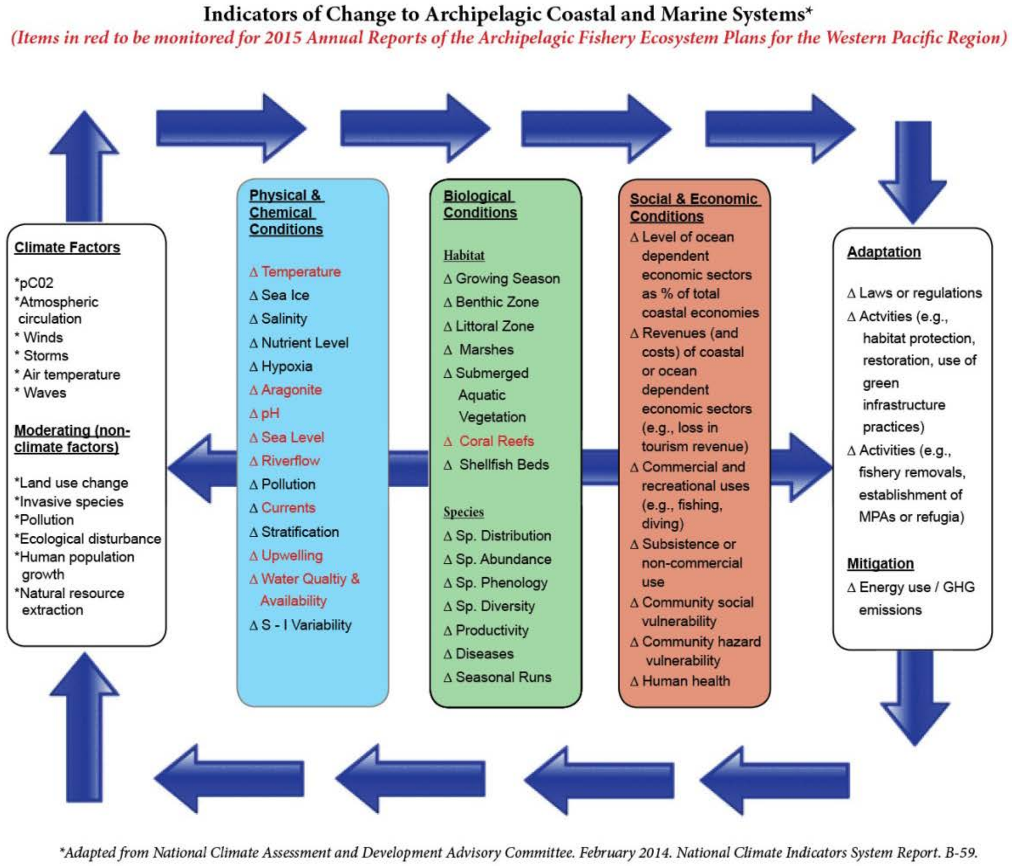


Figure 15. Indicators of change to archipelagic coastal and marine systems.

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.

2.4.3 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.

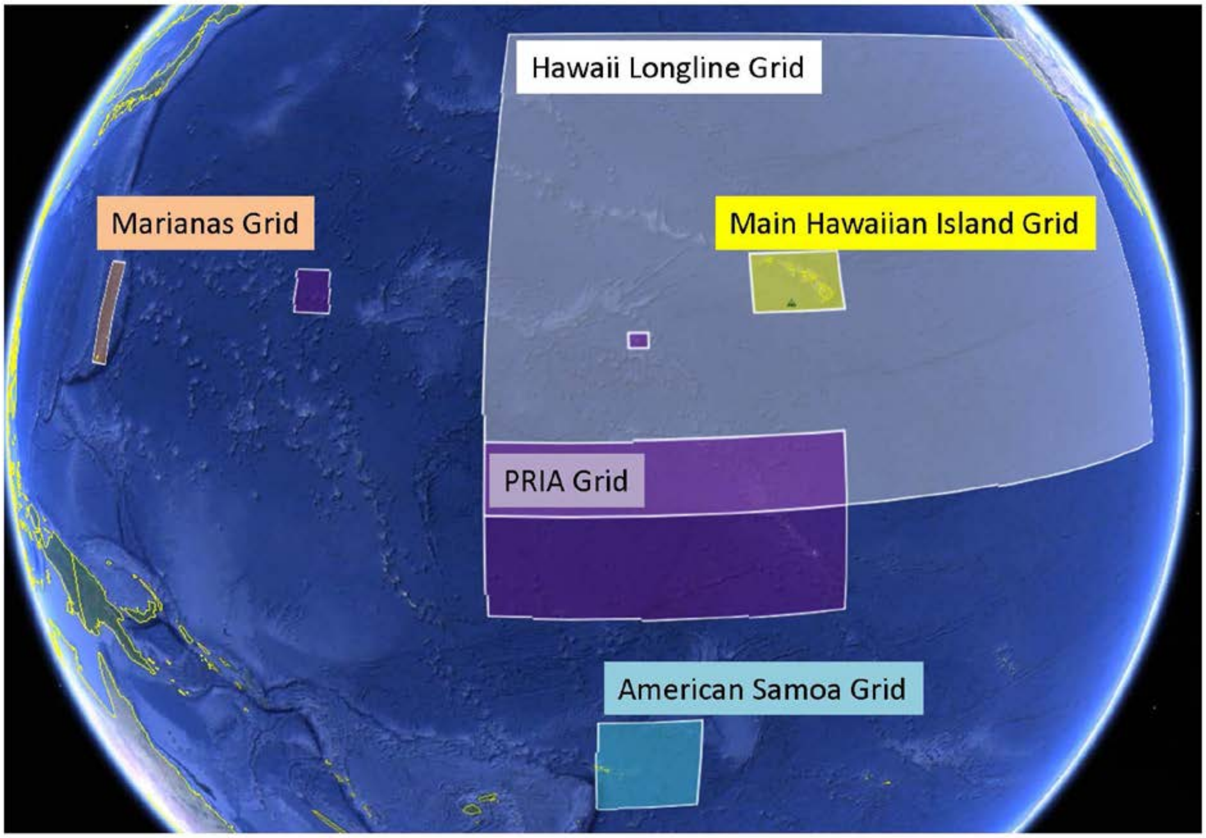


Figure 16. Regional Spatial Grids.

Table 61. Hawaii climate and ocean indicator summary.

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

Indicator	Definition and Rationale	Indicator Status
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[2] (SST)	Satellite remotely-sensed sea surface temperature. SST is projected to rise, and impacts phenomena ranging from winds to fish distribution.	2014-2015 showed extreme high temperature anomalies relative to record.
Degree Heating Weeks (DHW)	Satellite remotely-sensed sea surface temperature, transformed to a metric relevant for coral bleching. 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.	2014-2015 showed extreme high temperature anomalies, with values surpassing 12 DHW in 2015. 2016 returned within historical bounds.
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 supplies.	In 2015, sea level in Honolulu was slightly above the mean sea level trend which continues to increase annually. The 2015 increase in Hawaii is highly correlated with El Niño.
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 from between 1.0-2.0m on the Big Island highest off the southern and eastern shores with Maui and Oahu showing a range between 1.0-1.5m and Kauai showing a range between 1.5-2.0m.

[2] 2016 data are incomplete.

2.4.3.1 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.

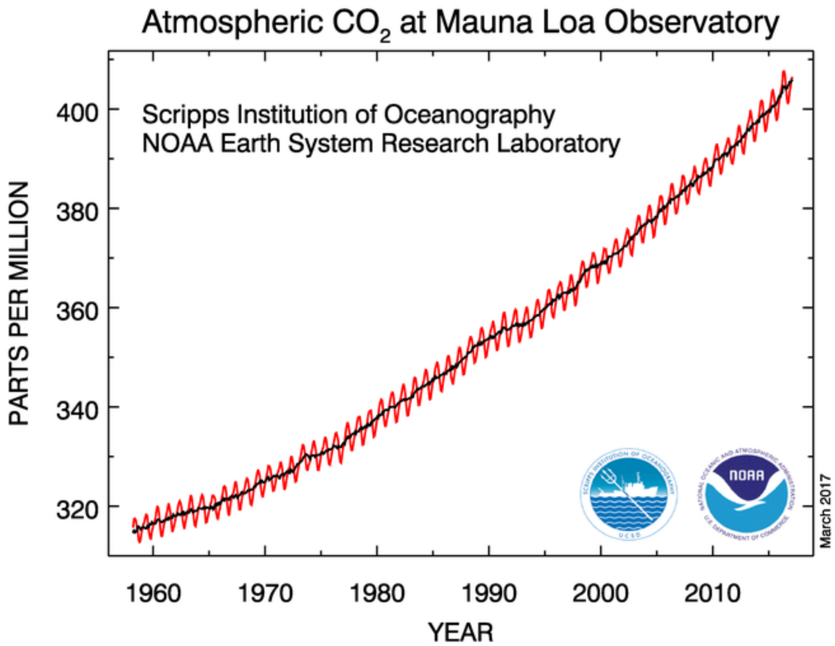


Figure 17. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data.

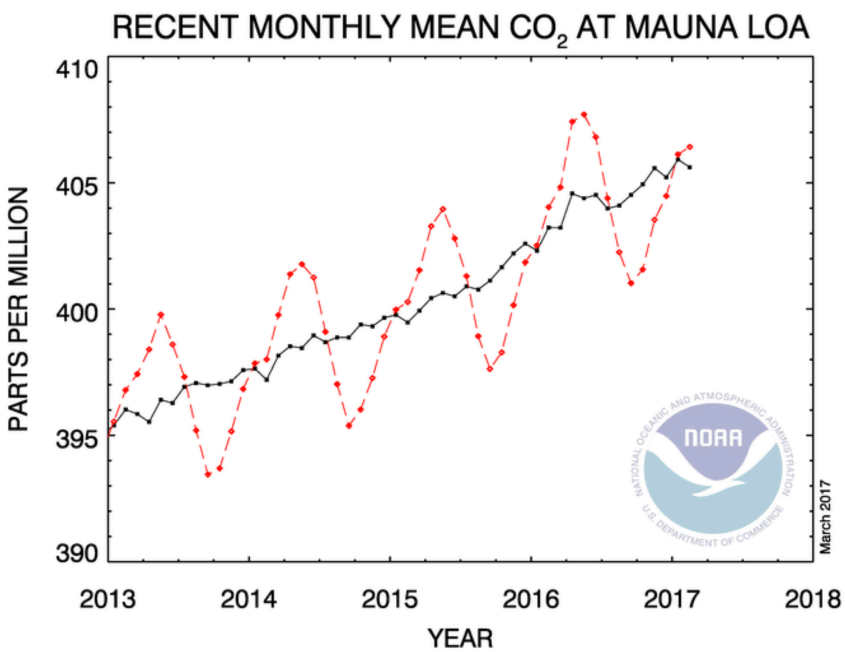


Figure 18. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii, 2013-2017. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data.

2.4.3.2 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.

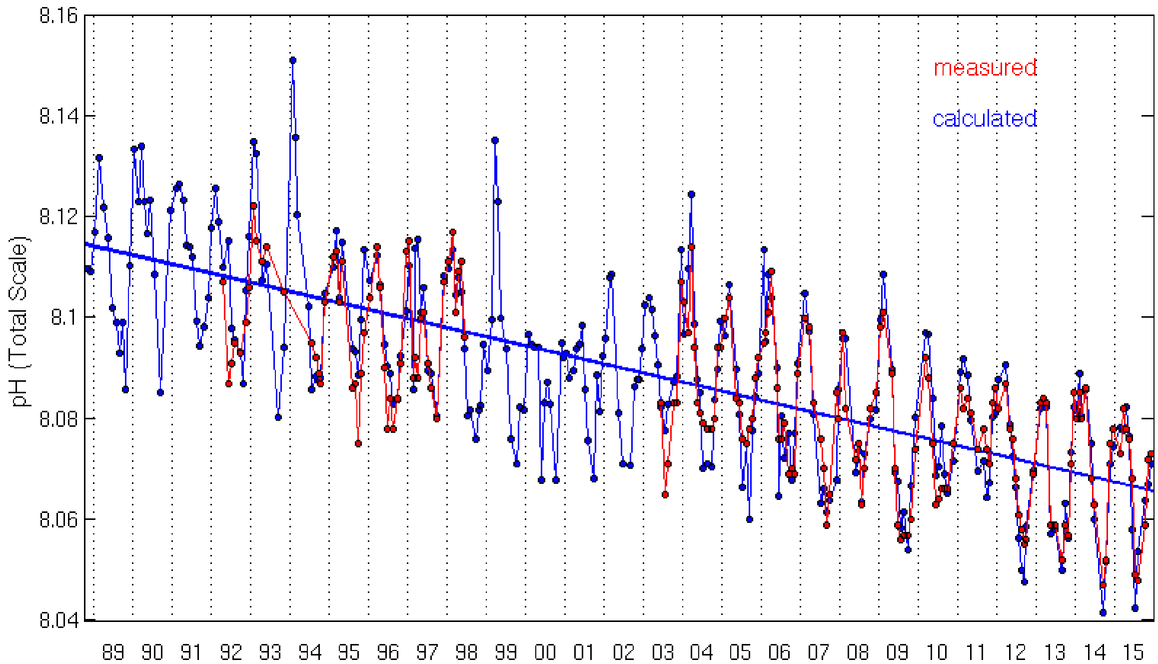


Figure 19. pH Trend at Station Aloha, 1989-2015.

2.4.3.3 Oceanic Niño Index (ONI)

Description: Warm (red) and cold (blue) periods based on a threshold of +/- 0.5^{o}C for the Oceanic Niño Index (ONI) [three-month running mean of ERSST.v4 SST anomalies in the Niño 3.4 region (5^{o}N-5^{o}S, 120^{o}-170^{o}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.

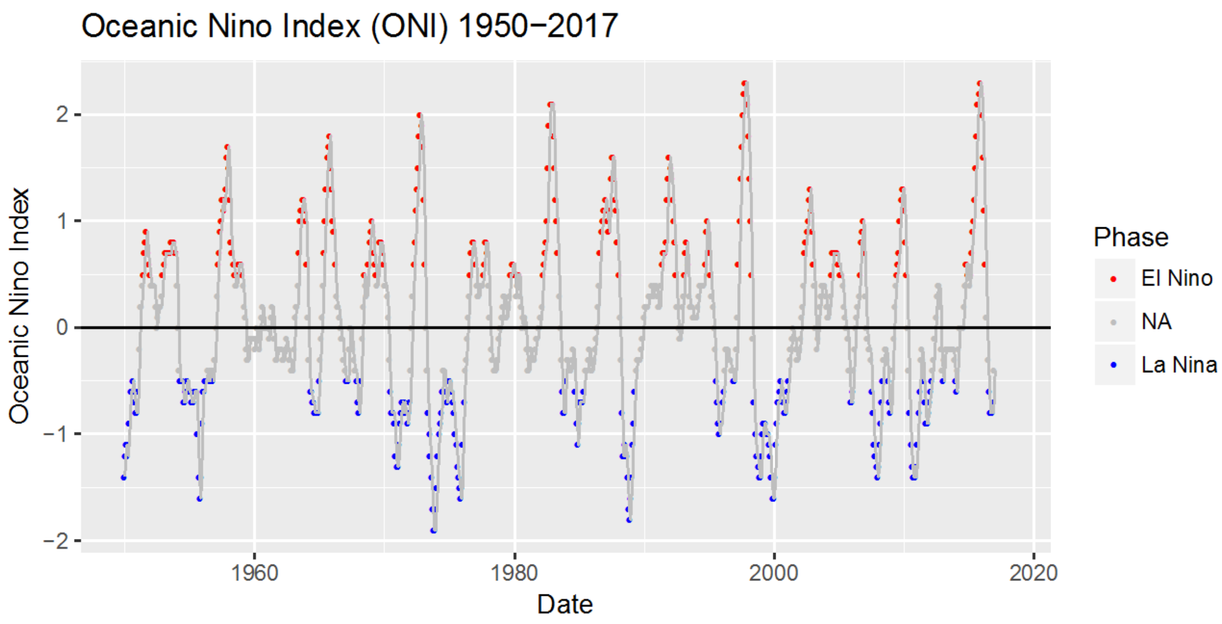


Figure 20. Oceanic Nino Index, 1950-2017.

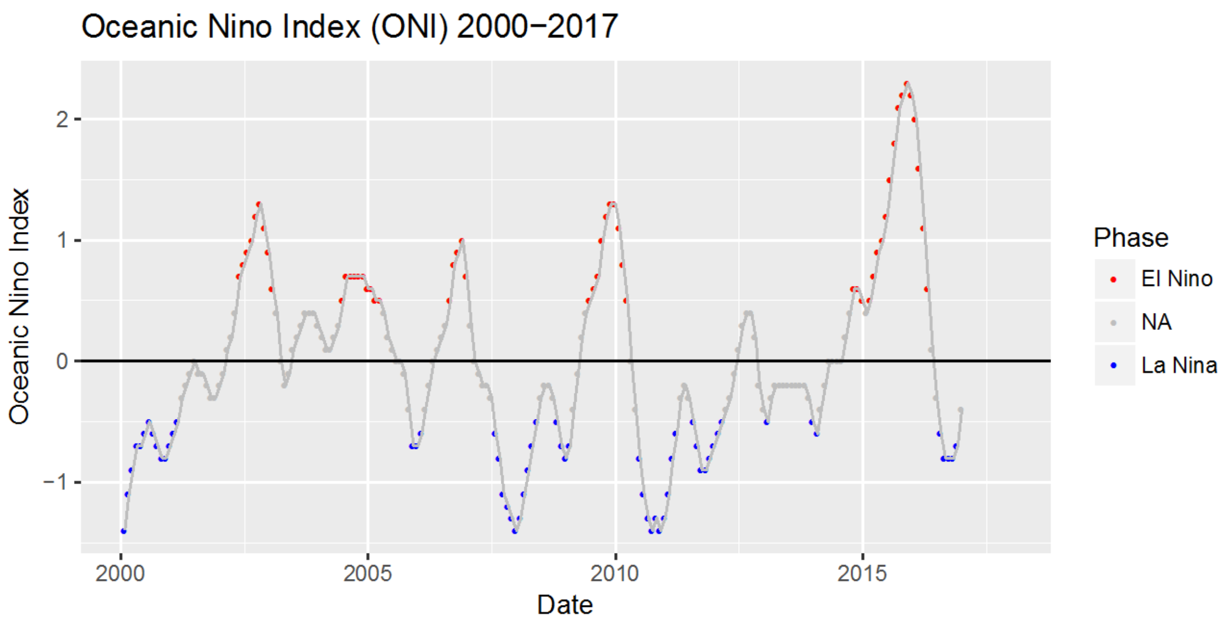
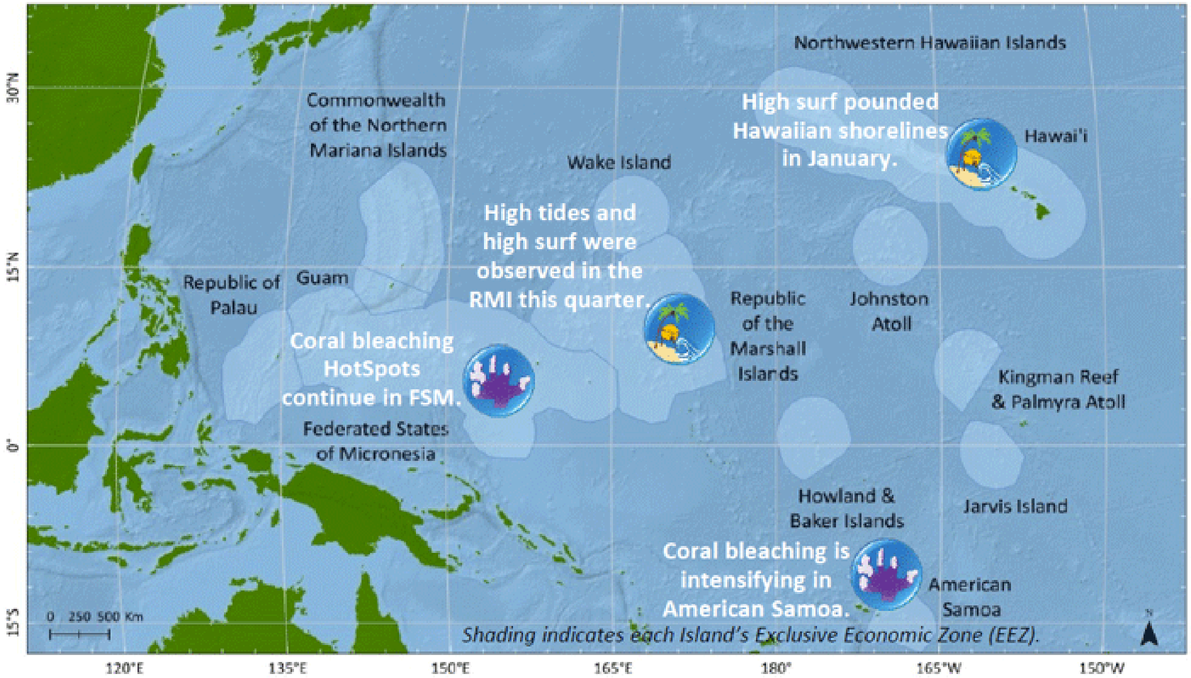


Figure 21. Oceanic Nino Index, 2000-2017.

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, wherea 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 22. Q4 2016 Climate Impact and Outlook Infographic.

2.4.3.4 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.

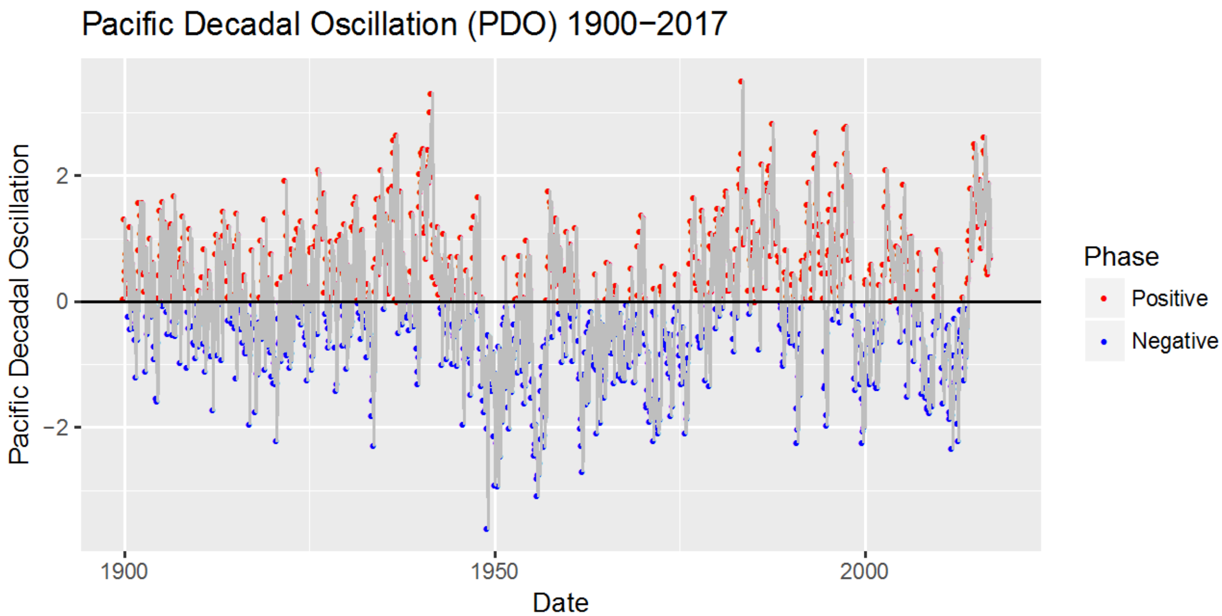


Figure 23. Pacific Decadal Oscillation, 1900-2017.

