ANNUAL STOCK ASSESSMENT AND FISHERY EVALUATION REPORT: PACIFIC REMOTE ISLAND AREA FISHERY ECOSYSTEM PLAN 2017

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

PHONE: (808) 522-8220
FAX: (808) 522-8226
www.wpcouncil.org

The ANNUAL STOCK ASSESSMENT AND FISHERY EVALUATION REPORT for the PACIFIC REMOTE ISLAD AREA FISHERY ECOSYSTEM PLAN 2017 was drafted by the Fishery Ecosystem Plan Team. This is a collaborative effort primarily between the Western Pacific Regional Fishery Management Council, NMFS-Pacific Island Fisheries Science Center, Pacific Islands Regional Office, Division of Aquatic Resources (HI) Department of Marine and Wildlife Resources (AS), Division of Aquatic and Wildlife Resources (Guam), and Division of Fish and Wildlife (CNMI).

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

Edited By: Marlowe Sabater, Asuka Ishizaki, Thomas Remington, and Sylvia Spalding, WPRFMC.

This document can be cited as follows:

WPRFMC, 2018. Annual Stock Assessment and Fishery Evaluation Report: Pacific Remote Island Area Fishery Ecosystem Plan 2017. Sabater, M., Ishizaki, A., Remington, T., and Spalding, S. (Eds.) Western Pacific Regional Fishery Management Council. Honolulu, Hawaii 96813 USA.

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

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

NMFS Pacific Islands Regional Office: Melanie Brown and Sarah Ellgen.

Pacific Islands Regional Planning Body: Sarah Pautzke.

The Council also acknowledges the staff of the **NMFS PIFSC Western Pacific Fisheries Information Network** (WPacFIN) for providing the technical support to generate the data summaries.

The Council would like to thank the following individuals for their contributions to the report:
Catherine Pham, Lennon Thomas, and Dawn Golden.

This page was intentionally left blank.

Executive Summary

As part of its five-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 reports is twofold: to monitor the performance of the fishery and ecosystem to assess the effectiveness of the FEP in meeting its management objectives, and to maintain the structure of the FEP living document. The reports are typically comprised of three chapters: fishery performance, ecosystem considerations, and data integration. The 2017 Pacific Remote Island Area (PRIA) annual SAFE report does not contain fully-developed fishery performance or data integration chapters. The Council will iteratively improve the annual SAFE report as resources allow.

An ecosystem considerations section was added to the annual SAFE report following the Council's review of its FEPs and revised management objectives (pending Secretarial transmittal). Fishery independent ecosystem survey data, socioeconomics, protected species, oceanic and climate indicators, essential fish habitat, and marine planning information are all included in the ecosystem considerations section. Fishery dependent data sections will continue to be included as resources allow.

Fishery independent ecosystem survey data were acquired through visual surveys conducted in the PRIA, American Samoa, Guam, the Commonwealth of the Northern Mariana Islands, the Main Hawaiian Islands, and the Northwestern Hawaiian Islands. This report describes mean fish biomass for coral reefs in each of these locations. Additionally, the mean reef fish biomass and mean size of fishes (>10 cm) for PRIA are presented by sampling year and reef area. Finally, the reef fish population estimates for each PRIA study site are provided for across hardbottom habitat (0-30 m).

The socioeconomics section outlines the pertinent economic, social, and community information available for assessing the successes and impacts of management measures or the achievements of the Fishery Ecosystem Plan for the PRIA. The section begins with an overview of the socioeconomic context for the region, and then provides a summary of relevant studies for the PRIA. Because human habitation is limited in the PRIA, socioeconomic information is also limited. The socioeconomics section of this report will be expanded in later years if activity increases. There were no new data reported for any fisheries within the PRIA.

The protected species section of this report describes monitoring and summarizes protected species interactions in fisheries managed under the PRIA FEP. There are currently no bottomfish, crustacean, coral reef, or precious coral fisheries operating in the PRIA, and no historical observer data are available for fisheries under this FEP. No new fishing activity has been reported, and there is no other information to indicate that impacts to protected species from PRIA fisheries have changed in recent years.

The climate change section of this report includes measurements of changing climate and related oceanic conditions in the geographic areas that the Western Pacific Regional Fishery Management Council has jurisdiction. 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 as well as the 'Ocean and Coasts' chapter of the 2014 Pilot Indicator Systems report prepared by the National Climate Assessment and Development Advisory Committee. The primary goal for selecting the climatic 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 fishery-relevant, be informative, build intuition about current conditions in light of changing climate, provide historical context, and distinguish patterns and trends. The trend of atmospheric concentration of carbon dioxide (CO_2), for example, is increasing exponentially with a time series maximum at 406.53 ppm. Since 1989, 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+]). The year 2017 had some high temperature anomalies, with values surpassing seven degree heating weeks in the Wake Island region. The East Pacific hurricane season saw 18 named storms in 2017, nine of which were hurricanes and four major. The north central Pacific, conversely, had no storms over the course of the previous year.

The effective fish habitat (EFH) section of the 2017 annual SAFE report includes cumulative impacts on EFH, and is supplemented by a detailed coral reef crustacean life history and habitat review found in the Appendix. Guidelines also require a report on the condition of the habitat; mapping progress and benthic cover are included as preliminary indicators pending development of habitat condition indicators for the PRIA not otherwise represented in other sections of this report. The annual SAFE report also addresses any Council directives toward its plan team, though there were no directives in 2017.

The marine planning section of the 2017 annual SAFE 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 to be presented. No new ocean activities with multi-year planning horizons were identified for the PRIA in 2017.

The data integration section of this report is under development. The Council hosted a data integration workshop in late 2016 with participants from the NMFS Pacific Islands Regional Office and Pacific Islands Fisheries Science Center (PIFSC) to identify policy-relevant fishery ecosystem relationships. The archipelagic data integration chapters of the 2017 annual SAFE reports were updated for Hawaii, American Samoa, Guam, and CNMI in 2017, however no updates were made for the PRIA data integration chapter as there are currently no fisheries operating in the PRIA. The data integration chapter will be expanded in later years if activity increases in these regions.

The Archipelagic Plan Team had no recommendations respect to the Archipelagic PRIA FEPs.

This page was intentionally left blank.

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

ACRONYMS AND ABBREVIATIONS

Acronym	**Meaning**
ABC	Acceptable Biological Catch
ACL	Annual Catch Limits
AM	Accountability Measures
BiOp	Biological Opinion
BOEM	Bureau of Ocean Energy Management
BSIA	best scientific information available
CFR	Code of Federal Regulations
CMS	coastal and marine spatial
CNMI	Commonwealth of the Northern Mariana Islands
CPUE	Catch per Unit Effort
CREMUS	Coral Reef Eco Management Unit Species
CREP	Coral Reef Ecosystem Program (PIFSC)
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EO	Executive Order
ESA	Endangered Species Act
FEP	Fishery Ecosystem Plan
FMP	Fishery Management Plan
HAPC	Habitat Area of Particular Concern
ITS	Incidental Take Statement
LOF	List of Fisheries
MFMT	Maximum Fishing Mortality Threshold
MHI	Main Hawaiian Islands
MMA	marine managed area
MPA	marine protected area
MPCC	Marine Planning and Climate Change
MPCCC	Council's MPCC Committee
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSST	Minimum Stock Size Threshold
MSY	Maximum Sustainable Yield
MUS	management unit species
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
NEPA	National Environmental and Policy Act
NMFS	National Marine Fisheries Service
NWHI	Northwestern Hawaiian Islands
OFL	Over-fishing Limit
OY	Optimum Yield
Pelagic FEP	Fishery Ecosystem Plan for the Pacific Pelagic Fisheries
PI	Pacific Islands
PIFSC	Pacific Islands Fisheries Science Center

PIRO	NOAA NMFS Pacific Islands Regional Office
PMUS	pelagic management unit species
RAMP	Reef Assessment and Monitoring Program (CREP)
ROA	Risk of Overfishing Analysis
RPB	Regional Planning Body
SAFE	Stock Assessment and Fishery Evaluation
SDC	Status Determination Criteria
SEEM	Social, Ecological, Economic, and Mgmt. Uncertainty Analysis
TAC	Total Annual Catch
USACE	United States Army Corps of Engineers
WPRFMC	Western Pacific Regional Fishery Management Council

This page was intentionally left blank.

1 FISHERY PERFORMANCE

Fisheries in the Pacific Remote Island Areas (PRIA), including Palmyra Atoll, Kingman Reef, Jarvis Island, Baker Island, Howland Island, Johnston Atoll, and Wake Island, are limited. Fishery performance will be made available for the PRIA in future reports as resources allow.

1.1 NUMBER OF FEDERAL PERMIT HOLDERS

The Code of Federal Regulations, Title 50 Part 665 requires the following Federal permits for fishing in the exclusive economic zone (EEZ) of the PRIA:

1.1.1 Special Coral Reef Ecosystem Permit

Regulations require this special coral reef ecosystem fishing permit for anyone fishing for coral reef ecosystem management unit species (MUS) 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. NMFS will make an exception to this permit requirement for any person issued a permit to fish under any fishery ecosystem plan who incidentally catches American Samoa coral reef ecosystem MUS while fishing for bottomfish MUS, crustacean MUS, western Pacific pelagic MUS, precious coral, or seamount groundfish.

1.1.2 Western Pacific Precious Corals Permit

Regulations require a Western Pacific Precious Corals permit for anyone harvesting or landing black, bamboo, pink, red, or gold corals in the EEZs of the U.S. Western Pacific.

1.1.3 Western Pacific Crustaceans Permit (Lobster or Deepwater Shrimp)

Regulations require a Western Pacific Crustaceans permit for any owner of a U.S. fishing vessel used to fish for lobster or deepwater shrimp in the EEZs around of the U.S. Western Pacific.

1.1.4 PRIA Bottomfish Permit

Regulations require obtaining a PRIA Bottomfish permit for anyone using bottomfish gear to fish for bottomfish MUS in the EEZ around the PRIA. Commercial fishing is prohibited within the boundaries of the Pacific Remote Islands Marine National Monument.

There is no record of coral reef or precious coral fishery permits issued for the EEZ around the PRIAs since 2008. Table 1 provides the number of permits issued for PRIA fisheries from 2008 to 2017. Historical data from the PIFSC were accessed on February 9, 2017, and data for 2018 are from the Pacific Islands Regional Office (PIRO) Sustainable Fisheries Division (SFD) permits program as of January 3, 2018.

Table 1. Number of federal permit holders in the lobster, shrimp, and bottomfish fisheries of the PRIA from 2008 to 2017.

PRIA Fisheries	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Lobster	2	3								
Shrimp			1							

PRIA Fisheries	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Bottomfish	2	3	6	5	4	1	2		1	1

1.2 ADMINISTRATIVE AND REGULATORY ACTIONS

This summary describes management actions for PRIA fisheries that NMFS implemented after the April 2017 Joint FEP Plan Team meeting.

On April 21, 2017, NMFS specified final 2016 annual catch limits (ACLs) for Pacific Island bottomfish, crustacean, precious coral, and coral reef ecosystem fisheries as well as accountability measures (AMs) to correct or mitigate any overages of catch limits. The final specifications were applicable from January 1, 2016, through December 31, 2016, except for precious coral fisheries, which were applicable from July 1, 2016, through June 30, 2017. Although the 2016 fishing year ended for most stocks, NMFS evaluated 2016 catches against these final ACLs when data became available in mid-2017. The ACLs and AMs support the long-term sustainability of fishery resources of the U.S. Pacific Islands. This rule was effective on May 22, 2017.

On December 11, 2017, NMFS specified final 2017 ACLs for Pacific Island crustacean, precious coral, and territorial bottomfish fisheries as well as AMs to mitigate any overages of catch limits. The ACLs and AMs were effective for fishing year 2017. Although the 2017 fishing year had nearly ended for most stocks, NMFS would evaluate 2017 catches against these final ACLs when data become available in mid-2018. The ACLs and AMs support the long-term sustainability of fishery resources of the U.S. Pacific Islands. The final specifications were applicable from January 1, 2017, through December 31, 2017, except for precious coral fisheries, which are applicable from July 1, 2017 through June 30, 2018.

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 coral reef fishes per unit area derived from visual survey data between 2009 and 2015. These data are shown in Figure 1.

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 <30 meter 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 are used. At each SPC, divers record the number, size, and species of all fishes within or passing through paired 15 meter-diameter cylinders over 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 ecosystem status, and has repeatedly been shown to be sensitive to changes in fishing pressure, habitat quality, and oceanographic regime.

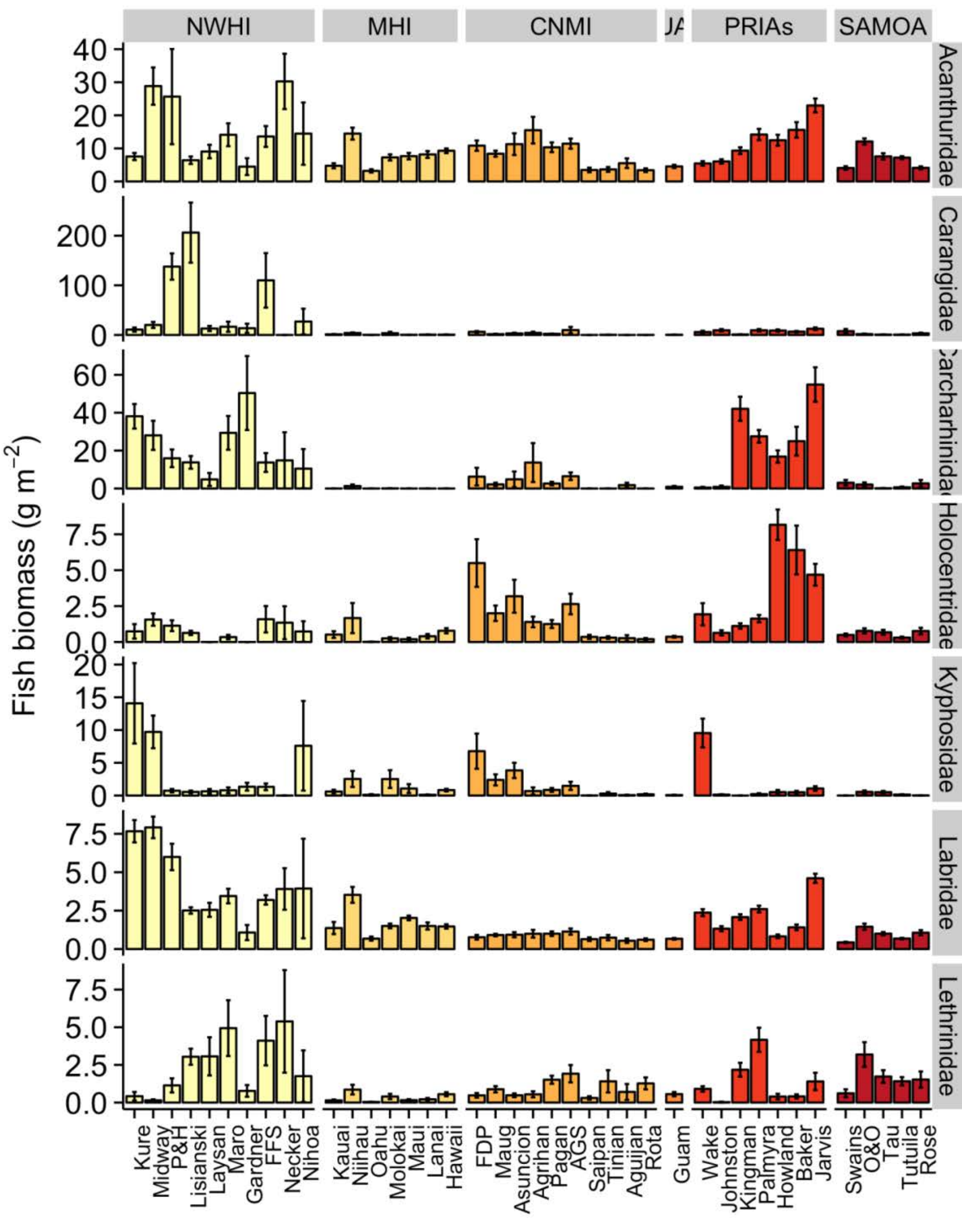
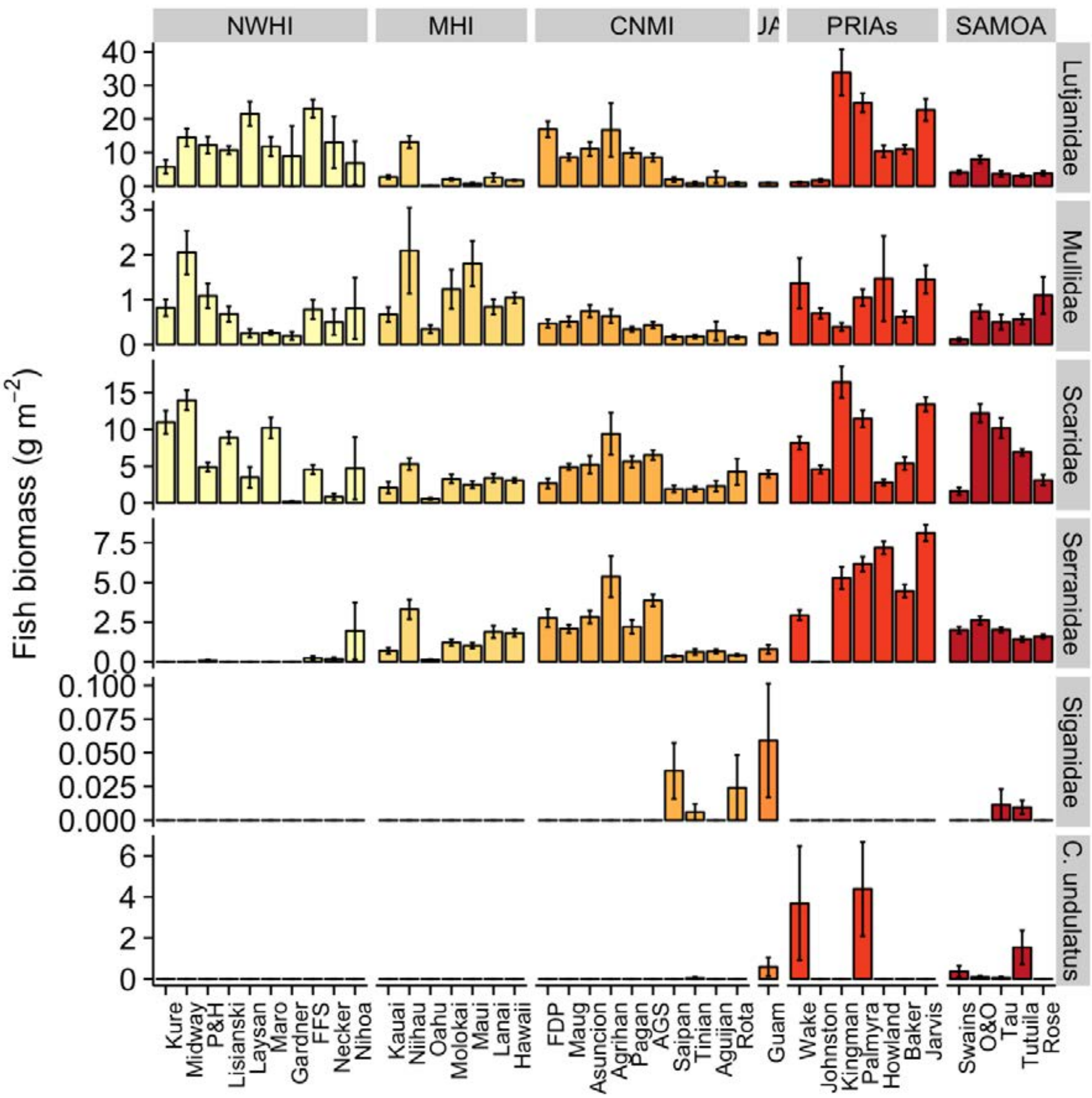


Figure 1. Mean fish biomass (g/m^2 ± standard error) of Coral Reef Management Unit Species (CREMUS) grouped by U.S. Pacific reef area from the years 2009 to 2015. Islands are ordered within region by latitude. Figure continued from previous page.



2.1.2 Archipelagic Reef Fish Biomass

Description: ‘Reef fish biomass’ is mean biomass of coral reef fishes per unit area derived from visual survey data between 2009 and 2015. These data are shown in Figure 2.

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

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 and sampling design, and methods to generate reef fish biomass are described above (Section 2.1.1).

Rationale: Identical to the rationale described in Section 2.1.1.

