ANNUAL STOCK ASSESSMENT AND FISHERY EVALUATION REPORT: FISHERY ECOSYSTEM PLAN FOR THE AMERICAN SAMOA ARCHIPELAGO

2016

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

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

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Executive Summary

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

The fishery performance section of this report first presents a general description of the local commercial fishery including both the bottomfish and coral reef management unit species (MUS). The fishery data collection system is then explained and time series of meta-data dashboard statistics are provided. The collection system encompasses shore-based and boat-based creel surveys, commercial receipt books, and fisher inventories. The fishery statistics for each MUS are organized into a summary dashboard table showcasing the values for the most recent fishing year and a comparison to short-term (10 years) and long-term (20 years) averages. Time series for catch and effort statistics are also provided. For 2016, the rabbitfish catch in American Samoa exceeded the annual catch limits (ACLs).

The bottomfish fishery performance appeared to be stable. On a short-term average, total catches of all species caught using the bottomfishing gear and total landing sold have decreased but are within the 10 year variations in catches. However, when considering only the bottomfish management unit species, the total estimated landings increased by 11% on the short term while the commercial landings decreased by 85% indicating that majority of the BMUS catches were non-commercial. Catch-per-unit-effort (CPUE), effort estimate, and bycatch from the fishery exhibited a decrease compared to the short-term average. The participation in the bottomfish fishery 2016 increased by 33%.

The coral reef fishery performance appeared to have contrasting trends. The 2016 catches from the boat based fisheries is significantly lower (point estimate lower than the standard deviation) compared to the short-term average following a 10-year decreasing trend. In contrast, the shore-based coral reef fisheries have an estimated catch in 2016 that is significantly higher than the short-term average following a 10-year increasing trend.

The CPUE in the coral reef boat-based fisheries in 2016 is lower in the mixed bottomfishing and trolling methods and the spearfishing method. Trolling CPUE is significantly higher in 2016 following the 10-year increasing trend. The shore-based hook-and-line and rod-and-reel showed a lower estimated CPUE, whereas the spear, gleaning, and gillnetting showed higher CPUE (significant for spear and gillnet).

Fishing effort was generally lower for 5 coral reef fishery methods. Boat-based mixed method and shore-based hook-and-line showed a significantly higher fishing effort while the rod-and-reel although higher in 2016 was within the standard deviation.

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 American Samoa, Pacific Remote Island Area, Commonwealth of Northern Mariana Islands, Guam, Main Hawaiian Islands, and Northwest Hawaiian Islands. This report illustrates the mean fish biomass for the reef areas within these locations. Additionally, the mean reef fish biomass and mean size of fishes (>10 cm) for American Samoa are presented by sampling year and reef area. Finally, the reef fish population estimates for each study site within American Samoa are provided for hardbottom habitat (0-30 m).

For American Samoa, life history parameters including maximum age, asymptotic length, growth coefficient, hypothetical age at length zero, natural mortality, age at 50% maturity, age at sex switching, length at which 50% of a fish species are capable of spawning, and length of sex switching are provided for eight species of reef fish and 12 species of bottomfish.

Summarized length derived parameters for coral reef fish and bottomfish in American Samoa include: maximum fish length, mean length, sample size, sample size for L-W regression, and length-weight coefficients. Values for 23 species of reef fish and two species of bottomfish are presented for American Samoa.

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 American Samoan 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 American Samoa, followed by summaries of relevant studies and data for each fishery within American Samoa. 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 American Samoa FEP. These fisheries generally have limited impacts to protected species, and do not have federal observer coverage. Consequently, this report tracks fishing effort and other characteristics to detect potential changes to the level of impacts to protected species. Fishery performance data contained in this report indicate that there have been no notable changes in the fisheries that would affect the potential for interactions with protected species, and there is no other information to indicate that impacts to protected species have changed in recent years.

The climate change section of this report includes indicators of current and changing climate and related oceanic conditions in the geographic areas for which the Western Pacific Regional Fishery Management Council has responsibility. In developing this section, the Council relied on a number of recent reports conducted in the context of the U.S. National Climate Assessment including, most notably, the 2012 Pacific Islands Regional Climate Assessment and the Ocean and Coasts chapter of the 2014 report on a Pilot Indicator System prepared by the National Climate Assessment and Development Advisory Committee. The primary goal for selecting the indicators used in this report is to provide fisheries-related communities, resource managers and businesses with climate-related situational awareness. In this context, indicators were selected to be fisheries relevant and informative, build intuition about current conditions in light of changing climate, provide historical context and recognize patterns and trends. The atmospheric concentration of carbon dioxide (CO_2) trend is increasing exponentially with a time 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. Coral bleaching patterns were evident on the reef slope areas around 30-50ft along a large portion of the main island of Tutuila in the last quarter of 2016. The central Pacific saw seven named storms in 2016, three of which were hurricanes and two major.

The American Samoa 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 American Samoa 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 the annual 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. No ocean activities with multi-year planning horizons were identified for American Samoa. However, the Pacific Islands Regional Planning Body (RPB), established under the National Ocean Policy, is actively developing an ocean plan for American Samoa. This plan will be used as the template for other jurisdictions represented in the RPB. American Samoa stakeholders have identified a vision, goals, and objectives for the ocean plan, which have been endorsed by the RPB.

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 evaluation of 2016 catch to the 2016 ACL, the Archipelagic Fishery Ecosystem Plan Team provides the Council with the following rationale for the overages in American Samoa rabbitfish:

- The American Samoa rabbitfish recent three-year average of catch amounting to 435 lbs exceeded its ACL of 163 lbs. This catch was attributed mostly with the night time spear fishery. The increase in catch can be attributed to the data collection improvements where DMWR implemented the evening shift that captures the night time shore-based spear fishery.

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

- American Samoa rabbitfish = 0 lbs

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

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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
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
DMWR	Department of Marine and Wildlife 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
GAC	Global Area Coverage
GFS	global forecast system
HAPC	Habitat Area of Particular Concern
IBTrACS	International Best Track Archive for Climate Stewardship
LOF	List of Fisheries
LVPA	Large Vessel Prohibited Area
MFMT	Maximum Fishing Mortality Threshold
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
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
USACE	United States Army Corps of Engineers
WPacFIN	Western Pacific Fishery Information Network
WPRFMC	Western Pacific Regional Fishery Management Council
WPSAR	Western Pacific Stock Assessment Review
WW3	Wave Watch 3

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1 FISHERY PERFORMANCE

1.1 FISHERY DESCRIPTIONS

The Samoa Archipelago is a remote chain of 13 islands of varying sizes and an atoll, located 14^0 south of the equator near the International Date Line. The islands lie between 13° and 14° south latitude and 169° and 173° west longitude, about 480 km (300 mi) from west to east, covering an area of 3,030 sq. km (1,170 sq. miles). With its tropical setting and its latitudinal range lying within the known limits of coral growth, coral reefs fringe the islands and atolls in the archipelago. The archipelago is approximately 4,200 km south of Hawai'i, in the central South Pacific Ocean. The archipelago is divided into two political entities: the Independent Samoa and American Samoa. The Independent Samoa has two large islands (Upolu and Savaii) and eight islets. American Samoa is comprised of five volcanic islands (Tutuila, Aunu'u, Ofu, Olosega, and Ta'u), one low-island (Swains Island) and a coral atoll (Rose Atoll). The five volcanic islands that are part of the American Samoa territory are very steep with mountainous terrain and high sea cliffs and of various sizes. Tutuila Island, the largest (137 km^2) and most populated island, is the most eroded with the most extensive shelf area and has banks and barrier reefs. Aunuu is a small island very close to Tutuila. Ofu and Olosega (together as 13 km^2) are twin volcanic islands separated by a strait which is a shallow and narrow break in the reef flat between the islands. Tau is the easternmost island (45 km^2) with a more steeply-sloping bathymetry.

The Samoa archipelago was formed by a series of volcanic eruptions from the "Samoan hotspot" (Hart et al. 2000). Based on the classic hotspot model, Savaii Island (the westernmost) in Samoa would be the oldest and Tau island (the easternmost) in American Samoa the youngest of the islands in the archipelago. Geological data indicate that Savaii is about four to five million years old, Upolu in Samoa about two to three million years old, Tutuila about 1.5 million years old, Ofu-Olosega about 300,000 years old and Tau about 100,000 years old. Swains and Rose are built on much older volcanoes but are not part of the Samoan volcanic chain (Hart et al. 2004). The geological age and formation of Rose Atoll is not well-known and Swains is part of the Tokelau hot-spot chain which is about 59-72 million years old (Neall and Trewick 2008, Konter et al 2008). There are numerous banks in the archipelago the origins of which are barely known. The South Bank near Tutuila Island, for instance, is of another geological origin.

American Samoa experiences occasional cyclones due to its geographic location in the Pacific. Cyclones occur from 1-13 years intervals with the six strong occurrences during the last 30 years (Esau,1981; Tusi, 1987; Ofa, 1990; Val, 1991; Heta, 2004 and; Olaf, 2005). The territory had two tsunamis in the last 100 years due to its proximity to the geologically active Tonga Trench.

It is in this geological and physical setting that the Samoans have established their culture in the last 3,500 years. For three millennia, the Samoans have relied on the ocean for their sustenance. Fishing activity and fish constitute an integral part of the 'fa'asamoa' or the Samoan culture. Chiefly position entitlements and other cultural activities use fish during the fa'alalave or ceremonies.

1.1.1 Bottomfish Fishery

Deep, zooxanthellate, scleractinian coral reefs have been documented in the Pacific often occur around islands in clear tropical oceanic waters (Lang 1974; Fricke and Meischner 1985; Kahng and Maragos 2006). These mesophotic coral ecosystems are found at depths of 30 to 40 m up to 150 m and have been exploited by bottomfishing fishermen mainly targeting snappers, emperors and groupers. Bottomfishing utilizing traditional canoes by the indigenous residents of American Samoa has been a subsistence practice since the Samoans settled into the Tutuila, Manua and Aunu'u islands. It was not until the early 1970's that the bottomfish fishery developed into a commercial scheme utilizing motorized boats. The bottomfish fishery of American Samoa was typically commercial overnight bottomfish handlining using skipjack as bait, on 28-30 foot aluminum/plywood "alia" (A term used for larger boats in Samoa). Imported bottomfish from the independent state of Samoa help satisfy the demand for bottomfish however it weakens the local bottomfish fishery. A government-subsidized program, called the Dory Project, was initiated in 1972 to develop the offshore fisheries into a commercial venture, and resulted in an abrupt increase in the fishing fleet and total landings. In 1982, a fisheries development project aimed at exporting high-priced deep-water snappers to Hawaii caused another notable increase in bottomfish landings and revenues. Between 1982 and 1988, the botttomfish fishery comprised as much as 50% (by weight) of the total commercial landings.

American Samoa's bottomfish fishery was relatively bigger between 1982 and 1985 when this fishery was new and booming. In 1988 a decline in bottomfish fisheries occurred as many skilled and full-time commercial fishermen converted to trolling. Profits and revenues in bottomfishing suffered devastating blows from four separate hurricanes; Tusi in 1987, Ofa in February of 1990,Val in December of 1991 and Heta in January of 2004 and finally the 2009 tsunami. The gradual depletion of newly-discovered banks and migration of many fishermen into other fishing vendors resulted in the decline of landings in the mid-1980s. Fuel prices have gradually soared in the past four years causing yet another strain in the bottomfish fisheries. The average price of bottomfish has also declined due to the shift of local bottomfish demand to imported bottomfish competing closely with local prices. In 2004, 60% of coolers imported from the independent state of Samoa on the Lady Naomi Ferry were designated for commercial purposes; from the Commercial Invoice System 50% of these coolers were bottomfish.

Beginning in 1988, the nature of American Samoa's fisheries changed dramatically with a shift in importance from bottomfish fishing towards trolling. In the past eight years, the dominant (by weight of fish landed) fishing method has been longlining. Bottomfishing has been in decline for years but was dealt a final devastating blow by the 2009 tsunami. A fishery failure was declared and the US Congress allocated $1 million to revive the fishery. This fund has been used to repair boats damaged by the tsunami, maintain the floating docks used by the alia boats and build a boat ramp. In 2013, the American Samoan government also implemented a subsidy program that provided financial relief on the rising fuel prices. (The fuel price has since gone significantly lower.)

1.1.2 Coral Reef Fishery

Traditional coral reef fishing in the lagoons and shallow reef areas included methods such as gleaning and using bamboo poles with lines and baits or with a multi-pronged spear attached.

The deepwater and pelagic fisheries have traditionally used wooden canoes, hand-woven sennit lines with shell hooks and stone sinkers, and lures made of wood and shell pieces.

Presumably, the change from traditional to present-day methods of fisheries started with Western contact in the 18th century. Today the fisheries in American Samoa can be broadly categorized in terms of habitat and target species as pelagic fisheries, bottomfishing in mesophotic reefs and the nearshore coral reef fisheries. For creel monitoring program purposes, fisheries is either subsistence (or shore-based and mostly for personal consumption) or commercial (or boat-based and mostly sold). Bottomfishing is actually a combination of mesophotic reef fishing and/or pelagic fishing (trolling). The coral reef fishery involve gleaning, spearfishing (snorkel or free dive from shore or using boat), rod and reel using nylon lines and metal hooks, bamboo pole, throw nets and gillnets. SCUBA spearfishing was introduced in 1994, restricted for use by native American Samoans only around 1997–1998 and finally banned in 2002 following recommendations by the biologists from the Department of Marine and Wildlife Resources and local scientists.

1.2 FISHERY DATA COLLECTION SYSTEM

American Samoa has been regularly conducting fishery-dependent monitoring since 1982 for the boat-based fishery and 1990 for the shore-based fishery. The boat-based fishery is mostly trolling for tuna, skipjacks and trevally, and bottomfishing for snappers, emperor and groupers. The shore-based fishery is mostly gleaning for shellfish and octopus, rod and reel for groupers and jacks and spearfishing for surgeon and parrotfishes. Both the boat-based and shore-based data collection involves two runs; first is the participation run to determine the number of boats/fisherman out to fish and identify the type of gear being used; while the second is the interview run where the fishermen are interviewed for the effort and economic data and concurrently measuring the length and weight of each fish identified to species level.

1.2.1 Boat-Based Creel Survey

The boat-based data collection focuses mostly on the main docks in Fagatogo and Pago Pago and opportunistically surveying off sites like Aunuu, Auasi, and Asili. The shore-based data collection conducts its run by randomly selecting eight hour periods and location four to five times per week. Survey locations are: west side of Tutuila from Poloa to Vaitogi; central Tutuila from Tafuna to Laulii; and eastern Tutuila from Laulii to Tula. Boat-based and shore-based data collection are also being conducted in Manua. The boat-based data collection in Ofu-Olosega and Tau are opportunistic since there is no set schedule for boats to go out and land their catches.

The survey follows a random stratified design. The stratification is by survey area, weekday/weekend, and time of day. The survey is divided into two phases: 1) participation run; and 2) catch interview phase. The participation run attempts to estimate the amount of participation by counting the number of boats “not on the dock” or the presence of trailers. The catch interview phase occurs after the participation run that documents catch composition, catch per unit effort (CPUE), length-weight information, catch disposition, and some socio-economic information. The data is transcribed weekly into the WPacFIN database. Catch expansion is done on an annual scale through a simple expansion algorithm using expanded effort and CPUE. For more details of the boat-based creel survey see Oram et al. (in press).

1.2.2 Shore-Based Creel Survey

The shore-based data collection follows the same scheme as the boat-based creel survey. The following information are generated through these data collection programs: 1) catch landing; 2) effort; 3) CPUE; 4) catch composition; 5) length accurate to the nearest centimeter; 6) weights in pounds. The survey follows a random stratified design. The stratification is by survey area, weekday/weekend, and time of day. The survey is divided into 2 phases: 1) participation run; and 2) catch interview phase. The participation run attempts to estimate the amount of participation by counting the number of fishermen along the shoreline. The gear type, number of gear, and number of fishers are recorded. The catch interview phase occurs after the participation run that documents catch composition, catch per unit effort (CPUE), length-weight information, catch disposition, and some socio-economic information. The data is transcribed weekly into the WPacFIN database. Catch expansion is done on an annual scale through a simple expansion algorithm using expanded effort and CPUE. For more details of the boat-based creel survey see Oram et al. (in press).

1.2.3 Commercial Receipt Book System

Entities that sell any seafood products are required by law to report their sales to DMWR (ASCA § 24.0305). This is done through a receipt book system collected on the fifth day of every month. Information required to be reported are as follows: (a) the weight and number of each species of fish or shellfish received; (b) the name of the fisherman providing the fish or shellfish; (c) boat name and registration number, if applicable; (d) the name of the dealer; (e) the date of receipt; (f) the price paid per species; (g) the type of fishing gear used; (h) whether the fish or shellfish are intended for sale in fresh, frozen or in processed form; (i) which fish or shellfish were taken within and outside the territorial waters; and (j) other statistical information as the department may require.

1.2.4 Boat inventory

An annual boat inventory is being conducted to determine and track down fishing boats and their ownership. This will provide information on how many boats are potentially available to engage in the fishery.

1.3 META-DATA DASHBOARD STATISTICS

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

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

1.3.1 Creel surveys meta-data statistics

Calculations: Shore-based data

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

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

Catch Interviews: Count of the number of unique occurrences of the combination of date and run number in the participation detail data/count of unique surveyor initials and date in PAR. This is divided into two categories, interviews conducted during a complete survey (Regular), and opportunistic interviews (Opp) which are completed on days when the whole survey is not conducted.

Calculation: Boat-based data

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

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

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

Year	Shore-based				Boat-based		
	# Interview Days	# Participation Runs	# Catch Interviews		# Sample Days	# Catch Interviews	
			Regular	Opportunistic		Regular	Opportunistic
1986					186	682	1
1987					110	346	0
1988	124	0	179	0	158	470	0
1989	126	0	184	0	160	514	0
1990	145	261	393	0	160	331	21
1991	129	458	349	0	134	281	4
1992	84	274	133	0	127	244	4
1993	140	305	255	0	140	285	8
1994	167	544	382	0	209	516	5
1995	157	524	302	0	239	638	8
1996	136	230	218	0	222	654	3
1997	82	0	108	0	226	1135	1

Year	**Shore-based**				**Boat-based**		
	# Interview Days	**# Participation Runs**	**# Catch Interviews**		**# Sample Days**	**# Catch Interviews**	
1998	104	0	143	0	229	1067	1
1999	34	0	51	0	207	887	0
2000	52	0	67	0	206	729	0
2001	0	0	0	0	205	441	2
2002	20	293	42	38	194	376	0
2003	5	196	7	11	220	503	0
2004	0	409	0	0	239	506	5
2005	33	437	51	4	238	340	0
2006	53	695	89	21	238	325	7
2007	119	1143	227	50	251	485	6
2008	86	904	127	13	225	303	11
2009	98	963	173	10	165	174	9
2010	102	892	176	5	188	168	2
2011	139	1234	246	39	240	203	1
2012	77	648	108	9	269	285	14
2013	107	1028	191	156	262	245	0
2014	68	925	77	27	236	353	27
2015	84	953	150	43	233	247	26
2016	98	879	144	18	224	165	47
10 YEARS AVG	98	957	162	37	229	263	14
10 YEARS SD	20	150	49	42	30	95	14
20 YEARS SD	68	580	109	22	225	447	8
20 YEARS SD	40	426	71	34	24	283	12

1.3.2 Commercial receipt book statistics

Calculations:

# of Vendors: Count of the number of unique buyer codes found in the commercial purchase header data from the Commercial Receipt Book.

Invoices: Count of the number of unique invoice numbers found in the commercial header data from the Commercial Receipt Book.

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

Year	Number of Vendors	Total Invoices Collected
1997	18	1763
1998	22	1741
1999	19	1525
2000	19	1169
2001	32	1372
2002	27	1076
2003	31	1263
2004	28	937
2005	68	1000
2006	60	1201
2007	65	1355
2008	47	1020
2009	45	806
2010	34	620
2011	30	776
2012	29	827
2013	32	773
2014	41	1124
2015	45	1577
2016	50	1353
10 YEARS AVG	42	1023
10 YEARS SD	11	301
20 YEARS AVG	37	1164
20 YEARS SD	15	322

1.4 FISHERY SUMMARY DASHBOARD STATISTICS

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

Legend Key:

↗ - *increasing trend in the time series*

↘ - *decreasing trend in the time series*

⇔ - *no trend in the time series*

⊕ - *above 1 standard deviation*

⊖ - *below 1 standard deviation*

⊙ - *within 1 standard deviation*

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

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

Fishery	**Fishery statistics**	**Short-term (recent 10 years)**	**Long-term (20 years)**
Bottomfish	**Estimated catch (lbs)**		
All species caught in the BF gear	Boat and shore creel data estimated (expanded) total lbs (all BF trips)	**41,214[▼15%]** ⇔ ⊙	**41,214[▼2%]** ⇔ ⊙
	Estimated total lbs (all species) commercial purchase data	**4,492[▼17%]** ↘ ⊙	**4,492[▼23]** ↘ ⊙
Bottomfish management unit species only	Total creel data Estimated (expanded) total lbs (all BF trips)	**18,772[▲22%]** ↗ ⊙	**18,772 [▲45%]** ↗ ⊙
	Estimated total lbs (all species) commercial purchase data	**272[▼82%]** ↘ ⊙	**272[▼85%]** ↘ ⊙
	Catch-per-unit effort (lbs/fisher-hrs)		
	CPUE (creel data only)	**0.0396[▼23%]** ↘ ⊙	**0.0396[▼34%]** ↘ ⊙
	Fishing effort *(only available for creel data)*		
	Estimated (expanded) total gear-hours using bottomfishing method	**138,159[▼56%]** ⇔ ⊙	**138,159[▼37%]** ⇔ ⊙

	Fishing participants		
	Estimated total # of fisher that went bottomfishing	**1,092[▲14%]** ⇔ ⊕	**1,092 [▲15%]** ⇔ ⊕
	Bycatch (all BB)		
	Total number of bycatch caught	**2,122[▼71%]** ↘ ⊖	**2,122[▼67%]** ⇔ ⊖
	# bycatch released	**0**	**0**
	# bycatch kept	**2,122[▼71%]** ↘ ⊖	**2,122[▼71%]** ↘ ⊖
	Federal permits		
	# federal permit holders (PIRO)		
Coral Reef	**Estimated catch (lbs all gears)**		
	Boat-based creel data (expanded estimate all gears, defined by a list of species?)	**54,841[▼56%]** ⇔ ⊖	**54,841[▼57%]** ↘ ⊖
	Shore-based creel (expanded estimate all gears, defined by a list of species?)	**93,036[▲109%]** ↗ ⊕	**93,036[▲263%]** ↘ ⊕
	Commercial Purchase	**719[▼30%]** ⇔ ⊙	**719[▼26%]** ⇔ ⊙
	Catch-per-unit-effort (lbs/fisher-hrs)		
	BB mixed method	**0.0962[▼91%]** ⇔ ⊙	**0.0962[▼88%]** ⇔ ⊙
	BB spear	**0.0429[▼70%]** ⇔ ⊙	**0.0429[▼96%]** ↘ ⊙
	BB troll	**0.3796[▲73%]** ↗ ⊕	**0.3796[▲186%]** ↗ ⊕
	SB H&L	**0.2018[▼78%]** ↗ ⊙	**0.2018[▼74%]** ⇔ ⊙
	SB rod and reel	**0.0182[▼8%]** ⇔ ⊙	**0.0182[▼23%]** ⇔ ⊙

	SB spear	**0.1796[▲84%]** ↗ ⊕	**0.1796[▼45%]** ↔ ⊙
	SB gleaning	**0.3775[▲13%]** ↗ ⊙	**0.3775[▲18%]** ↗ ⊙
	SB gill net	**3.9[▲374%]** ↗ ⊕	**3.9[▲233%]** ↔ ⊕
	Fishing effort (# of gear-hours by gear type)		
	BB mixed method	**79,350[▲467%]** ↗ ⊕	**79,350[▲510%]** ↔ ⊕
	BB spear	**40,300[▼65%]** ↔ ⊙	**40,300[▼32%]** ↗ ⊙
	BB troll	**27,264[▼59%]** ↔ ⊙	**27,264[▼91%]** ↘ ⊙
	SB H&L	**114[▲119%]** ↗ ⊕	**114[▲280%]** ↗ ⊕
	SB rod and reel	**20,400[▲21%]** ↗ ⊙	**20,400[▲100%]** ↗ ⊙
	SB spear	**3,045[▼91%]** ↔ ⊙	**3,045[▼84%]** ↔ ⊙
	SB gleaning	**204[▼79%]** ↔ ⊙	**204[▼64%]** ↔ ⊙
	SB gillnet	**10[▼97%]** ↘ ⊙	**10[▼94%]** ↔ ⊙
	Fishing participants (# of fishers)		
	BB mixed method	**1,092[▲4%]** ↗ ⊙	**1,092[▲9%]** ↗ ⊙
	BB spear	**1,612[▼3%]** ↔ ⊙	**1,612[▲2%]** ↔ ⊙
	BB troll	**1,013[▲9%]** ↔ ⊙	**1,013 [▲13%]** ↔ ⊙
	SB H&L	**80[▲18%]** ↔ ⊙	**80[▼33%]** ↔ ⊙
	SB rod and reel	**3,305[▲102%]** ↗ ⊕	**3,305[▲53%]** ↔ ⊙
	SB spear	**263[▼36%]** ↔ ⊙	**NA**

	SB gleaning	**507[▲5%]** ⇔ ⊙	**507[▼53%]** ↘ ⊙
	SB gill net	**20[▼87%]** ↘ ⊙	**20[▼91%]** ↘ ⊙
	Boat-based Bycatch		
	Total number of bycatch caught	**5,257[▼61%]** ⇔ ⊖	**5,257[▼58%]** ⇔ ⊖
	# bycatch released	**0**	**0**
	# bycatch kept	**5,257[▼61%]** ⇔ ⊖	**5,257[▼58%]** ⇔ ⊖
	Shore-based Bycatch		
	Total number of bycatch caught	3,350**[▼2%]** ⇔ ⊙	
	# bycatch released	3,309**[▼3%]** ⇔ ⊙	
	# bycatch kept	41[**▲720%]** ↗ ⊕	
	Federal permits		
	# federal permit holders (PIRO)		

1.5 CATCH STATISTICS

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

1.5.1 Catch by data stream

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

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

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

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

Year	Creel Survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
1986	5598		5598	
1987	1248		1248	
1988	40004		40004	
1989	46985		46985	
1990	14509	6586	21095	
1991	18388	106734	125122	3423
1992	14395	102325	116720	3059
1993	17293	7652	24945	7418
1994	47918	3372	51290	9296
1995	37641	2635	40276	15833
1996	38299	93302	131601	7550
1997	46118		46118	4559
1998	20926		20926	5182
1999	22330		22330	8165
2000	31373		31373	10865
2001	51305		51305	7462
2002	51006		51006	4454
2003	26234		26234	5517
2004	23155	5911	29066	6381
2005	14421	9152	23573	5011
2006	7978	17984	25962	4501
2007	24870	5079	29949	9840
2008	46108	3090	49198	8679
2009	75015	9915	84930	8949
2010	16204	2269	18473	2294
2011	27366	27712	55078	1428
2012	6645	2686	9331	3195
2013	16738	79340	96078	2603
2014	33053	12762	45815	6539
2015	46618	7026	53644	6314
2016	35334	5880	41214	4492

Year	Creel Survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
10 YEARS AVG	32795	15576	48371	5433
10 YEARS SD	18619	22427	25497	2900
20 YEARS AVG	31140	14524	40580	5822
20 YEARS SD	16741	19914	21223	2509

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

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

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

Year	Creel survey Estimates		Creel Total	Commercial landings
	Boat-based	Shore-based		
1986	4523		4523	
1987	476		476	
1988	12879		12879	
1989	12115		12115	
1990	3332	1651	4983	
1991	6256	19237	25493	2066
1992	4260	20305	24565	1819
1993	8131	1606	9737	2845
1994	16639	928	17567	2422
1995	14519	985	15504	3662
1996	16079	18670	34749	1445
1997	18042		18042	1151
1998	9919		9919	1149
1999	11644		11644	2498
2000	7917		7917	2560
2001	18201		18201	2659
2002	13541		13541	483
2003	5023		5023	1797
2004	6703	1170	7873	2565
2005	6806	1243	8049	2116
2006	2437	2880	5317	2980
2007	8670	803	9473	2295

Year	**Creel survey Estimates**		**Creel Total**	**Commercial landings**
	Boat-based	**Shore-based**		
2008	16144	523	16667	4267
2009	22390	1281	23671	2330
2010	4255	224	4479	709
2011	8087	3356	11443	480
2012	1113	460	1573	734
2013	4694	27770	32464	603
2014	13102	3012	16114	2354
2015	17555	1249	18804	1403
2016	18137	585	18722	272
10 YEARS AVG	11415	3926	15341	1545
10 YEARS SD	6706	8013	8634	1194
20 YEARS AVG	10719	3427	12947	1770
20 YEARS SD	5975	7097	7293	1033

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

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

Year	**Creel survey Estimates**		**Creel Total**	**Commercial Landings**
	Boat-based	**Shore-based**		
1986	249397		249397	
1987	128187		128187	
1988	211396		211396	
1989	168624		168624	
1990	37061	142832	179893	
1991	38061	224224	262285	838
1992	33150	104074	137224	537
1993	32726	96502	129228	682
1994	159410	56286	215696	549
1995	83806	59486	143292	641
1996	95936	89202	185138	1079
1997	264332		264332	603
1998	196428		196428	992
1999	160142		160142	998

Year	Creel survey Estimates		Creel Total	Commercial Landings
	Boat-based	Shore-based		
2000	163629		163629	976
2001	121450		121450	1081
2002	139015		139015	1122
2003	78044		78044	516
2004	68962	2937	71899	576
2005	34445	30956	65401	990
2006	39618	33261	72879	1279
2007	133937	45788	179725	1213
2008	142139	44963	187102	939
2009	187621	15650	203271	549
2010	150309	54811	205120	786
2011	125235	68000	193235	629
2012	90407	21043	111450	876
2013	143260	51612	194872	830
2014	97329	21912	119241	869
2015	131729	28620	160349	2929
2016	54841	93036	147877	719
10 YEARS AVG	125681	44544	170224	1034
10 YEARS SD	34920	22829	32361	655
20 YEARS AVG	126144	25629	151773	974
20 YEARS SD	54982	26447	52599	498

1.5.2 Expanded catch estimates by fishing methods

Catch information is provided for the top shore-based and boat-based fishing methods that contribute >90% of the annual catch.

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

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

Year	Shore-based methods						Boat-based methods			
	R&R	Spear	Glean	Gill net	H&L	Throw net	Bottomfish	Bottom-troll Mixed	Spear	Troll
1990	688	0	1462	0	505	1278	3341	4816	1360	41137
1991	1591	0	539	0	396	721	5047	4439	717	27293
1992	192	0	480	0	19	661	4821	0	0	35268
1993	389	0	836	0	67	516	7260	2019	70	27151

1994	608	0	1038	0	27	390	14136	3272	1563	57543
1995	490	0	1240	124	54	252	10106	8838	309	73451
1996	417	0	863	39	21	691	11943	6040	0	49093
1997	201	0	470	0	0	566	9637	6842	9124	30413
1998	345	0	679	0	462	445	4208	793	785	17364
1999	118	0	126	0	209	171	6725	926	746	26152
2000	104	0	327	0	0	168	5084	1986	638	15307
2001	NULL	NULL	NULL	NULL	NULL	NULL	7766	2459	1601	11379
2002	134	57	59	15	6	90	6136	1774	1245	10544
2003	7	23	45	0	0	13	8687	1574	1250	20341
2004	NULL	NULL	NULL	NULL	NULL	NULL	8056	3023	463	21613
2005	25	80	3	55	0	39	5408	4016	30	11567
2006	122	190	23	60	1	211	7109	1169	601	14557
2007	360	854	350	323	33	315	18692	1125	7362	12040
2008	199	302	94	31	2	96	20080	1073	3713	20136
2009	203	564	87	53	12	193	34875	2226	8913	2862
2010	97	526	102	29	20	234	7988	507	23170	3461
2011	280	2225	160	167	19	214	10737	5249	18890	13634
2012	82	520	63	117	6	153	5390	1133	7279	8552
2013	303	4777	184	87	151	511	6098	1787	16770	7865
2014	95	844	18	7	15	132	14713	3374	7950	19577
2015	422	628	20	18	15	246	13339	3769	3814	5551
2016	372	547	77	39	23	192	5469	7636	1730	10350
10 YRS AVG	241	1179	116	87	30	229	13738	2788	9959	10403
10 YRS SD	118	1303	93	92	41	111	8667	2141	6813	5749
20 YRS AVG	193	674	160	56	54	222	10310	2622	5804	14163
20 YRS SD	123	1124	178	79	113	148	7115	1957	6609	7116

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

The time series for catch is an indicator of fishery performance. Fluctuations in the catch can be attributed to various factors and there is no single explanatory variable for the trends. The 10 species group in the boat and shore-based catch for the coral reef fishery make up 70% and 85% of the total annual catches, respectively.

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

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

Table 8. Catch time series of the 11 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the boat-based creel data. The bottomfish, BMUS and CREMUS complex comprise majority of the total boat-based landing (Surg. = surgeonfish; Snap. = snapper; Empr. = emperor; Parrot. = parrotfish; Grpr. = grouper; Jack. = jacks; Crus. = crustacean; Sqrl. = squirrelfish; Atul. = atulai)

Year	BF	BMUS	Surg	Snap	Empr	Parrot	Grpr	Jack	Crus	Sqrl	Atul
1986	11196	9046	0	1782	275	0	1163	1874	6297	737	
1987	2496	952	4030	544	113	1835	150	769	5089	243	
1988	80008	25759	34501	30894	20870	9441	12204	3905	17971	4698	2322
1989	93969	24229	38460	34752	21890	15924	14538	7922	9204	8896	
1990	29021	6666	1645	11779	9213	638	2708	2033	373	296	216
1991	36773	12511	777	14167	9187	333	3578	1519	309	544	
1992	28790	8522		11525	11988		2026	2538		69	
1993	34586	16263	442	11025	7094	660	3792	1274	101	468	
1994	95836	33278	18553	31268	24974	31115	13311	5343	3052	1631	
1995	75285	29038	3176	23329	13039	5920	10657	9348	586	916	5
1996	76597	32156	7117	24544	21919	2818	7117	5794	826	1359	43
1997	92238	36085	99259	30518	14573	35104	17757	4881	10638	7395	544
1998	41856	19838	71581	6728	2774	44462	10362	5466	9458	2530	
1999	44660	23288	69331	7633	2853	27539	11219	3584	4480	5197	
2000	62746	15835	44569	30549	17956	21811	9218	7154	3538	5095	1262
2001	102608	36399	11603	49171	35371	1906	6755	669	3355	1019	110
2002	102011	27082	9504	58026	32698	3056	12579	4080	1507	3268	
2003	52470	10045	6177	25822	14268	1686	14751	2188	2066	1166	
2004	46310	13405	4675	13990	15593	1464	4580	2710	1350	1050	
2005	28846	13615	211	8829	4401	149	2609	849	118	363	
2006	15959	4875	1508	4193	2109	961	1799	4191	506	579	70
2007	49737	17338	11230	22578	13668	6138	4537	3653	6823	1478	5170
2008	92222	32290	6405	36363	26724	4441	7315	5024	2301	2188	3517
2009	150031	44779	15744	66422	46968	9777	6867	5553	5722	2622	396
2010	32412	8510	50604	14417	9256	29424	3771	1204	28714	4490	30
2011	54732	16173	21033	24673	16189	13818	4770	1573	6335	3454	73
2012	13298	2228	3177	5925	3778	3523	737	3073	1148	742	6963
2013	33478	9388	13678	17485	7129	4841	2390	2533	3582	2397	2197
2014	66106	26203	17076	33874	13064	15333	5453	2211	280	1805	312
2015	93238	35110	22272	46397	24923	23247	4272	2053	23	1902	
2016	70665	36272	2846	25423	7032	5385	1712	3192	539	853	144

10 YRS AVG	65592	22829	16407	29356	16873	11593	4182	3007	5547	2193	1880
10 YRS SD	37237	13412	13112	16523	12305	8403	2012	1345	8100	1083	2395
20 YRS AVG	62281	21438	24124	26451	15566	12703	6673	3292	4624	2480	1039
20 YRS SD	33482	11949	27229	17415	11951	12816	4533	1688	6290	1811	1910

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

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

Table 9. Catch time series of the 10 managed species complexes (rank ordered by management importance and average catch of recent 10 years) from the shore-based creel data. The CREMUS complex comprise > 85% of the total boat-based landing. (Surg. = surgeonfish; Snap. = snapper; Mlsk. = mollusk; Parrot. = parrotfish; Grpr. = grouper; Wras. = wrasse; Crus. = crustacean; Sqrl. = squirrelfish; Atul. = atule; Mull. = mullet)

Year	**Atul**	**Mlsk**	**Surg**	**Parrot**	**Mull**	**Grpr**	**Sqrl**	**Wras**	**Crus**	**Snap**
1988	2322	6293	34501	9441		12204	4698	1028	17971	30894
1989		1196	38460	15924		14538	8896	360	9204	34752
1990	47051	10629	17725	1870	18013	4634	2248	135	1625	17148
1991	113242	18109	15549	2571	1561	9124	5322	789	964	16867
1992	7412	9455	17819	2743	4212	6709	10647	172	397	12235
1993	7642	38656	11424	2318	1001	7948	1951	308	8361	12939
1994	12942	16569	20299	33156	694	14802	2296	303	6207	33000
1995	25	22546	7521	7951	2068	12588	2519	167	3749	24071
1996	25534	24936	9152	5299	1312	8318	10140	435	1813	25497
1997	555	382	99366	35136	54	17793	7399		10642	30595
1998		692	71670	44481		10372	2535	879	9496	7006
1999	143	900	69453	27559	111	11268	5217	370	4493	7726
2000	1342	2	44734	21828	152	9262	5105		3541	30714
2001	174	130	11809	1923	45	6766	1117		3366	49308
2002	374	140	9669	3104		12602	3278		1517	58105
2003		103	6220	1698	20	14763	1170	120	2068	25917
2004	98	667	5223	1584	435	4649	1234	339	1411	14161
2005	1197	6762	6319	1552	2563	3401	1231	3158	921	9904
2006	803	2598	6932	2600	3451	4461	1040	1944	1467	5831
2007	7849	13067	18304	8401	2870	8065	2185	1342	7636	23808

2008	9168	16525	10323	5613	1231	9944	3369	2484	2748	36752
2009	634	3307	18569	10627	437	8109	3775	851	5939	66777
2010	2140	4758	63080	49861	2248	5749	8834	1145	31076	14910
2011	16069	9063	35583	25926	2744	6651	7254	128	8282	25407
2012	10861	4502	8235	4669	1287	1560	1353	206	1674	6239
2013	8372	17510	20641	6714	3417	3823	3603	571	5070	18198
2014	884	5829	20710	16073	780	8186	3742	269	1048	34259
2015	4706	5202	29317	23942	705	4824	2684	254	876	47399
2016	2820	32149	13975	21026	1015	3711	3930	449	11727	26123
10 YRS AVG	6350	11191	23874	17285	1673	6062	4073	770	7608	29987
10 YRS SD	4738	8536	15198	13138	1000	2461	2159	693	8512	16508
20 YRS AVG	3409	6214	28507	15716	1178	7798	3503	725	5750	26957
20 YRS SD	4470	7947	26437	14579	1203	4028	2225	866	6713	17297

1.6 CATCH PER UNIT EFFORT (CPUE) STATISTICS

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

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

Table 10. Catch per unit effort time series by dominant fishing methods from the shore-based fisheries. CPUE estimates were derived from the top three to five dominant taxonomic groups that make up more than 50% of the catch. The percentage of catch is shown in parenthesis beside the method.

Year	Gear CPUE (Lbs/Gear-hr)				
	R&R	Spear	Gleaning	Gill net	H&L
1990	0.0532		0.5061		0.037
1991	0.0561		0.1922		0.0299
1992	0.5486		0.4786		0.1152
1993	0.0745		0.2136		5.5833
1994	0.0322		0.0943		0.0229
1995	0.0904		0.0792	4.5926	0.0741
1996	0.0925		0.2517	0.1866	0.0367

Year	Gear CPUE (Lbs/Gear-hr)				
	R&R	Spear	Gleaning	Gill net	H&L
1997					
1998					
1999					
2000					
2001					
2002	0.0124	2.28	0.2341	2.5	0.375
2003	0.0374	1.0952	0.4945		
2004					
2005	0.047	0.1379	0.25	3.9286	0
2006	0.0341	0.1	0.1769	0.5714	0.5
2007	0.012	0.1069	0.0594	0.2553	0.6735
2008	0.0455	0.0944	0.1741	0.5741	0.1333
2009	0.0166	0.1112	0.1014	0.4907	0.24
2010	0.0226	0.0502	0.488	0.725	0.6667
2011	0.0105	0.0319	0.1309	0.3591	0.2468
2012	0.0138	0.1337	0.3462	0.1275	0.3333
2013	0.0157	0.0213	0.381	0.956	1.1185
2014	0.0335	0.0799	0.9	0.2333	5
2015	0.0098	0.1661	0.3704	0.6	0.625
2016	0.0182	0.1796	0.3775	3.9	0.2018
10 YRS AVG	0.0198	0.0975	0.3329	0.8221	0.9239
10 YRS SD	0.0108	0.0507	0.2337	1.0529	1.389
20 YRS AVG	0.0235	0.3277	0.3203	1.1708	0.778
20 YRS SD	0.0128	0.6002	0.2089	1.3019	1.2512

Table 11. Catch per unit effort time series by dominant fishing methods from the boat-based fisheries. CPUE estimates were derived from the top –three to five dominant taxonomic groups that make up more than 50% of the catch. The percentage of catch is shown in parenthesis beside the method.

Year	Boat_based Gear CPUE (Lbs/Fisher-hrs)			
	Bottomfishing	Bottom-troll Mix	Spear	Troll
1986	0.0229	0.0511	0.1295	0.017
1987	0.2175	0.0905	0.1038	0.0402
1988	0.1295	0.1536	0.078	0.0415
1989	0.1061	0.1229	0.1812	0.02
1990	0.1219	0.2537	0.6667	0.024
1991	0.0734	0.3007	3.1867	0.0319
1992	0.0904			0.0436
1993	0.0512	0.6262	0.9333	0.0299
1994	0.032	0.2245	0.4554	0.0196

Year	**Boat_based Gear CPUE (Lbs/Fisher-hrs)**			
	Bottomfishing	**Bottom-troll Mix**	**Spear**	**Troll**
1995	0.0629	0.0893	2.8611	0.0159
1996	0.0567	0.2842		0.0226
1997	0.0643	0.094	0.3283	0.0183
1998	0.1427	0.3746	5.4514	0.0282
1999	0.0698	0.9789	1.7933	0.0326
2000	0.0701	0.5629	3.2222	0.031
2001	0.083	0.3971	0.6266	0.0382
2002	0.049	0.5843	0.5231	0.0509
2003	0.0687	0.8211	1.0629	0.0628
2004	0.027	0.2928	1.3538	0.0548
2005	0.0709	0.2499	3	0.0633
2006	0.0404	0.3619	0.7457	0.0811
2007	0.0355	0.2856	0.0396	0.1147
2008	0.0425	0.3794	0.0984	0.1609
2009	0.0526	0.5162	0.3038	0.2901
2010	0.0921	7.6818	0.0642	0.2161
2011	0.0888	0.486	0.1406	0.2276
2012	0.0528	0.9257	0.447	0.4691
2013	0.052	0.3961	0.1181	0.0936
2014	0.0292	0.2549	0.0442	0.1164
2015	0.0307	0.1911	0.1371	0.1243
2016	0.0396	0.0962	0.0429	0.3796
10 YEARS AVG	0.0516	1.1213	0.1436	0.2192
10 YEARS SD	0.0211	2.1975	0.1255	0.1196
20 YEARS AVG	0.0601	0.7965	0.9772	0.1327
20 YEARS SD	0.027	1.5977	1.3762	0.1217

1.7 EFFORT STATISTICS

This section summarizes the effort trends in the coral reef and bottomfish fishery. Fishing effort trends provide insights on the level of fishing pressure through time. Effort information is provided for the top shore-based and boat-based fishing methods that contribute 70% and 85% of the annual catch.

Calculations: Effort estimates (hours) are generated by summing the effort data collected from interviews by gear type. For the Shore-based estimates, data collection started in 1990.

Table 12. Time series of effort estimates from the coral reef and bottomfish fisheries

Year	**Estimated Effort by Gear or Fishing Method**	
	Shore-based gear-hours	**Boat-based gear-hours**

	R&R	**Spear**	**Gleaning**	**Gill net**	**H&L**	**Bottom**	**Bottom-troll mixed**	**Spear**	**Troll**
1986						912795	403245	77520	4131687
1987						13566	132344	93852	1110185
1988						76648	74643	201500	1661806
1989						66444	113378	73400	2935686
1990	12936	0	2889	0	13653	27412	18981	2040	1714502
1991	28380	0	2805	0	13261	68728	14763	225	854982
1992	350	0	1003	0	165	53352	0	0	808452
1993	5220	0	3913	0	12	141860	3224	75	907888
1994	18860	0	11005	0	1178	441090	14573	3432	2930446
1995	5421	0	15660	27	729	160608	98988	108	4621875
1996	4510	0	3429	209	572	210627	21251	0	2172555
1997	0	0	0	0	0	149838	72760	27792	1658858
1998	0	0	0	0	0	29484	2117	144	615660
1999	0	0	0	0	0	96385	946	416	803368
2000	0	0	0	0	0	72480	3528	198	493230
2001						93612	6192	2555	298139
2002	10816	25	252	6	16	125255	3036	2380	207018
2003	187	21	91	0	0	126464	1917	1176	324016
2004						297850	10325	342	394128
2005	532	580	12	14	1	76255	16068	10	182688
2006	3575	1900	130	105	2	176076	3230	806	179574
2007	29882	7986	5893	1265	49	526008	3939	185992	104937
2008	4371	3200	540	54	15	472656	2828	37750	125159
2009	12231	5074	858	108	50	662800	4312	29340	9864
2010	4284	10472	209	40	30	86736	66	360840	16014
2011	26543	69776	1222	465	77	120908	10800	134310	59899
2012	5922	3888	182	918	18	102051	1224	16284	18231
2013	19352	224349	483	91	135	117176	4512	142029	84040
2014	2838	10564	20	30	3	504672	13237	179860	168210
2015	42880	3780	54	30	24	434434	19725	27820	44660
2016	20400	3045	204	10	114	138159	79350	40300	27264
10 YRS AVG	16870	34213	967	301	52	316560	13999	115453	65828
10 YRS SD	12692	66223	1681	422	42	211209	22542	103448	50708
20 YRS AVG	10212	19148	564	174	30	220465	13006	59517	290748
20 YRS SD	12270	52156	1333	346	40	184383	21676	92263	377860

1.8 PARTICIPANTS

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

Calculations:

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

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

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

Year	Bottomfish		Coral Reef BB			Coral Reef SB Fishery				
	No. fishers	No. of Gears	Bottom-troll Mixed	Spear	Troll	R&R	Spear	Glean	Gill net	H&L
1986	1001	983	992	1909	1153					
1987	991	973	909	1696	1058					
1988	969	976	1131	1629	1130					
1989	1125	1087	1297	1875	1231					
1990	881	938	1098	1556	1138	10298	0	7758	0	17282
1991	1027	1061	991	1643	1095	14574	0	8578	0	8244
1992	906	1307			1087	3783	0	11990	0	882
1993	1032	1064	1356	1825	1177	7683	0	16242	0	1034
1994	1198	1215	1267	1582	1086	10169	0	9308	0	4758
1995	1168	1173	1066	2190	1104	6236	0	10942	410	1663
1996	946	928	951		959	13424	0	7218	294	9994
1997	940	982	1020	1449	990					
1998	916	926	1005	1872	939					
1999	981	955	984	1252	893					
2000	1005	911	1014	1884	911					
2001	851	871	939	1096	851					
2002	969	1097	936	1560	809	4945	2965	3821	511	281
2003	965	803	845	1252	849	4523	1993	4024	268	422
2004	969	1779	932	1896	804	3430	1446	1474	324	195
2005	844	604	842	1565	742	1581	739	1289	206	86

Year	**Bottomfish**		**Coral Reef BB**			**Coral Reef SB Fishery**				
	No. fishers	**No. of Gears**	**Bottom-troll Mixed**	**Spear**	**Troll**	**R&R**	**Spear**	**Glean**	**Gill net**	**H&L**
2006	953	843	991	1386	814	1632	313	735	389	146
2007	1008	1006	951	1549	947	2030	559	582	396	73
2008	1042	1015	890	1372	908	1566	549	827	169	101
2009	1145	1131	1092	1884	802	1089	556	785	132	78
2010	1042	1012	945	1950	1036	839	525	347	93	55
2011	959	982	878	2016	939	1828	489	341	129	95
2012	667	644	1531	800	888	1300	301	384	390	35
2013	835	1451	1380	1838	973	1591	430	596	57	94
2014	839	856	865	1906	868	700	210	247	61	12
2015	911	986	906	1630	927	2118	242	234	94	53
2016	1092	2993	1092	1612	1013	3305	263	507	20	80
10 YRS AVG	954	1208	1053	1656	930	1637	412	485	154	68
10 YRS SD	136	625	218	345	65	717	136	200	126	27
20 YRS AVG	947	1092	1002	1588	895	2165	772	1080	216	120
20 YRS SD	103	502	168	319	76	1250	750	1167	148	103

WPacFIN recommended an alternative method for monitoring fishing participation. The fishery data collectors count the number of gears being used by fishing methods. Each gear has a potential for catching fish contributing to the CPUE.

Year	**Bottomfish**		**Coral Reef BB**			**Coral Reef SB Fishery**				
	No. of trips	**No. of Gears**	**Bottom-troll Mixed trips**	**Spear trips**	**Troll trips**	**R&R gears**	**Spear gears**	**Gleaning gears**	**Gill net gears**	**H&L gears**
1986	983	288	973	1909	1114					
1987	973	70	935	1710	1033					
1988	976	125	1171	1629	1182					
1989	1087	115	1406	1903	1249					
1990	938	73	1137	1556	1143	10147	0	7219	0	16962
1991	1061	117	1130	1643	1122	14498	0	8406	0	8234
1992	1307	121	0	0	1102	3558	0	11685	0	850
1993	1064	151	1408	365	1110	7338	0	15308	0	1005
1994	1215	246	1267	1784	1103	9710	0	9243	0	4710

1995	1173	131	1059	2190	1261	6194	0	10917	125	1655
1996	928	185	939	0	981	12493	0	7202	212	9684
1997	982	199	1050	1389	1099					
1998	926	54	1005	1872	964					
1999	955	107	850	1252	978					
2000	911	160	821	314	865					
2001	871	252	939	1096	903					
2002	1097	378	936	1560	1041	4102	2492	3233	256	192
2003	803	272	595	805	624	4158	1821	3909	211	402
2004	1779	402	885	1475	753	3199	1372	1233	139	158
2005	604	220	712	1565	690	1444	636	1255	189	86
2006	843	160	991	1118	777	1540	297	708	281	119
2007	1006	331	951	1366	886	1847	566	562	223	67
2008	1015	468	1208	1345	876	1376	549	789	89	80
2009	1131	622	1092	1595	691	976	529	758	66	54
2010	1012	251	945	1712	671	712	500	339	51	51
2011	982	265	895	1863	807	1927	642	363	65	98
2012	644	264	1467	748	741	1418	437	402	207	41
2013	1451	413	1233	1795	823	1550	490	588	34	87
2014	856	401	1049	1882	955	700	279	231	73	12
2015	986	469	20200	1630	965	2627	300	226	62	57
2016	2993	400	1195	1622	965	4423	258	706	10	75
10 YRS AVG	1208	388	3024	1556	838	1756	455	496	88	62
10 YRS SD	625	110	5728	320	105	1050	126	201	67	24
20 YRS AVG	1092	304	1951	1400	854	2133	745	1020	130	105
20 YRS SD	502	136	4191	405	129	1222	623	1052	86	91

1.9 BYCATCH ESTIMATES

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

Calculations:

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

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

Numbers released = caught - kept

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

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

Year	Bycatch from boat-based non-bottomfishing gear type			
	Numbers caught	Kept	Released	% bycatch
1986	0	0	0	0
1987	0	0	0	0
1988	43	43	0	0
1989	0	0	0	0
1990	0	0	0	0
1991	0	0	0	0
1992	5277	5277	0	0
1993	2637	2637	0	0
1994	7562	7562	0	0
1995	10279	10279	0	0
1996	7088	7088	0	0
1997	24977	24977	0	0
1998	17491	17491	0	0
1999	16705	16705	0	0
2000	12642	12641	1	0.0001
2001	8651	8649	2	0.0002
2002	6531	6522	9	0.0014
2003	8936	8931	5	0.0006
2004	8611	8604	7	0.0008
2005	5036	5036	0	0
2006	6306	6306	0	0
2007	17555	17555	0	0
2008	9799	9799	0	0
2009	9630	9630	0	0
2010	22283	22283	0	0
2011	18659	18659	0	0
2012	15512	15512	0	0

2013	13919	13919	0	0
2014	13855	13855	0	0
2015	7280	7280	0	0
2016	5257	5257	0	0
10 YEARS AVG	13375	13375	0	0
10 YEARS SD	5096	5096	0	0
20 YEARS AVG	12482	12481	1	0.0002
20 YEARS SD	5648	5649	3	0.0004

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

Year	**Bycatch from boat-based bottomfishing gear type**			
	Numbers caught	**Kept**	**Released**	**% bycatch**
1986	0	0	0	0
1987	0	0	0	0
1988	91	91	0	0
1989	0	0	0	0
1990	0	0	0	0
1991	0	0	0	0
1992	2440	2440	0	0
1993	2394	2394	0	0
1994	7657	7657	0	0
1995	3405	3405	0	0
1996	5999	5999	0	0
1997	5193	5193	0	0
1998	1844	1844	0	0
1999	5630	5630	0	0
2000	6438	6438	0	0
2001	6202	6202	0	0
2002	6959	6959	0	0
2003	7797	7796	1	0.0001
2004	6734	6734	0	0
2005	3684	3684	0	0
2006	5833	5833	0	0
2007	6936	6936	0	0
2008	8588	8588	0	0
2009	19521	19521	0	0
2010	5021	5021	0	0
2011	7359	7359	0	0
2012	5137	5137	0	0

2013	4525	4525	0	0
2014	6627	6627	0	0
2015	7268	7268	0	0
2016	2122	2122	0	0
10 YEARS AVG	7310	7310	0	0
10 YEARS SD	4427	4427	0	0
20 YEARS AVG	6471	6471	0	0
20 YEARS SD	3443	3443	0	0

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

Year	**Bycatch from shore-based (all gears combined)**			
	Numbers caught	**Kept**	**Released**	**% bycatch**
2005	655	658	3	0.0046
2006	1613	1619	6	0.0037
2007	5441	5442	1	0.0002
2008	2145	2145	0	0
2009	2199	2199	0	0
2010	1993	1994	1	0.0005
2011	3980	3981	1	0.0003
2012	1572	1572	0	0
2013	9214	9220	6	0.0007
2014	1829	1829	0	0
2015	2469	2469	0	0
2016	3268	3309	41	0.0124
10 YEARS AVG	3411	3416	5	0.0014
10 YEARS SD	2236	2237	12	0.0037

1.10 NUMBER OF FEDERAL PERMIT HOLDERS

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

1.10.1 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.