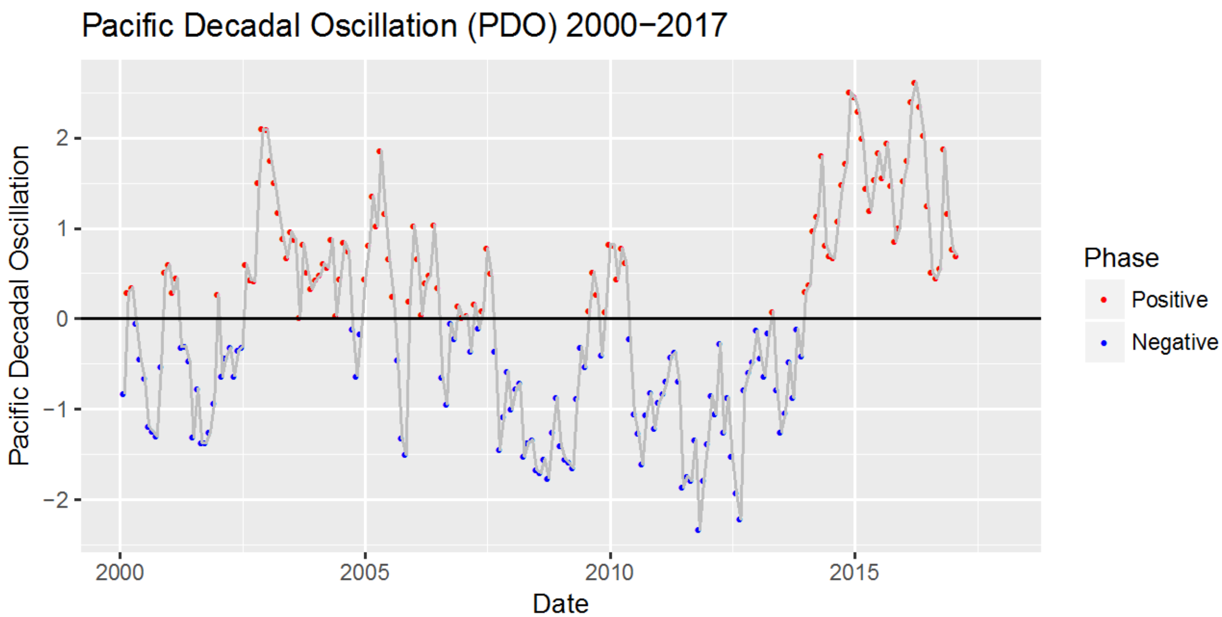


Figure 24. Pacific Decadal Oscillation, 2000-2017.

2.4.3.5 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.

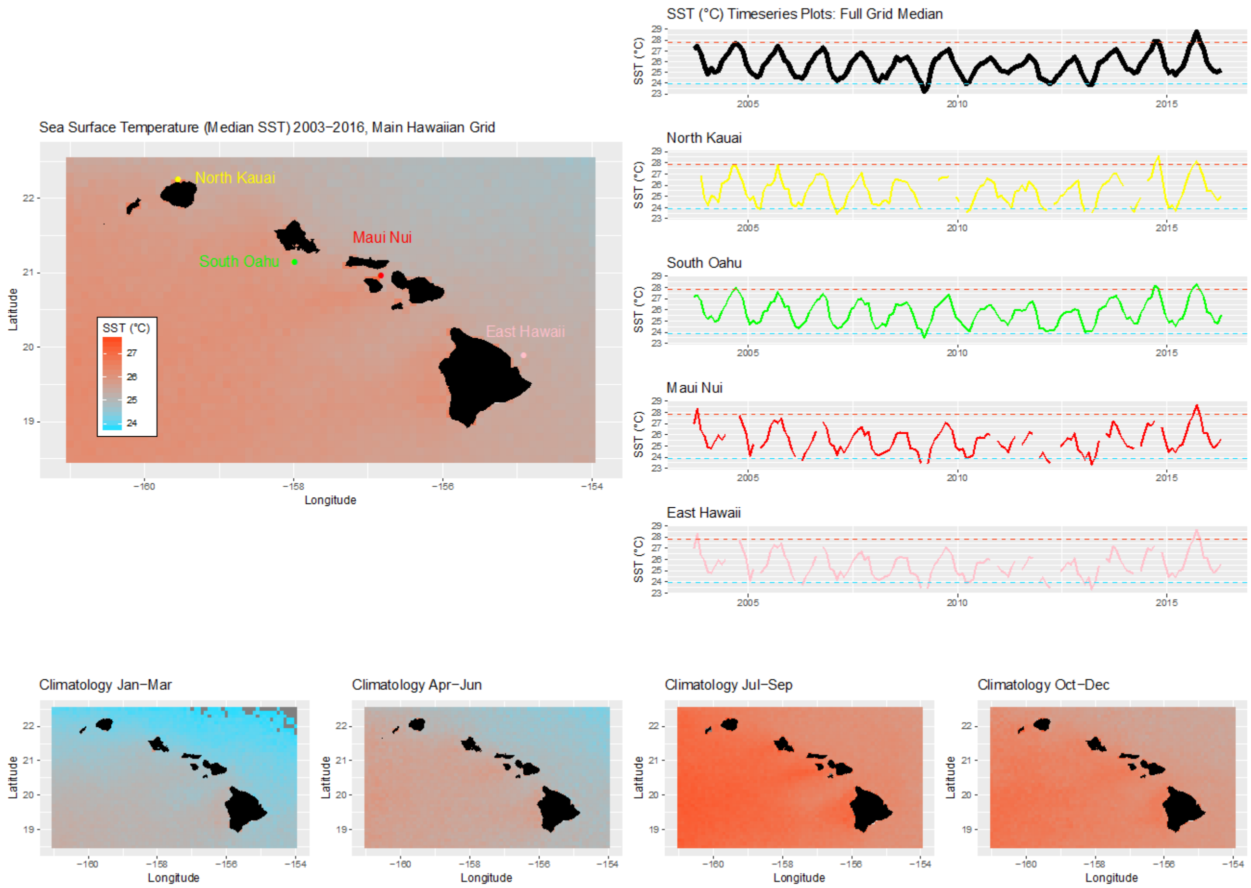


Figure 25. Sea Surface Temperature plots, including 2003-2016 aggregate, timeseries by island, and season climatology.

2.4.3.6 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]. 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.

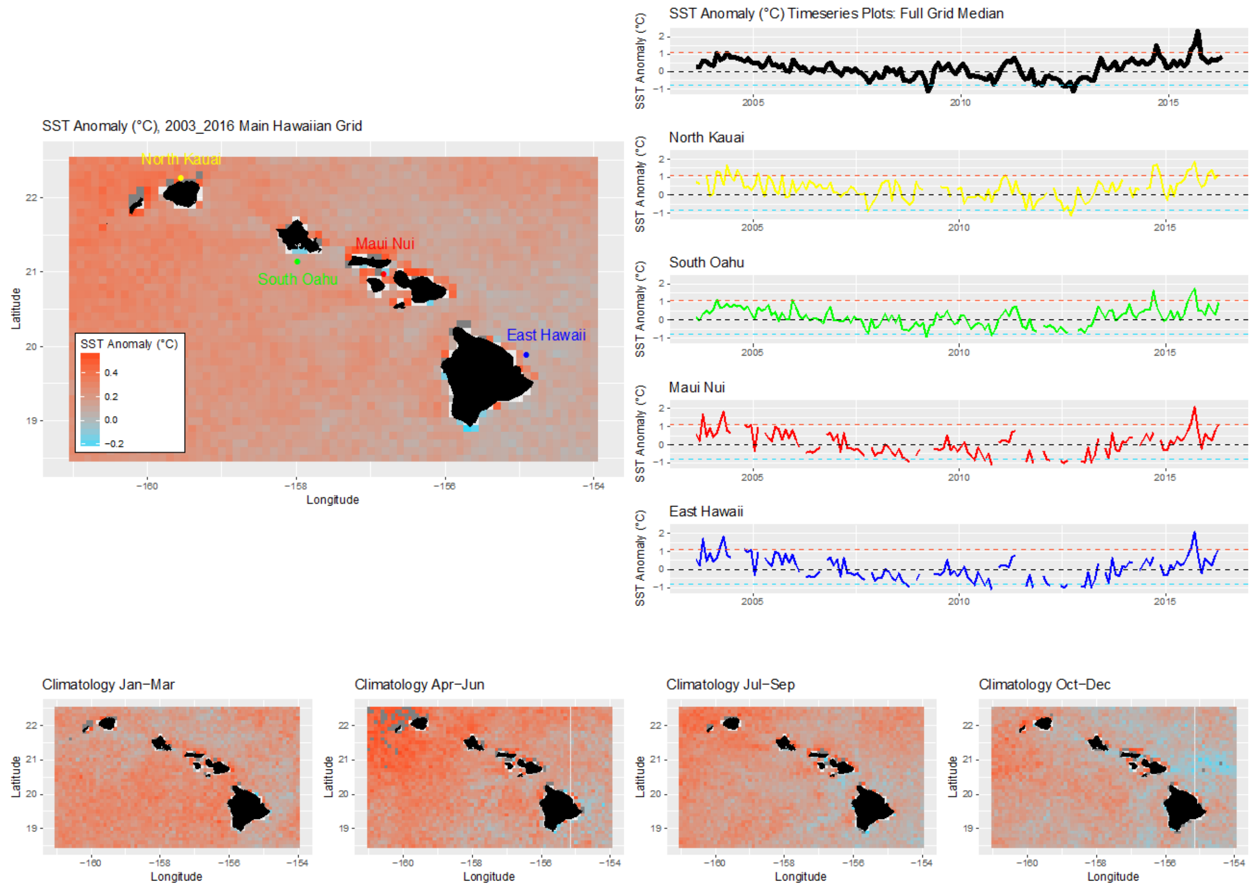


Figure 26. Sea surface temperature anomaly plots, including aggregate, time series by island, and seasonal climatology.

2.4.3.7 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.

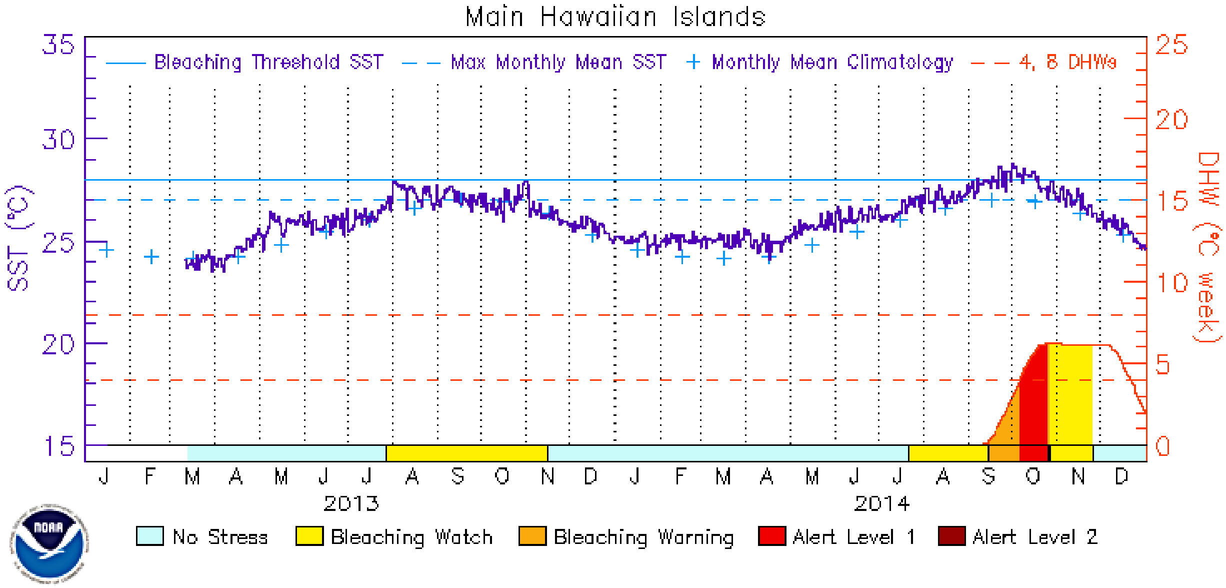
Region/Location: Global.

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.



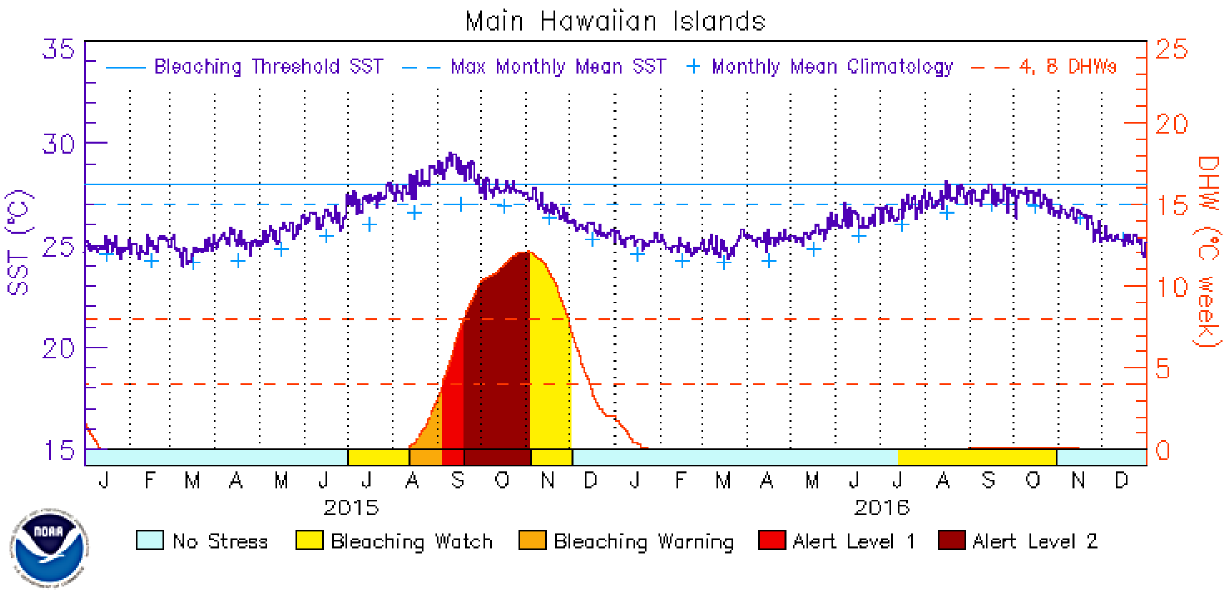


Figure 27. Degree Heating Weeks Timeseries in the Main Hawaiian Islands, 2013-2016.

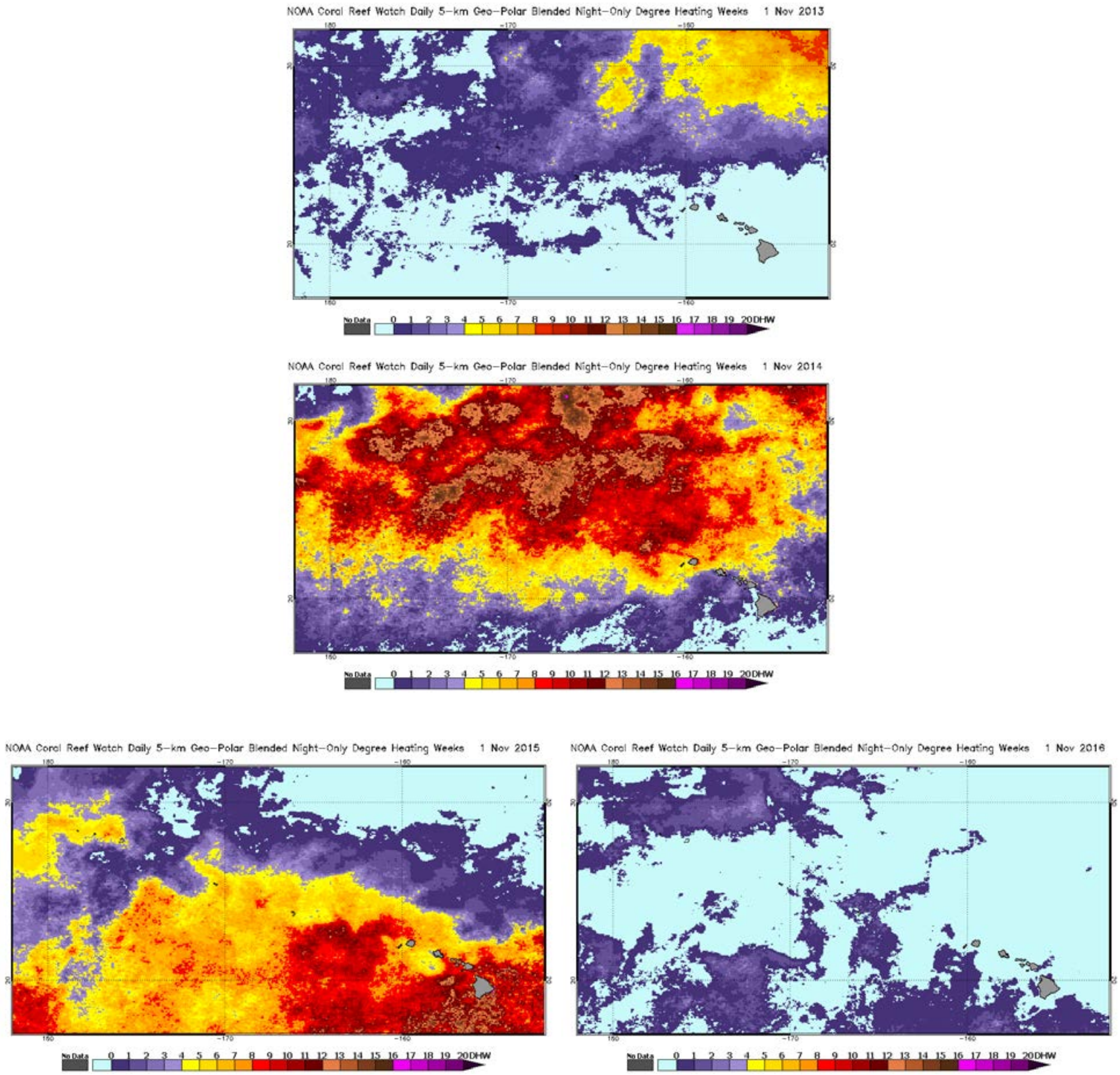


Figure 28. Degree Heating Weeks Maps, showing Annual DHW Maximum (Nov 1, 2013-2016) in the Hawaiian Islands.

2.4.3.8 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 knots; 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.

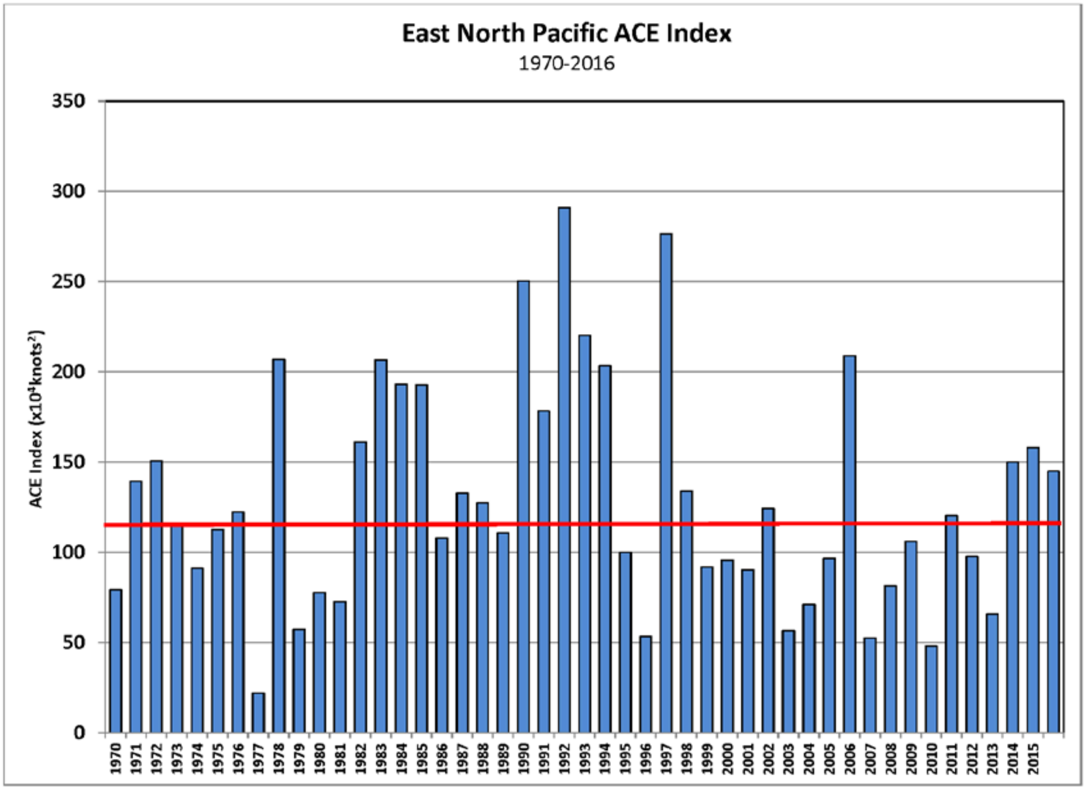


Figure 29. 2016 East Pacific Tropical Cyclone ACE 1970-2016. Source: NOAA's National Hurricane Center

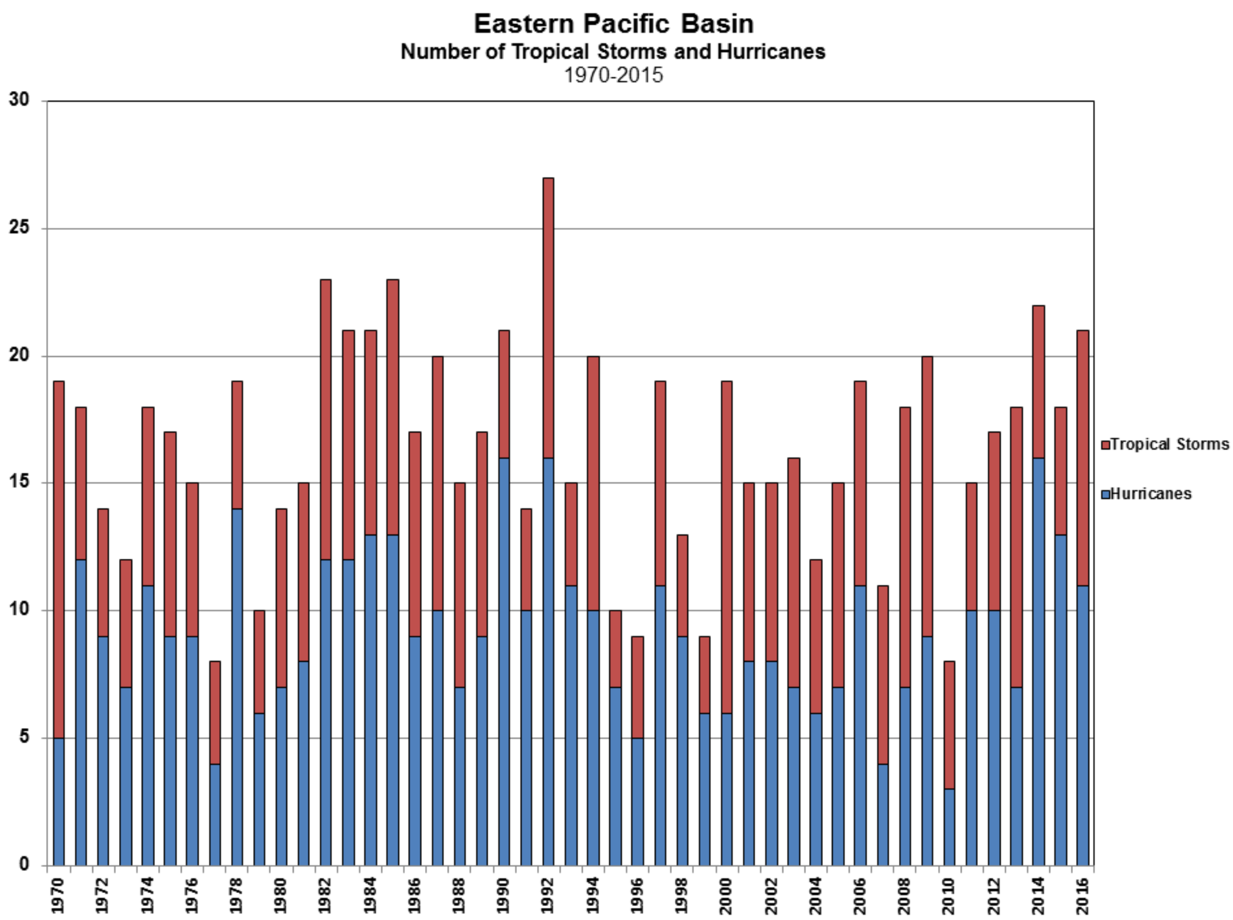


Figure 30. East Pacific tropical cyclone count 1970-2016. Source: NOAA's National Hurricane Center