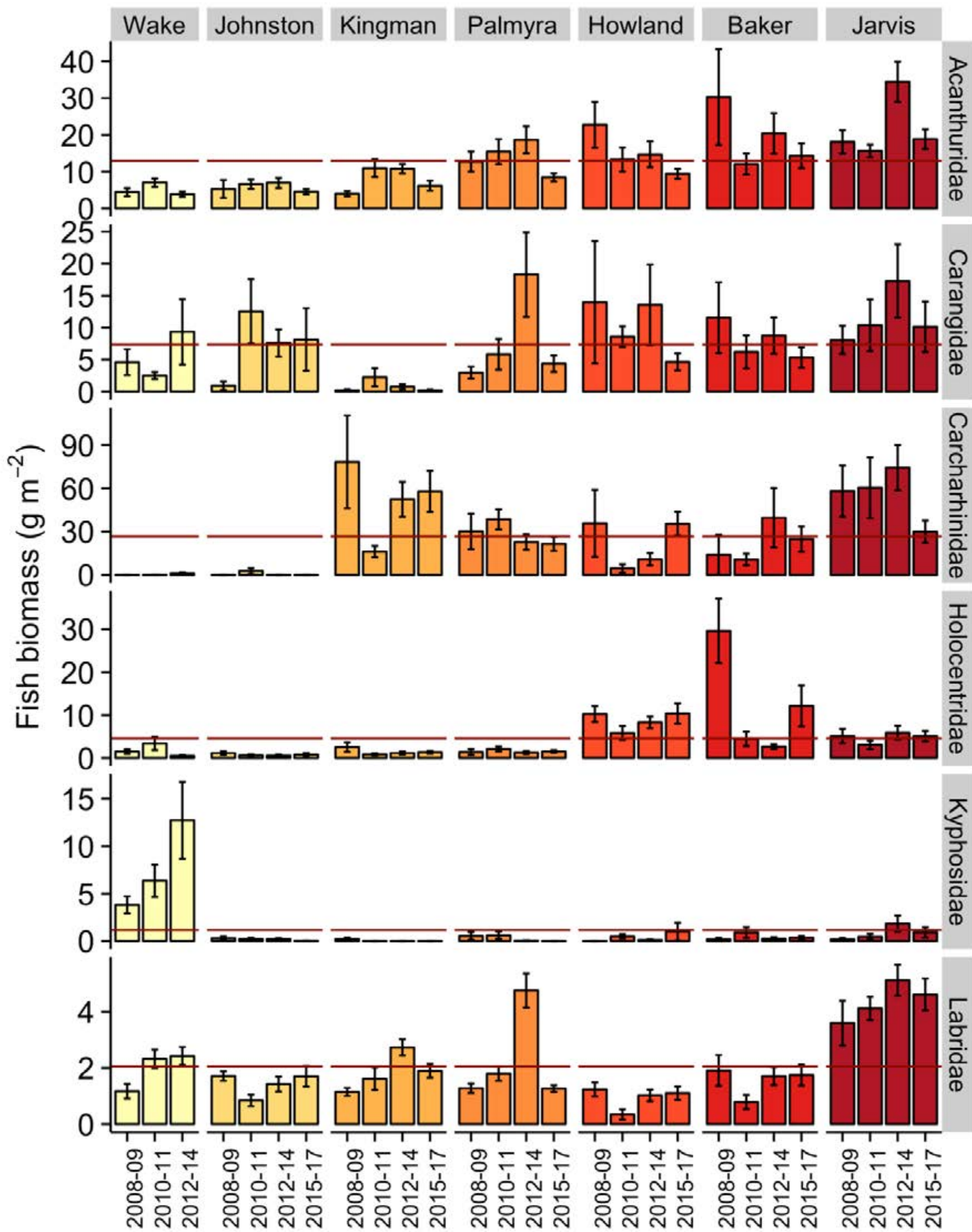
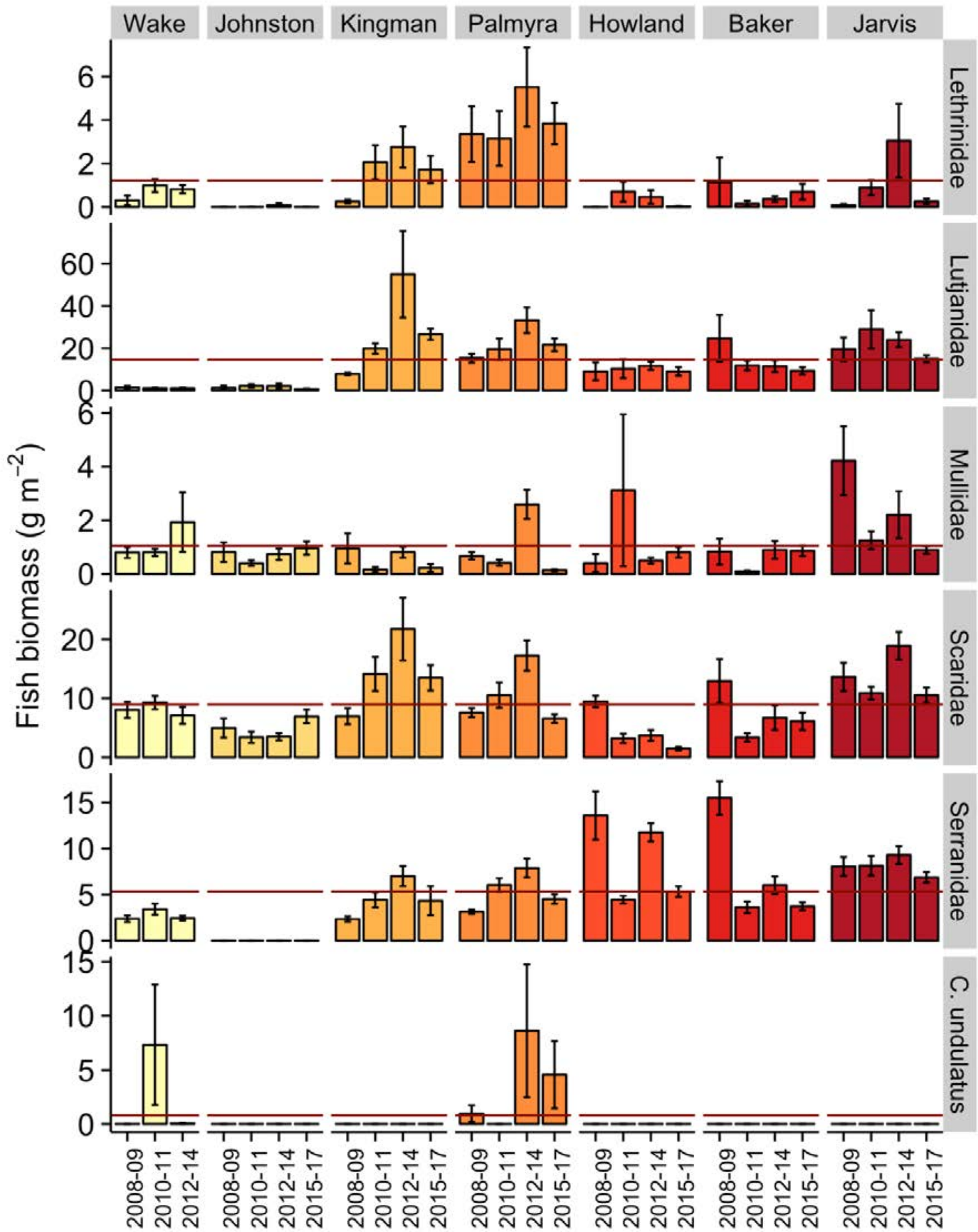

Wake
Johnston
Kingman
Palmyra
Howland
Baker
Jarvis
Acanthuridae
Carangidae
Carcharhinidae
Holocentridae
Kyphosidae
Labridae
Fish biomass (g m⁻²)
2008-09
2010-11
2012-14
2015-17

Figure 2. Mean fish biomass (g/m^2 ± standard error) of PRIA CREMUS from the years 2009 to 2015. The American Samoa archipelago mean estimates are represented by the red line. Figure continued from previous page.



2.1.3 Archipelagic Mean Fish Size

Description: 'Mean fish size' is mean size of reef fishes > 10 cm TL (i.e. excluding small fishes) derived from visual survey data (details of survey program below) between 2009 and 2015. These data are shown in Figure 3.

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

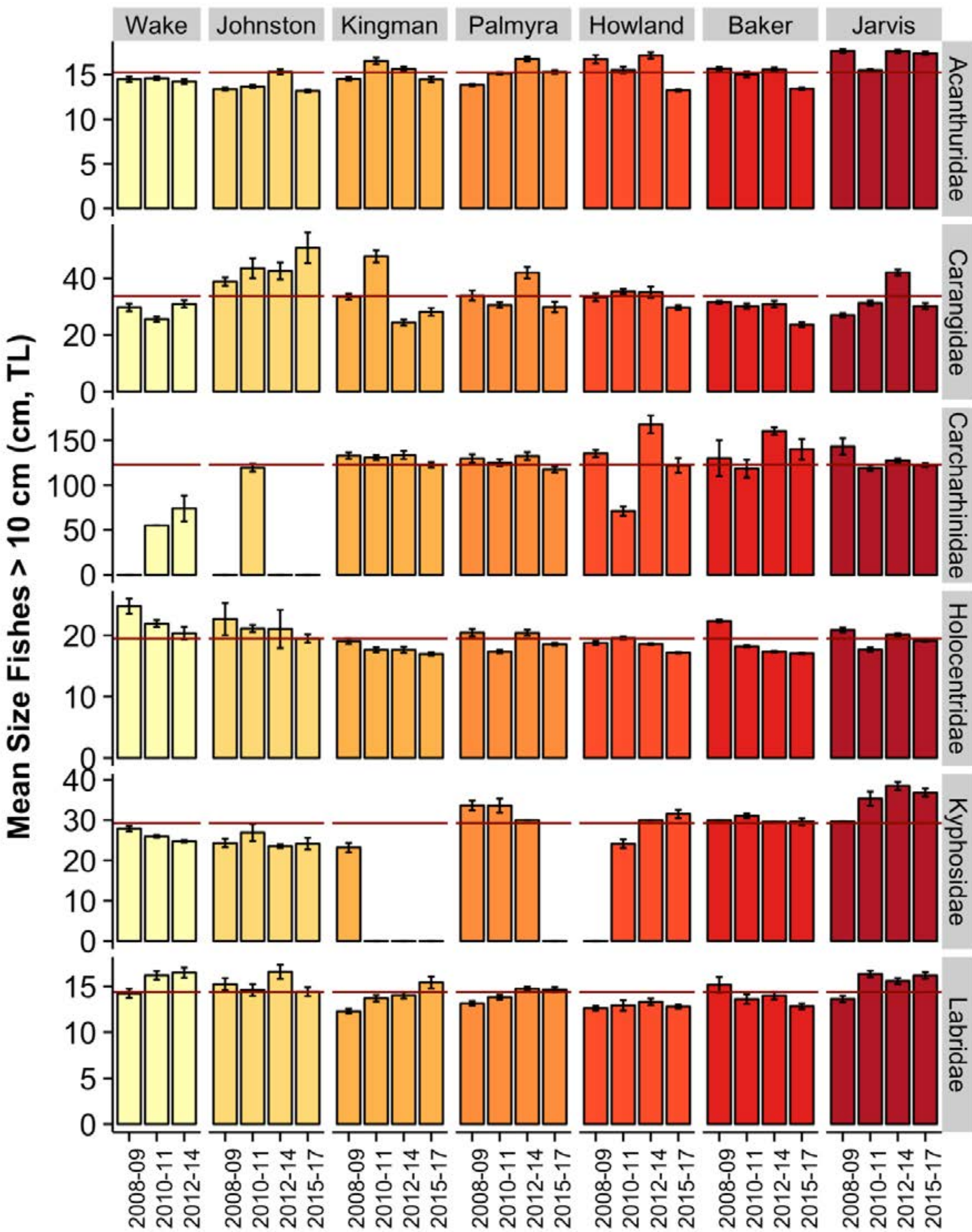
Timeframe: Triennial.

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

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

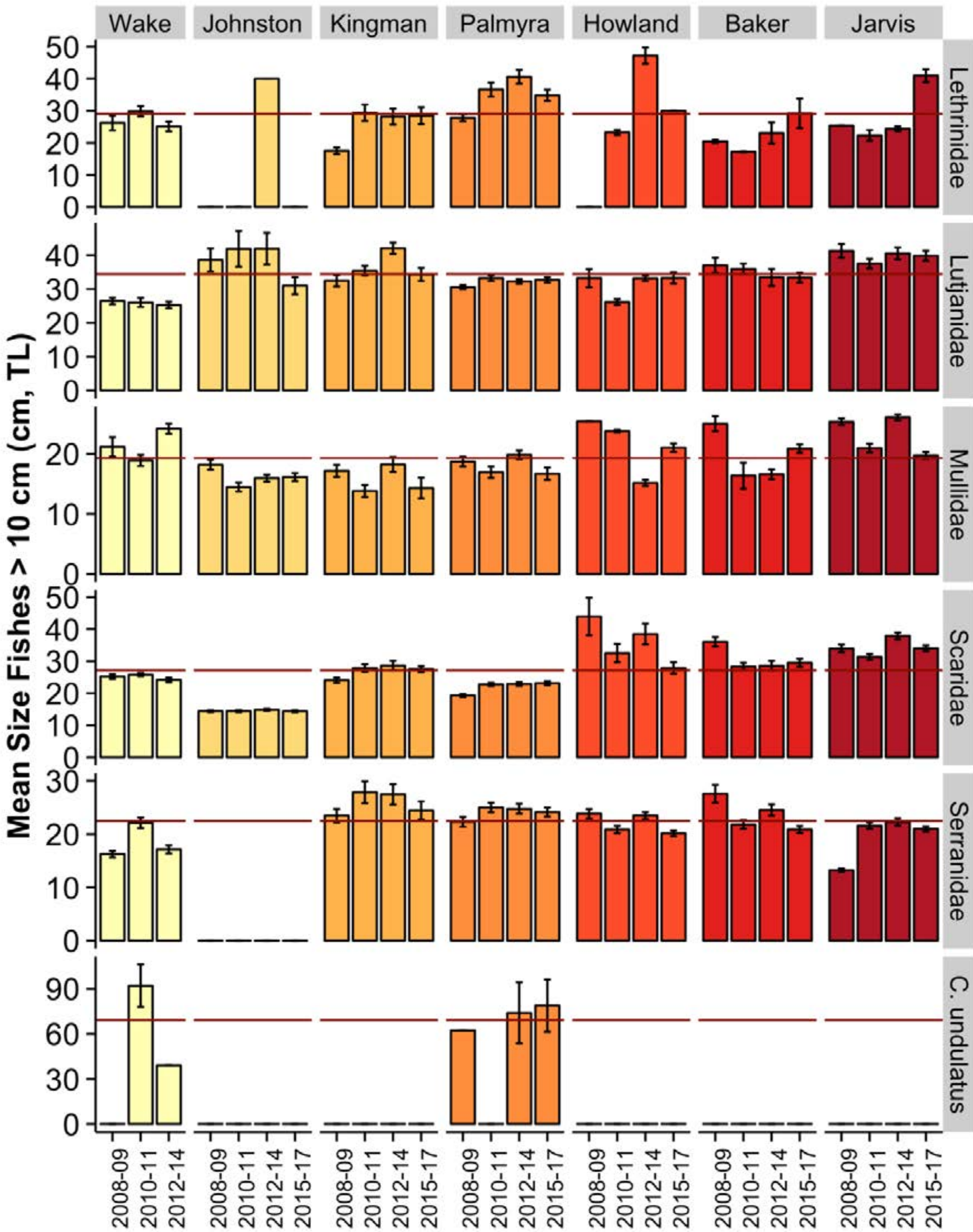
Data Source: Data used to generate biomass estimates comes from visual surveys conducted by NOAA PIFSC Coral Reef Ecosystem and partners, as part of the Pacific Reef Assessment and Monitoring Program (http://www.pifsc.noaa.gov/cred/pacific_ramp.php). Survey methods and sampling design, and methods to generate reef fish biomass are described above (Section 2.1.1). 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.

Rationale: Mean size is important as it is widely used as an indicator of fishing pressure. A fishery can sometimes preferentially target large individuals, and can also the number of fishes reaching older (and larger) size classes. Large fishes 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.



Wake
Johnston
Kingman
Palmyra
Howland
Baker
Jarvis
Acanthuridae
Carangidae
Carcharhinidae
Holocentridae
Kyphosidae
Labridae
Mean Size Fishes > 10 cm (cm, TL)
2008-09
2010-11
2012-14
2015-17

Figure 3. Mean fish size (cm, TL ± standard error) of PRIA CREMUS from the years 2009 to 2015. The American Samoa archipelago mean estimates are plotted for reference (red line). Figure continued from previous page.



2.1.4 Reef Fish Population Estimates

Description: 'Reef fish population estimates' are calculated by multiplying mean biomass per unit area by estimated hardbottom area in a consistent habitat across all islands (specifically, the area of hardbottom forereef habitat in < 30 meters of water). These data are shown in Table 2.

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

Spatial Scale:

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

Data Source: Data used to generate mean size estimates come 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 2.1.1). Those estimates are converted to population estimates by multiplying biomass (g/m^2) per island by the estimated area of hardbottom habitat <30 meters deep at the island, which is the survey domain for the monitoring program that biomass data comes from. Measures of estimated habitat area per island are derived from GIS bathymetry and NOAA Coral Reef Ecosystems Program habitat maps. Many reef fish taxa are present in other habitats than is surveyed by the program, and 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 response to divers. Curious fishes, particularly in locations where divers are not perceived as a threat, will tend to be overestimated by visual survey, while skittish fishes will tend to be undercounted. It is also likely that numbers of jacks and sharks in some locations, such as the NWHI are overestimated by visual survey. Nevertheless, 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 2. Reef fish population estimates for CREMUS in 0-30 m hardbottom habitat only of the PRIAs. *N* is number of sites surveyed per island/atoll.

Island/Atoll	Total area of reef (Ha)	*N*	Estimated population biomass (metric tons) in survey domain of < 30 m hard bottom					
			Acanthuridae	**Carangidae**	**Carcharhinids**	**Holocentridae**	**Kyphosidae**	**Labridae**
Wake	1,282.0	75	69.9	76.1	6.3	24.8	122.3	30.4
Johnston	9,410.2	104	570.1	887.6	81.2	60.1	13.5	124.7
Kingman	3,721.1	130	346.8	39.8	1,566.1	41.5	-	77.4
Palmyra	4,212.7	160	597.7	400.5	1,160.4	68.6	9.2	109.7
Howland	172.9	90	21.5	15.5	29.1	14.1	0.9	1.4
Baker	390.3	81	60.9	26.4	97.5	25.0	2.0	5.5
Jarvis	365.9	134	84.1	46.1	200.8	17.1	3.9	16.9
TOTAL	**19,555.1**	**774**	**1,754.9**	**1,490.6**	**3,217.0**	**249.3**	**111.2**	**363.0**
Island/Atoll	**Total area of reef (Ha)**	***N***	**Lethrinidae**	**Lutjanidae**	**Mullidae**	**Scaridae**	**Serranidae**	***C. undulatus***
Wake	1,282.0	75	11.6	13.5	17.5	104.9	37.5	47.2
Johnston	9,410.2	104	2.9	155.1	65.6	433.2	-	-
Kingman	3,721.1	130	81.1	1,259.5	14.7	611.9	195.9	-
Palmyra	4,212.7	160	175.5	1,045.6	44.0	482.1	259.2	184.8
Howland	172.9	90	0.7	17.9	2.5	4.8	12.4	-
Baker	390.3	81	1.6	42.6	2.4	21.0	17.4	-
Jarvis	365.9	134	5.1	82.9	5.3	49.2	29.7	-
TOTAL	**19,555.1**	**774**	**280.1**	**2,661.1**	**148.8**	**1,707.2**	**549.1**	**220.8**

Note: No Siganidae or *Bolbometopon muricatum* were observed in the PRIAs during these surveys.

2.2 PROTECTED SPECIES

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

2.2.1 Monitoring Protected Species Interactions in the PRIA FEP Fisheries

This report monitors the status of protected species interactions in the PRIA FEP fisheries using proxy indicators such as fishing effort and changes in gear types as these fisheries do not have observer coverage. Logbook programs are not expected to provide reliable data about protected species interactions due to the lack of active fisheries in these areas.

2.2.1.1 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 prohibitions benefit protected species by preventing potential interactions with non-selective fishing gear.

2.2.1.2 ESA Consultations

ESA consultations were conducted by NMFS and the U.S. Fish and Wildlife Service (USFWS; for species under their jurisdiction) to ensure ongoing fisheries operations managed under the PRIA FEP are not jeopardizing the continued existence of any listed species or adversely modifying critical habitat. The results of these consultations, conducted under section 7 of the ESA, are briefly described below and summarized in Table 3.

NMFS concluded in an informal consultation dated February 20, 2015 that all fisheries managed under the PRIA FEP are not likely to adversely affect the Indo-West Pacific DPS of scalloped hammerhead shark. NMFS concluded on January 16, 2015 that all fisheries managed under the PRIA FEP have no effects on ESA-listed reef-building corals.

In January 2018, oceanic whitetip sharks and giant manta rays were listed under the ESA (83 FR 4153 and 83 FR 2916, respectively). If NMFS determines that the PRIA fisheries are likely to adversely affect these species, NMFS will initiate consultation for these two species for the applicable fisheries

Table 3. Summary of ESA consultations for PRIA FEP Fisheries.

Fishery	Consultation Date	Consultation Type[a]	Outcome[b]	Species
Bottomfish	3/8/2002	BiOp	NLAA	Loggerhead sea turtle, leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, sei whale, sperm whale
Coral reef ecosystem	3/7/2002	LOC	NLAA	Loggerhead sea turtle, leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, sei whale, sperm whale
	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
Crustacean	9/28/2007	LOC	NLAA	Loggerhead sea turtle, leatherback sea turtle, olive ridley sea turtle, green sea turtle, hawksbill sea turtle, humpback whale, blue whale, fin whale, sei whale, sperm whale
Precious coral	10/4/1978	BiOp	Does not constitute threat	Sperm whale, leatherback sea turtle
	12/20/2000	LOC	NLAA	Humpback whale, green sea turtle, hawksbill sea turtle
All fisheries	1/16/2015	No effect memo	No effect	Reef-building corals
	2/20/2015	LOC	NLAA	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 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)

Crustacean Fishery

An informal consultation completed by NMFS on September 28, 2007 concluded that PRIA 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).

Coral Reef Fishery

An informal consultation completed by NMFS on March 7, 2002 concluded that fishing activities conducted under the Coral Reef Ecosystems FMP are not likely to adversely affect five sea turtle species (loggerhead, leatherback, olive ridley, green, and hawksbill turtles) and five marine mammal species (humpback, blue, fin, sei, and sperm whales).

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
An informal consultation completed by NMFS on December 20, 2000 concluded that PRIA precious coral fisheries are not likely to adversely affect humpback whales, green turtles, or hawksbill turtles.

2.2.1.3 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. PRIA fisheries are not classified under the LOF due to the lack of active commercial fisheries.

2.2.2 Status of Protected Species Interactions in the PRIA FEP Fisheries

There are currently no bottomfish, crustacean, coral reef, or precious coral fisheries operating in the PRIA, and no historical observer data are available for fisheries under this FEP. No new fishing activity has been reported, and there is no other information to indicate that impacts to protected species from PRIA fisheries have changed in recent years.

2.2.3 Identification of Emerging Issues

Several ESA-listed species are being evaluated for critical habitat designation (Table 4). If critical habitats are designated, they will be included in this SAFE report and impacts from FEP-managed fisheries will be evaluated under applicable mandates.

Table 4. 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)	Listed as Threatened (83 FR 4153, 1/30/18)	Not determinable because of insufficient data (83 FR 4153, 1/30/18)	TBA
Pacific bluefin tuna	*Thunnus orientalis*	Positive (81 FR 70074, 10/11/2016)	Not warranted (82 FR 37060, 8/8/17)	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)	Listed as Threatened (83 FR 2916, 1/22/18)	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 TBA	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 TBA[a]	TBA

[a] NMFS and USFWS have been tasked with higher priorities regarding sea turtle listings under the ESA, and do not anticipate proposing green turtle critical habitat designations in the immediate future.

2.2.4 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 commercial and 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.

2.3 SOCIOECONOMICS

This section outlines the pertinent economic, social, and community information available for assessing the successes and impacts of management measures and the achievements of the Fishery Ecosystem Plan (FEP) for the Pacific Remote Island Area (PRIA; Western Pacific Regional Fishery Management Council, 2016). It meets the objective of "Support Fishing Communities" adopted at the 165th Council meeting; specifically, it identifies the various social and economic groups within the regions' fishing communities and their interconnections. The section begins with an overview of the socioeconomic context for the region, and then provides a summary of relevant studies and data for the PRIA.

In 1996, the Magnuson-Stevens Fishery Conservation and Management Act's National Standard 8 (NS8) specified that conservation and management measures nee to account for the importance of fishery resources in fishing communities, to support sustained participation in the fisheries, and to minimize adverse economic impacts, provided that these considerations do not compromise conservation. Unlike other regions of the U.S., the settlement of the Western Pacific region was intimately tied to the ocean, which is reflected in local culture, customs, and traditions (Figure 4).