1.10.2 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.

1.10.3 Western Pacific Crustacean 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.

There is no record of special coral reef or precious coral fishery permits issued for the EEZ around American Samoa since 2007. Few crustacean fishery permits have been issued as shown in Table 17. Table 17 provides the number of permits issued to American Samoa 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 17. Number of federal permits holders between 2007 and 2017 for the crustacean fisheries

Crustacean Fishery	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Lobster	1	6*	4*					1			
Shrimp				1*	1*			1			

*Same permit applies to American Samoa, Guam, and CNMI.

1.11 STATUS DETERMINATION CRITERIA

1.11.1 Bottomfish Fishery

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

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

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

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

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 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 ($F_{RO\text{-}REBUILD}$) as a function of the SSBP ratio, are specified as indicated in Table 19. Again, E_{MSY} is used as a proxy for F_{MSY}.

Table 19. Recruitment overfishing control rule specifications for the bottomfish management unit species in American Samoa

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

1.11.2 Coral Reef Fishery

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

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

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

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

Establishing Reference Point Values

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

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

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

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

1.11.3 Current Stock Status

1.11.3.1 Bottomfish

Biological and other fishery data are poor for all bottomfish species in the Mariana Archipelago. Generally, data are only available on commercial landings by species and catch-per-unit-effort (CPUE) for the multi-species complexes as a whole. At this time it is not possible to partition these effort measures among the various bottomfish MUS. The most recent stock assessment update (Yau et al. 2016) for the American Samoa bottomfish management unit species complex (comprised of 17 species of shallow and deep species of snapper, grouper, jacks, and emperors) was based on estimate of total catch, an abundance index derived from the nominal CPUE generated from the creel surveys, and a fishery-independent point estimate of MSY from the Our Living Oceans Report (Humphreys and Moffitt 1999, Moffitt & Humphreys 2009). The assessment utilized a state-space surplus production model with explicit process and observation error terms (Meyer and Millar 1999). Determinations of overfishing and overfished status can then be made by comparing current biomass and harvest rates to MSY-level reference points. To date, the American Samoa BMUS is not subject to overfishing and is not overfished (Table 21).

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

Parameter	Value	Notes	Status
MSY	76.74 ± 14.06	Expressed in 1000 lbs (± std error)	
H_{2013}	0.039	Expressed in percentage	
H_{MSY}	0.238 ± 0.062	Expressed in percentage (± std error)	
H/H_{MSY}	0.17		No overfishing occurring
B_{2013}	661.3	Expressed in thousand pounds	
B_{MSY}	333.7 ± 65.3	Expressed in 1000 lbs (± std error)	
B/ B_{MSY}	1.98		Not overfished

1.11.3.2 Coral reef

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

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

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

Coral Reef MUS Complex	MSY (lbs)
Selar crumenophthalmus – atulai or bigeye scad	45,300

Coral Reef MUS Complex	**MSY (lbs)**
Acanthuridae – surgeonfish	148,600
Carangidae – jacks	24,300
Crustaceans – crabs	7,800
Holocentridae – squirrelfish	16,800
Kyphosidae – chubs/rudderfish	2,600
Labridae – wrasses[1]	19,000
Lethrinidae – emperors	23,700
Lutjanidae – snappers	65,400
Mollusks – turbo snail; octopus; giant clams	12,700
Mugilidae – mullets	8,200
Mullidae – goatfish	29,600
Scaridae – parrotfish[2]	294,600
Serranidae – groupers	30,500
Siganidae – rabbitfish	200
All Other CREMUS Combined - Other CRE-finfish - Other invertebrates - Misc. bottomfish - Misc. reef fish - Misc. shallow bottomfish	28,500
Cheilinus undulatus – humphead (Napoleon) wrasse	N.A.
Bolbometopon muricatum – bumphead parrotfish	N.A.
Carcharhinidae – reef sharks	2,300

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

1.12.1 Brief description of the ACL process

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

Catch Target (ACT). 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 American Samoa is an overage adjustment. The ACL is downward adjusted with the amount of overage from the ACL based on a three-year running average.

1.12.2 Current OFL, ABC, ACL, and recent catch

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

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

Fishery	**MUS**	**OFL**	**ABC**	**ACL**	**Catch**
Bottomfish	Bottomfish multi-species complex		106,000	106,000	21,278
Crustacean	Deepwater shrimp	N.A.	80,000	80,000	NAF
	Spiny lobster	7,300	5,100	4,845	1,287
	Slipper lobster	N.A.	30	30	5
	Kona crab	N.A.	3,200	3,200	NAF
Precious coral	Black coral	8,250	790	790	NAF
	Precious coral in AS expl. area	N.A.	2,205	2,205	NAF
Coral Reef	*Selar crumenophthalmus*	45,300	38,400	37,400	1,907
	Acanthuridae-surgeonfish	148,600	133,800	129,400	14,189
	Carangidae-jacks	24,300	20,800	19,900	7,650
	Crustaceans-crabs	7,800	4,700	4,300	1,598
	Holocentridae-squirrelfish	16,800	15,500	15,100	2,637
	Kyphosidae-rudderfish	2,600	2,200	2,000	929
	Labridae-wrasse	19,000	16,600	16,200	274
	Lethrinidae-emperors	23,700	20,400	19,600	6,865
	Lutjanidae-snappers	65,400	64,400	63,100	18,243
	Mollusk-turbo snails; octopus; clams	29,600	20,200	18,400	14,366
	Mullidae-goatfish	12,700	12,000	11,900	764
	Mugilidae-mullets	8,200	5,200	4,600	625
	Scaridae-parrotfish	294,600	280,100	272,000	6,252
	Serranidae-groupers	30,500	27,300	25,300	4,555
	Siganidae-rabbitfish	200	181	163	435
	All other CREMUS combined	28,500	20,300	18,400	2,721
	Cheilinus undulatus	N.A.	1,743	1,743	10
	Bolbometopon muricatum	N.A.	235	235	ND
	Carcharhinidae-reef sharks	2,300	1,700	1,615	ND

The catch shown in Table 23 takes the average of the recent three years as recommended by the Council at its 160th meeting to avoid large fluctuations in catch due to data quality and outliers. NAF indicates no active fisheries as of date. ND indicates no data available or the species was not detected in the surveys.

1.13 BEST SCIENTIFIC INFORMATION AVAILABLE

1.13.1 Bottomfish fishery

1.13.1.1 Stock assessment benchmark

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

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

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

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

1.13.1.2 Stock assessment updates

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

1.13.1.3 Other information available

Approximately every five years PIFSC administers a socioeconomic survey to small boat fishermen in American Samoa. 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.

1.13.2 Coral reef fishery

1.13.2.1 Stock assessment benchmark

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

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

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

Model: Biomass Augmented Catch MSY approach based on the original catch-MSY model (Martell and Froese 2013; Sabater and Kleiber 2014).

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

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

1.13.2.2 Stock assessment updates

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

1.13.2.3 Other information available

Approximately every five years PIFSC administers a socioeconomic survey to small boat fishermen in American Samoa. 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.

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). The criteria developed from this workshop had been applied to American Samoa. Scoring was conducted with representatives from American Samoa. This was the basis for the SEEM analysis that determined the risk levels to specify ACLs.

1.14 HARVEST CAPACITY AND EXTENT

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

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

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

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

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

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

Fishery	MUS	ACL	Catch	Harvest extent (%)	Harvest capacity (%)
Bottomfish	Bottomfish multi-species complex	106,000	21,278	20.1	79.9
Crustacean	Deepwater shrimp	80,000	NAF		100.0
	Spiny lobster	4,845	997	20.6	79.4
	Slipper lobster	30	13	43.3	56.7
	Kona crab	3,200	NAF		
Precious coral	Black coral	790	NAF		
	Precious coral in AS expl. area	2,205	NAF		
Coral Reef	*Selar crumenophthalmus*	37,400	1,907	5.1	94.9
	Acanthuridae-surgeonfish	129,400	14,189	11.0	89.0
	Carangidae-jacks	19,900	7,650	38.4	61.6
	Crustaceans-crabs	4,300	1,598	37.2	62.8
	Holocentridae-squirrelfish	15,100	2,637	17.5	82.5
	Kyphosidae-rudderfish	2,000	929	46.5	53.6
	Labridae-wrasse	16,200	274	1.7	98.3
	Lethrinidae-emperors	19,600	6,865	35.0	65.0
	Lutjanidae-snappers	63,100	18,243	28.9	71.1
	Mollusk-turbo snails; octopus; clams	18,400	14,366	78.1	21.9
	Mullidae-goatfish	11,900	764	16.6	83.4
	Mugilidae-mullets	4,600	625	5.3	94.7
	Scaridae-parrotfish	272,000	6,252	2.3	97.7
	Serranidae-groupers	25,300	4,555	18.0	82.0
	Siganidae-rabbitfish	163	435	266.7	-166.7
	All other CREMUS combined	18,400	2,721	14.8	85.2
	Cheilinus undulatus	1,743	10	0.6	99.4
	Bolbometopon muricatum	235	ND		
	Carcharhinidae-reef sharks	1,615	ND		

1.15 ADMINISTRATIVE AND REGULATORY ACTIONS

PIRO took no management actions related to the American Samoa FEP since the April 2016 Joint FEP Plan Team meeting. One proposed rule was published as described below.

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

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2 ECOSYSTEM CONSIDERATIONS

2.1 CORAL REEF FISH ECOSYSTEM PARAMETERS

2.1.1 Regional Reef Fish Biomass

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

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

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

Spatial Scale:

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

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

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

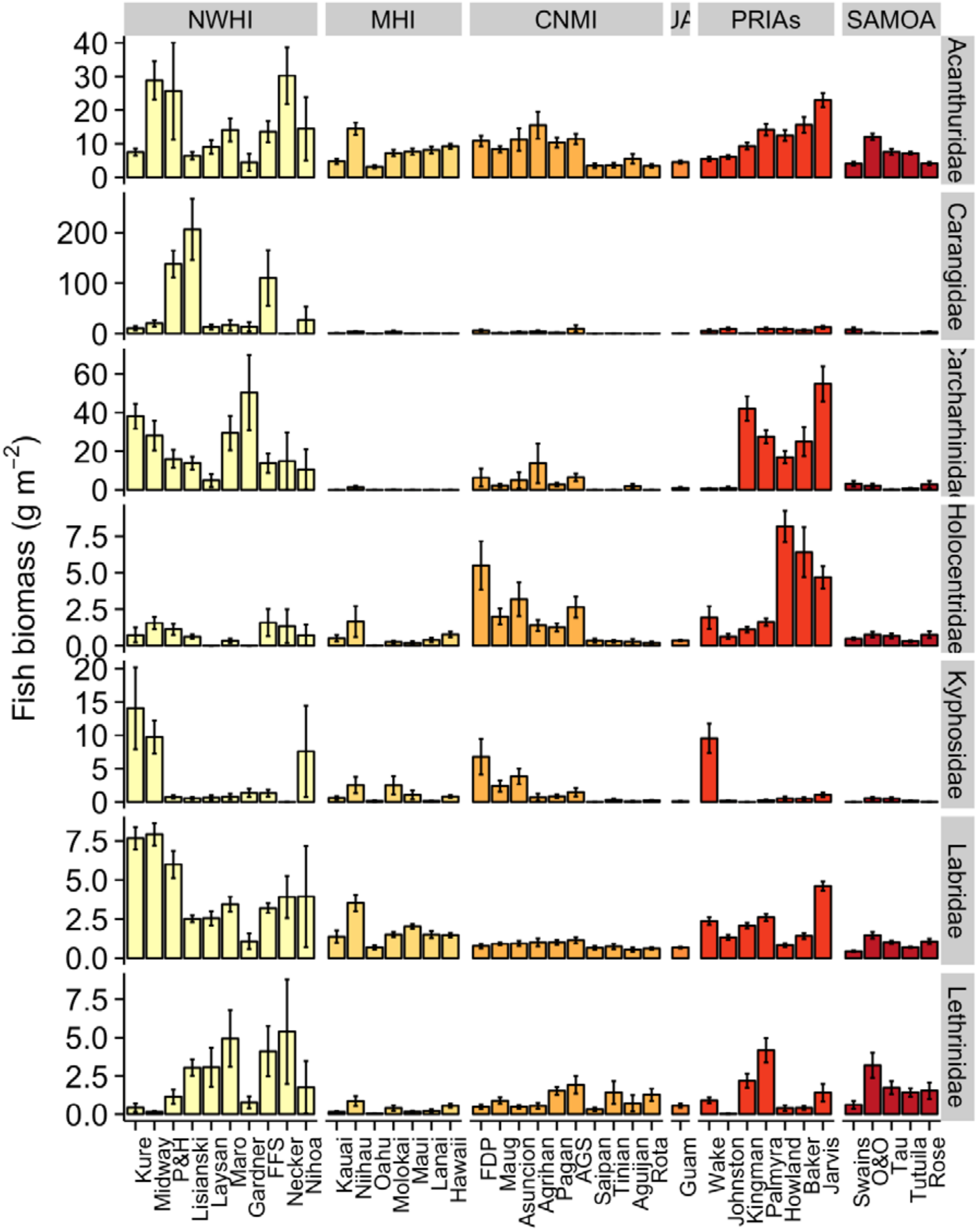
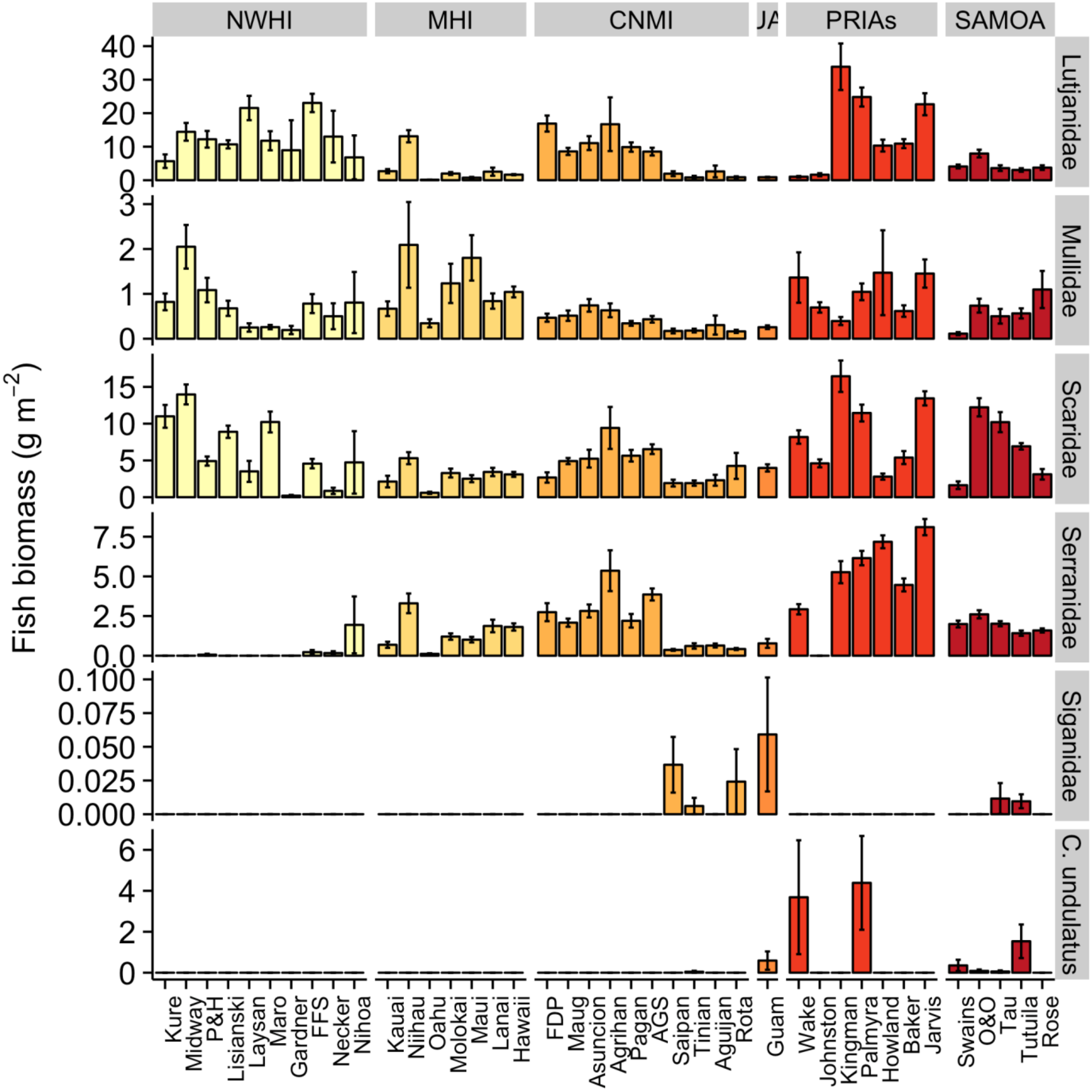

NWHI
MHI
CNMI
JA
PRIAs
SAMOA
Acanthuridae
Carangidae
archarhinida
Holocentridae
Kyphosidae
Labridae
Lethrinidae
Fish biomass (g m^{-2})
40
30
20
10
0
200
100
0
60
40
20
0
7.5
5.0
2.5
0.0
20
15
10
5
0
7.5
5.0
2.5
0.0
7.5
5.0
2.5
0.0
Kure
Midway
P&H
Lisianski
Laysan
Maro
Gardner
FFS
Necker
Nihoa
Kauai
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

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



2.1.2 Archipelagic 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 date 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.

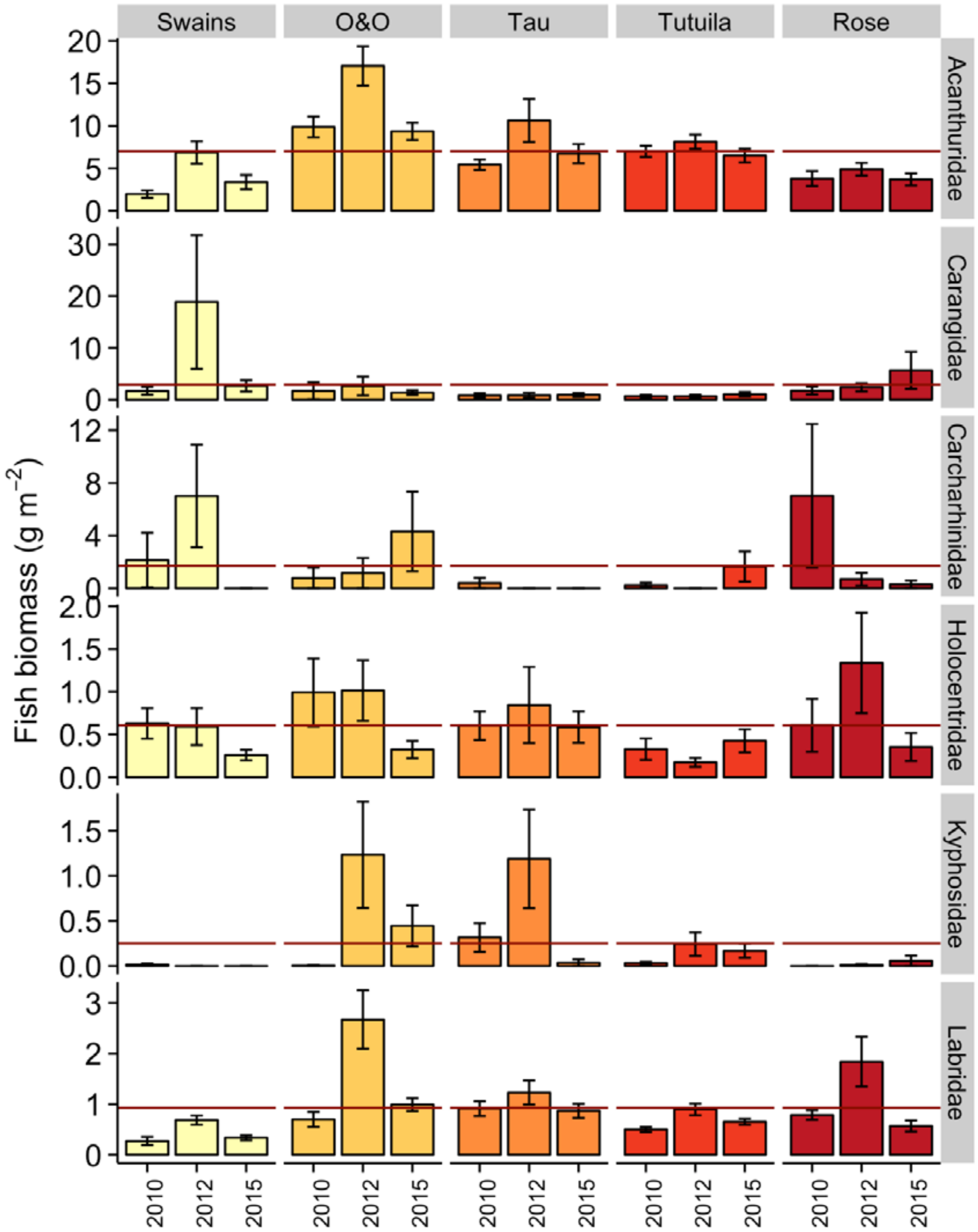
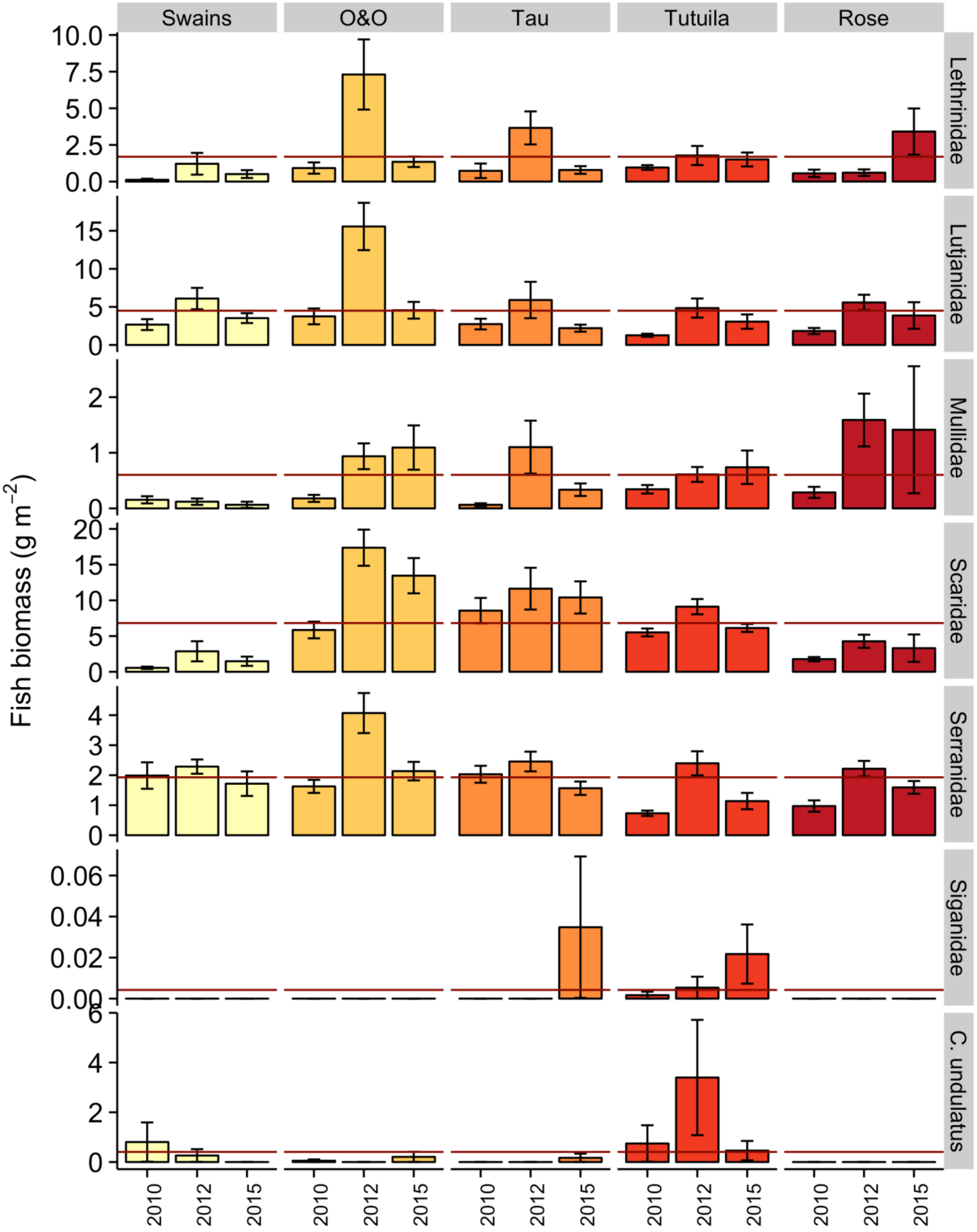

Swains
O&O
Tau
Tutuila
Rose
Acanthuridae
Carangidae
Carcharhinidae
Holocentridae
Kyphosidae
Labridae
Fish biomass (g m^{-2})
0
5
10
15
20
0
10
20
30
0
4
8
12
0.0
0.5
1.0
1.5
2.0
0.0
0.5
1.0
1.5
0
1
2
3
2010
2012
2015

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



2.1.3 Archipelagic Mean Size

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

Category:

- ✓ Fishery independent
- ☐ Fishery dependent
- ☐ Biological

Timeframe: Triennial

Jurisdiction:

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

Scale:

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

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

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

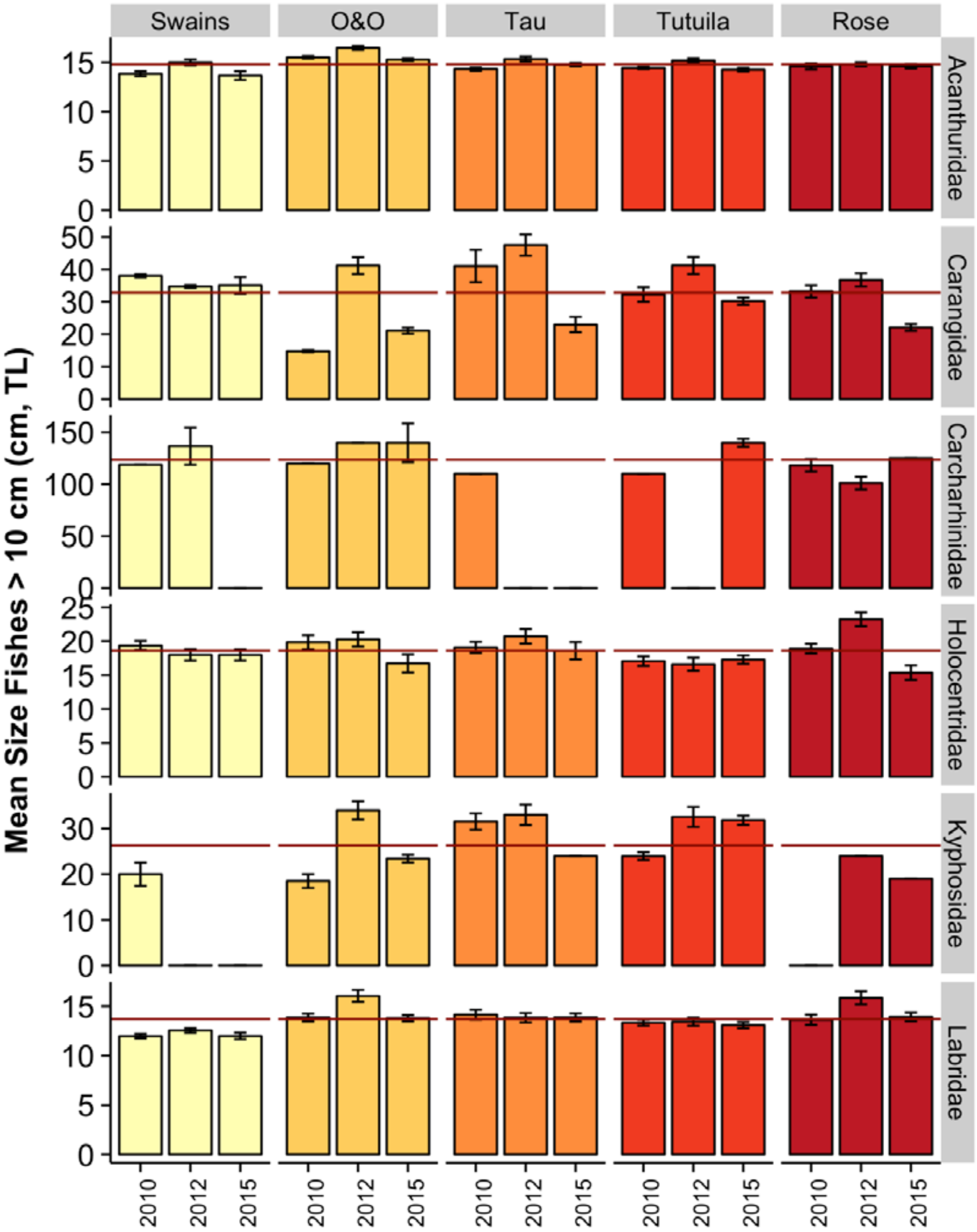
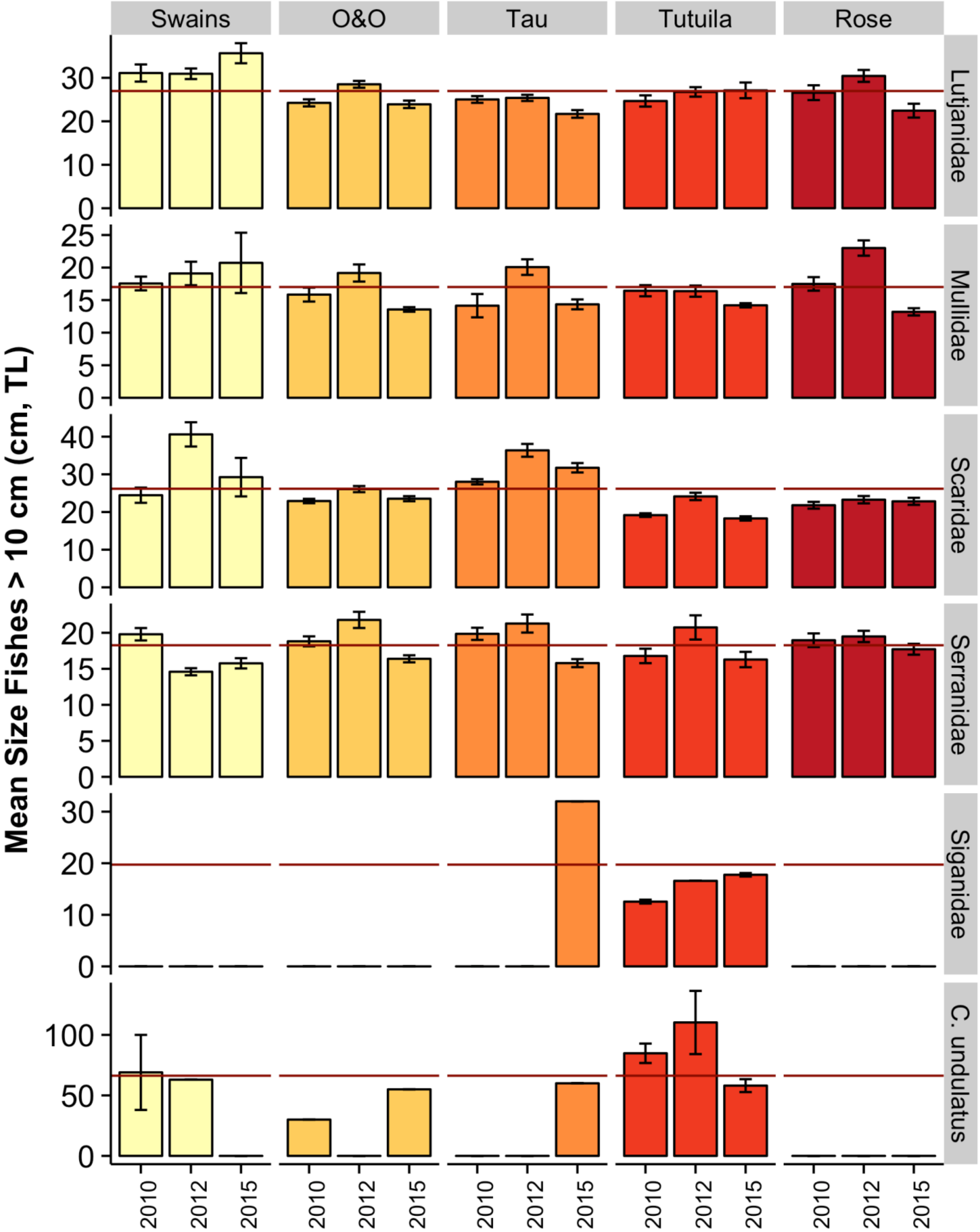


Figure 3. American Samoa showing the mean reef fish size (cm ± SE) per CREMUS grouping per year. The American Samoa archipelago mean estimates are plotted for reference (red line). Continues on to the next page.



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

			ESTIMATED POPULATION BIOMASS (metric Tonnes) in SURVEY DOMAIN OF <30m HARDBOTTOM											
ISLAND	Total Area of reef (Ha)	N	Acanthuridae	Carangidae	Carcharhinids	Holocentridae	Kyphosidae	Labridae	Lethrinidae	Lutjanidae	Mullidae	Scaridae	Serranidae	Siganidae
Swains	281	94	11.4	21.7	8.6	1.4	0.0	1.2	1.7	11.5	0.3	4.6	5.6	-
Ofu & Olosega	793	112	95.9	14.9	16.5	6.2	4.5	11.5	25.3	63.2	5.8	97.0	20.7	-
Tau	904	92	68.6	7.7	1.2	6.1	4.6	9.1	15.6	32.7	4.5	92.2	18.2	0.1
Tutuila	4,182	374	301.4	32.4	26.5	12.9	6.2	28.6	59.2	128.1	23.6	289.5	59.4	0.4
Rose	442	129	18.2	14.4	11.8	3.4	0.1	4.7	6.8	16.6	4.9	13.8	7.0	-
South Bank	25	2	0.3	0.9	-	0.0	-	0.0	0.1	-	-	-	-	-
TOTAL	**6,627**	**803**	**497.0**	**91.7**	**64.8**	**30.1**	**15.5**	**55.3**	**109.0**	**252.9**	**39.3**	**498.5**	**111.4**	**0.5**

Note (1): No *Bolbometopon muricatum* were recorded during American Samoa surveys.

(2) *Cheilinus undulatus* were observed at Swains (1.0 t), Ofu&Olosega (0.7 t), Tau (0.5t) & Tutuila (64.2 t)

2.2 LIFE HISTORY INFORMATION AND LENGTH DERIVED VARIABLES

The SAFE Report will serve as the repository of available life history information for the Western Pacific region. Life history data particularly age and growth information inform the stock assessment on fish productivity and population dynamics. Some assessments particularly for data poor stocks like coral reefs utilize information from other areas that introduces errors and uncertainties in the population estimates. An archipelago specific life history parameter ensures accuracy in the input parameters used in the assessment.

The NMFS BioSampling Program allows for significant collection of life history samples like otoliths and gonads from priority species in the bottomfish and coral reef fisheries. These life history samples, once processed and data extracted, will contribute to the body of scientific information for the two data-poor fisheries in the region. The life history information available from the region will be monitored by the Fishery Ecosystem Plan Team and will be tracked through this section of the report.

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

2.2.1 Coral Reef Fish Life History

2.2.1.1 Age, Growth, & Reproductive Maturity

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

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

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

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

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

Spatial Scale:

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

Data Source: Sources of data are directly derived from market samples collected by the American Samoa contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the "Reference" column in Table 1 for specific details on data sources by species.

Parameter definitions:

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

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

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

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

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

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

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

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

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

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

Table 26. Available age, growth, and reproductive maturity information for coral reef species targeted for life history sampling (otoliths and gonads) in American Samoa. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications (^{d}) are denoted in "Reference" column.

Species	Age, growth, reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Myripristis amaena							NA		NA	
Myripristis berndti							NA	166[b]	NA	
Myripristis murdjan							NA		NA	
Naso unicornis	X[a]	X[a]	X[a]	X[a]		X[a]	NA	X[a]	NA	
Sargocentron caudimaculatum							NA		NA	
Sargocentron spiniferum							NA		NA	
Sargocentron tiere							NA	150[b]	NA	
Scarus rubrovioaceus	14[d]	40.6 (f), 47.8 (m)[d]	0.63 (f), 0.5 (m)[d]	-0.06 (f), -0.06 (m)[d]		2.6 (f) [d]		31.9 (f)[d]	42.3[d]	Taylor and Pardee (2017)

[a] signifies estimate pending further evaluation in an initiated and ongoing study

[b] signifies a preliminary estimate taken from ongoing analyses

[c] signifies an estimate documented in an unpublished report or draft manuscript

[d] signifies an estimate documented in a finalized report or published journal article (including in press)

2.2.1.2 Fish Length Derived Parameters

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

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

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

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

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

Spatial Scale:

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

Data Source: NMFS BioSampling Program

Parameter definition:

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

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

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

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

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

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

Table 27. Available length-derived information for various coral reef species in American Samoa.

Species	***Length derived parameters***						**Reference**
	L_{max}	L_{bar}	***n***	***L-W***	***a***	***b***	
Acanthurus lineatus	24.5	18.8	1955	0.87	0.068	2.68	
Ctenochaetus striatus	25.2	18.0	424	0.87	0.043	2.83	
Naso lituratus	47.4	22.2	8752	0.93	0.022	3.02	
Sargocentron tiere	25.0	18.0	3002	0.85	0.069	2.62	
Chlorurus japanensis	46.2	26.4	6852	0.97	0.018	3.07	
Naso unicornis	55.0	32.3	5042	0.99	0.033	2.85	
Scarus rubroviolaceus	54	34.9	4556	0.99	0.012	3.17	
Panulirus penicillatus	15.8	9.1	3365	0.94	2.614	2.41	
Scaru oviceps	44.5	23.6	3987	0.97	0.013	3.17	
Myripristis berndti	27.2	17.8	4228	0.89	0.100	2.53	
Acanthurus nigricans	36.0	16.9	3003	0.79	0.171	2.42	

Species	***Length derived parameters***						**Reference**
	L_{max}	L_{bar}	***n***	***L-W***	***a***	***b***	
Lutjanus gibbus	56.8	30.9	2291	0.96	0.04	2.8	
Lethrinus xanthochilus	54.5	36.8	2186	0.97	0.028	2.85	
Epinephelus melanostigma	54.9	26.5	2653	0.95	0.012	3.10	
Myripristis amaena	22.5	16.9	2849	0.82	0.149	2.39	
Acanthurus guttatus	24.5	16.8	1872	0.87	0.084	2.69	
Panulirus sp.	15.3	8.6	3331	0.91	5.755	2.06	
Myripristis murdjan	27.5	17.0	1707	0.84	0.72	1.83	
Scarus frenatus	44.5	26.9	1777	0.98	0.014	3.14	
Selar crumenopthalmus	32.7	19.3	298	0.96	0.007	3.30	
Parupeneus bifasciatus	34.5	22.6	1413	0.96	0.015	3.12	
Variola albimarginatus	43.6	27.0	965	0.89	0.122	2.42	
Scarus globiceps	33.9	23.5	1258	0.95	0.02	3.03	

2.2.2 Bottomfish Life History

2.2.2.1 Age, Growth, & reproductive Maturity

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

(L_∞, *k*, and t_0) which together characterize the shape of the length-at-age growth relationship. The ^{14}C derived ages typically provide more accurate estimates of older ages (≥30 years) and hence more realistic values of T_{max} compared to annuli or DGI-based counts of otolith sections.

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

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

Category:

- ☐ Fishery independent
- ☐ Fishery dependent
- ✓ Biological

Timeframe: N/A

Jurisdiction:

- ✓ American Samoa
- ☐ Guam
- ☐ Commonwealth of Northern Mariana Islands
- ☐ Main Hawaiian Islands

- ☐ Northwest Hawaiian Islands
- ☐ Pacific Remote Island Areas

Spatial Scale:

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

Data Source: Sources of data are directly derived from field samples collected at sea on NOAA research vessels and from the American Samoa contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the "Reference" column in Table 3 for specific details on data sources by species.

Parameter definitions:

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

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

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

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

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

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

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

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

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

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

Table 28. Available age, growth, and reproductive maturity information for bottomfish species targeted for life history sampling (otoliths and gonads) in American Samoa. Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm fork length (FL); k in units of year^{-1}; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable. Superscript letters indicate

status of parameter estimate (see footnotes below table). Published or in press publications (^{d}) are denoted in "Reference" column.

Species	Age, growth, and reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Aphareus rutilans							NA		NA	
Aprion virescens							NA		NA	
Etelis carbunculus							NA		NA	
Etelis coruscans							NA		NA	
Lethrinus amboinensis										
Lethrinus xanthochilus										
Lutjanus gibbus							NA		NA	
Pristipomoides auricilla							NA		NA	
Pristipomoides filamentosus							NA		NA	
Pristipomoides flavipinnis							NA		NA	
Pristipomoides sieboldii							NA		NA	
Pristipomoides zonatus							NA		NA	

[a] signifies estimate pending further evaluation in an initiated and ongoing study

[b] signifies a preliminary estimate taken from ongoing analyses

[c] signifies an estimate documented in an unpublished report or draft manuscript

[d] signifies an estimate documented in a finalized report or published journal article (including in press)

2.2.2.2 Fish Length Derived Parameters

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

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

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

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

Category:

☐ Fishery independent
☐ Fishery dependent
✓ Biological

Timeframe: N/A

Jurisdiction:

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

Spatial Scale:

☐ Regional
☐ Archipelagic
✓ Island
☐ Site

Data Source: NMFS BioSampling Program

Parameter definition:

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

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

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

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

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

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

Table 29. Available length-derived information for various bottomfish species in American Samoa.

Species	***Length derived parameters***						**Reference**
	L_{max}	***L_{bar}***	***n***	***L-W***	***a***	***b***	
Lutjanus kasmira	35.0	22.3	459	0.92	0.017	3.02	
Lethrinus rubrioperculatus	57	27.3	2348	0.97	0.029	2.86	

2.3 SOCIOECONOMICS

This section outlines the pertinent economic, social, and community information available for assessing the successes and impacts of management measures or the achievements of the Fishery Ecosystem Plan for the American Samoan Archipelago (Western Pacific Regional Fishery Management Council, 2016a). 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 American Samoa, followed by summaries of relevant studies and data for each fishery within American Samoa.

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

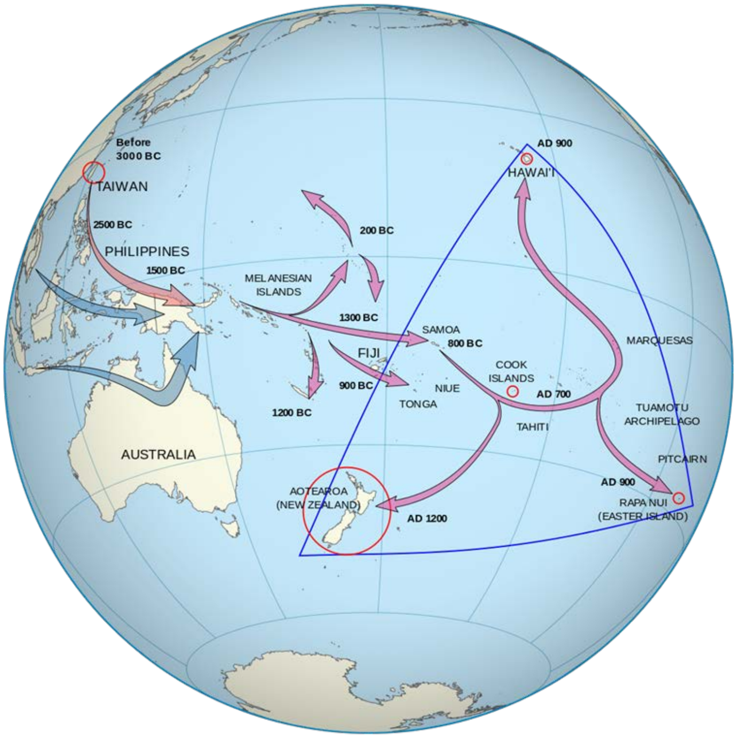


Figure 4. Settlement of the Pacific Islands, courtesy Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Polynesian_Migration.svg.

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.

2.3.1 Response to Previous Council Recommendations

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

At its 166th meeting held in Tumon, Guam, the Council 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).

2.3.2 Introduction

Fishing has played a crucial role in American Samoan culture and society since the Samoan archipelago was populated. An overview of American Samoa history, culture, geography, and relationship with the U.S. is described in Section 1.3 of the Fishery Ecosystem Plan for American Samoa (Western Pacific Regional Fishery Management Council, 2016a). Over the past decade, a number of studies have synthesized more specifics about the role of fishing and marine resources across American Samoa, as well as information about the people who engage in the fisheries or use fishery resources (see Armstrong, et al. 2011, Grace-McCaskey 2015, Levine and Allen 2009, and Richmond and Levine, 2012). These studies describe the importance of marine resources in cultural, economics, and subsistence aspects of Samoan village life. Fishing was held in high esteem in traditional Samoan culture, with fishing skill bringing high social status and fishing activities figuring prominently in mythology. The basic units of Samoan social structure are the family and village, with the family as the central unit. The village leadership decided, according to season, what sort of community fishing should take place. The tautai, or master fisherman, of the village was a key decision maker who was awarded higher status than others (who might otherwise outrank him) when it came to matters of fishing. Village-level systems of governance and resource tenure are still largely intact, and Samoan cultural systems and representation are formally incorporated into the territorial government. Reciprocity is emphasized over individual accumulation. Gifts of food (especially fish and other marine resources) mark every occasion and maintain Samoan social structure to this day.

Recent studies have found that American Samoa is ethnically and culturally very homogeneous (Levine et al., 2016, Richmond and Levine 2012). Polynesians account for the vast majority (93%) of the territory's people, and the primary language spoken at home is Samoan (91%), although English is often spoken in school and business settings. Contemporary American Samoan culture is characterized by a combination of traditional Samoan values and systems of social organization, as well as the strong influence of Christianity. Maintaining *fa'a Samoa* or "the Samoan way" was considered a priority under the territorial constitution. Given the cultural homogeneity, nearly everyone in American Samoa accepts and complies with Samoan traditions of land and resource tenure.

However, over the last half century or more, fishing has become less prominent as a central and organizing community force. During this time, modern fishing gear and technology was introduced, tuna canneries became a major economic force in Pago Pago, the population more than tripled, and the gradual but continuous introduction of Western cultural norms and practices altered American Samoans' relationship with the sea. While many traditions and village-based systems of governance have been maintained, the islands have experienced a shift from a subsistence-oriented economy where sharing of fish catch was extremely important to a cash-based economy, where fishing is often viewed as a more commercial venture.

A recent study by Levine et al. (2016) found that American Samoans still consume seafood frequently, with 78% of respondents stating that they eat fish or seafood once a week or more. Most American Samoans purchase seafood from stores or restaurants, with 65% of survey respondents listing this as their first or second choice for obtaining seafood. Other common means for obtaining fish include markets and roadside vendors (45%) and fish caught by household members (37%). This corroborates Levine and Allen's (2009) observation that American Samoans largely rely on, and in many cases prefer, store-bought food to locally caught fish, with the majority of fish consumed in American Samoa imported from Samoa.

The introduction of outboard engines and other technology in the 1950s and 1960s allowed American Samoan boats to go farther and faster, but also made it necessary for boat owners and operators to sell a portion of their catch to pay for fuel and engine maintenance. The disruption of other traditional values, as well as the introduction of a cash economy based primarily on government jobs and cannery employment, also decreased reliance on traditional, subsistence fishing and allowed commercial fishing to develop on the islands (Levine and Allen, 2009).

Unlike other areas within the Western Pacific Region, American Samoa also experienced the development of domestic industrial-scale fisheries, including tuna processing, transshipment, and home port industries. This is due to the harbor at Pago Pago, 390,000 km^2 of EEZ, and certain special provisions of U.S. law, which allowed the development of American Samoa's decades-old fish processing industry. For example, the territory is exempt from the Nicholson Act, which prohibits foreign ships from landing their catches in U.S. ports, and American Samoan products with less than 50 percent market value from foreign sources enter the U.S. duty free.

The two most important economic sectors are the American Samoa Government (ASG), which receives income and capital subsidies from the federal government, and tuna canning. According to the Statistical Yearbook (American Samoa Government, 2015), main imports include fish brought in for processing. Exports are primarily canned tuna and by-products, including fish meal and pet food. In 2015, domestic exports from American Samoa amounted to $387,554,000, of which $365,587,000 (or 94%) comprised canned tuna (American Samoa Government, 2015). Private businesses and commerce comprise a smaller third sector. Unlike some of its South Pacific neighbors, American Samoa has never had a robust tourist industry.

In 2015, the ASG employed 6,804 people (38 percent of total employment; American Samoa Government, 2015, p. 117), and the private sector employed 8,290 people (Figure 5). Two canneries employed 2,759 people, which is 16% of the people employed. Ancillary businesses involved in re-provisioning the fishing fleet generate a significant number of jobs and amount of income for local residents.

The canneries have been operating since 1954, represent the largest private-sector source of employment in the region, and, until recently, were the principle industry in the territory. Although as many as 90% of cannery workers are not American Samoa citizens, the canneries play a large role in the American Samoa economy, e.g. via delivery of goods or services to tuna processors and expenditures and buying patterns of cannery workers. Trends in world trade, specifically reductions in tariffs, have been reducing the competitive advantage of American Samoa's duty-free access to the U.S. canned tuna market, and the viability of the canneries has been questionable for almost a decade. In 2009, the Chicken of the Sea cannery closed, resulting in a loss of approximately 2,000 jobs. It was bought by Tri Marine International, which invested $70 million in rebuilding and expansion, and reopened in 2015. In October, 2016, SunKist Co. suspended operations due to lack of fish, in part due to Effort Limit Area for Purse Seine (ELAPS) closures (Pacific Islands Report, 2016). That same month, Tri Marine International announced that it would suspend production indefinitely in December 2016 (Honolulu Star Advertiser, 2016), and there are currently no plans to reopen (Pacific Islands Report, 2017). Tuna cannery closures in American Samoa are likely to have significant impacts on the American Samoa economy and communities, although the specifics are unknown.

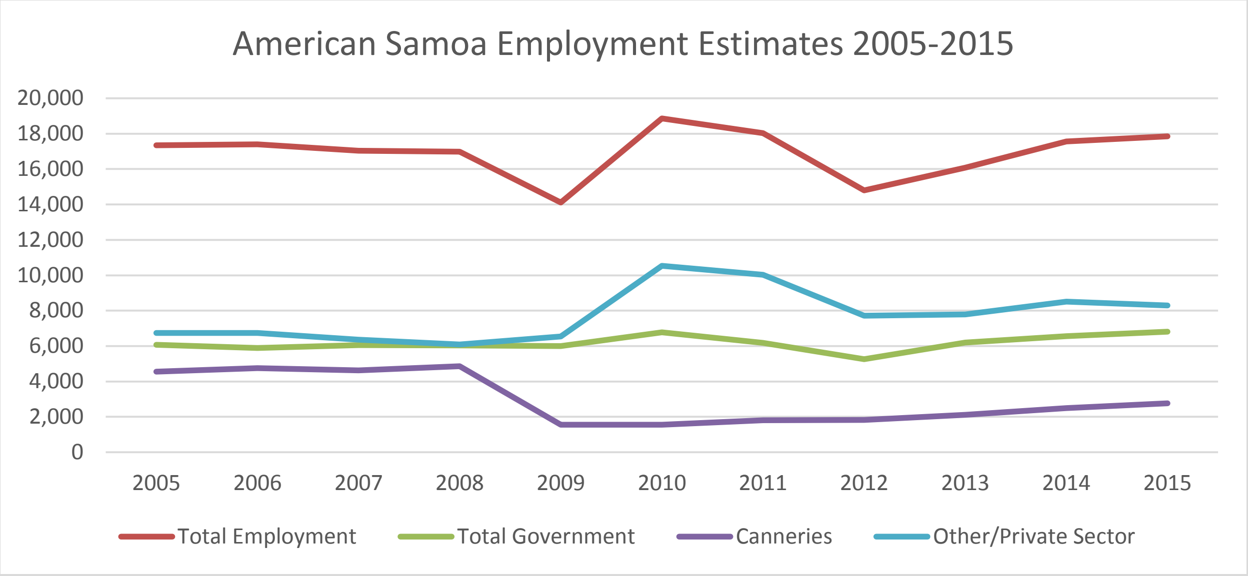


Figure 5. American Samoa Employment Estimates, 2005-2015. Data from American Samoa Statistical Yearbook 2015, American Samoa Government (2015).