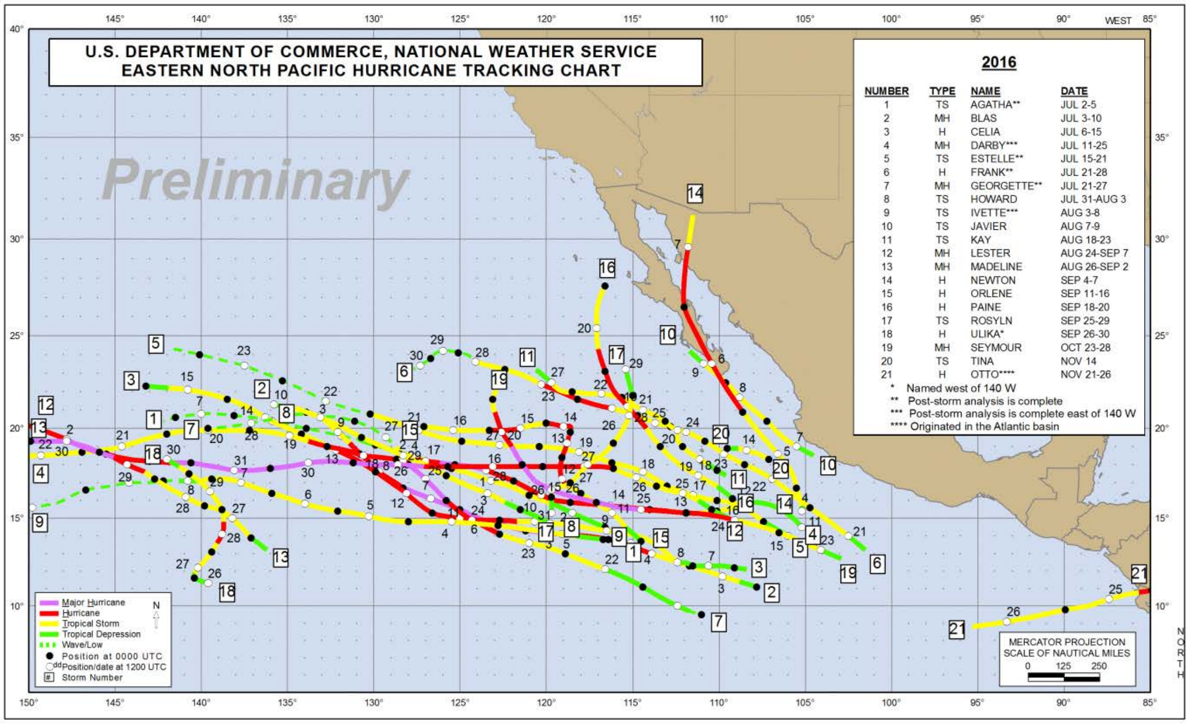


Figure 31. 2015 Eastern Pacific Tropical Cyclone Tracks. Source: NOAA's National Hurricane Center

The NOAA National Centers for Environmental Information, State of the Climate: Hurricanes and Tropical Storms for Annual 2016, published online January 2017, notes that "The 2016 East Pacific hurricane season had 21 named storms, including 11 hurricanes, five 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. It is noteworthy that from July through September there were 18 named storms, the most for any 3-month period.

The Central Pacific had seven named storms, three of which were hurricanes and two of which were major hurricanes. Tropical storm Darby became the second tropical cyclone in three years to make landfall in Hawaii - only the fifth landfalling cyclone since records began in 1949.

The ACE index for the East Pacific basin during 2016 was 145 (x10^4 knots^2), which about 44 percent above the 1981-2010 mean of 104 (x10^4 knots^2).

" Inserted from: http://www.ncdc.noaa.gov/sotc/tropical-cyclones/201513

Cyclone Tracks 2016 (http://weather.unisys.com/hurricane)

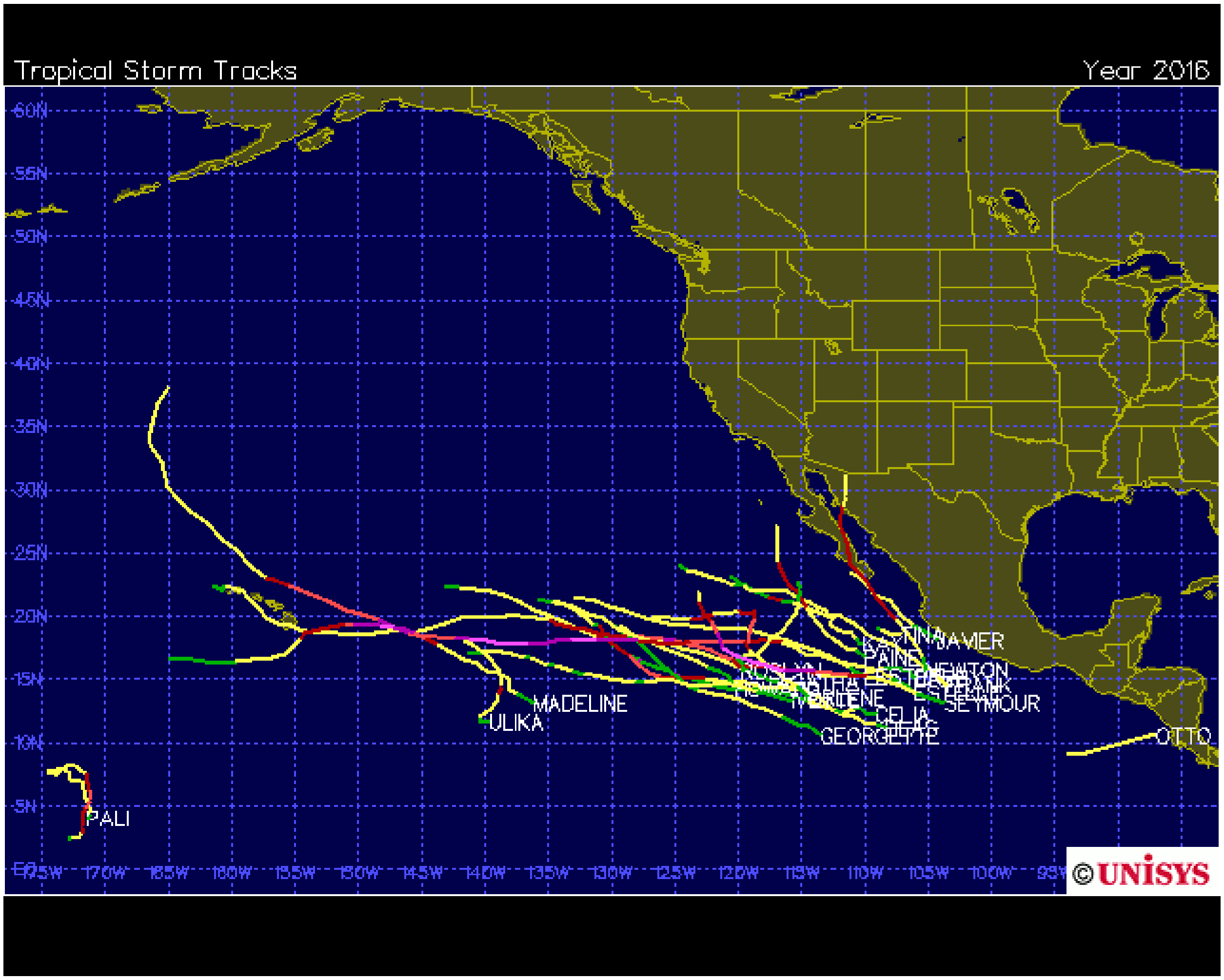


Figure 32. Eastern Pacific Cyclone Tracks in 2016. Source: http://weather.unisys.com/hurricane/e_pacific/2016.

References: NOAA National Centers for Environmental Information, State of the Climate: Hurricanes and Tropical Storms for Annual 2015, published online January 2016, retrieved on August 5, 2016 from http://www.ncdc.noaa.gov/sotc/tropical-cyclones/201513.

2.4.3.9 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.

2.4.3.9.1 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.

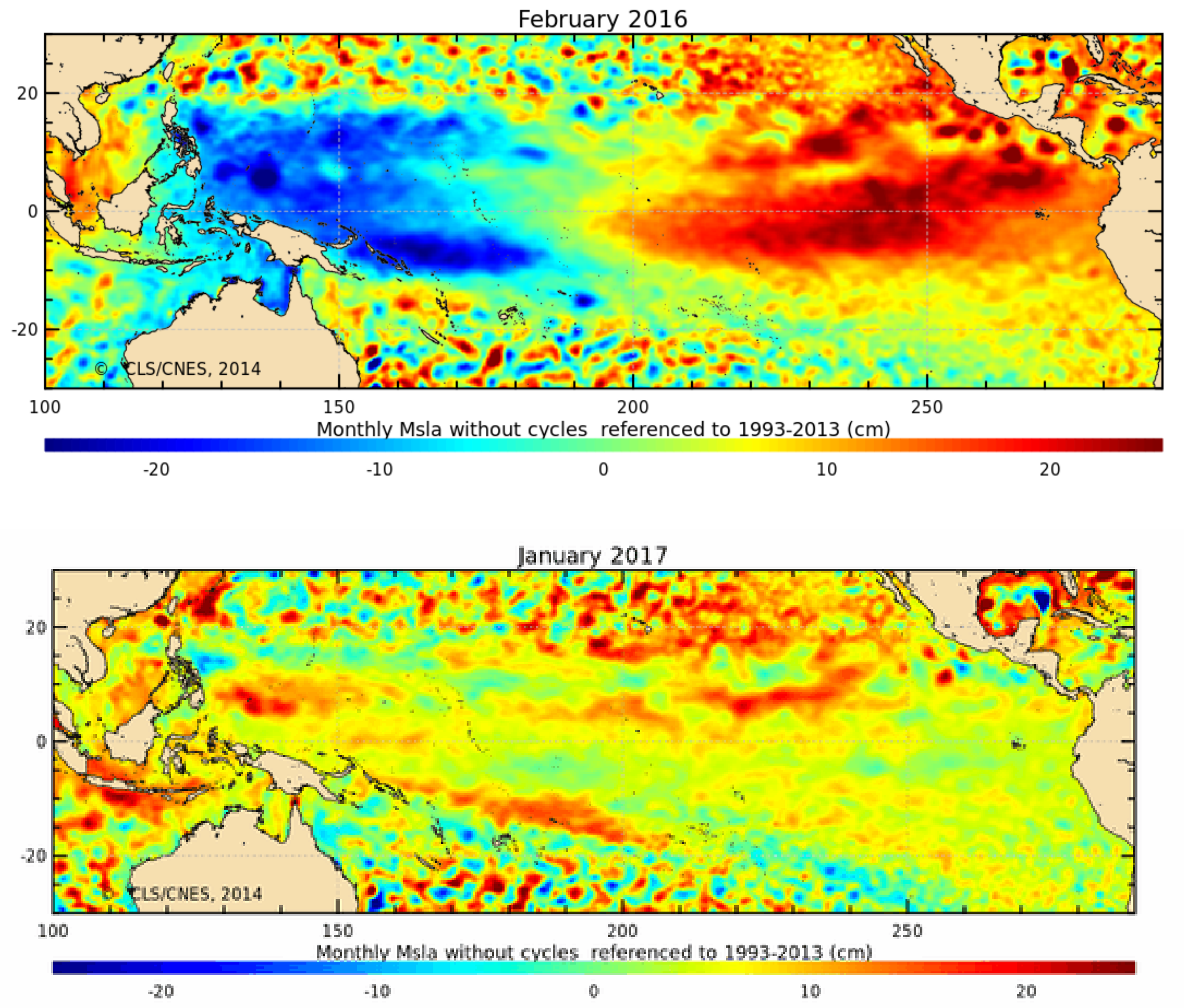
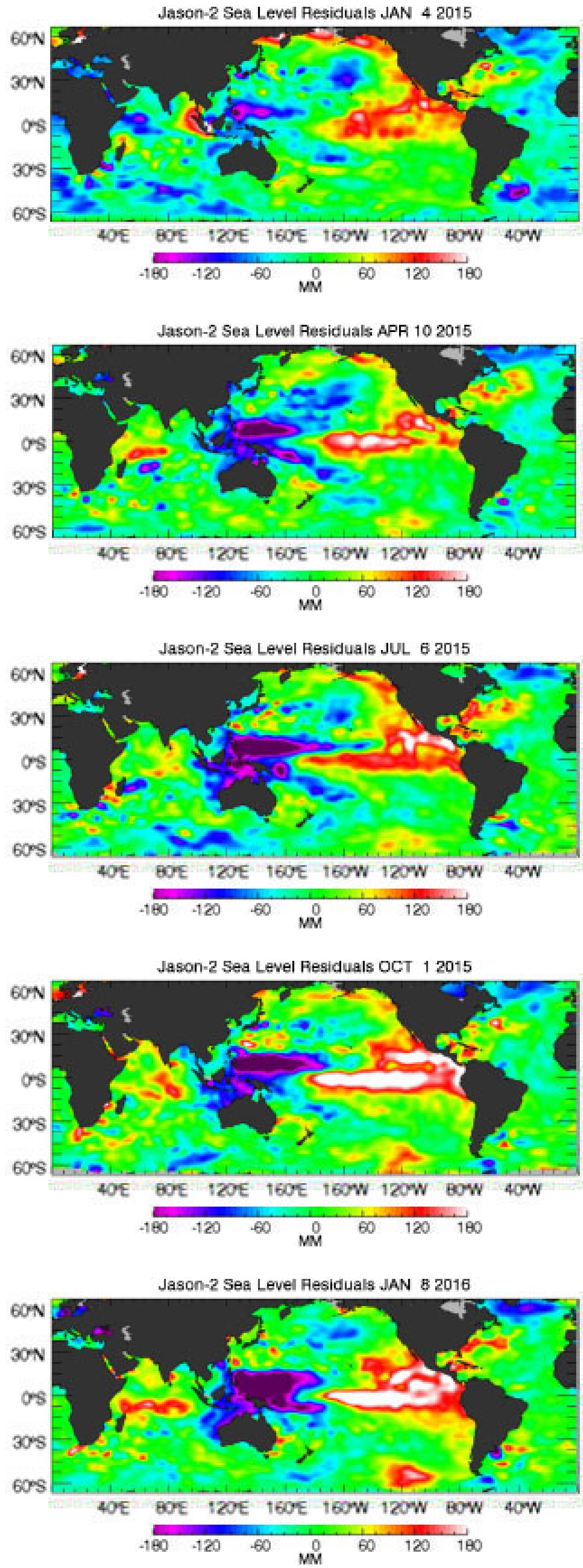
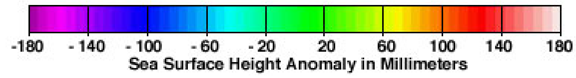
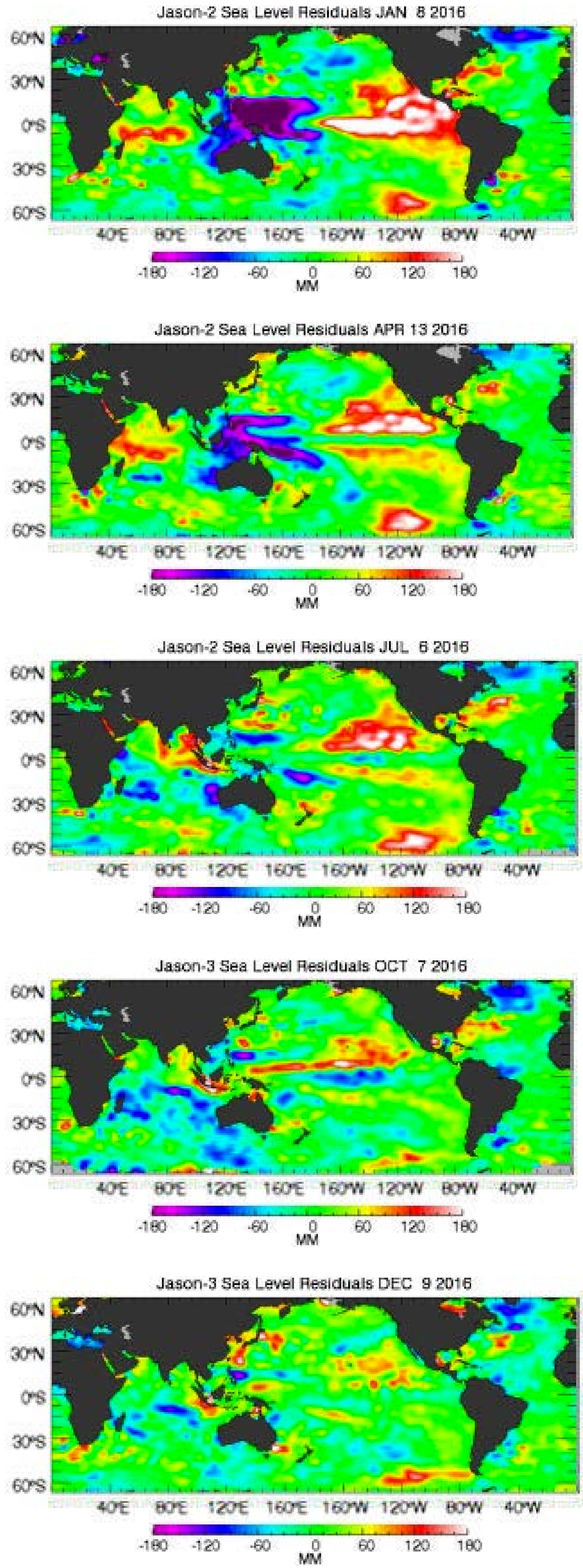


Figure 33. Comparing mean sea level anomaly for February 2016 (El Niño), and January 2017 (Neutral) .

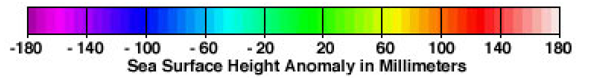


Quarterly time series of mean sea level anomalies during 2015 provide a glimpse into the evolution of the 2015-2016 El Niño throughout the year using satellite altimetry measurements of sea level height (http://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/archive/index.cfm?y=2015**)**





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/lateststdata/archive/index.cfm?y=2016**)**



2.4.3.9.2 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=1612340.

Figure 34 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).

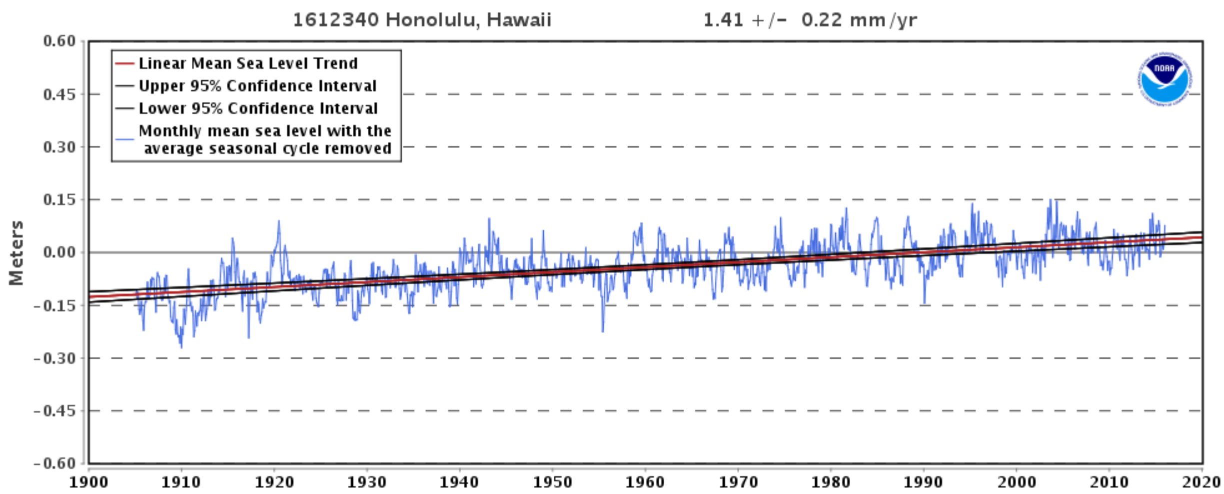


Figure 34. Local sea level in Honolulu, HI 1900-2016.

Figure 35 shows the interannual variation of monthly mean sea level and the five-month running average. The average seasonal cycle and linear sea level trend have been removed. Interannual variation is caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The interannual variation for many Pacific stations is closely related to the El Niño Southern Oscillation (ENSO).

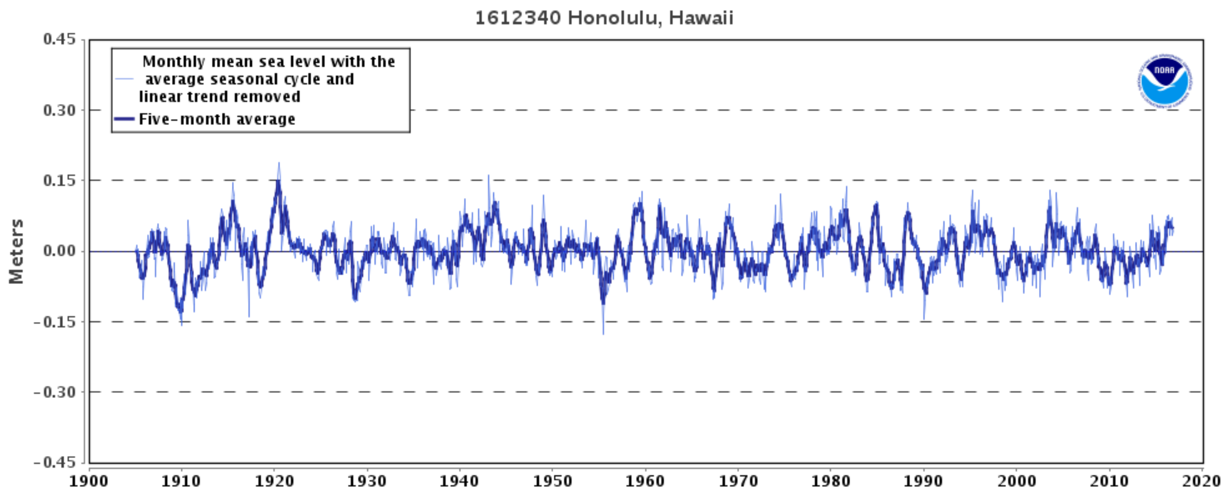
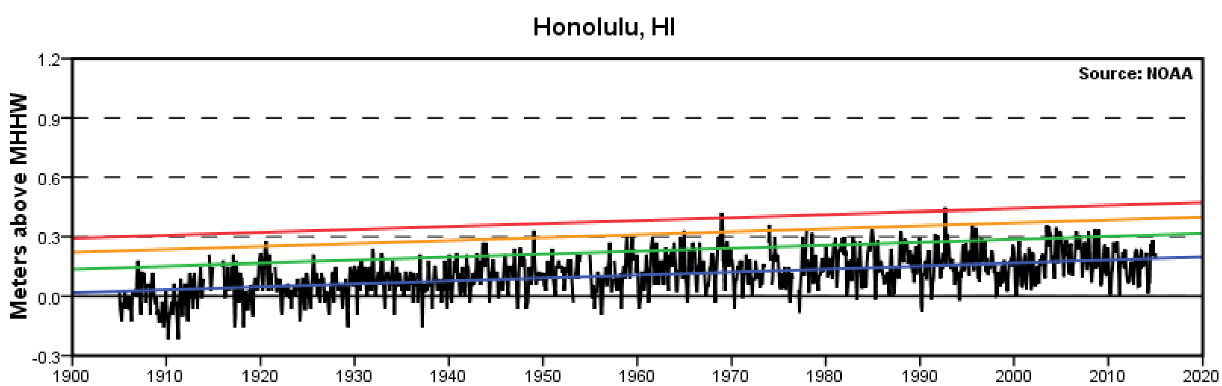


Figure 35. Monthly mean sea level and five-month average sea level at Honolulu, HI 1900-2015.