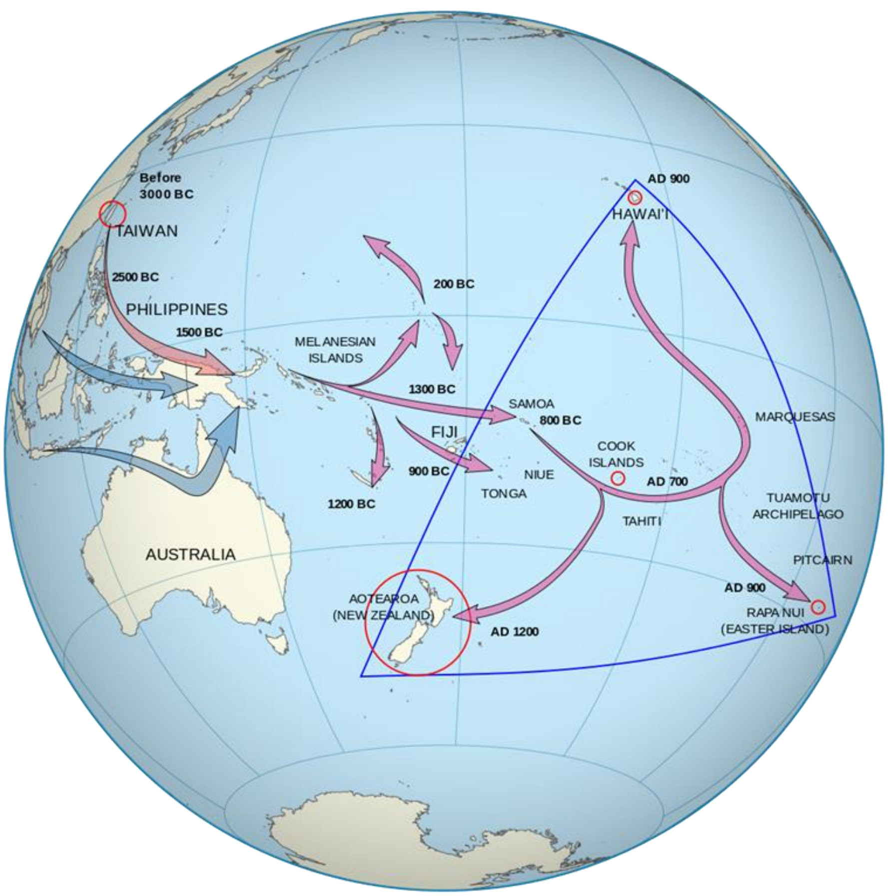


Figure 4. Settlement of the Pacific Islands, courtesy Wikimedia Commons. Found at https://commons.wikimedia.org/wiki/File:Polynesian_Migration.svg.

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 have a similar reliance on marine resources. Thus, fishing and seafood are integral to local community ways of life. This is reflected in the amount of seafood eaten in the region relative to the rest of the United States, as well as in the language, customs, ceremonies, and community events. The amount of available seafood can also affect seasonality in prices of fish. Because fishing is such an integral part of the culture, it is difficult to discern commercial from non-commercial fishing where most trips involving multiple motivations and multiple uses of the fish caught. While the economic perspective is an important consideration, fishermen report other motivations, such as customary exchange, as being equally important. Due to changing economies and westernization, waning 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 166th meeting held in Tumon, Guam, the Council directed staff to develop a brief report identifying data sources, quality, and coverage for a range of socioeconomic parameters in the annual/SAFE reports, as resources permit. This report also identifies the quality and coverage of the socioeconomic data, including any data gaps. The data synthesis was conducted and used to guide the development of the socioeconomic section with further input and guidance from the Council Social Science Planning Committee and Archipelagic Plan Team.

For future Annual/SAFE reports, the Council also directed the Plan Team to consider including enhanced information on social, economic, and cultural impacts of climate change resulting in increased pressure on the ocean and its resources. PIFSC developed a Regional Action Plan and Climate Science Strategy as a first step in providing the information (Polovina *et al*., 2016).

2.3.2 Background

Human habitation in the PRIA is limited. The FEP for the PRIA provides a description of the geography, history, and socioeconomic considerations of the archipelago (WPRFMC, 2016). Grace-McCaskey (2014) provided a brief review of the importance of these areas from a cultural perspective. She noted that although the PRIA were uninhabited when first visited by Westerners, Polynesians and Micronesians likely had been periodically visiting these islands for centuries. Many of the islands in the PRIA were altered during WWII, and many have subsequently become National Wildlife Refuges or part of the Pacific Remote Islands Marine National Monument. Only Wake, Johnston, and Palmyra have seasonal- and year-round residents, primarily related to the U.S. military and refuge management. The surrounding reef ecosystems are considered to be some of the healthiest in the world due to their distance to areas of high human population densities, though some are experiencing residual impacts from military activity nearby. There are no designated fishing communities residing in the PRIA. Most of the fishing effort has been concentrated around Johnston and Palmyra by members of the Hawaii fishing community.

2.3.3 Ongoing Research and Information Collection

There is currently no ongoing research specific to the PRIA. In 2017, an external review of the Economics and Human Dimensions Program was undertaken (PIFSC, 2017). Recommendations from this review will help focus and prioritize a strategic research agenda going forward.

2.3.4 Relevant PIFSC Economics and Human Dimensions Publications: 2017

Bennett, N.J., Teh, L., Ota, Y., Christie, P., Ayers, A., Day, J.C., Franks, P., Gill, D., Gruby, R.L., Kittinger, J.N., and Koehn, J.Z., 2017. An appeal for a code of conduct for marine conservation. *Marine Policy*, *81*, pp. 411-418. https://doi.org/10.1016/j.marpol.2017.03.035.

Pacific Islands Fisheries Science Center (PIFSC), 2017. Background and PIFSC Response: Panel Reports of the Economics and Human Dimensions Program Review. 18 p. https://go.usa.gov/xnDyP.

2.3.5 References

Grace-McCaskey, C., 2014. Examining the potential of using secondary data to better understand human-reef relationships across the Pacific. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96818-5007. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-14-01, 69 p. https://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_14-01.pdf

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

WPRFMC, 2016. Annual Stock Assessment and Fishery Evaluation Report: Pacific Remote Island Area Fishery Ecosystem Plan 2016. Sabater, M., Ishizaki, A., Walker, R., Spalding, S. (Eds.) Western Pacific Regional Fishery Management Council. Honolulu, Hawaii 96813 USA.

2.4 CLIMATE AND OCEANIC INDICATORS

2.4.1 Introduction

Beginning with the 2015 Annual Report, we have included 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 and 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.

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

2.4.2 Conceptual Model

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

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

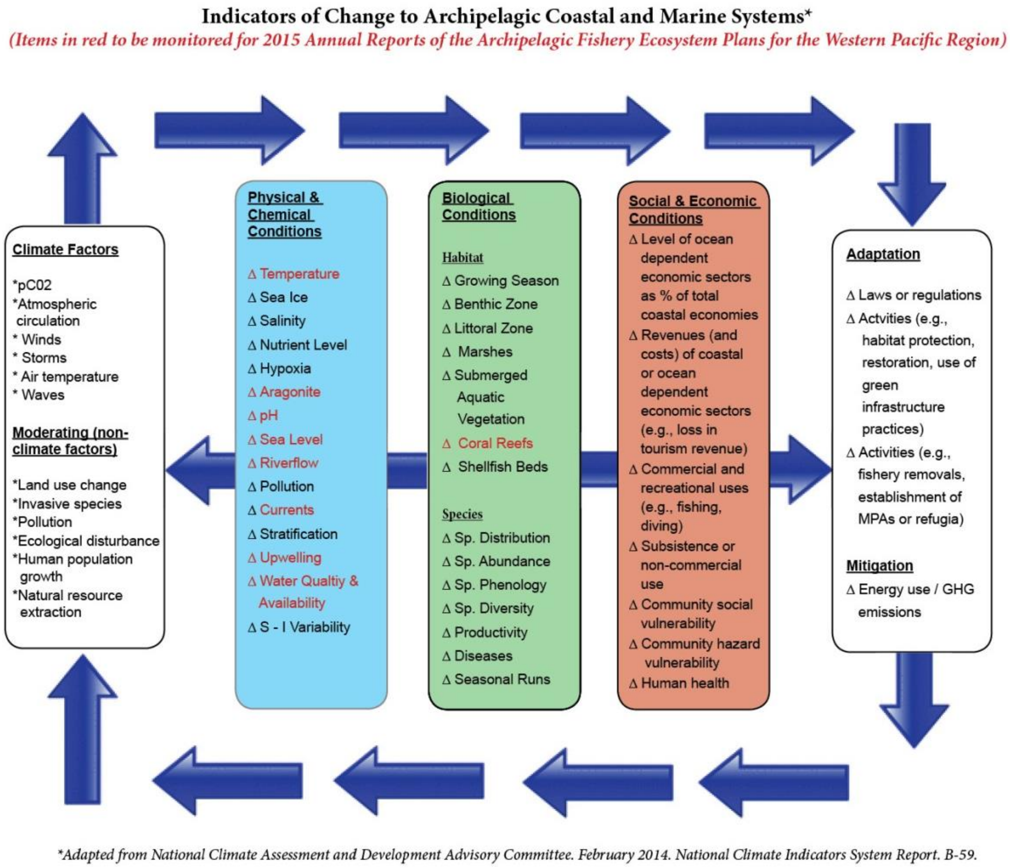


Figure 5. Simplified representation of the climate and non-climate stressors in the coastal and marine ecosystems.

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 Annual Report; the specific indicators used in the Report are listed in Section 2.4.3. Other indicators will be added over time as datasets become available and understanding of the nature of the causal chain from stressors to impacts emerges.

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

2.4.3 Selected Indicators

The primary goal for selecting the Indicators used in this (and future reports) is to provide fisheries-related communities, resource managers, and businesses with 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.

Beginning with the 2015 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) – Like ENSO, the PDO reflects changes between periods of persistently warm or persistently cool ocean temperatures, but over a period of 20 – 30 years versus 6 – 18 months for ENSO event. The climatic finger prints of the PDO are most visible in the Northeastern Pacific, but secondary signatures exist in the tropics.

Sea Surface Temperature –Monthly sea surface temperature and anomaly blended from three data sources covering 1985-2017: Pathfinder v 5.0, the Global Area Coverage, and the GOES-POES dataset from both the AVHRR instrument aboard the NOAA Polar Operational Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES). 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, and showing the current year relative to past years, sea surface temperature anomaly provides context on one of the most directly observable measures we have for tracking increasing ocean temperature.

Coral Thermal Stress Exposure – In tropical coastal habitats, one tangible impact of high temperature anomalies is the possibility of mass coral bleaching. To help gauge the history and impact of thermal stress on coastal corals, we present a satellite-derived metric called Degree Heating Weeks.

Chlorophyll-A – Monthly chlorophyll-a spanning 2002-2017 from the MODIS sensor aboard the NASA Aqua satellite. Chlorophyll-A is derived from ocean color, and is a proxy for the amount of phytoplankton in the seawater. Combined with temperature, it can give an index of primary production.

Chlorophyll-Anomaly – Deviation from seasonal and inter-annual chlorophyll-a (chl-A) patterns can provide a means of assessing the relative distinctiveness of 2017, as well as how chl-A varies over time.

Heavy Weather (Tropical Cyclones & Storm Force Winds) -- Measures of tropical cyclone occurrence, strength, and energy. Percentage occurrence of winds > 34 knots. Tropical cyclones and high winds may have the potential to significantly impact fishing operations.

Rainfall – Rainfall has been proposed as a potentially important correlate for the catch of some nearshore species, especially nearshore pelagics.

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 PRIA so only regional information on this Indicator is included.

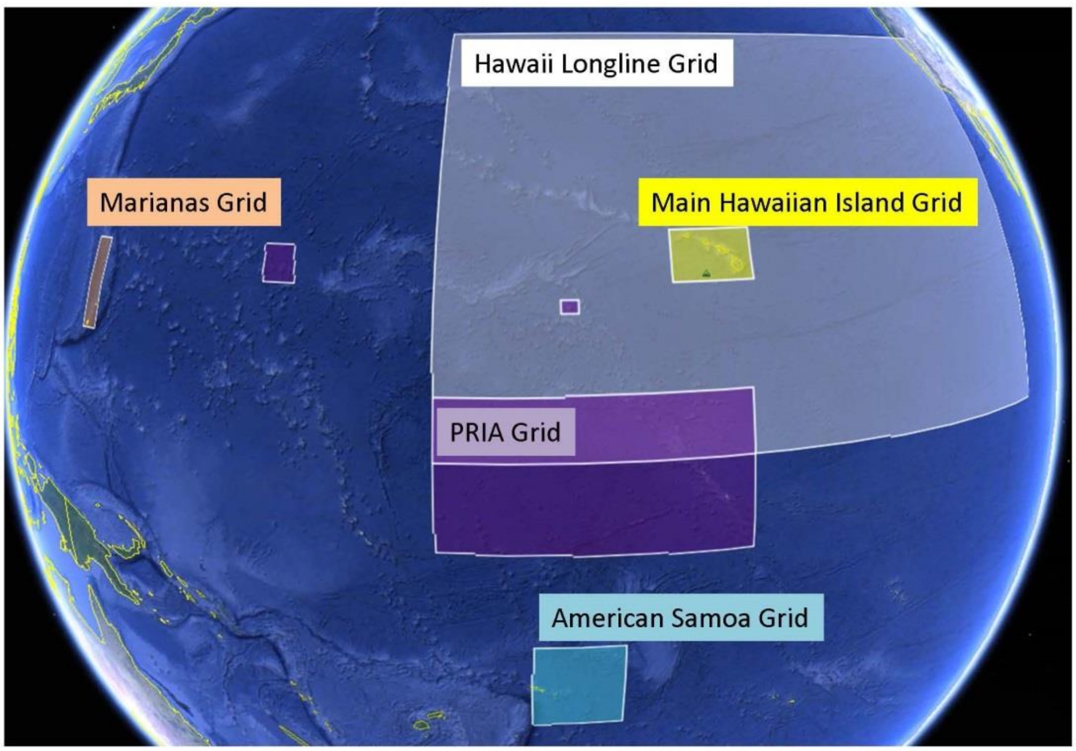


Figure 6. Regional spatial grids representing the scale of the climate change indicators being monitored.

Table 5. 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 mean 406.53 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.	2017: ENSO Neutral
Pacific Decadal Oscillation (PDO)	PDO can be thought of as a long-lived, multi-decadal ENSO cycle that has well-documented fishery implications related to ocean temperature and productivity.	2017: positive (warm) from Jan – June, negative (cool) from Jul – Dec
Sea Surface Temperature* (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 PRIA ranged between 27-30º C with 2017 showing anomalies dependent on latitude: along the equator, 2017 showed a negative anomaly, while at ~4 deg. N, the 2017 anomaly moves positive.
Coral Thermal Bleaching Exposure (DHW)	Satellite remotely-sensed metric of time and temperature above thresholds relevant for coral bleaching. Metric used is Degree Heating Weeks (DHW).	The equatorial PRIA showed prolonged, substantial DHW stress in 2015-2016, in which DHW values exceeded the range in which mass mortality is expected (DHW>8). Wake Atoll showed more regular, but less prolonged heating events ('14, '15, '17).
Chlorophyll-A (Chl-A)	Satellite remotely-sensed chlorophyll-a. Chl-A is projected to drop over much of the central Pacific, and is directly linked ecosystem productivity.	The Chl-A around the PRIA ranges from 0.08 to 0.35 mg/m^3, with 2017 showing a near-zero and spatially variable anomaly.

Tropical Cyclones	Measures of tropical cyclone occurrence, strength, and energy. Tropical cyclones have the potential to significantly impact fishing operations.	Eastern Pacific, 2017: 31 storms, a level slightly lower than average.
		South Pacific, 2017: 6 storms, low – lowest since 2012.
		Central Pacific, 2017: 0 storms. Very low.
Rainfall/Precipitation	CMAP re-analysis of CPC Precipitation Data	2017 showed negative anomalies in rainfall.
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.

2.4.3.1 Atmospheric Concentration of Carbon Dioxide (CO_2)

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, warming influence) of greenhouse gases in the atmosphere has increased substantially over the last several decades.

Status: Atmospheric CO_2 is increasing exponentially. In 2017, the annual mean concentration of CO_2 was 406.53 ppm. In 1959, the first year of the time series, it was 315.97 ppm. The annual mean passed 350 ppm in 1988 and 400 ppm in 2015.

Description: Monthly mean atmospheric carbon dioxide (CO_2) at Mauna Loa Observatory, Hawai`i in parts per million (ppm) from March 1958 to present.

The observed increase in monthly average carbon dioxide concentration is primarily due 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, Hawai`i are due to the seasonal imbalance between the photosynthesis and respiration of plants on land. During the summer growing season 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 this hemisphere's larger land mass.

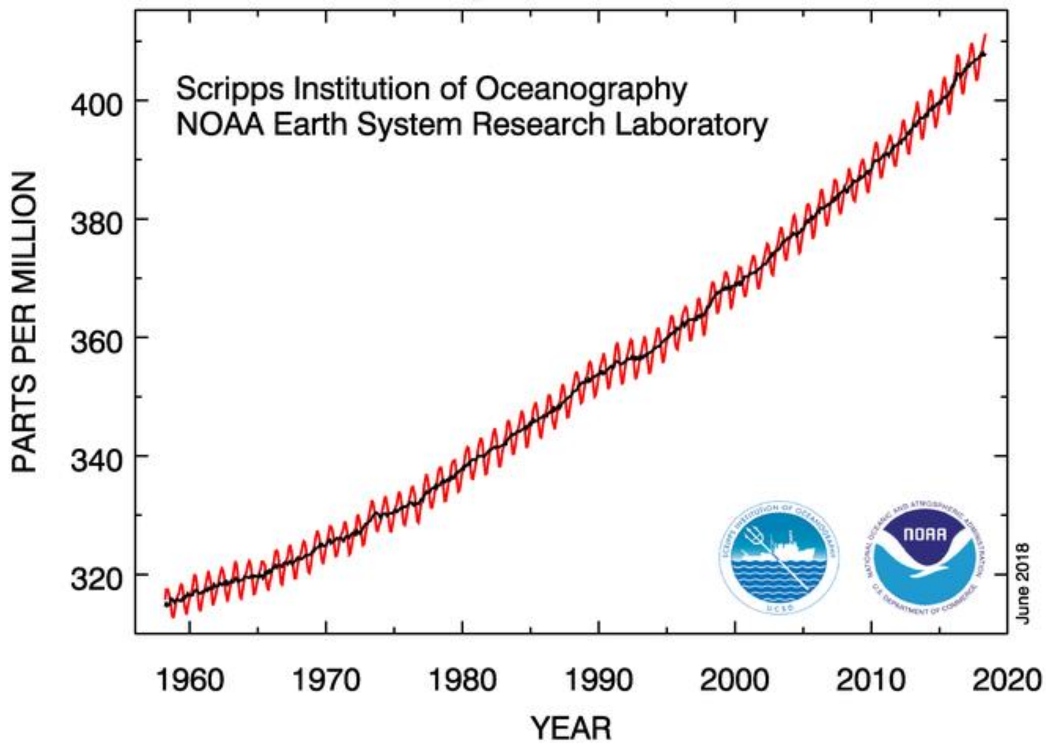


Figure 7. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawai`i. The red line shows monthly averages and the black line shows seasonally corrected data.

Timeframe: Annual, monthly

Region/Location: Mauna Loa, Hawai`i but representative of global atmospheric carbon dioxide concentration

Data Source: "Full Mauna Loa CO_2 record" available at https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html. Data from additional monitoring stations, including the Tutuila, American Samoa station are available at https://www.esrl.noaa.gov/gmd/dv/iadv/.

Measurement Platform: *In-situ* station

2.4.3.1.1 References

Keeling, C.D., Bacastow, R.B., Bainbridge, A.E., Ekdahl, C.A., Guenther, P.R., Waterman, L.S., 1976. Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. *Tellus*, *28*, pp. 538-551.

Thoning, K.W., Tans, P.P., Komhyr, W.D., 1989. Atmospheric carbon dioxide at Mauna Loa Observatory 2. Analysis of the NOAA GMCC data, 1974-1985. *Journal of Geophysical Research*, *94*, pp. 8549-8565.

2.4.3.2 Oceanic pH

Rationale: Ocean pH is a measure of how greenhouse gas emissions have already impacted the ocean. This indicator demonstrates that oceanic pH has decreased significantly over the past several decades (i.e., the ocean has become more acidic). Increasing ocean acidification (indicated by lower oceanic pH) limits the ability of marine organisms to build shells and other hard structures. Recent research has shown that pelagic organisms such pteropods and other prey for commercially-valuable fish species are already being negatively impacted by increasing acidification (Feely *et al.*, 2016). The full impact of ocean acidification on the pelagic food web is an area of active research (Fabry *et al.*, 2008).

Status: Oceanic pH has shown a significant linear decrease of 0.0369 pH units, or roughly an 8.9% increase in acidity, over the nearly 30 years spanned by this time series. Additionally, the highest pH value reported for the most recent year (8.0846) is roughly equal to the lowest pH value reported in the first year of the time series (8.0845).

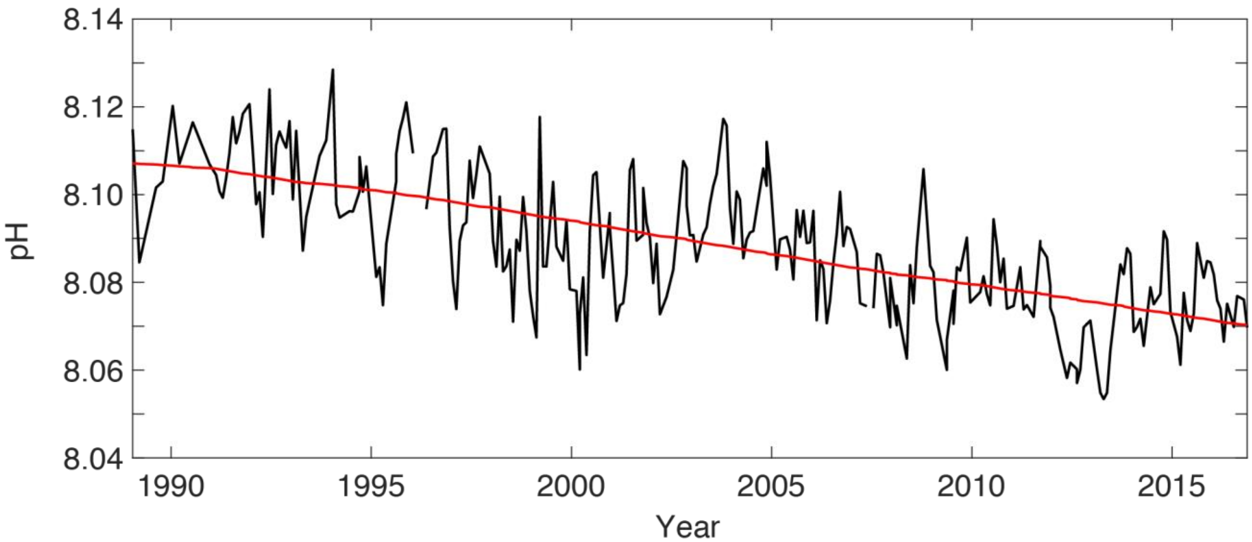


Figure 8. pH Trend at Station ALOHA, 1989 – 2016. Note: Measured pH values are plotted in black. The linear fit to this time series is shown in red.