Even before Tri Marine International's closure, American Samoa's economy was identified as being in a highly transitional state that should be monitored closely (Grace McCaskey, 2015). It will be important to monitor any changes and developments related to the tuna industry, given the historically close connection between the tuna canneries, employment levels, population trends, and the economic welfare of the territory. It is also possible that increased federal aid in recent years has masked the full extent of the economic recession.

Members of the American Samoa fishing community have also expressed concerns about the impact of National Marine Sanctuary of American Samoa (NMSAS) expansion and management of the Rose Atoll Marine National Monument on fishing activities. In both of these cases, the local communities have been concerned about the impacts on fishing practices as well as broader social and cultural issues, such as traditional marine tenure and the ability of villages to manage their own resources.

While pelagic fisheries play a larger role in the broader economy, insular fisheries are fundamentally important from a sociocultural and dietary standpoint (see Levine and Allen 2009 for review). Village leaders still have a significant degree of control over their nearshore waters, enforcing their own village rules and regulations, although the strength of many of these village-based management systems has weakened. The American Samoa Department of Marine and Wildlife Resources (DMWR) is the primary agency for fisheries management. DMWR also monitors the status of nearshore fish and marine habitats through the collection of fishery independent data, although it has limited patrolling and enforcement capacity. In 2000, the DMWR initiated the Community-based Fisheries Management Program (CFMP) to assist villages in managing and conserving their inshore fishery resources by a voluntary scheme of co-management with the government. In general, villages manage their marine areas through establishment of village marine protected areas (MPAs) sometimes called VMPAs (to distinguish this program from federal or territorial MPAs). Because VMPAs are managed by local communities that have a direct interest in their success, compliance with bans on fishing is generally high, and most villages with MPAs actively enforce their own rules.

Richmond and Levine (2012) described the role of community-based marine resource management in American Samoa. Organized trips for specialized fishing are marked by much ceremony and tradition. While more frequent in the past, organized fishing efforts continue to take place in a few villages in American Samoa. Village-wide fish drives are timed with the tides and the spawning of certain species, and after these efforts, the fish are traditionally distributed to all village families who participated in the fishing.

2.3.3 People who Fish

Few studies have been conducted that include demographics or other information about people who fish in American Samoa. Information at the fishery level will be reported in the fishery specific sections below. Qualitative research has resulted in some general observations about trends in fishing by American Samoans.

One household survey by Levine et al. (2016) found that over half of residents participate in fishing or gathering of marine resources. Approximately 15% reported fishing once a week or more and over 30% of households stated that they engaged in fishing or gathering at least once a month. Commercial fishing is very uncommon in American Samoa, only 3% of those who fish stated that they frequently fished to sell their catch, and 62% never sell their catch. More commonly, people fish to feed themselves and their family, or to give to extended friends, family, pastors, and village leaders.

As described in Richmond and Levine (2012), nearshore fishing in American Samoa is still largely for subsistence purposes, and most nearshore fishermen do not sell their catch. A 2005 survey of 425 people from 34 villages found that 55% of respondents fished for subsistence to some degree, although most fished only infrequently (Kilarski et al., 2006). Of those who reported fishing, 72% fished once a week or less (44% of these fished only 1–2 times per month), while 16% fished 10 or more times per month. Thus, approximately 9% of the population surveyed could be considered “frequent subsistence fishermen.” The majority of survey respondents also indicated that fish were important not just for food and cultural use, but for maintenance of a healthy ecosystem.

As in the more recent study by Levine et al (2016), Kilarski et al. (2006) also found that most fishermen do not sell their catch. Only 12% of respondents sold fish, and more than half of those sold only once or twice a month. Only 10% of commercial sellers reported selling fish more than 10 times per month, suggesting a relatively low economic reliance on nearshore commercial fishing in the territory. Most respondents (64%) reported that they buy fish, indicating that localized fishing activities supply only a portion of locally consumed seafood. Fishermen also fished infrequently for cultural purposes, although as with other fisheries in the Western Pacific, cultural, subsistence, and recreational fishing categories are difficult to distinguish as one fishing outing could be motivated by all three reasons.

While fishing and marine resources are universally considered to be important aspects of fa’a Samoa, access to cash income has made American Samoans less inclined to engage in strenuous fishing activities when food imports are so readily available (Levine and Allen, 2009). Only a small number of American Samoans, engage in boat-based or commercial fishing. Although unemployment in the territory has increased, the percentage of individuals participating in subsistence activities (including fishing for food or home use) decreased between 2000 and 2013 (Grace McCaskey, 2015). However, a large number of island residents have been employed by the canneries in Pago Pago, which facilitated the ready availability of low-cost fish for many islanders, meaning the livelihood and economy of American Samoans are still tightly tied to fishing activities.

As noted by Levine and Allen (2009), the trend of decreasing reliance on local fish as a food source is reflective of a society that has been undergoing a shift from a subsistence-oriented economy to a cash economy. Changes such as a decrease in leisure time, a shift in dietary preferences towards store-bought foods or a preference to buy fish at the market rather than expend effort in fishing, and increased availability of inexpensive imported reef fish from Western Samoa and Tonga, also may be contributing to decreasing rates of subsistence fishing (Richmond and Levine, 2012).

2.3.4 Costs of Fishing

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

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

2.3.5 Bottomfish Fishery

Levine and Allen (2009) described the bottomfish fishery as part of their review of American Samoa as a fishing community. Prior to the arrival of Europeans in Samoa, the indigenous people had developed specialized techniques for catching bottomfish from outrigger canoes (paopao). Some of the bottomfish, such as trevally (malauli), held a particular social significance and were reserved for the matai chiefs.

In the early 1970s, the American Samoa Office of Economic Opportunity (OEO) funded the Dory Project, which provided easy credit and loans to fishermen to develop offshore fisheries. Records indicate that 70% of these dories were engaged in bottomfishing activities, conducted primarily at night on the shallow reef area around Tutuila. The result was an abrupt increase in the fishing fleet and total landings, but the limited nearshore bottomfish habitat meant that catch rates there declined rapidly and fishermen began to venture farther offshore to previously unexploited seamounts and banks to maintain profitable catch rates.

In the 1980s, dories were replaced by alia catamarans, larger, more powerful boats that could stay multiple days at sea. Alias primarily engaged in trolling and bottomfishing, with spearfishing, netting, and vertical longlining undertaken on occasion. Bottomfishing peaked between 1982 and 1988, with landings comprised as much as half of the total catch of the commercial fishery in American Samoa. In December 1980, a fish market opened in Fagatogo, which allowed fishermen to market their catch at a centralized, relatively sanitary location. Although the price for bottomfish rose between the 1970s and 1980s, it was still difficult for fishermen to make a profit from bottomfish sales due to competition with sales of inexpensive incidental catch from longline and purse seine vessels landing at the canneries.

Since 1988, there has been with a steady decrease in the importance of bottomfish fishing, as people converted to trolling and longlining for pelagic species, increasing fuel prices forced others out of the fishery, and imported fish from Western Samoa and Tonga became more available. Markrich and Hawkins (2016) noted that today there are fewer than 20 boats active in the bottomfish fishery. The demand for bottomfish varies depending on the need for fish at government and cultural events, though alia fishermen do return to bottomfish fishing during periods when longline catches or prices are low.

2.3.5.1 Commercial Participation, Landings, Revenues, Prices

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

2.3.6 Crustacean Fishery

In American Samoa, spiny lobsters constitute the bulk of the crustacean fishery (see Markrich and Hawkins, 2016 for description of this fishery). Lobsters are often present at important meals such as weddings, funerals and holidays. In the past, lobsters were typically harvested and consumed on the village/family level. They are now primarily caught by commercial fishermen in territorial waters and purchased at the market. Crustaceans harvested in American Samoa are processed at sea on the vessel and marketed as fresh product or as frozen lobster tails.

2.3.6.1 Commercial Participation, Landings, Revenues, Prices

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

2.3.7 Coral Reef Fishery

American Samoa’s nearshore fishing is focused on the narrow fringing coral reef that partially surrounds the islands (see Levine and Allen 2009, Richmond and Levine 2012). A diverse array of fish and shellfish is harvested by local residents on an almost daily basis. Most fishing is accomplished by individuals on foot in areas adjacent to their village. While the gender division in fishing is not as strict as it was in the past, women and children still predominantly engage in gathering shellfish and small fish in the intertidal zone, while men fish farther off shore. Traditionally, women were not permitted by Samoan custom to fish outside the reef. Common fishing techniques included intertidal gleaning, diving, rod and reel, netting and trapping (including communal fish drives), and boat-based fishing.

There are a number of traditional fisheries associated with seasonal run of certain species. Atule, or bigeye scad, is a coastal migratory species that spawns in mass near shore. Atule are caught through a village-wide effort in some areas where they spawn, with villagers driving the fish to a central location to be harvested. I'asina (juvenile goatfish) are caught in hand-woven funnel traps called enu. Thousands of i'asina may appear along sandy shorelines during the months of October–April. The palolo worm *(Palola viridis)*, a coral-dwelling polychaete worm, is another unique species that is caught in large numbers in the Samoa Islands during spawning events. Palolo generally emerge once a year, one week after the full moon in October or November, to release their reproductive segments (epitokes) into nearshore waters. These epitokes are a local delicacy, and Samoans will gather in the thousands at midnight on the predicted spawning event to collect them in hand nets and screens.

Despite increasing levels of participation in the commercial fishing industry in American Samoa, most nearshore fishermen do not sell their catch. Traditionally, fish in American Samoa were not sold, but were shared with others or distributed amongst the community. Many American Samoans still believe that some species such as the palolo should not be sold as this will ruin catches in future years. Sharing fish amongst the wider village community is still an important cultural practice. For example, atule are divided equally amongst village members after a group harvesting event, and palolo is still distributed to family members, with a portion reserved and given to village pastors. However, since the advent of refrigeration, people are more likely to catch more fish during these mass spawning events and share them less, as the fish can be stored for longer periods.

The American Samoa Department of Marine and Wildlife Sources (DMWR) has conducted inshore creel surveys along the southern shore of Tutuila Island since 1990. They documented a significant decrease in the level of shoreline fishing effort over the past three decades, which has also been noted by others, despite the increase in the human population over the same time period.

Studies that have examined how residents value coral reef resources have found that most people perceive coral reefs as an important source of food, as well as providing nonuse benefits related to social, cultural, and biodiversity aspects (Levine and Allen 2009, Levine et al 2016). Less importance was placed on ecosystem, recreational benefits, shoreline protection, or other direct use benefits. Because there is relatively little tourism, the economic value of American Samoa’s coral reefs is estimated to be somewhat lower than other islands in the Western Pacific; an analysis in 2004 estimated their value at $5 million per year (Grace-McCaskey 2014).

2.3.7.1 Commercial Participation, Landings, Revenues, Prices

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

2.3.8 Precious Coral Fishery

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

2.3.8.1 Commercial Participation, Landings, Revenues, Prices

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

2.3.9 Ongoing Research and Information Collection

Social indicators are being compiled for American Samoa, following the methodology for the national project to describe and evaluate community well-being in terms of social, economic, and psychological welfare (https://www.st.nmfs.noaa.gov/humandimensions/social-indicators/index). In addition, a web-based tool is being developed to compile relevant socioeconomic data into a "Community Snapshot" by Census County Division or equivalent.

2.3.10 Relevant PIFSC Economics and Human Dimensions Publications: 2016

No publications specific to American Samoa were produced in 2016.

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Western Pacific Regional Fishery Management Council. 2016b. Minutes of the 168th Meeting of the Western Pacific Regional Fishery Management Council. Honolulu, HI. 124 p.

2.4 PROTECTED SPECIES

This section of the report summarizes information on protected species interactions in fisheries managed under the American Samoa 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), Marine Mammal Protection Act (MMPA), and/or Migratory Bird Treaty Act (MBTA). A list of protected species found in or near American Samoa waters and a list of critical habitat designations in the Pacific Ocean are included in Appendix B.

2.4.1 Indicators for Monitoring Protected Species Interactions in the American Samoa FEP Fisheries

This report monitors the status of protected species interactions in the American Samoa FEP fisheries using proxy indicators such as fishing effort and changes in gear types as these fisheries do not have observer coverage. Creel surveys and logbook programs are not expected to provide reliable data about protected species interactions. Discussion of protected species interactions is focused on fishing operations in federal waters and associated transit through Territorial waters.

2.4.1.1 FEP Conservation Measures

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

2.4.1.2 ESA Consultations

ESA consultations were conducted by NMFS and the U.S. Fish and Wildlife Service (for species under their jurisdiction including seabirds) to ensure ongoing fisheries operations managed under the American Samoa FEP are not jeopardizing the continued existence of any listed species or adversely modifying critical habitat. The results of these consultations conducted under section 7 of the ESA are briefly described below and summarized in **Error! Reference source not found.**

Table 30. Summary of ESA consultations for American Samoa FEP Fisheries

Fishery	**Consultation date**	**Consultation type**[a]	**Outcome**[b]	**Species**
Bottomfish	3/8/2002	BiOp	NLAA	Blue whale, fin whale, green sea turtle, hawksbill sea turtle, humpback whale, leatherback sea turtle, loggerhead sea turtle, olive ridley sea turtle, sei whale, sperm whale

Fishery	**Consultation date**	**Consultation type**[a]	**Outcome**[b]	**Species**
Coral reef ecosystem	3/7/2002	LOC	NLAA	Blue whale, fin whale, green sea turtle, hawksbill sea turtle, humpback whale, leatherback sea turtle, loggerhead sea turtle, olive ridley sea turtle, sei whale, sperm whale
	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
Crustaceans	9/28/2007	LOC	NLAA	Blue whale, fin whale, green sea turtle, hawksbill sea turtle, humpback whale, leatherback sea turtle, loggerhead sea turtle, olive ridley sea turtle, sei whale, sperm whale
Precious corals	10/4/1978	BiOp	Does not constitute threat	Leatherback sea turtle, sperm whale
	12/20/2000	LOC	NLAA	Green sea turtle, hawksbill sea turtle, humpback whale
All fisheries	4/9/2015	LOC	NLAA	Reef-building corals, scalloped hammerhead shark (Indo-West Pacific DPS)

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

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

Bottomfish Fishery

In a biological opinion issued on March 3, 2002, NMFS concluded that the ongoing operation of the Western Pacific Region’s bottomfish and seamount groundfish fisheries is not likely to jeopardize the continued existence of five sea turtle species (loggerhead, leatherback, olive ridley, green and hawksbill turtles) and five marine mammal species (humpback, blue, fin, sei and sperm whales). NMFS also concluded in an informal consultation dated April 9, 2015 that fisheries managed under the American Samoa FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

Crustacean Fishery

An informal consultation completed by NMFS on September 28, 2007 concluded that American Samoa crustacean fisheries are not likely to adversely affect five sea turtle species (loggerhead, leatherback, olive ridley, green and hawksbill turtles) and five marine mammal species (humpback, blue, fin, sei and sperm whales). NMFS also concluded in an informal consultation dated April 9, 2015 that fisheries managed under the American Samoa FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

Coral Reef Ecosystem Fishery

An informal consultation completed by NMFS on March 7, 2002 concluded that the American Samoa coral reef ecosystem fisheries are not likely to adversely affect five sea turtle species (loggerhead, leatherback, olive ridley, green and hawksbill turtles) and five marine mammal species (humpback, blue, fin, sei and sperm whales). NMFS also concluded in an informal consultation dated April 9, 2015 that fisheries managed under the American Samoa FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

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).

Precious Coral Fishery

In a biological opinion issued on October 4, 1978, NMFS concluded that the ongoing operation of the Western Pacific Region's precious coral fisheries was not likely to jeopardize the continued existence of any threatened or endangered species under NMFS's jurisdiction or destroy or adversely modify critical habitat. An informal consultation completed by NMFS on December 20, 2000 concluded that American Samoa precious coral fisheries are not likely to adversely affect humpback whales, green turtles or hawksbill turtles. An additional informal consultation completed by NMFS on April 9, 2015 concluded that fisheries managed under the American Samoa FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark and ESA-listed reef-building corals.

2.4.1.3 Non-ESA Marine Mammals

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

2.4.2 Status of Protected Species Interactions in the American Samoa FEP Fisheries

Bottomfish Fishery

There are no observer data available for the American Samoa bottomfish fishery. However based on the information in the 2002 BiOp for fisheries operating under the American Samoa FEP, these fisheries are not expected to interact with any ESA-listed species in Federal waters around American Samoa. NMFS has also concluded that the American Samoa bottomfish commercial fisheries will not affect marine mammals in any manner not considered or authorized under the Marine Mammal Protection Act.

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

Crustacean Fishery

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

Coral Reef Fishery

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

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

Precious Coral Fishery

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

2.4.3 Identification of Emerging Issues

Several species are currently candidates for listing under the ESA, and several more ESA-listed species are being evaluated for critical habitat designation (Table 31). 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 31. Candidate ESA species, and ESA-listed species being evaluated for critical habitat designation.

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

2.4.4 Identification of Research, Data and Assessment Needs

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

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

2.5 CLIMATE AND OCEANIC INDICATORS

2.5.1 Introduction

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

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

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

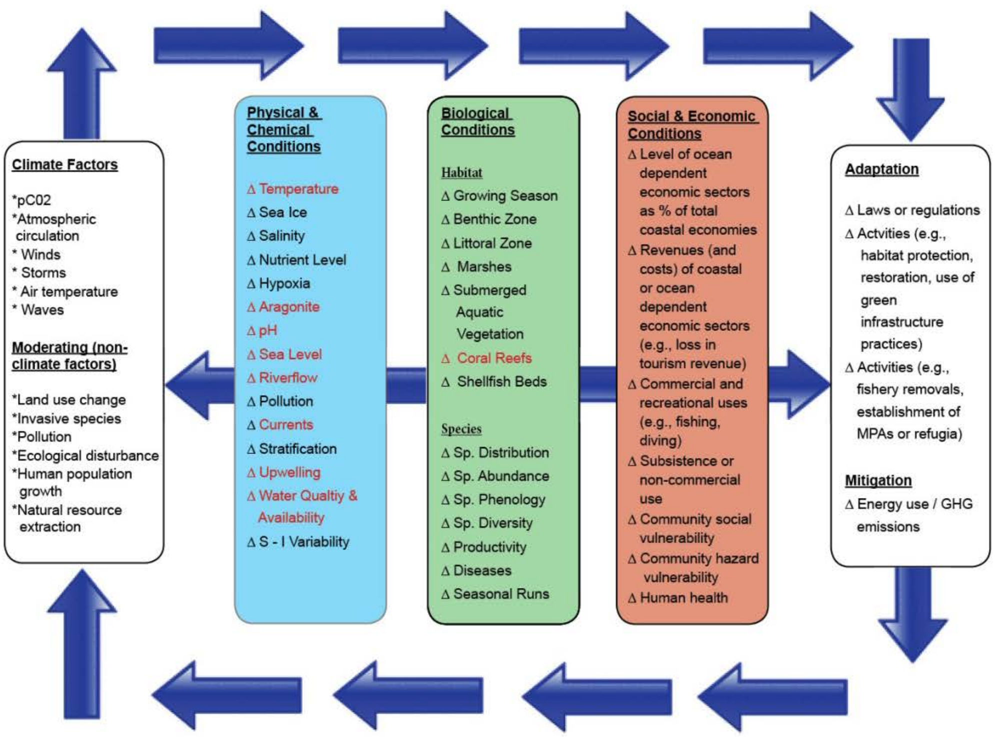
2.5.2 Conceptual Model

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

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

Indicators of Change to Archipelagic Coastal and Marine Systems*

(Items in red to be monitored for 2015 Annual Reports of the Archipelagic Fishery Ecosystem Plans for the Western Pacific Region)



**Adapted from National Climate Assessment and Development Advisory Committee. February 2014. National Climate Indicators System Report. B-59.*

Figure 6. Indicators of change to archipelagic coastal and marine systems.

As described in the 2014 NCADAC report, the conceptual model represents a “simplified representation of climate and non-climate stressors in coastal and marine ecosystems.” For the purposes of this Annual Report, the modified Conceptual Model allows the Council and its partners to identify indicators of interest to be monitored on a continuing basis in coming years. The indicators shown in red were considered for inclusion in the 2016 Annual Report; the specific indicators used in the Report are listed in Section 2.3. Other indicators will be added over time as datasets become available and understanding of the nature of the causal chain from stressors to impacts emerges.

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

2.5.3 Selected Indicators

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

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

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

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

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

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

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

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

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

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

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

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

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

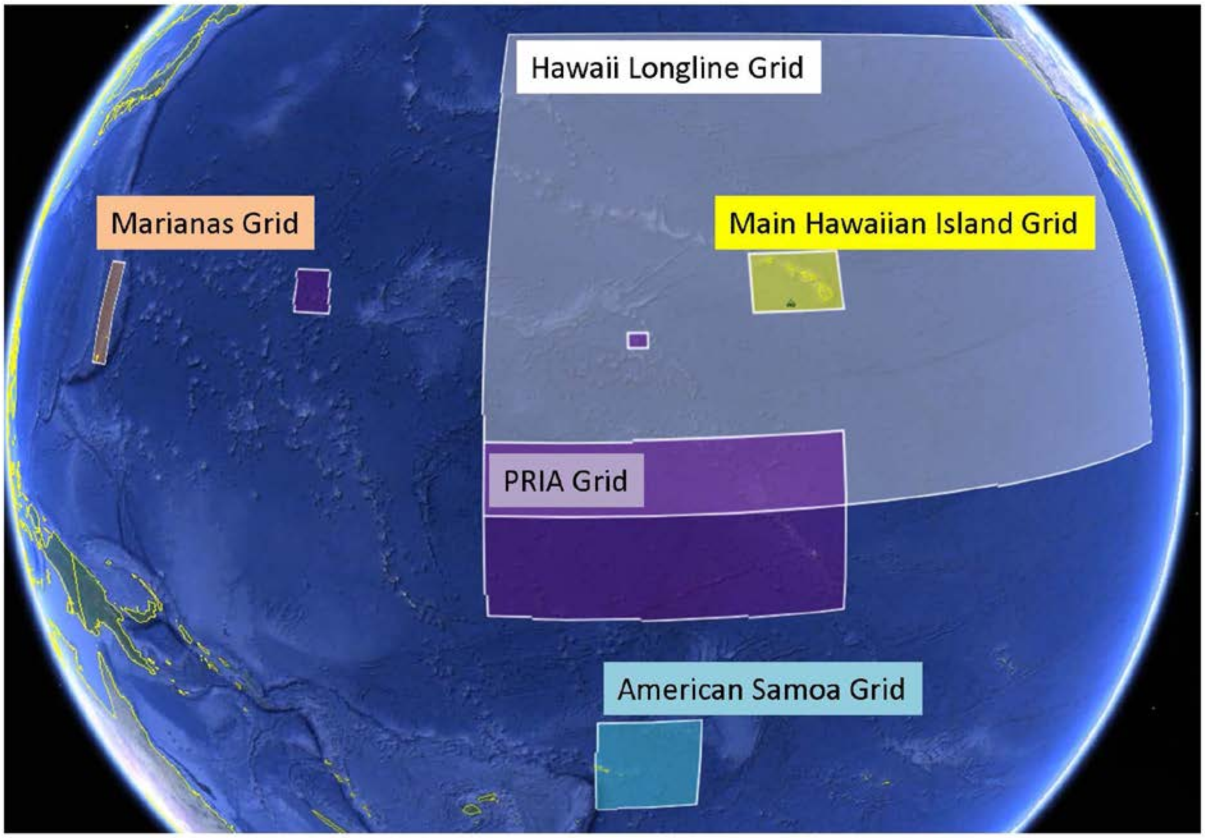


Figure 7. Regional Spatial Grids

Table 32. 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
Oceanic Niño Index (ONI)	Sea surface temperature anomaly from Niño 3.4 region (5°N - 5°S, 120° - 170°W). This index is used to determine the phase of the El Niño – Southern Oscillation (ENSO), which has implications across the region, affecting migratory patterns of key commercial fish stocks which in turn affect the location, safety, and costs of commercial fishing.	2015: Strong El Niño 2016: weak La Niña dissipating, potential rapid return to El Niño
Pacific Decadal Oscillation (PDO)	The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period).	2016: Strong Positive Phase
Sea Surface Temperature[1] (SST)	Satellite remotely-sensed sea surface temperature. SST is projected to rise, and impacts phenomena ranging from winds to fish distribution.	SST in waters surrounding most of American Samoa ranged between 29-30º C with waters around Rose Atoll ranging between 28-29º C in 2015.
Degree Heating Weeks (DHW)	Satellite remotely-sensed sea surface temperature, transformed to a metric relevant for coral bleaching. Each degree heating week indicates a one degree excess over long term summer means (Maximum Monthly Mean SST), that persists for a week. At 4 DHW, bleaching is expected, at 8 DHW bleaching is expected to be widespread and to induce mortality.	2015 showed extreme high temperature anomalies, with values surpassing 8 DHW in 2015
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

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[1] 2016 data are incomplete.

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.	Although varying over time the monthly mean sea level trend is increasing.
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 west (1.5-2.0m) increasing to the east where significant wave heights near Rose Atoll were in the 2.0-2.5 m on average.

2.5.1.1 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.

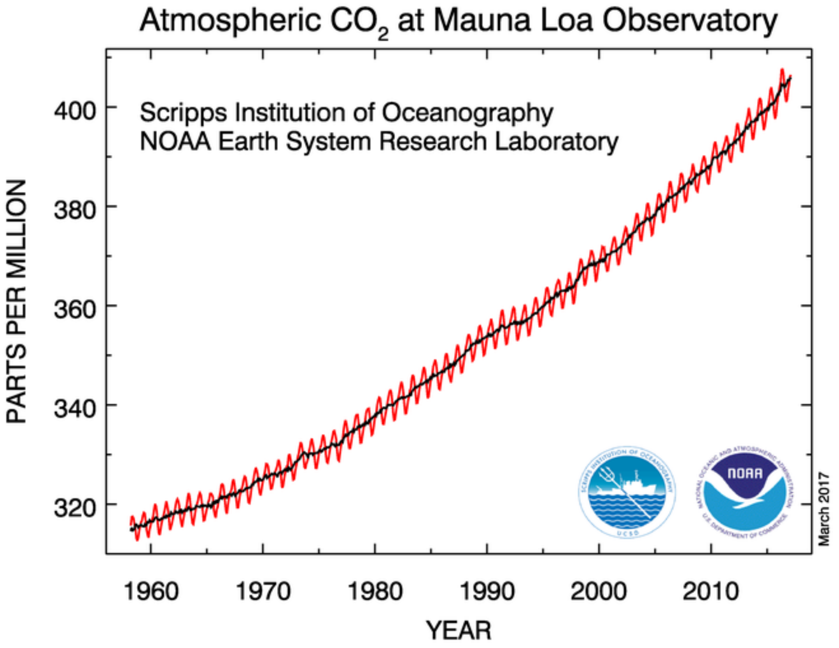


Figure 8. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data.

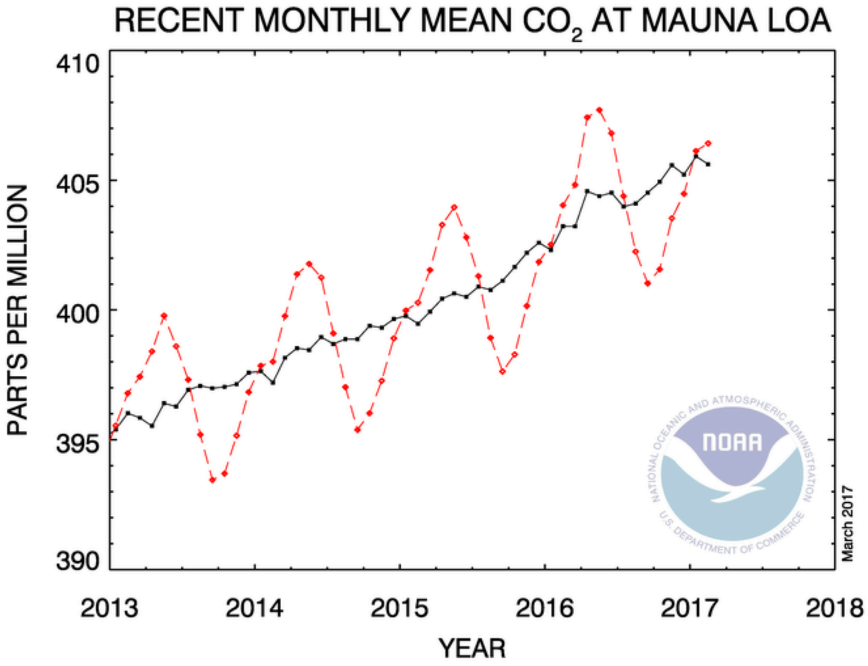


Figure 9. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii, 2013-2017. The carbon dioxide data (red curve), measured as the mole fraction (ppm) in dry air, on Mauna Loa. The black curve represents the seasonally corrected data.

2.5.3.1 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.

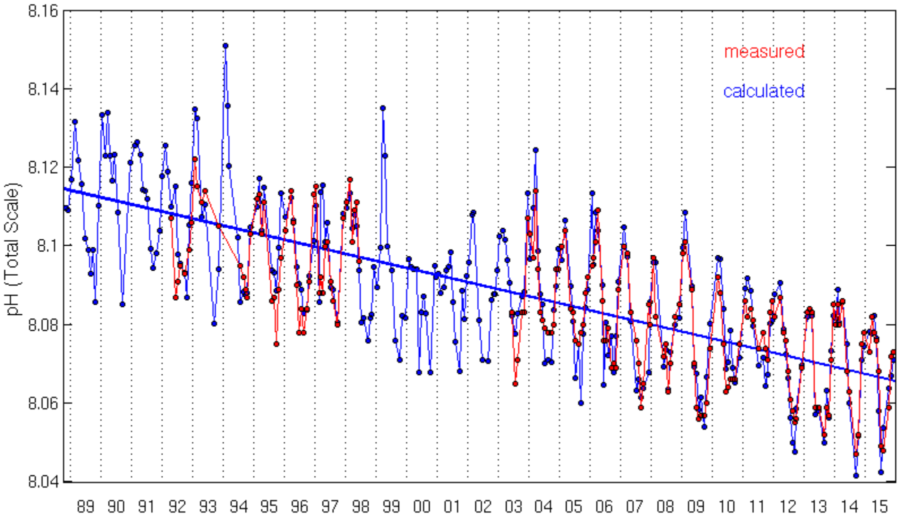


Figure 10. pH Trend at Station Aloha, 1989-2015.

2.5.3.2 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.

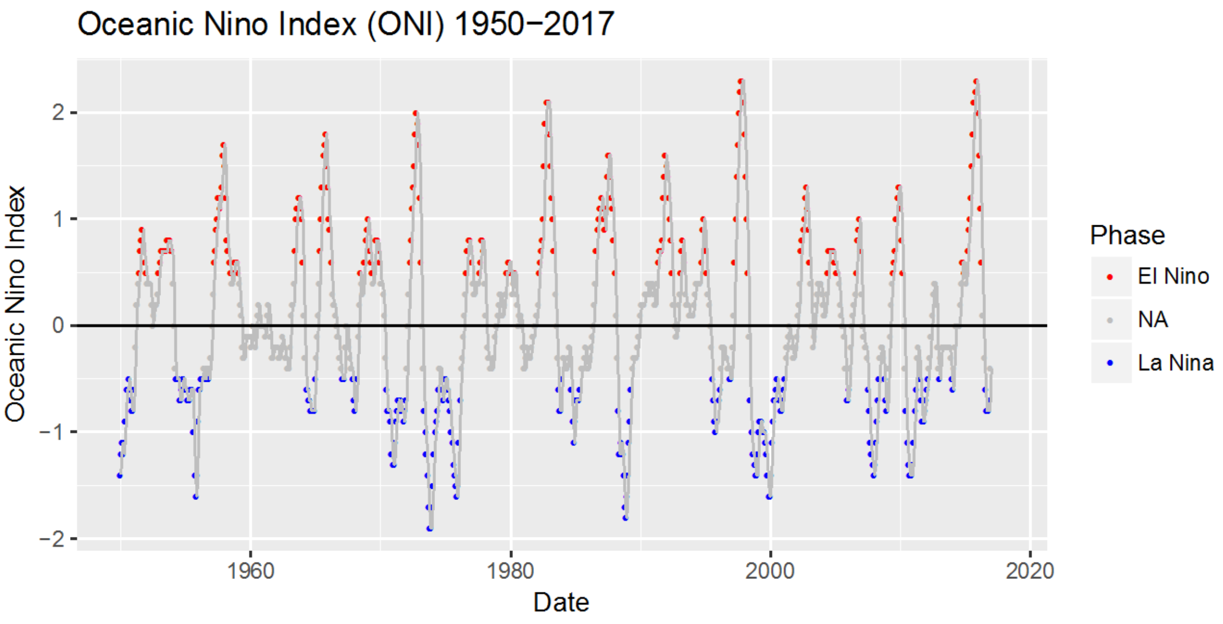


Figure 11. Oceanic Nino Index, 1950-2017.

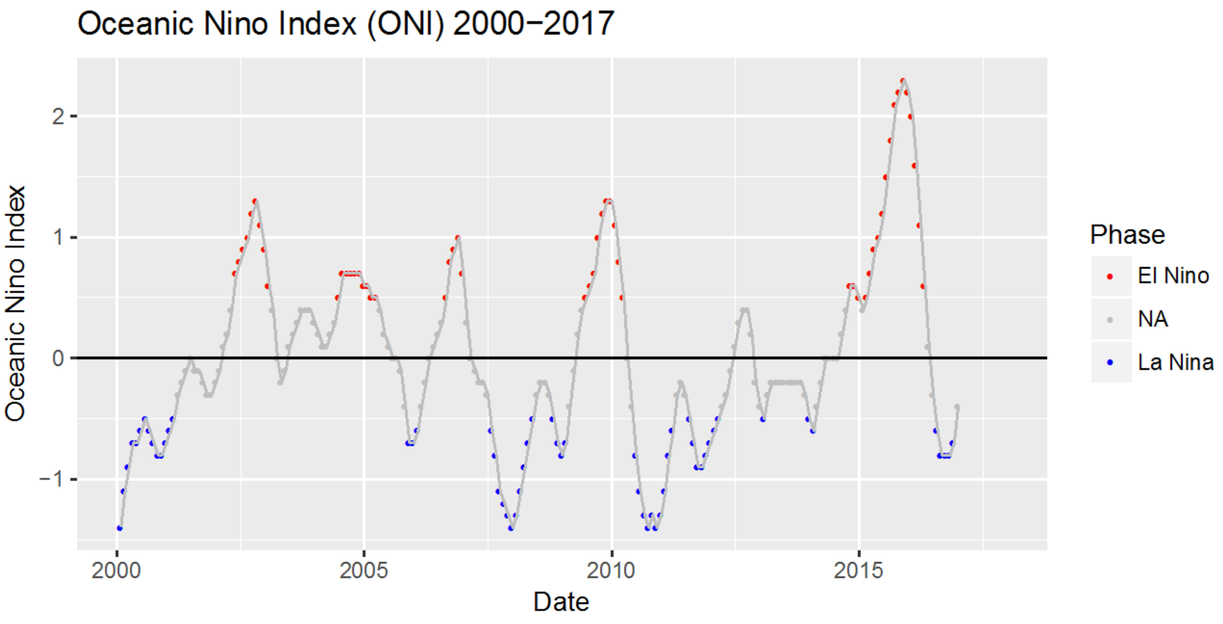


Figure 12. Oceanic Nino Index, 2000-2017.

2.5.1.2 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.

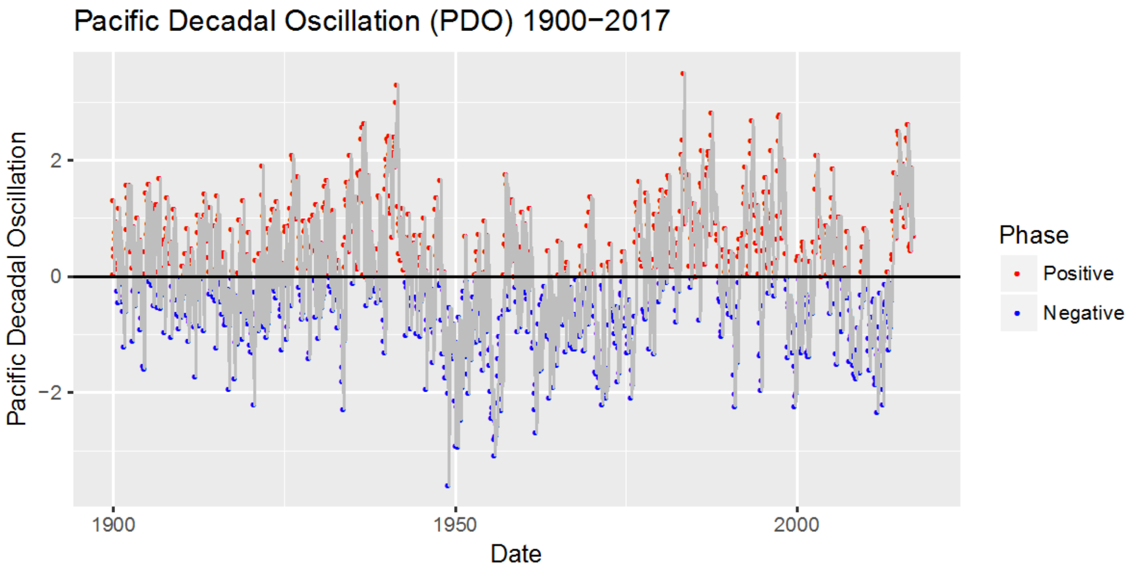


Figure 13. Pacific Decadal Oscillation, 1900-2017.

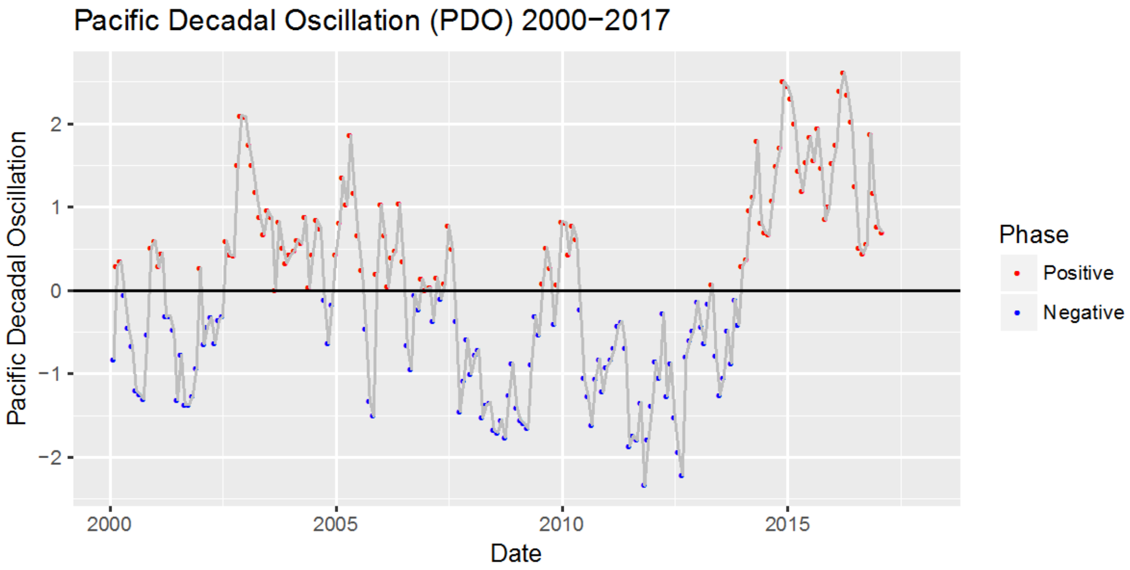
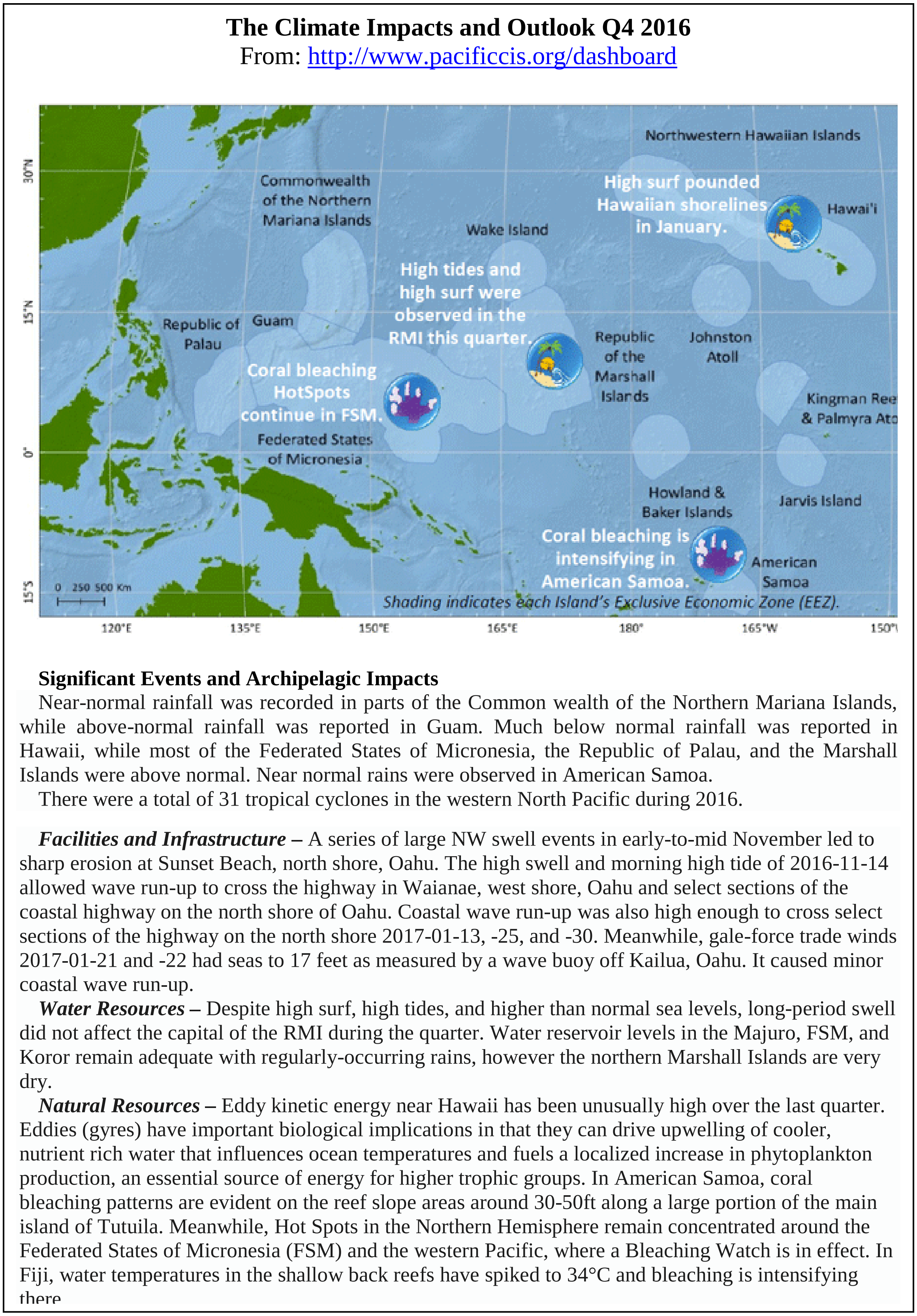


Figure 14. Pacific Decadal Oscillation, 2000-2017.



The Climate Impacts and Outlook Q4 2016

From: http://www.pacificcis.org/dashboard

Significant Events and Archipelagic Impacts

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

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

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

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

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

Figure 15. Q4 2016 Climate Impact and Outlook Infographic.

2.5.3.3 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.

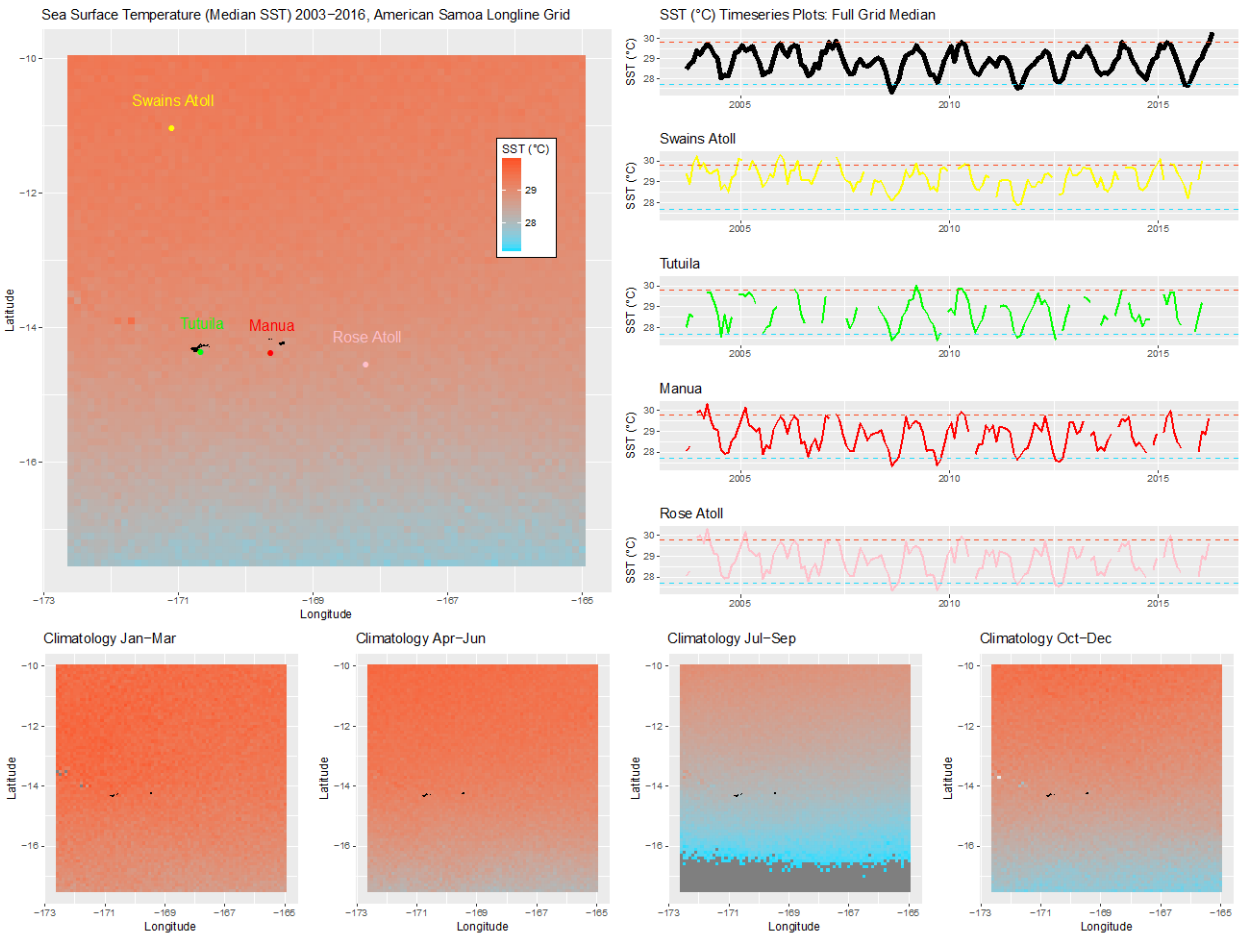


Figure 16. **Sea surface temperature plots**

2.5.3.4 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.

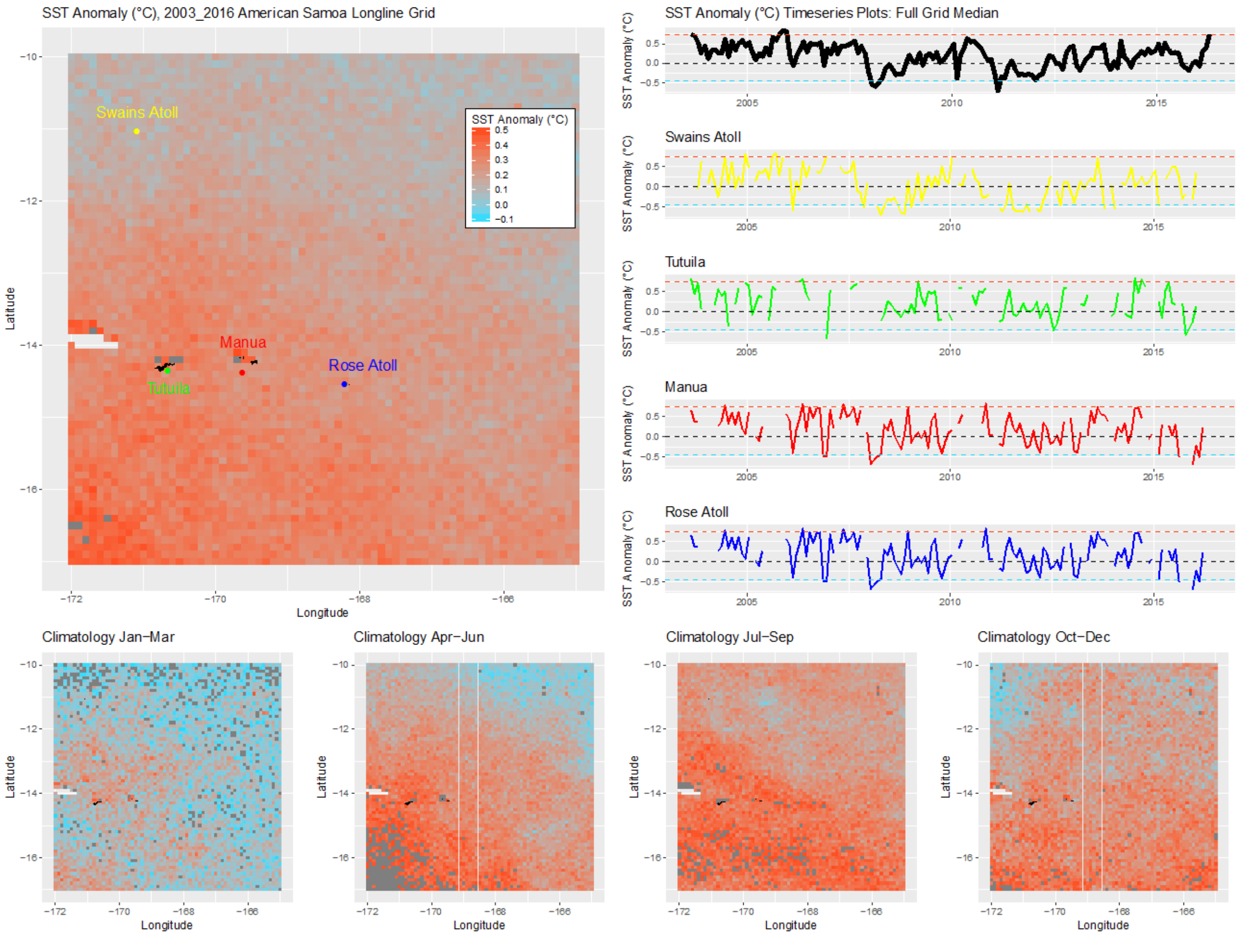


Figure 17. **Sea surface temperature anomaly**

2.5.3.5 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.

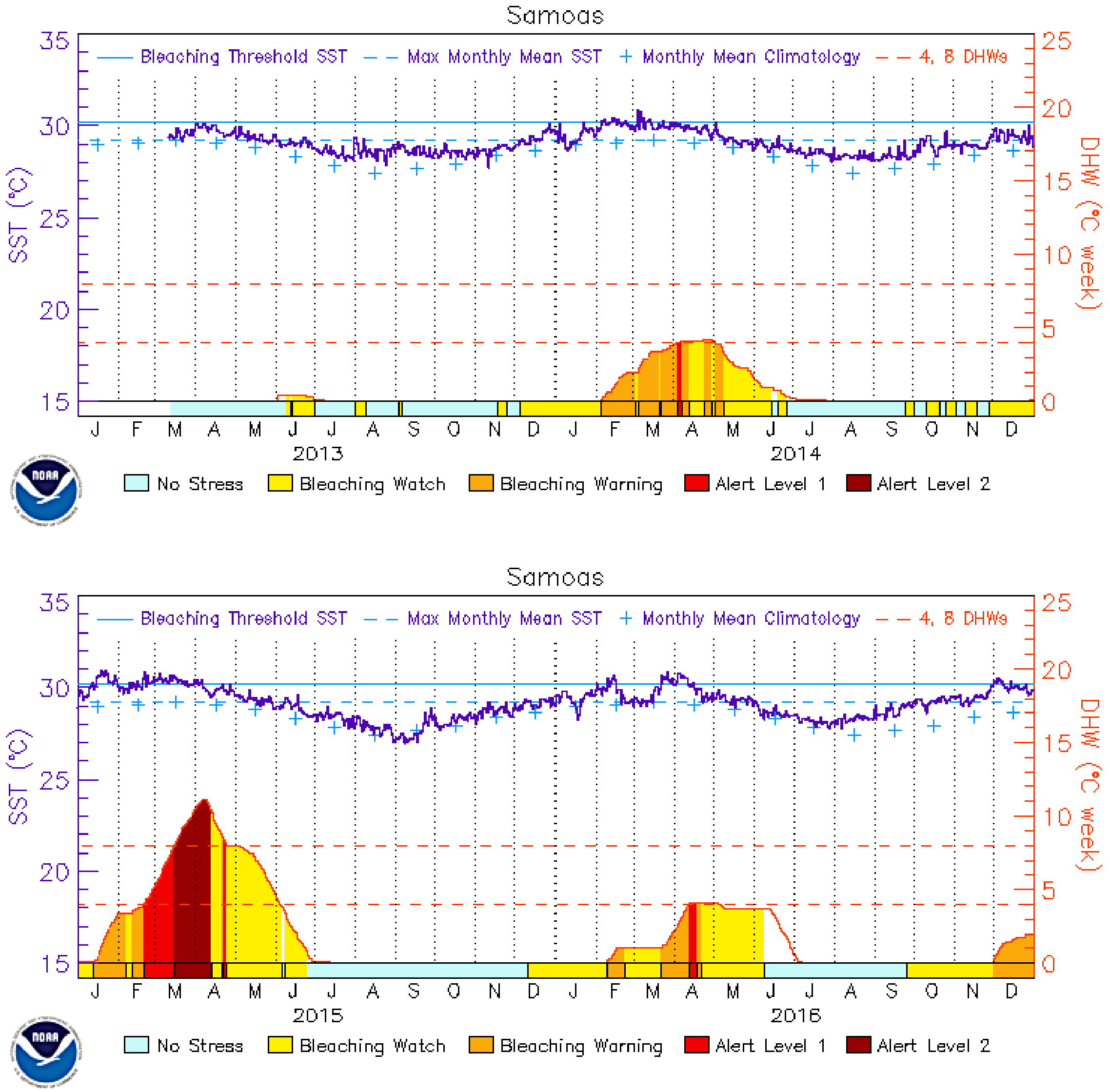


Figure 18. Degree Heating Weeks Timeseries in the Samoan Archipelago 2013-2016.