The monthly extreme water levels include a Mean Sea Level (MSL) trend of 1.41 millimeters/year with a 95% confidence interval of +/- 0.21 millimeters/year based on monthly MSL data from 1905 to 2015 - which is equivalent to a change of 0.46 feet in 100 years. Figure 36 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.



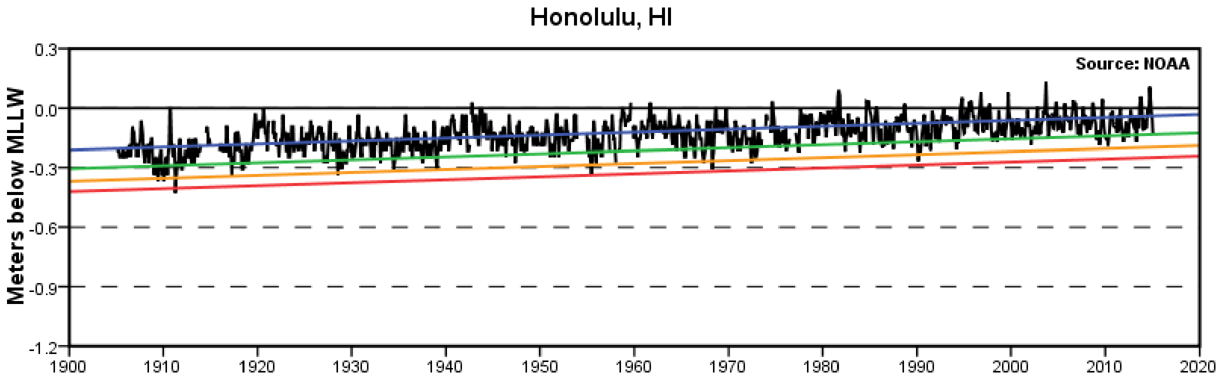


Figure 36. Average sea level above mean high high water and below mean low low water at Honolulu, HI 1900-2015.

2.4.3.10 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 Hawaiʻi 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 Hawaiʻi 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: 2010-2017, 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.

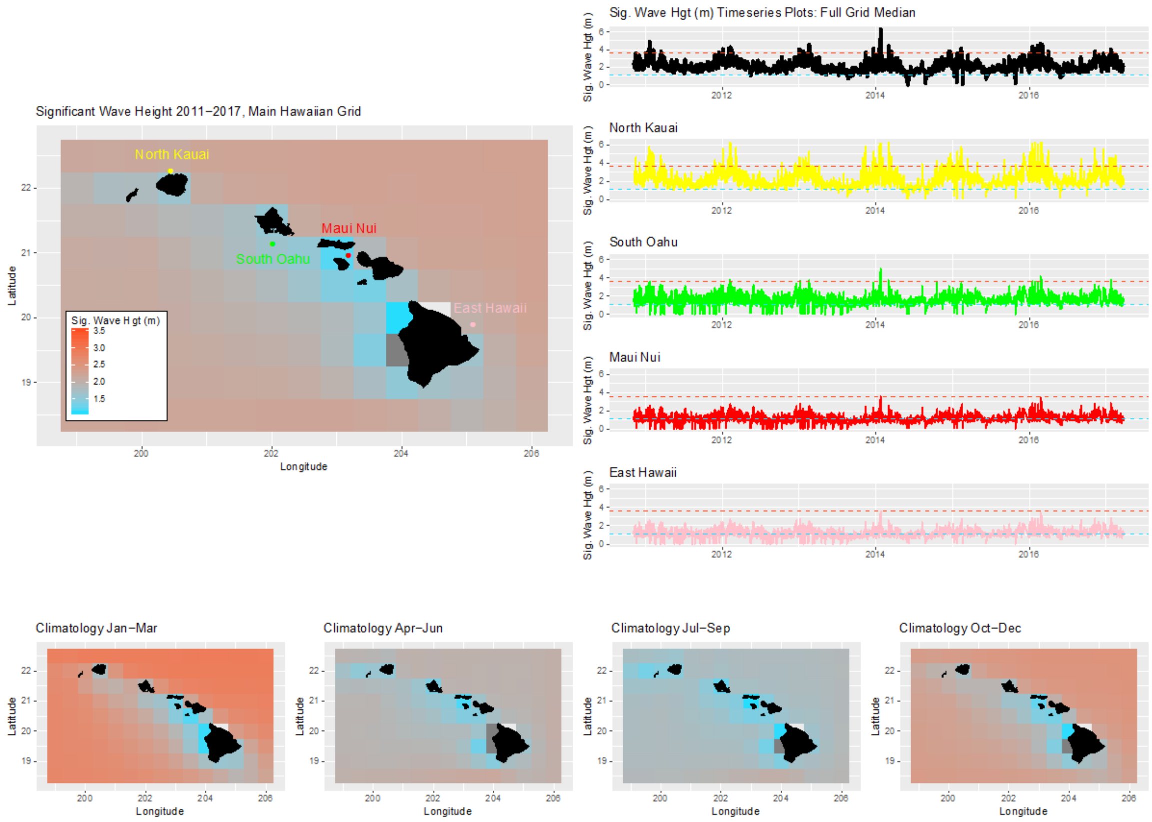


Figure 37. Wave watch summary for the Main Hawaiian Islands regional grid.

2.4.4 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.

2.4.5 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.

2.5 ESSENTIAL FISH HABITAT

2.5.1 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.” Habitat Areas of Particular Concern (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 5 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.

2.5.1.1 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 (HAPC). 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 is described in the FEP but implemented in the SAFE 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 Hawaii 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 2.5.4.
- Updated research and information needs, which can be found in Section 2.5.5. 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.

2.5.1.2 Habitat Objectives of FEP

The habitat objective of the FEP is to refine EFH and minimize impacts to EFH, with the following sub-objectives:

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.

2.5.1.3 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.

2.5.2 Habitat Use by MUS and Trends in Habitat Condition

The Hawaiian Archipelago is an island chain in the central North Pacific Ocean. It runs for approximately 1,500 miles in a northwest direction, from Hawaii Island in the southeast to Kure Atoll in the northwest and is among the most isolated island areas in the world. The chain can be divided according to the large and mountainous Main Hawaiian Islands (MHI) (Hawaii, Maui, Lanai, Molokai, Kahoolawe, Oahu, Kauai, and Niihau) and the small, low-lying Northwest Hawaiian Islands (NWHI), which include Necker, French Frigate Shoals, Laysan, and Midway atoll. The largest of the MHI is Hawaii Island at just over 4,000 square miles – the largest in Polynesia, while Kahoolawe is the smallest, at 44.6 square miles.

The archipelago developed as the Pacific plate moved slowly over a hotspot in the Earth's mantle. Thus, the islands on the northwest end of the archipelago are older; it is estimated that Kure Atoll is approximately 28 million years old while Hawaii Island is approximately 400,000 years old. The highest point in Hawaii is Mauna Kea, at approximately 13,800 feet.

The MHI are all in tropical latitudes. The archipelago becomes subtropical at about French Frigate Shoals (23° 46' N). The climate of the Hawaiian Islands is generally tropical, but there is great climactic variation, due primarily to elevation and leeward vs. windward areas. Easterly trade winds bring much of the rain, and so the windward sides of all the islands are typically wetter. The south and west (leeward) sides of the islands tend to be drier. Hawaii receives the majority of its precipitation from October to April, while drier conditions generally prevail from May to September. Tropical storms and hurricanes occur in the northern hemisphere hurricane and typhoon season, which runs from June through November.

There is fairly little shallow water habitat in Hawaii, owing to the islands' steep rise from the abyssal deep. However, there are some larger areas, such as Penguin Bank between Oahu and Molokai, which are relatively shallow. Hawaii has extensive coral reef habitat, though the MHI, because they are much younger, have more fringing reef habitat than the NWHI, which has more shallow reef habitat overall.

Essential fish habitat in the Hawaiian Archipelago 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 MHI and NWHI have been the subject of a comprehensive monitoring program through the PIFSC Coral Reef Ecosystem Program (CREP) biennially since 2002, surveys are focused on the nearshore environments surrounding the islands, atolls and reefs (PIBHMC).

The mission of the PIFSC Coral Reef Ecosystem Program (CREP) 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). CREP'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). CREP 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.

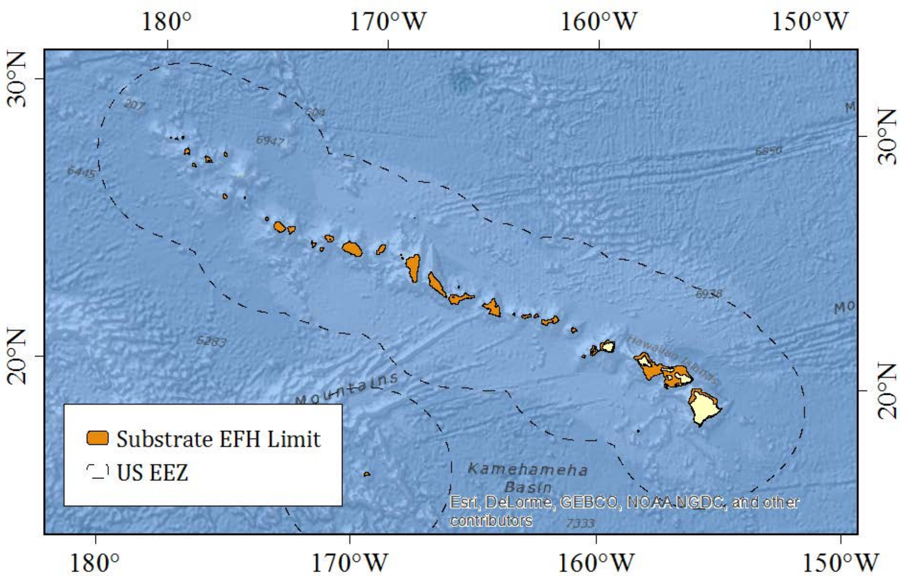


Figure 38. Substrate EFH limit of 700 m isobath around the islands and surrounding banks of the Hawaiian Archipelago. Data Source: GMRT.

2.5.2.1 Habitat Mapping

Interpreted IKONOS benthic habitat maps in the 0 – 30 m depth range have been completed for all islands in the MHI and NWHI (CRCP 2011). While there are gaps in multibeam coverage in the MHI (CRCP 2011), 60 m resolution bathymetry and backscatter are available from the Falkor for much of the NWHI (MHI Multibeam Bathymetry and Backscatter Synthesis).

Table 62. Summary of habitat mapping in the MHI

Depth Range	Timeline/Mapping Product	Progress	Source
0-30 m	IKONOS Benthic Habitat Maps	All islands complete	CRCP 2011
	2000-2010 Bathymetry	84%	DesRochers 2016
	2011-2015 Multibeam Bathymetry	4%	DesRochers 2016
	2011-2015 Satellite WorldView 2 Bathymetry	5%	DesRochers 2016
0-150 m	Multibeam Bathymetry	Gaps exist around Maui, Lanai, and Kahoolawe. Access restricted at Kahoolawe.	CRCP 2011
30-150 m	2000-2010 Bathymetry	86%	DesRochers 2016
	2011-2015 Multibeam Bathymetry	2%	DesRochers 2016
Over all multibeam depths	Derived Products	Few exist	CRCP 2011

Table 63. Summary of habitat mapping in the NWHI.

Depth Range	Timeline/Mapping Product	Progress	Source
0-30 m	IKONOS Benthic Habitat Maps	All islands complete	CRCP 2011
	2000-2010 Bathymetry	6%	DesRochers 2016

	2011-2015 Multibeam Bathymetry	-	DesRochers 2016
	2011-2015 Satellite WorldView 2 Bathymetry	-	DesRochers 2016
30-150 m	2000-2010 Bathymetry	49%	DesRochers 2016
	2011-2015 Multibeam Bathymetry	4%	DesRochers 2016

The land and seafloor area surrounding the islands of the MHI as well as primary data coverage are reproduced from CRCP 2011 in Figure 39.

ISLAND CODE	KAL	NII	KAU	OAH	MOL	LAN	MAI	MOI	KAH	NUI	HAW
SHAPE & RELATIVE SIZE											
LAND AREA (km²)	<1	187	1437	1549	670	365	1886	<1	116		10442
SEA FLOOR AREA 0-30 m (km²)	3	108	242	423	199	55	197	?	4		202
SEA FLOOR AREA 30-150 m (km²)	62	182	297	467	*	*	*	*	*	2801	699
BATHYMETRY 0-30 m (km²)	0	41	237	422	144	17	178	?	0		134
BATHYMETRY 30-150 m (km²)	19	181	292	454	*	*	*	*	*	2346	584
OPTICAL COVERAGE 0-30 m (km)	4	41	45	44	30	32	66	1	0		91
OPTICAL COVERAGE 30-150 m (km)	0	13	11	23	*	*	*	*	*	161	0

? unknown
— no data
*combined and presented as Maui Nui

Figure 39. MHI Land and Seafloor Area and Primary Data Coverage from CRCP 2011.

The land and seafloor area surrounding the islands of the MHI as well as primary data coverage are reproduced from CRCP 2011 in Figure 40.

ISLAND CODE	KUR	MID	PHR	NEV	LIS	PIO	NHS	LAY	MAR	RAI	GAR	SRW	BBW	BBM	BBB	FFS	NEC	TWI	WNB	NIH
LAND AREA (km^2)	<1	6	<1	0	2	0	0	4	0	0	0	0	0	0	0	<1	<1	0	0	<1
SEA FLOOR AREA 0-30 m (km^2)	83	102	467	0	1004	306	0	488	1075	128	1269	250	3	<1	0	678	1028	0	0	<1
SEA FLOOR AREA 30-150 m (km^2)	218	236	276	90	226	125	360	69	696	310	1136	124	142	135	23	244	473	63	320	573
BATHYMETRY 0-30 m (km^2)	25	24	23	0	0	<1	0	0	73	0	<1	<1	2	<1	0	222	8	0	<1	<1
BATHYMETRY 30-150 m (km^2)	218	180	251	34	125	54	20	58	588	0	126	40	142	135	23	214	312	13	165	163
OPTICAL COVERAGE 0-30 m (km)	32	43	63	0	57	0	0	14	40	1	4	0	<1	<1	0	106	8	0	0	0
OPTICAL COVERAGE 30-150 m (km)	21	13	20	0	8	0	0	<1	2	<1	<1	1	3	<1	<1	90	6	0	0	0

? unknown
— no data
*numbers refer to area from 0-150 m

Figure 40. NWHI Land and Seafloor Area and Primary Data Coverage from CRCP 2011.

2.5.2.2 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 crustacean 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 300m isobath to the 700 m isobath (73 FR 70603, November 21, 2008).

2.5.2.2.1 RAMP Indicators

Benthic percent cover of coral, macroalgae, and crustose coralline algae from CREP are found in the following tables. CREP 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 minutes long and cover about 2-3 km of habitat. Each survey is divided into five-minute 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 64. Mean percent cover of live coral from RAMP sites collected from towed-diver surveys in the MHI

	2005	2006	2008	2010	2016
Hawaii		18.38	17.11	22.1	25.65
Kauai	6.06	12.27	7.04	6.04	6.99
Kaula		6.9			
Lanai	30.48	26.61	22.42	23.34	30.42
Maui	18.99	20.33	12.06	14.62	11.91
Molokai	35.66	6.96	6.92	52.17	18.85
Niihau	5.03	2.39	2.29	2.26	3.44
Oahu	9.36	12.21	9.45	8.19	

Table 65. Mean percent cover of macroalgae from RAMP sites collected from towed-diver surveys in the MHI

	2005	2006	2008	2010	2016
Hawaii		5.46	1.01	1.05	0.29
Kauai	35.67	27.92	16.45	16.25	9.61
Kaula		5.94			
Lanai	7.38	13.18	17.13	11.14	2.69
Maui	17.84	16.24	12.04	2.13	12.12
Molokai	23.31	24.22	12.71	4.75	9.47
Niihau	41.3	14.57	2.58	2.22	0.03
Oahu	37.03	27.41	12.58	13.03	

Table 66. Mean percent cover of crustose coralline algae from RAMP sites collected from towed-diver surveys in the MHI

	2005	2006	2008	2010	2016
Hawaii		14.82	16.09	6.94	5.97
Kauai	3.67	2.94	4.14	1.71	2.7
Kaula		7.4			
Lanai	2.42	1.31	3.72	2.82	0.03
Maui	4.37	4.83	6.82	4.31	1.22
Molokai	3.71	3.79	5.24	4.19	0.65
Niihau	10.87	6.68	8.05	1.88	0.28
Oahu	13.95	2.74	4.28	2.42	

Table 67. Mean percent cover of live coral from RAMP sites collected from towed-diver surveys in the NWHI

Row Labels	2000	2001	2002	2003	2004	2006	2008	2010	2016

French Frigate	27.23	5	14.22	13.47	11.29	18.25	15.23	13.28	17.53
Gardner	3			2.5	1.65				
Kure	7.3		9.61	12.34	12.63	17.2	17.6	14.57	13.08
Laysan	9.96		9.76	4	7.33	6.96	8.43		
Lisianski	28.17		24.29	15.2	26.81	27.22	25.69	27.56	26.96
Maro	27.38	18.31	13.77	16.54	25.59	22.67	19.78		
Midway			5.58	3.06	1.24	3.91	2.66		
Necker	6.5			14.52		14.92			
Nihoa	3.89								
Pearl & Hermes	15.82		10.71	6.47	9.45	11.64	10.79	8.25	7.91
Raita		2.5							

Table 68. Mean percent cover of macroalgae from RAMP sites collected from towed-diver surveys in the NWHI

	2000	2001	2002	2003	2004	2006	2008	2010	2016
French Frigate	0	10.5	30.13	29.05	23.15	17.33	17.81	18.42	9.6
Gardner	0			73.63	26.94				
Kure	0		38.84	42.79	29.84	23.14	26.22	12.99	11.00
Laysan	0		26.9	47.03	30.63	28.66	25.7		
Lisianski	0		20.04	24.61	17.14	21.46	20.83	13.85	10.92
Maro	0	17.01	20.39	17.69	30.01	20.79	18.19		
Midway			42.28	44.9	24.86	11.02	19.93		
Necker	0			23.39		33.51			
Nihoa	0								
Pearl & Hermes	0		36.94	41.51	114.87	33.56	33.79	36.96	39.84
Raita		68.83							

Table 69. Mean percent cover of crustose coralline algae from RAMP sites collected from towed-diver surveys in the NWHI

	2000	2001	2002	2003	2004	2006	2008	2010	2016
French Frigate	0	0	8.55	8.56	2.52	9.46	8.55	1.87	4.21
Gardner	0			9.13	1.5				
Kure	0		3.38	7.65	5.87	7.31	6.91	4.11	7.18
Laysan	0		3.95	11.17	5.11	10.21	7.93		
Lisianski	0		14.21	7.97	12.11	17.19	17.42	11.78	13.29
Maro	0	13.95	15.17	12.89	4.36	16.54	15.29		
Midway			7.58	3.69	7.17	5.8	5.62		
Necker	0			7.86		1.48			
Nihoa	0								
Pearl & Hermes	0		14.13	14.38	11.84	10.07	12.43	7.61	14.44

	2000	2001	2002	2003	2004	2006	2008	2010	2016
Raita		0.42							

2.5.2.3 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.

2.5.3 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)

2.5.4 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.

2.5.4.1 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 70. Level of EFH available for Hawaii precious corals management unit species complex.

Species	Pelagic phase (larval stage)	Benthic phase	Source(s)
Pink Coral (*Corallium*)			

Species	**Pelagic phase (larval stage)**	**Benthic phase**	**Source(s)**
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

2.5.4.2 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 71. Level of EFH information available for Hawaii 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
Pristipomoides auricilla (yellowtail snapper)	0	0	0	2

Life History Stage	**Eggs**	**Larvae**	**Juvenile**	**Adult**
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

2.5.4.3 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 72. Level of EFH information available for Hawaii crustaceans 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

2.5.4.4 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.

2.5.5 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:

2.5.5.1 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

2.5.5.2 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

2.5.5.3 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

2.5.5.4 Precious Coral Fishery

- Statistically sound estimates of distribution, abundance, and condition of precious corals throughout the MHI. Targeted surveys of areas that meet the depth and hardness criteria could provide very accurate estimates.
- Environmental conditions necessary for precious coral settlement, growth, and reproduction. The same surveys used for abundance and distribution could collect these data as well.
- Quantitative measures of growth and productivity.

- Taxonomic investigations to ascertain if the H. laauense that is commonly observed between 200 and 600 meters depth is the same species as those H. laauense observed below 1000 meters in depth.
- Continuous backscatter or LIDAR data in depths shallower than 60 m.

2.5.6 References

Annette DesRochers. “Benthic Habitat Mapping.” NOAA Fisheries Center, Honolulu, HI. Presentation. April 6, 2016.

Coral Reef Ecosystem Program; Pacific Islands Fisheries Science Center 2016. Benthic Percent Cover Derived from Analysis of Benthic Images Collected during Towed-diver Surveys of the U.S. Pacific Reefs Since 2003 (NCEI Accession <unassigned>). NOAA National Centers for Environmental Information. Unpublished Dataset. April 5, 2016.

Pacific Islands Fisheries Science Center Ecosystem Sciences Coral Reef Ecosystem Survey Methods. Benthic Monitoring. http://www.pifsc.noaa.gov/cred/survey_methods.php. Updated April 1, 2016. Accessed April 5, 2016.

Pacific Islands Fisheries Science Center (2011) Coral reef ecosystems of American Samoa: a 2002–2010 overview. NOAA Fisheries Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-11-02, 48 p.

Miller, J; Battista, T.; Pritchett, A; Rohmann, S; Rooney, J. Coral Reef Conservation Program Mapping Achievements and Unmet Needs. March 14, 2011. 68 p.

Main Hawaiian Islands Multibeam Bathymetry and Backscatter Synthesis. Hawaii Mapping Research Group, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa. http://www.soest.hawaii.edu/HMRG/multibeam/index.php. Accessed April 4, 2016.

2.6 MARINE PLANNING

2.6.1 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.

2.6.2 Response to Previous Council Recommendations

There are no standing Council recommendations indicating review deadlines for Hawaii marine managed areas.

2.6.3 Marine Managed Areas established under FEPs

Council-established marine managed areas (MMAs) were compiled in Table 73 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. Regulated fishing areas, including the Papahānaumokuākea Marine National Monument, are shown in Figure 41.