Description: Trends in surface (5 m) pH at Station ALOHA, north of Oahu (22.75°N, 158°W), collected by the Hawai`i Ocean Time-series (HOT) from October 1988 to 2016 (2017 data are not yet available). Oceanic pH is a measure of ocean acidity, which increases as the ocean absorbs carbon dioxide from the atmosphere. Lower pH values represent greater acidity. The multi-decadal time series at Station ALOHA represents the best available documentation of the significant downward trend in oceanic pH since the time series began in 1988. Oceanic pH varies over both time and space, though the conditions at Station ALOHA are considered broadly representative of those across the Western and Central Pacific’s pelagic fishing grounds.

Timeframe: Monthly

Region/Location: Station ALOHA: 22.75°N, 158°W

Data Source: Hawai`i Ocean Time-series at http://hahana.soest.hawaii.edu/hot/. The Hawai`i Ocean Time-series is maintained by the University of Hawai`i's School for Ocean and Earth Science and Technology.

Measurement Platform: *In-situ* station

References:

An overview of the relationship between acidity and pH can be found at: http://www.pmel.noaa.gov/co2/story/A+primer+on+pH

A detailed description of how HOT determines pH can be found at: http://hahana.soest.hawaii.edu/hot/methods/ph.html

Methods for calculating pH from TA and DIC can be found at: https://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/CO2_System_in_Seawater/csys.html

2.4.3.2.1 References

Fabry, V.J., Seibel, B.A., Feely, R.A., Orr, J.C., 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science*, *65*, pp. 414-432.

Feely, R.A., Alin, S.R., Carter, B., Bednarsek, N., Hales, B., Chan, F., Hill, T.M., Gaylord, B., Sanford, E., Byrne, R.H., Sabine, C.L., Greeley, D., Juranek, L., 2016. Chemical and biological impacts of ocean acidification along the west coast of North America. *Estuarine, Coastal and Shelf Science*, *183*, pp. 260-270. doi: 10.1016/j.ecss.2016.08.043

2.4.3.3 Oceanic Niño Index

Rationale: The ENSO cycle is known to have impacts on Pacific fisheries targeting species including but not limited to tuna. The ONI focuses on ocean temperature, which has the most direct effect on these fisheries.

Status: The ONI was neutral in 2017.

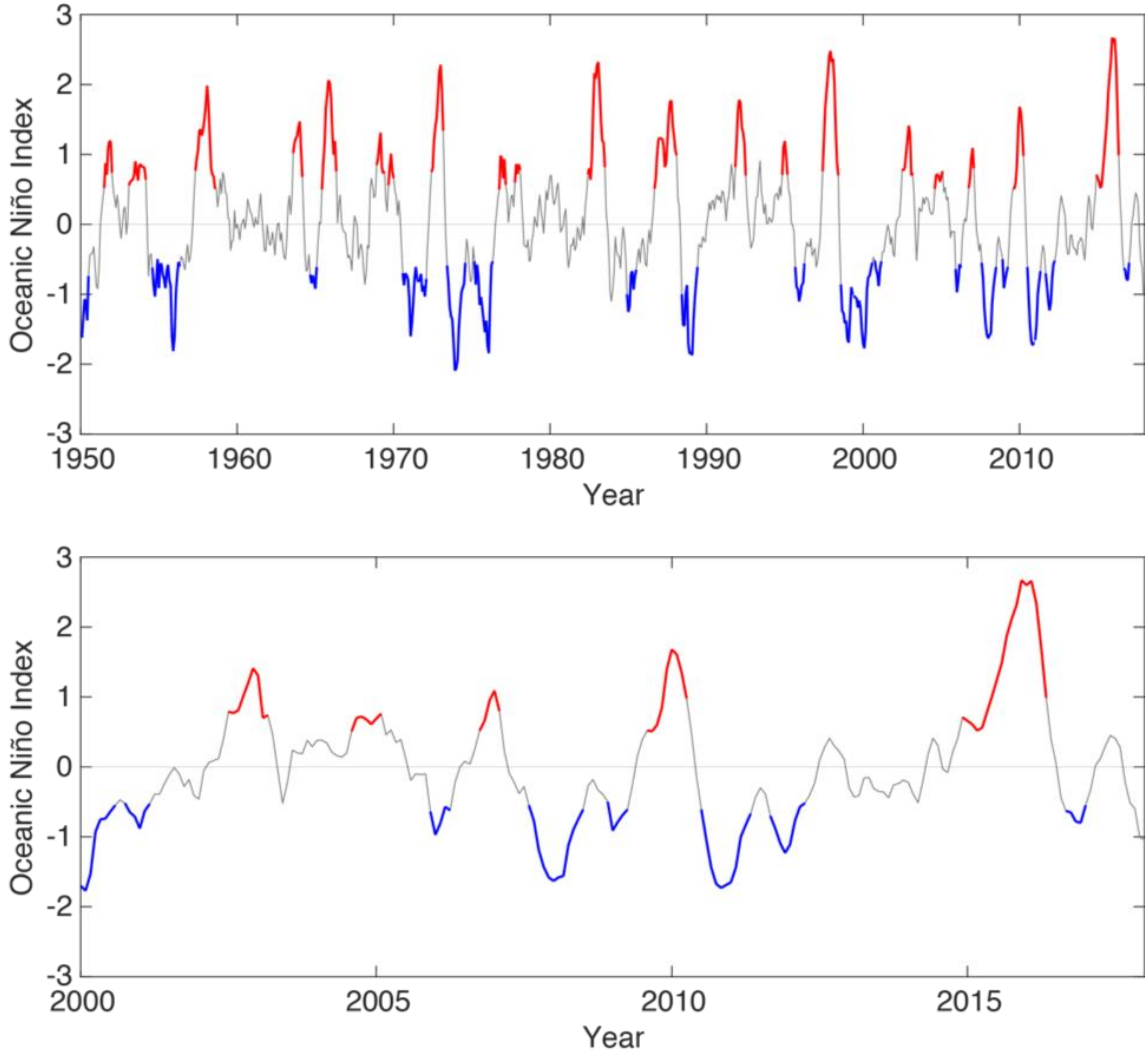


Figure 9. Oceanic Niño Index, 1950-2017 and 2000–2017. Note: Monthly time series of the Oceanic Niño Index for 1950 – 2017 (top) and 2000 – 2017 (bottom). El Niño periods are highlighted in red. La Niña periods are highlighted in blue.

Description: The three-month running mean of ERSST .v4 sea surface temperature (SST) anomalies in the Niño 3.4 region (5°S – 5°N, 120° – 170°W). The Oceanic Niño Index (ONI) is a measure of the El Niño – Southern Oscillation (ENSO) phase. Warm and cool phases, termed El Niño and La Niña respectively, are based in part on an ONI threshold of ± 0.5 °C being met for a minimum of five consecutive overlapping seasons. Additional atmospheric indices are needed to confirm an El Niño or La Niña event, as the ENSO is a coupled ocean-atmosphere phenomenon. The atmospheric half of this Pacific basin oscillation is measured using the Southern Oscillation Index.

Timeframe: Every three months

Region/Location: Niño3.4 region: 5°S – 5°N, 120° – 170°W

Data Source: NOAA NCEI at https://www.ncdc.noaa.gov/teleconnections/enso/indicators/sst.php.

Measurement Platform: *In-situ* station, satellite, model

2.4.3.3.1 References

A full description of ENSO and its global impacts can be found at: https://www.climate.gov/news-features/understanding-climate/el-ni%C3%B1o-and-la-ni%C3%B1a-frequently-asked-questions

2.4.3.4 Pacific Decadal Oscillation

Rationale: The Pacific Decadal Oscillation (PDO) was initially named by a fisheries scientist, Steven Hare, in 1996 while researching connections between Alaska salmon production cycles and Pacific climate. Like ENSO, the PDO reflects changes between periods of persistently warm or persistently cool ocean temperatures, but over a period of 20 – 30 years versus 6 – 18 months for ENSO event. The climatic finger prints of the PDO are most visible in the Northeastern Pacific, but secondary signatures exist in the tropics.

Status: The PDO was positive, or warm, from January through June of 2017. For the remainder of the year, the PDO was negative, or cool. It remains to be seen whether the negative conditions during the second half of the year represent a short-term fluctuation or a true phase change.

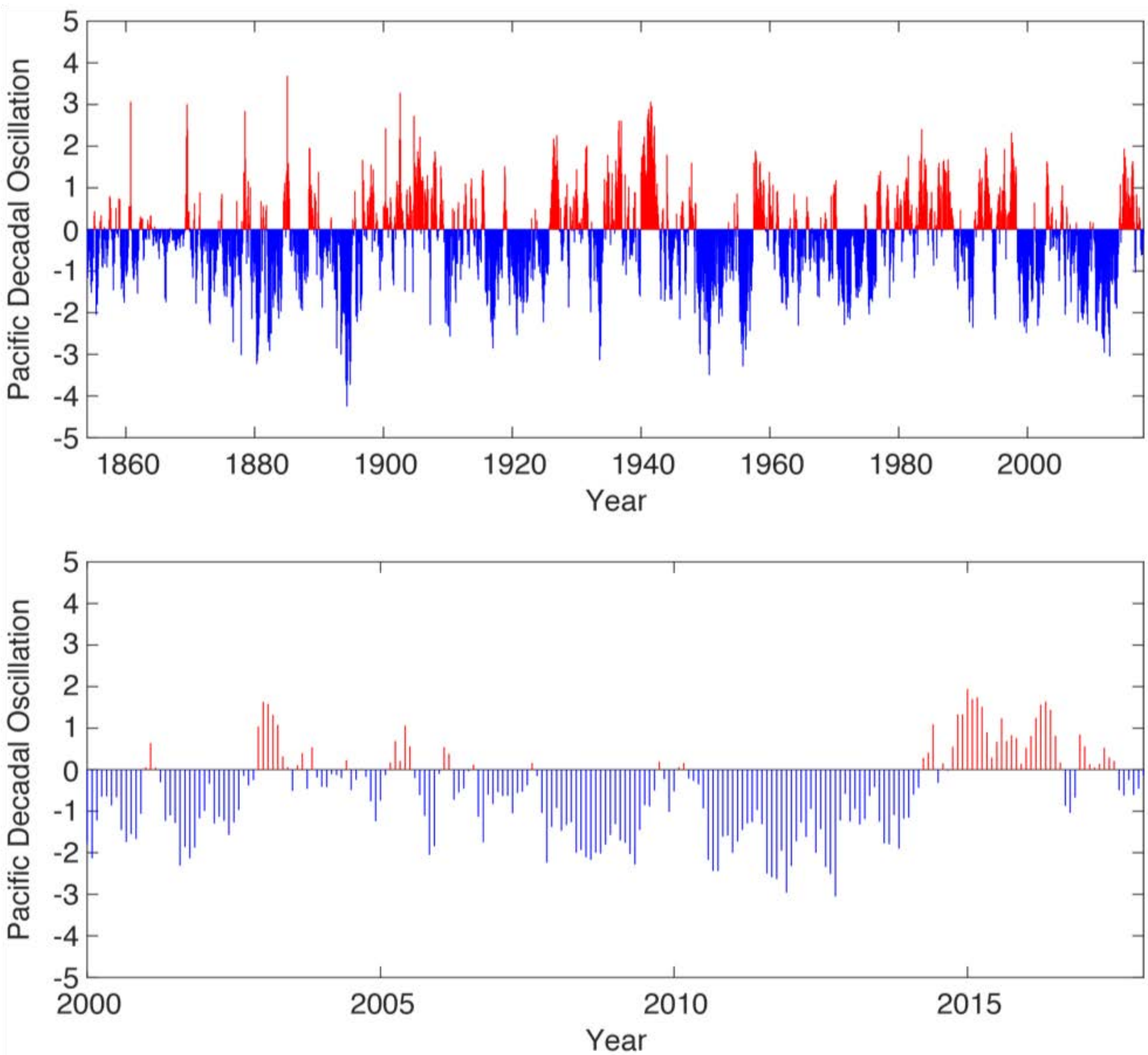


Figure 10. Pacific Decadal Oscillation, 1854–2017 (top) and 2000–2017 (bottom). Note: Positive, or warm, phases are plotted in red. Negative, or cool, phases are plotted in blue.

Description: The Pacific Decadal Oscillation (PDO) is often described as a long-lived El Niño-like pattern of Pacific climate variability. As seen with the better-known El Niño – Southern Oscillation (ENSO), extremes in the PDO pattern are marked by widespread variations in the Pacific Basin and the North American climate. In parallel with the ENSO phenomenon, the extreme cases of the PDO have been classified as either warm or cool, as defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean. When sea surface temperatures (SSTs) are anomalously cool in the interior North Pacific and warm along the North American coast, and when sea level pressures are below average in the North Pacific, the PDO has a positive value. When the climate anomaly patterns are reversed, with warm SST anomalies in the interior and cool SST anomalies along the North American coast, or above average sea level pressures over the North Pacific, the PDO has a negative value.

The National Centers for Environmental Information (NCEI) PDO index is based on NOAA's extended reconstruction of SST (ERSST .v4).

Description inserted from https://www.ncdc.noaa.gov/teleconnections/pdo/.

Timeframe: Annual, monthly

Region/Location: Pacific Basin north of 20°N.

Data Source: NOAA NCEI at https://www.ncdc.noaa.gov/teleconnections/pdo/. NCEI is responsible for hosting and providing access to one of the most significant archives on Earth, with comprehensive oceanic, atmospheric, and geophysical data.

Measurement Platform: *In-situ* station, satellite, model

2.4.3.4.1 References

Mantua, N., 2000: The Pacific Decadal Oscillation. Available at http://research.jisao.washington.edu/pdo/. Accessed Feb. 2017.

2.4.3.5 Sea Surface Temperature & Anomaly

Description: Monthly sea surface temperature from 1982-2017, stitched together from three sources: (1) for 1982-2009 we use the Pathfinder v 5.0 dataset – a reanalysis of historical data from the Advanced Very High Resolution Radiometer (AVHRR); (2) to span 2010-2012 we use the AVHRR Global Area Coverage (GAC) dataset, and (3) data from 2013 to present we use the GOES-POES dataset, (see below for details). Both Pathfinder and GOES-POES provide 0.05º spatial resolution, while GAC provides 0.1º. A monthly climatology was generated across the entire period (1982-2017) to provide both a 2017 spatial anomaly, and an anomaly time series.

Short Descriptions:

Text from the OceanWatch Central Pacific Node:

(1) The NOAA/NASA AVHRR Pathfinder v5 and v5.1 sea-surface temperature dataset is a reanalysis of historical AVHRR data that have been improved using extensive calibration, validation and other information to yield a consistent research quality time series for global climate studies. At 0.05 degrees per pixel (approximately 4 km/pixel), this dataset provides a global spatial coverage ranging from October 1981-2009. Our data holdings include descending passes (nighttime).

(2) The Advanced Very High Resolution Radiometer (AVHRR) satellite sensors onboard the NOAA POES (Polar-orbiting Operational Environmental Satellites) satellite constellation have been collecting sea-surface temperature (SST) measurements since 1981. This dataset combines the NOAA/NASA AVHRR Pathfinder v4.1 dataset (January 1985 - January 2003) and the AVHRR Global Area Coverage (GAC) dataset (January 2003 - present) to provide a long time series of SST. These datasets are reduced-resolution legacy datasets and will be discontinued by NOAA in 2016. The dataset is composed of SST measurements from descending passes (nighttime). 3-day composites are only available for GAC, from 2003 - 2016.

(3) The GOES-POES dataset is a blended product, combining SST information from the Geostationary Operational Environmental Satellites (GOES) and the Polar-orbiting Operational Environmental Satellites (POES). This global SST analysis provides a daily gap-free map of the foundation sea surface temperature, generating high density SST data and improving the monitoring of small scale dynamic features in the coastal coral reef environment.

Technical Summary:

Pathfinder v5 & GAC datasets: Text from: https://podaac-www.jpl.nasa.gov/dataset/ AVHRR_PATHFINDER_L3_SST_MONTHLY_NIGHTTIME_V5

The 4 km Advanced Very High Resolution Radiometer (AVHRR) Pathfinder Version 5 sea surface temperature (SST) dataset is a reanalysis of historical AVHRR data that have been improved using extensive calibration, validation and other information to yield a consistent research quality time series for global climate studies. This SST time series represents the longest continual global ocean physical measurement from space. Development of the Pathfinder dataset is sponsored by the NOAA National Oceanographic Data Center (NODC) in collaboration with the University of Miami Rosensteil School of Marine and Atmospheric

Science (RSMAS) while distribution is a collaborative effort between the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) and the NODC. From a historical perspective, the Pathfinder program was originally initiated in the 1990s as a joint NOAA/NASA research activity for reprocessing of satellite based data sets including SST.
The AVHRR is a space-borne scanning sensor on the National Oceanic and Atmospheric Administration (NOAA) family of Polar Orbiting Environmental Satellites (POES) having an operational legacy that traces back to the Television Infrared Observation Satellite-N (TIROS-N) launched in 1978. AVHRR instruments measure the radiance of the Earth in 5 (or 6) relatively wide spectral bands. The first two are centered on the red (0.6 micrometer) and near-infrared (0.9 micrometer) regions, the third one is located around 3.5 micrometers, and the last two sample the emitted thermal radiation, around 11 and 12 micrometers, respectively. The legacy 5 band instrument is known as AVHRR/2 while the more recent version, the AVHRR/3 (first carried on the NOAA-15 platform), acquires data in a 6th channel located at 1.6 micrometer. Typically the 11 and 12 micron channels are used to derive SST sometimes in combination with the 3.5 micron channel. For the Pathfinder SST algorithm only the 11 and 12 micron channels are used. The NOAA platforms are sun synchronous generally viewing the same earth location twice a day (latitude dependent) due to the relatively large AVHRR swath of approximately 2400 km.
The highest ground resolution that can be obtained from the current AVHRR instruments is 1.1 km at nadir.

This particular dataset is produced from Global Area Coverage (GAC) data that are derived from an on-board sample averaging of the full resolution global AVHRR data. Four out of every five samples along the scan line are used to compute on average value and the data from only every third scan line are processed, yielding an effective 4 km resolution at nadir. The collection of NOAA satellite platforms used in the AVHRR Pathfinder SST time series includes NOAA-7, NOAA-9, NOAA-11, NOAA-14, NOAA-16, NOAA-17, and NOAA-18. These platforms contain "afternoon" orbits having a daytime ascending node of between 13:30 and 14:30 local time (at time of launch) with the exception of NOAA-17 that has a daytime descending node of approximately 10:00 local time. SST AVHRR Pathfinder includes separate daytime and nighttime daily, 5 day, 8 day, monthly and yearly datasets. This particular dataset represent nighttime monthly averaged observations.

GOES-POES dataset - Text from:
https://www.star.nesdis.noaa.gov/sod/mecb/blended_validation/background.php

The National Oceanic and Atmospheric Administration's Office of Satellite Data Processing and Distribution are generating operational sea surface temperature (SST) retrievals from the Geostationary Operational Environmental Satellite (GOES) 11 and 12 satellite imagers. They are situated at longitude 135°W and 75°W, respectively, thus allowing the acquisition of high-temporal-resolution SST retrievals.

A new cloud masking methodology based on a probabilistic (Bayesian) approach has been implemented for improved retrieval accuracy. This new GOES SST Bayesian algorithm provides SST retrievals with an estimate of the probability of cloud contamination. This indicates the confidence level of the cloud detection for the retrieval, which can be related to retrieval accuracy.

The GOES-11 and 12 imagers observe both northern and southern hemisphere every half an hour. These 5-band (0.6, 3.9, 6.7, 10.7, 12 or 13.3 micron) and 4-band (0.6, 3.9, 6.7, 10.7. or 13.3 micron) images are processed to retrieve SST retrievals at 4-km resolution. The window infrared channels determine the SST, and all channels (except the 6.7 and 13.3 μm) determine the cloud contamination. These retrievals are remapped, averaged, and composited hourly and posted to a server for user access. The retrievals are available approximately 90 minutes after the nominal epoch of the SST determinations. Three-hour and 24-hour averages are also made available. CoastWatch Regional Imagery is generated every three hours by combining the 1hourly SST images for these areas.

Timeframe: 1982-2017, Daily data available, Monthly means shown.

Region/Location: Global.

Data Source:

(1) "AVHRR Pathfinder v. 5 (ERDDAP Monthly)"
(2) "AVHRR GAC v. 5 (ERDDAP Monthly)"
(3) "GOES-POES v. 5 (ERDDAP Monthly)"

http://oceanwatch.pifsc.noaa.gov/doc.html

Measurement Platform: *AVHRR, POES Satellite, GOES 12 and 12 Satellites*

Rationale: Sea surface temperature is one of the most directly observable measures we have for tracking increasing ocean temperature.

2.4.3.5.1 References

Li, X., Pichel, W.G., Clemente-Colón, P., and Sapper J.F., 2001a. Deriving the operational nonlinear multi-channel sea surface temperature algorithm coefficients for NOAA-15 AVHRR/3, *Int. J. Remote Sens*., *22*(4), pp. 699 - 704.

Li, X., Pichel, W.G., Clemente-Colón, P., Krasnopolsky, V., and Sapper J.F., 2001b. Validation of coastal sea and lake surface temperature measurements derived from NOAA/AVHRR Data, *Int. J. Remote Sens*., *22*(7), pp. 1285-1303.

Stowe, L.L., Davis, P.A., and McClain, E.P., 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*, pp. 656-681.

Walton C.C., Pichel, W.G., Sapper, J.F., May, D.A., 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), pp. 27999-28012.