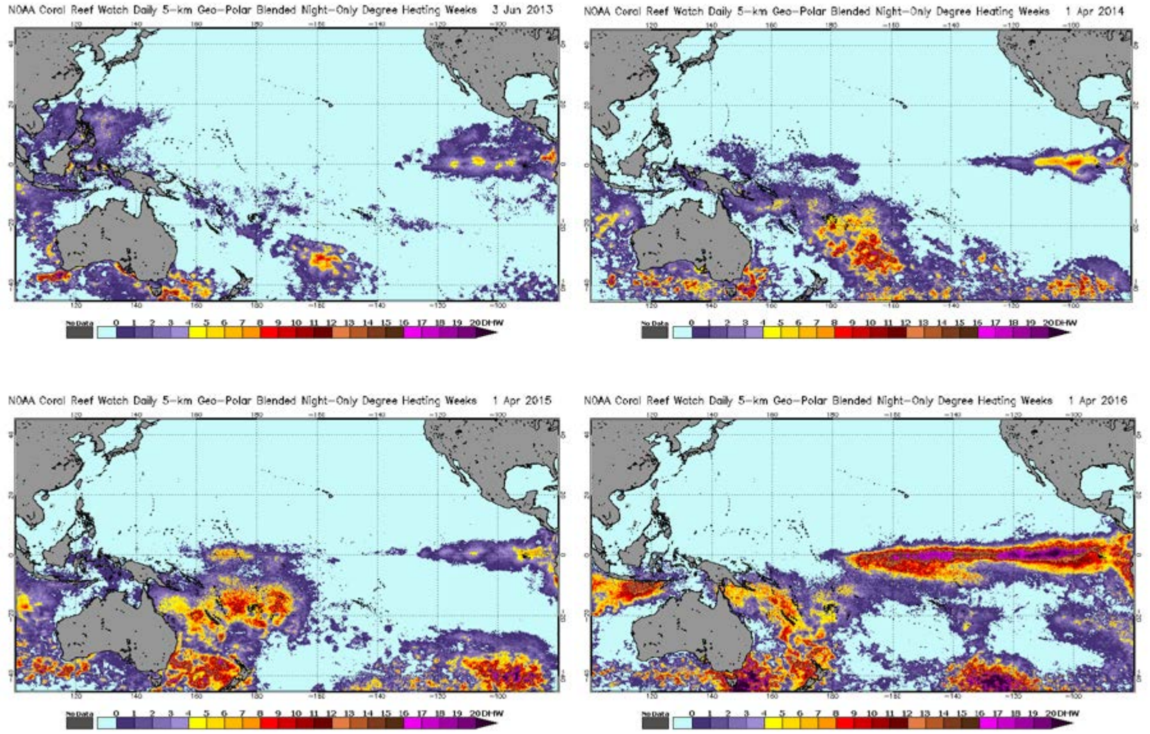


Figure 19. Degree Heating Weeks Maps, showing Annual DHW Maximum (Jun 3, 2013; Apr 1, 2014-2016) across the Pacific Ocean.

2.5.1.3 Heavy Weather (Tropical Cyclones)

Description: This indicator uses historical data from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) International Best Track Archive for Climate Stewardship (IBTrACS) to track the number of tropical cyclones in the western, central, and south Pacific basins. This indicator also monitors the Accumulated Cyclone Energy (ACE) Index and the Power Dissipation Index (PDI) which are two ways of monitoring the frequency, strength, and duration of tropical cyclones based on wind speed measurements.

The annual frequency of storms passing through the western North Pacific basin is tracked and a stacked time series plot will show the representative breakdown of the Saffir-Simpson hurricane categories. Three solid lines across the graph will also be plotted representing a) the annual long-term average number of named storms, b) the annual average number of typhoons, and c) the annual average number of major typhoons (Cat 3 and above). Three more lines will also be shown (in light gray) representing the annual average number of named-storms for ENSO a) neutral, b) warm, and c) cool.

Every cyclone has an ACE Index value, which is a number based on the maximum wind speed measured at six-hourly intervals over the entire time that the cyclone is classified as at least a tropical storm (wind speed of at least 34 knot; 39 mph). Therefore, a storm's ACE Index value accounts for both strength and duration. This plot will show the historical ACE values for each typhoon season and will have a solid line representing the annual average ACE value. Three more lines will also be shown (in light gray) representing the annual average ACE values for ENSO a) neutral, b) warm, and c) cool.

Timeframe: Yearly

Region/Location: Hawaii and U.S. Affiliated Pacific Islands

Data Source/Responsible Party: NCDC's International Best Track Archive for Climate Stewardship (IBTrACS).

Measurement Platform: Satellite

Rationale: The effects of tropical cyclones are numerous and well-known. At sea, storms disrupt and endanger shipping traffic as well as fishing effort and safety. The Hawaii longline fishery, for example, had serious problems between August and November 2015 with vessels dodging storms at sea, delayed departures and inability to make it safely back to Honolulu because of bad weather. When cyclones encounter land, their intense rains and high winds can cause severe property damage, loss of life, soil erosion, and flooding. The associated storm surge, the large volume of ocean water pushed toward shore by the cyclone's strong winds, can cause severe flooding and destruction.

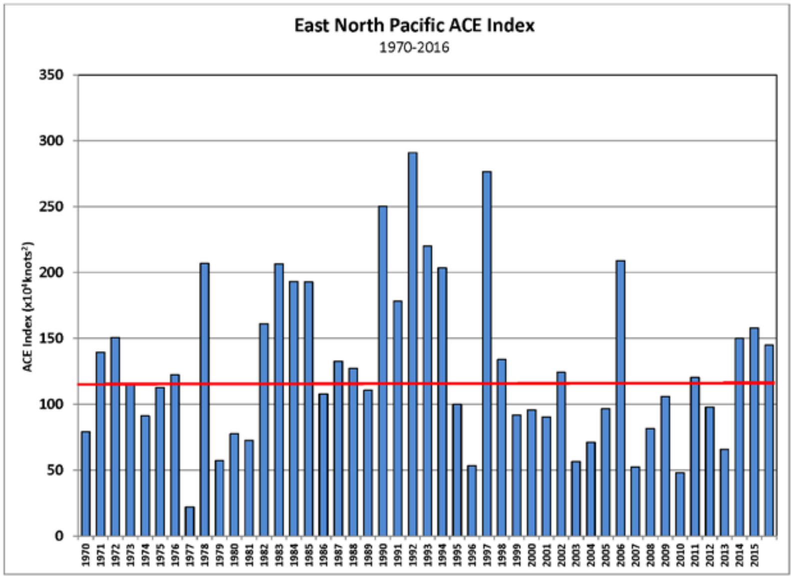


Figure 20. 2016 East Pacific Tropical Cyclone ACE 1970-2016. Source: NOAA's National Hurricane Center

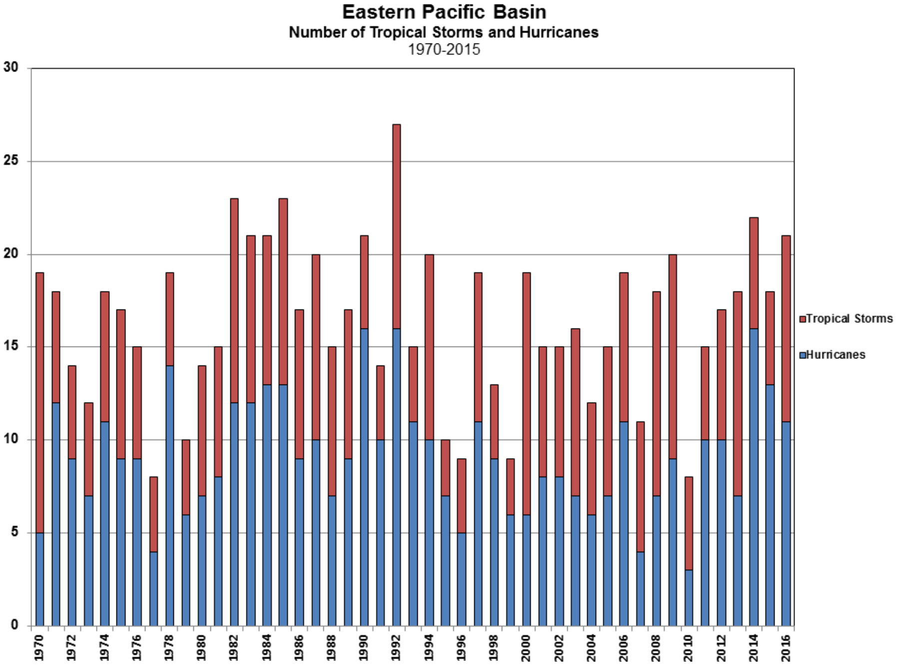
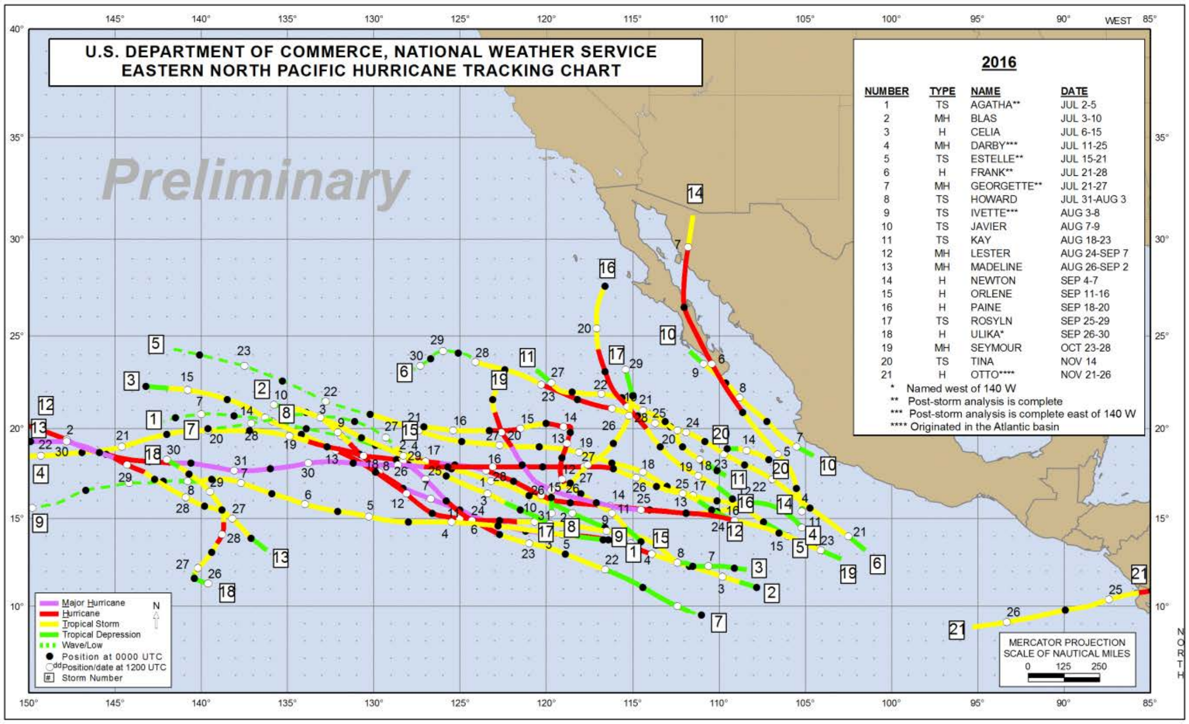


Figure 21. East Pacific tropical cyclone count 1970-2016. Source: NOAA's National Hurricane Center



2016

NUMBER	TYPE	NAME	DATE
1	TS	AGATHA**	JUL 2-5
2	MH	BLAS	JUL 3-10
3	H	CELIA	JUL 6-15
4	MH	DARBY***	JUL 11-25
5	TS	ESTELLE**	JUL 15-21
6	H	FRANK**	JUL 21-28
7	MH	GEORGETTE**	JUL 21-27
8	TS	HOWARD	JUL 31-AUG 3
9	TS	IVETTE***	AUG 3-8
10	TS	JAVIER	AUG 7-9
11	TS	KAY	AUG 18-23
12	MH	LESTER	AUG 24-SEP 7
13	MH	MADELINE	AUG 26-SEP 2
14	H	NEWTON	SEP 4-7
15	H	ORLENE	SEP 11-16
16	H	PAINE	SEP 18-20
17	TS	ROSYLN	SEP 25-29
18	H	ULIKA*	SEP 26-30
19	MH	SEYMOUR	OCT 23-28
20	TS	TINA	NOV 14
21	H	OTTO****	NOV 21-26

* Named west of 140 W
** Post-storm analysis is complete
*** Post-storm analysis is complete east of 140 W
**** Originated in the Atlantic basin

Figure 22. 2016 Eastern Pacific Tropical Cyclone Tracks. Source: NOAA's National Hurricane Center

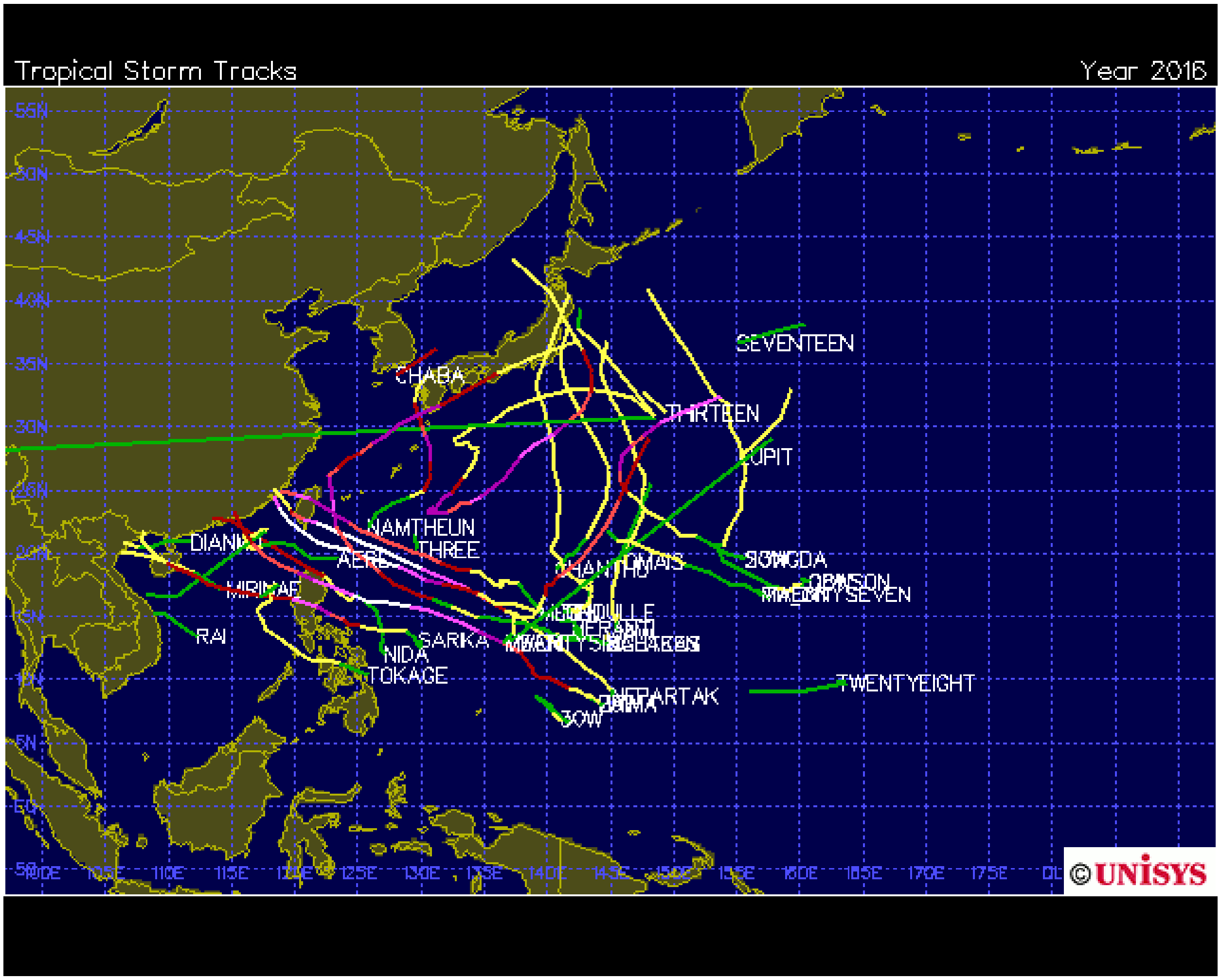


Figure 23. Western Pacific Cyclone Tracks 2016. Source: http://weather.unisys.com/hurricane/w_pacific/2016

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

2.5.3.6 Sea Level (Sea Surface Height and Anomaly)

Description: Monthly mean sea level time series, including extremes

Timeframe: Monthly

Region/Location: Observations from selected sites within the Hawaiian Archipelago

Data Source/Responsible Party: Basin-wide context from satellite altimetry:
http://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/el-nino-bulletin.html

Quarterly time series of mean sea level anomalies from satellite altimetry:
http://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/archive/index.cfm?y=2015

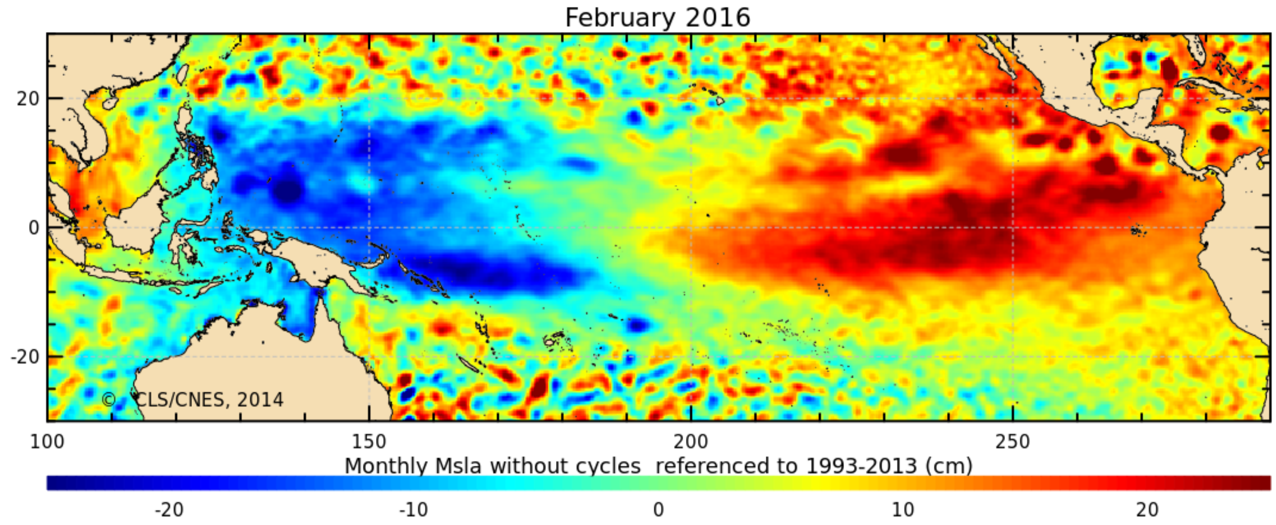
Sea Surface Height and Anomaly from NOAA Ocean Service, Tides and Currents, Sea Level Trends https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1612340

Measurement Platform: Satellite and *in situ* tide gauges

Rationale: Rising sea levels can result in a number of coastal impacts, including inundation of infrastructure, increased damage resulting from storm-driven waves and flooding, and saltwater intrusion into freshwater supplies.

2.5.3.6.1 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.



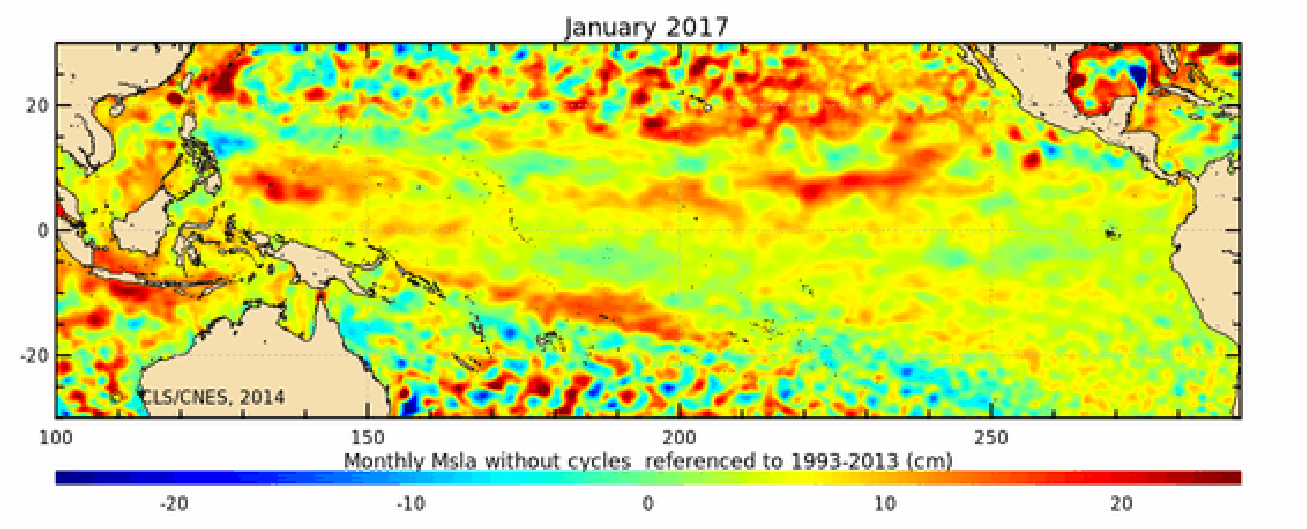
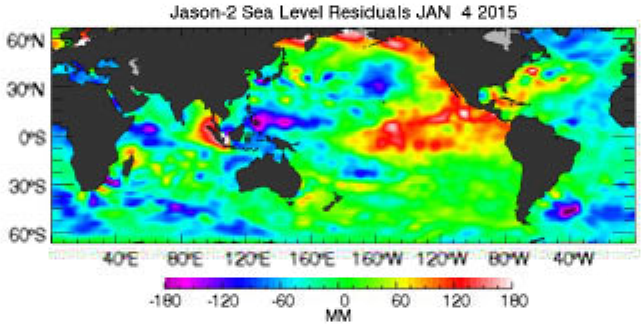
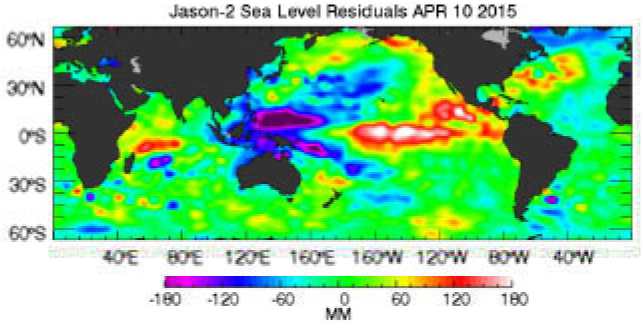
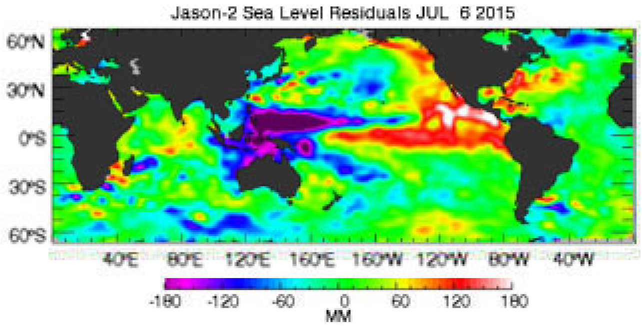
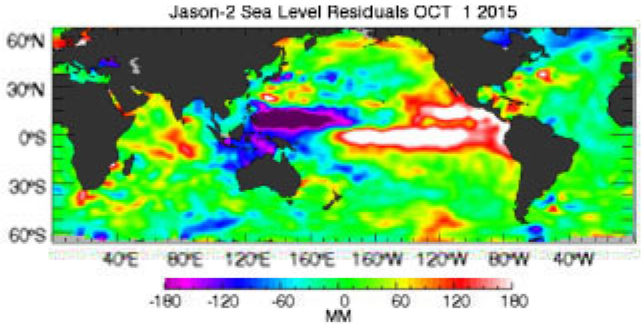


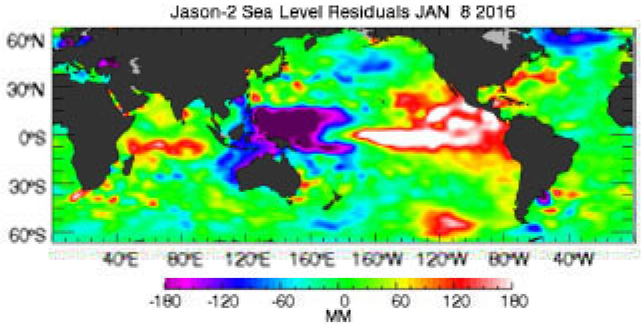
Figure 24. Comparing mean sea level anomaly for February 2016 (El Niño), and January 2017 (Neutral) .



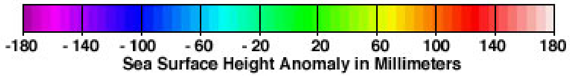


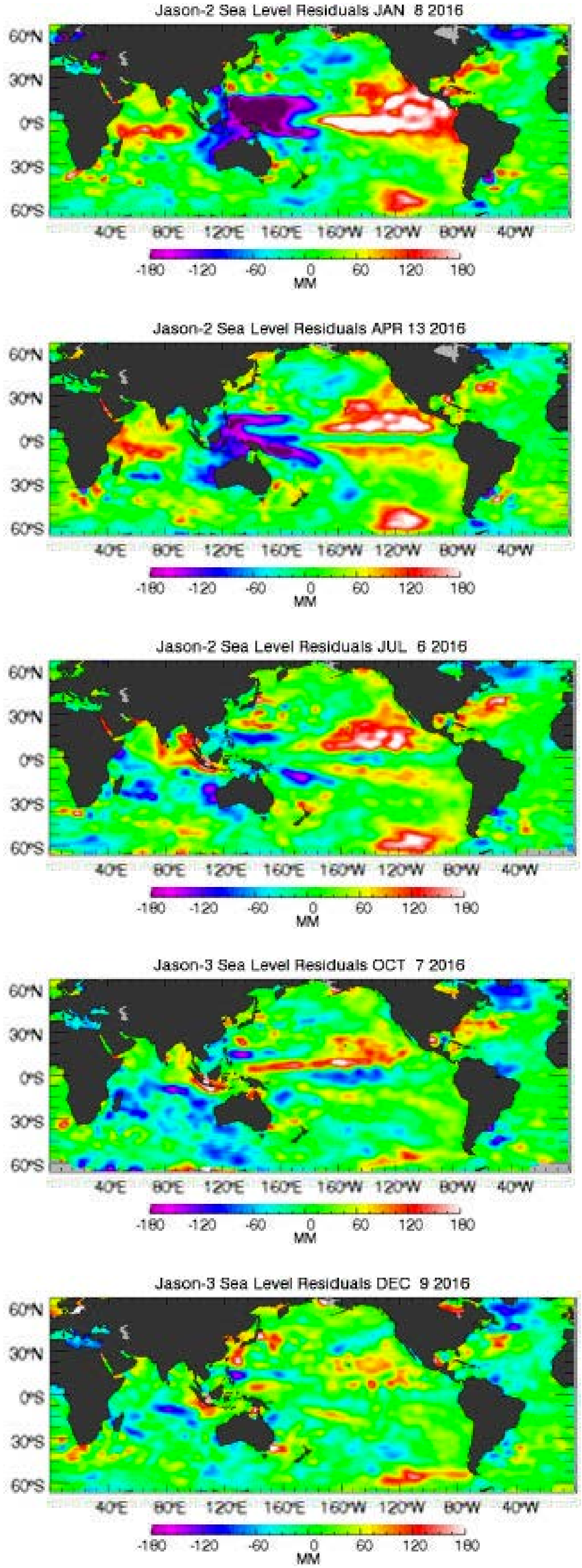




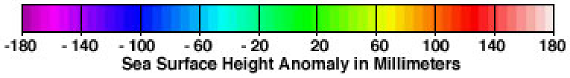


Quarterly time series of mean sea level anomalies during 2015 provide a glimpse into the evolution of the 2015-2016 El Niño throughout the year using satellite altimetry measurements of sea level height (http://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/archive/index.cfm?y=2015)





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



2.5.3.6.2 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=1770000.

Figure 25 shows the monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The long-term linear trend is also shown, including its 95% confidence interval. The plotted values are relative to the most recent Mean Sea Level datum established by CO-OPS. The calculated trends for all stations are available as a table in millimeters/year and in feet/century (0.3 meters = 1 foot). If present, solid vertical lines indicate times of any major earthquakes in the vicinity of the station and dashed vertical lines bracket any periods of questionable data or datum shift.

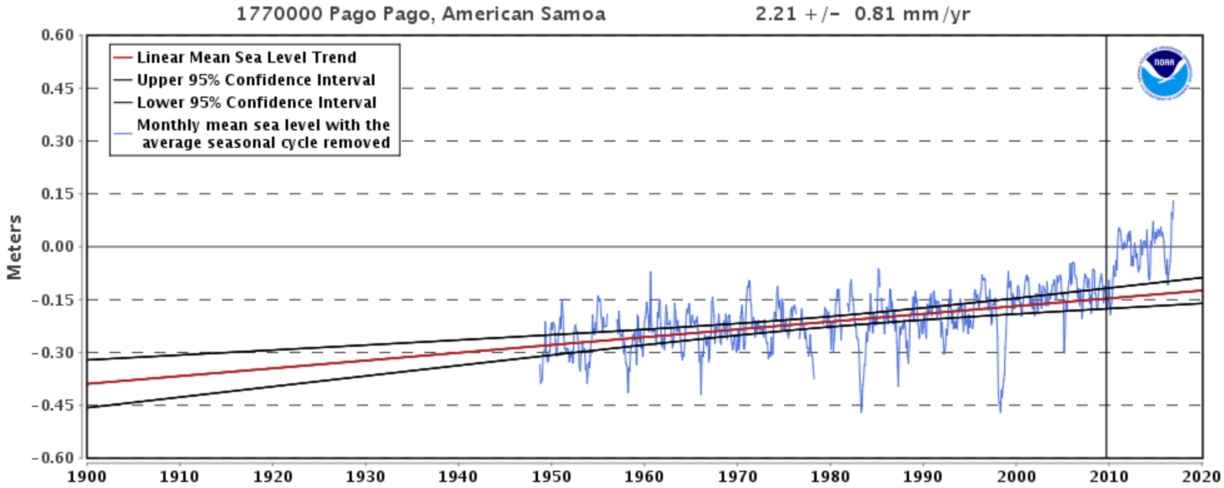


Figure 25. Monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents.

Figure 26 show 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.

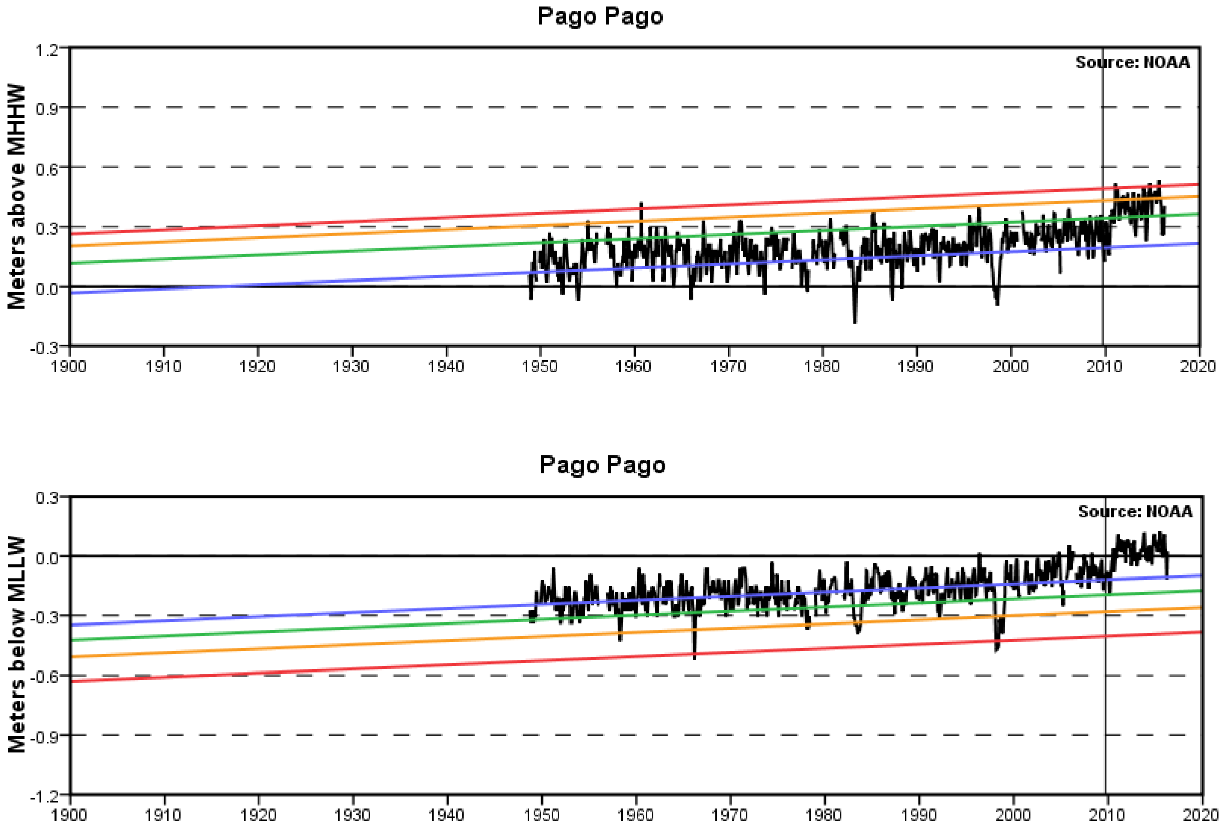


Figure 26**. The monthly extreme water levels include a Mean Sea Level (MSL) trend of 2.07 millimeters/year with a 95% confidence interval of +/- 0.9 millimeters/year based on monthly MSL data from 1948 to 2006 which is equivalent to a change of 0.68 feet in 100 years.**

2.5.1.4 Wave Watch 3 Global Wave Model

Description: To describe patterns in wave forcing, we present data from the Wave Watch 3 global wave model run by the Department of Ocean and Resources Engineering at the University of Hawai‘i in collaboration with NOAA/NCEP and NWS Honolulu. PacIOOS describes the model at http://oos.soest.hawaii.edu/pacioos/focus/modeling/wave_models.php: “The global model is initialized daily and is forced with NOAA/NCEP's global forecast system (GFS) winds. This model is designed to capture the large-scale ocean waves, provide spectral boundary conditions for the Hawai‘i and Mariana Islands regional WW3 model, and most importantly, the 7 day model outputs a 5 day forecast.”

Data presented here come from the global model, but regional WW3 models with higher resolution exist for Hawaii, Marianas and Samoa, and in some cases, very high resolution SWAN models exist for islands within those groups.

Timeframe: 2010-2016, Daily data.

Region/Location: Global.

Data Source: “WaveWatch III (WW3) Global Wave Model”: http://oos.soest.hawaii.edu/erddap/griddap/NWW3_Global_Best.html

Measurement Platform: *Global Forecast System Winds, WW3 model*

Rationale: Wave forcing can have major implications for both coastal ecosystems and pelagic fishing operations.

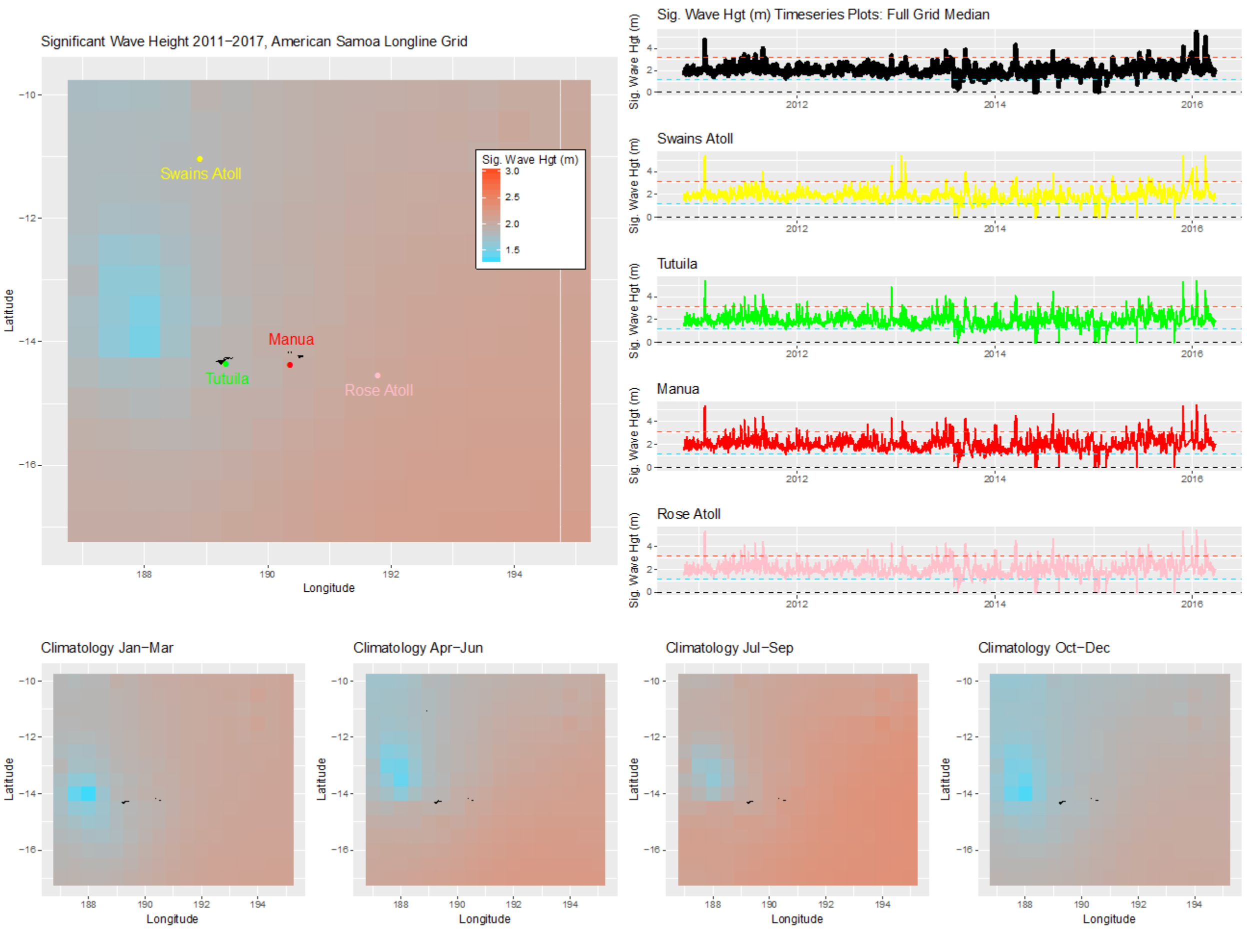


Figure 27. American Samoa Wave Watch grids

2.5.4 Observational and Research Needs

Through preparation of the 2016 Archipelagic Annual Reports, the Council has identified a number of observational and research needs that, if addressed, would improve the information content of future Climate and Ocean Indicators chapters. This information would provide fishery managers, fishing industry and community stakeholders with better understanding and predictive capacity vital to sustaining resilient and vibrant fishery systems in the Western Pacific.

- Emphasize the importance of continuing the climate and ocean indicators used in this report so that a consistent, long-term record can be maintained;
- Develop agreements among stakeholders and research partners to ensure the sustainability, availability and accessibility of climate and ocean indicators, their associated datasets and analytical methods used in this and future reports;
- Improve monitoring and understanding of the impacts of changes in ocean temperature, pH and ocean acidity, ocean oxygen content and hypoxia, and sea level rise through active collaboration by all fishery stakeholders and research partners;
- Develop, test and provide access to additional climate and ocean indicators that can improve the Archipelagic Conceptual Model;
- Explore the connections among sea surface conditions, stratification and mixing;
- Investigate the connections between climate variables and other indicators in the Archipelagic Conceptual Model to improve understanding of changes in physical, biochemical, biologic and socio-economic processes and their interactions in the regional ecosystem;
- Develop predictive models that can be used for scenario planning to account for unexpected changes and uncertainties in the regional ecosystem and fisheries;
- Foster applied research in ecosystem modeling to better describe current conditions and to better anticipate the future under alternative models of climate and ocean change including changes in expected human benefits and their variability;
- Improve understanding of the connections between PDO and fisheries ecosystems beyond the North Pacific;
- Improve understanding of mahi and swordfish size in relation to the orientation of the Transition Zone Chlorophyll Front (TZCF);
- Explore the biological implications of tropical cyclones;
- Standardize fish community size structure data for gear type;
- Clarify and elucidate the interactions among (1) changes in climate, (2) ecosystems and (3) social, economic and cultural impacts on fishing communities;
- Explore the implications and effectiveness of large marine protected areas including intergenerational losses of knowledge due to lack of access to traditional fishing areas;
- Cultural knowledge and practices for adapting to changing climate in the past and how they might contribute to future climate adaptation.
- Enhanced information on social, economic and cultural impacts of a changing climate and increased pressure on the ocean and its resources.
- Analysis of potential relationship between traditional runs of fish and climate change indicators.
- Explore the use of electronic monitoring and autonomous vehicles including small vessel prototypes.

- Explore additional and/or alternative climate and ocean that may have important effects on archipelagic fisheries systems including:
    - Ocean currents and anomalies;
    - Near-surface wind velocities and anomalies;
    - Wave forcing anomalies and wave power;
    - Storm frequency;
    - Estimates of phytoplankton abundance and size from satellite remotely-sensed SST and chlorophyll measurements;
    - Nutrients;
    - Eddy kinetic energy (EKE) which can be derived from satellite and remotely-sensed sea surface height data and can be indicative of productivity-enhancing eddies;
    - Time series of species richness and diversity from catch data which could potentially provide insight into how the ecosystem is responding to physical climate influences;
    - Identifying and monitoring key socio-economic and cultural indicators of the impacts of changing climate on resources, fishing communities, operations and resilience and;
    - Cultural knowledge and practices for adapting to changing climate in the past and how they might contribute to future climate adaptation.

2.5.5 A Look to the Future

Future Annual Reports will include additional indicators as they become available and their relevance to the development, evaluation and revision of ecosystem-fishery plans becomes clear. Working with national and jurisdictional partners, the Council will make all datasets used in the preparation of this and future reports available and easily accessible.

2.6 ESSENTIAL FISH HABITAT

2.6.1 Introduction

The Magnuson-Stevens Fishery Conservation and Management Act includes provisions concerning the identification and conservation of essential fish habitat (EFH), and under the EFH final rule, habitat areas of particular concern (HAPC) (50 Code of Federal Regulations [CFR] 600.815). The Magnuson-Stevens Act defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." HAPC are those areas of EFH identified pursuant to 50 CFR 600.815(a)(8), and meeting one or more of the following considerations: (1) ecological function provided by the habitat is important; (2) habitat is sensitive to human-induced environmental degradation; (3) development activities are, or will be, stressing the habitat type; or (4) the habitat type is rare.

The National Marine Fisheries Service (NMFS) and regional Fishery Management Councils (Councils) must describe and identify EFH in fishery management plans (FMPs), minimize to the extent practicable the adverse effects of fishing on EFH, and identify other actions to encourage the conservation and enhancement of EFH. Federal agencies that authorize, fund, or undertake actions that may adversely affect EFH must consult with NMFS, and NMFS must provide conservation recommendations to federal and state agencies regarding actions that would adversely affect EFH. Councils also have the authority to comment on federal or state agency actions that would adversely affect the habitat, including EFH, of managed species.

The EFH Final Rule strongly recommends regional fisheries management councils and NMFS to conduct a review and revision of the EFH components of fisheries management plans every five years (600.815(a)(10)). The council's FEPs state that new EFH information should be reviewed, as necessary, during preparation of the annual reports by the Plan Teams. Additionally, the EFH Final Rule states "Councils should report on their review of EFH information as part of the annual Stock Assessment and Fishery Evaluation (SAFE) report prepared pursuant to §600.315(e)." The habitat portion of the annual report is designed to meet the FEP requirements and EFH Final Rule guidelines regarding EFH reviews.

National Standard 2 guidelines recommend that the SAFE report summarize the best scientific information available concerning the past, present, and possible future condition of EFH described by the FEPs.

2.6.1.1 EFH Information

The EFH components of fisheries management plans include the description and identification of EFH, lists of prey species and locations for each managed species, and optionally, habitat areas of particular concern. Impact-oriented components of FMPs include federal fishing activities that may adversely affect EFH; non-federal fishing activities that may adversely affect EFH; non-fishing activities that may adversely affect EFH; conservation and enhancement recommendations; and a cumulative impacts analysis on EFH. The last two components include the research and information needs section, which feeds into the Council's Five Year Research Priorities, and the EFH update procedure, which is described in the FEP but implemented in the annual report.

The Council has described EFH for five management unit species (MUS) under its management authority: pelagic (PMUS), bottomfish (BMUS), crustaceans (CMUS), coral reef ecosystem (CREMUS), and precious corals (PCMUS). The AS FEP describes EFH for the BMUS, CMUS, CREMUS, and PCMUS.

EFH reviews of the biological components, including the description and identification of EFH, lists of prey species and locations, and HAPC, consist of three to four parts:

- Updated species descriptions, which can be found appended to the SAFE report. These can be used to directly update the FEP.
- Updated EFH levels of information tables, which can be found in Section 0.
- Updated research and information needs, which can be found in Section 2.6.5. These can be used to directly update the FEP.
- An analysis that distinguishes EFH from all potential habitats used by the species, which is the basis for an options paper for the Council. This part is developed if enough information exists to refine EFH.

2.6.1.2 Habitat Objectives of FEP

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

a. Review EFH and HAPC designations every five years based on the best available scientific information and update such designations based on the best available scientific information, when available

b. Identify and prioritize research to: assess adverse impacts to EFH and HAPC from fishing (including aquaculture) and non-fishing activities, including, but not limited to, activities that introduce land-based pollution into the marine environment.

This annual report reviews the precious coral EFH components and non-fishing impacts components, resetting the five-year timeline for review. The Council's support of non-fishing activities research is monitored through the program plan and five year research priorities, not the annual report.

2.6.1.3 Response to Previous Council Recommendations

At its 168th meeting held in Honolulu, HI, the Council adopted the EFH Agreement and directed staff to incorporate it into the Regional Operating Agreement, as necessary. The habitat expert on the plan team is ideally the PIFSC staffer with 5 year EFH responsibilities outlined in the EFH Agreement. The Plan Team reviews EFH information as necessary and recommends update to the Council.

2.6.2 Habitat Use by MUS and Trends in Habitat Condition

American Samoa is made up of five high volcanic islands (Tutuila, Aunu'u, Ofu, Olosega, and Ta'u) with fringing reefs, two coral atolls (Rose Atoll or Muliava and Swains Island), and several seamounts and banks. The high islands have surrounding banks where sand can accumulate, in contrast with the Rose and Swains, where slopes plunge steeply to abyssal depths

(PIFSC 2008). Tutuila is the largest island in the territory, and has banks (320 sq km) surrounding the island that extend between one and nine km offshore (PIBHMC) and extends more than three km from shore in most places (PIFSC 2008). The islands of Ofu, Olosega, and Ta'u make up the Manu'a Islands group, which have more limited shallow submerged banks (Figure 28). The nearshore habitat consists of narrow reef flat lagoons and fringing coral reefs (PIFSC 2008). While the five high, volcanic islands are part of the hot-spot chain that also includes the surrounding seamounts of Muli, Vailulu'u, South Bank and independent Samoa, Swains Island is part of the Tokelau hot-spot chain (Neall & Trewick 2008). Rose Atoll's geological origin is not well studied.

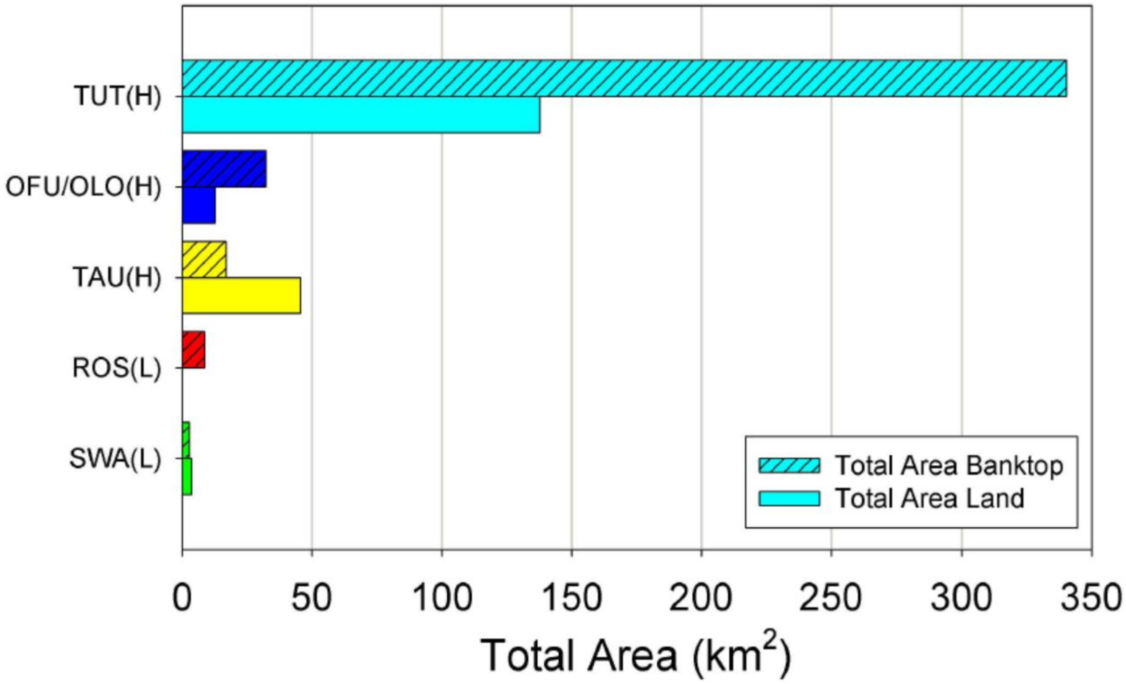


Figure 28. Total banktop area and total terrestrial land area of Tutuila and Aunu'u (TUT), Ofu and Olosega (OFU/OLU), Ta'u (TAU), Rose (ROS) and Swains (SWA). High volcanic islands are denoted with the letter H, low carbonate islands/atolls with the letter L. From PIFSC 2008.

Essential fish habitat in the Territory of American Samoa for the four MUS comprises all substrate from the shoreline to the 700 m isobath (Figure 29). 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 American Samoa have been the subject of a comprehensive monitoring program through the PIFSC Coral Reef Ecosystem Division (CRED), the offshore banks and pelagic environment in which MSA-managed fisheries operate have been less studied.

The mission of the PIFSC Coral Reef Ecosystem Division (CRED) is to "provide high-quality, scientific information about the status of coral reef ecosystems of the U.S. Pacific islands to the public, resource managers, and policymakers on local, regional, national, and international levels" (PIFSC 2011). CRED's Reef Assessment and Monitoring Program (RAMP) conducts comprehensive ecosystem monitoring surveys at about 50 island, atoll, and shallow bank sites in the Western Pacific Region on a one to three year schedule (PIFSC 2008). CRED coral reef monitoring reports provide the most comprehensive description of nearshore habitat quality in the region. The benthic habitat mapping program provides information on the quantity of habitat.