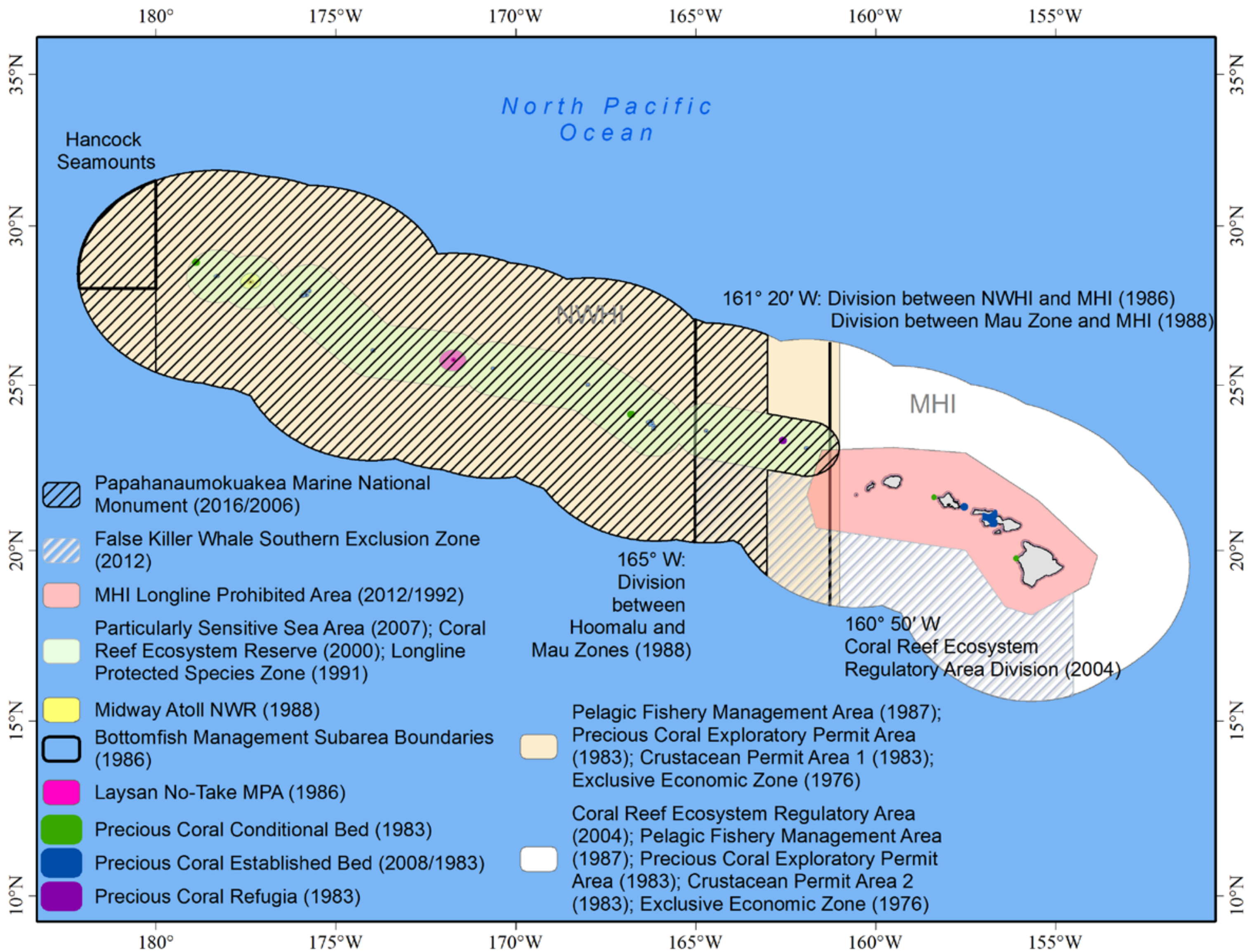


Figure 41. Regulated fishing areas of the Hawaiian Islands.

Table 73. MMAs established under FEP 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								
NWHI Longline Protected Species Zone	Pelagic (Hawaii)	NWHI	665.806(a)(1) 56 FR 52214 Pelagic FMP Am. 3	351,514.00	Longline fishing prohibited	Prevent longline interaction with monk seals	1991	-
MHI Longline Prohibited Area	Pelagic (Hawaii)	MHI	665.806(a)(2) 57 FR 7661 Pelagic FMP Am. 5	248,682.38	Longline fishing prohibited	Prevent gear conflicts between longline vessels and troll/handline vessels	1992	-
Bottomfish Restrictions								
Hancock Seamounts Ecosystem Management Area (HSEMA)	Hawaii Archipelago	NW of Midway Island	HSEMA: 665.209 75 FR 52921 Moratorium: 51 FR 27413 Bottomfish FMP	60,826.75	Moratorium	The intent of the continued moratorium is to facilitate rebuilding of the armorhead stock, and the intent of the ecosystem management area is to facilitate research on armorhead and other seamount groundfish	2010	-
Precious Coral Permit Areas								

Name	FEP	Island	50 CFR /FR /Amendment Reference	Marine Area (km^2)	Fishing Restriction	Goals	Most Recent Evaluation	Review Deadline
Keahole Point	Hawaii Archipelago	Hawaii Island	665.261(2)(i) 73 FR 47098 Precious Corals FMP Am. 7	2.7	Fishing by permit only	Manage harvest	2008	-
Kaena Point	Hawaii Archipelago	Oahu	665.261(2)(ii) 73 FR 47098 Precious Corals FMP Am. 7	2.7	Fishing by permit only	Manage harvest	2008	-
Makapuu	Hawaii Archipelago	Oahu	665.261(1)(i) 73 FR 47098 Precious Corals FMP Am. 7	43.15	Fishing by permit only	Manage harvest	2008	-
Brooks Bank	Hawaii Archipelago	NWHI	665.261(2)(iii) 73 FR 47098 Precious Corals FMP Am. 7	43.15	Fishing by permit only	Manage harvest	2008	-
180 Fathom Bank	Hawaii Archipelago	NWHI	665.261(2)(iv) 73 FR 47098 Precious Corals FMP Am. 7	43.15	Fishing by permit only	Manage harvest	2008	-

Name	FEP	Island	50 CFR /FR /Amendment Reference	Marine Area (km^2)	Fishing Restriction	Goals	Most Recent Evaluation	Review Deadline
Westpac Bed	Hawaii Archipelago	NWHI	665.261(3) 73 FR 47098 Precious Corals FMP Am. 7	43.15	Fishing prohibited	Manage harvest	2008	-
Auau Channel	Hawaii Archipelago	Maui Nui	665.261(1)(ii) 73 FR 47098 Precious Corals FMP Am. 7	728.42	Fishing by permit only	Harvest quota for black coral of 5,000 kg every two years for federal and state waters	2008	-

2.6.4 Fishing Activities and Facilities

2.6.4.1 Aquaculture facilities

Hawaiʻi has one permitted offshore aquaculture facility. The information in Table 74 was transferred from the Joint NMFS and U.S. Army Corps of Engineers EFH Assessment for the Proposed Issuance of a Permit to Authorize the Use of a Net Pen and Feed Barge Moored in Federal Waters West of the Island of Hawaii to Fish for a Coral Reef Ecosystem Management Unit Species, *Seriola rivoliana* (RIN 0648-XD961), unless otherwise noted.

Table 74. Aquaculture facilities.

Name	Size	Location	Species	Stage
Kampachi Farms	Shape: Cylindrical Height: 33 ft Diameter: 39 ft Volume: 36,600 ft^3	5.5 nautical miles (nm) west of Keauhou Bay and 7 nm south-southwest of Kailua Bay, off the west coast of Hawaiʻi Island 19 deg 33 min N 156 deg 04 min W. mooring scope is 10,400 foot radius.	*Seriola rivoliana*	Permit authorizes culture and harvest of 30,000 kampachi over 2 years Array broke loose from mooring on Dec. 12, 2016; net pen sank in 12,000 feet of water. NMFS working with operators to understand cause of mooring line failure and plans for future activities under permit (pers. comm. David Nichols, March 1, 2017).

2.6.5 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.

2.6.5.1 Alternative energy facilities

Hawaiʻi has three proposed wind energy facilities in Federal waters and several existing alternative energy facilities. The information in

Table 75 is from various sources.

Table 75. Alternative Energy Facilities and Development

Name	Type	Location	Impact to Fisheries	Stage of Development	Source
AWH Oʻahu Northwest Project	408 MW Wind	12 miles W of Kaʻena Pt, Oʻahu	Hazard to navigation; benthic impacts	BOEM Area Identification and EA	BOEM Hawai`i

Name	Type	Location	Impact to Fisheries	Stage of Development	Source
			from cables		
AWH O'ahu South Project	408 MW Wind	17 miles S of Waikiki, O'ahu	Hazard to navigation; benthic impacts from cables; close to Penguin Bank	BOEM Area Identification and EA	BOEM Hawai`i
Progression South Coast of Oahu Project	400 MW Wind	SSE of Barber's Pt and SW of Waikiki, O'ahu	Hazard to navigation; in popular trolling area; benthic impacts from cables	BOEM Area Identification and EA	Progression Energy BOEM Lease Application, BOEM Hawai`i
Statoil Wind US, LLC	-	-	-	BOEM Area Identification and EA	BOEM Hawaii
Natural Energy Laboratory of Hawai`i	120 kW OTEC Test Site/ 1 MW Test Site	West Hawai`i	Intake	120 kW operational; DEA for 1 MW Test Site using existing infrastructure submitted July 2012 HEPA Exemption List memo Dec. 27, 2016	http://nelha.Hawai`i.gov/energy-portfolio/ Final Environmental Assessment, NELHA, July 2012
Honolulu Sea Water Air Conditioning	SWAC	4 miles S of Kaka'ako, O'ahu	Benthic impacts; intake	USACE Record of Decision (ROD) signed; completion and commissioning in 2017.	http://honoluluswac.com/pressroom.html https://www.trenchlessinternational.com/2016/05/11/mapping-utilities-downtown-honolulu/
Marine Corps Base Hawai`i Wave Energy Test Site	Shallow- and Deep-Water Wave Energy	1, 2 and 2.5 km N of Mokapu, O'ahu	Hazard to navigation	Shallow and Deep-water wave energy units are operational	Final Environmental Assessment, NAVFACPAC, January 2014 http://www.eenews.net/stories/1060046254

2.6.5.2 Military training and testing activities and impacts

The Department of Defense major planning activities in the region are summarized below. Maps of the Hawaii-Southern California Range Complex from the Hawaii Range Complex FEIS are included in the maps section.

Action	Description	Phase	Impacts
Hawaii-Southern California Training and Testing	Increase naval testing and training activities	DEIS Expected Summer 2017	Likely access and habitat impacts. The action may include expansion of

			warning areas near PMRF.
Long Range Strike Weapon Systems Evaluation Program (WSEP)	Conduct operational evaluations of Long Range Strike weapons and other munitions as part of Long Range Strike WSEP operations at the Pacific Missile Range Facility at Kauai, Hawaii	Comment period closed Feb. 6, 2017 on NMFS authorization to take marine mammals incidental to conducting munitions testing for their Long Range Strike Weapons Systems Evaluation Program (LRS WSEP) over the course of five years, from September 1, 2017 through August 31, 2022 (82 FR 1702).	Access – closures during training

2.6.6 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.

2.6.7 References

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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 list table for the Hawaii FEP

1. MHI Deep 7 Bottomfish Multi-species Stock Complex (FSSI)

HDAR Species Code	**Species Name**	**Scientific Name**
19	Opakapaka	*Pristipomoides filamentosus*
22	Onaga	*Etelis coruscans*
21/36	Ehu	*Etelis carbunculus*
15	Hapuupuu	*Epinephelus quernus*
97	Gindai	*Pristipomoides zonatus*
17	Kalekale	*Pristipomoides seiboldii*
58	Lehi	*Aphareus rutilans*

2. MHI Non-Deep 7 Bottomfish Multi-species Stock Complex (non-FSSI)

HDAR Species Code	**Species Name**	**Scientific Name**
208	yellowtail snapper (kalekale)	*Pristipomoides auricilla*
20	gray jobfish (uku)	*Aprion virescens*
205	giant trevally (white ulua)	*Caranx ignoblis*
202	black trevally (black ulua)	*Caranx lugubris*
114	taape	*Lutjanis kasmira*
16	greater amberjack (kahala)	*Seriola dumerili*
200	pig lipped trevally (butaguchi)	*Pseudocaranx dentex*

NOTE: Taape (*Lutjanis kasmira*) is listed in the Hawaii CREMUS group, Lutjanidae (Snapper)

Kahala (*Seriola rivoliana*) is listed in the Hawaii CREMUS group, Carangidae (Jacks)

MHI Deep 7 bottomfish not inlcuded in the 2012 ACL tracking exercise

Seamount groundfish not included in the 2012 ACL tracking exercise

3. Crustacean deep-water shrimp complex (non-FSSI)

HDAR Species Code	**Species Name**	**Scientific Name**
708	deepwater shrimp	*Heterocarpus* spp.
709	deepwater shrimp (ensifer)	*Heterocarpus* spp.

4. Crustacean spiny lobster complex (non-FSSI)

HDAR Species Code	**Species Name**	**Scientific Name**
716	spiny lobster	*Panulirus marginatus*
717	spiny lobster	*Panulirus penicillatus*

5. Crustacean slipper lobster complex (non-FSSI)

HDAR Species Code	**Species Name**	**Scientific Name**
718	Slipper lobster	Scyllaridae

6. Crustacean Kona crab complex (non-FSSI)

HDAR Species Code	Species Name	Scientific Name
701	Kona crab	*Ranina ranina*

7. Auau Channel Black coral complex (non-FSSI)

HDAR Species Code	Species Name	Scientific Name
860	Black Coral	*Antipathes griggi*
860	Black Coral	*Antipathes dichotoma*
860	Black Coral	*Antipathes grandis*
860	Black Coral	*Antipathes ulex*

8. Precious corals on identified beds and exploratory beds (non-FSSI)

HDAR Species Code	Species Name	Scientific Name
871	Pink coral	*Corallium secundum*
872	Pink coral	*Corallium regale*
873	Pink coral	*Corallium laauense*
891	Bamboo coral	*Lepidisis olapa*
892	Bamboo coral	*Acanella* spp.
880/881	Gold Coral	*Gerardia* spp.
882	Gold Coral	*Callogorgia gilberti*
883	Gold Coral	*Narella* spp.
884	Gold Coral	*Calyptrophora* spp.

9. Coral reef ecosystem (non-FSSI)

HDAR Species Code	**Species Name**	**Scientific Name**	**Grouping**
28	Bigeye Scad (Adult)	*Selar crumenophthalmus*	Akule
37	Bigeye Scad (Juvenile)	*Selar crumenophthalmus*	Akule
81	OPELU	*Decapterus* spp.	Opelu
16	BARRED JACK	*Carangoides ferdau*	Carangidae
18	DOBE	*Caranx (Urapsis) helvolus*	Carangidae
23	KAGAMI	*Alectis ciliaris*	Carangidae
48	KAHALA	*Seriola rivoliana*	Carangidae
56	KAMANU	*Elagatis bipinnulata*	Carangidae
79	LAE	*Scomberoides lysan,*	Carangidae
79	LAE	*Scomberoides sancti-petri*	Carangidae
89	NO-BITE	*Caranx equula*	Carangidae
104	OMAKA	*Atule mata*	Carangidae
112	OMILU	*Caranx melampygus*	Carangidae
203	PAOPAO	*Gnathanodon speciosus*	Carangidae
204	PAPA	*Carangoides orthogramus*	Carangidae
220	PAPIO, ULUA (MISC.)	*Carangidae*	Carangidae
221	SASA	*Caranx sexafaciatus*	Carangidae
52	KUMU	*Parupeneus porphyeus*	Mullidae
110	MALU	*Parupeneus pleurostigma*	Mullidae
68	MOANA	*Parupeneus spp.*	Mullidae

206	MOANO KALE	*Parupeneus cyclostomus*	Mullidae
70	MOELUA; GOAT FISH (RED)	*Mulloidichthys sp.*	Mullidae
121	MUNU	*Parupeneus bifasciatus*	Mullidae
103	WEKE (MISC.)	*Mullidae*	Mullidae
128	WEKE A'A	*Mulloidichthys flavolineatus*	Mullidae
24	WEKE NONO	*Mulloidichthys pflugeri*	Mullidae
122	WEKE PUEO	*Upeneus arge*	Mullidae
127	WEKE-ULA	*Mulloidichthys vanicolensis*	Mullidae
47	KALA	*Naso annulatus*	Acanthuridae
47	KALA	*Naso brevirostris*	Acanthuridae
47	KALA	*Naso Unicornus*	Acanthuridae
125	KALALEI	*Naso lituratus*	Acanthuridae
51	KOLE	*Ctenochaetus strigosus*	Acanthuridae
59	MAIII	*Acanthurus nigrofuscus*	Acanthuridae
60	MAIKO	*Acanthurus nigroris*	Acanthuridae
61	MAIKOIKO	*Acanthurus leucopareius*	Acanthuridae
64	MANINI	*Acanthurus triostegus*	Acanthuridae
72	NAENAE	*Acanthurus olivaceus*	Acanthuridae
124	OPELU KALA	*Naso hexacanthus*	Acanthuridae
85	PAKUIKUI	*Acanthurus achilles*	Acanthuridae
86	PALANI	*Acanthurus dussumieri*	Acanthuridae
92	PUALU	*Acanthurus blochii,*	Acanthuridae
92	PUALU	*A. xanthopterus*	Acanthuridae
83	YELLOW TANG	*Zebrasoma flavescens*	Acanthuridae

126	API	*Acanturus guttus*	Acanthuridae
129	BLACK KOLE	*Ctenochaetus hawaiiensis*	Acanthuridae
209	GOLDEN KALI	*Erythrocles schegelii*	Lutjanidae
123	GURUTSU, GOROTSUKI	*Aphareus furca*	Lutjanidae
207	RANDALL'S SNAPPER	*Randallichthys filamentosus*	Lutjanidae
	TAAPE	*Lutjanus kasmira*	Lutjanidae
115	TOAU	*Lutjanus fulvus*	Lutjanidae
38	WAHANUI	*Aphareus furcatus*	Lutjanidae
29	ALAIHI	Squirrelfish	Holocentridae
101	ALAIHI MAMA	Squirrelfish	Holocentridae
100	MENPACHI	Squirrelfish	Holocentridae
90	PAUU	Squirrelfish	Holocentridae
30	AMAAMA	*Mugil cephalus*	Mugilidae
32	SUMMER MULLET	*Mugil sp.*	Mugilidae
726	HE'E (DAY TAKO)	*Octopus cyanea*	Mollusk
727	HE'E PU LOA	*Octopus ornatus*	Mollusk
720	OLEPE	*Albula glossodonta*	Mollusk
721	OCTOPUS	*Octopus* spp.	Mollusk
87	PANUHUNUHU	*Scarus* spp.	Scaridae
88	PANUNU	*Scarus* spp.	Scaridae
96	UHU (MISC.)	*Catalomus* spp.	Scaridae
710	A'AMA	*Graspus tenuicrustatus*	CRE-crustaceans
711	BLUE PINCHER CRAB	*Callinectes sapidus*	CRE-crustaceans
700	CRAB (MISC.)	n/a	CRE-crustaceans

703	HAWAIIAN CRAB	*Podophthalmus vigil*	CRE-crustaceans
702	KUAHONU CRAB	*Portunus sanguinolentus*	CRE-crustaceans
713	METABETAEUS LOHENA	*Metabetaeus lohena*	CRE-crustaceans
705	MISC. SHRIMP/PRAWN	n/a	CRE-crustaceans
712	OPAE ULA	*Halocaridina rubra*	CRE-crustaceans
704	SAMOAN CRAB	*Scylla serrata*	CRE-crustaceans
65	SHARK (MISC.) MANO, SPINY DOGFISH, GREY REEF	Carcharhinidae	Carcharhinidae
66	HAMMERHEAD SHARK	Spheyrnidae	Carcharhinidae
753	HA'UKE'UKE	*Colobocentrotus atratus*	Other Invertebrates
754	HAWAE	*Tripneustes gratilla*	Other Invertebrates
751	WANA	*Diadema* sp.	Other Invertebrates
751	WANA	*Echinothrix* sp.	Other Invertebrates
752	NAMAKO	Holothuroidea	Other Invertebrates
755	SLATE PENCIL URCHINS	*Heterocentrotus mammillatus*	Other Invertebrates
27	AHOLEHOLE	*Kuhlia sandvicensis*	Other CRE Finfish
31	AWA	*Chanos chanos*	Other CRE Finfish
33	AWAAWA	*Elops hawaiensis*	Other CRE Finfish
34	AWEOWEO	*Heteropriacanthus cruentatus*	Other CRE Finfish
133	GOLD SPOT HERRING	*Herklotsichthys quadrimaculatus*	Other CRE Finfish
39	HAULIULI	*Gempylus serpens*	Other CRE Finfish
300	HOGO	*Pontinus macrocephalus*	Other CRE Finfish
43	HUMUHUMU	Balistidae	Other CRE Finfish
44	IAO	*Pranesus insularum*	Other CRE Finfish

45	IHEIHE	Hemiramphidae	Other CRE Finfish
46	KAKU	*Sphyraena barracuda*	Other CRE Finfish
49	KAWALEA	*Sphyraena helleri*	Other CRE Finfish
53	KUPIPI	*Abudefduf sordidus*	Other CRE Finfish
57	LAUWILIWILI	*Chaetodon auriga*	Other CRE Finfish
77	LOULU	Monacanthidae	Other CRE Finfish
67	MAKAIWA	*Etrumeus micropus*	Other CRE Finfish
62	MALOLO	Exocoetidae	Other CRE Finfish
63	MA'O MA'O	*Abudefduf abdominalis*	Other CRE Finfish
69	MOI	*Polydactylus sexfilis*	Other CRE Finfish
109	MOLA MOLA	Mola mola	Other CRE Finfish
73	NEHU	*Stolephorus purpureus*	Other CRE Finfish
75	NOHU	*Scorpaenopsis* spp.	Other CRE Finfish
76	NUNU	*Aulostomus chinensis*	Other CRE Finfish
78	OIO	*Gracilaria parvispora*	Other CRE Finfish
80	OOPU HUE	*Diodon* spp.	Other CRE Finfish
84	PAKII	*Bothus* spp.	Other CRE Finfish
91	PIHA	*Spratelloides delicatulus*	Other CRE Finfish
119	POO PAA	*Cirrhitus* spp.	Other CRE Finfish
93	PUHI (MISC.)	*Gymnothorax* spp.	Other CRE Finfish
95	PUHI (WHITE)	Muraenidae	Other CRE Finfish
725	PUPU	Congridae spp.	Other CRE Finfish
111	SABA	*Scomber japonicus*	Other CRE Finfish
113	TILAPIA	*Tilapia* sp.	Other CRE Finfish

99	UPAPALU	*Apogon kallopterus*	Other CRE Finfish
800	LIMU (MISC.)	*Gracilaria* spp.	Algae
801	LIMU KOHU	*Asparagopsis taxiformis*	Algae
802	MANAUEA	*Gracilaria coronopifolia*	Algae
803	OGO	*Aulostromus chinensis*	Algae
804	WAWAEIOLE	*Ulva fasciata*	Algae
74	NENUE	*Kyphosus bigibbus,*	Rudderfish
74	NENUE	*Kyphosus cinerescens*	Wrasse
25	A'AWA	*Bodianus bilunulatus*	Wrasse
35	WRASSE (MISC.)	Labridae	Wrasse
41	HILU	*Coris flavovittata*	Wrasse
42	HINALEA	*Thalassoma* spp.	Wrasse
54	KUPOUPOU	*Cheilio inermis*	Wrasse
55	LAENIHI	*Xyichthys pavo*	Wrasse
82	OPULE	*Anampses cuvier*	Wrasse
105	MALLATEA	Labridae	Wrasse
120	POOU	*Cheilinus unifasciatus*	Wrasse
	MU	*Monotaxis grandoculis*	Emperor
	ROI	*Cephalopholus arugs*	Grouper

Appendix B. List of Protected Species and Designated Critical Habitat.

Table B1. Protected species found or reasonably believed to be found in or near Hawai`i waters.