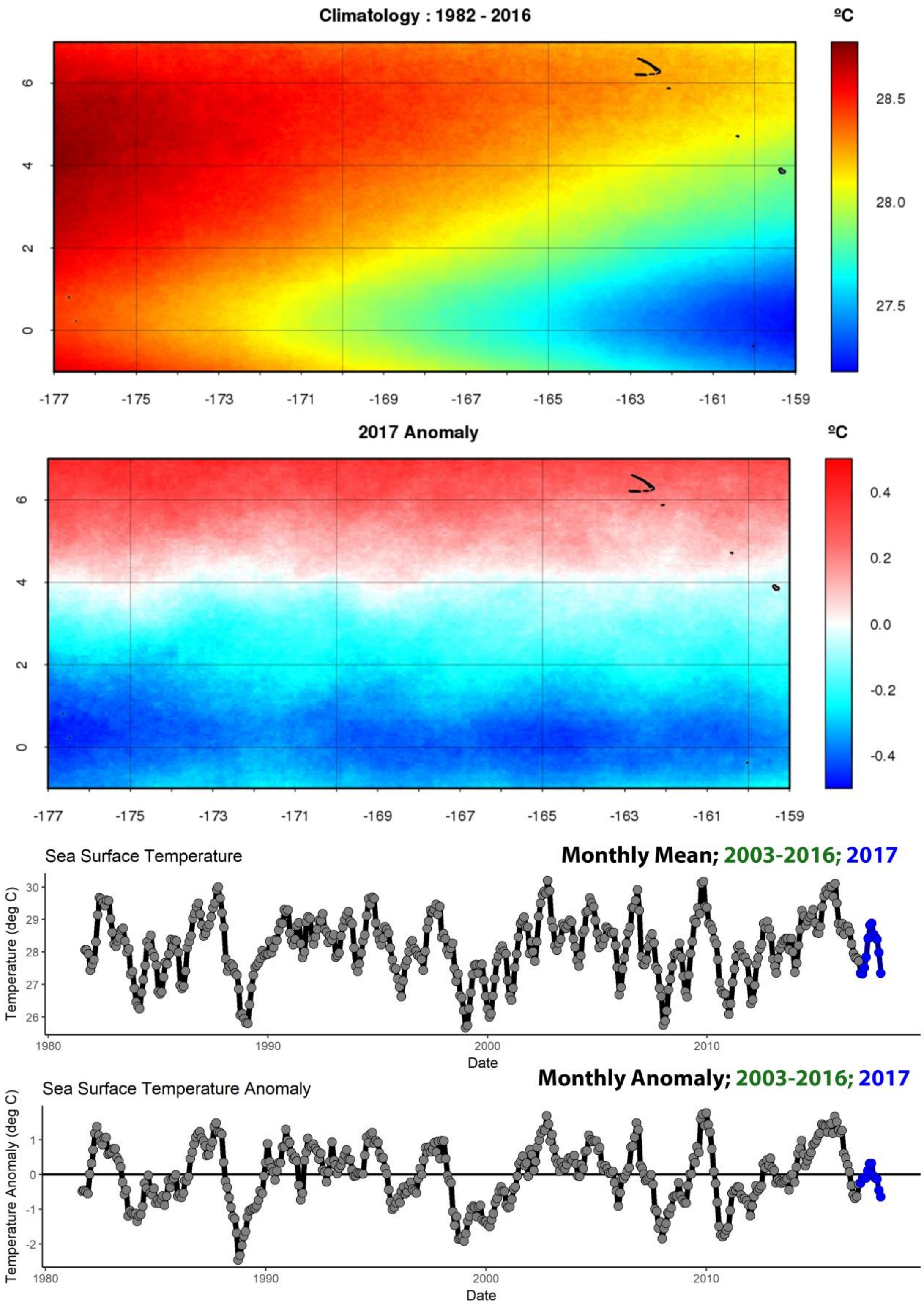


Figure 11. Sea surface temperature (SST) and SST Anomaly across the PRIA (excluding Wake Island and Johnston Atoll).

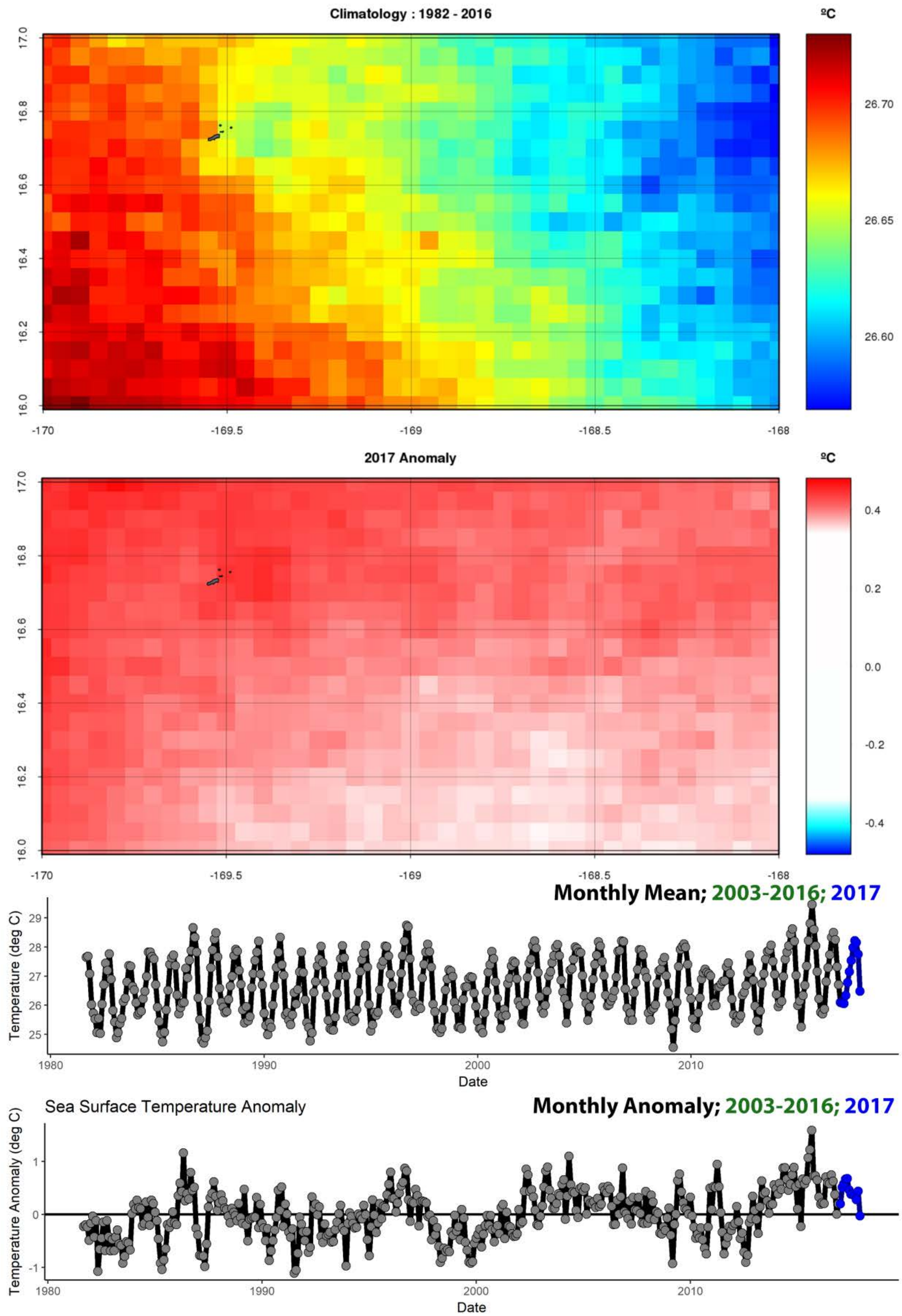


Figure 12. Sea surface temperature (SST) and SST Anomaly at Johnston Atoll.

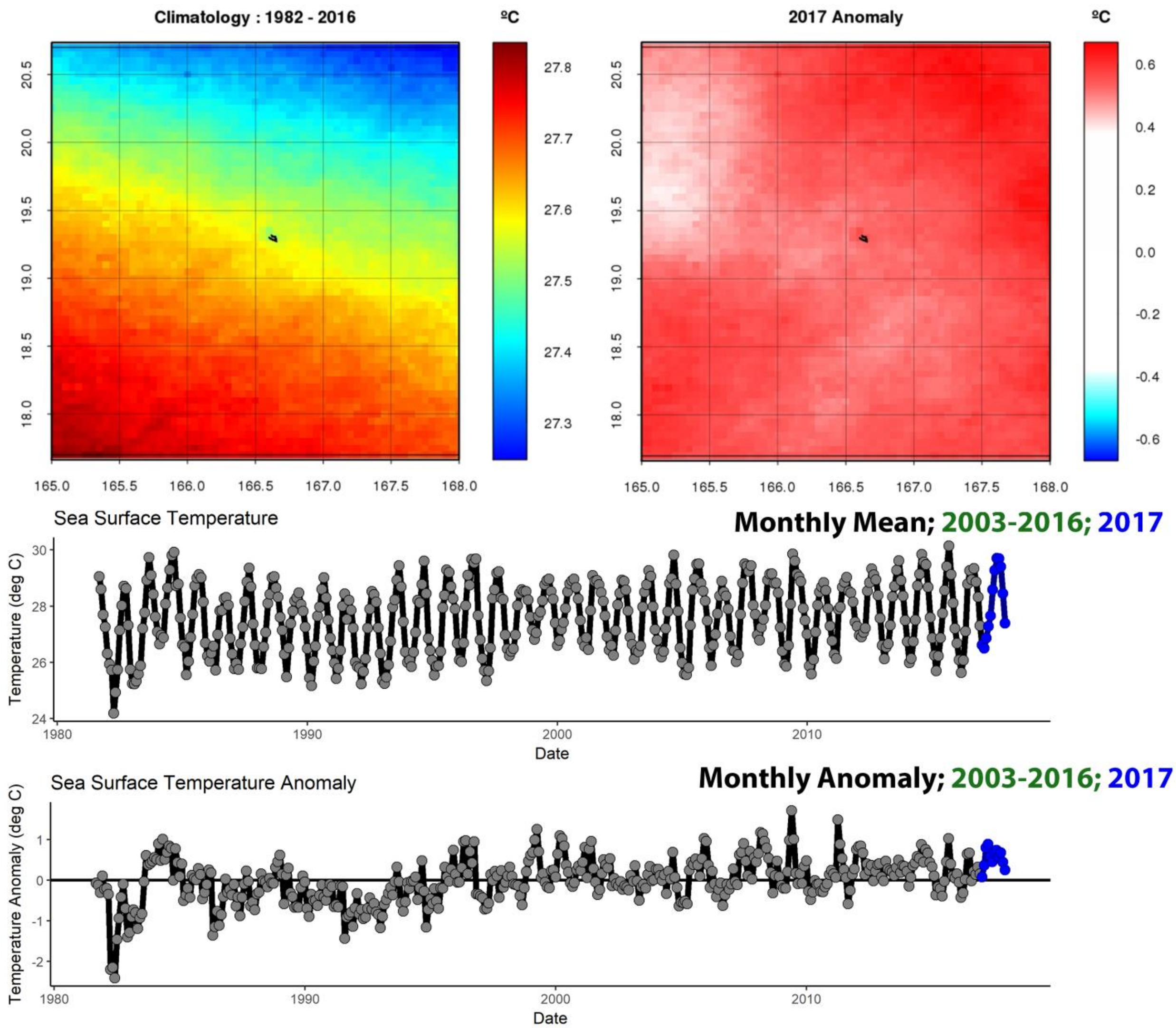


Figure 13. Sea surface temperature (SST) and SST Anomaly at Wake Atoll.

2.4.3.5 Coral Thermal Stress Exposure: Degree Heating Weeks

Description: Here we present a metric of exposure to thermal stress that is relevant to coral bleaching. Degree Heating Weeks (DHW) measure time and temperature above a reference 'summer maximum', presented as a rolling sum of weekly thermal anomalies over a 12-week window. Higher DHW measures imply a greater likelihood of mass coral bleaching or mortality from thermal stress.

Short Description:

Text inserted from the NOAA Coral Reef Watch website.

The NOAA Coral Reef Watch program uses satellite data to provide current reef environmental conditions to quickly identify areas at risk for coral bleaching. Bleaching is the process by which corals lose the symbiotic algae that give them their distinctive colors. If a coral is severely bleached, disease and death become likely.

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.

Technical Summary

Text inserted from https://coralreefwatch.noaa.gov/satellite/bleaching5km/index.php.

The NOAA Coral Reef Watch (CRW) experimental daily global 5km (0.05 degree) satellite coral bleaching heat stress monitoring product suite presented here is the third version (Version 3). The 5km suite is based on the NOAA/NESDIS operational daily global 5km geostationary-polar-orbiting (Geo-Polar) Blended Night-only SST Analysis. Current CRW 5km products include sea surface temperature (SST), SST Anomaly, Coral Bleaching Hotspots, Degree Heating Week (DHW), a 7-day maximum Bleaching Alert Area, and a 7-day SST Trend. CRW also has a 5km Regional Virtual Stations/Bleaching Heat Stress Gauges product and a free, automated 5km Bleaching Alert Email System that are based on this product suite.

A significantly improved climatology was introduced in the Version 3 products. It was derived from a combination of NOAA/NESDIS' 2002-2012 reprocessed daily global 5km Geo-Polar Blended Night-only SST Analysis and the 1985-2002 daily global 5km SST reanalysis, produced by the United Kingdom Met Office, on the Operational SST and Sea Ice Analysis (OSTIA) system. The near-real-time OSTIA SST was recently incorporated into the generation of NESDIS' operational daily 5km Blended SST that CRW's 5km coral bleaching heat stress monitoring product suite is based on. Hence, the 2002-2012 reprocessed 5km Geo-Polar Blended

SST that has just become available, extended with the 1985-2002 portion of the 5km OSTIA SST reanalysis, is the best historical 1985-2012 global SST dataset for deriving a climatology that is internally consistent and compatible with CRW's near-real-time 5km satellite coral bleaching heat stress monitoring products. Although the reprocessed 5km Geo-Polar Blended SST dataset is available to the end of 2016, to be consistent with the time period (1985-2012) of the climatology used in our Version 2 5km product suite, the Version 3 climatology is based on the same time period. It was then re-centered to the center of the baseline time period of 1985-1990 plus 1993, using the method described in Heron *et al.*, (2015)and Liu *et al.*, (2014), and was based on our monitoring algorithm (also described in these articles). More recent years may be incorporated in the climatology for future versions of CRW's 5 km products, but potential impacts on the products require further evaluation first.

This Version 3 suite was released on May 4, 2017, along with a new version of CRW's 5km Regional Virtual Stations/Bleaching Heat Stress Gauges product. Version 2 of the 5km product suite (that Version 3 replaces) was released on May 5, 2014, and Version 1 was released on July 5, 2012 (based on NESDIS' operational daily global 5 km Geo-Polar Blended Day-Night SST Analysis and an earlier version of the climatology derived from the PFV5.2).

Development of this next-generation 5 km product suite was accomplished through a collaboration of NOAA Coral Reef Watch, the University of South Florida, NASA-Ames, the UNEP World Conservation Monitoring Centre, and the Cooperative Institute for Research in Environmental Science, with funding support from the NASA Biodiversity and Ecological Forecasting program, the NOAA Coral Reef Conservation Program, and the NOAA/NESDIS Ocean Remote Sensing Program. Production of the Version 3 suite was made possible through funding from the NOAA Coral Reef Conservation Program. The 5km product suite, which was featured in the NASA Applied Sciences Program's 2013 Annual Report, will undergo continuous improvements.

Regional Virtual Stations Product Description: NOAA Coral Reef Watch (CRW) has developed a set of experimental 5 km Regional Virtual Stations (213 total).

NOAA CRW also expanded the geographic network of 5 km Virtual Stations to include all coral reefs around the world, based on available references. These included the Millennium Coral Reef project maps, the IUCN Coral Reefs of the World three-volume set, the UNEP/WCMC World Atlas of Coral Reefs, several country scale atlas publications, and a few other resources. These references were also used to develop the outline (in black) for each 5 km Regional Virtual Station. Each Virtual Station outline is based on a global 5 km reef pixel mask developed by NOAA CRW, with the addition of a 20 km buffer around each 5 km reef mask. If we have missed a coral reef that you know of, please let us know the name and coordinates of the missing reef.

Timeframe: 2013-2017, Daily data.

Region/Location: Global.

Data Source: “NOAA Coral Reef Watch” https://coralreefwatch.noaa.gov

Measurement Platform: NOAA/NESDIS operational daily global 5km geostationary-polar-orbiting (Geo-Polar) Blended Night-only SST Analysis

Rationale: Degree heating weeks are one of the most widely used metrics for assessing exposure to coral bleaching-relevant thermal stress.

2.4.3.5.1 References

Liu, G., Heron, S.F., Eakin, C.M., Muller-Karger, F.E., Vega-Rodriguez, M., Guild, L.S., De La Cour, J.L., Geiger, E.F., Skirving, W.J., Burgess, T.F. and Strong, A.E., 2014. Reef-scale thermal stress monitoring of coral ecosystems: new 5-km global products from NOAA Coral Reef Watch. *Remote Sensing*, *6*(11), pp.11579-11606.

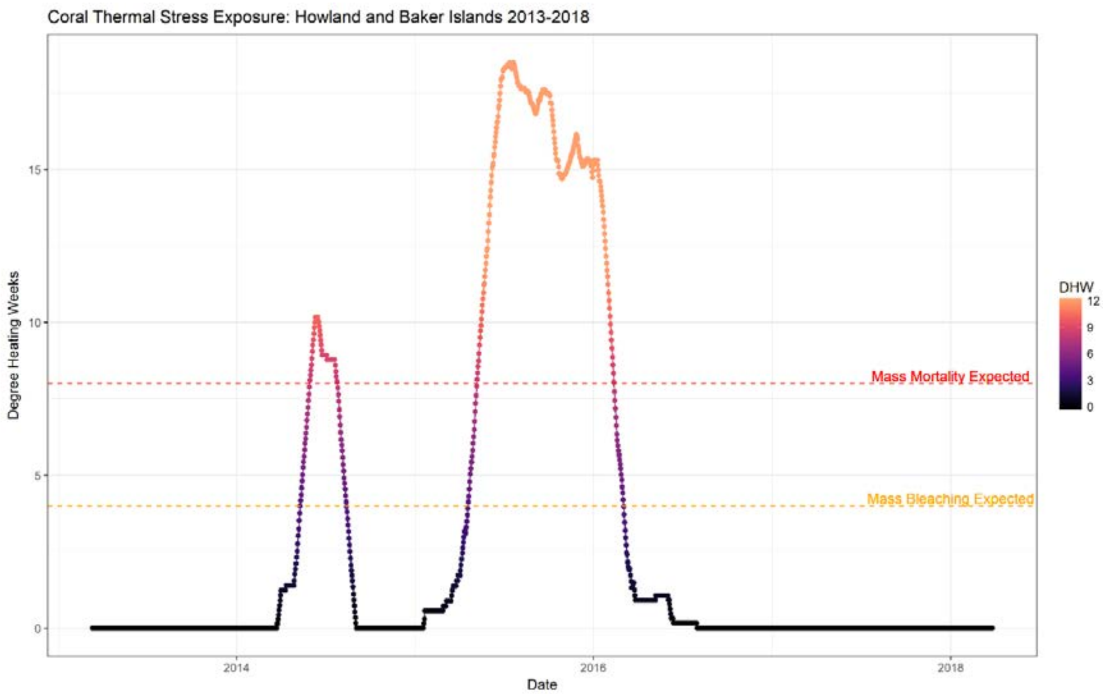


Figure 14. Coral Thermal Stress Exposure, Howland-Baker Virtual Station 2013-2017. Coral Reef Watch Degree Heating Weeks.

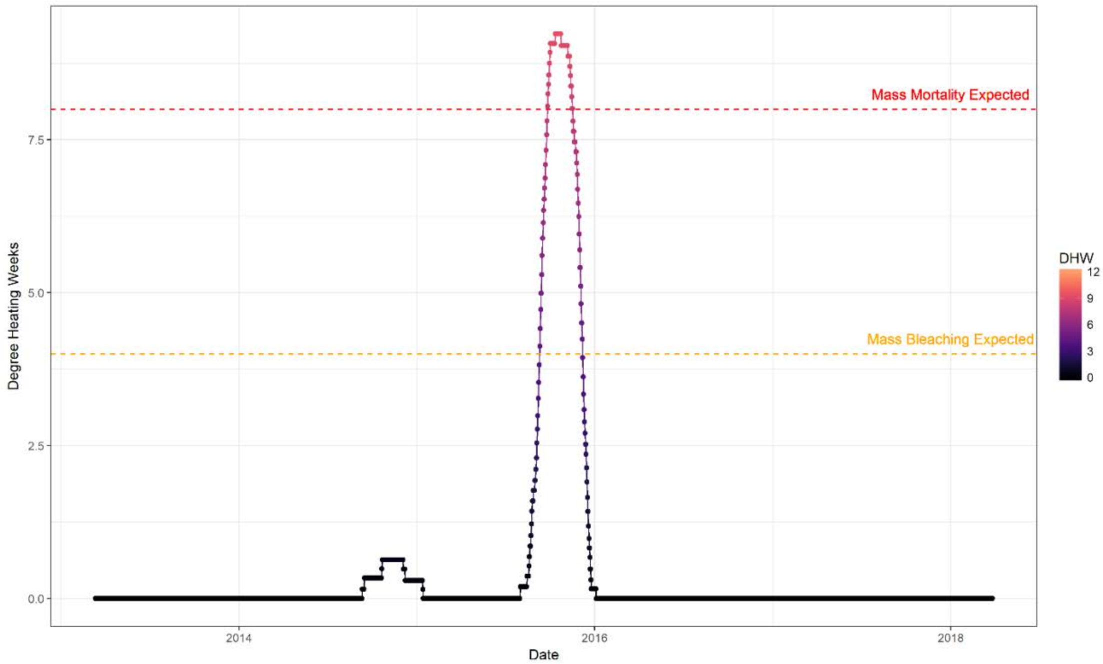


Figure 15. Coral Thermal Stress Exposure measured at Johnston Atoll Virtual Station 2013-2017 (Coral Reef Watch Degree Heating Weeks).

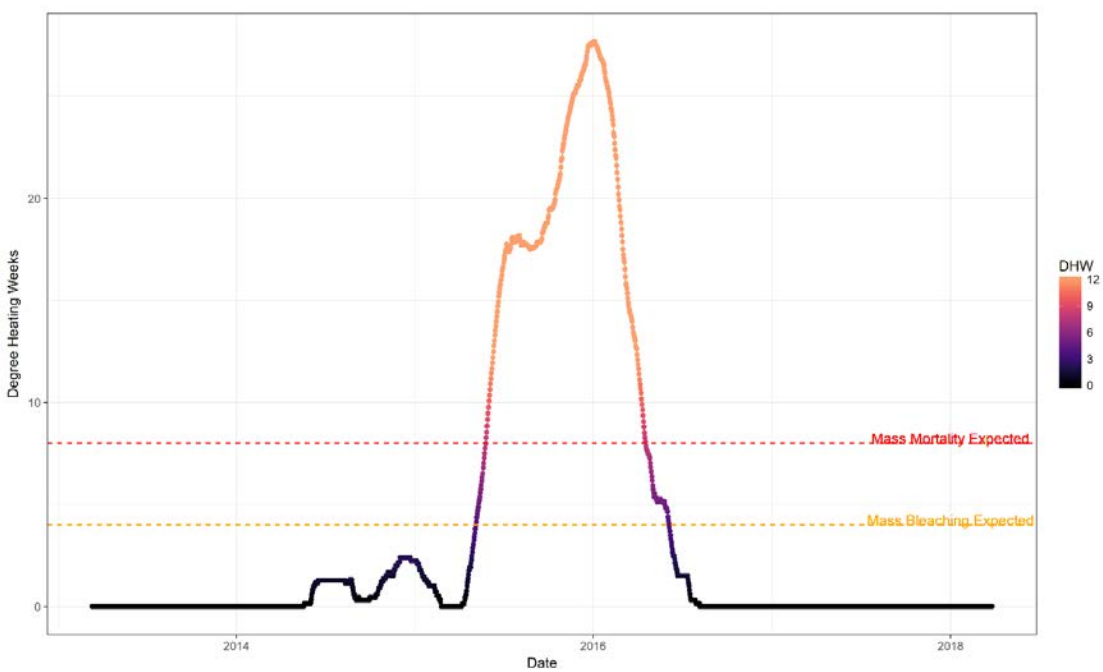


Figure 16. Coral Thermal Stress Exposure measured at Northern Line Islands Virtual Station 2013-2017 (Coral Reef Watch Degree Heating Weeks).