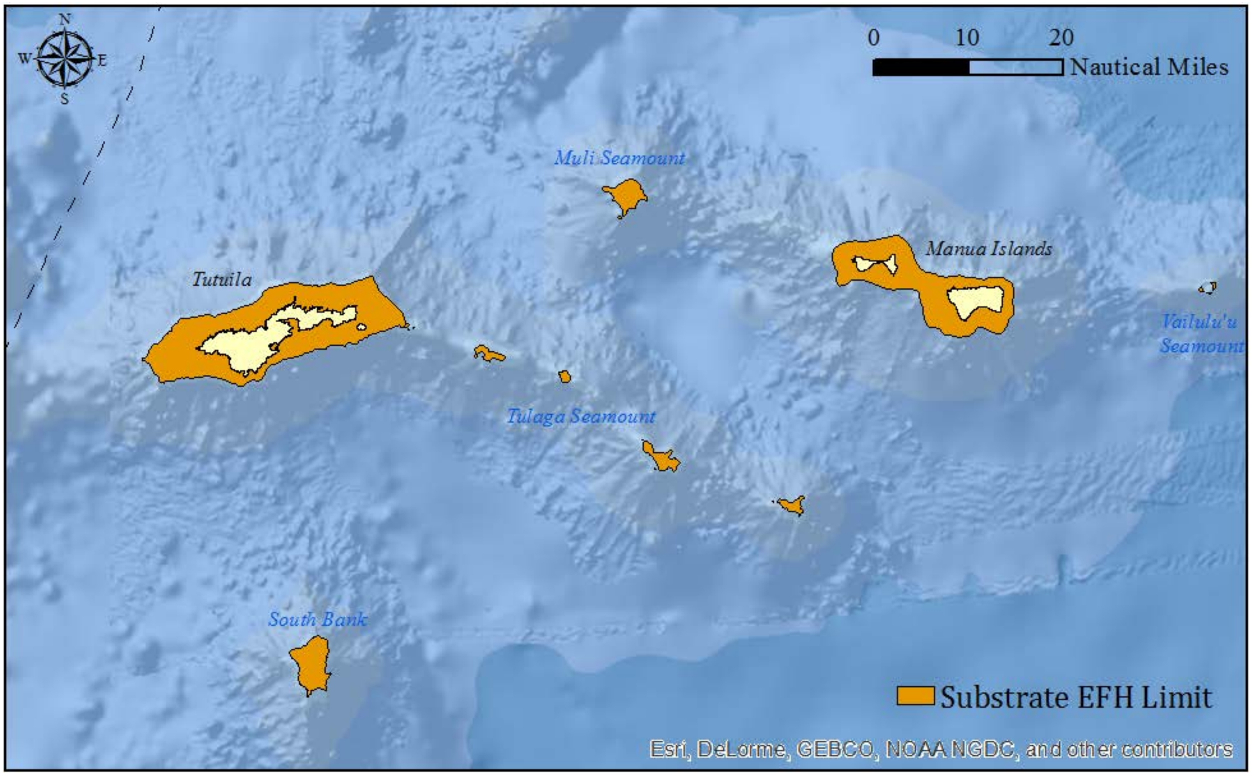


Figure 29. Substrate EFH limit of 700 m isobath around the high islands and surrounding banks of American Samoa. Data source: GMRT.

2.6.2.1 Habitat Mapping

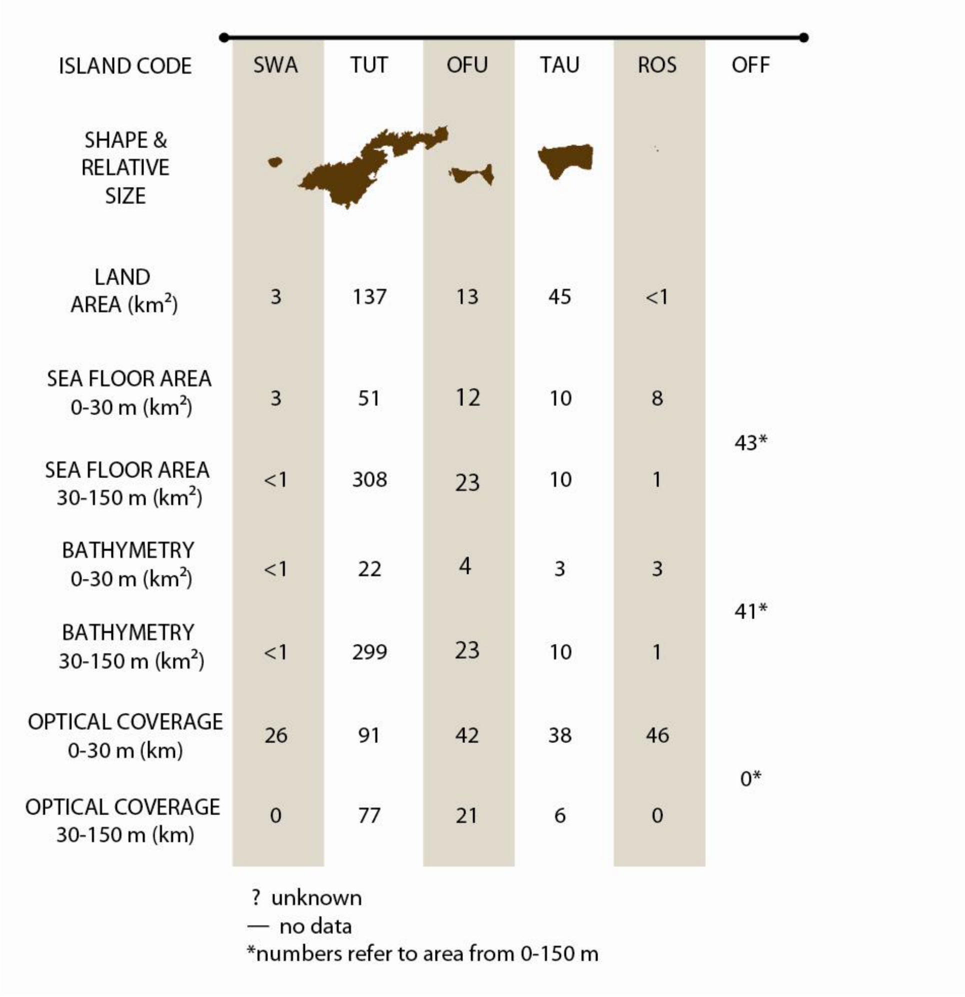
Interpreted IKONOS benthic habitat maps in the 0 – 30 m depth range have been completed for all islands in American Samoa (CRCP 2011). Between the PIBHMC and academically collected data, there is nearly 100% multibeam coverage of the territory between 20 and 3000 m depths (PIBHMC).

Table 33. Summary of habitat mapping in American Samoa

Depth Range	Timeframe/Mapping Product	Progress	Source
0-30 m	2000-2010 Bathymetry	39%	DesRochers 2016
	IKONOS Benthic Habitat Maps	All	NCCOS Data Collections: Territory Benthic Habitat Maps

Depth Range	**Timeframe/Mapping Product**	**Progress**	**Source**
	2011-2015 Satellite WorldView 2 Bathymetry	1%	DesRochers 2016
	2011-2015 Multibeam Bathymetry	-	DesRochers 2016
30-150 m	2000-2010 Bathymetry	97%	DesRochers 2016
	2011 – 2015 Multibeam Bathymetry	-	DesRochers 2016
20-3000 m	Multibeam Bathymetry	Nearly 100% mapping coverage	Pacific Islands Benthic Habitat Mapping Center

The land and seafloor area surrounding the islands of American Samoa as well as primary data coverage are reproduced from CRCP 2011 in Figure 30.



ISLAND CODE	SWA	TUT	OFU	TAU	ROS	OFF
SHAPE & RELATIVE SIZE						
LAND AREA (km²)	3	137	13	45	<1	
SEA FLOOR AREA 0-30 m (km²)	3	51	12	10	8	43*
SEA FLOOR AREA 30-150 m (km²)	<1	308	23	10	1	
BATHYMETRY 0-30 m (km²)	<1	22	4	3	3	41*
BATHYMETRY 30-150 m (km²)	<1	299	23	10	1	
OPTICAL COVERAGE 0-30 m (km)	26	91	42	38	46	0*
OPTICAL COVERAGE 30-150 m (km)	0	77	21	6	0	

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

Figure 30. American Samoa Land and Seafloor Area and Primary Data Coverage from CRCP 2011.

2.6.2.1.1 Benthic Habitat

Juvenile and adult life stages of coral reef MUS and crustaceans including spiny and slipper lobsters and Kona crab extends from the shoreline to the 100 m isobath (64 FR 19067, April 19, 1999). All benthic habitat is considered EFH for crustaceans species (64 FR 19067, April 19, 1999), while the type of bottom habitat varies by family for coral reef species (69 FR 8336, February 24, 2004). Juvenile and adult bottomfish EFH extends from the shoreline to the 400 m isobath (64 FR 19067, April 19, 1999), and juvenile and adult deepwater shrimp habitat extends from the 300 m isobath to the 700 m isobath (73 FR 70603, November 21, 2008).

Table 34 shows the depths of geologic features, the occurrence of MUS EFH at that feature, and the availability of long-term monitoring data at diving depths.

Table 34. Occurrence of EFH by feature. 1PIBMHC

Feature	Summit Minimum Depth	Coral Reef/Crustaceans exc. Deepwater Shrimp	Bottomfish	Deepwater Shrimp	Long Term Monitoring
Tutuila	Emergent	✓	✓	✓	✓
Manu'a Group	Emergent	✓	✓	✓	✓
Swains Island	Emergent	✓	✓	✓	✓
Rose Atoll	Emergent	✓	✓	✓	✓
Muli Seamount	50 m[1]	✓	✓	✓	
Tulaga Seamount		✓	✓	✓	
South Bank		✓	✓	✓	2010 only
Vailulu'u Seamount	580 m[1]			✓	

2.6.2.1.2 RAMP Indicators

Benthic percent cover of coral, macroalgae, and crustose coralline algae from CRED are found in the following tables. CRED uses the benthic towed-diver survey method to monitor changes in benthic composition. In this method, "a pair of scuba divers (one collecting fish data, the other collecting benthic data) is towed about one meter above the reef roughly 60 m behind a small boat at a constant speed of about 1.5 kt. Each diver maneuvers a towboard platform, which is connected to the boat by a bridle and towline and outfitted with a communications telegraph and various survey equipment, including a downward-facing digital SLR camera (Canon EOS 50D, Canon Inc., Tokyo). The benthic towed diver records general habitat complexity and type (e.g., spur and groove, pavement), percent cover by functional-group (hard corals, stressed corals, soft corals, macroalgae, crustose coralline algae, sand, and rubble) and for macroinvertebrates (crown-of-thorns seastars, sea cucumbers, free and boring urchins, and giant clams).
Towed-diver surveys are typically 50 min long and cover about two to three km of habitat. Each survey is divided into five-min segments, with data recorded separately per segment to allow for later location of observations within the ~ 200-300 m length of each segment. Throughout each survey, latitude and longitude of the survey track are recorded on the small boat using a GPS; and after the survey, diver tracks are generated with the GPS data and a layback algorithm that accounts for position of the diver relative to the boat. (PIFSC Website, 2016).

Table 35. Mean percent cover of live coral from RAMP sites collected from towed-diver surveys in American Samoa

	2002	2004	2006	2008	2010	2012	2015
Ofu & Olosega	18.1	14.21	17.76	21.21	18.88	31.43	38.4
Rose	26.23	24.2	17.99	17.83	14.45	23.83	27.8
South Bank					2.09		
Swains	59.92	32.36	43.91	37.5	31.82	53.13	39.54
Tau	28.39	23.35	19.04	20.22	18.21	29.93	35.22
Tutuila	26.17	18.93	13.52	19.75	18.2	27.55	26.56

Table 36. Mean percent cover of macroalgae from RAMP sites collected from towed-diver surveys in American Samoa

	2002	2004	2006	2008	2010	2012	2015
Ofu & Olosega	14.74	24.76	5.35	7.74	4.61	8.64	6.42
Rose	16.1	26.46	5.99	16.86	12.67	18.52	25.13
South Bank					26.25		
Swains	14.6	26.69	36.07	30.44	23.8	27.45	26.69
Tau	12.43	30.14	9.15	7.5	4.12	5.8	5.59
Tutuila	12.71	32.38	10.24	10.49	7.25	9.17	11.54

Table 37. Mean percent cover of crustose coralline algae from RAMP sites collected from towed-diver surveys in American Samoa

	2002	2004	2006	2008	2010	2012	2015
Ofu & Olosega	38.13	41.58	42.97	37.93	19.86	24.34	30.05
Rose	35.4	43.13	47.45	42.74	59.12	55.44	50.53
South Bank					1.76		
Swains	15.29	30.48	19.4	17.08	22.76	24.61	17.08
Tau	31.83	21.46	27.7	29.38	19.72	20.88	25.25
Tutuila	17.46	28.23	17.09	25.25	17.58	16.94	18.2

2.6.2.2 Oceanography and Water Quality

The water column is also designated as EFH for selected MUS life stages at various depths. For larval stages of all species except deepwater shrimp, the water column is EFH from the shoreline to the EEZ. Coral reef species egg and larval EFH is to a depth of 100 m; crustaceans, 150m; and bottomfish, 400 m. Please see the Ecosystem and Climate Change section for information related to oceanography and water quality.

2.6.3 Report on Review of EFH Information

Two EFH reviews were completed this year:

- Review of precious corals biological components (Appendix C)
- Omnibus review of non-fishing impacts to EFH, cumulative impacts, and conservation and enhancement recommendations (Appendix D)

2.6.4 EFH Levels

NMFS guidelines codified at 50 C.F.R. § 600.815 recommend Councils organize data used to describe and identify EFH into the following four levels:

1. Level 1: Distribution data are available for some or all portions of the geographic range of the species.
2. Level 2: Habitat-related densities of the species are available.
3. Level 3: Growth, reproduction, or survival rates within habitats are available.
4. Level 4: Production rates by habitat are available.

The Council adopted a fifth level, denoted Level 0, for situations in which there is no information available about the geographic extent of a particular managed species' life stage. The existing level of data for individual MUS in each fishery are presented in tables per fishery. Each fishery section also includes the description of EFH method used to assess the value of the habitat to the species, description of data sources used if there was analysis; and description of method for analysis.

2.6.4.1 Precious Corals

Essential Fish Habitat for precious corals was originally designated in Amendment 4 to the Precious Corals Fishery Management Plan (64 FR 19067, April 19, 1999), using the level of data found in the table.

Table 38. Level of EFH information available for Western Pacific precious corals management unit species.

Note: all observations are from the Hawaiian Islands.

Species	**Pelagic phase (larval stage)**	**Benthic phase**	**Source(s)**
Pink Coral (*Corallium)*			
Pleurocorallium secundum (prev. *Corallium secundum)*	0	1	Figueroa & Baco, 2014 HURL Database

Species	**Pelagic phase (larval stage)**	**Benthic phase**	**Source(s)**
C. regale	0	1	HURL Database
Hemicorallium laauense (prev. C. laauense)	0	1	HURL Database
Gold Coral			
Kulamanamana haumeaae (prev.	0	1	Sinniger, *et al.* (2013) HURL Database
Callogorgia gilberti	0	1	HURL Database
Narella spp.	0	1	HURL Database
Bamboo Coral			
Lepidisis olapa	0	1	HURL Database
Acanella spp.	0	1	HURL Database
Black Coral			
Antipathes griggi (prev. *Antipathes dichotoma)*	0	2	Opresko, 2009 HURL Database
A. grandis	0	1	HURL Database
Myriopathes ulex (prev. *A. ulex)*	0	1	Opresko, 2009 HURL Database

2.6.4.2 Bottomfish and Seamount Groundfish

Essential Fish Habitat for bottomfish and seamount groundfish was originally designated in Amendment 6 to the Bottomfish and Seamount Groundfish FMP (64 FR 19067, April 19, 1999).

Table 39. Level of EFH information available for the Western Pacific bottomfish and seamount groundfish management unit species complex.

Life History Stage	**Eggs**	**Larvae**	**Juvenile**	**Adult**
Bottomfish: (scientific/english common)				
Aphareus rutilans (red snapper/silvermouth)	0	0	0	2
Aprion virescens (gray snapper/jobfish)	0	0	1	2
Caranx ignoblis (giant trevally/jack)	0	0	1	2
C lugubris (black trevally/jack)	0	0	0	2
Epinephelus faciatus (blacktip grouper)	0	0	0	1
E quernus (sea bass)	0	0	1	2
Etelis carbunculus (red snapper)	0	0	1	2
E coruscans (red snapper)	0	0	1	2
Lethrinus amboinensis (ambon emperor)	0	0	0	1
L rubrioperculatus (redgill emperor)	0	0	0	1
Lutjanus kasmira (blueline snapper)	0	0	1	1

Life History Stage	Eggs	Larvae	Juvenile	Adult
Pristipomoides auricilla (yellowtail snapper)	0	0	0	2
P filamentosus (pink snapper)	0	0	1	2
P flavipinnis (yelloweye snapper)	0	0	0	2
P seiboldi (pink snapper)	0	0	1	2
P zonatus (snapper)	0	0	0	2
Pseudocaranx dentex (thicklip trevally)	0	0	1	2
Seriola dumerili (amberjack)	0	0	0	2
Variola louti (lunartail grouper)	0	0	0	2
Seamount Groundfish:				
Beryx splendens (alfonsin)	0	1	2	2
Hyperoglyphe japonica (ratfish/butterfish)	0	0	0	1
Pseudopentaceros richardsoni (armorhead)	0	1	1	3

2.6.4.3 Crustaceans

Essential Fish Habitat for crustaceans MUS was originally designated in Amendment 10 to the Crustaceans FMP (64 FR 19067, April 19, 1999). EFH definitions were also approved for deepwater shrimp through an amendment to the Crustaceans FMP in 2008 (73 FR 70603, November 21, 2008).

Table 40. Level of EFH information available for the crustacean management unit species complex.

Life History Stage	Eggs	Larvae	Juvenile	Adult
Crustaceans: (english common\scientific)				
Spiny lobster (*Panulirus marginatus*)	2	1	1-2	2-3
Spiny lobster (*Panulirus pencillatus*)	1	1	1	2
Common slipper lobster (*Scyllarides squammosus*)	2	1	1	2-3
Ridgeback slipper lobster (*Scyllarides haanii*)	2	0	1	2-3
Chinese slipper lobster (*Parribacus antarcticus*)	2	0	1	2-3
Kona crab (*Ranina ranina*)	1	0	1	1-2

2.6.4.4 Coral Reef

Essential Fish Habitat for coral reef ecosystem species was originally designated in the Coral Reef Ecosystem FMP (69 FR 8336, February 24, 2004). An EFH review of CREMUS will not be undertaken until the Council completes its process of redesignating certain CREMUS into the ecosystem component classification. Ecosystem component species do not require EFH designations, as they are not a managed species.

2.6.5 Research and Information Needs

Based, in part, on the information provided in the tables above the Council identified the following scientific data which are needed to more effectively address the EFH provisions:

2.6.5.1 All FMP Fisheries

- Distribution of early life history stages (eggs and larvae) of management unit species by habitat
- Juvenile habitat (including physical, chemical, and biological features that determine suitable juvenile habitat)
- Food habits (feeding depth, major prey species etc)
- Habitat-related densities for all MUS life history stages
- Growth, reproduction and survival rates for MUS within habitats

2.6.5.2 Bottomfish Fishery

- Inventory of marine habitats in the EEZ of the Western Pacific region
- Data to obtain a better SPR estimate for American Samoa's bottomfish complex
- Baseline (virgin stock) parameters (CPUE, percent immature) for the Guam/NMI deep-water and shallow-water bottomfish complexes
- High resolution maps of bottom topography/currents/water masses/primary productivity
- Habitat utilization patterns for different life history stages and species

2.6.5.3 Crustaceans Fishery

- Identification of post-larval settlement habitat of all CMUS
- Identification of "source/sink" relationships in the NWHI and other regions (ie, relationships between spawning sites settlement using circulation models, genetic techniques, etc)
- Establish baseline parameters (CPUE) for the Guam/Northern Marinas crustacean populations
- Research to determine habitat related densities for all CMUS life history stages in American Samoa, Guam, Hawaii and NMI
- High resolution mapping of bottom topography, bathymetry, currents, substrate types, algal beds, habitat relief

2.6.5.4 Precious Corals Fishery

- Distribution, abundance and status of precious corals in American Samoa.

2.6.6 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.

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

Russell Brainard et al. (2008) Coral Reef Ecosystem Monitoring Report for America Samoa: 2002-2006. NOAA Fisheries Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-08-02, 514 p.

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.

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.

Vincent E. Neall and Steven A. Trewick (3 September 2008) The age and origin of the Pacific islands: a geological overview. Phil. Trans. R. Soc. B 363, 3293-3308.

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

2.7 MARINE PLANNING

2.7.1 Introduction

Marine planning is a science-based tool being utilized regionally, nationally and globally to identify and address issues of multiple human uses, ecosystem health and cumulative impacts in the coastal and ocean environment. The Council's efforts to formalize incorporation of marine planning in its actions began in response to Executive Order 13547, Stewardship of the Ocean, Our Coasts, and the Great Lakes. Executive Order 13158, Marine Protected Areas (MPAs), proposes that agencies strengthen the management, protection, and conservation of existing MPAs, develop a national system of MPAs representing diverse ecosystems, and avoid causing harm to MPAs through federal activities. MPAs, or marine managed areas (MMAs) are one tool used in fisheries management and marine planning.

At its 165th meeting in March 2016, in Honolulu, Hawai`i, the Council approved the following objective for the FEPs: Consider the Implications of Spatial Management Arrangements in Council Decision-making. The following sub-objectives apply:

a. Identify and prioritize research that examines the positive and negative consequences of areas that restrict or prohibit fishing to fisheries, fishery ecosystems, and fishermen, such as the Bottomfish Fishing Restricted Areas, military installations, NWHI restrictions, and Marine Life Conservation Districts.

b. Establish effective spatially-based fishing zones.

c. Consider modifying or removing spatial-based fishing restrictions that are no longer necessary or effective in meeting their management objectives.

d. As needed, periodically evaluate the management effectiveness of existing spatial-based fishing zones in Federal waters.

In order to monitor implementation of this objective, this annual report includes the Council's spatially-based fishing restrictions or marine managed areas (MMAs), the goals associated with those, and the most recent evaluation. Council research needs are identified and prioritized through the 5 Year Research Priorities and other processes, and are not tracked in this report.

In order to meet the EFH and National Environmental Policy Act (NEPA) mandates, this annual report tracks activities that occur in the ocean that are of interest to the Council, and incidents or facilities that may contribute to cumulative impact. The National Marine Fisheries Service (NMFS) is responsible for NEPA compliance, and the Council must assess the environmental effects of ocean activities for the FEP's EFH cumulative impacts section. These are redundant efforts; therefore, this report can provide material or suggest resources to meet both mandates.

2.7.2 Response to Previous Council Recommendations

At its 147th meeting, the Council recommended a no-take area from 0-12 nautical miles around Rose Atoll with the Council to review the no-take regulations after three years. Please see the 2016 Pelagic SAFE report for an evaluation of the no-take regulations.

At its 162nd meeting, the Council recommended a regulatory amendment for the temporary exemption to the Large Vessel Protected Area (LVPA) by American Samoa longline limited entry permitted vessels greater than 50ft in length. The Council will review the LVPA exemption on an annual basis with regards, but not limited to, catch rates of fishery participants; small vessel participation; and fisheries development initiatives. At its 169th meeting, the Council heard an evaluation of the LVPA.

Regarding the US District Court's Decision on the LVPA exemption rule, the Council:

6 a) Directs staff to work with NMFS and NOAA General Counsel on reviewing the judge's decision and to evaluate next steps which could include requesting the Court to stay the decision pending reconsideration or appeal of the courts' decision.

6 b) Directs staff to present options for consideration at the June Council meeting for a Council recommendation on any necessary or appropriate LVPA regulations.

2.7.3 Marine Managed Areas established under FEPs

Council-established marine managed areas (MMAs) were compiled in

Table 41 from 50 CFR § 665, Western Pacific Fisheries, the Federal Register, and Council amendment documents. Geodesic areas were calculated in square kilometers in ArcGIS 10.2. All regulated fishing areas and large MMAs, including Rose Atoll Marine National Monument, are shown in Figure 31.

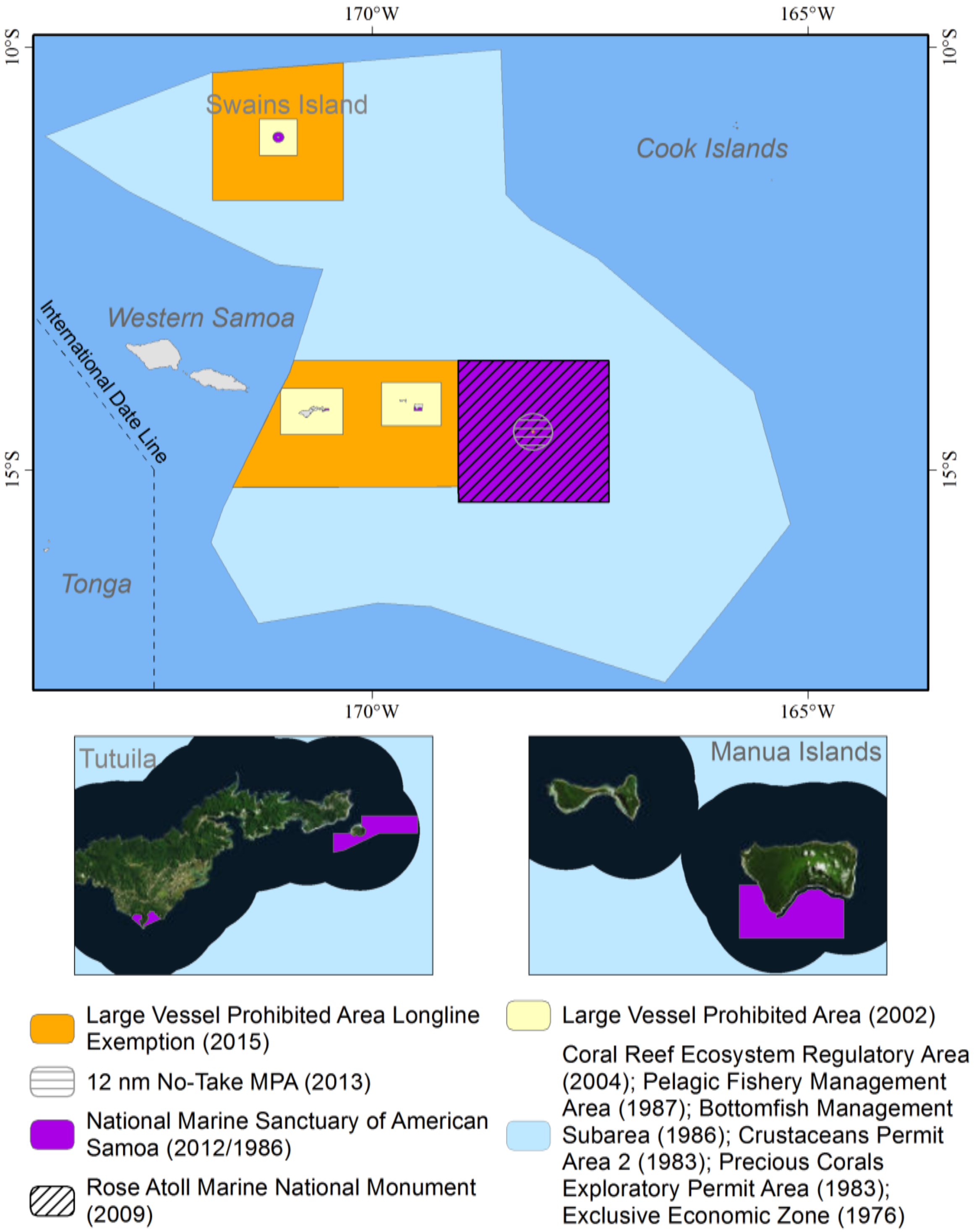


Figure 31. Regulated fishing areas of American Samoa.

Table 41. MMAs established under FEPs from 50 CFR § 665.

Name	FEP	Island	50 CFR /FR /Amendment Reference	Marine Area (km^2)	Fishing Restriction	Goals	Most Recent Evaluation	Review Deadline
Large Vessel Prohibited Area	Pelagic (American Samoa)	Tutuila, Manu’a, and Rose Atoll	665.806 (b)(1) 81 FR 5619	74,857.32	Vessels ≥ 50 ft prohibited	Prevent gear conflict with smaller alia vessels; longline vessels >50 ft exempted from 12 to 50 nm to improve the viability of the American Samoa longline fishery and achieve optimum yield from the fishery while preventing overfishing	Jan 29, 2016	Jan 29, 2017 (March meeting)
Large Vessel Prohibited Area	Pelagic (American Samoa)	Swains Island	665.806 (b)(2) 81 FR 5619 Pelagic FEP	28,352.17	Vessels ≥ 50 ft prohibited	Prevent gear conflict with smaller alia vessels; longline vessels over 50 ft exempted between 12 and 50 nm due to improve the viability of the American Samoa longline fishery and achieve optimum yield from the fishery while preventing overfishing	Jan 29, 2016	Jan 29, 2017 (March meeting)
Rose Atoll No-Take MPA/Rose Atoll Marine National Monument	American Samoa Archipelago/ Pelagic	Rose Atoll	665.99 and 665.799(a)(2) 69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 American Samoa FEP Am. 3	-	All Take Prohibited	Minimize adverse human impacts on coral reef resources; commercial fishing prohibited within 12 nmi	June 3, 2013	June 3, 2016 (Council to review no-take regulations after three years)

2.7.4 Fishing Activities and Facilities

There are no aquaculture activities occurring in the waters of American Samoa at this time.

2.7.5 Non-Fishing activities and Facilities

There are no alternative energy facilities or military training and testing activities occurring in the Federal or territorial waters of American Samoa at this time. The Plan Team will add to this section as new facilities are proposed and/or built.

2.7.6 Pacific Islands Regional Planning Body Report

The Council is a member of the Pacific Islands RPB and as such, the interests of the Council will be incorporated into the regional CMS plan. It is through the Council member that the Council may submit recommendations to the Pacific Islands RPB.

The Pacific Islands RPB met in Honolulu from February 15-16, 2017. The RPB's American Samoa Ocean Planning Team has developed its goals and objectives on which the RPB provided comments and endorsement. The RPB, by consensus, decided to:

- revise its charter with select Maritime Administration comments, a glossary or terms of reference, and handle standard operating procedure concerns through internal documentation rather than amendments to the Charter;
- kick off a Marianas Ocean Planning Team later in 2017; and
- defer the decision on beginning planning in the PRIA until an update is received on the Pacific Remote Islands Marine National Monument Management Plan at the next RPB teleconference.

The American Samoa Ocean Planning Team will continue its work concurrently with a stakeholder assessment. The Data Team will continue its work per the work plan developed in 2016.

2.7.7 References

Fisheries in the Western Pacific. Title 50 *Code of Federal Regulations*, Pt. 665. Electronic Code of Federal Regulations data current as of March 16, 2016. Viewed at http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=b28abb7da3229173411daf43959fcbd1&n=50y13.0.1.1.2&r=PART&ty=HTML#_top.

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Western Pacific Fisheries; Fishing in the Marianas Trench, Pacific Remote Islands, and Rose Atoll Marine National Monuments, Final Rule. *Federal Register* 78 (3 June 2013): 32996-33007. Downloaded from http://www.wpcouncil.org/precious/Documents/FMP/Amendment5-FR-FinalRule.pdf.

Western Pacific Regional Fishery Management Council. Fishery Management Plan and Fishery Ecosystem Plan Amendments available from http://www.wpcouncil.org/.

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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 variable (temp. at depth)	All	16	2
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 American Samoa FEP

1. Bottomfish Multi-species Stock Complex (FSSI)

DMWR Creel Species Code	**Species Name**	**Scientific Name**
247	red snapper, silvermouth (lehi) (silverjaw jobfish)	*Aphareus rutilans*
239	grey snapper, jobfish	*Aprion virescens*
119	giant trevally, jack	*Caranx ignoblis*
111	black trevally, jack	*Caranx lugubris*
221	blacktip grouper	*Epinephelus fasciatus*
229	lunar tail grouper (yellow edge lyretail)	*Variola laoti*
249	red snapper	*Etelis carbunculus*
248	longtail snapper	*Etelis coruscans*
262	ambon emperor	*Lethrinus amboinensis*
267	redgill emperor	*Lethrinus rubrioperculatus*
231	blueline snapper	*Lutjanis kasmira*
246	yellowtail snapper (goldflag jobfish)	*Pristipomoides auricilla*
242	pink snapper (paka)	*Pristimpomoides filamentosus*
241	yelloweye snapper	*Pristipomoides flavipinnis*
none	pink snapper (kalekale)	*Pristipomoides seiboldi*
245	flower snapper (gindai)	*Pristipomoides zonatus*
126	amberjack	*Seriola dumerili*

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

DMWR Creel Species Code	**Species Name**	**Scientific Name**
none	deepwater shrimp	*Heterocarpus* spp.

3. Crustacean spiny lobster complex (non-FSSI)

DMWR Creel Species Code	**Species Name**	**Scientific Name**
504	spiny lobster	*Panulirus marginatus*
504	spiny lobster	*Panulirus penicillatus*

4. Crustacean slipper lobster complex (non-FSSI)

DMWR Creel Species Code	**Species Name**	**Scientific Name**
505	Slipper lobster	Scyllaridae

5. Crustacean Kona crab complex (non-FSSI)

DMWR Creel Species Code	**Species Name**	**Scientific Name**
502	Kona crab	*Ranina ranina*

6. Precious coral black coral complex (non-FSSI)

DMWR Creel Species Code	Species Name	Scientific Name
none	Black Coral	*Anitpathes dichotoma*
none	Black Coral	*Antipathes grandis*
none	Black Coral	*Antipathes ulex*

7. Exploratory area precious coral (except black coral) (non-FSSI)

DMWR Creel Species Code	Species Name	Scientific Name
none	Pink coral	*Corallium secundum*
none	Pink coral	*Corallium regale*
none	Pink coral	*Corallium laauense*
none	Bamboo coral	*Lepidisis olapa*
none	Bamboo coral	*Acanella* spp.
none	Gold Coral	*Gerardia* spp.
none	Gold Coral	*Callogorgia gilberti*
none	Gold Coral	*Narella* spp.
none	Gold Coral	*Calyptrophora* spp.

8. Coral reef ecosystem (non-FSSI)

DMWR Creel Species Code	Species Name	Scientific Name	Grouping
328	Achilles tang	*Acanthurus achilles*	Acanthuridae
337	Barred unicornfish	*Naso thynnoides*	Acanthuridae
3311	Bignose unicornfish	*Naso vlamingii*	Acanthuridae
336	Black tongue unicornfish	*Naso hexacanthius*	Acanthuridae
3205	Blackstreak surgeonfish	*Acanthurus nigricauda*	Acanthuridae
321	Blue-banded surgeonfish	*Acanthurus lineatus*	Acanthuridae
3206	Bluelined surgeonfish	*Acanthurus nigroris*	Acanthuridae
339	Bluespine unicornfish	*Naso unicornis*	Acanthuridae
326	Brown surgeonfish	*Acanthurus nigrofuscus*	Acanthuridae
323	Convict tang	*Acanthurus triostegus*	Acanthuridae
3203	Elongate surgeonfish	*Acanthurus mata*	Acanthuridae
3201	Eye-striped surgeonfish	*Acanthurus dussumeiri*	Acanthuridae
335	Gray unicornfish	*Naso caesius*	Acanthuridae
333	Humpback unicornfish	*Naso brachycentron*	Acanthuridae
338	Humpnose unicornish	*Naso tuberosus*	Acanthuridae
3208	Mimic surgeonfish	*Acanthurus pyorferus*	Acanthuridae
327	Naso tang	*Naso spp.*	Acanthuridae
332	Orangespine unicornfish	*Naso lituratus*	Acanthuridae
3207	Orange-spot surgeonfish	*Acanthurus olivaceus*	Acanthuridae
3281	Pacific sailfin tang	*Zebrasoma veliferum*	Acanthuridae

329	Ringtail surgeonfish	*Acanthurus blochii*	Acanthuridae
334	Spotted unicornfish	*Naso brevirostris*	Acanthuridae
322	Striped bristletooth	*Ctenochaetus striatus*	Acanthuridae
320	Surgeonfishes/tangs	*Acanthurus sp.*	Acanthuridae
3221	Twospot bristletooth	*Ctenochaetus binotatus*	Acanthuridae
330	Unicornfishes (misc)	*Naso spp.*	Acanthuridae
3202	Whitebar surgeonfish	*Acanthurus leucopareius*	Acanthuridae
3204	Whitecheek surgeonfish	*Acanthurus nigricans*	Acanthuridae
331	Whitemargin unicornfish	*Naso annulatus*	Acanthuridae
325	Whitespotted surgeonfish	*Acanthurus guttatus*	Acanthuridae
3222	Yellow-eyed bristletooth	*Ctenochaetus strigosus*	Acanthuridae
324	Yellowfin surgeonfish	*Acanthurus xanthopterus*	Acanthuridae
390	Inshore snappers	*Lutjanidae*	Lutjanidae
238	Brown jobfish	*Aphareus furca*	Lutjanidae
256	Scarlet snapper	*Etelis radiosus*	Lutjanidae
392	Red snapper	*Lutjanus bohar*	Lutjanidae
235	Twinspot/red snapper	*Lutjanus bohar*	Lutjanidae
233	Yellow margined snapper	*Lutjanus fulvus*	Lutjanidae
236	Humpback snapper	*Lutjanus gibbus*	Lutjanidae
234	Onespot snapper	*Lutjanus monostigma*	Lutjanidae
232	Rufous snapper	*Lutjanus rufolineatus*	Lutjanidae
237	Blood snapper	*Lutjanus sanguineus*	Lutjanidae
257	Timor snapper	*Lutjanus timorensis*	Lutjanidae
251	Black snapper	*Macolor niger*	Lutjanidae

253	Kusakar's snapper	*Paracaesio kusakarii*	Lutjanidae
252	Stone's snapper	*Paracaesio stonei*	Lutjanidae
250	Multidens snapper	*Pristipomoides multidens*	Lutjanidae
102	Bigeye scad	*Selar crumenophthalmus*	Atule
524	Mangrove clam	*Anodontia edentula*	Mollusk
522	Pen shell clam	*Atrina rigida*	Mollusk
523	Pipi clam	*Donax deltoides*	Mollusk
510	Squid	*Teuthida*	Mollusk
521	Clams (misc)	*Bivalvia*	Mollusk
531	Cone snail	*Conus* sp.	Mollusk
5061	Octopus (cyanea)	*Octopus cyanea*	Mollusk
5062	Octopus (ornatus)	*Octopus ornatus*	Mollusk
506	Octopus	*Octopus* sp.	Mollusk
520	Giant clam	*Tridacna* sp.	Mollusk
530	Turban snail	*Trochus* sp.	Mollusk
536	Green snails	*Turbo* sp.	Mollusk
116	Blue kingfish trevally	*Carangoides caeruleopinnatus*	Carangidae
114	Goldspot trevally	*Carangoides orthogrammus*	Carangidae
109	Trevally (misc)	*Carangoides* sp.	Carangidae
110	Jacks (misc)	*Caranx* sp.	Carangidae
113	Bluefin trevally	*Caranx melampygus*	Carangidae
115	Brassy trevally	*Caranx papuensis*	Carangidae
112	Bigeye trevally	*Caranx sexfasciatus*	Carangidae

410	Rainbow runner	*Elagatis bipinnulatus*	Carangidae
106	Leatherback	*Scomberoides lysan*	Carangidae
127	Snubnose pompano	*Trachinotus blochii*	Carangidae
117	Whitemouth trevally	*Uraspis secunda*	Carangidae
104	Mackerel scad (opelu)	*Decapterus* sp.	Carangidae
260	Emperors (misc)	Lethrinidae	Lethrinidae
255	Goldenline bream	*Gnathodentex aureolineatus*	Lethrinidae
264	Yellowspot emperor	*Gnathodentex aurolineatus*	Lethrinidae
263	Blueline bream	*Gymnocranius grandoculis*	Lethrinidae
266	Orangespot emperor	*Lethrinus erythracanthus*	Lethrinidae
261	Longnose emperor	*Lethrinus elongatus*	Lethrinidae
254	Bigeye emperor	*Monotaxis grandoculis*	Lethrinidae
2601	Sweetlip emperor	*Lethrinus miniatus*	Lethrinidae
3501	Stareye parrotfish	*Calotomus carolinus*	Scaridae
3503	Longnose parrotfish	*Hipposcarus longiceps*	Scaridae
3502	Yellowband parrotfish	*Scarus schlegeli*	Scaridae
350	Parrotfishes (misc)	*Scarus* sp.	Scaridae
380	Inshore groupers	Serranidae	Serranidae
211	Eightbar grouper	*Epinephelus octofasciatus*	Serranidae
206	Giant grouper	*Epinephelus lanceolatus*	Serranidae
202	Golden hind	*Cephalopholis aurantia*	Serranidae
212	Greasy grouper	*Epinephelus tauvina*	Serranidae
210	Groupers (misc)	*Epinephelus* sp.	Serranidae
224	Hexagon grouper	*Epinephelus hexagonatus*	Serranidae

209	Honeycomb grouper	*Epinephelus merra*	Serranidae
207	Longspine grouper	*Epinephelus longispinnis*	Serranidae
228	Netfin grouper	*Epinephelus miliaris*	Serranidae
208	One-bloch grouper	*Epinephelus melanostigma*	Serranidae
213	Peacock grouper	*Cephalopholis argus*	Serranidae
205	Pygmy grouper	*Cephalopholis spiloparaea*	Serranidae
217	Saddleback grouper	*Plectropomus laevis*	Serranidae
204	Six-banded grouper	*Cephalopholis sexmaculatus*	Serranidae
201	Slender grouper	*Anyperodon leucogrammicus*	Serranidae
227	Smalltooth grouper	*Epinephelus microdon*	Serranidae
226	Spotted grouper	*Epinephelus maculatus*	Serranidae
216	Squaretail grouper	*Plectropomus areolatus*	Serranidae
223	Striped grouper	*Epinephelus morrhua*	Serranidae
215	Tomato grouper	*Cephalopholis sennerati*	Serranidae
203	Ybanded grouper	*Cephalopholis igarashiensis*	Serranidae
222	Yellowspot grouper	*Epinephelus timorensis*	Serranidae
218	Leopard coral trout	*Plectropomus leopardus*	Serranidae
219	Powell's grouper	*Saloptia powelli*	Serranidae
220	White-edged lyretail	*Variola albimarginata*	Serranidae
345	Bigscale soldierfish	*Myripristis berndti*	Holocentridae
348	Blackfin squirrelfish	*Neoniphon opercularis*	Holocentridae
359	Blackspot squirrelfish	*Sargocentron melanospilos*	Holocentridae
3414	Blotcheye soldierfish	*Myripristis murdjan*	Holocentridae
3511	Bluelined squirrelfish	*Sargocentron tiere*	Holocentridae

3411	Brick soldierfish	*Myripristis amaena*	Holocentridae
342	Bronze soldierfish	*Myripristis adusta*	Holocentridae
353	Crown squirrelfish	*Sargocentron diadema*	Holocentridae
3413	Double tooth soldierfish	*Myripristis hexagona*	Holocentridae
356	Filelined squirrelfish	*Sargocentron microstoma*	Holocentridae
3513	Hawaiian squirrelfish	*Sargocentron xantherythrum*	Holocentridae
343	Pearly soldierfish	*Myripristis kuntee*	Holocentridae
354	Peppered squirrelfish	*Sargocentron punctatissimum*	Holocentridae
3512	Pink squirrelfish	*Sargocentron tieroides*	Holocentridae
341	Saber squirrelfish	*Sargocentron spiniferum*	Holocentridae
351	Sammara squirrelfish	*Neoniphon sammara*	Holocentridae
344	Scarlet soldierfish	*Myripristis pralinius*	Holocentridae
340	Squirrelfish	*Sargocentron* sp.	Holocentridae
352	Tailspot squirrelfish	*Sargocentron caudimaculatum*	Holocentridae
346	Violet soldierfish	*Myripristis violaceus*	Holocentridae
358	Violet squirrelfish	*Sargocentron violaceum*	Holocentridae
3415	Whitetip soldierfish	*Myripristis vittata*	Holocentridae
3412	Yellowfin soldierfish	*Myripristis chryseres*	Holocentridae
347	Yellowstriped squirrelfish	*Neoniphon aurolineatus*	Holocentridae
130	Mullets	Mullets	Mugilidae
1301	Fringelip mullet	Mullets	Mugilidae
1303	Diamond scale mullet	Mullets	Mugilidae
1302	False mullet	Mullets	Mugilidae

	Crabs	Decapoda	CRE-crustacean
509	Grapsid crab	Graspidae	CRE-crustacean
5013	Pa'a crab	*Ocypode ceratopthalma*	CRE-crustacean
5011	Seven-11 crab	*Carpilius maculatus*	CRE-crustacean
5012	Small crab	Decapoda	CRE-crustacean
503	Mangrove crab	*Scylla serrate*	CRE-crustacean
5014	Large red crab	*Sesama erythrodactyla*	CRE-crustacean
507	Hermit crab	*Coenobita clypeatus*	CRE-crustacean
	Bumphead parrotfish	*Bolbometopon muricatum*	Bumphead parrotfish
3601	Napoleon wrasse	*Cheilius undulatus*	Napoleon wrasse
1540	Reef sharks (misc)	Carcharhinidae	Carcharhinidae
1541	Silvertip shark	*Carcharhinus albimarginatus*	Carcharhinidae
1542	Grey reef shark	*Carcharhinus amblyrhynchos*	Carcharhinidae
1543	Galapagos shark	*Carcharhinus galapagenis*	Carcharhinidae
154	Blacktip reef shark	*Carcharhinus melanopterus*	Carcharhinidae
	White tip reef shark	*Carcharhinus triaenodon*	Carcharhinidae
158	Hammerhead shark	Sphyrnidae	Carcharhinidae
500	Invertebrates (misc)	n/a	Invertebrate
550	Sea urchins (misc)	Diadema	Invertebrate
553	Black sea urchin	Diadema	Invertebrate
552	White sea urchin	*Salmacis* spp.	Invertebrate
827	Cubed loli	*Holothuria atra* (cubed)	Invertebrate
828	Cubed leapord sea cucumber	*Bahadschia argus* (cubed)	Invertebrate
824	Surf redfish	*Actinopyga maurtiana*	Invertebrate

822	Sea cucumber (misc)	Cucumariidae	Invertebrate
823	Sea cucumber - gau	Cucumariidae	Invertebrate
821	Sea cucumber gonads	Cucumariidae	Invertebrate
825	Leapord sea cucumber	*Bahadschia argus*	Invertebrate
820	Loli	*Holothuria atra*	Invertebrate
132	Flyingfish	Exocoetidae	Other CRE-Finfish
133	Cornetfish	*Fistularia commersonii*	Other CRE-Finfish
135	Mojarras	Gerreidae	Other CRE-Finfish
181	Gobies	Gobiidae	Other CRE-Finfish
357	Sweetlips	*Plectorhinchus* sp.	Other CRE-Finfish
136	Halfbeaks	Hemiramphidae	Other CRE-Finfish
363	Flagtails	Kuhliidae	Other CRE-Finfish
3631	Barred flagtail	*Kuhlia mugil*	Other CRE-Finfish
720	Mountain bass	*Kuhlia* sp.	Other CRE-Finfish
137	Ponyfish	Leiognathidae	Other CRE-Finfish
368	Tilefishes	Malacanthus sp.	Other CRE-Finfish
460	Sunfish	*Masturus lanceolatus*	Other CRE-Finfish
138	Filefishes	*Monacanthidae*	Other CRE-Finfish
139	Silver batfish	*Monodactylus argenteus*	Other CRE-Finfish
176	Moray eels	*Gymnothorax* sp.	Other CRE-Finfish
175	Dragon eel	*Enchelycore pardalis*	Other CRE-Finfish
1741	Yellowmargin moray eel	*Gymnothorax flavimarginatus*	Other CRE-Finfish
1742	Giant moray eel	*Gymnothorax javanicus*	Other CRE-Finfish
174	Spotted moray eels	*Gymnothorax* sp.	Other CRE-Finfish

1743	Undulated moray eel	*Gymnothorax undulatus*	Other CRE-Finfish
160	Rays	Batiodea	Other CRE-Finfish
162	Eagle ray	*Aetobatis narinari*	Other CRE-Finfish
906	Monogram monocle bream	*Scolopsis monogramma*	Other CRE-Finfish
152	Nurse shark	*Pempheris* sp.	Other CRE-Finfish
379	Sweepers	Pempheridae	Other CRE-Finfish
185	Prettyfins	Cyprinididae	Other CRE-Finfish
140	Threadfin	*Polynemus* sp.	Other CRE-Finfish
143	Angelfishes	*Centropyge flavissimus*	Other CRE-Finfish
1431	Emperor angelfish	*Pomacanthus imperator*	Other CRE-Finfish
3181	Banded sergeant	*Abudefduf septemfasciatus*	Other CRE-Finfish
318	Sergeant major	*Abudefduf sp.*	Other CRE-Finfish
142	Damselfish	*Dascyllus trimaculatus*	Other CRE-Finfish
365	Bigeyes	Priacanthidae	Other CRE-Finfish
367	Glasseye	*Heteropriacanthus cruentatus*	Other CRE-Finfish
366	Paeony bulleye	*Priacanthus blochii*	Other CRE-Finfish
369	Moontail bullseye	*Priacanthus hamrur*	Other CRE-Finfish
349	Bigeye squirrelfish	Priacanthus sp.	Other CRE-Finfish
184	Dottybacks	Pseudochromidae	Other CRE-Finfish
144	Scorpionfishes	Scorpaenidae	Other CRE-Finfish
146	Lionfish	Pterois sp.	Other CRE-Finfish
145	Stonefish	Synaceia sp.	Other CRE-Finfish
122	Small barracuda	Sphyraenidae	Other CRE-Finfish
121	Great barracuda	*Sphyraena barracuda*	Other CRE-Finfish

123	Bigeye barracuda	*Sphyraena forsteri*	Other CRE-Finfish
124	Heller's barracuda	*Sphyraena helleri*	Other CRE-Finfish
125	Blackfin barracuda	*Sphyraena qenie*	Other CRE-Finfish
120	Barracudas (misc)	*Sphyraena sp.*	Other CRE-Finfish
191	Seahorses	Sygnathidae	Other CRE-Finfish
147	Lizardfish	Synodontidae	Other CRE-Finfish
355	Terapon perch	*Terapon jarbua*	Other CRE-Finfish
388	Moorish Idol	*Zanclus cornutus*	Other CRE-Finfish
710	Freshwater eel	*Anguilla marmorata*	Other CRE-Finfish
187	Flashlightfishes	*Anomalopidae*	Other CRE-Finfish
189	Frogfishes	*Antennariidae*	Other CRE-Finfish
315	Cardinalfish	*Apogonidae*	Other CRE-Finfish
103	Silversides	*Hypoathernia temminckii*	Other CRE-Finfish
101	Trumpetfish	*Aulostomus chinensis*	Other CRE-Finfish
383	Triggerfish	*Balistidae*	Other CRE-Finfish
3821	Orangestripe triggerfish	*Balistapus undulatus*	Other CRE-Finfish
382	Clown triggerfish	*Balistoides conspicillum*	Other CRE-Finfish
387	Titan triggerfish	*Balistoides viridescens*	Other CRE-Finfish
134	Needlefish	*Belonidae*	Other CRE-Finfish
105	Blennies	*Blennidae*	Other CRE-Finfish
3051	Angler flatfish	*Asterorhombus fijiensis*	Other CRE-Finfish
107	Gold banded fusilier	*Caesio caerulaurea*	Other CRE-Finfish
186	Coral crouchers	*Caracanthus maculatus*	Other CRE-Finfish
385	Butterflyfishes (misc)	*Chaetodon sp.*	Other CRE-Finfish

3851	Butterflyfish (auriga)	*Chaetodon auriga*	Other CRE-Finfish
3854	Saddleback butterflyfish	*Chaetodon ephippium*	Other CRE-Finfish
3852	Racoon butterflyfish	*Chaetodon lunula*	Other CRE-Finfish
3853	Butterflyfish (melanotic)	*Chaetodon melannotus*	Other CRE-Finfish
180	Milkfish	*Chanos chanos*	Other CRE-Finfish
700	Tilapia	*Tilapia zillii*	Other CRE-Finfish
319	Two spotted hawkfish	*Amplycirrhitus bimacula*	Other CRE-Finfish
3191	Stocky hawkfish	*Cirrhitus pinnalatus*	Other CRE-Finfish
3192	Flame hawkfish	*Neocirrhites armatus*	Other CRE-Finfish
131	Herrings	*Clupeidae*	Other CRE-Finfish
173	White eel	*Conger cinereus*	Other CRE-Finfish
172	Conger eels	*Conger sp.*	Other CRE-Finfish
386	Porcupinefish	*Diodon (Porcupine) sp.*	Other CRE-Finfish
183	Remoras	*Echeneidae*	Other CRE-Finfish
188	Anchovies	*Engraulidae*	Other CRE-Finfish
182	Batfishes	*Ephippidae*	Other CRE-Finfish
200	Bottomfish (misc)	*n/a*	Misc. Bottomfish
300	Reef fish (misc)	*n/a*	Misc. Reef Fish
3606	Arenatus wrasse	*Oxycheilinus arenatus*	Wrasse
3605	Bandcheck wrasse	*Oxycheilinus diagrammus*	Wrasse
3610	Barred thicklip	*Hemigymnus fasciatus*	Wrasse
3614	Bird wrasse	*Hemigymnus fasciatus*	Wrasse
3609	Blackeye thicklip	*Hemigymnus melapterus*	Wrasse
3616	Checkerboard wrasse	*Halichoeres hortulanus*	Wrasse

3615	Cheilinus wrasse (misc)	*Cheilinus sp.*	Wrasse
361	Christmas wrasse	*Thalassoma trilobata*	Wrasse
3608	Cigar wrasse	*Cheilio inermus*	Wrasse
3613	Red ribbon wrasse	*Thalassoma quinquevittaitum*	Wrasse
3619	Rockmover wrasse	*Novaculichthys taeniorus*	Wrasse
3611	Sunset wrasse	*Thalassoma lutescens*	Wrasse
3612	Surge wrasse	*Thalassoma purpureum*	Wrasse
3602	Triple tail wrasse	*Cheilinus trilobatus*	Wrasse
3617	Weedy surge wrasse	*Halichoeres margaritaceus*	Wrasse
3607	Whitepatch wrasse	*Xyrichtys aneitensis*	Wrasse
360	Wrasses (misc)	*Labridae*	Wrasse
3603	Floral wrasse	*Cheilinus chlorourus*	Wrasse
3604	Harlequin tuskfish	*Cheilinus fasciatus*	Wrasse
3033	Rudderfish (biggibus)	*Kyphosus bigibus*	Rudderfish
303	Rudderfish (cinerascens)	*Kyphosus cinerascens*	Rudderfish
3032	Western drummer	*Kyphosus cornelii*	Rudderfish
3034	Rudderfish	*Kyphosus sp.*	Rudderfish
3031	Lowfin drummer	*Kyphosus vaigiensis*	Rudderfish
3734	Goatfish (misc)	*Mullidae*	Goatfish
371	Yellowstripe goatfish	*Mulloidichthys flavolineatus*	Goatfish
375	Orange goatfish	*Mulloidichthys pfluegeri*	Goatfish
370	Yellow goatfishes	*Mulloidichthys sp.*	Goatfish
372	Yellowfin goatfish	*Mulloidichthys vanicolensis*	Goatfish
373	Dash-and-dot goatfish	*Parupeneus barberinus*	Goatfish

3731	Doublebar goatfish	*Parupeneus bifasciatus*	Goatfish
3732	White-lined goatfish	*Parupeneus ciliatus*	Goatfish
374	Yellowsaddle goatfish	*Parupeneus cyclostomus*	Goatfish
376	Redspot goatfish	*Parupeneus heptacanthus*	Goatfish
377	Indian goatfish	*Parupeneus indicus*	Goatfish
378	Parupenus insularis	*Parupeneus insularis*	Goatfish
3733	Multi-barred goatfish	*Parupeneus multifasciatus*	Goatfish
381	Side spot goatfish	*Parupeneus pleurostigma*	Goatfish
3370	Banded goatfish (misc)	*Parupeneus sp.*	Goatfish
310	Rabbitfish	*Siganidae*	Rabbitfish
3101	Forktail rabbitfish	*Siganus aregenteus*	Rabbitfish
311	Scribbled rabbitfish	*Siganus spinus*	Rabbitfish
801	Red algae	Red Algae	Rabbitfish
800	Seaweeds	Seaweeds	Rabbitfish

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

Table B1. Protected species found or reasonably believed to be found in or near American Samoa waters.