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
Seabirds					
Laysan Albatross	*Phoebastria immutabilis*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Black-Footed Albatross	*Phoebastria nigripes*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Short-Tailed Albatross	*Phoebastria albatrus*	Endangered	N/A	Breeding visitor in the NWHI	35 FR 8495, 65 FR 46643, Pyle & Pyle 2009
Northern Fulmar	*Fulmarus glacialis*	Not Listed	N/A	Winter resident	Pyle & Pyle 2009
Kermadec Petrel	*Pterodroma neglecta*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Herald Petrel	*Pterodroma arminjoniana*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Murphy's Petrel	*Pterodroma ultima*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Mottled Petrel	*Pterodroma inexpectata*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Juan Fernandez Petrel	*Pterodroma externa*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Hawaiian Petrel	*Pterodroma sandwichensis (Pterodroma phaeopygia sandwichensis)*	Endangered	N/A	Breeding visitor in the MHI	32 FR 4001, Pyle & Pyle 2009
White-Necked Petrel	*Pterodroma cervicalis*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Bonin Petrel	*Pterodroma hypoleuca*	Not Listed	N/A	Breeding visitor in the NWHI	Pyle & Pyle 2009
Black-Winged Petrel	*Pterodroma nigripennis*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Cook Petrel	*Pterodroma*	Not Listed	N/A	Migrant	Pyle & Pyle 2009

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
	cookii				
Stejneger Petrel	*Pterodroma longirostris*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Pycroft Petrel	*Pterodroma pycrofti*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Bulwer’s Petrel	*Bulweria bulwerii*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Flesh-Footed Shearwater	*Ardenna carneipes*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Wedge-Tailed Shearwater	*Ardenna pacifica*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Buller's Shearwater	*Ardenna bulleri*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Sooty Shearwater	*Ardenna grisea*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Short-Tailed Shearwater	*Ardenna tenuirostris*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Christmas Shearwater	*Puffinus nativitatis*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Newell's Shearwater	*Puffinus newelli (Puffinus auricularis newelli)*	Threatened	N/A	Breeding visitor	40 FR 44149, Pyle & Pyle 2009
Wilson's Storm-Petrel	*Oceanites oceanicus*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	Not Listed	N/A	Winter resident	Pyle & Pyle 2009
Band-Rumped Storm-Petrel	*Oceanodroma castro*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Tristram Storm-Petrel	*Oceanodroma tristrami*	Not Listed	N/A	Breeding visitor in the NWHI	Pyle & Pyle 2009
White-Tailed Tropicbird	*Phaethon lepturus*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
Red-Tailed Tropicbird	*Phaethon rubricauda*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Masked Booby	*Sula dactylatra*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Brown Booby	*Sula leucogaster*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Red-Footed Booby	*Sula sula*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Great Frigatebird	*Fregata minor*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Lesser Frigatebird	*Fregata ariel*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Laughing Gull	*Leucophaeus atricilla*	Not Listed	N/A	Winter resident in the MHI	Pyle & Pyle 2009
Franklin Gull	*Leucophaeus pipixcan*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Ring-Billed Gull	*Larus delawarensis*	Not Listed	N/A	Winter resident in the MHI	Pyle & Pyle 2009
Herring Gull	*Larus argentatus*	Not Listed	N/A	Winter resident in the NWHI	Pyle & Pyle 2009
Slaty-Backed Gull	*Larus schistisagus*	Not Listed	N/A	Winter resident in the NWHI	Pyle & Pyle 2009
Glaucous-Winged Gull	*Larus glaucescens*	Not Listed	N/A	Winter resident	Pyle & Pyle 2009
Brown Noddy	*Anous stolidus*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Black Noddy	*Anous minutus*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Blue-Gray Noddy	*Procelsterna cerulea*	Not Listed	N/A	Breeding visitor in the NWHI	Pyle & Pyle 2009
White Tern	*Gygis alba*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Sooty Tern	*Onychoprion fuscatus*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009
Gray-Backed Tern	*Onychoprion lunatus*	Not Listed	N/A	Breeding visitor	Pyle & Pyle 2009

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
Little Tern	*Sternula albifrons*	Not Listed	N/A	Breeding visitor in the NWHI	Pyle & Pyle 2009
Least Tern	*Sternula antillarum*	Not Listed	N/A	Breeding visitor in the NWHI	Pyle & Pyle 2009
Arctic Tern	*Sterna paradisaea*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
South Polar Skua	*Stercorarius maccormicki*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Pomarine Jaeger	*Stercorarius pomarinus*	Not Listed	N/A	Winter resident in the MHI	Pyle & Pyle 2009
Parasitic Jaeger	*Stercorarius parasiticus*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Long-Tailed Jaeger	*Stercorarius longicaudus*	Not Listed	N/A	Migrant	Pyle & Pyle 2009
Sea turtles					
Green Sea Turtle	*Chelonia mydas*	Threatened (Central North Pacific DPS)	N/A	Most common turtle in the Hawaiian Islands, much more common in nearshore state waters (foraging grounds) than offshore federal waters. Most nesting occurs on French Frigate Shoals in the NWHI. Foraging and haulout in the MHI.	43 FR 32800, 81 FR 20057, Balazs et al. 1992, Kolinski et al. 2001
Green Sea Turtle	*Chelonia mydas*	Threatened (East Pacific DPS)	N/A	Nest primarily in Mexico and the Galapagos Islands. Little known about their pelagic range west of 90°W, but may range as far as the Marshall Islands. Genetic testing confirmed that they are incidentally taken in the HI DSLL fishery.	43 FR 32800, 81 FR 20057, WPRFMC 2009, Cliffton et al. 1982, Karl & Bowen 1999
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered[a]	N/A	Small population foraging around Hawai`i and low level nesting on Maui and Hawai`i Islands. Occur worldwide in tropical and subtropical waters.	35 FR 8491, NMFS & USFWS 2007, Balazs et al. 1992, Katahira et al. 1994

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered[a]	N/A	Not common in Hawai`i. Occur worldwide in tropical, subtropical, and subpolar waters.	35 FR 8491, Eckert et al. 2012
Loggerhead Sea Turtle	*Caretta caretta*	Endangered (North Pacific DPS)	N/A	Rare in Hawai`i. Found worldwide along continental shelves, bays, estuaries and lagoons of tropical, subtropical, and temperate waters.	43 FR 32800, 76 FR 58868, Dodd 1990, Balazs 1979
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	Rare in Hawai`i. Occurs worldwide in tropical and warm temperate ocean waters.	43 FR 32800, Pitman 1990, Balacz 1982
Marine mammals					
Blainville's Beaked Whale	*Mesoplodon densirostris*	Not Listed	Non-strategic	Uncommon in Hawaiian waters. Possible separate nearshore and pelagic stocks.	McSweeney et al. 2007, Schorr et al., 2009, Baird et al. 2013
Blue Whale	*Balaenoptera musculus*	Endangered	Strategic	Acoustically recorded off of Oahu and Midway Atoll, small number of sightings around Hawai`i. Considered extremely rare, generally occur in winter and summer.	35 FR 18319, Bradford et al. 2013, Northrop et al. 1971, Thompson & Friedl 1982, Stafford et al. 2001
Bottlenose Dolphin	*Tursiops truncatus*	Not Listed	Non-strategic	Common in both inshore shallow waters and offshore deep waters. Evidence for five different populations associated	Baird et al. 2009, Martien et al 2012

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
				with different island groups and depths.	
Bryde's Whale	*Balaenoptera edeni*	Not Listed	Unknown	Common in Hawaiian islands.	Bradford et al. 2013
Common Dolphin	*Delphinus delphis*	Not Listed	N/A	Found worldwide in temperate and subtropical seas.	Perrin et al. 2009
Cuvier's Beaked Whale	*Ziphius cavirostris*	Not Listed	Non-strategic	Occur year round in Hawaiian waters. Possible separate nearshore and pelagic stocks. Nearshore stock found up to 67 km from shore.	McSweeney et al. 2007, Baird et al. 2013
Dall's Porpoise	*Phocoenoides dalli*	Not Listed	Non-strategic	Range across the entire north Pacific Ocean.	Hall 1979
Dwarf Sperm Whale	*Kogia sima*	Not Listed	Non-strategic	Possible resident population. Most common in waters between 500 m and 1,000 m in depth.	Baird et al. 2013
False Killer Whale	*Pseudorca crassidens*	Endangered (MHI Insular DPS)	Strategic	Found in waters within a modified 72 km radius around the MHI. Range overlaps with those of two other stocks around Kauai/Niihau. Population declining.	77 FR 70915, Bradford et al. 2015, Baird 2009, Reeves et al. 2009, Oleson et al. 2010
False Killer Whale	*Pseudorca crassidens*	Not Listed	Non-strategic	Two stocks with overlapping ranges around Kauai/Niihau: 1) the Northwestern Hawaiian Islands stock, which includes animals inhabiting waters within the Papahānaumokuākea Marine National Monument and to the east around Kauai, and 2) the Hawai`i pelagic stock, which includes false killer whales inhabiting waters greater than 11 km from the main Hawaiian Islands, including adjacent	Bradford et al. 2015

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
				high seas waters. Little known about these stocks.	
Fin Whale	*Balaenoptera physalus*	Endangered	Strategic	Infrequent sightings in Hawai`i waters. Considered rare in Hawai`i, though may migrate into Hawaiian waters during fall/winter based on acoustic recordings.	35 FR 18319, Hamilton et al. 2009, Thompson & Friedl 1982
Fraser's Dolphin	*Lagenodelphis hosei*	Not Listed	Non-strategic	Distributed worldwide in tropical waters. Rare in Hawaiian waters.	Perrin et al. 2009, Baird et al. 2013, Bradford et al. 2013, Barlow 2006
Hawaiian Monk Seal	*Neomonachus schauinslandi*	Endangered[a]	Strategic	Endemic tropical seal. Occurs throughout the archipelago. MHI population spends some time foraging in federal waters during the day.	41 FR 51611, Baker at al. 2011
Humpback Whale	*Megaptera novaeangliae*	Delisted Due to Recovery (Hawai`i DPS)	Strategic	Migrate through the archipelago and breed during the winter. Common during winter months, when they are generally found within the 100 m isobath.	35 FR 18319, 81 FR 62259, Childerhouse et al. 2008, Wolman & Jurasz 1976, Herman & Antinoja 1977, Rice & Wolman 1978
Killer Whale	*Orcinus orca*	Not Listed	Non-strategic	Rare in Hawai`i. Prefer colder waters within 800	Mitchell 1975, Baird et al. 2006

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
				km of continents.	
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. Rare in Hawai`i.	Dalebout 2003, Baird et al. 2013
Melon-Headed Whale	*Peponocephala electra*	Not Listed	Non-strategic	Found in tropical and warm-temperate waters worldwide, found primarily in equatorial waters. Uncommon in Hawai`i.	Perryman et al. 1994, Barlow 2006, Bradford et al. 2013
Minke Whale	*Balaenoptera acutorostrata*	Not Listed	Non-strategic	Occur seasonally around Hawai`i.	Barlow 2003, Rankin & Barlow 2005
Pantropical Spotted dolphin	*Stenella attenuata attenuata*	Not Listed	Non-strategic	Common and abundant throughout the Hawaiian archipelago, including nearshore. Three stocks found in Hawaiian islands.	Baird et al. 2013
Pygmy Killer Whale	*Feresa attenuata*	Not Listed	Non-strategic	Small resident population.	McSweeney et al. 2009
Pygmy Sperm Whale	*Kogia breviceps*	Not Listed	Non-strategic	Rare, found in nearshore waters.	Baird et al. 2013
Risso's Dolphin	*Grampus griseus*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide. Uncommon in Hawai`i.	Perrin et al. 2009
Rough-Toothed Dolphin	*Steno bredanensis*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide. Present throughout Hawai`i and in offshore waters.	Perrin et al. 2009, Baird et al. 2013, Barlow 2006, Bradford et al. 2013
Sei Whale	*Balaenoptera borealis*	Endangered	Strategic	Rare in Hawai`i. Generally found in offshore temperate waters.	35 FR 18319, Barlow 2003, Bradford et al. 2013

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
Short-Finned Pilot Whale	*Globicephala macrorhynchus*	Not Listed	Non-strategic	Commonly observed around MHI and present around NWHI.	Shallenberger 1981, Bradford et al. 2013, Baird et al. 2013
Sperm Whale	*Physeter macrocephalus*	Endangered	Strategic	Found in tropical to polar waters worldwide, most abundant cetaceans in the region. Sighted off the NWHI and the MHI.	35 FR 18319, Barlow 2006, Lee 1993, Rice 1960, Mobley et al. 2000, Shallenberger 1981
Spinner Dolphin	*Stenella longirostris*	Not Listed	Non-strategic	Occur in shallow protected bays during the day, feed offshore at night. Four stocks associated with island groups.	Karczmarski 2005, Norris & Dohl 1980, Hill et al. 2010, Norris et al. 1994, Andews et al. 2010
Striped Dolphin	*Stenella coeruleoalba*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters throughout the world	Perrin et al. 2009
Sharks					
Scalloped hammerhead	*Sphyrna lewini*	Endangered (Eastern Pacific DPS)	N/A	Found in coastal areas from southern California to Peru.	Compagno 1984, Baum et al. 2007, Bester 2011
Scalloped hammerhead	*Sphyrna lewini*	Threatened (Indo-West Pacific DPS)	N/A	Occur over continental and insular shelves, and adjacent deep waters, but is rarely found in waters < 22°C. Range from the intertidal and surface to depths up to 450–512 m.	Compagno 1984, Schulze-Haugen & Kohler 2003, Sanches 1991, Klimley 1993

[a] 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	*Dermochelys*	Endangered	Approximately 16,910 square miles (43,798 square km) stretching along the California	77 FR 4170

Sea Turtle	*coriacea*		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.	
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 Essential Fish Habitat Review and Recommendations for Precious Corals Management

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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.

1.1.1.1.1 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.

<u>Guam and the Commonwealth of the Northern Marianas</u>

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>U.S. Pacific Island Remote Areas</u>

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.

<u>Hawaii</u>

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.

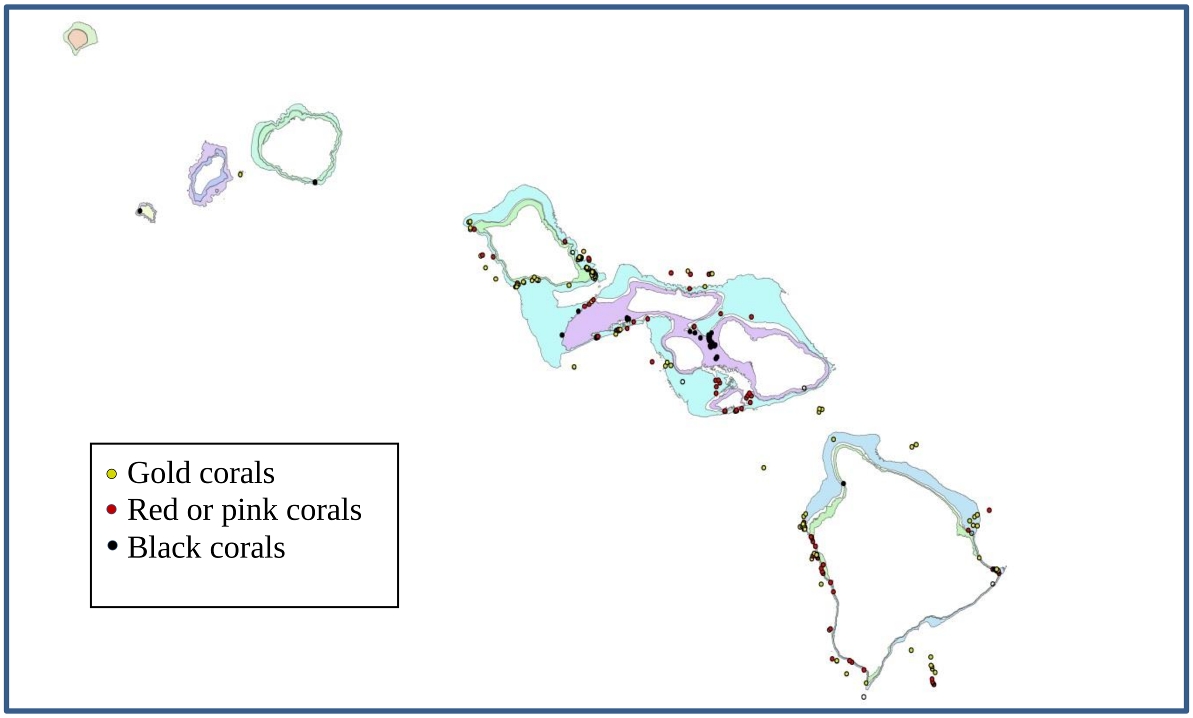

Figure 1. Observations of precious corals in the main Hawaiian islands

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^{o}N) to the Island of Hawaii (18^{o}N); *Corallium* sp. nov. is found between 28^{o}–36^{o}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

1.3.1 Species Descriptions References

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2 ESSENTIAL FISH HABITAT AND HABITAT AREAS OF PARTICULAR CONCERN

The Western Pacific Regional Fishery Management Council (WPRFMC) designated essential fish habitat (EFH) for precious coral deep- and shallow-water species assemblages to reduce the complexity and the number of EFH identifications required for individual species and life stages. Since these designations were approved, we now know a great deal more about the juvenile and adult stages of the precious corals life cycles. The vast majority of shallow-water precious corals occur between 30-120 meters depth, and are comprised of a few species of black corals (Grigg, 1993; Kelley and Drysdale, *unpublished data*, 2012; Wagner *et al.*, 2015). Most deep-water precious corals in the main Hawaiian Islands are found between 200-600 meters and include the pink, gold, and bamboo corals, though some commercially insignificant bamboo, pink, and black corals have been observed as deep as 1800 meters (Parrish, *et al.*, 2015). EFH for the deep-water precious corals includes the six known beds of precious corals defined as follows (50 CFR § 665.261 (1-3)):

(1) *Established beds.* (i) Makapu'u (Oahu), Permit Area E-B-1, includes the area within a radius of 2.0 nm of a point at 21°18.0′ N. lat., 157°32.5′ W. long.

(2) *Conditional beds.* (i) Keahole Point (Hawaii), Permit Area C-B-1, includes the area within a radius of 0.5 nm of a point at 19°46.0′ N. lat., 156°06.0′ W. long.

(ii) Kaena Point (Oahu), Permit Area C-B-2, includes the area within a radius of 0.5 nm of a point at 21°35.4′ N. lat., 158°22.9′ W. long.

(iii) Brooks Bank, Permit Area C-B-3, includes the area within a radius of 2.0 nm of a point at 24°06.0′ N. lat., 166°48.0′W. long.

(iv) 180 Fathom Bank, Permit Area C-B-4, 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.

(3) *Refugia.* Westpac Bed, Permit Area R-1, includes the area within a radius of 2.0 nm of a point at 23°18′ N. lat., 162°35′ W. long.

Three black coral beds in the MHI were designated as EFH for the shallow-water species: between Milolii and South Point on Hawaii, Auau Channel between Maui and Lanai and the southern border of Kauai (WPRFMC 1998). The boundaries of the Auau Channel bed were codified in the implementation of Amendment 7 to the Fishery Management Plan (FMP) for the Precious Coral Fisheries of the Western Pacific Region (50 CFR § 665.261 (1)(ii):

(ii) Au'au Channel (Maui), Permit Area E-B-2, 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.

The WPRFMC estimated the location of EFH between Milolii and South Point on Hawaii and the southern border of Kauai as the seabed bounded by the 20 m and 100 m isobaths, as depicted in maps appended to the 1998 EFH amendments (See Figure 2 and Figure 3) (WPRFMC 1998).

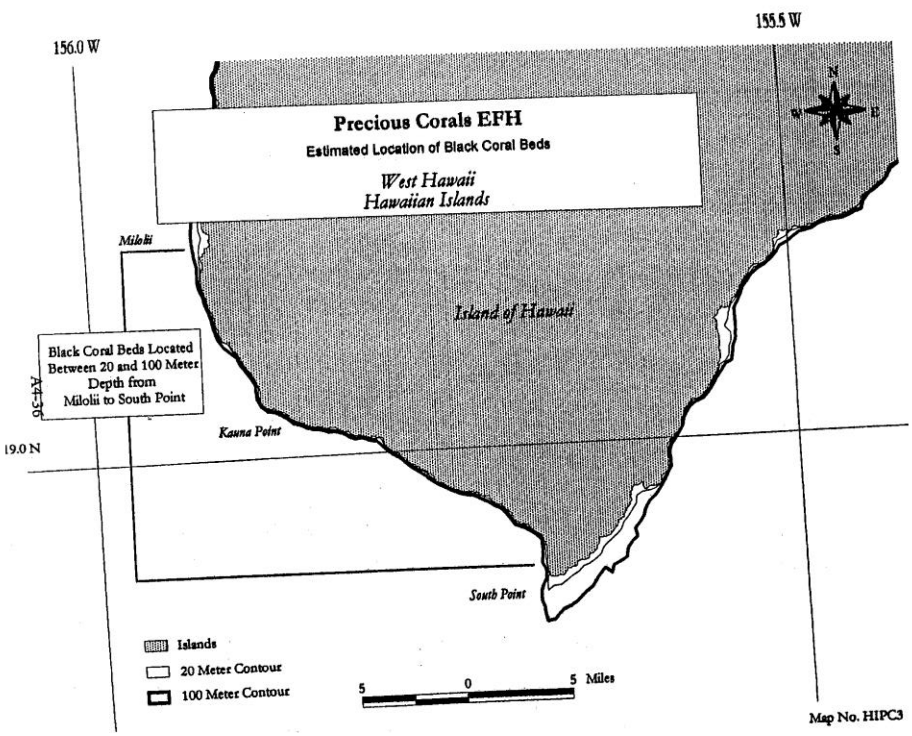

Figure 2. Estimated location of shallow-water precious coral EFH between Milolii and South Point, Hawaii.

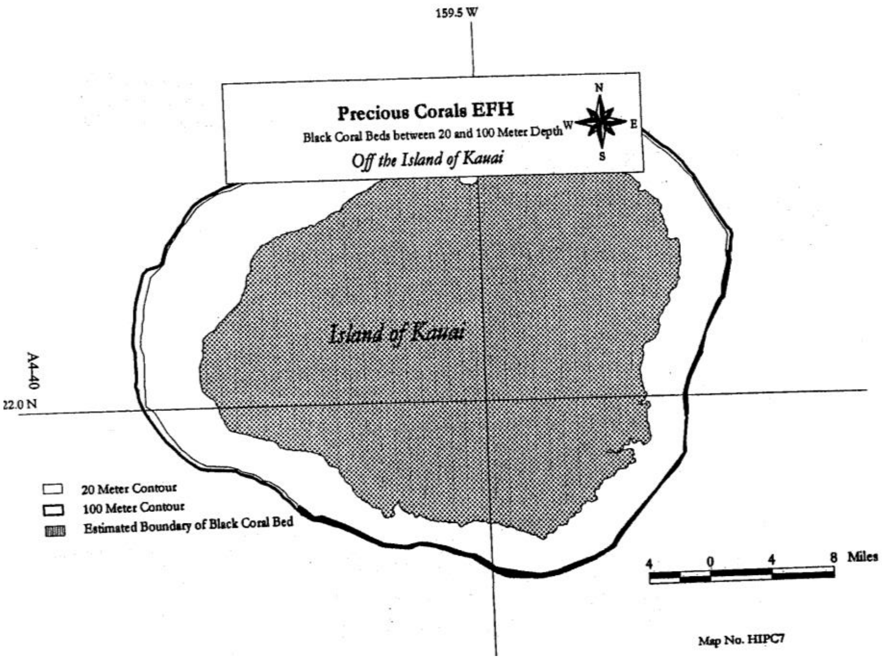

Figure 3. Estimated location of shallow-water precious coral EFH south of Kauai.

Makapuu, Wespac and Brooks Bank were designated as habitat areas of particular concern (HAPC) for deep-water species (WPRFMC 1998). Makapuu bed was designated as HAPC because of the ecological function it provides, the rarity of the habitat type and its sensitivity to human-induced environmental degradation. The potential commercial importance and the amount of scientific information that has been collected on Makapuu bed were also considered. Makapuu Bank is also considered to be relatively unique among the known coral agglomerations in the MHI because of the diversity and density of precious corals found in a relatively small area (Parrish *et al.*, 2015). Additional information regarding the geographic extent of the coral beds at Makapuu has become available (Long and Baco, 2014), but we still lack data on the eastern boundary of the Makapuu bed to offer more definitive HAPC maps at this time.

Wespac bed was designated as HAPC because of the ecological function it provides and the rarity of the habitat type. Its refugia status was also considered. Brooks Bank was designated HAPC because of the ecological function it provides and the rarity of the habitat type. Its possible importance as foraging habitat for the Hawaiian monk seal was also considered.