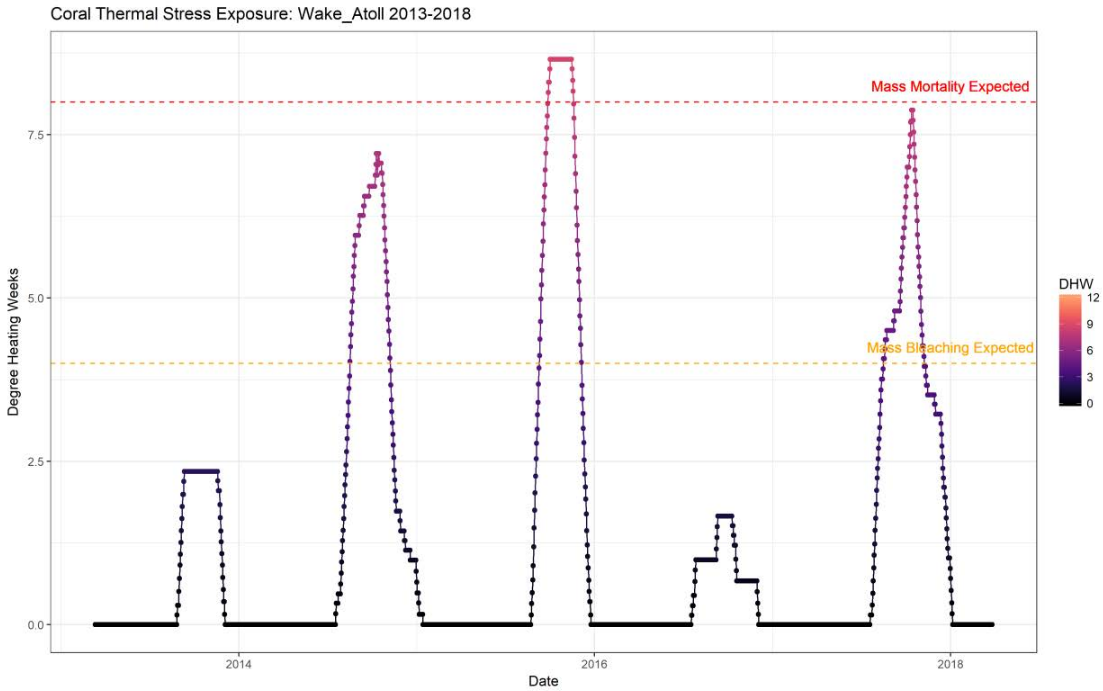


Figure 17. Coral Thermal Stress measured at Wake Atoll Virtual Station 2013-2017 (Coral Reef Watch Degree Heating Weeks).

2.4.3.6 Chlorophyll-A and Anomaly

Description: Chlorophyll-A Concentration from 2002-2017, derived from the MODIS Ocean Color sensor aboard the NASA Aqua Satellite. A monthly climatology was generated across the entire period (1982-2017) to provide both a 2017 spatial anomaly, and an anomaly time series.

Short Description:

Text inserted from the OceanWatch Central Pacific Node:

The MODIS (Moderate Resolution Imaging Spectro-radiometer) sensor was deployed onboard the NASA Aqua satellite. It is a multi-disciplinary sensor providing data for the ocean, land, aerosol, and cloud research and is used for detecting chlorophyll-a concentrations in the world's oceans, among other applications. Aqua MODIS views the entire Earth's surface every 2 days, acquiring data in 36 spectral bands. The data available here is the latest reprocessing from June 2015, which NASA undertook to correct for some sensor drift issues.

Technical Summary:

Text inserted from:

https://podaac-www.jpl.nasa.gov/dataset/MODIS_Aqua_L3_CHLA_Monthly_4km_V2014.0_R

The Moderate-resolution Imaging Spectro-radiometer (MODIS) is a scientific instrument (radiometer) launched by NASA in 2002 on board the Aqua satellite platform (a second series is on the Terra platform) to study global dynamics of the Earth's atmosphere, land and oceans. MODIS captures data in 36 spectral bands ranging in wavelength from 0.4 um to 14.4 um and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m, and 29 bands at 1 km). The Aqua platform is in a sun synchronous, near polar orbit at 705 km altitude and the MODIS instrument images the entire Earth every 1 to 2 days. The Level 3 standard mapped image (SMI) chlorophyll-a dataset has a monthly temporal resolution and 4.6 km (at the equator) spatial resolution. The SMI dataset is an image representation of binned MODIS data (more detailed information on the SMI format can be found at http://oceancolor.gsfc.nasa.gov). The MODIS Aqua instrument provides quantitative data on global ocean bio-optical properties to examine oceanic factors that affect global change and to assess the oceans' role in the global carbon cycle, as well as other biogeochemical cycles. Subtle changes in chlorophyll-a signify various types and quantities of marine phytoplankton (microscopic marine plants), the knowledge of which has both scientific and practical applications. This is a local dataset derived from the NASA Ocean Biology Processing Group (OBPG) meant to expose these data to tools and services at the PO.DAAC.

Timeframe: 2003-2017, Daily data available, Monthly means shown.

Region/Location: Global.

Data Source:

"MODIS-Aqua (ERDDAP Monthly)" http://oceanwatch.pifsc.noaa.gov/doc.html

Measurement Platform: *MODIS sensor on NASA Aqua Satellite*

Rationale: Chlorophyll-A is one of the most directly observable measures we have for tracking increasing ocean productivity.

2.4.3.6.1 References

Savchenko, A., Ouzounov, D., Ahmad, S., Acker, J., Leptoukh, G., Koziana, J., and Nickless, D., 2004. Terra and Aqua MODI products available from NASA GES DAAC. *Advances in Space Research*, *34*(4), pp. 710-714.

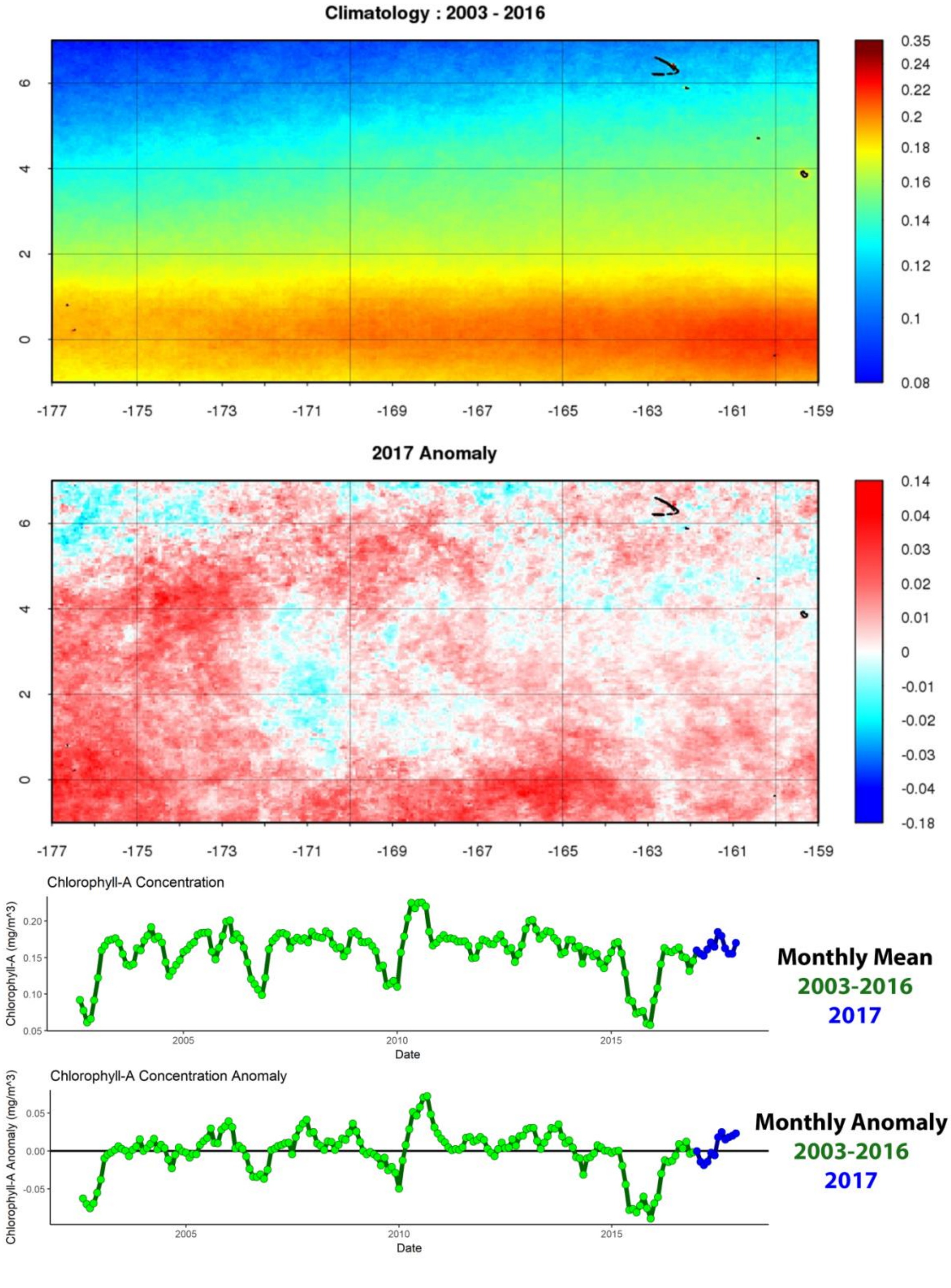


Figure 18. Chlorophyll-A (Chl-A) and Chl-A Anomaly across the PRIA (excluding Johnston Atoll and Wake Atoll) from 2003-2017.

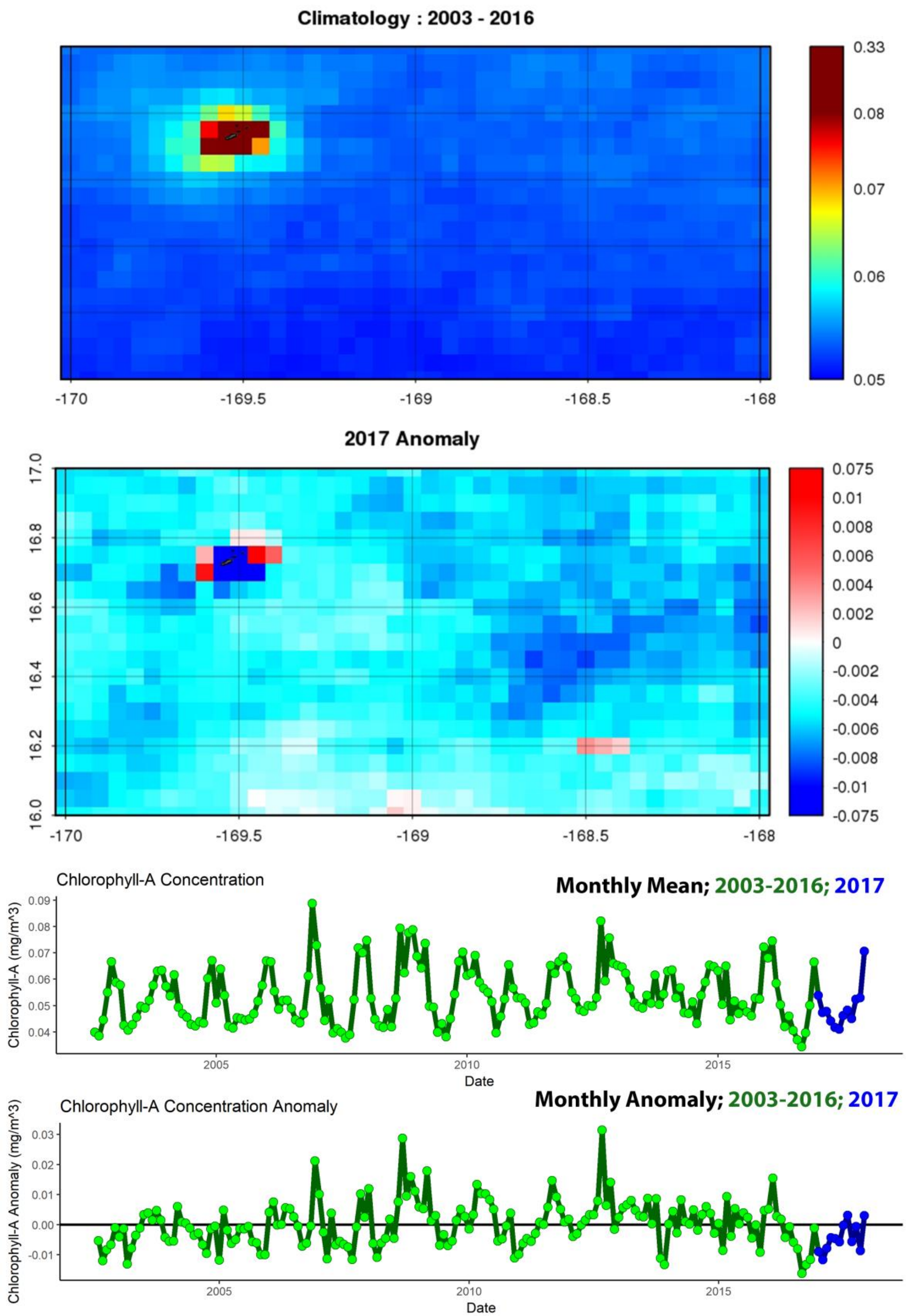


Figure 19. Chlorophyll-A (Chl-A) and Chl-A Anomaly at Johnston Atoll from 2003-2017.

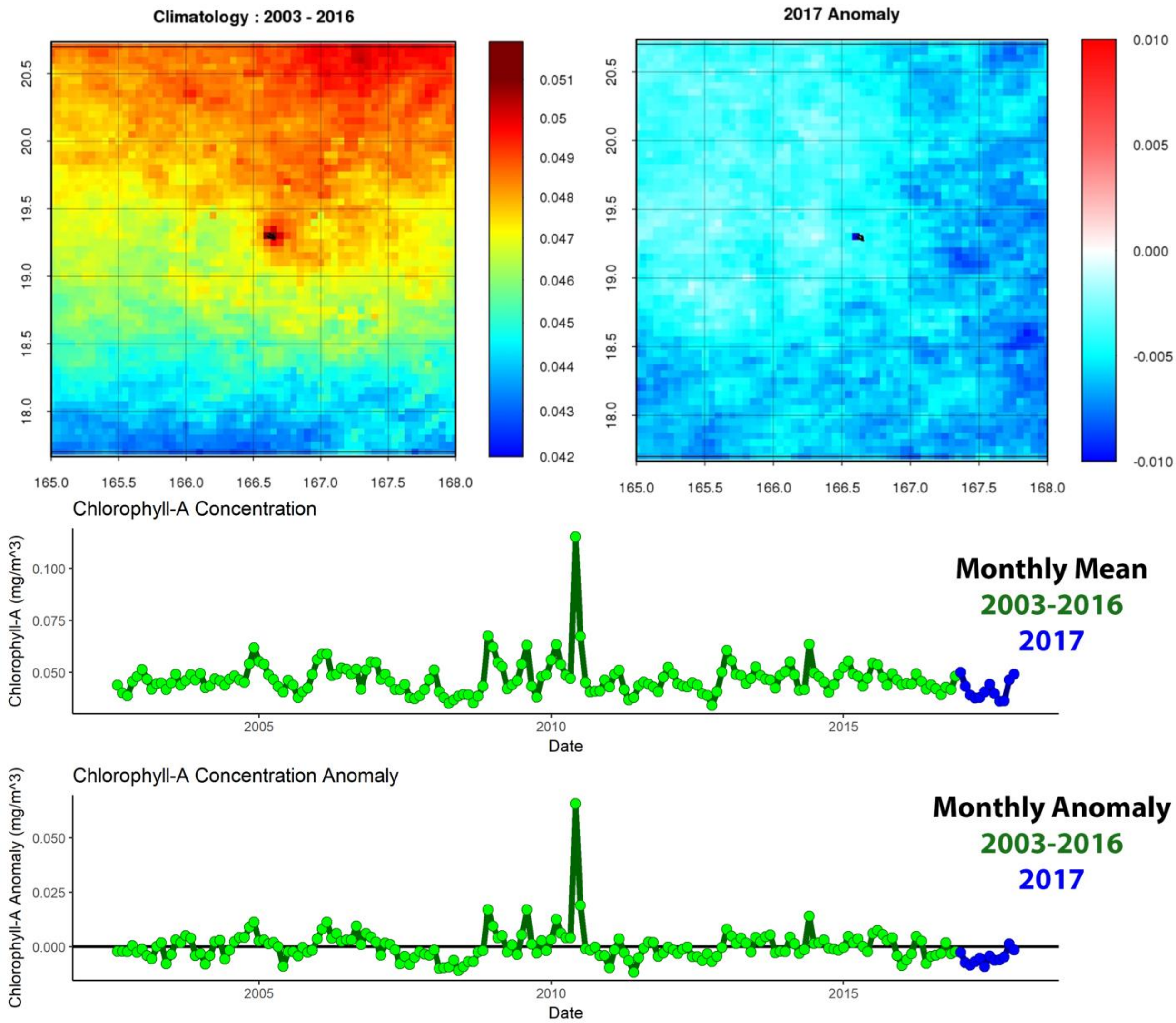


Figure 20. Chlorophyll-A (Chl-A) and Chl-A Anomaly at Wake Atoll from 2003-2017.

2.4.3.7 Heavy Weather (Tropical Cyclones & Storm-Force Winds)

Description: This indicator uses historical data from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) International Best Track Archive for Climate Stewardship (IBTrACS; Knapp *et al.*, 2010) 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, one way of monitoring the strength and duration of tropical cyclones based only on wind speed measurements.

The annual frequency of storms passing through the Pacific basin is tracked and a stacked time series plot shows the representative breakdown of the Saffir-Simpson hurricane categories. Three solid color groups in the graph represent a) the annual number of named storms, b) the annual number of typhoons, and c) the annual number of major typhoons (Cat 3 and above).

Every cyclone has an ACE Index value, which is a computed value 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 shows the historical ACE values for each typhoon season and has a solid line representing the 1981-2010 average ACE value.

In addition, we also plot the percentage occurrence of "storm-force" winds, wind occurrences greater than, or equal to, 34 knots since 1980 in the three sub-regions. The value of 34 knots represents "Gale, fresh gale" on the Beaufort scale, which corresponds to 5-8 m wave heights and boating becomes very challenging. Characterizing the percent occurrence of these gale-force winds gives an indication of storminess5 frequency within each sub-region. Indeed, slight increases in the frequency of gale-force winds are noted in both the South and Western Pacific basins, while a downward trend is evident in the Central Pacific. (Marra *et al.,* 2017)

Timeframe: Yearly

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

Data Source/Responsible Party: NCEI'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.

Neither the Pacific ENSO Applications Climate Center nor the Bulletin of the AMS has yet published their annual tropical cyclone report covering the central or south pacific in 2017.

While reports on activity during 2017 are not yet available for the south and central pacific, the NOAA National Centers for Environmental Information, State of the Climate: Hurricanes and Tropical Storms for Annual 2017, published online January 2018, notes that “The 2017 East Pacific hurricane season had 18 named storms, including nine hurricanes, four of which became major.” The 1981-2010 average number of named storms in the East Pacific was 16.5, with 8.9 hurricanes, and 4.3 major hurricanes. Five Eastern Pacific tropical cyclones made landfall in 2017. Tropical Storm Selma made landfall in El Salvador and tropical storms Beatrix, Calvin, Lidia and Hurricane Max made landfall in Mexico. Tropical Storm Selma was the first named tropical cyclone on record to make landfall in El Salvador. Tropical Storm Adrian formed on May 9th, marking the earliest occurrence of a named storm in the East Pacific basin. The previous earliest occurrence was Tropical Storm Alma forming on May 12, 1990. For the first year since 2012 no tropical cyclones passed near the Hawaiian Islands. The ACE index for the East Pacific basin during 2016 was 98 (x10^4 knots^2), which is below the 1981-2010 average of 132 (x10^4 knots^2), and the lowest since 2013.” Inserted from https://www.ncdc.noaa.gov/sotc/tropical-cyclones/201713.

2.4.3.6.2 References

NOAA National Centers for Environmental Information, State of the Climate: Hurricanes and Tropical Storms for Annual 2017, published online January 2018, retrieved on March 30, 2018. Accessed from http://www.ncdc.noaa.gov/sotc/tropical-cyclones/201713.

Kanamitsu, M., Ebisuzaki, W., Woollen, J., Yang, S.K., Hnilo, J.J., Fiorino, M. and Potter, G.L., 2002. NCEP–DOE AMIP-II Reanalysis (R-2), *B. Am. Meteorol. Soc.*, *83*, pp. 1631–1643, https://doi.org/10.1175/BAMS-83- 11-1631.

Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann, 2010: The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data. *Bulletin of the American Meteorological Society*, *91*, 363-376. doi:10.1175/2009BAMS2755.1.

State of Environmental Conditions in Hawaii and the U.S. Affiliated Pacific Islands under a Changing Climate, 2017. Coordinating Authors: J.J. Marra and M.C. Kruk. Contributing Authors: M. Abecassis; H. Diamond; A. Genz; S.F. Heron; M. Lander; G. Liu; J. T. Potemra; W.V. Sweet; P. Thompson; M.W. Widlansky; and P. Woodworth-Jefcoats. September, 2017. NOAA NCEI.