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
Seabirds					
Audubon's Shearwater	*Puffinus lherminieri*	Not Listed	N/A	Resident	Craig 2005
Black Noddy	*Anous minutus*	Not Listed	N/A	Resident	Craig 2005
Black-Naped Tern	*Sterna sumatrana*	Not Listed	N/A	Visitor	Craig 2005
Blue-Gray Noddy	*Procelsterna cerulea*	Not Listed	N/A	Resident	Craig 2005
Bridled Tern	*Onychoprion anaethetus*	Not Listed	N/A	Visitor	Craig 2005
Brown Booby	*Sula leucogaster*	Not Listed	N/A	Resident	Craig 2005
Brown Noddy	*Anous stolidus*	Not Listed	N/A	Resident	Craig 2005
Christmas Shearwater	*Puffinus nativitatis*	Not Listed	N/A	Resident?	Craig 2005
Collared Petrel	*Pterodroma brevipes*	Not Listed	N/A	Resident?	Craig 2005
White Tern	*Gygis alba*	Not Listed	N/A	Resident	Craig 2005
Greater Crested Tern	*Thalasseus bergii*	Not Listed	N/A	Visitor	Craig 2005
Gray-Backed Tern	*Onychoprion lunatus*	Not Listed	N/A	Resident	Craig 2005
Great Frigatebird	*Fregata minor*	Not Listed	N/A	Resident	Craig 2005
Herald Petrel	*Pterodroma heraldica*	Not Listed	N/A	Resident	Craig 2005
Laughing Gull	*Leucophaeus atricilla*	Not Listed	N/A	Visitor	Craig 2005
Lesser Frigatebird	*Fregata ariel*	Not Listed	N/A	Resident	Craig 2005
Masked Booby	*Sula dactylatra*	Not Listed	N/A	Resident	Craig 2005
Newell's Shearwater	*Puffinus auricularis newelli*	Threatened	N/A	Visitor	40 FR 44149, Craig 2005
Red-Footed Booby	*Sula sula*	Not Listed	N/A	Resident	Craig 2005
Red-Tailed Tropicbird	*Phaethon rubricauda*	Not Listed	N/A	Resident	Craig 2005
Short-Tailed Shearwater	*Ardenna tenuirostris*	Not Listed	N/A	Visitor	Craig 2005
Sooty Shearwater	*Ardenna grisea*	Not Listed	N/A	Visitor	Craig 2005
Sooty Tern	*Sterna fuscata*	Not Listed	N/A	Resident	Craig 2005
Tahiti Petrel	*Pterodroma rostrata*	Not Listed	N/A	Resident	Craig 2005
Wedge-Tailed	*Ardenna pacifica*	Not Listed	N/A	Resident?	Craig 2005

Common name	**Scientific name**	**ESA listing status**	**MMPA status**	**Occurrence**	**References**
Shearwater					
White-Necked Petrel	*Pterodroma cervicalis*	Not Listed	N/A	Visitor	Craig 2005
White-Faced Storm-Petrel	*Pelagodroma marina*	Not Listed	N/A	Visitor	Craig 2005
White-Tailed Tropicbird	*Phaethon lepturus*	Not Listed	N/A	Resident	Craig 2005
White-Throated Storm-Petrel	*Nesofregetta fuliginosa*	Not Listed	N/A	Resident?	Craig 2005
Sea Turtles					
Green Sea Turtle	*Chelonia mydas*	Endangered (Central South Pacific DPS)	N/A	Frequently seen. Nest at Rose Atoll in small numbers.	43 FR 32800, 81 FR 20057, Balacz 1994
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered[a]	N/A	Frequently seen. Nest at Rose Atoll, Swain's Island, and Tutuila.	35 FR 8491, NMFS & USFWS 2013, Tuato'o-Bartley et al. 1993
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered[a]	N/A	Very rare. One juvenile recovered dead in experimental longline fishing.	35 FR 8491, Grant 1994
Loggerhead Sea Turtle	*Caretta caretta*	Endangered (South Pacific DPS)	N/A	No known sightings. Found worldwide along continental shelves, bays, estuaries and lagoons of tropical, subtropical, and temperate waters.	43 FR 32800, 76 FR 58868, Utzurrum 2002, Dodd 1990
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. Three known sightings.	43 FR 32800, Utzurrum 2002
Marine mammals					
Blainville's Beaked Whale	*Mesoplodon densirostris*	Not Listed	Non-strategic	Found worldwide in tropical and temperate waters	Mead 1989
Blue Whale	*Balaenoptera musculus*	Endangered	Strategic	No known sightings. Occur worldwide, and are known to be found in the western South Pacific.	35 FR 18319, Olson et al. 2015
Bottlenose Dolphin	*Tursiops truncatus*	Not Listed	Non-strategic	Distributed worldwide in tropical and warm-temperate waters	Perrin et al. 2009
Bryde's Whale	*Balaenoptera edeni*	Not Listed	Unknown	Distributed widely across tropical and warm-temperate Pacific Ocean.	Leatherwood et al. 1982

Common name	**Scientific name**	**ESA listing status**	**MMPA status**	**Occurrence**	**References**
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 worldwide.	Heyning 1989
Dwarf Sperm Whale	*Kogia sima*	Not Listed	Non-strategic	Found worldwide in tropical and warm-temperate waters.	Nagorsen 1985
False Killer Whale	*Pseudorca crassidens*	Not Listed	Unknown	Found in waters within the US EEZ of A. Samoa	Bradford et al. 2015
Fin Whale	*Balaenoptera physalus*	Endangered	Strategic	No known sightings. Found worldwide.	35 FR 18319, Hamilton et al. 2009
Fraser's Dolphin	*Lagenodelphis hosei*	Not Listed	Non-strategic	Found worldwide in tropical waters.	Perrin et al. 2009
Humpback Whale	*Megaptera novaeangliae*	Delisted Due to Recovery (Oceania DPS)	Strategic	Migrate through the archipelago and breed during the winter in American Samoan waters.	35 FR 18319, 81 FR 62259, Guarrige et al. 2007, SPWRC 2008
Killer Whale	*Orcinus orca*	Not Listed	Non-strategic	Found worldwide. Prefer colder waters within 800 km of continents.	Leatherwood & Dalheim 1978, Mitchell 1975, Baird et al. 2006
Longman's Beaked Whale	*Indopacetus pacificus*	Not Listed	Non-strategic	Found in tropical waters from the eastern Pacific westward through the Indian Ocean to the eastern coast of Africa.	Dalebout 2003
Melon-Headed Whale	*Peponocephala electra*	Not Listed	Non-strategic	Found in tropical and warm-temperate waters worldwide, primarily found in equatorial waters.	Perryman et al. 1994
Minke Whale	*Balaenoptera acutorostrata*	Not Listed	Non-strategic	Uncommon in this region, usually seen over continental shelves in the Pacific Ocean.	Brueggeman et al. 1990
Pantropical Spotted Dolphin	*Stenella attenuata attenuata*	Not Listed	Non-strategic	Found in tropical and subtropical waters worldwide.	Perrin et al. 2009
Pygmy Killer Whale	*Feresa attenuata*	Not Listed	Non-strategic	Found in tropical and subtropical waters worldwide.	Ross & Leatherwood 1994
Pygmy Sperm Whale	*Kogia breviceps*	Not Listed	Non-strategic	Found worldwide in tropical and warm-temperate waters.	Caldwell & Caldwell 1989
Risso's Dolphin	*Grampus griseus*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide.	Perrin et al. 2009

Common name	Scientific name	ESA listing status	MMPA status	Occurrence	References
Rough-Toothed Dolphin	*Steno bredanensis*	Not Listed	Unknown	Found in tropical to warm-temperate waters worldwide. Common in A. Samoa waters.	Perrin et al. 2009, Craig 2005
Sei Whale	*Balaenoptera borealis*	Endangered	Strategic	Generally found in offshore temperate waters.	35 FR 18319, Barlow 2003, Bradford et al. 2013
Short-Finned Pilot Whale	*Globicephala macrorhynchus*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide.	Shallenberger 1981, Baird et al. 2013, Bradford et al. 2013
Sperm Whale	*Physeter macrocephalus*	Endangered	Strategic	Found in tropical to polar waters worldwide, most abundant cetaceans in the region.	35 FR 18319, Rice 1960, Barlow 2006, Lee 1993, Mobley et al. 2000, Shallenberger 1981
Spinner Dolphin	*Stenella longirostris*	Not Listed	Unknown	Common in American Samoa, found in waters with mean depth of 44 m.	Reeves et al. 1999, Johnston et al. 2008
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*	Threatened (Indo-West Pacific DPS)	N/A	Occur over continental and insular shelves, and adjacent deep waters, but rarely found in waters < 22°C. Range from the intertidal and surface to depths up to 450–512 m.	Compagno 1984, Schulze-Haugen & Kohler 2003, Sanches 1991, Klimley 1993
Corals					
N/A	*Acropora globiceps*	Threatened	N/A	Occur on upper reef slopes, reef flats, and adjacent habitats in depths from 0 to 8 m	Veron 2014
N/A	*Acropora jacquelineae*	Threatened	N/A	Found in numerous subtidal reef slope and back-reef habitats, including but not limited to, lower reef slopes, walls and ledges, mid-slopes, and upper reef slopes protected from wave action, and its depth range is 10 to 35 m.	Veron 2014

Common name	**Scientific name**	**ESA listing status**	**MMPA status**	**Occurrence**	**References**
N/A	*Acropora retusa*	Threatened	N/A	Occur in shallow reef slope and back-reef areas, such as upper reef slopes, reef flats, and shallow lagoons. Depth range is 1 to 5 m.	Veron 2014
N/A	*Acropora speciosa*	Threatened	N/A	Found in protected environments with clear water and high diversity of *Acropora* and steep slopes or deep, shaded waters. Depth range is 12 to 40 meters, and have been found in mesophotic habitat (40-150 m).	Veron 2014
N/A	*Euphyllia paradivisa*	Threatened	N/A	Found in environments protected from wave action on at least upper reef slopes, mid-slope terraces, and lagoons in depths ranging from 2 to 25 m depth.	Veron 2014
N/A	*Isopora crateriformis*	Threatened	N/A	Found in shallow, high-wave energy environments, from low tide to at least 12 meters deep, and have been reported from mesophotic depths (less than 50 m depth).	Veron 2014

[a] These species have critical habitat designated under the ESA. See Table B1.

Table B1. ESA-listed species' critical habitat in the Pacific Ocean[a].

Common name	**Scientific name**	**ESA listing status**	**Critical habitat**	**References**
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered	None in the Pacific Ocean.	63 FR 46693
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered	Approximately 16,910 square miles (43,798 square km) stretching along the California coast from Point Arena to Point Arguello east of the 3,000 meter depth contour; and 25,004 square miles (64,760 square km) stretching from Cape Flattery, Washington to Cape Blanco, Oregon east of the 2,000 meter depth contour.	77 FR 4170
Hawaiian Monk Seal	*Neomonachus schauinslandi*	Endangered	Ten areas in the Northwestern Hawaiian Islands (NWHI) and six in the main Hawaiian Islands (MHI). These areas contain one or a combination of habitat types: Preferred pupping and nursing areas, significant haul-	53 FR 18988, 51 FR 16047, 80 FR 50925

			out areas, and/or marine foraging areas, that will support conservation for the species.	
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

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, 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.

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

American Samoa

There is little information available for the deepwater species of precious corals in American Samoa. Much of the information available comes from the personal accounts of fishermen. In the South Pacific there are no known commercial beds of pink coral (Carleton and Philipson 1987). Survey work begun in 1975 by the Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC) identified three areas of *Corallium* off Western Samoa: off eastern Upolu, off Falealupo and at Tupuola Bank (Carleton and Philipson 1987). Pink coral has been reported off Cape Taputapu, but no information concerning the quality or quantity of these corals or the depths where they occur is available. Unidentified precious corals have also been reported in the past off Fanuatapu at depths of around 90 m. Precious corals are known to occur at an uncharted seamount, about three-fourths of a mile off the northwest tip of Falealupo Bank at depths of around 300 m.

Commercial quantities of one or more species of black coral are known to exist at depths of 40 m and deeper within the territorial waters of American Samoa. Wagner (*pers. comm.*, 2015) has tentatively identified as many as 12 species (not previously catalogued in Am. Samoa) of black corals in depths between 50m and 90m, with 6 of these potential new species exhibiting growth forms that could lead to harvestable sizes. However, Wagner did not find any locations with the types of densities and sizes that would support any commercial harvest of these corals.

Guam and the Commonwealth of the Northern Marianas

There are no known commercial quantities of precious corals in the Northern Mariana Islands archipelago (Grigg and Eldredge 1975). In the past, Japanese fishermen claimed to have taken some *Corallium* north of Pagan Island and off Rota and Saipan. Preliminary results from surveys conducted throughout the Marianas Islands in 2016 indicate a scattered distribution with no areas of large agglomerations of precious corals found in waters deeper than 250 m.

U.S. Pacific Island Remote Areas

There are no known commercial quantities of precious corals in the remote Pacific Island areas, though individual colonies of precious corals have been seen at Jarvis, Palmyra, Kingman (Parrish and Baco, 2007) and Johnston Atoll, and planned surveys in 2017 may provide more information about abundance and distribution of precious corals found in waters deeper than 250 meters in these areas.

Hawaii

In the Hawaiian Archipelago there are seven legally-defined beds of pink, gold and bamboo corals, which are shown in Table 2. It is difficult to determine from the publication record exactly why these particular areas were singled out for legal recognition, other than the fact that they contain some unspecified densities of precious corals within their geographic boundaries. In the MHI, the Makapuu bed is located off Makapuu, Oahu, at depths of between 250 and 575 meters. Discovered in 1966, it the precious coral bed that has been most extensively surveyed in the Hawaiian chain. Its total area is about 4.5 km^2. Its substrate consists largely of hard limestone

(Grigg, 1988). Careful examination during numerous dives with submersibles has determined that about 20% of the total area of the Makapuu bed is comprised of irregular lenses of thin sand, 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).

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.**

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.

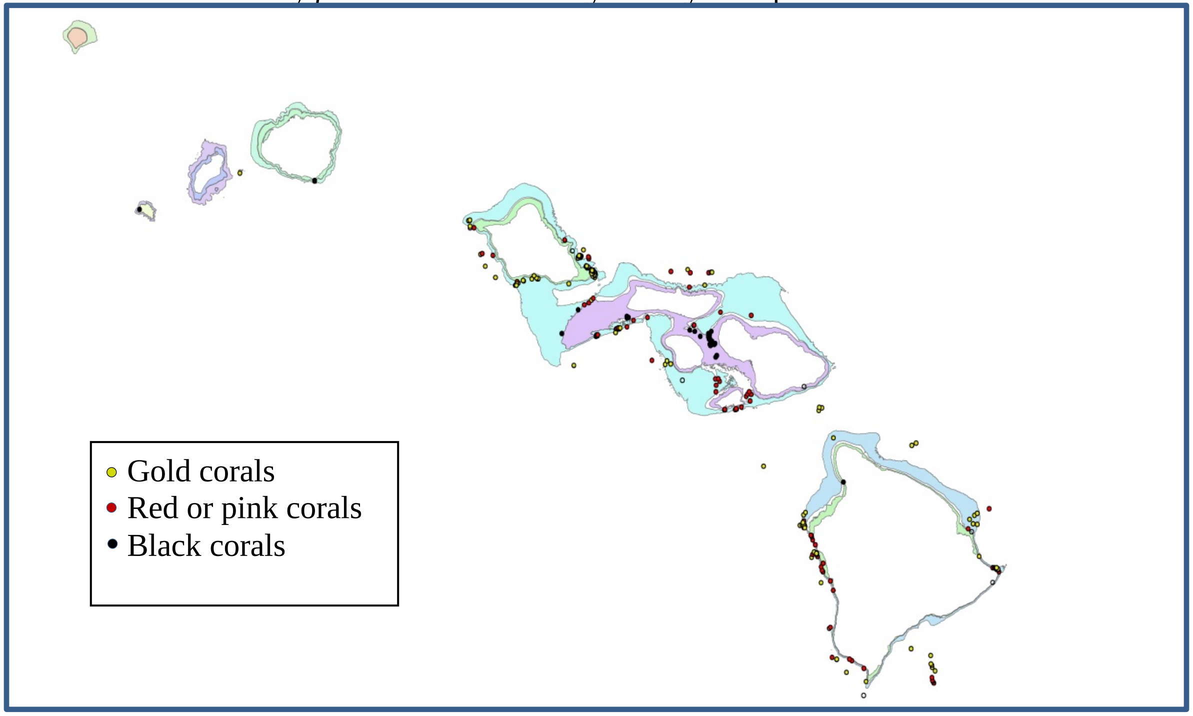

Figure 1. Observations of precious corals in the main Hawaiian islands

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^oC, he observes. Temperature may determine the lower depth limits of some species of precious coral, including two species of black corals in the MHI. In the MHI, the lower depth range of two species of black corals (*A.griggi* and *A. grandis*) coincides with the top of the thermocline (about 100 m). Although, *A. griggi* can be found to depths of 100 m, it is rare below the 75 m depth limit at which commercial harvest occurs in Hawai‘i. Thus, the supposed depth refuge from harvest does not really exist, and was probably based on taxonomic misidentification, thereby calling into question population models used for the management of the Hawaiian black coral fishery (Wagner *et al.*, 2012; Wagner, 2011).

In pink coral (*P. secundum*), the sexes are separate (Grigg, 1993). Based on the best available data, it is believed that *P. secundum* becomes sexually mature at a height of approximately 12 cm (13 years) (Grigg, 1976). Pink coral reproduce annually, with spawning occurring during the summer, during the months of June and July. Coral polyps produce eggs and sperm. Fertilization of the oocytes is completed externally in the water column (Grigg, 1976; 1993). The resulting larvae, called planulae, drift with the prevailing currents until finding a suitable site for settlement.

Pink, bamboo and gold corals all have planktonic larval stages and sessile adult stages. Larvae settle on solid substrate where they form colonial branching colonies. Grigg (1993) notes that the lengths of the larval stage of all deepwater species of precious corals is unknown. Clean swept areas exposed to strong currents provide important sites for settlement of the larvae, Grigg adds. The larvae of several species of black coral (*Antipathes*) are negatively photoactic, he notes. They are most abundant in dimly lit areas, such as beneath overhangs in waters deeper than 30 m. In an earlier study, Grigg (1976) found that “within their depth ranges, both species are highly aggregated and are most frequently found under vertical dropoffs. Such features are commonly associated with terraces and undercut notches relict of ancient sea level still stands. Such features are common off Kauai and Maui in the MHI. Both species are particularly abundant off of Maui and Kauai, suggesting that their abundance is related to suitable habitat.” Off of Oahu, many submarine terraces that otherwise would be suitable habitat for black corals are covered with sediments (Grigg, 1976).

A variety of invertebrates and fish are known to utilize the same habitat as precious corals. These species of fish include onaga (*Etelis coruscans*), kahala (*Seriola dumerili*) and deepwater shrimp (*Heterocarpus ensifer*). These species do not seem to depend on the coral for shelter or food.

Densities of pink, gold and bamboo coral have been estimated for an unexploited section of the Makapuu bed (Grigg, 1976). As noted in the FMP for precious corals, the average density of pink coral in the Makapuu bed is 0.022 colonies/m^2. This figure was extrapolated to the entire bed (3.6 million m^2), giving an estimated standing crop of 79,200 colonies. At the 95% confidence limit, the standing crop is 47,500 to 111,700 colonies. The standing crop of colonies was converted to biomass ($3N_iW_i$), resulting in an estimate of 43,500 kg of pink coral in the Makapuu bed.

In addition to coral densities, Grigg (1976) determined the age-frequency distribution of pink coral colonies in Makapuu bed. He applied annual growth rates to the size frequency to calculate the age structure of pink coral at Makapuu Bed (Table 4). More recent work by Roark *et al.* (2006) suggests that annual growth ring dating may underestimate the ages of many species of deep water corals, and that most of the colonies that have been dated using the ring method are probably older and slower growing than first estimated.

Estimates of density were also made for bamboo (*Lepidisis olapa*) and gold coral (*Kulamanamana haumeaae (*prev. *Gerardia* sp.*)* for Makapuu bed. The distributions of both these species are patchy. As noted in the FMP, the area where they occur comprises only half of that occupied by pink coral (1.8 km^2). Estimates of the unexploited abundance of bamboo and gold coral were 18,000 and 5,400 colonies, respectively. Estimates of density for the unexploited bamboo coral and gold coral in the Makapuu bed are 0.01 colonies/m^2 and 0.003 colonies/m^2. Using a rough estimate for the mean weights of gold and bamboo coral colonies (2.2 kg and 0.6 kg), a standing crop of about 11,880 kg of gold coral and 10,800 kg for bamboo for Makapuu bed was obtained.

Growth rates for several species of precious corals found in the western Pacific region have been estimated. Grigg (1976) stated that the height of pink coral (*P. secundum*) colonies increases about 0.9 cm/yr up to about 30 years of age. These growth rates are probably overestimated, and should be revisited using modern methodologies, such as radiometric dating (Roark *et al.*, 2006). As noted in the FMP for precious corals, the height of the largest colonies of *Pleurocorallium secundum* at Makapuu bed rarely exceed 60 cm. Colonies of gold coral are known to grow up to 250 cm tall while bamboo corals may reach 300 cm. The natural mortality rate of pink coral at Makapuu bed is believed to be 0.066, equivalent to an annual survival rate of about 93%.

Table 4: Age-Frequency Distribution of *Pleurocorallium secundum* (Source: Grigg, 1973)

Age Group (years)	Number of Colonies
0–10	44
10–20	73
0–30	22
30–40	12
40–50	7
50–60	0

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Non-fishing effects that may adversely affect essential fish habitat in the Pacific Islands region

FINAL REPORT

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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 Hawai‘i (HI), the Territory of American Samoa (AS), the Territory of Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and the U.S. Pacific Remote Island Areas (PRIA).

1.2 Fishery Ecosystem Plans

In 1996, the MSA was reauthorized and called for the creation of an Ecosystem Principles Advisory Panel (EPAP) to develop recommendations to expand the application of ecosystem principles in fisheries management. Fishery ecosystem plans (FEPs) were identified as an important mechanism for implementing ecosystem-based fisheries management (EPAP 1999), and could be used to complement the MSA's existing fishery management framework, which requires Regional Fishery Management Councils to develop FMPs that contain conservation and management measures. Per the EPAP, FEPs should contain a management framework to control the harvest of marine resources based on available information regarding the structure and function of the ecosystem in which the harvests occur.

Between 2005 and 2009, the WPRFMC replaced their FMPs with five FEPs for the Western Pacific Region containing fishery conservation and management measures in accordance with provisions as stipulated in Section 303(a) of the MSA. FEPs were developed for each of the geographical/ jurisdictional areas of the Western Pacific Region (State of Hawaiʻi, the Territory of American Samoa, the Mariana Islands, PRIA) and for Pacific-wide pelagic fisheries. These FEPs include the required provisions of an FMP and support the ecosystem-based management of the fisheries.

1.2.1 Effects of Non-fishing Activities

Fishery species and their habitats are subjected to a range of non-fishing human activities and other sources of stress. These activities can affect EFH by altering the magnitude and direction of potential stressors, which in turn may either: 1) directly affect organisms (*e.g.*, injury, mortality, etc.) and/or the biological processes that control their population dynamics (*e.g.*, reproduction, behavior), or 2) indirectly affect organisms by altering interspecies interactions or by affecting the quality or quantity of their environment through alteration of physical, chemical or ecological processes that ensure ecosystem condition, function, and persistence.

The EFH regulations require FMPs to identify non-fishing activities that may adversely affect EFH (50 CFR §600.815(4)), and to provide conservation and enhancement measures to avoid, minimize, mitigate, or otherwise offset adverse effects for federal activities, including (but not limited to): dredging; filling; excavating; mining; impounding, discharging or diverting water; discharging water with different thermal characteristics; conducting activities that contribute to non-point source pollution and sedimentation, introduce potentially hazardous materials, introduce exotic species; and converting aquatic habitat such that it eliminates, diminishes, or disrupts the functions of EFH. Any federal agency undertaking an activity that may adversely affect EFH is required to consult with the NMFS, who is responsible for issuing appropriate recommendations.

In addition to specific human activities, other “natural” stressors can exert considerable force on EFH, and in this report, are important sources of stress. These include events such as weather cycles, hurricanes/typhoons, and natural climatic variability such as the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), and other stressors arising from human activities that have global scale effects, such as climate change and ocean acidification from greenhouse gas emissions. While managers cannot regulate or otherwise control these types of events, their occurrence can often be predicted and appropriate management responses can lessen the adverse effects that do and are reasonably expected to occur.

1.2.2 Cumulative Effects

Cumulative effects are effects on the environment that result from the incremental impact of an action when added to other past, present, and reasonably foreseeable future actions, regardless of who undertakes such actions. Cumulative effects can result from individually minor, but collectively significant effects resulting from two or more actions taking place over a period of time. The EFH regulations require FMPs, to the extent feasible and practicable, to analyze how the cumulative effects of fishing and non-fishing activities influence the function of EFH on an ecosystem scale (50 CFR §600.815(5)).

1.3 Purpose of this Report

Under the MSA, a review of information available on EFH must be completed at least once every five years, and EFH provisions of FMPs must be revised or amended, as warranted (50 CFR §600.815(10)). This five-year review should evaluate published scientific literature, unpublished scientific reports, information solicited from interested parties, and previously unavailable or inaccessible data. The WPRFMC reviews and updates the EFH section of the Western Pacific Region FEPs based on a five-year schedule of rotating reviews through its annual Stock Assessment and Fishery Evaluation report process.

This report is intended to review the potential effects (including potential cumulative effects) resulting from a range of non-fishing activities and other potential sources of stress. This review is intended to gather new information on: (1) non-fishing activities that may adversely affect EFH, (2) known and potential adverse effects of these activities on EFH, and (3) options to avoid, minimize, mitigate, or otherwise offset adverse effects on EFH. This information will assist the WPRFMC in determining whether modifications to the existing non-fishing effects sections of the five Western Pacific Region FEPs are warranted. While this information is highly valuable to inform impacts-analyses, the goal was not to address the approach to EFH consultations.

This review includes the following sections:

1) A brief description of the marine and estuarine ecosystems that comprise EFH in the Western Pacific Region (Section 2.0).
2) A discussion, by broad categories, of the non-fishing activities and other sources of stress that could affect EFH in the Western Pacific Region, (Section 3.0).
3) An assessment of potential effects of stressors on the marine and estuarine ecosystem that comprise the region’s EFH (Section 4.0).
4) A discussion of cumulative effects with specific guidance for assessing the effects of multiple stressors (Section 5.0).
5) A list of conservation measures to avoid, minimize, mitigate, or otherwise offset adverse effects (Section 6.0).
6) A comprehensive bibliography of relevant references reviewed and cited in this report (Section 8.0).

2.0 EFH in the Western Pacific Region

Regional Fishery Management Councils, with assistance from the NMFS, must identify and describe EFH for all Management Unit Species (MUS). EFH is defined as the waters and substrate necessary to a fishery species (*e.g.*, finfish, mollusks, crustaceans and all other forms of marine animal and plant life other than marine reptiles, marine mammals and birds) for spawning, breeding, feeding, or growth to maturity. EFH for managed fishery resources in the Western Pacific Region has been designated in the FEPs prepared by the WPRFMC and includes designations for five MUS: Bottomfish and Seamount Groundfish, Crustaceans, Precious Corals, Coral Reef Ecosystems, and Pelagic species.

For this report, an ecosystem refers to any taxonomically-diverse assemblage of species and the non-living components of their environment that interact with the unit or system (*e.g.*, a coral reef ecosystem). In contrast, habitat is the physical surroundings that influence and is used by a species (*e.g.*, sandflats are feeding habitat for many goatfishes). Due to a lack of habitat-related data for most MUS, the WPRFMC has broadly defined EFH to include all waters to a depth of 1,000 meters (m) and benthos to a depth of 700 m within the EEZ and encompassing all marine and estuarine ecosystems of the Western Pacific jurisdictions. In this report, effects to EFH are evaluated from the context of individual ecosystem function within a designated EFH because the EFH identified for all MUS are often comprised of multiple marine and estuarine ecosystems (Table 1). In addition, most ecological studies assessing the ecological effects of non-fishing activities are conducted at the organismal and ecosystem scales, and each ecosystem may display a different response to a given activity. As such, the broad definition of EFH in the five FEPs creates management and regulatory challenges due to the range and diversity of non-fishing activities (see Section 3.0) that occurs within these numerous and diverse marine ecosystems, and the potential effects of those activities on the stressors that impact these ecosystems. Additional refinement of the effects of non-fishing activities on EFH, and subsequent management of them, would benefit from a narrowing of the EFH designation to better describe the habitat of species within each MUS group.

Ecosystem structure and function varies over time due to a suite of dynamic and interacting processes (Christensen *et al.* 1996, Kay and Schneider 1994, EPAP 1999). Boundaries of marine ecosystems are often difficult to clearly and unambiguously delineate because most are interlinked by population- and ecosystem-level processes critical to each ecosystems' proper function and persistence. Although marine ecosystems are generally open systems, bathymetric and oceanographic features allow them to be reasonably identified (EPAP 1999), and for management purposes, WPRFMC has delineated them geographically, making them place-based. Each ecosystem type, as defined in the five Western Pacific Region FEPs, is discussed briefly below.

2.1 Benthic Ecosystems

Benthic ecosystems are those found on the bottom of the ocean, beginning at the shore line (*e.g.*, the intertidal, mangroves, etc.) and extending subtidally out to sea. Unlike continental coastal

Table 1. The marine and estuarine ecosystems comprising the EFH designations for the nine species complexes (comprising six MUS groups) in the Western Pacific Region.

MUS Group/Species Complex	Ecosystems within the EFH
Bottomfish and Seamount Groundfish	
Bottomfish	Deep reef slopes (<400 m), banks and seamounts, pelagic
Seamount Groundfish	Banks and seamounts at Hancock Seamounts (80-600 m), pelagic
Crustaceans	
Crustaceans: spiny and slipper lobsters, Kona crab	Coral reef, banks and seamounts, pelagic
Crustaceans: deepwater shrimp	Deep reef slopes, banks and seamounts, pelagic
Precious Coral	
Precious coral: deep-water complex	Deep-reef slopes, deep ocean floor, banks and seamounts, pelagic
Precious coral: shallow-water complex	Coral reef, deep reef slopes (to 100 m)
Currently-harvested Coral Reef Ecosystem	Coral reef, intertidal, seagrasses, mangroves, deep-slopes, banks and seamounts, pelagic
Potentially-harvested Coral Reef Ecosystem	Coral reef, intertidal, seagrasses, mangroves, deep-slopes, banks and seamounts, pelagic
Pelagic	Pelagic (<1,000 m), banks and seamounts

waters, islands within the Western Pacific Region tend to have narrow subtidal shelfs that support species-rich, nearshore marine ecosystems (*e.g.*, coral reefs, seagrass beds, etc.) that slope steeply into deep-water ecosystems (Figure 1). Consistent with those included in the Western Pacific Region FEPs, this section presents a brief description of the following benthic ecosystems: (a) intertidal, (b) mangrove forests or mangals, (c) seagrasses, (d) coral reefs, (e) deep reef slopes, (f) banks and seamounts, and (g) deep-ocean floor.

2.1.1 Intertidal

The intertidal zone exists between the highest and lowest extent of the tides and spends at least part of its time exposed to air. The duration and frequency of exposure is correlated with the vertical position on the shore; areas closer to the high tide mark are more frequently exposed and for longer durations than areas closer to the low tide mark. Intertidal areas can be comprised of hard (*e.g.*, basalt, limestone, etc.) or unconsolidated (*e.g.*, sand, cobble, etc.) substratum, which will dictate the types of associated fauna. Sandy shallows and tidal pools are important nursery areas for many subtidal invertebrate and fish species (Major 1978, Leber *et al.* 1998, Cox *et al.*

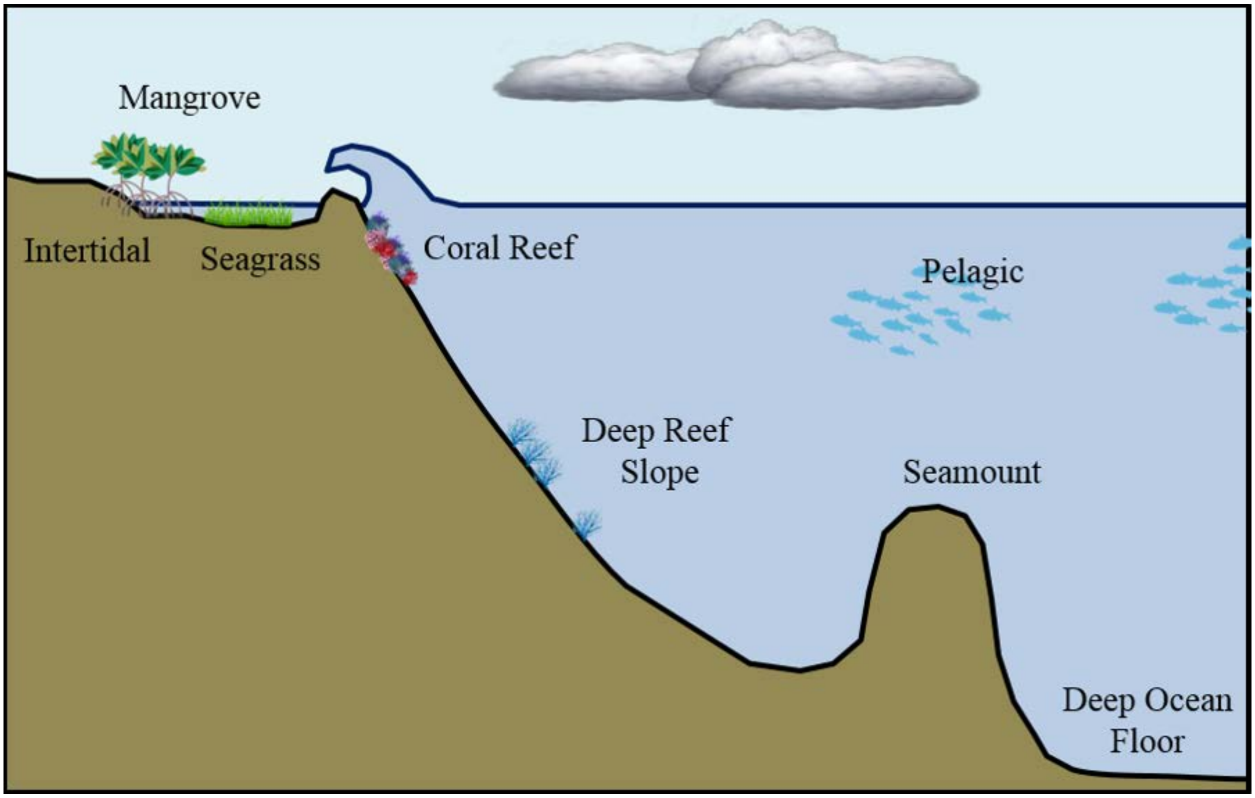

Figure 1. Schematic of the marine ecosystems that comprise the EFH of the Western Pacific Region.

2011, Iglesias 2012), including those that spend their adult life in other marine ecosystem such as coral reefs.

Intertidal organisms often display pronounced vertical zonation, where the lower limits of organisms are often determined by the presence of predators or competing species, and the upper limits are controlled by physiological limits and species' tolerance to temperature and drying (Garrity 1984, Levington 2001), although in the tropics, this may not always be the case (Minton and Gochfeld 2001). Due to challenging environmental conditions, intertidal areas generally have lower species richness and diversity than subtidal areas.

Along tropical rocky intertidal areas, marine algae and epilithic biofilms (comprised of cyanobacteria and diatoms) are the principle primary producers (Williams 1993, Williams *et al.* 2000, Macusi and Ashoka Deepananda 2013). Primary consumers such as snails and sea urchins graze on algae and biofilms, and support an array of secondary consumers that include a variety of invertebrates, sea birds and fish (Williams *et al.* 1993). Sandy intertidal areas usually support lower diversity than rocky intertidal areas, and may include a variety of burrowing mollusks, crustaceans, and worms, depending upon the amount of wave energy, which directly controls sediment grain size. Intertidal organisms are marine, and nearly all have a life history stage—usually a planktonic larval stage—that is dependent upon the ocean.

2.1.2 Mangrove Forests (Mangal)

Mangrove forests, or mangals, are tropical, coastal, forest ecosystems comprised of mangrove trees, which are adapted to grow in saline or brackish water. Mangrove forests are generally characterized as depositional coastal environments (Victor *et al.* 2004), where fine sediment, often high in organic content, collects in areas protected from high-energy wave action (Barbier *et al.* 2011). They help stabilize shorelines and reduce effects of natural disasters such as tsunamis and hurricanes (Scavia *et al.* 2002). Due to their high productivity and relatively sheltered environment, mangroves in some areas serve as important nursery habitat for many ecologically and commercially important coral reef fishery species, although research from several areas in the Pacific suggests that mangroves are less important than other coastal ecosystemns as nursery habitat for certain species (Laegdsgaard and Johnson 1995, Thollot 1992, Tupper 2007). Where mangroves have been found to be important as nurseries, they tend to have water quality conditions (*e.g.*, salinity, turbidity, etc.) similar to coral reefs (Cocheret de la Morinière *et al.* 2002), whereas in areas in which mangroves were not important reef fish nurseries, water tended to be less saline and more turbid. This is consistent with findings that juveniles of reef fishes inhabit the lower, more saline areas of mangals until migrating to the coral reef (Parrish 1989, Mumby *et al.* 2004, Abu El-Regal and Ibrahim 2014). Other fishes and crustaceans remain in the mangal throughout their adult lives, including mangrove crabs, which live in burrows among the mangrove roots. Mangals also provide food, medicine, fuel and building materials for certain local communities (Mumby *et al.* 2004 Gilman *et al.* 2006, Giri *et al.* 2011).

Mangrove trees possess an intricate salt filtration system (Lopez-Hoffman *et al.* 2007) and a complex root system to cope with salt water immersion, anoxic sediment, and wave action (Ball 1988). They can tolerate conditions ranging from brackish water to water with over twice the salinity of ocean water. Mangrove species zonation is generally correlated with soil water salinity (Ball 1988, Ukpong 1994), with less tolerant species located along the landward side of the forest or near freshwater inputs (*e.g.*, rivers). Some mangrove tree species have elaborate prop roots systems that form important substratum on which sessile organisms can settle and grow (MacDonald and Weis 2013), and which provide habitat for a variety of invertebrates and fish (Nagelkerken *et al.* 2010).

The natural eastern limit of mangroves in the Pacific is American Samoa (Ellison 1999), although three species (*Rhizophora mangle*, *Bruguiera gymnorrhiza*, and *Conocarpus erectus*) have become established in Hawai‘i since their introduction in the early 1900s, with *R. mangle* becoming the dominant plant in protected bays and along coastlines on all of the main islands (Allen 1998). While mangroves are highly regarded in most parts of the tropics for the ecosystem services they provide, in Hawai‘i they have significant negative ecological and economic effects, including reduction in habitat quality for native coastal wetland and mudflat species, displacement of native species in endemic ecosystems (*e.g.*, in anchialine pools), and overgrowth of native Hawaiian archaeological sites (Allen 1998, Chimner *et al.* 2006). Their values as nursery habitat for juvenile reef fish species is unclear, but generally they are considered detrimental.

Mangrove communities in American Samoa are composed of two species, *Bruguiera gymnorrhiza* and *Rhizophora mangle.* A majority of mangrove areas in American Samoa have been filled for residential and commercial development and roads since the early 1900s, and only five significant mangrove stands remain, covering approximately 52 hectares (ha) (Gillman *et al.* 2006). The role of mangroves in American Samoa as juvenile habitat for coral reef fish is unclear. Although numerous species are known to use areas fringed by mangal, the role of the forest themselves are unclear (Volk 1993).

In the Mariana Islands, mangroves cover an estimated 80 ha (Gillman *et al.* 2006) and comprise four species (*Rhizophora mucronata*, *R. apiculata, Bruguiera gymnorrhiza, Avicennia marina*). Only a single species is present in the CNMI (*Bruguiera gymnorrhiza*). Some mangrove areas on Guam (*e.g.*, Sasa Bay) have been identified as nursery habitat for jacks, barracudas, snappers, groupers, rabbitfish, mojarras, milkfish, and mullets (Wiles and Ritter 1993).

2.1.3 Seagrass Beds

Seagrasses are marine flowering plants widely distributed along tropical coastlines in the Western Pacific Region. Globally, seagrasses have an important role in fisheries production, and sediment accumulation and stabilization (, Jackson *et al.* 1989, Green and Short 2003, Dorenbosch *et al.* 2005, Larkum *et al.* 2006, Unsworth and Cullen 2008, Unsworth *et al.* 2010). Highly productive seagrass ecosystems have a relatively complex physical structure that provides a combination of food and shelter. This results in high biomass and secondary productivity, including for important fishery species in the Indo-Pacific (Parrish 1989, Beck *et al.* 2001, Honda *et al.* 2013, Nadiarti *et al.* 2015). In some area of the Pacific Ocean, seagrasses provide nursery area for species that support adjacent ecosystems, such as coral reefs and mangrove forests (Unsworth *et al.* 2010, Honda *et al.* 2013). While seagrasses may be less important in the Western Pacific Region as nursery habitat for fish and invertebrates, they are used in some jurisdictions by juvenile rabbitfish, goatfish, and snappers (Jones and Roberts 1975).

The role of seagrasses in binding sediment is important. Seagrass shoots baffle currents, thereby encouraging the settlement of sediment and inhibiting its resuspension (Short and Short 1984, Ward *et al.* 1984). By enhancing sediment retention, and through the relatively rapid uptake of nutrients both by seagrasses and their epiphytes, seagrass ecosystems can remove nutrients and other contaminants from the water column (Barbier *et al.* 2011). Once removed, these nutrients can be released more slowly through the eventual decomposition and consumption of leaf matter, thereby reducing problems of eutrophication and organic pollutants (Hemminga and Duarte 2000). Several studies that have documented the importance of seagrasses in reducing erosional forces during storm events (Koch *et al.* 2006, Barbier *et al.* 2011, Ganthy *et al.* 2014).

Seagrass diversity decreases from west to east across the Western Pacific Region. The Mariana Islands have three seagrass species (Lobban and Tsuda 2003), several of which form extensive and dense beds, especially on Saipan. American Samoa (Skelton 2003) and 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 Hawaiʻi, large *Halimeda* meadows and diverse macroalgal assemblages (*Lobophora variegata*, *Dictyota friabilis*, coralline algal rhodoliths, *Mesophyllum mesomorphum*, and *Peyssonnelia rubra*) have been observed covering both hard and soft substrata. These macroalgal communities generally do not comprise significant habitats for large-bodied fishes in the main Hawaiian Islands (Pyle *et al.* 2016), although endemic reef-associated fishes have been found in deep water *Microdicyton* (algae) beds in the Northwestern Hawaiian Islands (Kane *et al.* 2014). At greater depths, abundance of macroalgae declines and hard substratum is often dominated by monospecific stands of the hard coral *Leptoseris* spp. (Rooney *et al.* 2010, Pyle *et al.* 2016). Below approximately 100 m, live benthic cover was uniformly low, but on hardbottom features exposed to currents, precious black corals and the invasive octocoral *Carijoa* sp. could be locally abundant, with the latter often overgrowing large black coral colonies (Kahng and Grigg 2005).

Limited work in American Samoa has confirmed reef-building MCE at depths as great as 110 m. Encrusting corals belonging to the genus *Montipora* and massive corals in the genus *Porites* were most abundant at shallow depths with their cover gradually decreasing as depth increased. At depths of 60 to 70 m, plate corals in the genus *Acropora* dominated the MCE, giving way to species in the genera *Leptoseris*, *Pachyseris*, or *Montipora*. Branching coral cover was high in the 80 to 110 m depth range (Bare *et al.* 2010).

Extensive mesophotic reefs have been observed seaward of the Saipan Lagoon barrier reef, mainly on the Garapan Anchorage. Lindfield *et al.* (2016), using baited camera drops on Guam, Saipan, Tinian, and Rota, found high fish abundance on MCE (35-90 m) compared to inshore reefs (10-35 m), and suggest that MCE represent a depth refuge for many coral reef fish species. They also noted that coral structure disappeared at depths greater than 70 m and fish abundance decreased. At depths greater than 70 m, unconsolidated sediment was the primary bottom feature (Lindfield *et al.* 2016). In addition to hard scleractinian corals, sea fans, a type of soft coral, were a common feature on hard substrate at mesophotic depths in the Mariana Archipelago (Blythe-Skyrme *et al.* 2013).

Data are insufficient to identify the location or density of MCE in the PRIA, but the presence of deep-water corals (165 m) at Johnston Atoll (Kahng and Maragos 2006), along with the clear oligotrophic waters minimally influenced by terrigenous inputs, suggests that MCE are likely present at most or all islands within the PRIA (Blyth-Skyrme *et al*. 2013).

2.1.6 Banks and Seamounts

In the Western Pacific Region, banks and seamounts are submerged features formed by undersea volcanos. During the formation of seamounts, they never reached the surface of the ocean and thus maintain a generally "mountainous" shape, with steep slopes and relative little flat area on top of them. Banks are less specifically defined, but comprise shallow areas rising up from relatively deep waters that may have been formed by a submerged part of a larger landmass or a submerged atoll. Over 50,000 seamounts may exist in the Pacific Ocean (Rogers 2004), and banks and seamounts are found in all jurisdictions in the Western Pacific Region.

Seamounts can have a significant effect on the pelagic environment. They may deflect major ocean currents (*e.g.*, the Emperor Seamount Chain deflects the Kuroshio Current), and have the potential to form eddies, called Taylor Columns, that may become trapped or shed downstream (White and Mohn 2002, Rogers 2004). Taylor Columns are associated with the upwelling of nutrient-rich water from the deep ocean, and may lead to increased productivity in the upper waters above or downstream of seamounts (Brainard 1986, Rogers 2004), and may help retain pelagic larvae, although evidence for larval retention over seamounts, especially small ones, is sparse (Boehlert and Mundy 1993, Sponaugle *et al.* 2002).

In the Western Pacific Region, coral reef ecosystems tend to be found on the shallower parts of banks and seamounts, but can extend downslope into the mesophotic zone. Deeper parts of seamounts and banks may be composed of rock, coral rubble, sand, or shell deposits. Bank and seamount assemblages tend to be dominated by those found on nearby shallow areas and do not have unusual diversity or endemism (Howell *et al.* 2010). Seamounts and banks are important feeding and reproduction grounds for many deep water or pelagic species of fish. Plankton biomass may be increased over and around seamounts and form a source of prey for seamount-associated species (Rogers 2004). This forms the basis for the WPRFMC's designation of the water column down to 1,000 m above seamounts with summits shallower than 2,000 m as Habitat Areas of Particular Concern for the Pelagic MUS.

2.1.7 Deep Ocean Floor

The deep ocean (waters and seafloor deeper than ~200 m), supports a high diversity of ecosystems and species (Hessler and Sanders 1967, Grassle and Maciolek 1992, Sogin *et al.* 2006, Ramirez-Llodra *et al.* 2010, Mora *et al.* 2011), as well as abundant mineral resources (Herzig and Hannington 1995, Kato *et al.* 2011). Relatively little is known about this region due to the challenges associated with studying this environment, limiting our understanding of the resilience of this ecosystem to and its recovery from adverse effects. The deep ocean has a role in nutrient regeneration and global biogeochemical cycling that is essential for sustaining primary and secondary productivity in the oceans, and adverse effects that decrease the biodiversity of the deep ocean could affect this important ecosystem function (Danovaro *et al.* 2008). Pressure to extract deep ocean resources is increasing (Mengerink *et al.* 2014), including fishing, drilling for hydrocarbon extraction, and mining of rare earth elements (*e.g.*, Morato *et al.* 2006, Benn *et al.* 2010).

The deep ocean floor is generally comprised of soft-sediment, but biologically created "hardbottom" can cover tens of square kilometers and provide extensive three-dimension relief (Thurber *et al.* 2014). Probably the best-known example of biogenic habitat in the deep ocean is created by “cold-water” corals. Submersible explorations in 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

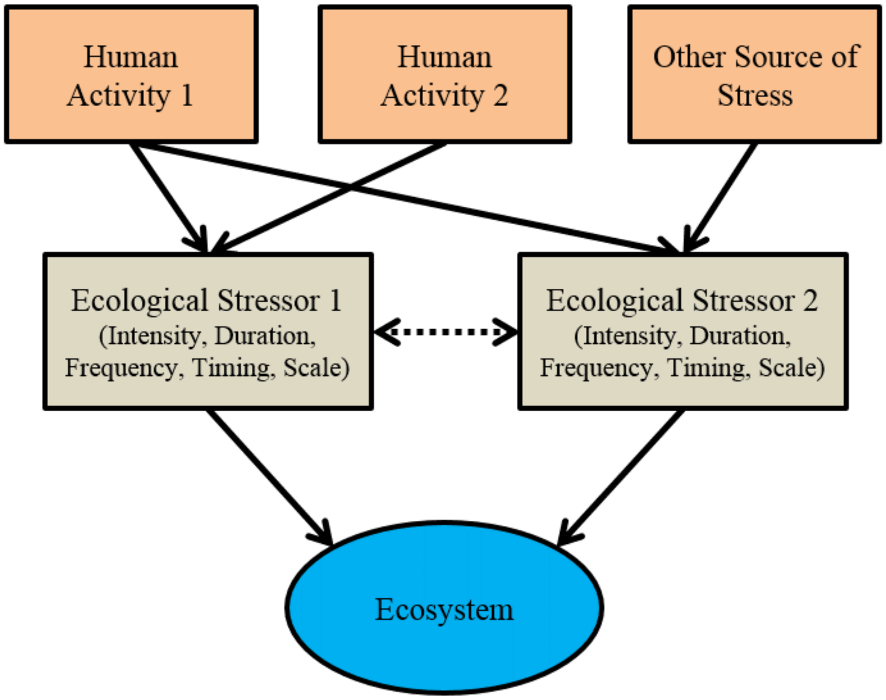

Figure 2. Conceptual flow diagram showing the linkage of human activities and other sources of stress on an ecosystem. Activities and sources of stress alter the intensity, duration, frequency, timing and/or scale of potential ecological stressors, which act directly on species or ecological processes 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	Stressors Indirect
Climate change	● HI ● AS ● MI ● PRIA ● Pelagic	● Acidification ● Shift in productivity ● Thermal ● Sea level rise	● Salinity ● Irradiance ● Invasive species ● Disease ● Physical damage ● Sediment ● Nutrient inputs ● Hydrocarbons ● Herbicide/Pesticide ● Metals ● PCBs ● Ordnance[†] ● Endocrine disruptors

[†] Mariana Islands and Hawaii

3.2 Energy Production

With the desire to reduce fossil fuel usage and obtain energy independence, a considerable investment has been made to develop and assess the feasibility of alternative energy in the Pacific Islands. The jurisdictions in the Western Pacific Region have no fossil fuel resources, but energy can be obtained from wind, solar, ocean currents (hydrokinetic), ocean thermal, and geothermal means. It is no longer a question of whether alternative energy production will be implemented, but when. In the past decade, numerous utility-scale alternative energy projects have been proposed in the Hawaiian Islands, but only a handful have reached the construction stage. Hawaiʻi has committed to a long-term plan to convert entirely to renewable energy sources by 2050 (DOE 2015); the current proposal, called the Hawaiʻi Clean Energy Initiative, includes 31 types of activities whose specific projects could affect EFH. In American Samoa, an Energy Action Plan (Ness *et al.* 2016) proposes an array of renewable energy projects to be completed by 2020. One of those projects, converting the Island of Ta'u to 100% solar power generation (1.4 megawatts), was completed in 2016 (Heathman 2016). Both Guam (Conrad and Ness 2013a) and the CNMI (Conrad and Ness 2013b) have Energy Action Plans, but have yet to make significant progress in their implementation. Palmyra Atoll currently has a small research station (operated by The Nature Conservancy and the Palmyra Atoll Research Consortium) on its largest island that is powered by a combination of solar and wind power arrays, supported by a diesel generator. When assessing the potential effects on EFH, these renewable energy activities can be divided into two sub-categories: land-based and ocean-based energy activities.