For shallow-water precious corals, the WPRFMC designated the Auau Channel as HAPC because of the ecological function it provides, the rarity of the habitat type and its sensitivity to human-induced environmental degradation. Its commercial importance was also considered.

2.1 Approaches for the refinement of EFH and HAPC for Deep-water Precious Corals in the Hawaiian Archipelago

Precious coral EFH designations in the Hawaiian Islands are not currently based on the known depth ranges or other habitat requirements of precious coral management unit species (PCMUS), but instead have been delineated based on the observation of known coral beds with a certain amount of habitat complexity. It is still appropriate to distinguish between the shallow and deepwater complexes, because the harvested species of black corals clearly inhabit the shallower depth ranges, while the red/pink, gold, and bamboo corals are only found at greater depths, with no overlap in the depth ranges. We may want to reconsider the idea that all of these corals have limited distribution throughout their respective depth ranges, because this may merely be an artifact of limited sampling and observation efforts. The WPRFMC rejected the alternative of designating EFH based on the depth range of individual precious corals MUS because of the perceived rarity of occurrence of suitable habitat conditions (WPRFMC 1998), but surveys by HURL and other research entities over the last 20 years have found precious corals throughout the Hawaiian archipelago on hard substrate at the suitable depth ranges. Although more than 75% of antipatharian black coral species worldwide are found at depths below 50 m (Cairns 2007), the 2 species that are most commonly harvested in Hawaii (*Antipathes griggi* and *Antipathes grandis*) both occur in waters shallower than 120 meters, and require hard substrates, temporally reliable current flow, and relatively low sedimentation (Parrish and Baco, 2007; Wagner, 2014). The same environmental conditions, but greater depths, are needed for the settlement and growth of the pink, gold and bamboo corals that have been commercially harvested in Hawaiian waters. These corals are often found in mixed aggregations, but they are also observed as more monotypic stands (Parrish, 2007). Gold corals are parasitic on bamboo corals, but large stands of bamboo corals have been found with no gold coral colonization (Parrish and Roark, 2009).

We now have access to comprehensive, high-resolution bathymetry and backscatter data collected by a number of government agencies and research institutions that delineate seabottom areas with the appropriate depth and hardness characteristics required by precious corals, but these data do not include comnprehensive oceanographic data (ex. current flows, dissolved oxygen, particulate matter) that may be necessary to accurately predict optimum precious coral habitats. John Smith (2016, *unpublished data*) from the University of Hawaii has synthesized the backscatter data into a product that can be used to create maps of hard substrate between the relevant depths for certain precious corals (200-600 meters). Shallow-water bathymetry maps can also be generated for the black coral complex (20-120 meters), but there are substantial gaps in backscatter data for the depths shallower than 60 meters. The National Marine Fisheries Service (NMFS) Pacific Islands Fisheries Science Center (PIFSC) has used these data to generate maps that could be used to define potential deep coral habitat. It is known that precious corals require hard substrate and are only found in certain depth ranges (Parrish *et al.*, 2015), so these maps could serve to create a much more comprehensive representation of potential habitat than the current known-beds designations. Kelley and Drysdale (2012, *unpublished data*) have used the Hawaii Undersea Research Lab (HURL) database of precious coral observations to demonstrate that the current EFH definitions exclude more than 44% of precious coral observations in the main Hawaiian islands (MHI).

The EFH Final Rule encourages fishery management councils to describe habitat based on the highest level of detail available. Available information should be organized into the following levels of detail (50 CFR § 600.815(a)(1)(iii):

1. Distribution data are available for some or all portions of the geographic range of the species.

2. Habitat-related densities of the species are available.
3. Growth, reproduction, or survival rates within habitat are available.
4. Production rates by habitat are available.

The levels of available information for precious coral species are found in Table 3.

Table 3. Level of EFH information available for Hawaii precious corals management unit species.

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

In addition to the 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; Kelley and Drysdale, 2012, *unpublished data*; Putts and Kahng, 2016, *unpublished data*). Given the number of observations and the wide distribution of deep-water precious corals in the MHI, it is almost certain that undiscovered beds of precious corals exist in the exclusive economic zone (EEZ) waters of the region managed by the WPRFMC, with the densest beds limited to hard substrates between the depths of 200 and 600 meters. Whether these beds would contain organisms at sufficient densities and size distributions to support commercial harvests is yet to be determined. It is also likely that many of the areas that meet these depth and hardness criteria will not have coral agglomerations, because precious corals also need hard substrates, temporally reliable current flow, and relatively low sedimentation, among other undetermined water quality conditions to thrive (Parrish *et al*., 2015).

The Plan Team provides four approaches for update of Hawaii FEP deep-water precious coral EFH designations, based on the original EFH approaches for designation of precious corals in the Western Pacific Region and advances in mapping technology: no change; defining EFH between 200 and 600 meters depth with hard substrate; refining the current EFH designations with a depth and 3km distance envelope around abundance data occurring in the known bed locations; and expanding the current EFH designations based on a depth and 3km distance envelope to include all areas where precious corals have been recently surveyed.

2.1.1 No Change

This approach for no action would retain the current definitions of EFH and HAPC. EFH for the deep-water precious corals includes the six known beds of precious corals at Makapuu, Keahole point, Kaena Point, Brooks Bank, 180 Fathom Bank, and Westpac. The Makapuu, Westpac, and Brooks Bank beds are also designated as HAPC.

The boundaries of the precious coral beds are codified in the Fishery Ecosystem Plan (FEP) for the Hawaii Archipelago implementing regulations. This approach excludes 44% of precious coral observations (Level 1 abundance data) within the US EEZ around Hawaii. This designation only provides the geographic extent of EFH, inferred from the bed definitions in the implementing regulations, without providing any habitat characteristics of the waters and substrate necessary to the species for spawning, feeding, or growth to maturity. Figure 4 shows the existing management areas with all observations; maps for island areas can be found in Section 7.

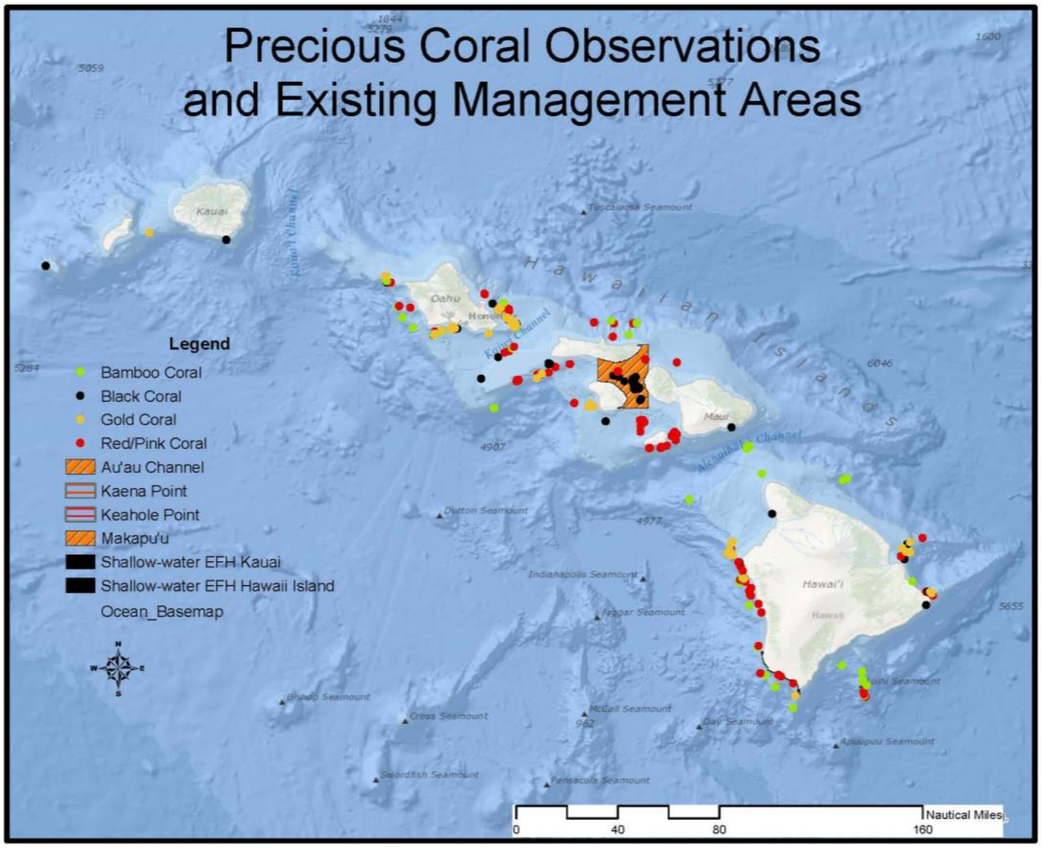

Figure 4. Existing EFH and new observations.

2.1.2 Possible Habitat - 200 and 600 meters depth, hard substrate

Precious corals EFH may be defined using new high-resolution bathymetry and backscatter data that identify the areas between 200 meters and 600 meters depth that also have the hard substrate necessary to support growth of the MUS. In the future, better understanding of the water quality characteristics necessary to optimize precious coral growth (such as current flow, dissolved oxygen, particulate organic matter), along with more complete measurements of these data, may be included to provide more specificity to these definitions.

This change would increase the percentage of precious coral observations within the EFH areas of the MHI from 56% to 92%, using precious coral observation data from the HURL database (Kelley and Drysdale, 2012, *unpublished data)*. This approach would designate EFH in most of the potential habitat areas of the precious coral species, as an MUS complex. The areas that meet these criteria, to the extent that they can be mapped, are shown in Figure 5; maps for island areas can be found in Section 7.

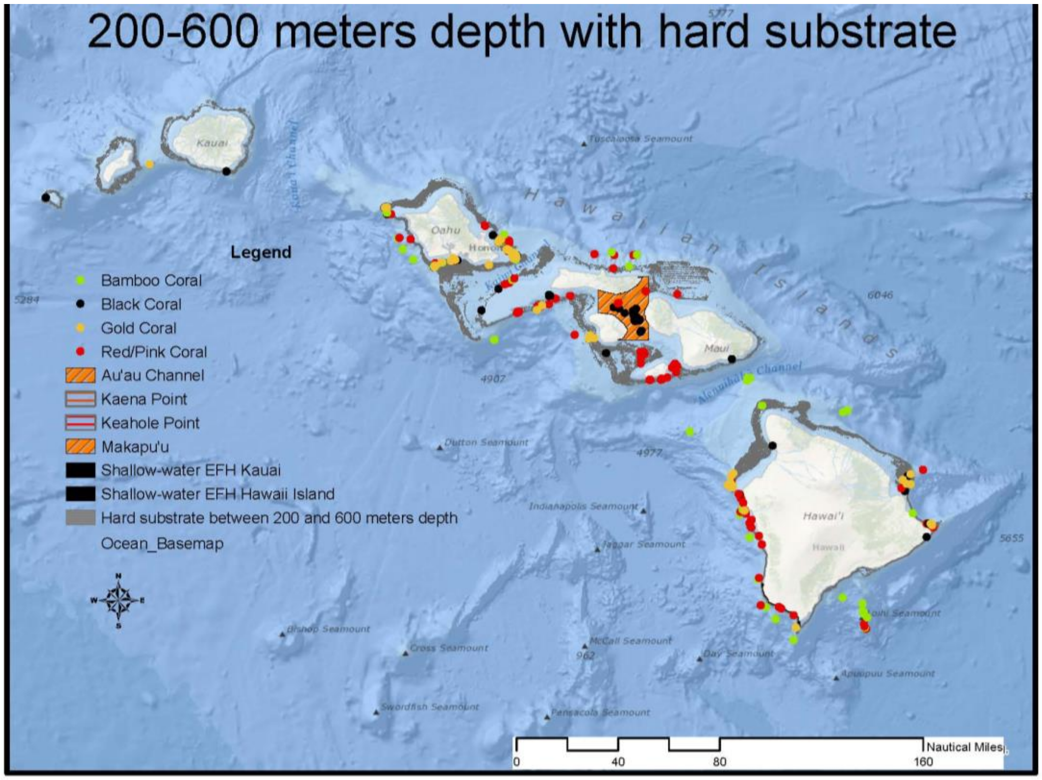

Figure 5. Possible habitat.

2.1.3 Observations - Refining bed designations based on depth, hardness, and 3 linear km envelopes around existing bed locations

This approach would define the geographic extent of precious coral EFH based on the existing EFH beds. John Smith's depth and substrate data would be used to create polygon boundaries around the existing EFH beds, aligned in a 3 km distance envelope around the observations. This approach is shown across the MHI in Figure 6; maps for island areas can be found in Section 7.

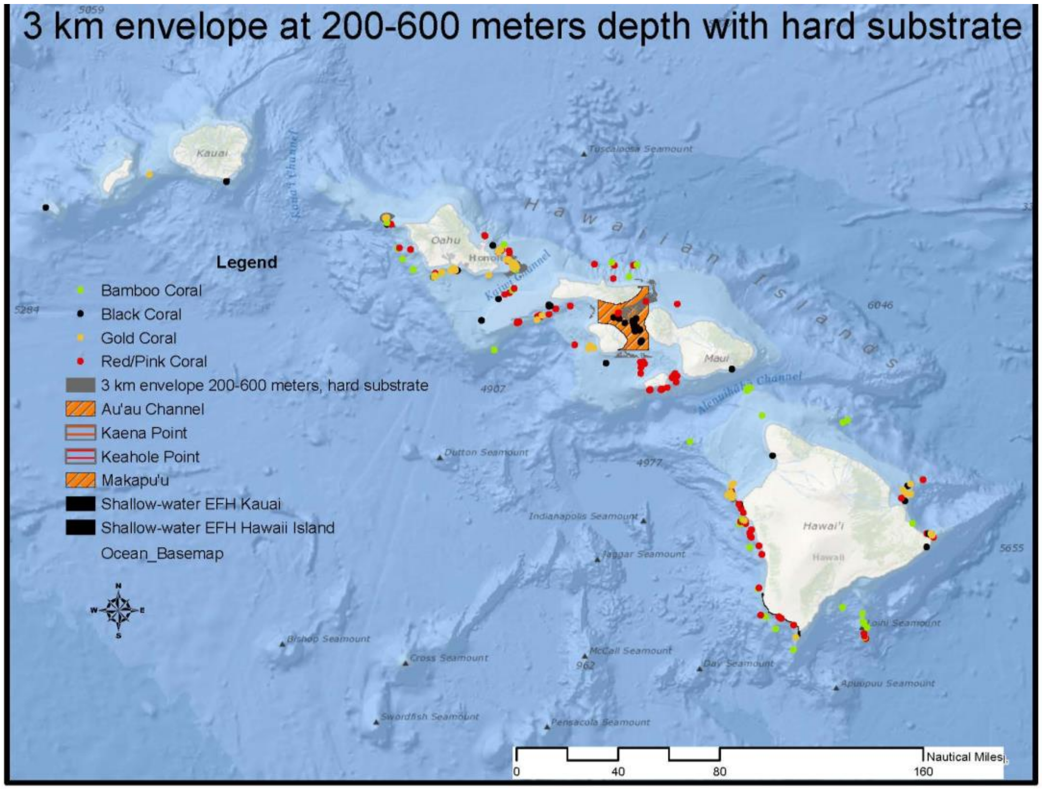

Figure 6. 3 km envelope around existing beds.

2.1.4 Observations – Refining bed designations based on depth, hardness, and 3 linear km envelopes around existing and new bed locations

This approach would define the geographic extent of precious coral EFH based on the existing EFH beds and the newly identified beds. John Smith's depth and substrate data would be used to create polygon boundaries around the existing EFH beds and new precious coral observations, aligned in a 3 km distance envelope around the observations. This approach is shown across the MHI in Figure 7; maps for island areas can be found in Section 7.

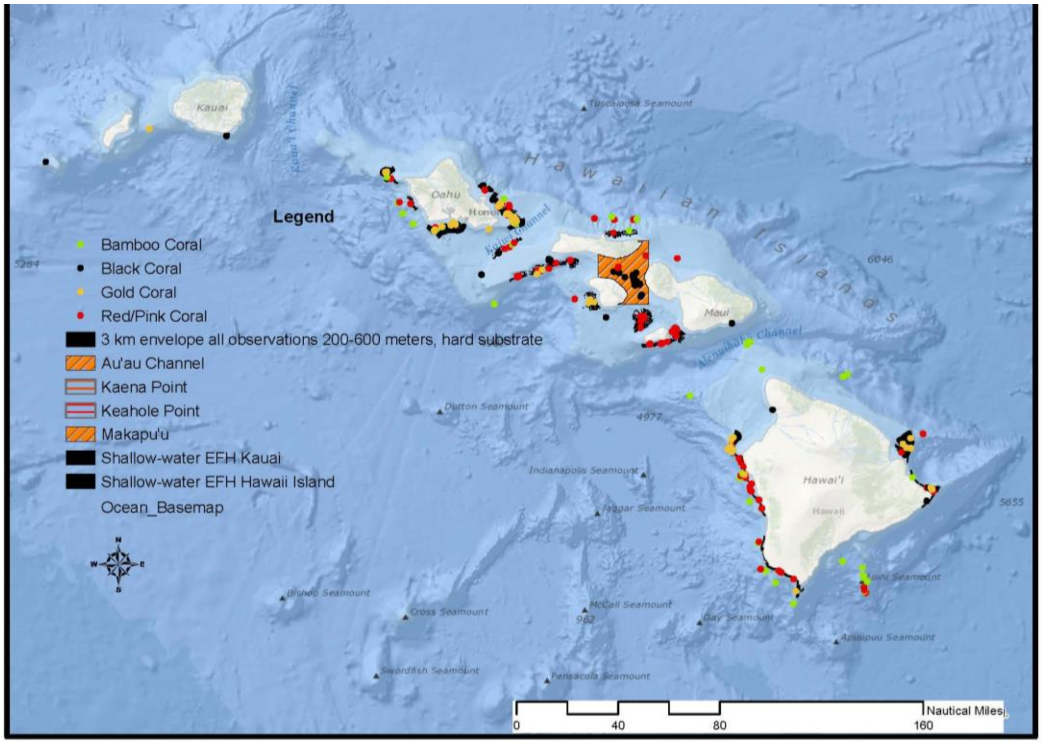

Figure 7. 3 km envelope around existing beds and new observations.

2.2 Refinement of EFH and HAPC for Shallow-water Precious Corals in the Hawaiian Archipelago

The shallow-water precious corals inhabit depths between 20 and 120. We present two approaches for the refinement of EFH. Maps of this approach are in Section 7.

2.2.1 No change

This approach for no action would retain the current definitions of EFH and HAPC.
Three black coral beds in the MHI were designated as EFH for the shallow-water species: between Milolii and South Point on Hawaii, Auau Channel between Maui and Lanai and the southern border of Kauai (WPRFMC 1998). The bed at Auau Channel is defined in the FEP implementing regulations, and is also designated as HAPC.

This approach excludes 40% of the black coral observations in the Hawaiian Archipelago. This designation only provides the geographic extent of EFH for one of the designated areas, as inferred from the implementing regulations, without providing any habitat characteristics of the waters and substrate necessary to the species for spawning, feeding, or growth to maturity. While maps are provided of the estimated beds between Milolii and South Point and the southern border of Kauai, these beds are not geographically described in the FEP implementing regulations or in text descriptions within the EFH or bed definitions sections of the FEP. This does not facilitate the EFH consultation process.

2.2.2 Refine geographic extent

This approach would provide an estimate of the geographic extent of the shallow water precious coral beds, facilitating the consultation process and meeting the requirement for the description and identification of EFH. This approach provides boundaries for the beds between Milolii and South Point on Hawaii Island and the south shore of Kauai. For Hawaii Island, the EFH would include all marine areas between 20-120 meters in depth, ranging from Ka Lae to Milolii Bay on Hawaii's southwest shore. For Kauai, the EFH would include all marine areas between 20-120 meters in depth, ranging from Kuunakaiole Pt. to Paoo Pt. on Kauai's south shore.

3 RECOMMENDATIONS ON THE UPDATE OF PRECIOUS CORAL MANAGEMENT MEASURES

The review of EFH information led the Plan Team to recommend further management action to ensure the Hawaii FEP precious coral status determination criteria and conservation and management measures are based on the best available scientific information.

3.1 Management Measures based on Minimum Sizes

Live pink coral harvested from any precious coral permit area must have attained a minimum height of 10 inches (25.4 cm) (WPRFMC 2001). The rationale for selecting a 10-inch size limit is based on arguments that should be revised in light of new information related to growth rates and reproductive maturity (Roark, 2006; Putts, 2017). The size limit which is presumed to correspond to maximum sustainable yield (MSY) is 11 inches. This MSY limit was adjusted downward to 10 inches based on industry harvesting practices, and the assumption that the downward adjustment would have negligible impacts on yield and provide an adequate reproductive cushion of 15 years after colonies reach reproductive maturity (Grigg, 1976; WPRFMC 1979). Framework Adjustment 1 applied the 10-inch minimum size limit relevant to beds in the main Hawaiian Islands in which non-selective gear types were prohibited to all permit areas. This was feasible because the framework adjustment also prohibited non-selective gear types throughout all permit areas (WPRFMC 2001a). Enforcement of the 10-inch minimum size was not possible with non-selective gear types, as the corals were damaged during harvest (WPRFMC 1979).

The MSY currently used for regulations was based on the assumption that *P. secundum* reaches reproductive maturity at an age estimated by Grigg (1976) to be between 12 and 13 years. This estimate of age at maturity was based on growth estimates that a *P. secundum* of 10 inches in length is approximately 28 years old (growing linearly at ~0.9 cm/yr). However, during surveys of lava flows of known age off the western flanks of Hawaii Island, Putts (*pers. comm*., 2017) determined that a mature community probably takes 150 years to become established. A study by Roark *et al.* (2006) showed that the radial growth rate for specimens of *P. secundum* in the Hawaiian Islands is ~0.17 mm yr^{-1} and average age is 67 to 71 years, which indicates that Grigg (1976) underestimated the age of larger *P. secundum* individuals by at least a factor of 2. If Roark's growth rate measures are correct, a larger size limit for *P. secundum* would be appropriate, as well as re-estimates of MSY. It is very difficult to directly translate radial growth rates to linear growth rates, but statistical methods could be used to suggest new size limits. Bruckner (2009) believes 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) due to their susceptibility to overharvesting in certain areas.

The gold coral harvest moratorium is due for review, with expiration of the measure scheduled for June of 2018. 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). 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. 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 2,742 years, with a mean life span of 950 years and a radial growth rate of only 15 to 45 µm/year (Roark *et al.*, 2006; Roark *et.al.*, 2009; Parrish and Roark, 2009).

3.2 Classification of Coral Beds

Even though nothing is known of the relationship between stock and recruitment, the FEP considers precious coral beds as separate management units because of the sessile habit of precious corals; and known beds are patchily distributed and widely separated from each other. The beds with associated management measures are classified as Established, Conditional, or Exploratory. Established beds are ones for which estimates of MSY may be reasonable, but not precise. Conditional beds are beds for which an estimate of MSY has been developed, even though those estimates were made without knowledge of the full extent of the beds. Kahng and Putts have data (2016, *unpublished*) that indicate that the Keahole and South Point beds may be much more extensive than previous observations indicated. Established and conditional beds only exist in the Hawaiian Archipelago. Exploratory Permit Areas are the unexplored areas of the EEZ in which precious coral beds have yet been located (WPRFMC 1988).

Beds which will be closed to exploitation for some period of time, or preserves, are a fourth bed category, denoted Refugia. Refugia may be designated by amendment to the FEP (WPRFMC 1979) and are reserved in the implementing regulations (75 FR 2198). The reasons for establishing Refugia are: (1) to preserve coral beds as natural areas for purposes of research (2) to establish control areas that could be used in the future to measure environmental impacts of coral harvesting; and (3) to establish possible reproductive reserves for enhancement of recruitment into the adjacent areas (WPRFMC 1979).

New observations and habitat data (EFH level 2) can be used to revise the statewide biomass estimates using a simple density extrapolation by taking average density and average colony size extrapolated to available area (Kahng, 2017, *pers. comm.*). Observations have been made that would indicate more biomass than previously recognized. The simple existing formula used to calculate maximum sustainable yield (MSY = 0.4 X pink coral mortality rate x biomass, which is density of the bed x area of the bed x mean weight of colonies) would produce different MSY if the new habitat density data were included in the calculations.