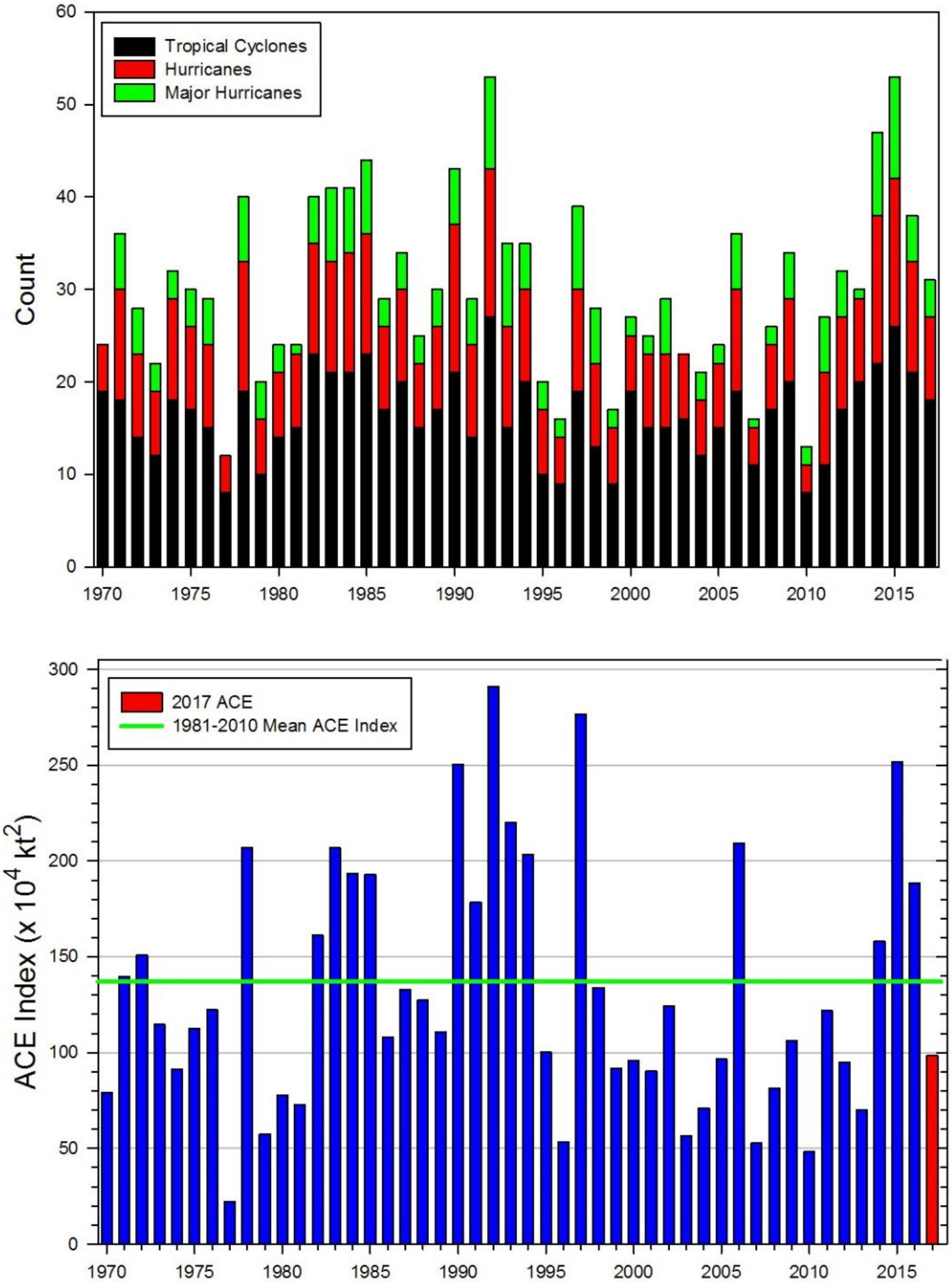


Figure 21. Annual Patterns of Tropical Cyclones in the Eastern Pacific, 1970-2017, with 1981-2010 mean superimposed. Source: NOAA's National Hurricane Center.

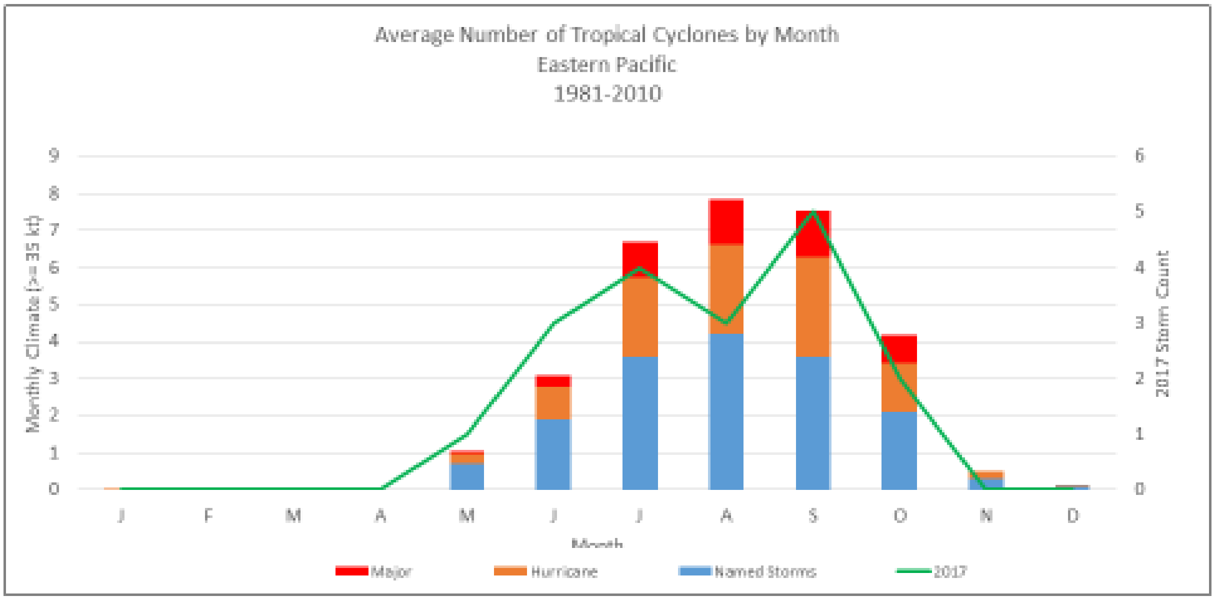


Figure 22. Seasonal Climatology of Tropical Cyclones in the Eastern Pacific, 1981-2010, with 2017 storms superimposed (sourced from NOAA's National Hurricane Center).

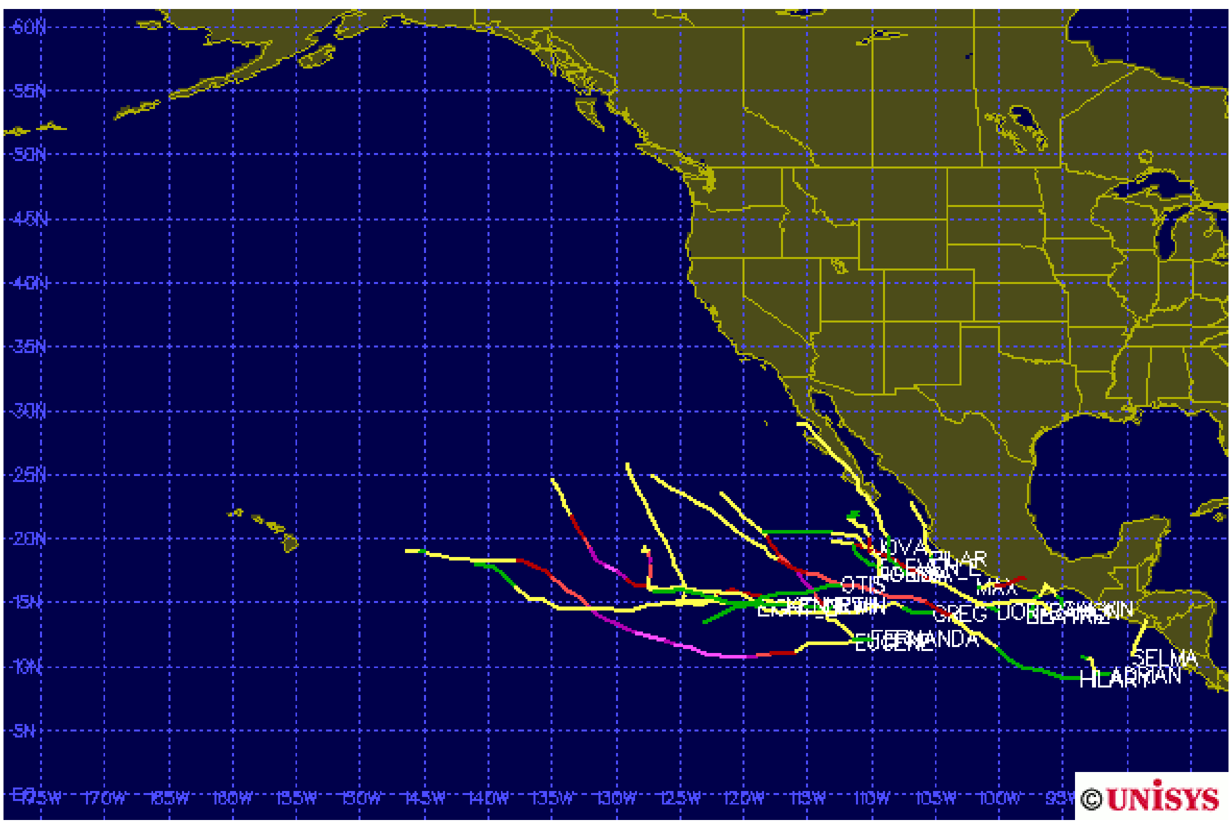
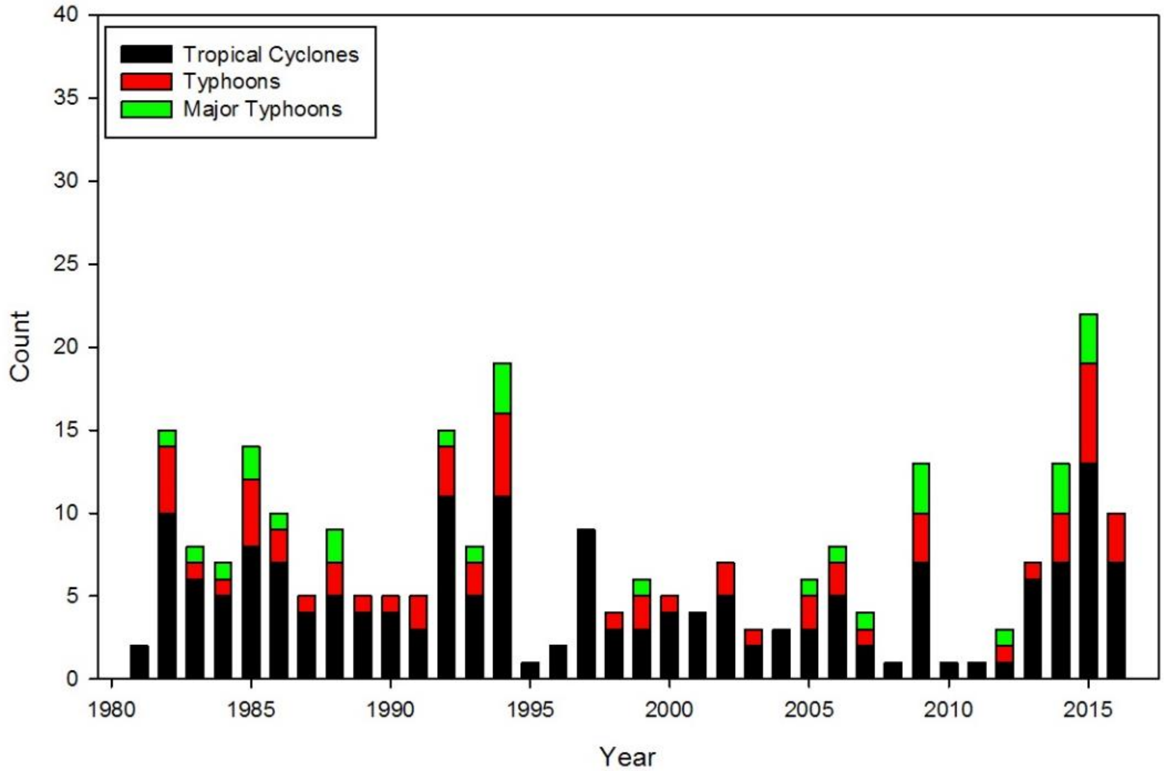


Figure 23. Eastern Pacific Cyclone Tracks in 2017.



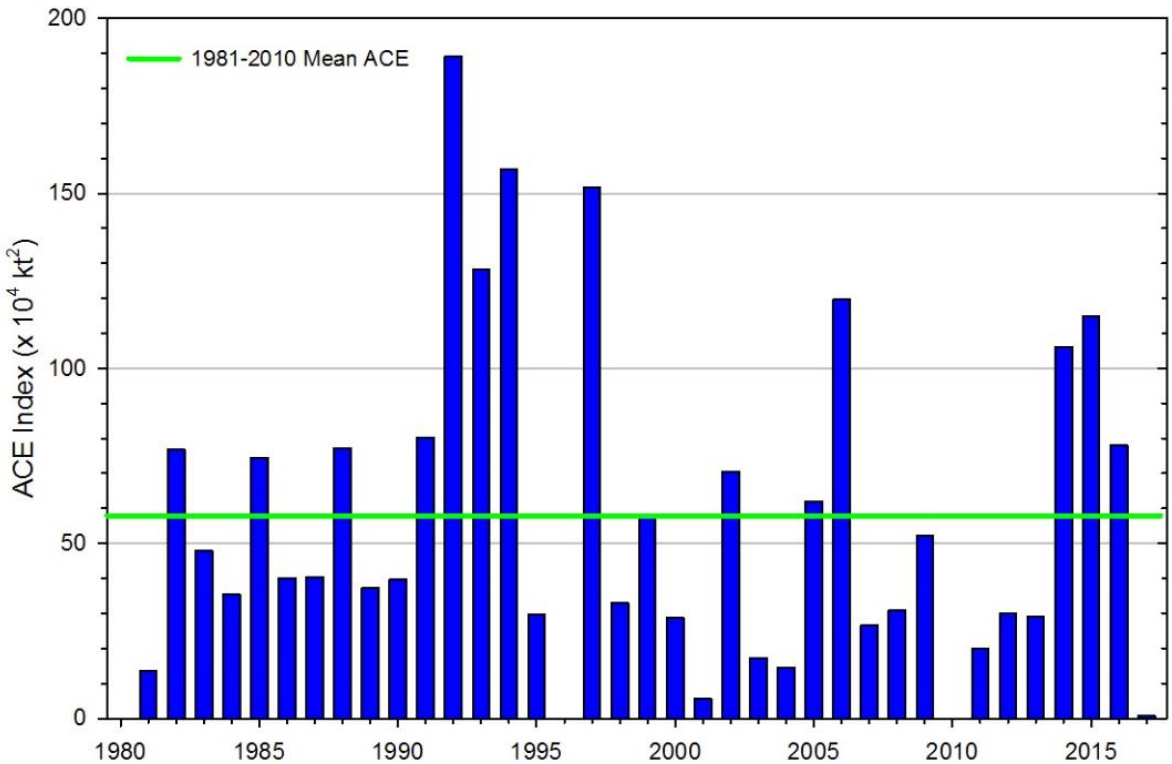


Figure 24. Annual Patterns of Tropical Cyclones in the Central Pacific, 1980-2017, with 1981-2010 mean superimposed (sourced from NOAA's National Hurricane Center).

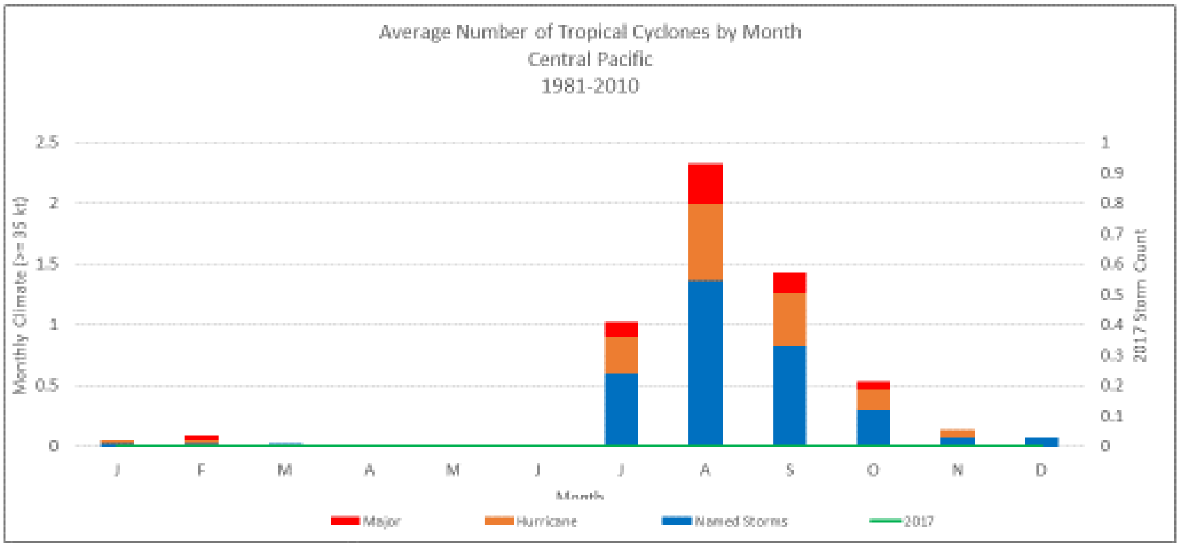


Figure 25. Seasonal Climatology of Tropical Cyclones in the Central Pacific, 1981-2010, with 2017 storms (zero) superimposed (sourced from NOAA's National Hurricane Center).

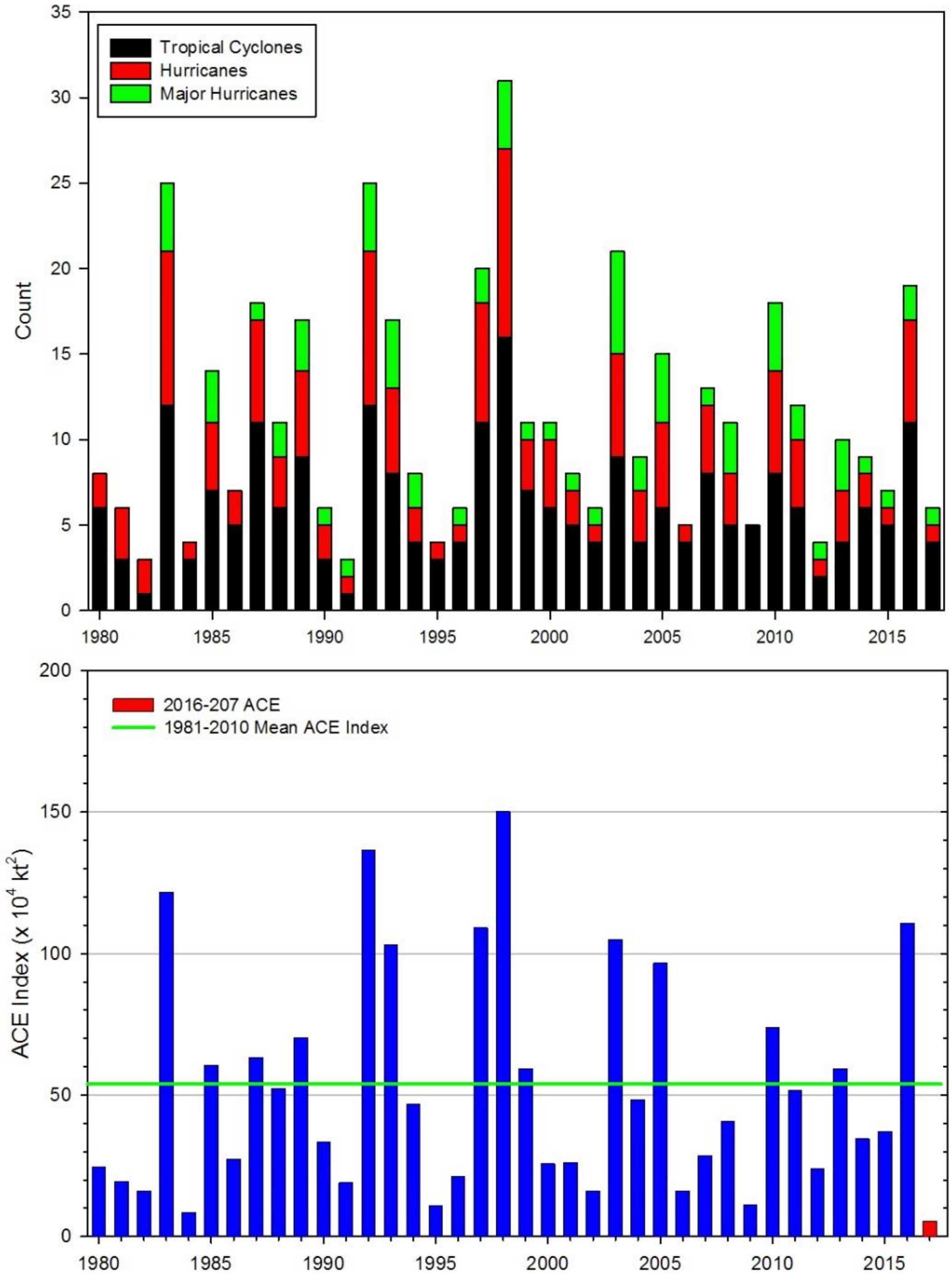


Figure 26. Annual Patterns of Tropical Cyclones in the South Pacific, 1980-2017, with 1981-2010 mean superimposed (sourced from NOAA's National Hurricane Center).

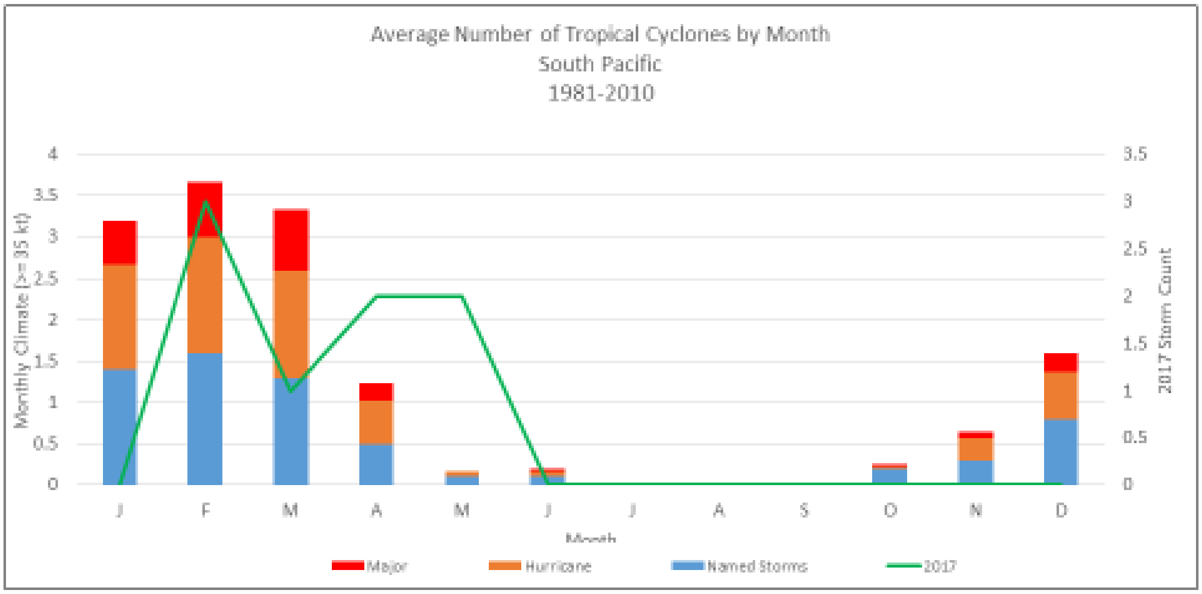


Figure 27. Seasonal Climatology of Tropical Cyclones in the South Pacific, 1981-2010, with 2017 storms (zero) superimposed (sourced from NOAA's National Hurricane Center).