Land-based energy projects include wind turbines, solar, geothermal facilities, and land-based Ocean Thermal Energy Conversion (OTEC). The stressors affected by the land-based portions of these projects would be similar to those found under land-based development/construction category. Some facilities, such as OTEC, require inwater intake and discharge structures which can contribute to direct effects on coastal and nearshore ecosystems. If energy produced through these projects remains on the island where it is generated, likely no additional effects to EFH would be expected, except for OTEC, which is discussed in more detail below. If energy is to be transferred to neighboring islands within an archipelago, the most practical transmission method would use submerged cables, either in surface or (more likely) buried conduits. Buried conduits would likely require removal or disturbance of the substratum, including coral reef, either through mechanical trenching, directional drilling, or a combination of the two.

Ocean-based energy projects include wind turbines and solar facilities placed on platforms in the ocean, and alternative energy approaches that use the physical (*e.g.*, wave or tidal energy) or thermal (*e.g.*, OTEC) properties of the ocean to generate power. Ocean-based energy projects require infrastructure, but it can be free floating or anchored to the bottom. Essential infrastructure feetures include power generating infrastructure and a means to transfer the generated energy to land. Proposals that have been considered in the Western Pacific Region include platform wind turbine farms, hydrokinetic generators (several designs are currently under testing off O‘ahu, Hawai‘i), and ocean-based OTEC. As with land-based projects, energy would be transferred to consumers via either surface or buried conduits.

The energy production potential for OTEC is considered to be much greater than for other ocean energy forms (Arvizu *et al.* 2011), and pilot projects have already been conducted in Hawai‘i. OTEC is considered an attractive and viable energy production method in the Pacific, but it presents specific challenges to EFH that do not occur with other alternative energy production methods. OTEC uses the temperature differential between cold deep and warmer surface waters to generate electricity. OTEC systems may be either closed-cycle or open-cycle. Closed-cycle OTEC uses refrigerants such as ammonia for powering the system's generators, while open-cycle designs vaporize warm surface seawater in a low-pressure chamber and use it as the working fluid. As a by-product, OTEC produces cold, nutrient-rich water that is generally discharged back into the ocean.

3.3 Mining

Quarries are land-based mining locations that are present in most of the jurisdictions in the Western Pacific Region. Most quarry activity is dedicated to mining limestone for construction material, and likely has little effect on marine ecosystems, although they can potentially contribute to runoff. Unlike some other Pacific Islands (*e.g.*, Yap, Pohnpei, etc.), no direct mining of coral block/aggregate directly from living reefs occurs in the Western Pacific Region.

Currently, **deep ocean mining** is not economically viable on a large-scale, but continued advances in deep ocean mining technology and an increasing demand for rare earth elements (REE), will make it a realistic endeavor across the Pacific in the foreseeable future. Current deep ocean mining practices involve deploying remotely operated vehicles to locate prospective mine sites at depths between 1,400-3,700 m (4,200-8,100 ft) (Ahnert and Borowski 2000). Once a suitable site has been located, a mining ship or station is set up to mine the area (The Economist 2006) and one of two mineral extraction techniques are employed: 1) a continuous-line bucket system (CLB) and/or 2) a hydraulic suction system. The CLB system is the preferred technique and operates much like a conveyor-belt, running from the sea floor to the surface of the ocean

Summary Table: Energy Production. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors Direct	 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	 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.

	Potential	Stressors	
Activity/Source	**Jurisdictions**	**Direct**	**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

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[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	 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	 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	Indirect
Marine debris	● HI ● AS ● MI ● PRIA ● Pelagic	● Invasive species ● FAD effect ● Physical damage ● Hydrocarbons ● Herbicide/Pesticide ● Metals ● PCBs	

		● Endocrine disruptors

However, sample collection and the installation of instrumentation has the potential to produce cumulative effects, especially if numerous research efforts are spatially and/or temporally concentrated.

3.9 Wastewater Discharge

Most terrestrial-derived "pollutants" are transported to and enter the nearshore ocean via water, whether it is the intentional disposal or through natural processes. For the purposes of this report, wastewater is defined as any water entering the ocean, via point source, groundwater, river system, or runoff that carries some pollutant (*e.g.*, sediment, chemicals, biological contaminants/ organisms) or has different physical properties (*e.g.*, different temperature or salinity) than the receiving body.

Summary Table: Other Human Non-fishing Use. See Section 4.0 for a detailed discussion of each stressor.

Activity/Source	Potential Jurisdictions	Stressors	
		Direct	**Indirect**
Military training	● HI ● AS ● MI ● Pelagic	● Noise ● Invasive species ● Physical damage ● Nutrient inputs ● Hydrocarbons ● Metals ● PCBs ● Ordnance ● Endocrine disruptors	● Salinity ● Irradiance ● Sediment ● Nutrient inputs ● PCBs ● Ordnance ● Endocrine disruptors
Recreational use	● HI ● AS ● MI	● Noise ● Invasive species ● FAD effect ● Physical damage ● Nutrient inputs ● Hydrocarbons ● Herbicide/Pesticide ● Metals ● Endocrine disruptors	● Sediment ● Endocrine disruptors
Scientific research	● HI ● AS ● MI ● PRIA ● Pelagic	● Invasive species ● Disease ● FAD effect ● Physical damage ● Hydrocarbons ● Metals	

In the jurisdictions of the Western Pacific Region, effluent from primary and secondary **sewage** treatment plants often discharge directly into the nearshore waters via outfalls. Discharges may be in relatively shallow (~30 m) to deep (>80 m) water. Alternatively, treated effluent can be discharged into upland injection wells, where there is the potential for it to migrate into the groundwater and eventually find its way to the ocean through submarine groundwater discharge. Following large rainfall events, high volumes of stormwater can overburden treatment facilities and result in the discharge of untreated human sewage. Many island communities around the Pacific are not connected to municipal sewage treatment facilities, and rely on cesspools or septic tanks. Cesspools and septic systems are common in many rural and coastal areas of 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.

	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟥	🟥	🟩	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟧
														Chemicals						
	Ocean Acidification	Shift in Productivity	Thermal	Salinity	Irradiance	Noise	Hypoxia	Invasive Species	Disease	FAD Effect	Physical Damage	Sediment	Nutrient Inputs	Hydrocarbons	Herbicide/Pesticide	Metals	PCBs	Ordnance	Endocrine Disruptors	Sea Level Rise
Climate Change	D	D	D	i	i			i	i		i	i	i	i	i	i	i	*	i	D
Energy Production																				
Landbased			D	D	i	i		i		D	D	iD	i	i	i	i	i	*	i	
Waterbased			D	D	D	i		D		D	D	D	D	D		D		*	D	
Mining																				
Quarries					i							i	i	i		i	i	*	i	
Deep Ocean					D	D					D	D		D		D				
Land-based Aquaculture			D	D	D		i	D	D	D		D	D		D	D	D	D	D	
Development/Construction																				

Landbased			i	i	i		i	i	i			i	i	i	i	i	i	*	i	
Coastal roads					iD	D	i	D	D	D	D	iD	iD	D	D	D	iD	*	D	
Waterbased-Dredging					D	D	i	D	D	D	D	D	D	D	D	D	D	*	D	
Waterbased-Non-dredging						D		D		D	D			D	D	D	D	*	D	
Artificial reefs						i		D		D	D			D						
Shipping/Boating																				
Shipping						D		D	D	D	D	D	D	D		D			D	
ATONs										D	D			D		D			D	
Anchorages						D				D	D			D		D			D	
Marine Debris								D		D	D			D	D	D	D		D	
Non-fishing Human Uses																				
Military training				i	i	D		D			D	i	iD	D		D	iD	*	iD	
Recreational use						D		D		D	D	i	D	D	D				iD	
Research								D	D	D	D			D		D				
Wastewater Discharge																				
Sewage			D	D	D		i		D			D	D	D	D	D			D	
Stormwater			D	D	D		i		D			D	D	D	D	D	D		D	
Other activities			D	D	D		i		D			D	D	D	D	D			D	

3. *Physical stressors* are associated with changes in exposure to kinetic energy. This type of ecological disturbance is often acute and episodic, and in this report, include: **Physical damage.**

4. *Pollution stressors* occur when chemicals or other contaminants are present in concentrations large enough to affect organisms and thereby cause ecological change. Pollution can include anthropogenic inputs of pesticides/herbicides, hydrocarbons, metals, and other toxic chemicals, but also can include inputs of sediment and nutrients. This report includes: **Sediment, Chemicals,** and **Nutrient inputs.**

5. ***Sea level rise*** is a unique marine stressor with important implications in the Western Pacific Region. On casual examination, sea level rise alone might appear to be unimportant to subtidal marine ecosystems, but it is a significant direct threat to intertidal and mangrove ecosystems. Additionally, it acts indirectly on other ecosystems through often synergistic interactions with other stressors (see Section 5.0).

4.1 Environmental Stresses

4.1.1 Ocean Acidification

Ocean acidification is the decrease in the pH of the oceans caused by the uptake of atmospheric carbon dioxide (CO_2) (Caldiera and Wickett 2003). Seawater is slightly basic (pH ~8.2) and acidification shifts it towards a less basic condition, *i.e.*, lower pH. Equally important, acidification decreases the carbonate concentration in seawater, and thus decreases the saturation state of calcium carbonate ($CaCO_3$) (Orr *et al.* 2005, Kleypas *et al.* 2006, Cooley and Doney 2009). This change in the chemical make-up of seawater can directly affect the biological process of calcification, essential for reef-building organisms, mollusks, echinoderms, and many types of plankton.

Over the past two centuries, atmospheric CO_2 has increased by over 43%, from pre-industrial levels of approximately 280 parts per million (ppm) (IPCC2007) to over 400 ppm in 2016 (NOAA 2016), and under "business-as-usual" models which assume continued greenhouse gas emissions at or exceeding current rates, atmospheric CO_2 could exceed 1,000 ppm by the end of the century (Kiehl 2011). This rate of CO_2 increase is driven primarily by human burning of fossil fuels and deforestation (Doney & Schimel 2007), and the current concentration of CO_2 is higher than that experienced on Earth for at least the past 800,000 years (Lüthi *et al.* 2008). Rising atmospheric CO_2 is tempered by oceanic uptake, which can absorb up nearly a third of the anthropogenic carbon added to the atmosphere (Sabine and Feely 2007, Sabine *et al.* 2004).

At the Hawaiʻi Ocean Time-Series (HOT) station ALOHA, the rate of increase of surface water CO_2 and atmospheric CO_2 are strongly correlated (Takahashi *et al.* 2006, Dore *et al.* 2009), indicating uptake of anthropogenic CO_2 is the primary cause of long-term decreases in pH and $CaCO_3$ saturation state. Since preindustrial times, the average ocean surface water (the ocean layer down to approximately 100 m) pH has fallen by approximately 0.1 pH units, from approximately 8.21 to 8.10 (Royal Society 2005) which is due to the logarithmic nature of the pH scale represents about a 30% increase in acidity (Caldiera and Wickett 2003). Buoy data from the equatorial Pacific (covering years 1997-2011) show pH ranged from 7.91-8.12 (Sutton *et al.* 2014), which is consistent with what has been observed in subtropical waters (pH = 8.06-8.14) via the HOT station ALOHA time series (Dore *et al.* 2009). Acidity is expected to decrease to7.88 pH units if the atmospheric CO_2 concentration reaches 1,000 ppm (IPCC 2007), although more current projections suggest pH might be lower under this business-as-usual model (IPCC 2014). Even under modest, likely-to-be-obtained climate change predictions (CO_2 = 560 ppm), oceanic pH is expected to be 7.92 pH units (IPCC 2014), and deep ocean waters and arctic surface waters are expected to be undersaturated ($CaCO_3$ saturation state <1). At pH 7.8, major ecological changes will occur because of the impairment of invertebrate reproduction (Wood *et al.* 2008, Wang *et al.* 2016) and recruitment (Nakamura *et al.* 2011), and shell dissolution of many benthic and planktonic invertebrate taxa (Smith & Buddemeier 1992, Kleypas *et al.* 1999, Hall-Spencer *et al.* 2008, Cooley and Doney 2009). Additionally, acidification will affect biological processes beyond calcification, including gene expression, metabolism, and cell death/regeneration (Kleypas *et al.* 2006, Todgham and Hoffman 2009). Already seasonal acidification events are appearing in upwelled waters along the California coastline in summer, decades earlier than models predict (Feely *et al.* 2008, Gruber *et al.* 2012).

However, the effect of ocean acidification on calcification is complicated by the fact that enhanced levels of CO_2 can increase photosynthetic rates (Behrenfeld *et al.* 2006, Kranz *et al.* 2009), which will affect net primary productivity (Hein and Sand-Jensen 1997, Behrenfeld *et al.* 2006, Jiao *et al.* 2010). In corals, much evidence suggests that under normal conditions, calcification rates generally rise proportionally with increases in rates of primary production, both at the colony and assemblage scale (Gattuso *et al.* 1999), yet in virtually all studies that have measured both photosynthesis and calcification in corals, any stimulation of photosynthesis by increased CO_2 was accompanied by a decrease, rather than an increase, in calcification (Reynaud *et al.* 2003). In 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 Hawaiʻi (Kuffner *et al.* 2008). This could have significant cascading effect through the coral reef ecosystem because CCA is an important structure-consolidating organism and a key settlement substratum for many corals. Under lower pH conditions, changes in CCA structure has significantly lowered the settlement density of coral larvae (Doropoulos *et al.* 2012).

Coral reef ecosystems are defined by their ability to produce a net surplus of $CaCO_3$ that produces the topographically complex reef structure necessary to support high marine biodiversity and biomass. Coral reef ecosystems have survived around many Pacific Islands because of their rapid accretion rates, giving them the ability to migrate upward and maintain themselves at a depth that has at least the minimum light levels required for continued growth. Under increasing ocean acidification, coral calcification rates will decrease, and dissolution rates will increase (Langdon *et al.* 2000, Yates and Halley 2006), particularly for those reefs at higher latitudes where seawater saturation state is expected to be closer to an undersaturated state. These reefs are already near the limit for reef growth, and will be further challenged by undersaturated seawater conditions. Interestingly, even though global warming may extend ocean water temperatures conducive to coral survival to higher latitudes, the decrease in reef $CaCO_3$ accretion expected at higher latitudes may restrict reef development to lower latitudes where aragonite saturation levels can support carbonate accumulation (Guinotte *et al.* 2003, Kleypas *et al.* 2001).

Even if calcification continues, reduced rates may impair the ability of calcifying organisms to compete with non-calcifying ones. Such a decrease has been observed in CCA assemblages when exposed to high-CO_2 conditions (Kuffner *et al.* 2008). Given that many taxa appear to exhibit species-specific responses (Fabry 2008, Ries *et al.* 2009, Doropoulos *et al.* 2012), assemblage- and ecosystem-level effects are likely to be complicated and difficult to predict, but are likely to result in major reorganizations of benthic and planktonic assemblages. These alterations will likely affect the physical and chemical structure of reefs. Topographical structure is a key ecological function strongly correlated with biodiversity, abundance, and biomass (Alvarez-Filip *et al.* 2009), and has direct implications on food webs dynamics.

Calcareous skeletal parts are widespread among many groups of benthic invertebrates and studies have reported drops in calcification rates at CO_2 levels below those expected under the current "business-as-usual" models for common species of mussels (*Mytilus edulis*) and oysters (*Crassostrea gigas*), a Pacific conch (*Strombus luhuanus*) and numerous species of sea urchin (Shirayama and Thorton 2005, Dupont *et al.* 2010), many of which occur in the Western Pacific Region. However, these findings cannot be easily generalized across taxa (Kroeker *et al.* 2014); many urchins and crustaceans show surprising resistance to low pH (Hendricks and Duarte 2010, Dupont *et al.* 2010, Kroeker *et al.* 2014), and calcification rates in the arms of a burrowing brittle star increased when they were grown in low pH water (Wood *et al.* 2008), but this finding is complicated in that while brittle stars experienced increased calcification, they also experienced decreased muscle mass in the arms, which would reduce arm movement and likely decrease respiration and feeding, suggesting that over the long-term, the organism would experience a reduction in fitness, highlighting the potential sub-lethal effects that can occur in seemingly resistant taxa (Dupont and Thorndyke 2013).

The effects of acidification may be exacerbated by certain developmental bottlenecks that are affected by low pH, and thus may have a disproportionately large influence on population dynamics that are missed by most experimental investigation (Dupont *et al.* 2010, although see Hendricks and Duarte 2010). The response of early developmental stages of invertebrates to ocean acidification has been investigated across a range of species, including bivalves and sea urchins. Under increasing acidification, sea urchins show reduced fertilization success, developmental rates, larval size, metamorphosis, spicule formation, and in their ability to settle (Kurihara and Shirayama 2004, Dupont *et al.* 2010; Evans and Watson-Wynn 2014). Likewise, developmental abnormalities have been observed in the oyster *C. gigas*, after 24 hours of exposure to high CO_2 levels (>2,000 ppm) and 80% of the larvae displayed malformed shells or remained unmineralized (Kurihara *et al.* 2007). Less dramatic, but still significant, effects have been observed at lower CO_2 levels, and even short exposure at the fertilization stage can carry over into later stage larvae, affecting growth rates and calcification (Barton *et al.* 2012). Greater susceptibility to increased acidification of larval and juvenile compared to adult mollusks is a pattern observed across a range of mollusks that have been studied (Kroeker *et al.* 2013).

In general, marine fish appear to be relatively tolerant to mild increases in CO_2 (Munday 2011a, Kroeker *et al.* 2014). Otolith development is unaffected by moderate increases in acidity (Munday *et al.* 2011b), although sublethal metabolic effects have been identified for some reef fish species (Munday *et al.* 2009). The most significant effects may occur through cellular changes that block olfactory senses, and consequently the ability of adults and juveniles to detect predators (Dixson *et al.* 2010; Munday *et al.* 2013; Heuer and Grosell 2014), and possibly to locate suitable settlement habitat (Dixson *et al.* 2008), which under some ecological conditions could have significant adverse effects on a population.

Deepwater corals in the Western Pacific Region are slow growing and long lived (Roark *et al.* 2006). Their carbonate structure serves as important habitat for many deep sea species and support high biodiversity of invertebrates (Parrish and Baco 2007). The maximum depth of deep water corals and their associated species appears to coincide with the depth of the aragonite saturation state horizon (Guinotte *et al.* 2006), which under the "business-as-usual" climate models is expected to shoal. As such, these deepwater coral systems are expected to be the first to experience a shift to an undersaturated seawater condition (Doney *et al.* 2009). This will likely lead to range/depth contractions, and could force slow-growing deepwater corals into direct competition with shallow water coral species, which are likely superior competitors.

The effects of elevated CO_2 and ocean acidification on primary productivity are complicated by the relationship between carbon uptake (as part of the photosynthetic process), temperature, calcification (where relevant), and nutrient availability. A potentially major consequence of ocean acidification will be significant changes in the inorganic and organic chemistry of seawater. Affected chemical species include biologically important elements such as boron, phosphorus, silicon, and nitrogen, as well as trace elements such as iron, zinc, vanadium, arsenic, and chromium (Doney *et al.* 2009). Concentrations of phosphate, silicate, fluoride, and ammonia species will decrease with increasing acidification (Zeebe and Wolf-Gladrow 2001), and will have far-reaching implications for phytoplankton and other ecological processes. Additionally, many trace elements (*e.g.*, aluminum, iron, chromium, etc.) show reduced bioavailability to organisms as result of hydrolyzation under increasing acidification. The overall effect of ocean acidification on the structure and function of these biologically important compounds is largely unknown, making predicting organismal and ecosystem effects difficult.

Seagrasses show a consistent and dramatic increase in light-saturated photosynthetic rates with increasing acidification (Zimmerman *et al.* 1997, Short and Neckles 1999, Invers *et al.* 2001), although it is possible these benefits could be offset by the negative effects of increased temperature on vegetative growth (Ehlers *et al.* 2008). Interestingly, regions near natural subsurface volcanic CO_2 vents in the Mediterranean Sea showed a marked absence of reef-building corals and reduced abundance of sea urchins, coralline algae, foraminifera, and gastropods. Instead, the benthos was dominated by sea grass, anemones, and non-native invasive algal species (Hall-Spencer *et al.* 2008), consistent with expectations from laboratory experiments.

The mangrove trees *Rhizophora mangle* showed increase photosynthesis under elevated CO_2 levels (Farnsworth *et al.* 1996), but this appears to be mediated by salinity. Trees grown under elevated CO_2 experienced little growth enhancement in high-salinity conditions, but more growth enhancement under low-salinity conditions (Ball *et al.* 1997), an effect that was magnified for less-tolerant species (Ball *et al.* 1997). Likewise, little effect on mangrove seedling growth or survival was found for three species in different mangrove genera when grown under highly acidic conditions (pH=5.0) (Rozainah *et al.* 2016), suggesting that mangrove trees will experience few adverse effects from CO_2 condition expected under "business-as-usual" climate models.

Most studies on the effect of ocean acidification on the calcification rates of non-larval planktonic organisms have focused on coccolithophores (a common tropical planktonic group), and have found inconsistent responses to acidified seawater. The bloom-forming coccolithophore species, *Emiliania huxleyi* and *Gephyrocapsa oceanica,* showed a 25-66% decrease in calcification rate when CO_2 was increased to 560–840 ppm (Riebesell *et al.* 2000, Zondervan *et al.* 2001, Zondervan *et al.* 2002, Sciandra *et al.* 2003, Delille *et al.* 2005, Engel *et al.* 2005). In contrast, other coccolithophore species have exhibited no significant change in calcification or malformations from being cultured in acidified seawater.

In laboratory experiments under conditions of 560 and 740 ppm CO_2, the shell mass of two foraminifera species (*Orbulina universa* and *Globigerinoides sacculifer*) decreased by four to 14% compared with preindustrial CO_2 controls. Finally, the sub-arctic pteropod *Clio pyramidata* showed net shell dissolution in the living organisms when the aragonite saturation state reached <1 (Orr *et al.* 2005, Fabry *et al.* 2008), a level expected to occur over the range of this species under the current "business-as-usual" models.

Most marine phytoplankton tested in single-species laboratory studies and field population experiments showed little change in photosynthetic rates under CO_2 conditions equivalent to ~760 ppm (Tortell *et al.* 1997, Hein and Sand-Jensen 1997, Burkhardt *et al.* 2001, Tortell and Morell 2002, Rost *et al.* 2003, Beardall and Raven 2004, Giordano *et al.* 2005, Martin and Tortell 2006). In contrast, a phytoplankton assemblage dominated by diatoms and coccolithophores showed nearly a 40% increase in carbon uptake at CO_2 levels consistent with the "business-as-usual" climate models (Riebesell *et al.* 2007) indicating increased photosynthesis. Whether species show increased rates of photosynthesis with progressive oceanic uptake of atmospheric CO_2 may depend on nutrient and trace metal availability, light conditions, and temperature. Extrapolating current experimental results to ocean regions presents significant challenges because the ocean warming that accompanies acidification increases stratification of the upper ocean, thereby reducing the upwelling of nutrients, which contributes to decreased phytoplankton biomass and productivity on a global scale (Behrenfeld *et al.* 2006). What is clear is that the species diversity and the composition of phytoplankton assemblages are likely to change, with some species facing a high probability of extinction. The potential for this change at the base of the food web to cascade upward through multiple trophic levels will directly depend on the dietary specialization of secondary and tertiary consumers. However, the potential for severe adverse effects throughout marine food webs is significant and particularly difficult to predict based on available information.

As with other plankton, the effect of ocean acidification on larval fishes appears to be highly variable. Potential effects include reduced growth and survival (Baumann *et al.* 2011), skeletal deformation (Pimentel *et al.* 2014), altered neurological function (Nilsson *et al.* 2012), altered otolith (ear stone) development (Checkley *et al.* 2009, Munday *et al.* 2011b, Hurst *et al.* 2012, Bignami *et al.* 2013), impaired tissue health (Frommel *et al.* 2011), and disrupted behavior (Munday *et al.* 2010, Ferrari *et al.* 2012, Hamilton *et al.* 2014). In contrast, several other studies reported no significant effects of ocean acidification on fish larvae (*e.g.*, Munday *et al.* 2011a, Frommel *et al.* 2013, Bignami *et al.* 2014), illustrating the variability in potential effects.

What is clear is that calcification in marine plankton will be adversely affected when surface waters become undersaturated. While the aragonite saturation state in tropical surface waters is not expected to drop below one under the current "business-as-usual" climate models, saturation state in deeper water layers is expected to be <1 and will likely affect the depth at which plankton can exist without experiencing shell demineralization (Orr *et al.* 2005). This will result in a contraction of marine phytoplankton ranges to shallower depths and lower latitudes. Unfortunately, predicting, and even detecting, such acidification-driven population shifts presents a significant challenge because of a lack of baseline data on the current distributions and abundances of most plankton species.

4.1.2 Shifts in Productivity

Open ocean productivity refers to the production of organic matter through the process of photosynthesis by phytoplankton (primary productivity) and the further production through the consumption and growth of non-photosynthetic heteroplankton (secondary productivity) suspended in the water column (Sigman and Hain 2012). Although productivity is the result of biological activity and the organisms responsible for it are subjected to many of the stressors described in this report, this report considers open ocean productivity as an environmental stressor because the location, diversity, abundance and biomass of pelagic assemblages, including important fishery species, are directly dependent on the amount of productivity in an area (Pauly and Christensen 1995, Chassot *et al.* 2010). Changes in the spatial distribution and amount of open ocean productivity are potentially among the most important non-fishing factors affecting all marine ecosystems, pelagic or benthic, and nearshore or open ocean.

In addition, this report treats open ocean productivity separately from nearshore productivity because the stressors affecting open ocean productivity tend to be regional, basin, or global in scale, all of which lack a strong local terrestrial component (although terrestrial inputs can be important via atmospheric deposition).

In addition to sunlight, phytoplankton require a suite of chemicals with which to grow and conduct photosynthesis, including nitrogen, phosphorous, iron, silicate, $CaCO_3$, and a variety of trace metals (Sigman and Hain 2012). Limitations in the availability of these requirements limit the amount of primary, and by extension secondary, productivity in a region of the ocean.

Open ocean productivity in the tropical Pacific is primarily associated with regions of upwelling, where nutrient-rich, deep-ocean water is brought to the surface. In regions without upwelling, thermal stratification creates a warm, nutrient-poor, or oligotrophic, surface layer (due to a lack

Summary Stressor Table: Potential effects of ocean acidification
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	● Decreased diversity ● Decreased survival of planktonic larval stages of important herbivorous and sessile invertebrates (*e.g.*, urchins, nerites) ● Increased algal photosynthetic activity, potential for a phase shift toward algal-dominated shoreline
Mangrove Forests	● Increased photosynthetic and growth rates for mangroves and other primary producers, but may depend on salinity ● Decreased abundance of calcifying organism ● Decreased survival of planktonic larval stages
Seagrass Beds	● Increased photosynthetic rates and primary productivity ● Denser seagrass beds, although vegetative growth may be tempered by increasing seawater temperature ● Decreased abundance of calcifying organism ● Decreased survival of planktonic larval stage
Coral Reefs	● Reduced calcification rates in reef-building organisms, including corals and coralline algae. ● Increased algal photosynthesis and growth ● Reduced calcification and survival of potentially important invertebrate grazers (*e.g.*, urchins) ● "Flattening" of reef structure leading to loss of species diversity, including important fishery species ● Potential for a phase-shift toward algal-dominated assemblage
Deep Reef Slopes	● Drop in aragonite saturation state <1 under "business-as-usual" climate change predictions ● Dissolution of calcifying organisms ● "Shoaling" of range distributions, potentially leading to increased competitive interactions with shallow-water species ● Extirpation of species likely ● Decreased diversity (including fishery species) associated with loss of structure-producing organisms ● Decreased survival of planktonic larval stages
Banks and Seamounts	See *Coral Reefs* and *Deep Reef Slopes*

Ecosystem	**Potential Effects**
Deep Ocean Floor	- Drop in aragonite saturation state <1 under "business-as-usual" climate change predictions - Dissolution of calcifying organisms - Extirpation of species is likely - Decreased diversity (including fishery species) associated with loss of structure-producing organisms
Pelagic Environment	- Increased photosynthesis in phytoplankton, but mediated by nutrients and trace minerals - Decreased abundance of calcifying organism - Decreased survival of planktonic larval stages - Shifts in species composition, which has potential to disrupt food web dynamics

of mixing with deeper layers) where both primary and secondary productivity are limited. Therefore, regions of productivity are strongly affected by oceanographic processes that alter the position and strength of upwelling. These oceanographic processes are usually the result of basin- or global-scale climatic events. Basin-scale events, including "short" duration ENSO events and longer duration PDO events, result in the shifting of surface water masses of differing temperature, which alters ocean stratification and moves the location of upwelling. At the global scale, climate change is expected to permanently change the amount, location, and quality of productivity.

In general, changing climate is likely to increase vertical stratification, reducing the upward flow of nutrients and lowering both primary (Falkowski *et al.* 1998, Behrenfeld *et al.* 2006, Toseland *et al.* 2013) and secondary (Roemmich and McGowan 1995) productivity. This effect is predicted to be most pronounced in the tropical oceans, including the Western Pacific Region. A six percent reduction in global oceanic primary production has already been observed between the early 1980s and the late 1990s (Gregg *et al.* 2003), and extrapolating into the future, suggests that marine biological productivity in the tropics and mid-latitudes will decline substantially (Cochrane *et al.* 2009). Both statistical and coupled biogeochemical models (Lehodey 2001, Lehodey *et al.*2003) have predicted the slowdown of Pacific meridional overturning circulation and a subsequent decrease of equatorial upwelling, which has been attributed as the cause of the primary production and biomass decrease over the past 40 years (McPhaden and Zhang 2002).

Changes in secondary productivity are likely to be linked closely with changes in primary productivity in the Western Pacific Region, and effects on tropical zooplankton are likely to be more pronounced than those already being observed at higher latitudes. The more heat-tolerant, low-latitude species might be more vulnerable to climate change stressors than less heat-tolerant species because they may live closer to their physiological limits (Tomanek and Somero 1999, Stillman 2002).

An increased in primary productivity has the potential to increase particulate organic matter (POM). Zooplankton, which consume phytoplankton, usually experience a time lag before they can respond to the increase in primary productivity. During this time lag, POM will be exported from the surface waters to the deep waters, where microbial assemblages will recycle it. This process consumes oxygen and can result in hypoxia in deep waters (see Section 4.1.7), creating what have been called "dead zones."

Currently, it is unclear how climate change will affect ENSO and PDO events in the Western Pacific Region (IPCC 2013). Climate change is expected to weaken tropical easterly trade winds, warm the surface ocean, and intensify the subsurface thermocline. ENSO variability is controlled by a delicate balance of competing feedbacks, and it is likely that one or more of the major physical processes that are responsible for determining the characteristics of ENSO will be modified by climate change (Collins *et al.* 2010). Unfortunately, our current understanding of ENSO variability does not make it possible to predict the potential changes that could occur (IPCC 2013). The WPWP, an immense region of warm water along whose eastern edge strong upwelling occurs, is likewise affected by ENSO events. The upwelling region is important to several species of tuna. During ENSO events, the eastern edge, and thus the region of high productivity can shift as much as 4,000 kilometers (km) eastward as a result of weakened easterly trade winds (Lehodey *et al.* 1997). Likewise, it is not clear how climate change stressors will affect the WPWP, but an effect is expected to cause a significant shift in both the amount and location of high productivity areas, which will result in concomitant shifts in pelagic assemblages, including important fishery species.

4.1.3 Thermal

Thermal stress occurs when the temperature of the environment changes such that it can disrupt the normal biological activity of an organism or the processes and/or function of an ecosystem. In the ocean, thermal stress is often associated with increased temperature of the water, but does not necessarily need to be the result of warming; a decrease in water temperature can be a source of thermal stress. Likewise, most current discussion and research of thermal stress has been focused around regional or global processes (*e.g.*, climate change, ENSO events, etc.), but thermal stress can occur at smaller scales (*e.g.*, a discharge for a power plant or OTEC facility). Regardless of the scale, the results of "climate change studies" that examine thermal effects are still relevant when assessing the potential adverse effects of a small-scale thermal stress event.

In the marine environment, much focus has been placed on the large-scale or global effect of climate change on sea surface water temperature, with a significant focus on both organismal response and potential ecosystem level changes. Corals and coral reef ecosystems have received the majority of the attention, as the potential thermal stress responses in these organisms are expected to have far-reaching and dire implications for coral colonies, associated species, and ecosystem level processes. To a lesser extent, thermal stress response has been investigated in other marine organisms.

Summary Stressor Table: Potential effects of shifting productivity
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	- Altered survival rates for planktonic larvae, especially those with a long larval duration - Reduced connectivity among insular populations, likely reducing recovery potential
Mangrove Forests	See *intertidal*
Seagrass Beds	See *intertidal*
Coral Reefs	See *intertidal*
Deep Reef Slopes	See *intertidal*
Banks and Seamounts	See *intertidal*
Deep Ocean Floor	- Altered transport of particulate organic material into the deep ocean, which could result in increased hypoxia (in areas with >POM) or fewer nutrient resources (in areas with <POM) - Decreased diversity and altered assemblage structure - Altered biochemical cycling, affecting nutrient and chemical composition of upwelled water - Reduced connectivity among insular populations, likely reducing recovery potential
Pelagic Environment	- Altered survival rates for planktonic larvae, especially those that have a long larval duration - Altered assemblage composition; likely resulting in a loss of biodiversity - Altered trophic structure and food web dynamics - Shifts in species composition, which has potential to disrupt food web dynamics. - Shift in location and position of pelagic assemblages

The relative thermal tolerance of many marine organisms is roughly correlated with the temperature variability occurring in the organism's natural climate regime (Pörtner *et al.* 2014). The highest temperature tolerances are generally found in species at temperate latitudes, where seasonally-driven temperature changes are often large. In contrast, polar and tropical species have relatively narrow natural thermal ranges and for many of these species, they inhabit waters near their physiological temperature tolerance limits (Storch *et al.* 2014), making even small changes in water temperature problematic. Additionally, the thermal range tolerated by a species can vary among its life history stages, with early stages (*e.g.*, eggs and larvae) generally more sensitive than later ones (Pörtner and Peck 2010). Temperature tolerance can also be affected by the presence of other environmental stressors, such as reduced oxygen or ocean acidification (Pörtner and Peck 2010, Deutsch *et al.* 2015).

The effects of elevated ocean temperature are perhaps best studied in reef-building corals. Elevated water temperatures can cause the symbiotic algae, called zooxanthellae, that are found in coral tissues to leave or be expelled, resulting in coral “bleaching.” The loss of zooxanthellae directly affects the coral's energy production, but this loss can be offset to a limited extent by heterotrophic feeding by the coral polyps. If bleaching is prolonged, however, a coral colony will suffer partial or total mortality because of starvation.

Many reef-building corals live close to their upper thermal tolerance and are thus extremely vulnerable to warming (Hughes *et al.* 2003, McWilliams *et al.* 2005). Numerous reports of coral bleaching due to recent warming have been reported (*e.g.*, Hoegh-Guldberg 1999, Sheppard 2003, Reaser *et al.* 2000), including in the Mariana Islands, Hawai‘i, and Jarvis Island in the PRIA. Bleaching usually occurs when temperatures exceed a “threshold” of about 0.8 to 1 °C above mean summer maximum levels for at least four to six weeks (Hoegh-Guldberg 1999, Pandolfi *et al.* 2011).

Bleaching susceptibility shows high inter- (McClanahan *et al.* 2004, Yee *et al.* 2008) and intra-specific variability (Baird and Marshall 2002) and varies as a consequence of the magnitude of the thermal stress (Kleypas *et al.* 2008), irradiance levels (Mumby *et al.* 2001, Dunne *et al.* 2001), zooxanthellae symbiont types (Berkelmans 2006, Baker *et al.* 2008), species identity (Loya *et al.* 2001), and the thermal history of the organism (Thompson and van Woesik 2009, Oliver and Palumbi 2011). Species identity is one of the best predictors of thermal tolerance due to a predictable hierarchy of susceptibility among coral taxa. Fast growing branching taxa, such as *Acropora* and *Pocillopora*, normally bleach rapidly and experience high rates of whole colony mortality (Baird and Marshall 2002). In contrast, massive taxa such as *Porites* and some faviids take longer to bleach, and often show lower colony mortality (Baird and Marshall 2002). Ultimately, variability in bleaching susceptibility may be driven by the predominant type of zooxanthellae hosted by corals (Glynn *et al.* 2001, Baker *et al.* 2008). For example, increasing thermal tolerance of *Pocillopora* at some locations in the eastern Pacific has been linked to increased prevalence of colonies that host a thermally tolerant clade D symbiont (Glynn *et al.* 2001). Similarly, *Pocillopora* in French Polynesia host a diversity of symbiont types, including clade D (Magalon *et al.* 2007), which may explain their low level of bleaching susceptibility during recent bleaching events compared with many other geographic locations (Pratchett *et al.* 2013).

Corals also show significant variation in their ability to recover following a bleaching event (Baird and Marshall 2002). If sufficient colony tissue survives, recovery can occur within a few years (Diaz-Pulido *et al.* 2009), but recovery often requires a decade or more (Glynn *et al.* 2001, Baker *et al.* 2008, Sheppard *et al.* 2008). In other cases, no appreciable recovery of coral cover has been observed up to a decade following a bleaching event (Graham *et al.* 2007, Somerfield *et al.* 2008). For coral species hosting multiple symbiont strains, shifts to thermally resistant strains are sometimes observed after bleaching events (Thonhill *et al.* 2006, Cunning *et al.* 2016), although reversion to domination by thermally sensitive strains may occur over several years, probably because of a trade-off between bleaching resistance and photosynthetic rate (Jones and Berklmans 2010).

Mass bleaching events, when most of the coral assemblage bleaches, have become more frequent and widespread in the past few decades (Baker *et al.* 2008). These events are often associated with high mortality (Baird and Marshall 2002) and decreased colony growth and reproduction among survivors (Mendes and Woodley 2002). The consistency of the species hierarchy to bleaching susceptibility has led to the prediction that hardier, slow-growing massive species will replace less hardy, fast-growing, branching species on reefs in the future (Loya *et al.* 2001, Hughes *et al.* 2003). Changes in the morphological composition of the coral assemblage (*e.g.*, loss of fast-growing branching and tabular species) would likely result in a loss, or “flattening,” of three-dimensional topographic structure (Alvarez-Filip *et al.* 2009), an ecological function that forms a critical part of reef fish habitat. Mass bleaching can be followed by increases in macroalgae, especially when herbivores are absent or avoid consuming macroalgal species (Ledlie *et al.* 2007). Loss of coral diversity and physical structure usually leads to declines in reef community biodiversity (Jones *et al.* 2004, Alvarez-Filip 2009). Fishes and invertebrates that consume or inhabit corals during some part of their life cycle will also likely decline in abundance, although such effects may likely be accompanied by a time lag (Graham *et al.* 2007, Grandcourt and Cesar 2003).

In addition to reef-building corals, zooxanthellae are also found in species of soft-corals, sea anemones, gorgonians, giant clams (*Tridacna* spp.), and some nudibranchs, all of which have the potential to bleach under exposure to stress (Lesser *et al.* 1990, Norton *et al.* 1995, Ishikura *et al.* 1999, Buck *et al.* 2002, Leggat *et al.* 2003, Neo and Todd 2013). As in corals, bleaching reduces photosynthetic rates, alters the metabolism, and affects their growth, ultimately lowering fitness, although the magnitude of the effects varies among species. Following the 1998 mass bleaching event, survival rates of bleached clams were >95% (Leggat *et al.* 2003), compared to some species of coral which experience mortality as great as 99% (Mumby *et al.* 2001). This suggests that *Tridacna* spp. may be better able to cope with bleaching events significantly better than corals.

For non-photosynthetic marine organisms, research is more limited, but the most apparent effects of sub-lethal temperature stress are associated with altered metabolic processes such as growth, changes in the timing and success of reproduction (Walther *et al.* 2002, Walther *et al.* 2005, Parmesan and Yohe 2003), and shifts in the distribution of species (*e.g.*, Thomas *et al.* 2004, Perry *et al.* 2005, Poloczanska *et al.* 2007). For example, laboratory experiments on coral reef fishes have shown that elevated sea water temperatures lead to reductions in critical swimming speeds (Johansen and Jones 2011) and growth (Munday *et al.* 2008), as well as altering the timing of reproduction, reproductive output, and the condition of juveniles and larvae (Munday *et al.* 2008, Donelson *et al.* 2010). Juveniles of many marine fishes are particularly susceptible to changes in temperature, and larvae may succumb to elevated temperatures that their adult stages can survive (Gagliano *et al.* 2007). Shifts in the hatching times of eggs may affect the survival chances of larvae if hatching becomes asynchronous with food availability (Brierley and Kingsford 2009).

Changes in temperature may also change fish behavior, specifically their catchability in the fishery. Increased temperatures are likely to increase metabolic and consumption rates in fish and invertebrates (Kennedy *et al.* 2002), which could lead to higher catch rates using baits and potentially increase the diversity of catch, including unwanted bycatch (Cheung *et al.* 2012). In contrast, increased temperature could also result in increased fish swimming speeds (Peck *et al.* 2006), which could alter the efficiency of towed fishing devices, such as trawl nets (Rijnsdorp *et al.* 2009).

Intertidal species may already exist close to their tolerance limits, and further thermal stress may cause range shifts along continental coastlines (Stillman 2003, Sorte *et al.* 2010), but similar distributional shifts will not be possible on insular shorelines, and may lead to local extirpation of intertidal organisms that cannot adapt to changing conditions. This will result in substantial changes to intertidal assemblages, especially for species that occupy lower vertical positions on the shore because they tend to show lower thermal thresholds (Williams and Morritt 1995, Marshall *et al.* 2015).

The direct effect of increased temperature on seagrasses and macroalgae depends on species-specific thermal tolerances, and the seagrasses' optimal temperature for photosynthesis, respiration, and growth. Warm water species can often increase their photosynthetic rate and respiration over a wide range of temperatures (Perez and Romero 1992, Terrados and Ros 1995). Both respiration and photosynthesis are positively correlated with sea water temperature, but respiration usually increases at a greater rate than photosynthesis, especially at higher temperatures, thus leading to a reduction in net photosynthesis (Bulthuis 1983b; Dennison 1987, Marsh *et al.* 1986, Pérez and Romero 1992, Herzka and Dunton 1997, Masini and Manning 1997, Tait and Schiel 2013, Colvard *et al.* 2014). Thus, species growing near the upper limit of their thermal tolerance, will decrease in net productivity in warming water. Increased thermal stress may also affect flowering (de Cock 1981, McMillan 1982, Durako and Moffler 1987) and seed germination (Harrison 1982, Phillips *et al.* 1983), although the effect of temperature may be complicated by interactions with other stressors, for example, salinity (Caye and Meinesz 1986, Conacher *et al.* 1994). On intertidal shores, photosynthetic biofilms show increased productivity, but net productivity fell as herbivore grazing rates increased under elevated temperature conditions (Russell *et al.* 2013).

While the effects of rising sea temperature on individual species of plankton are not well understood and are likely variable (Huertas *et al.* 2011), rising sea surface temperatures will affect plankton assemblages by upsetting natural carbon dioxide, nitrogen and phosphorous cycling (Toseland *et al.* 2013) through reduced mixing and upwelling brought on by an increase in temperature-driven ocean stratification (see Section 4.1.2). This will result in lower primary productivity and decreased diversity, likely resulting in substantial adverse effects which cascade upward through the food chain. For example, increased thermal stress could lead to a decoupling in the timing of reproduction and the timing of plankton blooms (Platt *et al.* 2003), resulting in trophic instability through breaks in food chains (Hipfner 2009, Richardson and Schoeman 2004).

Even species with higher thermal tolerance could be affected by loss of prey species, including commercially important fish species (Beaurgrand *et al.* 2003). Some of these species will themselves shift ranges as a consequence of warming, but this will not necessarily lead to assemblage decline; for example, fish species richness in the North Sea has increased over the last two decades of the 20th century as the region has warmed, but species composition has been significantly altered (Hiddink and Hofstede 2008).

4.1.4 Salinity

Changes in water salinity will have different effects on marine organisms depending upon their ability to osmoregulate. Even minor osmoregulatory stress will result in increased energetic demands, possibly leading to a cascade of effects which are dependent upon the level of metabolic stress incurred. Like temperature tolerances, a species' tolerance, and thus its ability to cope with changes in salinity, is often associated with the natural variability within its habitat; species in estuarine and coastal ecosystems such as mangrove forests tend to display tolerance to a greater range of salinity than organisms found in the nearshore or open ocean ecosystems where salinity fluctuations tend to be small.

Salinity will directly affect estuarine (*e.g.*, mangroves, river mouths) organisms through osmoregulatory stress or indirectly by degrading their habitat, including breeding and nursery areas (Marshall and Elliot 1998). Mangrove trees are facultative halophytes, and tend to grow best when salinity is between five and 75 ppt, although many species can tolerate salinity up to 90 ppt (Krauss *et al.* 2008, Parida and Jha 2010). Mangrove trees do not have a salt resistant metabolism, but instead are equipped with physiological mechanisms that enable them to exclude or excrete salt (Drennan and Pammenter 1982). These mechanisms included one or more of the following (Mohammad and Uraguchi 2013): salt filtration at the root level (Takemura *et al.* 2000, Kahn *et al.* 2001), salt excretion via glands positioned on the undersides of the leaves, and/or salt disposal via accumulation of salt within leaf cells followed by defoliation (Popp *et al.* 1993).

Salinity is directly correlated with the standing crop of mangrove vegetation and productivity (Chen and Twilley 1998, Chen and Twilley 1999, Mall *et al.* 1987, Ukpong 1991), and under normal conditions, the distribution of mangrove species can be explained primarily by salinity gradients (Ball 1988, Ukpong 1994). Therefore, changes in salinity will likely influence the species richness of a mangal, and distributions of species within the forest. Deviations above or below a species' optimal salinity can reduce vegetative growth (Chodhury 2015), likely because of reduced photosynthesis, net photosynthetic rate, stomatal conductance, and transpiration rate (Noor *et al.* 2015). Additionally, changes to salinity can reduce seedling survival and establishment rates (Ye *et al.* 2004, Ye *et al.* 2005), and stunt tree height (Ball and Pidsley 1995, Hao *et al.* 2009).

Summary Stressor Table: Potential effects of thermal stress.
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	● Increased primary productivity associated with biofilms, but lower net productivity due to temperature-driven increases in grazing rates ● Reduced growth due to increased metabolic demands for some animal species ● Changed timing and lower success of reproduction for some species ● Temperatures above thermal tolerance thresholds could result in extirpation of species unable to migrate due to insular habitat
Mangrove Forests	● Few effects on mangrove trees ● Reduced growth due to increased metabolic demands for some animal species ● Changed timing and lower success of reproduction for some species ● Shifts in species distribution and assemblage composition ● Change in behavior of fishes; potentially increased feeding
Seagrass Beds	● Increased photosynthesis and respiration; at higher temperatures a decrease in net productivity, which can alter nutrient cycling ● Reduced growth due to increased metabolic demands for some animal species ● Increased bleaching in zooxanthellae-bearing invertebrates ● Changed timing and lowered success of reproduction for some species ● Change in behavior of fishes; potentially increased feeding
Coral Reefs	● Increased bleaching in coral and other zooxanthellae-bearing organisms, resulting in some cases in organism death ● Flattening of reef structure leading to loss of diversity, abundance and biomass, including important fishery species ● Altered assemblage composition, including the potential for a phase-shift toward algal-dominated assemblage ● Changed timing and lowered success of reproduction for some animal species ● Reduced connectivity among populations, likely reducing recovery potential

Ecosystem	Potential Effects
Deep Reef Slopes	● Effects likely to be minor due to depth, water movement, and lack of dependency on particulate organic matter from surface waters
Banks and Seamounts	See *Coral Reefs* (shallow) and *Deep Reef Slopes* (deep)
Deep Ocean Floor	● Altered transport of POM into the deep ocean, which could result in increased hypoxia (if >POM) or fewer resources (if <POM) ● Altered biochemical cycling, affecting nutrient and chemical composition of upwelled water
Pelagic Environment	● Decreased net primary productivity ● Geographic shifts in productivity ● Altered survival rates for planktonic larvae, especially those that have a long larval duration ● Altered assemblage composition; likely resulting in a loss of biodiversity, leading to changed trophic structure and food web dynamics

While many seagrasses in the Western Pacific Region are primarily marine in nature, they often experience natural fluctuations in salinity because of their shallow, nearshore habitat.

Seagrasses show wide variability in salinity tolerance, which is correlated with the amount of natural variability in salinity found in their habitat. Changes in salinity have been associated with distributional shifts and changes in abundance of seagrasses (Young and Kirkman 1975, Dawes *et al.* 1989, Lazar and Dawes 1991, Quammen and Onuf 1993). For example, vegetative growth of *Zostera capensis*, a mid-saline seagrass in South Africa, is inhibited at high and low salinities, while *Ruppia cirrhosa*, a competing species adapted to fresher water, showed maximum growth near zero salinity (Adams and Bate 1994). Several studies of seagrass seedling survival conducted on a wide range of species have shown that seeds tend to germinate well at relatively low salinities, but optimal seedling growth and development often occur under higher salinity conditions (Caye and Meinesz 1986, Hootsmans *et al.* 1987, Loques *et al.* 1990). Although none of these studies examine species present in the Western Pacific Region, they suggest what may be a general pattern among seagrasses. Salinities that are above optimal can reduce biomass because adjusting osmotic regulation limits seagrass growth by competing for energy, carbohydrate, and nitrogen supplies (Stewart and Lee 1974, Cavalieri 1983, Yeo 1983). In contrast, low salinity has been shown to suppress protein metabolism and alter enzyme activity, again leading to reduced biomass (McGahee and Davis 1971, Haller *et al.* 1974, James and Hart 1993). In addition, salinity has been a major factor influencing the onset and severity of eelgrass diseases (Short *et al.* 1986, Muehlstein *et al.* 1991, Burdick *et al.* 1993), although little is known about tropical seagrass diseases.

Corals have few physiological mechanisms for osmoregulation (Muthiga and Szmant 1987, Mayfield and Gates 2007), so a change in salinity can directly alter metabolic processes and/or cause colony mortality. The effects of salinity changes on coral reefs have not been well-studied, likely because most reefs experience little fluctuation in natural salinity levels, but the response of corals to changing salinity appears to be related to the strength and duration of the exposure and the species affected. As with most other taxonomic groups, considerable inter-specific variation in salinity tolerance is present among coral species. For example, *Stylophora pistillata* is sensitive to small changes in salinity (Sakai *et al.* 1989) whereas *Porites compressa* is more tolerant (Coles 1992). *Platygyra sinensis*, *Acropora millepora*, and *Pocillopora damicornis* have also been found to be relatively tolerant to changes in salinity (Kuanui *et al.* 2015). All of these species are relatively common in the Western Pacific Region. Some coral species have shown evidence of an ability to acclimate to drops in salinity (Ferrier-Pages *et al.* 1999).

Regardless of individual tolerances, high coral mortality has been observed following intense rain events (Sakai *et al.* 1989), including in Hawai‘i (Jokiel *et al.* 1993 and references therein, Bahr *et al.* 2015). Where mortality did not occur, bleaching, and other metabolic (*e.g.*, increased respiration) and histopathological (swelling and lysis of cells) changes were noted (Glynn 1993, vanWoesik *et al.* 1995, Porter *et al.* 1999, Mayfield and Gates 2007). Severe tissue necrosis, followed by the death of the colonies, has been observed for corals incubated for extended periods in water with relatively small elevations in salinity (Ferrier-Pages *et al.* 1999). Changes in salinity can also adversely affect reproduction (Richmond 1993). Likewise, many coral reef-associated species show low tolerance to salinity changes. Mortality in a wide range of organisms (sea cucumbers, crabs and cryptic fish such as eels) has been observed following freshwater kill events in Hawai‘i (Jokiel *et al.* 1993, Bahr *et al.* 2015).

At large, oceanic scales, anticipated changes in the ocean’s temperature and salinity as a result of climate change will affect circulation patterns. In general, the Pacific Ocean north of the equator is decreasing in salinity, which is expected to affect upwelling strength and location (Bindoff *et al.* 2007). Unfortunately, studies on the effects of salinity changes on non-estuarine phyto- and zooplankton are limited. Estuarine plankton are sensitive to salinity changes, but in many cases, effects associated with temperature, acidification, and nutrient availability are significantly larger. Open ocean plankton assemblages will likely show a similar pattern: the effects of salinity changes on the assemblage will be minor compared to the effects of other stressors. This is reinforced by climate change predictions which predict only small changes in salinity over much of the tropical ocean. Exceptions could include areas where deep ocean mining or OTEC energy production are being conducted, but even under these activities, temperature and nutrient differentials of deep ocean water compared to surface waters are likely to outweigh salinity-related effects. However, more research in this area would be beneficial given the importance of open ocean productivity to broader ecosystem processes.