More accurate projections could be modeled using georeferenced biological and geophysical (currents, temperature, slope) data. This would require much more work by a qualified individual. Certain taxonomic, growth-rate, and depth-range questions would need to be resolved to provide more accurate density and MSY estimates.

3.3 MUS List

The PCMUS list should be revised as shown in Table 4 based on taxonomical updates.

Table 4. Revised precious corals management unit species.

Former Scientific Name	English Common Name	New Scientific Name
Corallium secundum	pink coral (also called red coral)	*Pleurocorallium secundum*
Corallium regale	pink coral (also called red coral)	*Hemicorallium laauense*
Corallium laauense	pink coral (also called red coral)	*Hemicorallium laauense*
Gerardia spp.	gold coral	*Kulamanamana haumeaae*
Narella spp.	gold coral	
Lepidisis olapa	bamboo coral	
Antipathes dichotoma	black coral	*Antipathes griggi*
Antipathes grandis	black coral	
Antipathes ulex	black coral	*Myriopathes ulex*

4 ASSESSMENT OF THE URGENCY AND EFFECTS OF RECOMMENDED ACTIONS

Section 5.5.7 of the Hawaii FEP states that the Council-appointed Plan Team will prepare an annual report on the fishery in the management area. The report will contain, among other things, recommendations for Council action and an assessment of the urgency and effects of such action(s).

The precious corals fishery has been fairly inactive in recent years, with only five or six permit holders reporting to the State of Hawaii commercial marine license database. Given the lifespan of the species, the MUS are some of the more vulnerable species managed through the Hawaii FEP. Because the environmental assessments for framework measures are likely out of date, quick changes to management measures may not be implementable within the timeframe required for the precautionary management of these vulnerable species, should activity in the fishery increase. Refining the essential fish habitat designations for the species will strengthen habitat conservation for the fishery, should activity increase, and the species' successful contribution to a healthy ecosystem.

The current management measures based on outdated growth rates are not an urgent fishery management problem, because the fishery is not very active. However, conservation and management measures must be based on the best scientific information available. The expiration of the gold coral moratorium offers an opportunity to revise precious corals management measures, as does the ongoing ecosystem component species amendment.

5 RESEARCH AND INFORMATION NEEDS

The WPRFMC would be able to more effectively address the EFH provisions for precious coral management unit species if the following information were available:

- Statistically sound estimates of distribution, abundance, and condition of precious corals throughout the MHI. Targeted surveys of areas that meet the depth and hardness criteria could provide very accurate estimates.
- Environmental conditions necessary for precious coral settlement, growth, and reproduction. The same surveys used for abundance and distribution could collect these data as well.
- Quantitative measures of growth and productivity.
- Taxonomic investigations to ascertain if the *H. laauense* that is commonly observed between 200 and 600 meters depth is the same species as those *H. laauense* observed below 1000 meters in depth.
- Continuous backscatter *or LIDAR* data in depths shallower than 60 m.

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7 MAPS

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

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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 Hawaiʻi (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 shelves 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.*

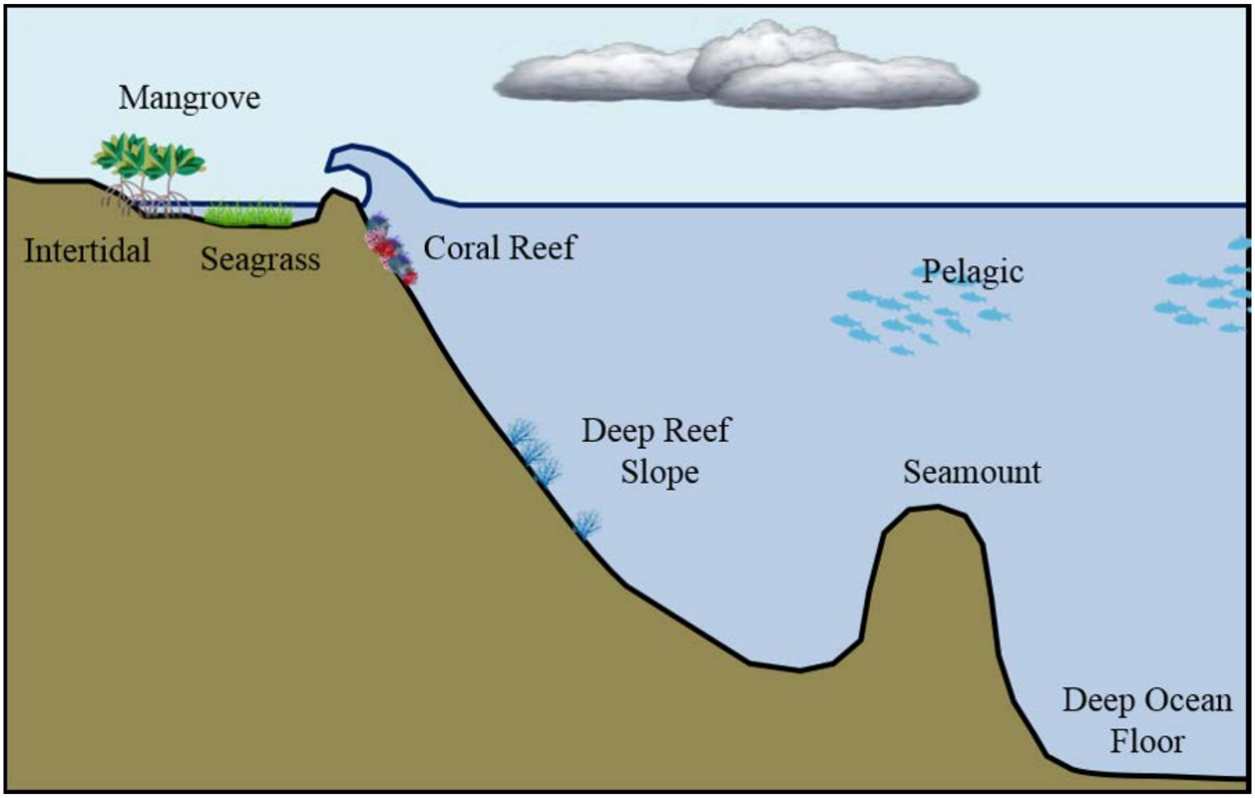

Figure 1. Schematic of the marine ecosystems that comprise the EFH of the Western Pacific Region.

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 Hawaiʻi 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 Hawaiʻi 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 Hawai‘i (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 Hawai‘i, 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 Hawai'i 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

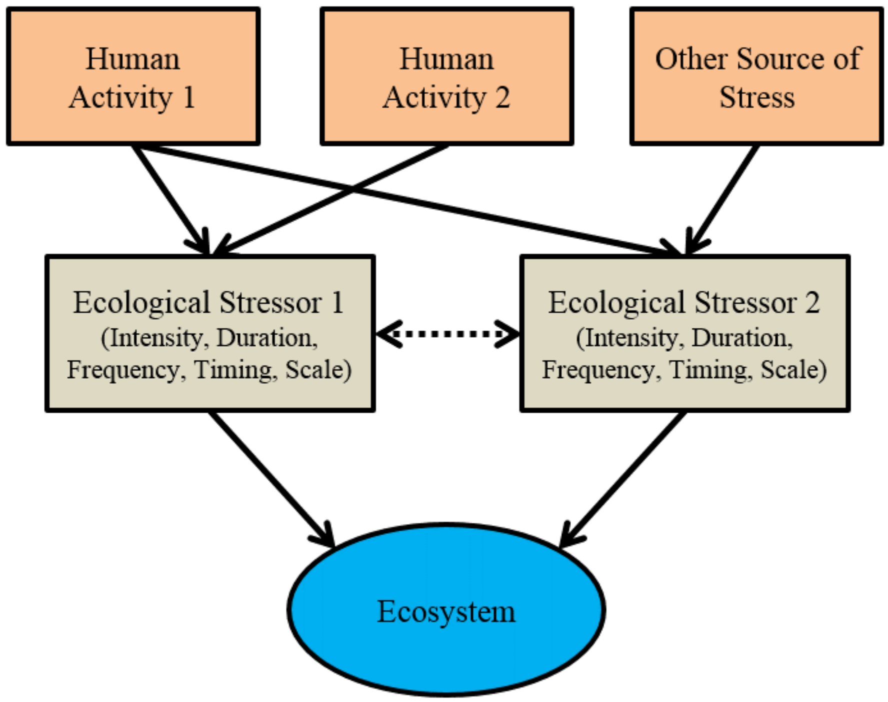

Figure 2. Conceptual flow diagram showing the linkage of human activities and other sources of stress on an ecosystem. Activities and sources of stress alter the intensity, duration, frequency, timing and/or scale of potential ecological stressors, which act directly on species or ecological processes 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	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 Hawaiʻi 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 Hawaiʻi, 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 Hawaiʻi, 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 Hawaiʻi 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 Hawaiʻi

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	Stressors 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 Hawaiʻi, 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 loʻi, 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.

	(blue)							(red)			(green)	(purple)		Chemicals						(orange)
	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 Hawaiʻi, 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, Hawaiʻi, 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 20^{th} 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 Hawaiʻi (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 Hawaiʻi (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 Hawaiʻi, 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 Kāneʻohe Bay, Hawaiʻi 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 Hawaiʻi, 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 Hawaiʻi 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 Hawaiʻi 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 Hawaiʻi, 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*

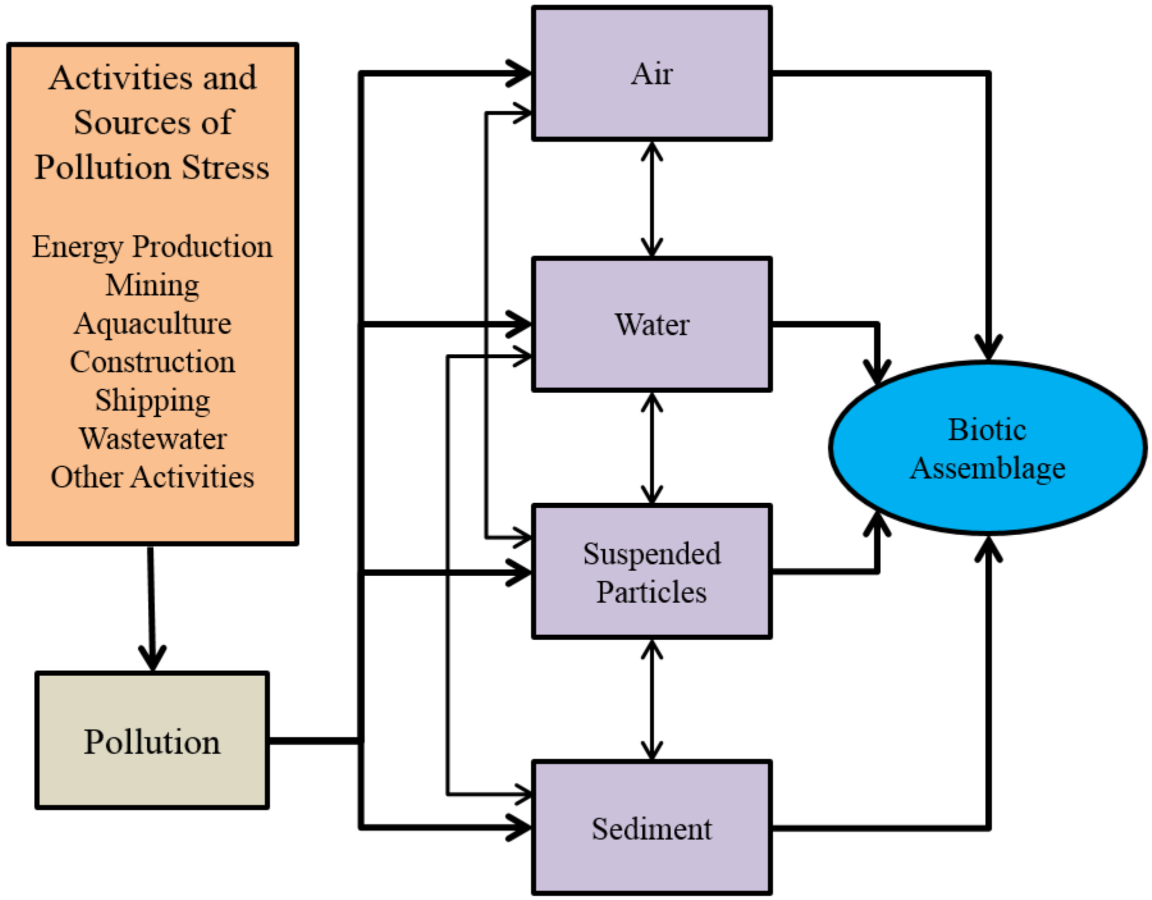

Figure 3. Conceptual model for pollutant pathways in marine ecosystems (modified from van Dam *et al.* 2011).

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).

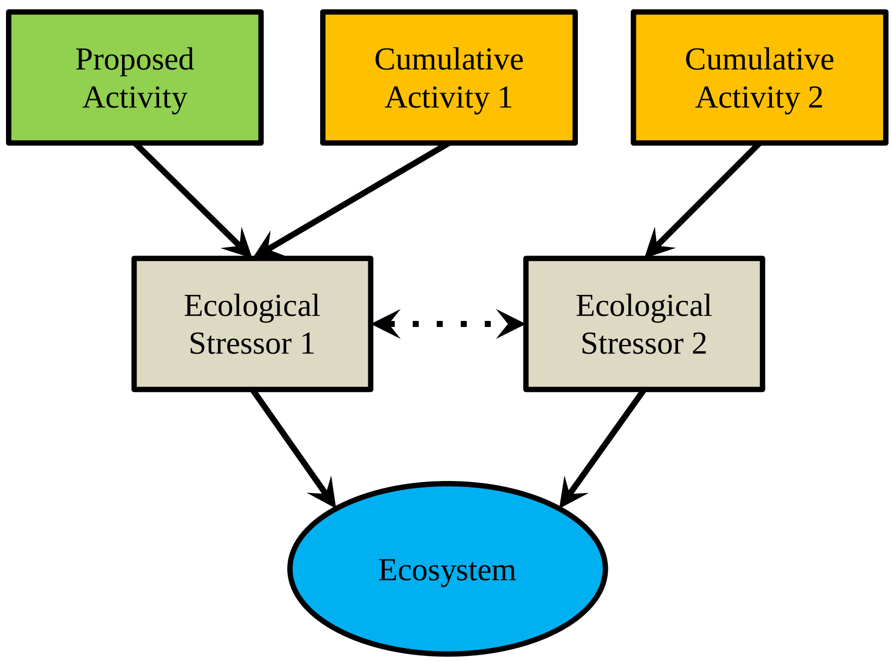

Figure 4. When assessing cumulative effects, the incremental effects of other past, present, and reasonably foreseeable future actions must be considered. In the flow diagram above, two types of cumulative effects are illustrated. In the first type, the Proposed Activity and Cumulative Activity 1 both 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.

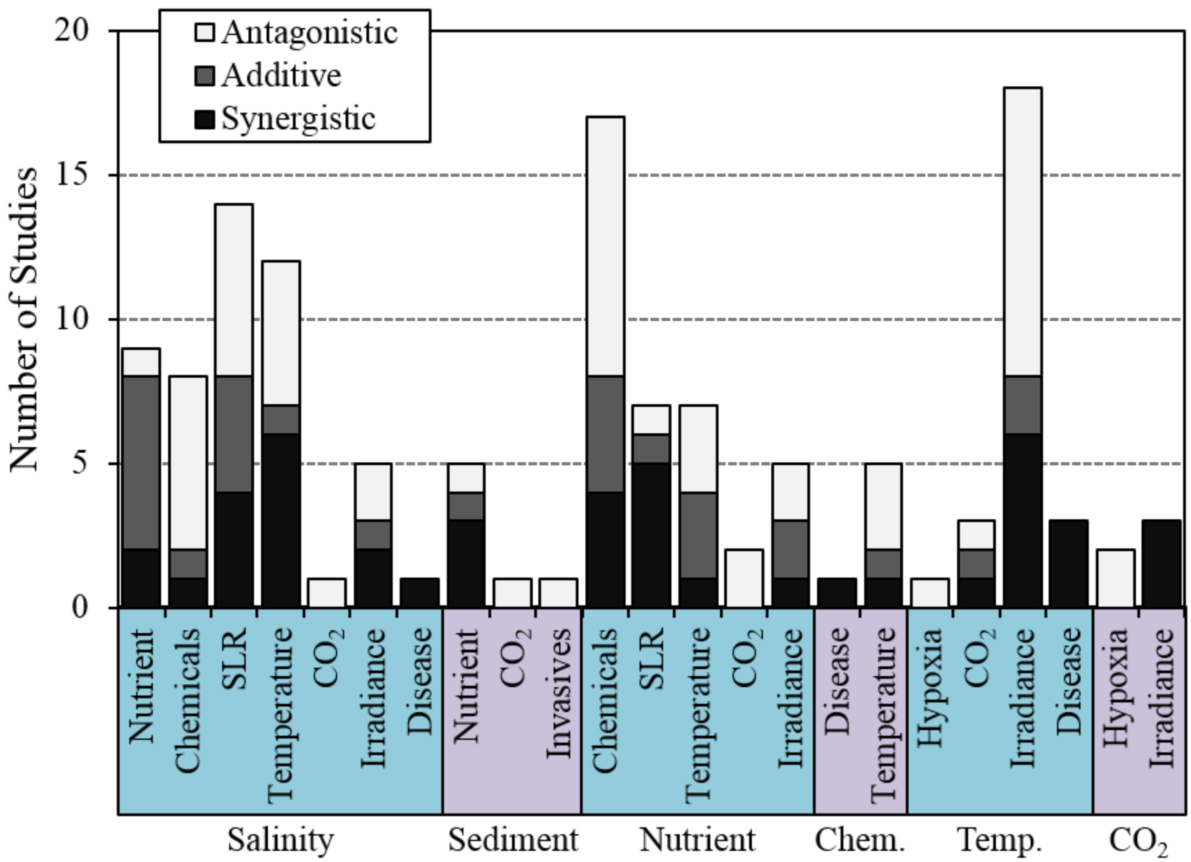

Figure 5. Frequency distribution of interaction types (additive, synergistic, and antagonistic) across stressor pairs. Stressor pairs are indicated within blocks on the x-axis that list one stressor horizontally (*e.g.*, salinity) with all stressor combinations listed vertically (*e.g.*, nutrient). See text for discussion of additive, synergistic, and antagonistic interactions. CO2=acidification, SLR=Sea Level Rise. Figure adapted from Crain *et al.* (2008).

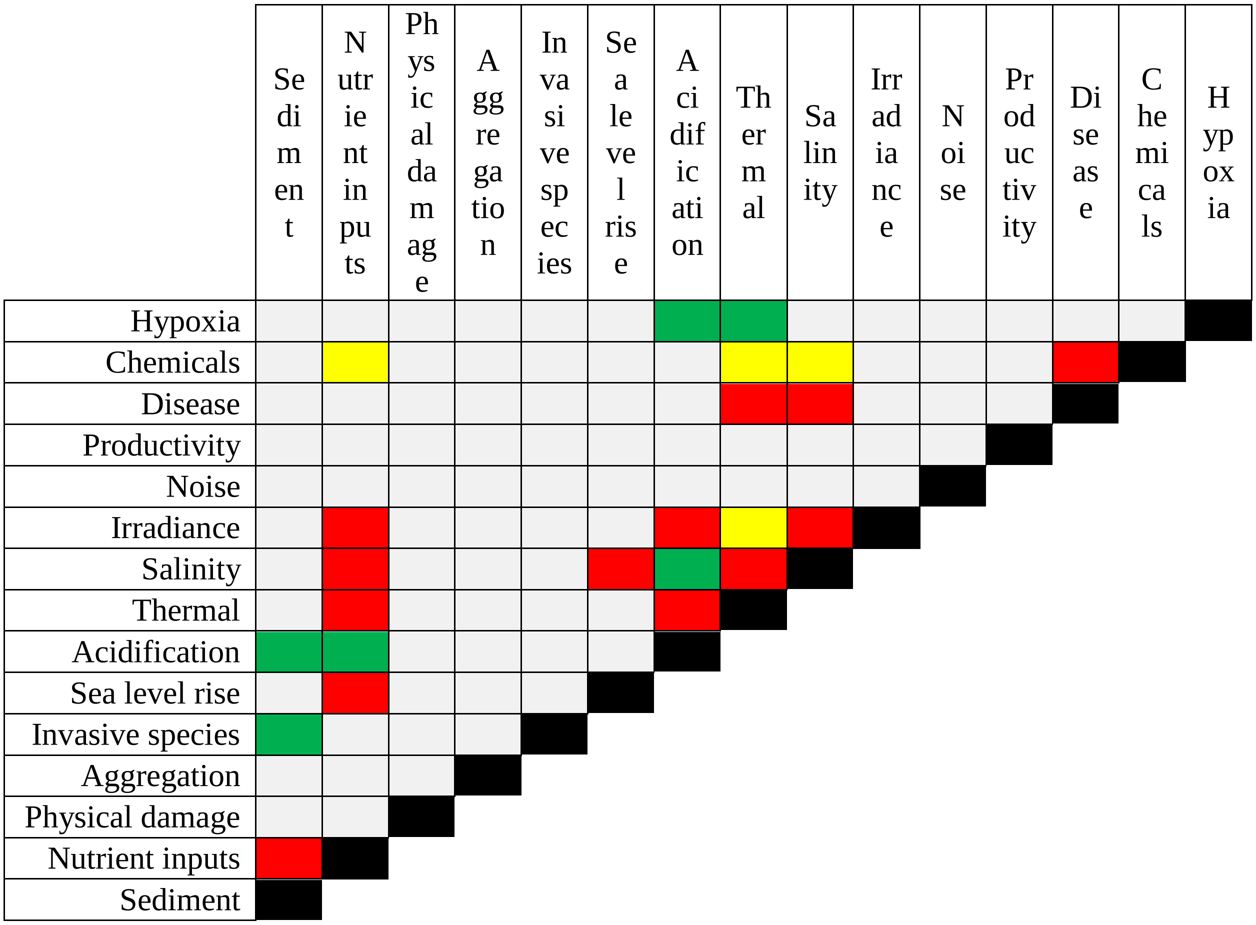

Figure 6. Interaction matrix for pairs of stressors acting on the marine ecosystems of the Western Pacific Region. Red = >50% of the studies show additive or synergistic interactions; yellow = <50% of the studies showed additive or synergistic interactions, green = studies showed only antagonistic interactions; 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:

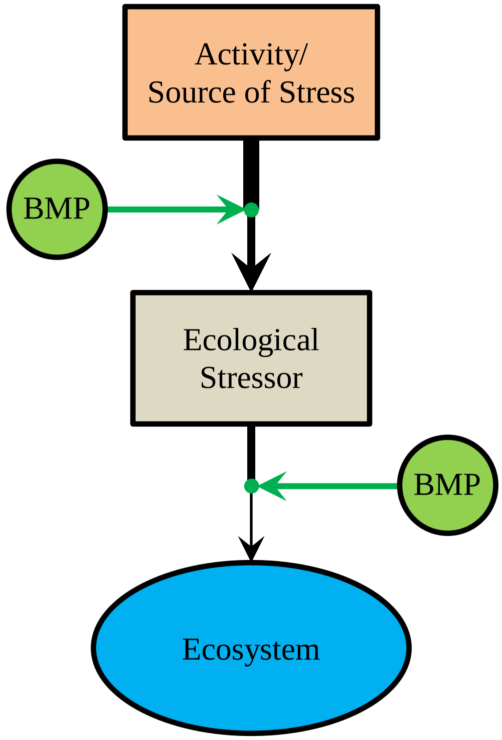

Figure 7. Conservation and enhancement recommendations, of which BMPs are common type, are practices intended to reduce the adverse effects of an activity on an ecosystem. BMPs can reduce the effect of an activity on the particular stressor (top) or reduce the effect of a stressor on an organism or ecosystem (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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