Summary Stressor Table: Potential effects of salinity
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	🟩 • Organism tend to be extremely tolerant to changes in salinity
Mangrove Forests	🟨 • Reduced photosynthesis in mangrove trees and stunted growth at salinities higher or lower than that optimal for the species • Shifts in mangrove species distributions/zonation based on salinity • Reduced seedling survival • Other mangrove associated organisms tend to be salinity tolerant, but will experience sublethal metabolic stress
Seagrass Beds	🟨 • Reduced photosynthesis, growth, and biomass at salinities higher or lower than that optimal for the species • Reduce seedling germination at high salinity • Reduced seedling growth at low salinity • Other seagrass-associated organisms tend to be salinity tolerant, but will experience sublethal metabolic stress
Coral Reefs	🟥 • Many species have low tolerance to salinity changes • Increased coral mortality (partial and full) • Increase mortality among coral reef-associated species (sea cucumbers, crabs and cryptic fish such as eels) that also show low tolerance to salinity changes
Deep Reef Slopes	🟥 Unknown (no research available), but likely similar to *Coral Reefs*
Banks and Seamounts	🟥 See *Coral Reefs* (shallow) and *Deep Reef Slopes* (deep)
Deep Ocean Floor	▨ Unknown; no research available
Pelagic Environment	🟨 • Decreased net primary productivity • Geographic shifts in productivity • Altered assemblage composition; likely resulting in a loss of biodiversity, leading to changed trophic structure and food web dynamics

4.1.5 Irradiance

Marine organisms are sensitive to changes in irradiance levels, both photosynthetically active radiation (PAR) and ultraviolet radiation (UV). Decreases in irradiance (often associated with decreased water clarity) generally results in lower photosynthetic rates. Increase irradiance, especially high UV exposure cause cellular damage.

Most research on corals has focused on increased irradiance, which has been linked to coral bleaching (Hoegh-Guldberg 1999, Jones *et al.* 1998) and damage to DNA. High irradiance can amplify the effect of thermal stress on corals (Coles and Jokiel 1978), whereas shading by high islands (Bruno *et al.* 2001), unusually cloudy conditions (Mumby *et al.* 2001), and even increased water turbidity (West and Salm 2003, Anthony *et al.* 2007), can ameliorate the effects of thermal stress on corals. Decreases in irradiance have been shown to affect settlement of coral larvae, and may account for depth zonation in at least five species of Indo-Pacific corals (Mundy and Babcock 1998).

Light limits the distribution and species composition of seagrass beds, and low irradiance levels reduce individual plant biomass and growth rates (Dennison 1987, Abal and Dennison 1996, Ralph *et al.* 2007, Campbell *et al.* 2007). Seagrasses have high respiratory (metabolic) demands needed to support and oxygenate their extensive root and rhizome biomass (Waycott *et al.* 2011), and they use only a limited range of the light spectrum. Seagrasses have a higher minimum light requirement than marine algae and phytoplankton (Dennison *et al.* 1993), making them competitively inferior under reduced light conditions. Thus, seagrasses are generally restricted to shallow coastal areas where ample sunlight can penetrate to the bottom, although considerable species variability exists (Dennison *et al.* 1993). For example, Indo-Pacific species of *Halophila* can grow at greater depth because of a lower minimum light requirement (Erftemeijer and Stapel 1999), a trait usually attributed to the morphology of *Halophila* (Middelboe and Markager 1997).

Seagrasses exhibit several physiological and morphological responses to reductions in irradiance. The magnitude and time required to initiate a response is species-specific, and depends on light intensity and duration, and interactions with other potential stressors, such as water temperature and nutrient availability (Bulthuis 1983a, Bulthuis 1983b, Gordon *et al.* 1994, van Lent *et al.* 1995, Abal 1996, Grice *et al.* 1996, Longstaff and Dennison 1999). Initial effects can include changes in amino acid content and chlorophyll levels (Longstaff and Dennison 1999). Later effects can include reduced biomass, shoot density, leaf production rates, and canopy height (Wiginton and McMillan 1979, Dennison and Alberte 1982, Dennison and Alberte 1985, Neverauskas 1988, Tomasko and Dawes 1989, Abal *et al.* 1994, Lee and Dunton 1997, Peralta *et al.* 2002).

Few studies have looked at the effects of irradiance on tropical Pacific macroalgae. While interspecific variation exists, the minimum light requirements of macroalgae (Sand-Jensen 1988, Duarte 1991, Markager and Sand-Jensen 1992, Dennison *et al.* 1993) and CCA (Littler *et al.* 1985) are lower than those of seagrasses. Thus, marine algae are generally able to survive and outcompete seagrasses under low light conditions, and their distribution (especially their maximum depth) is determined in part by their minimum light requirements for photosynthesis and growth.

Sun light is absorbed and scattered in the ocean, and irradiance decreases exponentially with depth. As with benthic primary producers, spatial and temporal variations in light affect the vertical distribution of phytoplankton. Under climate change forecasts, some areas of the Pacific Ocean are expected to experience increased cloud cover (*e.g.*, Western Pacific Warm Pool, Intertropical Convergence Zone, Pacific Equatorial Divergence), which will reduce irradiance and contribute to declines in primary productivity (Le Borgne *et al.* 2011). Other areas of the Pacific Ocean are expected to experience increased irradiation because of reduced cloud cover (*e.g.*, North and South Pacific Tropical Gyres). Primary productivity is sensitive to both too much and too little light. Photosynthesis can be reduced in the upper water column due to photo-inhibition. Alternatively, photosynthesis rates can drop three-fold if irradiance is reduced to 10% of that present on a sunny day (Le Borgne *et al.* 2011). The potential effects of these changes in irradiance on ocean productivity are unclear, but given that vertical mixing within the surface layer prevents planktonic organisms from staying in the upper photic zone for long, these changes in surface irradiation are expected to have a weak effect on ocean productivity (Le Borgne *et al.* 2011).

4.1.6 Noise

Sounds in the marine environment can originate from abiotic and biotic sources, including the movement of water, geologic events, and the noises generated by fish, marine mammals, and invertebrates. Organisms produce sounds to communicate over short and long distances with mates, offspring and other conspecifics, and/or to find prey or other objects of interest (Popper and Hastings 2009, Simpson *et al.* 2016).

Sources of anthropogenic sounds in the ocean are extensive and varied (Peng *et al.* 2015), and anthropogenic noise covers the full frequency bandwidth that marine animals use, from 1 hertz (Hz) – 200 kilohertz (kHz) (Stocker 2001). It also occurs throughout all ocean ecosystems, from shallow coral reef and seagrass beds down into the deep sea, including the deep ocean floor. Due to the efficiency of sound transmission in the ocean, noise travels great distances and containment is difficult.

Boats of all sizes are a significant source of noise. Pile driving is important in the construction of bridges, wind farms, and seaports. Sonar is used by military, the shipping and fishing industries, and in oceanographic research. Underwater explosions occasionally occur as part of military training, and, while seldom used in the Western Pacific Region, seismic devices such as air guns are used for oil exploration and for studies on undersea geology. Even bubble noise from scuba divers has been linked to altered fish behavior (Lobel 2005).

Noise in the marine environment has a broad range of potential effects, especially when it is very loud, *i.e.*, high amplitude (Casper *et al.* 2016), or when it is less intense but long-lasting (Popper and Hastings 2009). Intense, high amplitude sounds, such as pile driving, underwater explosions, and seismic air guns, can cause immediate death or tissue damage that might or might not directly result in the death of the organism (McCauley *et al.* 2003), but which might lower its fitness (Casper *et al.* 2016). Temporary hearing loss may also occur, which is likely to lower fitness until hearing recovers. Behavioral changes can occur, resulting in animals leaving

Summary Stressor Table: Potential effects of irradiance
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	● Organism tend to be tolerant to changes in irradiance
Mangrove Forests	● Few effects on mangrove trees unless extreme; leaves are above the water surface so unaffected by reduced water clarity
Seagrass Beds	● Reduced seagrass photosynthesis, biomass, shoot density, leaf production rates, and canopy height under reduced light conditions ● Potential for a phase-shift toward algal-dominated assemblage under low light regimes
Coral Reefs	● Increased risk of coral bleaching at high irradiance; depth dependent sensitivity to UV ● Reduced photosynthesis, calcification, and growth at low irradiance; potential for reduced fitness under prolonged shading ● Potential for a phase-shift toward algal-dominated assemblage under low light regimes
Deep Reef Slopes	● Photosynthetic organisms highly adapted to low light conditions and could experience photo-inhibition under elevated irradiance ● All photosynthetic organisms at the extreme lower irradiance threshold; further reductions would result in mortality, loss of diversity, abundance and biomass of the entire assemblage
Banks and Seamounts	See *Coral Reefs* (shallow) and *Deep Reef Slopes* (deep)
Deep Ocean Floor	Unknown, but the lack of photosynthetic organisms suggested minimal adverse effects would occur
Pelagic Environment	● Decreased primary productivity ● Altered assemblage composition; likely resulting in a loss of biodiversity, leading to changed trophic structure and food web dynamics

feeding or reproduction grounds (Slabbekoorn *et al.* 2010) or becoming more susceptible to mortality through decrease predator-avoidance responses (Simpson *et al.* 2016). Less intense but chronic noise, such as that produced by continuous boating, can cause a general increase in background noise over a large area. Although not likely to kill organisms, chronic noise can mask biologically important sounds and alter the natural soundscape, cause hearing loss, and/or have an adverse effect on an organism's stress levels and immune system.

Little empirical research has been conducted on the effects of noise on tropical marine species, but most of that has focused on marine mammals. Research conducted on model fishes (*e.g.*, tilapia, goldfish, etc.) have shown a wide range of potential effects from excessive noise, most of which were sub-lethal (see Popper and Hastings 2009 for a review). Nichols *et al.* (2015) found that coastal marine fishes secreted stress hormones in the presence of shipping noise. Bluefin tuna showed a disruption in their schooling structure and swimming behavior when exposed to boat noise, as well as an increase in aggressive behavior (Sarà *et al.* 2007). Embryonic clownfish showed increased heart rate in the presence of elevated noise (Simpson *et al.* 2005). Chronic boat noise can reduce the startle response of coral reef fish, increasing their susceptibility to predation (Simpson *et al.* 2015). While it is often assumed that most motile animals will leave noisy areas, this is not always the case (Iafrate *et al.* 2016).

Reef fish use aspects of reef noise to select suitable settlement habitat, and anthropogenic noise that interferes with their "soundscape" could adversely affect their behavior. Simpson *et al.* (2008) found settlement-stage fish of six reef fish families (Pomacentridae, Apogonidae, Lethrinidae, Gobiidae, Syngnathidae, and Blenniidae) preferentially settled into light traps emitting high-frequency reef noised compared to low-frequency reef noise or silent traps. Only the Siganidae showed no preference between any of the sound treatments. High-frequency reef noise is produced mainly by marine invertebrates, and appears to be used by the fish as a means of selectively orienting towards suitable settlement habitats. Masking of natural reef soundscapes by anthropogenic noise could result in changes to the abundances of species and alterations to the structure of reef fish assemblages.

Prawns have been shown to be as sensitive to sound as fish (Lovell *et al.* 2005), and increased metabolic rates have been observed in brown shrimp exposed to elevated noise conditions, causing a reduction in growth and reproduction over three months (Lagardère 1982). Intense noise, such as pile driving and seismic surveying has been shown to reduce feeding rates in mussels (Spiga and Caldwell 2016) and cause larval malformations in scallops (Aguilar de Soto *et al.* 2013). Temperate lobster increased their food consumption for weeks to months after low-level exposure to seismic noise (Payne *et al.* 2007), suggesting increased metabolic demands. Similar effects have also been found in multiple crab species (Edmonds *et al.* 2016, Wale *et al.* 2013a, 2013b), suggesting sub-lethal stress effects in the presence of boat noise might be common in crustaceans.

Anthropogenic noise may mask deep-water invertebrate scavengers' sensitivity to 'micro-seismic' events in the frequency range of 30 Hz – 250 Hz, which they use to detect food-fall up to distances of 100 m (Klages and Muyakshin 1999). Some animals appear to adapt to "threat" sounds; recent anecdotal evidence suggests that schools of pelagic shrimp have adapted evasion strategies toward the sound of shrimp trawlers (Stocker 2001). When the trawlers circle in, the shrimp dive deep, below the nets. Similar behavior has been noted among carangid fish to boats on Midway Atoll, where a catch and release fishery operated for several years (Minton, pers. obs.). The flight response at Midway was opposite that observed at neighboring Pearl and Hermes, where carangids were frequently attracted to small vessel sound, sometimes forming schools of hundreds of individuals.

4.1.7 Hypoxia

In the marine environment, oxygen from the atmosphere and produced as a by-product of photosynthesis dissolves in the water and helps to meet the respiratory demand of all marineorganisms. When the supply of oxygen is diminished or it is removed, or the consumption rate exceeds the resupply rate, dissolved oxygen concentrations can decline below the point that sustains most marine life. This condition of low dissolved oxygen is known as hypoxia. The complete absence of oxygen is called anoxia.

Oxygen solubility in seawater is a function of water temperature, and as the oceans have warmed over the past half century, dissolved oxygen has declined (Garcia *et al.* 2005). By the end of the century, ongoing warming together with rising atmospheric CO_2 will likely result in an expansion of low oxygen zones, perhaps by more than 50% of their present volume (Diaz and Rosenberg 2008, Oschlies *et al.* 2008). This will result in adverse effects on some of the world's most productive fishery regions.

While temperature controls the amount of oxygen that can dissolve in seawater (fully-saturated seawater at 25 °C [77 °F] has an oxygen concentration of about 8.25 milligrams (mg)/liter (L), water column stratification and increased decomposition of organic matter are two processes that contribute to hypoxic regions in the ocean. Stratification of the water column reduces mixing of oxygen-rich surface layers with deep ocean waters, and microbial decomposition of POM increases respiration in deep ocean waters, resulting in a net decrease in dissolved oxygen at depth. Increased productivity in surface waters, especially in areas with anthropogenic inputs of coastal nutrients, increases the amount of POM that sinks into deep water layers, creating or exacerbating what have been called "dead zones" (Diaz and Rosenberg 2008). Therefore, increased productivity, coupled with increased oceanic stratification, has the potential to result in oxygenated surface waters and a hypoxic deep ocean, leading to the loss of biodiversity.

Most marine organisms experience a hypoxic response when the oxygen concentration falls below 2-3 mg/L (Gray *et al.* 2002, Stramma *et al.* 2008), but considerable interspecific variability exits (Vaquer-Sunyer and Duarte 2008, Seibel 2011). Vaquer-Sunyer and Duarte (2008) suggest this threshold is too low, and noted that many species experience lethal effects below 4.6 mg/L, and significant sublethal effects at oxygen concentrations below 5 mg/L. Crustaceans and fish appear to be particularly susceptible to hypoxic conditions, and mollusks and non-coral cnidarians appeared most tolerant (Vaquer-Sunyer and Duarte 2008). While there is considerable variability among species in a taxonomic group, motile organisms appear to be more sensitive to hypoxic conditions than sessile ones; many fish and motile organisms can detect, and actively avoid hypoxic areas (Pihl *et al.* 1991). Wannamaker and Rice (2000) studied the behavior of six species of fish and one species of shrimp, and all could detect and avoid hypoxic conditions.

Summary Stressor Table: Potential effects of noise
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	🟩 ● Effects are expected to be minor for mid-to-high intertidal organisms due to lower exposure ● For low intertidal organisms, high amplitude noise can cause mortality, hearing damage, and disrupted behavior which may reduce fitness ● Chronic low amplitude noise may disrupt behavior ● Individuals may relocate from area of the noise ● Adverse effects generally resolve shortly after the cessation of the noise
Mangrove Forests	🟨 ● High amplitude noise can cause mortality, hearing damage, and disrupted behavior which may reduce fitness ● Chronic low amplitude noise may disrupt behavior ● Individuals may relocate from area of the noise ● Adverse effects generally resolve shortly after the cessation of the noise
Seagrass Beds	🟨 See *Mangrove Forests*
Coral Reefs	🟨 See *Mangrove Forests*
Deep Reef Slopes	🟨 See *Mangrove Forests*
Banks and Seamounts	🟨 See *Mangrove Forests*
Deep Ocean Floor	🟨 See *Mangrove Forests*
Pelagic Environment	🟨 See *Mangrove Forests*

While little research has been done on the effects of hypoxic conditions on tropical Pacific organisms, in general, marine animals respond to hypoxia by first attempting to maintain oxygen levels through increased respiration rate or increasing the number of oxygen-transporting cells, followed by conserving energy through metabolic depression and down-regulation of protein synthesis and other regulatory enzymes (Holeton and Randall 1967, Burggren and Randall 1978, van den Thillart and Smit 1984, Wu and Woo 1985, Dunn and Hochachka 1986, Boutilier *et al.* 1988, Chew and Ip 1992, Randall *et al.* 1992, Dalla Via *et al.* 1994). Reduction in movement is commonly employed by marine organisms to conserve energy and reduce metabolic demand under hypoxic conditions. For example, swimming of Atlantic cod (*Gadus morhua*) was reduced by ~60% under hypoxic conditions (Schurmann and Steffensen 1994), and digging activity in an Atlantic lobster ceased (Eriksson and Baden 1997).

Hypoxic conditions reduce growth and feeding, which may eventually affect individual fitness. Growth reductions have been shown in brittlestars, oysters (*Crassostrea virginica*), and mussels (*Mytilus edulis*) (Diaz and Rosenberg 1995), as well as in some polycheate worms (Forbes and Lopez 1990). Similarly, reduced growth has been demonstrated in fish subjected to hypoxia (Petersen and Phil 1995), likely a result of reduced feeding (Wu 2002). When subjected to hypoxic conditions, feeding rate was reduced in crabs, gastropods, annelid worms, and lobster, but this effect can vary with life history stage (Das and Stickle 1994, Baden *et al.* 1990a, Baden *et al.* 1990b, Llanso and Diaz 1994).

The effects of hypoxia on reproduction and development of marine animals remains poorly studied, but fish can suffer increased embryo and larval mortality when exposed to hypoxic conditions (Keckeis *et al.* 1996). High mortality and adverse effects on development and growth were found in oyster (*C. virginica*) larvae (Baker and Mann 1992), and mussel (*M. edulis*) embryos experienced delayed development (Wang and Widdows 1991). Hypoxia can also retard gonad development, fertilization success, reproductive output, larval hatching and larval success in the common carp (Wu *et al.* 2003).

Avoidance of hypoxic areas can make organisms more vulnerable to predation. Fish have been observed to change their feeding habits to prey upon hypoxia-stressed benthic invertebrates (Diaz *et al.* 1992). Hypoxia may also affect foraging of predators, reducing prey capture rates, (Sandberg *et al.* 1996, Abrahams *et al.* 2007, Altieri 2008, Johnson *et al.* 1984). Other important behaviors are also dependent upon oxygen concentrations. Fish schooling behavior responds to varying oxycline depth (Bertrand *et al.* 2008). Many benthic organisms such as sea anemones and polychaetes will leave their burrows, and bivalves will extend their siphons upward into the water column above the sediment–water interface, to gain access to more oxygenated water (Pihl *et al.* 1992, Nilsson and Rosenberg 1994, Hervant *et al.* 1996, Sandberg 1997).

Few studies have examined the effects of hypoxia on reef-building corals, even though oxygen concentrations can fluctuate widely on a diurnal cycle and be very low at night (Haas *et al.* 2010; Wild *et al.* 2010). Under low oxygen (2–4 mg/L) conditions, the Indo-Pacific coral *Acropora yongei* bleached, lost major portions of its tissue, and suffered mortality within three days. Its decline in health was accompanied by a significant decrease in photosynthetic performance (Haas *et al.* 2014). In Hawai‘i, a spill of 233,000 gallons of molasses in Honolulu Harbor resulted in hypoxia-related mortality in coral and fish (Basu 2013), although the extent of the kill is still unresolved. A wide range of Indo-Pacific reef fish have been shown to be more tolerant to hypoxia than expected; 31 species across seven families could tolerate oxygen concentrations as low as 1 mg/L (Nilsson and Ostlund-Nilsson 2004). However, their ability to tolerate hypoxic conditions decreased as water temperature increased (Nilsson *et al.* 2010).

Seagrasses tend to grow in hypoxic sediment and transport oxygen produced by photosynthesis to below-ground tissues (Sand-Jensen *et al.* 1982, Smith *et al.* 1984; Caffrey and Kemp 1991).

However, this photosynthetic oxygen pool can be depleted during the night, and insufficient oxygen supplied to the roots results in sulfide intrusions (Pedersen *et al.* 2004, Holmer *et al.* 2009), which has severe adverse effects growth and survival (Holmer and Bondgaard 2001, Koch *et al.* 2007, Mascaró *et al.* 2009, Borum *et al.* 2005, Frederiksen *et al.* 2007). Anoxia also impairs root growth, and nutrient uptake (Smith *et al.* 1988, Zimmerman and Alberte 1996). The depletion of oxygen reserves during night time respiration is exacerbated when water column oxygen concentration is lower (Holmer *et al.* 2009). Likewise, mangrove trees have special physiological adaptations to oxygenate roots and avoid sulphide intrusion, which have been demonstrated to depress normal growth and metabolism in *Rhizophora mangle* (Lin and Sternberg 1992).

At a population and ecosystem scale, sensitive species may be eliminated in hypoxic areas, thereby causing changes in species composition of benthic, fish, and phytoplankton assemblages. Decreases in species diversity and species richness are well documented in hypoxic areas, and changes to food web structure and functional groups have also been reported in areas with low oxygen availability (Wu 1982, Dauer 1993, Pihl 1994, Diaz and Rosenberg 1995, Altieri 2008). Under hypoxic conditions, there is a general tendency for suspension feeders to be replaced by deposit feeders (Levin 2000); demersal fish by pelagic fish; and macrobenthos by meiobenthos. Microflagellates and nanoplankton also tend to dominate phytoplankton assemblages in hypoxic environments (Josefson and Widbom 1988, Diaz and Rosenberg 1995, Qu *et al.* 2015, Rakocinski and Menke 2016, Briggs *et al.* 2017). A reduction in the biomass of fishes has been generally observed in hypoxic areas (Dyer *et al.* 1983, Rosenberg and Loo 1988, Pihl *et al.* 1992, Baden *et al.* 1990a, Baden *et al.* 1990b, Breitburg 1992, Petersen and Pihl 1995, Lekve *et al.* 1999), accompanied by shifts in species dominance, with less biomass of deep-dwelling species, but more biomass of opportunistic ones (Dauer 1993).

While data are limited, it appears recovery of benthic communities in temperate regions that have suffered hypoxic conditions can take several years (Diaz and Rosenberg 1995), but recovery may occur more quickly in subtropical environments (Wu 1982). Small-scale hypoxia associated with a point source discharge may recover more quickly because organisms can easily migrate from the surrounding, non-affected areas (Rosenberg 1976).

4.2 Biological Stresses

4.2.1 Invasive Species

Introduced species are organisms that have been moved, intentionally or unintentionally, into areas where they do not naturally occur. Many of them fail to establish persistent populations in their new environment; still others may establish breeding populations but do not experience rapid population growth or appear to cause adverse effects on the ecosystem (*e.g.*, they appear to "naturalize"). Other species, free of the ecological processes and interactions that controlled their population growth in their native range, rapidly increase in abundance to the point that they come to dominate their new environment, creating adverse ecological effects to other species of the ecosystem and the functions and services it may provide. These species are considered invasive (Goldberg and Wilkenson 2004).

Summary Stressor Table: Potential effects of hypoxia
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	● Hypoxia not a significant issue
Mangrove Forests	● Reduced mangrove tree growth and metabolism, contributing to lower productivity, altered nutrient cycling, reduced ability to filter contaminants ● Changed organism behavior, likely exposing organisms to increased predation risk ● Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality ● Increased mortality, especially if oxygen concentrations drop below ~2-4 mg/L ● Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure
Seagrass Beds	● Reduced seagrass growth and metabolism, contributing to lower productivity and altered nutrient cycling ● Increased dominance of macroalgae, which are more tolerant to hypoxia; potential for a phase-shift toward algal-dominated assemblage under low light regimes ● Changed organism behavior, likely exposing organisms to increased predation risk ● Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality ● Increased mortality, especially if oxygen concentrations drop below ~2-4 mg/L ● Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure
Coral Reefs	● Increase coral mortality at oxygen concentrations between 2-4 mg/L, resulting in loss of topographic structure ● Increased dominance of macroalgae, which are more tolerant to hypoxia; potential for a phase-shift toward algal-dominated assemblage under low light regimes ● Changed organism behavior, likely exposing organisms to increased predation risk ● Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality

Ecosystem	Potential Effects
	● Increased mortality, especially if oxygen concentrations drop below ~2-4 mg/L ● Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	● Potential for severe hypoxia to result from increase transport of POM into the deep water ● Changed organism behavior, likely exposing organisms to increased predation risk ● Displacement of mobile species to less hypoxic areas, potentially increasing predation-related mortality ● Increased mortality, especially if oxygen concentrations is low ● Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure ● Disruption of ocean-wide nutrient cycling
Pelagic Environment	● Likely not a significant problem near the surface due to mixing ● Displacement of mobile species to less hypoxic areas, potentially increasing predation- and fishing-related mortality ● Increased mortality, especially among larval forms which appear less tolerant to hypoxia than adults ● Altered species composition of benthic, fish, and phytoplankton assemblages, including decreased diversity and altered food web structure ● Mortality could increase export of particulate organic matter to deep ocean.

While most often invasive species are non-native, native species can also display invasive behaviors following a perturbation that disrupts the “normal” operation of their environment. For example, the native algae *Dictyosphaeria cavernosa*, became invasive in 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 Hawai‘i, but only a small number of them are invasive, including three species of algae, 19 invertebrates, and three fishes (Coles and Eldredge 2002, Carlton and Eldredge 2009, Randall 1987, Smith *et al.* 2002). Several of these invasive species are increasing in both abundance and spatial distribution, and threaten ecosystem function by outcompeting native species, especially native structure-forming organisms such as coral. This will contribute to decreased species diversity, changes in trophic structure, and loss of physical structure, but it is not clear exactly how this will affect individual species; effects will likely vary depending upon whether the species-specific interaction affected by invasive species is of a facultative or obligate nature, with the latter relationship likely more sensitive to effects.

On reefs subjected to nutrient enrichment or the removal of herbivores, invasive algae have overgrown corals and other benthic invertebrates; cover of invasive algae on some reefs in Hawai‘i has exceeded 50% (Smith *et al.* 2002, Concepcion *et al.* 2010). The snowflake coral *Carijoa riisei* has been observed overgrowing deep water black corals, causing the mortality of large, sexually mature colonies (Kahng and Grigg 2005). These same individuals provide important ecological functions to deep reef ecosystems. Invasive snappers have altered behavior and habitat use by some goatfish, potentially exposing them to higher mortality from fishing and possibly predation (Schumacher and Parrish 2005).

Fewer invasive species have been documented in other jurisdictions in the Western Pacific Region, but this is likely a result of inadequate survey effort. Given the correlation between shipping and harmful invasions (Seebens *et al.* 2014), regions with high port traffic but few reported invasions (*e.g.*, Guam and Saipan) probably contain more marine invaders than have been documented (Molnar *et al.* 2008), and may benefit from surveys targeted at identifying the presence of invasive species. A recent assessment of invasive species in the PRIA (Franklin and Mancini 2015) identified 15 non-native and potentially invasive species, including five species of bryozoan, two species of polychaete worms, three tunicate species, two sponge species, and one species each of macroalgae, fish, and hydroid. These species were identified from Palmyra Atoll and Johnston Island, both of which have a prior history of human and military activity, and have been the subject of comprehensive biological surveys over the past two decades. Other areas within the PRIA lack sufficient baseline biological information to make determinations (Franklin and Mancini 2015).

4.2.2 Disease

Diseases are a natural part of all ecosystems and play an important selective role in population dynamics. However, when disease outbreaks occur, mortalities can affect not only the host population, but have the potential to cascade through the ecosystem, leading to altered assemblage structure (Lessios 1988), including changes to benthic diversity, composition, and topographic structure, all of which have wide reaching implications on ecosystem function. However, despite decades of research, the ecological effect of diseases in the ocean remains relatively unknown, even when these diseases affect economically and ecologically important species (Ward and Lafferty 2004, Harvell *et al.* 2002). The lack of baseline data on historical disease levels in marine ecosystems is an impediment to determining diseases demographics, etiology, infectiousness, virulence, and spatial distribution.

Many marine organisms serve as potential hosts for a diversity of parasites and pathogens. Lafferty *et al.* (2015) identified 67 diseases with specific economic impacts. Most occurred in temperate waters, and while present in the wild, appeared to be problematic only under high-density aquaculture conditions. Marine disease outbreaks appear to be increasing over the past half century (Ward and Lafferty 2004), but not for all marine taxa. Turtles, corals, mammals, urchins, and mollusks have all shown significant increases in the rate of disease outbreaks, which cannot be attributed simply to increased vigilance or other reporting bias.

Over the past decade and a half, links between changing ocean temperatures and pathogens have been made (Porter *et al.* 2001, Harvell *et al.* 2002, Ward *et al.* 2007, Miller and Richardson 2014). Growth rates of marine bacteria (Shiah *et al.* 1994) and fungi (Holmquist *et al.* 1983) are positively correlated with temperature, and the optimum temperatures for fungal growth coincides with thresholds that trigger thermal stress and bleaching for many coral species (Holmquist *et al.* 1983, Coles *et al.* 1976), leading to the likely co-occurrence of bleaching and fungal infection. The 1998 mass bleaching of coral caused pronounced mortality worldwide, but the demise of some corals was accelerated by opportunistic infections (Harvell *et al.* 2001). Three coral pathogens grow well at temperatures close to or exceeding probable host optima, which suggests that they would increase in warmer seas (Harvell *et al.* 2002). Among marine invertebrates and seagrass, many disease outbreaks are also linked to temperature increases (Harvell *et al.* 2002), and increased ocean temperature has been linked to the northward expansion of oyster diseases in the mid-1980s (Ford 1996, Cook *et al.* 1998).

Additionally, stressors such as increasing water temperature and pollution, make hosts more susceptible to infection (Holmes 1996, Bruno *et al.* 2003, Trevathan-Tackett *et al.* 2013), although some stressors may affect parasites more than their hosts (Lafferty 1997). For example, stressors that decrease host population density may reduce density-dependent transmission of host-specific diseases by reducing contact rates between infected and uninfected individuals

Summary Stressor Table: Potential effects of invasive species
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	● Decreased species diversity, altered trophic structure ● Disrupted behavior and interactions among and between species
Mangrove Forests	● Decreased species diversity, altered trophic structure, ● Disrupted behavior and interactions among and between species ● Decreased value as nursery habitat ● Altered ecosystem functions to filter sediment, nutrients, and other pollutants
Seagrass Beds	● Decreased species diversity, altered trophic structure, and the potential for a phase-shift to an algal-dominated assemblage ● Potential disruption of nutrient cycling and transport among nearshore marine ecosystems ● Disrupted behavior and interactions among and between species
Coral Reefs	● Decreased species diversity, altered trophic structure and ecosystem function and services ● Disrupted behavior and interactions among and between species ● Increased potential for a phase-shift toward an algal-dominated assemblage
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	● Effects unclear due to a lack of research, but likely include decreased species diversity and altered trophic structure, and a potential disruption of nutrient cycling
Pelagic Environment	● Effects unclear due to a lack of research, but likely include decreased species diversity, altered trophic structure, and a potential decrease in productivity, alteration of food web dynamics, change in rate of POM export to deep ocean

(Lafferty and Holt 2003). However, any stressor that increases physiological stress in the host has the potential to increase the host's susceptibility to infection. For example, the bioaccumulation of toxins in marine mammals has been demonstrated to affect their immune system and increase susceptibility to disease (Lafferty and Gerber 2002).

Like many invertebrates, corals possess an innate immune system that is characterized by a series of mechanisms that defend the host from infection (Toledo-Hernández and Ruiz-Diaz 2014). In reef-building corals, mucus forms a physical barrier and acts as a first line of defense. Coral mucus is a viscous fluid made of a complex mixture of compounds secreted by the polyps, and which contains a variety of anti-bacterial compounds (Kvennefors *et al.* 2012, Krediet *et al.* 2013), including a variety of symbiotic microbes that prevent the settlement of potentially noxious bacteria (Brown and Bythell, 2005), and a range of viruses that also may play an important role in coral immunology (Nguyen-Kim *et al.* 2015). Factors that affect the mucus layer may have directly lower a coral's immunity to disease. While coral immune systems are generally considered rudimentary and simplistic (Pollock *et al.* 2011, Toledo-Hernández *et al.* 2013), recent research suggests they are surprisingly complex, with some components similar to those found in vertebrates (Reed *et al.* 2010, Palmer and Traylor-Knowles 2012).

The incidence of coral disease has been found to be positively correlated with increasing algal cover (Hayes and Goreau 1998, Harvell *et al.* 1999, Harvell *et al.* 2004), and a link between direct algal contact and coral disease has been established (Nugues *et al.* 2004, Bender *et al.* 2012). Macroalgae populations, including species of common Western Pacific Region genera *Halimeda*, *Hypnea* and *Chlorodesmia*, have been shown to harbor pathogens that have been directly linked to coral disease, although the specific mechanism of transfer between algae and coral is poorly understood (Sweet *et al.* 2013).

In general, Pacific reefs have been considered in good condition, with little concern given to coral and other diseases, but this may only reflect inadequate information for many geographic areas. As more studies are conducted on Pacific reefs, it is becoming clear that diseases exist and may be more widespread than originally believed (Ruiz-Moreno *et al.* 2012, Maynard *et al.* 2015), causing some experts to warn that Pacific coral reefs are on a trajectory of degradation similar to that experienced in the Caribbean where coral reefs have been decimated by disease (Galloway *et al.* 2009, Maynard *et al.* 2015).

Approximately 30 coral diseases are known from the Indo-Pacific region, affecting 97 species of coral (approximately 15% of all species) from 34 genera, and the identification of new diseases appears to be accelerating. Coral disease in the Western Pacific region is widespread with prevalence varying from a low of 0.14% in American Samoa to 0.5% in the Northwestern Hawaiian Islands, and up to ocean-wide highs of 10% along the Great Barrier Reef and 14% in the Philippines (Willis *et al.* 2009, Aeby 2009, Work *et al.* 2009). Disease progression can be variable, advancing across a few millimeters of tissue to >1 centimeter (cm) per day, and depending on the severity and length of the infection can cause partial or total colony mortality (Southerland *et al.* 2004).

Other coral reef organisms affected by identified diseases include coralline algae (Littler and Littler 1995, Aeby *et al.* 2005) and sea urchins, for which a massive die-off contributed to a regional phase-shift on Caribbean reefs (Mumby *et al.* 2006). Researchers believe an urchin disease outbreak may have responsible for a recent mass mortality of *Tripnuestes gratilla* (collector urchin) in Hawaiʻi (T. Work, pers. comm.).

No reports of seagrass disease have been located for the Western Pacific Region, but likely, seagrass diseases are present and their prevalence may increase in the Pacific in the future under warming seas. The limited information on seagrass disease comes from seagrass wasting diseases which has been reported in at least two Atlantic species: *Zostera marina* (eel grass) and *Thalassia testudinum* (turtle grass) (Loucks 2013). This disease was responsible for decimating *Z. marina* meadows in the 1930s with over 90% loss (Muehlstein 1989). The same micro-organism has been identified as the causative agent for both species, suggesting this disease has potential to affect numerous species in different genera. When not lethal, wasting disease has been shown to affect photosynthesis, growth, and leaf litter production (Ralph and Short 2002), which can affect nutrient transport and cycling.

Similarly, relatively few diseases of mangrove trees have been identified, and those that have been identified primarily affect *R. mangle* (Weir *et al.* 2000). Most are linked to a fungal causative agent, at least one of which has been identified in Hawaiian *R. mangle* populations (Kohlmeyer 1969), and which was responsible for rotting of woody tissue below the waterline.

4.2.3 Fish Aggregating Device (FAD) Effect

Nearly any floating object (anchored or unanchored) in the ocean will attract and aggregate organisms, mostly fish, underneath it. This behavioral response has led to the development of FADs as a fishery tool, but this report reviews the FAD effect from non-fishing activities including marine debris, anchored ships, navigational buoys, fixed structures, and floating platforms.

Unlike many of the other stressors discussed in this report, the FAD effect does not directly alter the condition of the physical or biological habitat. The only direct effect to the EFH is the deployment of the object into the environment, which then alters the behavior, and potentially the distribution and fitness of some species. Removal of the object would be expected to restore behavior to its pre-deployment condition. As such, the presence of the object itself is the primary effect on environment.

Fish aggregation has been best studied in relation to fishing FADs, which have been shown to have the potential to adversely affect fishery species and ecosystems (Wang *et al.* 2014), although considerable debate about their potential adverse effects exists (Dagorn *et al.* 2012). FADs have been shown to cause pelagic fishes to move away from their usual migration routes, which can lead them into regions with lower productivity (Fléchet 2008) and result in lower individual fitness and altered spatio-temporal dynamics of the population (Wang *et al.* 2014), but the converse has also been demonstrated (Dagorn *et al.* 2007, Dagorn *et al.* 2012). Compared to free-swimming tuna, tuna associated with FADs show significant differences in feeding patterns (Williams and Terawasi 2014, Fonteneau 2014, Wang *et al.* 2014), fish condition (Hallier and Gaertner 2008, Harley *et al.* 2014, Williams and Terawasi 2014), growth rates (Harley *et al.* 2014, Williams and Terawasi 2014), aggregation patterns (Fléchet 2008), and migratory

Summary Stressor Table: Potential effects of disease
Color reflects the relative severity of an adverse effect compared across all stressors: green=none to mild, yellow=moderate, red=severe.

Ecosystem	Potential Effects
Intertidal	• Species-specific disease may affect populations but not likely to significantly alter tropical intertidal assemblage • Depending on the species, could result in reduced species diversity, changes in trophic dynamics, and reduced resilience
Mangrove Forests	• Few diseases of mangrove trees have been identified and trees appear to be relatively resistant to disease. • For non-mangrove tree species, disease could result in reduced species diversity, and changes in trophic dynamics
Seagrass Beds	• Seagrass wasting disease has potential to eradicate seagrass beds, removing important nursery habitat • Reduced photosynthesis, growth, and leaf litter production • Altered nutrient transport processes • For non-coral species, disease could result in reduced species diversity, and changes in trophic dynamics
Coral Reefs	• Increased mortality in coral and important herbivores can lead to significant changes in assemblage diversity and composition, including the potential for a phase-shift toward an algal-dominated assemblage • “Flattening” of reef structure leading to loss of diversity, abundance and biomass, including important fishery species • Decreased coral recruitment if significant loss of CCA algae occurs • Sub-lethal effects reduce growth, reproduction and likely impair organism fitness
Deep Reef Slopes	See *Coral Reefs*
Banks and Seamounts	See *Coral Reefs*
Deep Ocean Floor	• Unknown, no research available
Pelagic Environment	• Depending on the species, could result in reduced species diversity, changes in trophic dynamics, and reduced resilience

direction and displacement rates (Hallier and Gaertner 2008, Williams and Terawasi 2014), although research conducted as part of the 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*

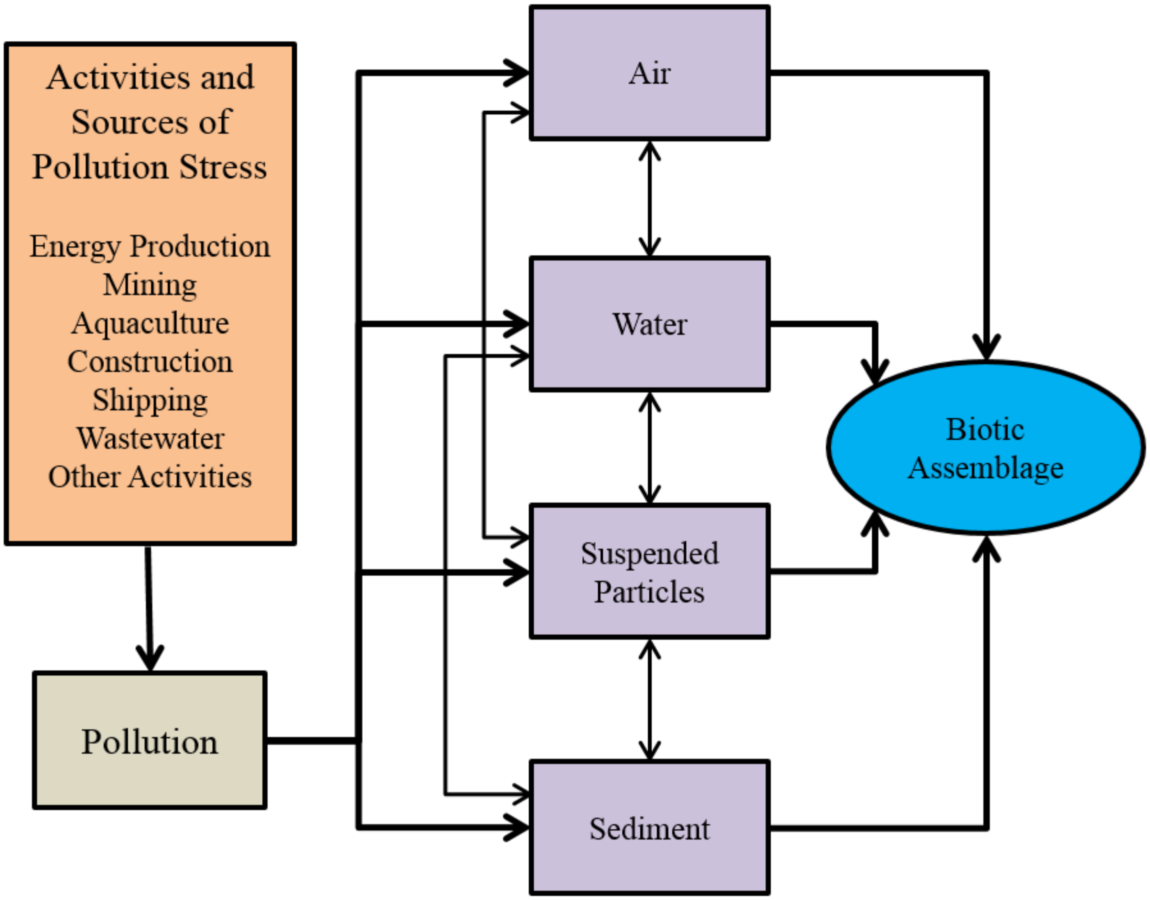

Figure 3. Conceptual model for pollutant pathways in marine ecosystems (modified from van Dam *et al.* 2011).

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).

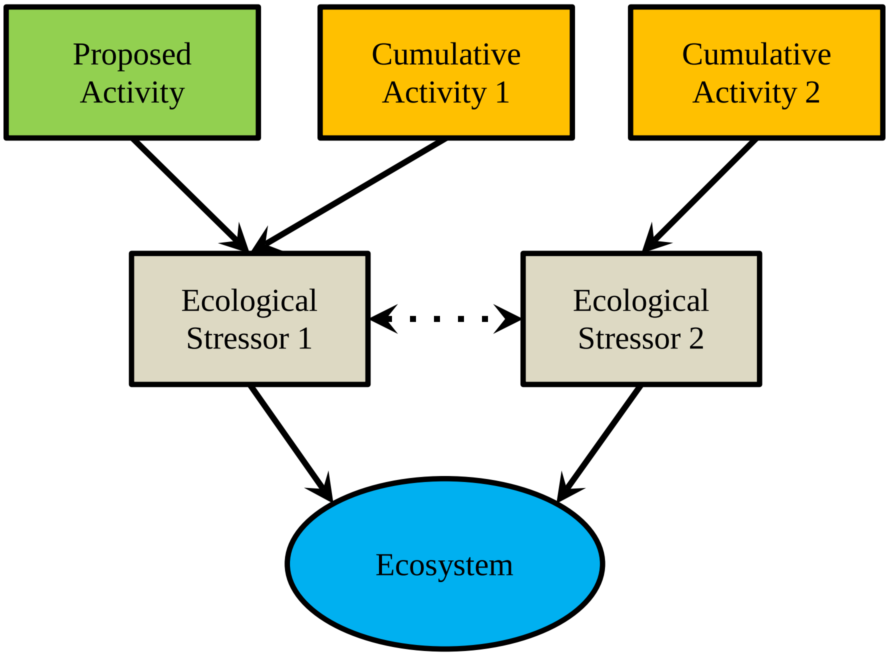

Figure 4. When assessing cumulative effects, the incremental effects of other past, present, and reasonably foreseeable future actions must be considered. In the flow diagram above, two types of cumulative effects are illustrated. In the first type, the Proposed Activity and Cumulative Activity 1 both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

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[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.

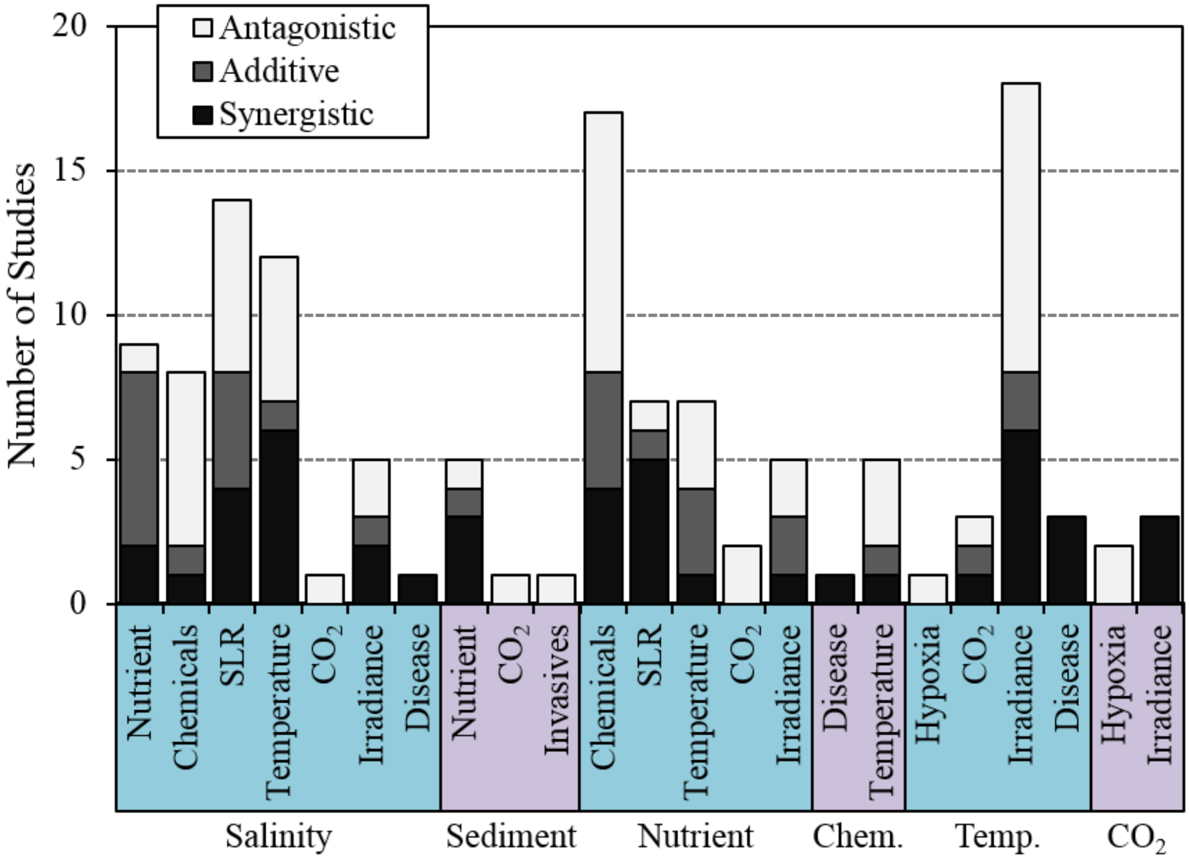
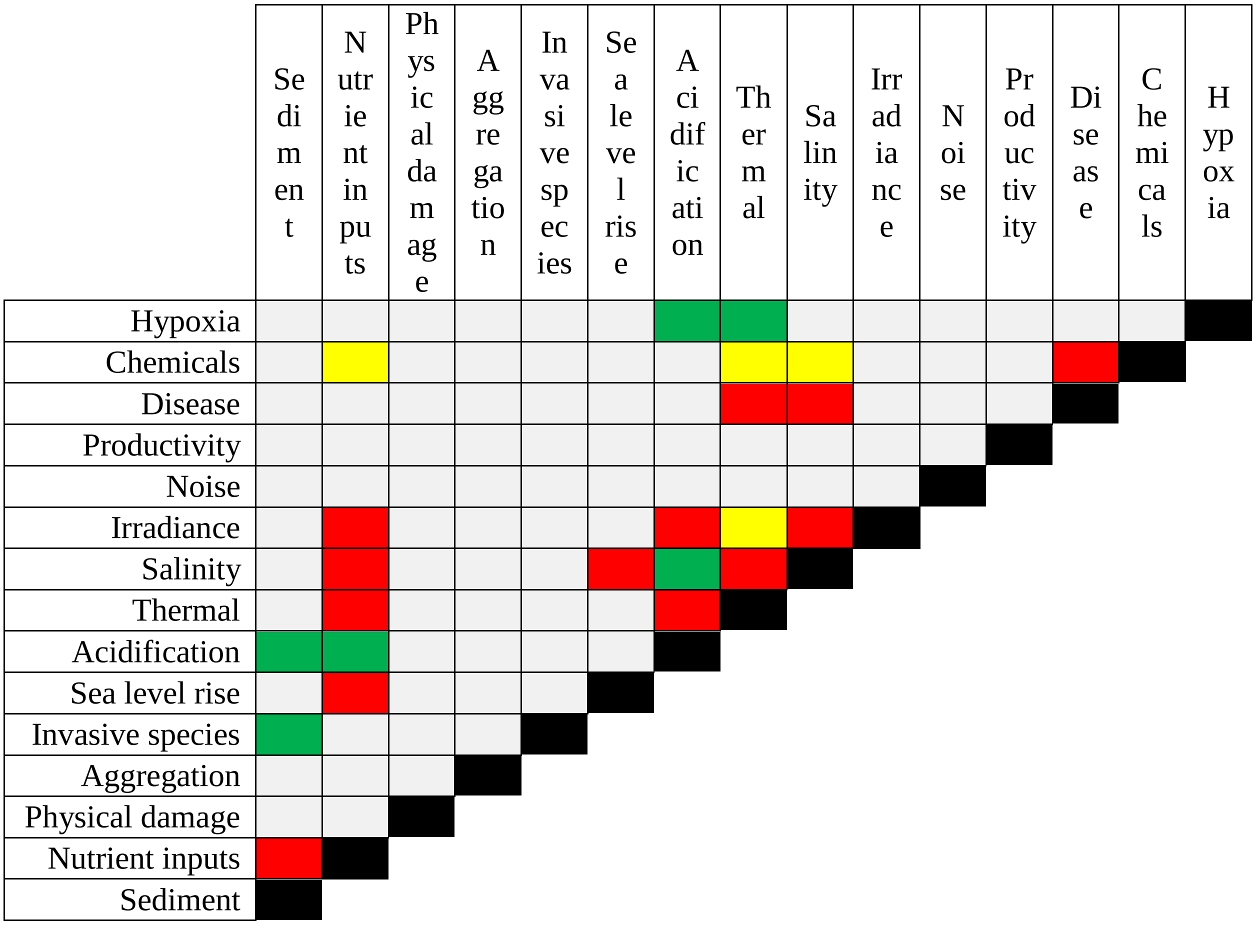


Figure 5. Frequency distribution of interaction types (additive, synergistic, and antagonistic) across stressor pairs. Stressor pairs are indicated within blocks on the x-axis that list one stressor horizontally (*e.g.*, salinity) with all stressor combinations listed vertically (*e.g.*, nutrient). See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



	Sediment	Nutrient inputs	Physical damage	Aggregation	Invasive species	Sea level rise	Acidification	Thermal	Salinity	Irradiance	Noise	Productivity	Disease	Chemicals	Hypoxia
Hypoxia	⬜	⬜	⬜	⬜	⬜	⬜	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬛
Chemicals	⬜	🟨	⬜	⬜	⬜	⬜	⬜	🟨	🟨	⬜	⬜	⬜	🟥	⬛	
Disease	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟥	🟥	⬜	⬜	⬜	⬛		
Productivity	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬛			
Noise	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬛				
Irradiance	⬜	🟥	⬜	⬜	⬜	⬜	🟥	🟨	🟥	⬛					
Salinity	⬜	🟥	⬜	⬜	⬜	🟥	🟩	🟥	⬛						
Thermal	⬜	🟥	⬜	⬜	⬜	⬜	🟥	⬛							
Acidification	🟩	🟩	⬜	⬜	⬜	⬜	⬛								
Sea level rise	⬜	🟥	⬜	⬜	⬜	⬛									
Invasive species	🟩	⬜	⬜	⬜	⬛										
Aggregation	⬜	⬜	⬜	⬛											
Physical damage	⬜	⬜	⬛												
Nutrient inputs	🟥	⬛													
Sediment	⬛														

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:

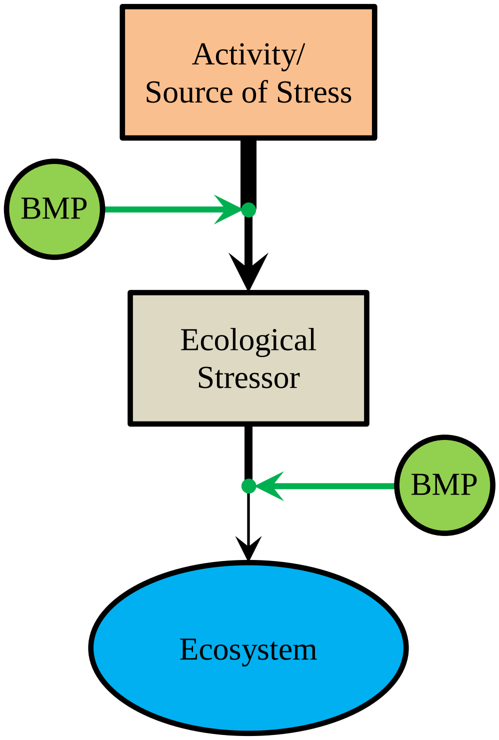


Figure 7. Conservation and enhancement recommendations, of which BMPs are common type, are practices intended to reduce the adverse effects of an activity on an ecosystem. BMPs can reduce the effect of an activity on the particular stressor (top) or reduce the effect of a stressor on an organism or ecosystem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

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[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, Hawaiʻi 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.

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[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.

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[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.

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[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

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[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,

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[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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