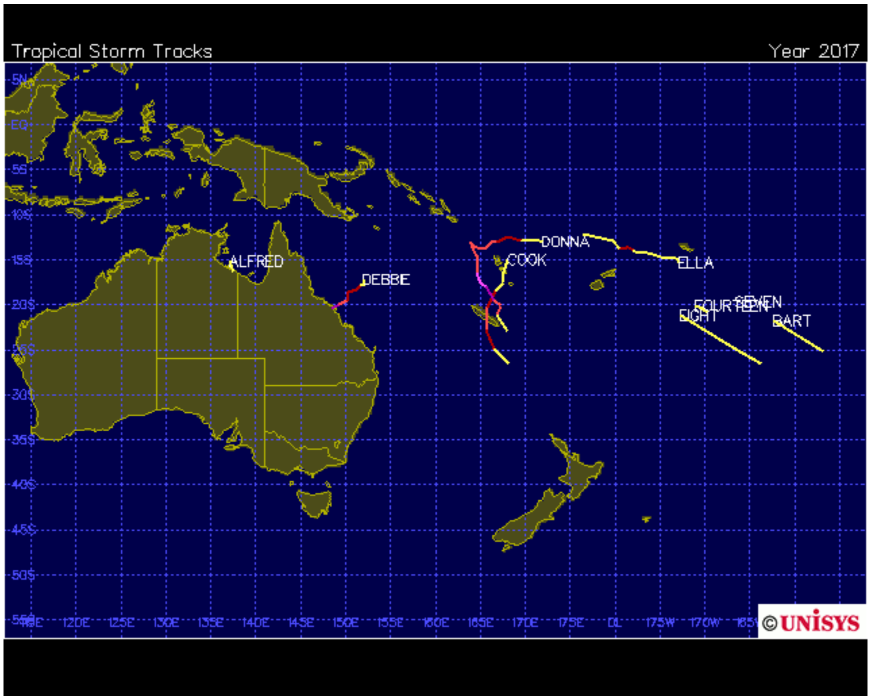


Figure 28. South Pacific Cyclone Tracks in 2017.

Further, we present the occurrence of "storm-force" winds, i.e. wind speeds greater than 34 knots.

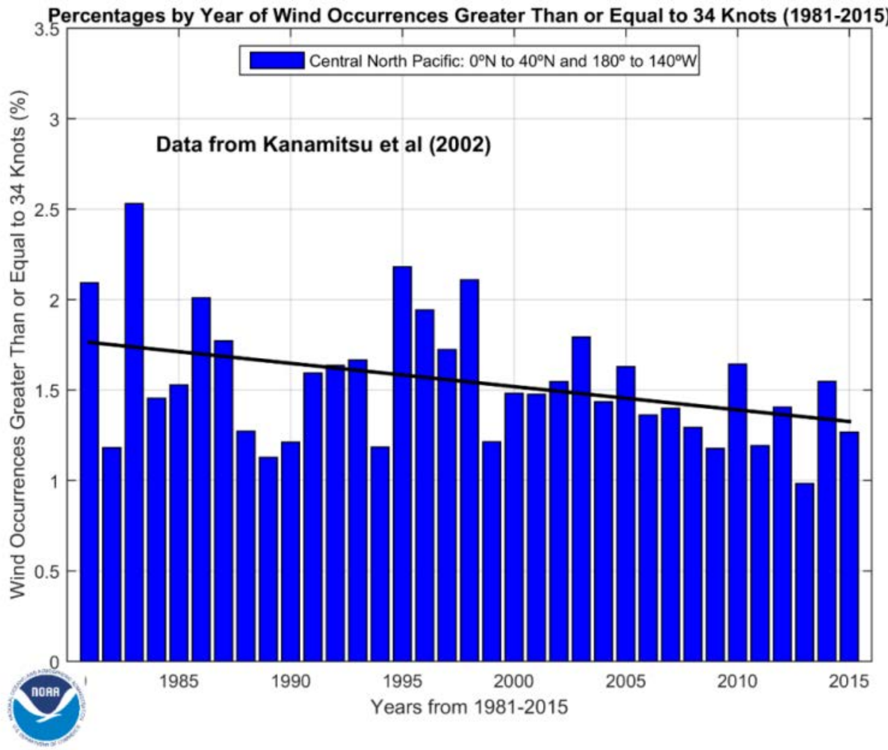


Figure 29. Storm-Force Wind in the Central North Pacific from 1981-2015.

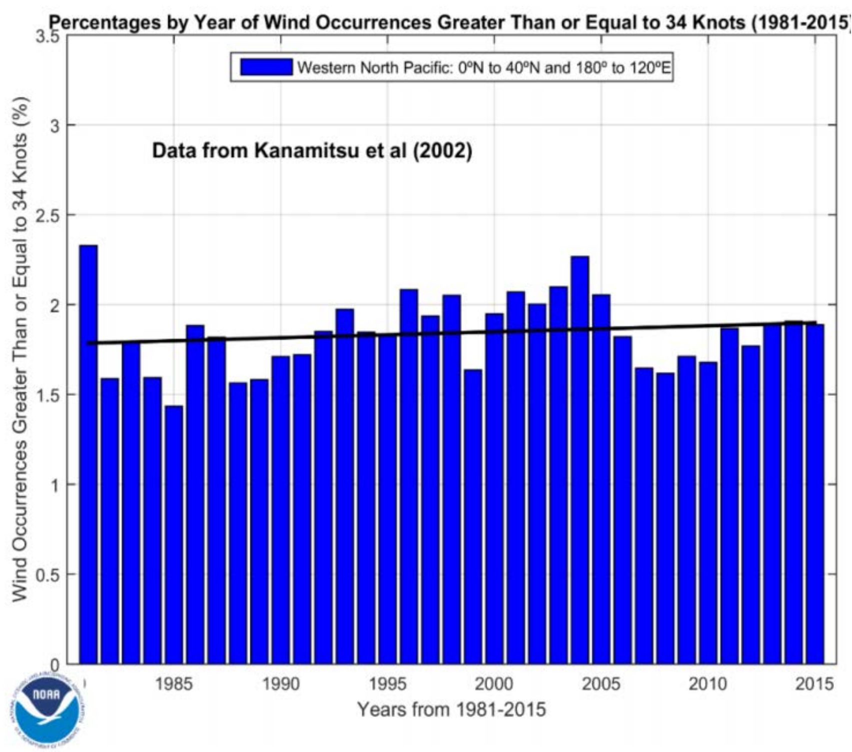


Figure 30. Storm-Force Wind in the Western North Pacific from 1981-2015.

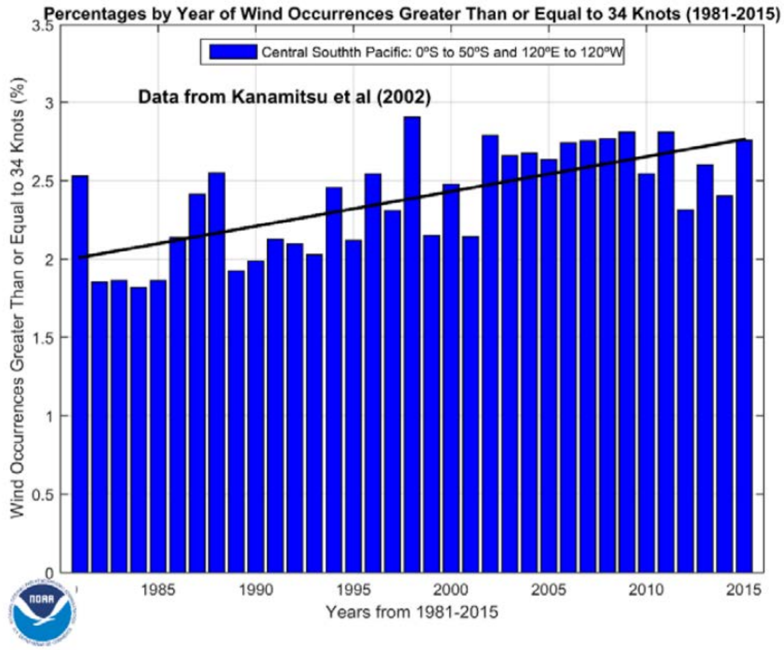


Figure 31. Storm-Force Wind in the Central South Pacific from 1981-2015.

2.4.3.8 Rainfall (CMAP Precipitation)

Rationale: Rainfall may have substantive effects on the nearshore environment and is a potentially important co-variate with the landings of particular stocks.

Description: The CPC Merged Analysis of Precipitation ("CMAP") is a technique which produces pentad and monthly analyses of global precipitation in which observations from rain gauges are merged with precipitation estimates from several satellite-based algorithms (infrared and microwave). The analyses are on a 2.5 x 2.5 degree latitude/longitude grid and extend back to 1979. These data are comparable (but should not be confused with) similarly combined analyses by the Project, which are described in Huffman *et al*. (1997).

It is important to note that the input data sources to make these analyses are not constant throughout the period of record. For example, SSM/I (passive microwave - scattering and emission) data became available in July of 1987; prior to that the only microwave-derived estimates available are from the MSU algorithm (Spencer, 1993) which is emission-based thus precipitation estimates are available only over oceanic areas. Furthermore, high temporal resolution IR data from geostationary satellites (every 3-hr) became available during 1986; prior to that, estimates from the OPI technique (Xie and Arkin, 1997) are used based on OLR from polar orbiting satellites.

The merging technique is thoroughly described in Xie and Arkin (1997). Briefly, the methodology is a two-step process. First, the random error is reduced by linearly combining the satellite estimates using the maximum likelihood method, in which case the linear combination coefficients are inversely proportional to the square of the local random error of the individual data sources. Over global land areas the random error is defined for each time period and grid location by comparing the data source with the rain gauge analysis over the surrounding area. Over oceans, the random error is defined by comparing the data sources with the rain gauge observations over the Pacific atolls. Bias is reduced when the data sources are blended in the second step using the blending technique of Reynolds (1988). Here the data output from step 1 is used to define the "shape" of the precipitation field and the rain gauge data are used to constrain the amplitude.

Monthly and pentad CMAP estimates back to the 1979 are available from CPC ftp server.

[Text taken from: http://www.cpc.ncep.noaa.gov/products/global_precip/html/wpage.cmap.html]

The monthly data set consists of two files containing monthly averaged precipitation rate values. Values are obtained from 5 kinds of satellite estimates (GPI, OPI, SSM/I scattering, SSM/I emission, and MSU) and gauge data. The enhanced file also includes blended NCEP/NCAR Reanalysis Precipitation values.

[Text taken from: https://www.esrl.noaa.gov/psd/data/gridded/data.cmap.html#detail]

Timeframe: Monthly

Region/Location: Global

Data Source *CMAP Precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/*

Measurement Platform: *In-situ* station gauges and satellite data.

2.4.3.8.1 References

Huffman, G.J., Adler, R.F., Arkin, P., Chang, A., Ferraro, R., Gruber, A., Janowiak, J., McNab, A., Rudolf, B. and Schneider, U., 1997. The global precipitation climatology project (GPCP) combined precipitation dataset. *Bulletin of the American Meteorological Society*, *78*(1), pp.5-20.

Reynolds, R.W., 1988. A real-time global sea surface temperature analysis. *Journal of Climate*, *1*(1), pp. 75-87.

Spencer, R.W., 1993. Global oceanic precipitation from the MSU during 1979—91 and comparisons to other climatologies. Journal of Climate, 6(7), pp.1301-1326.

Xie, P. and Arkin, P.A., 1997. Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. *Bulletin of the American Meteorological* Society, *78*(11), pp. 2539-2558.

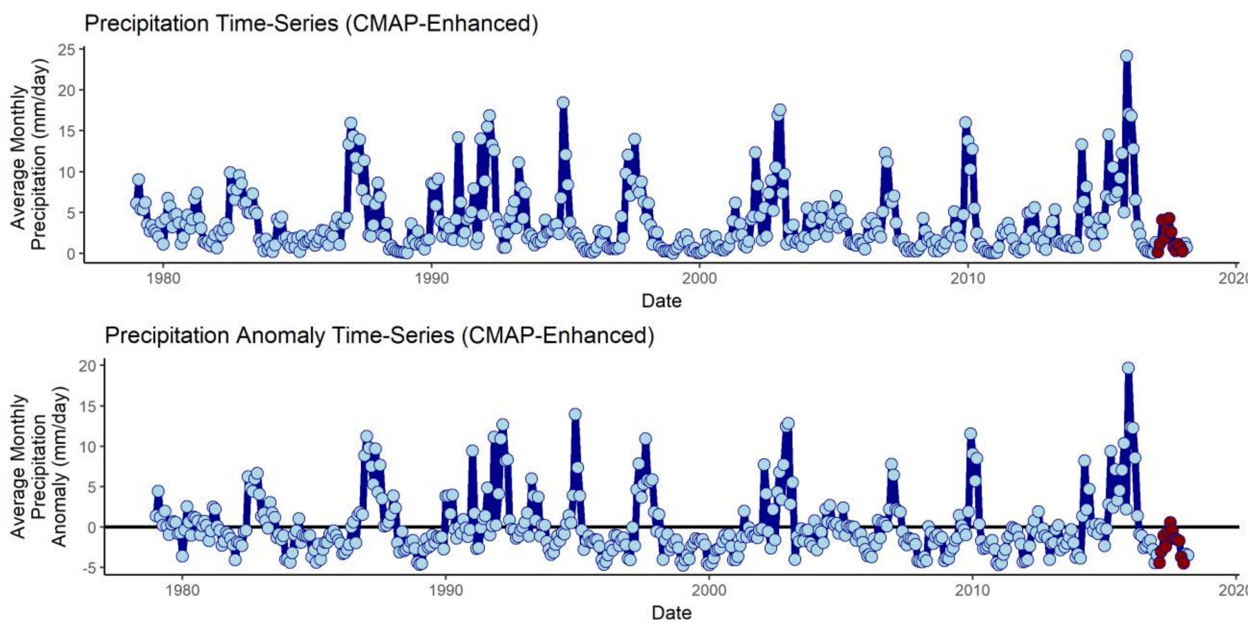


Figure 32. CMAP precipitation across the Howland-Baker Grid. 2017 values are in red.

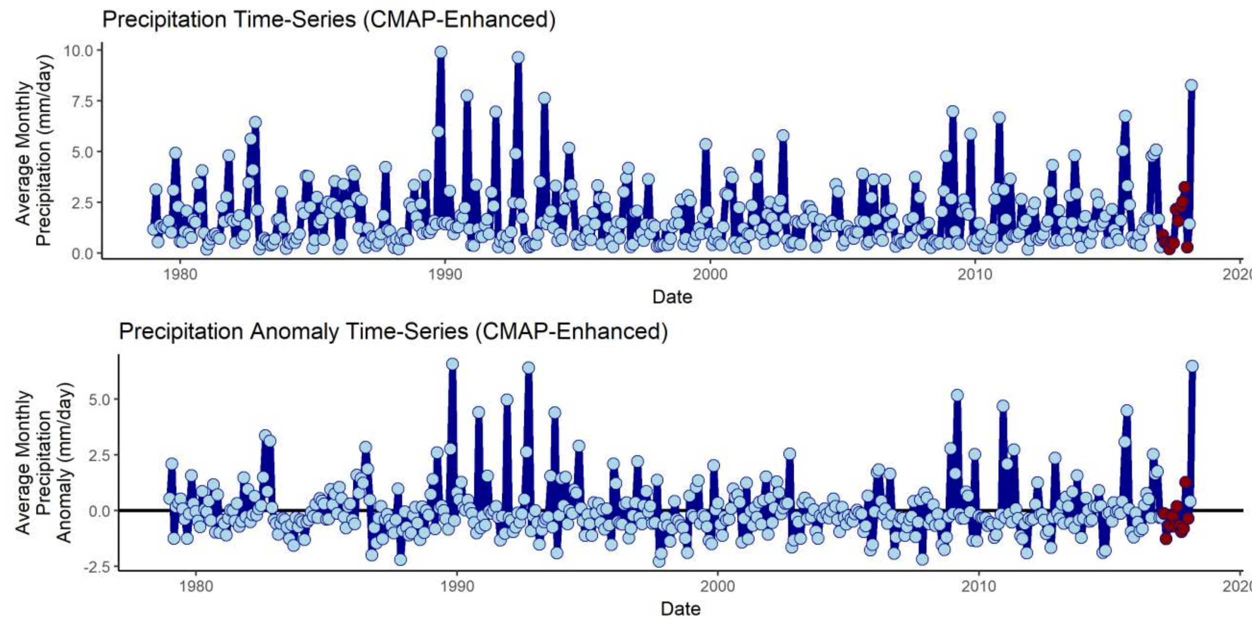


Figure 33. CMAP precipitation across the Johnston Atoll Grid. 2017 values are in red.

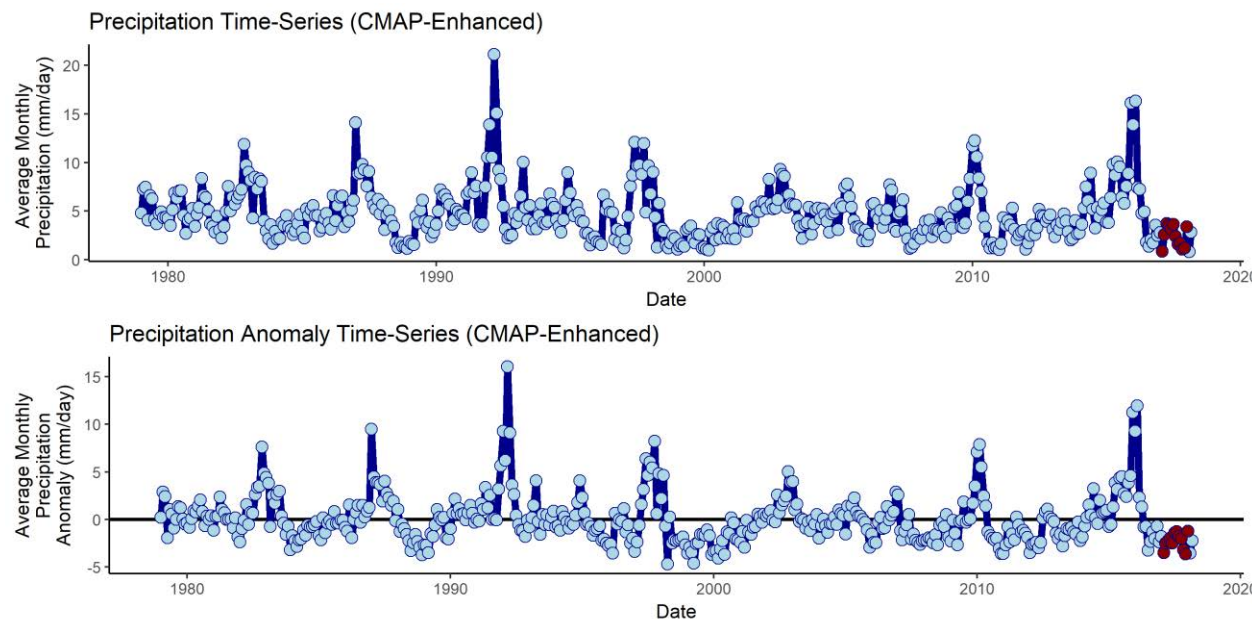


Figure 34. CMAP precipitation across the Line Islands Grid. 2017 values are in red.

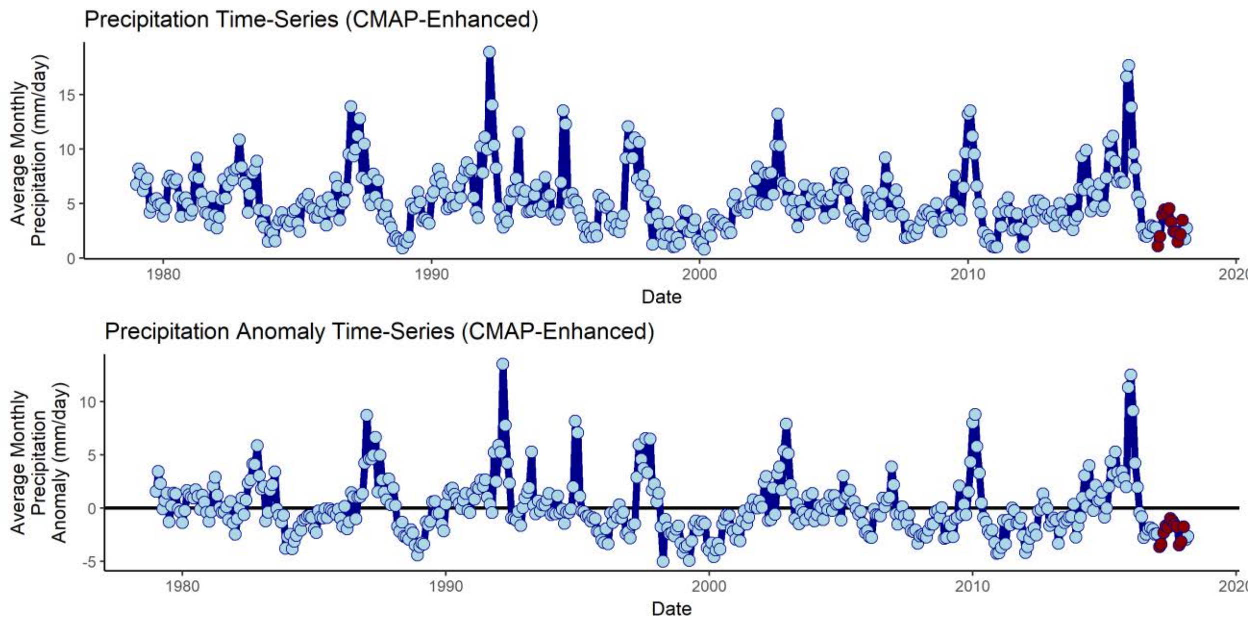


Figure 35. CMAP precipitation across the PRIA Grid. 2017 values are in red.

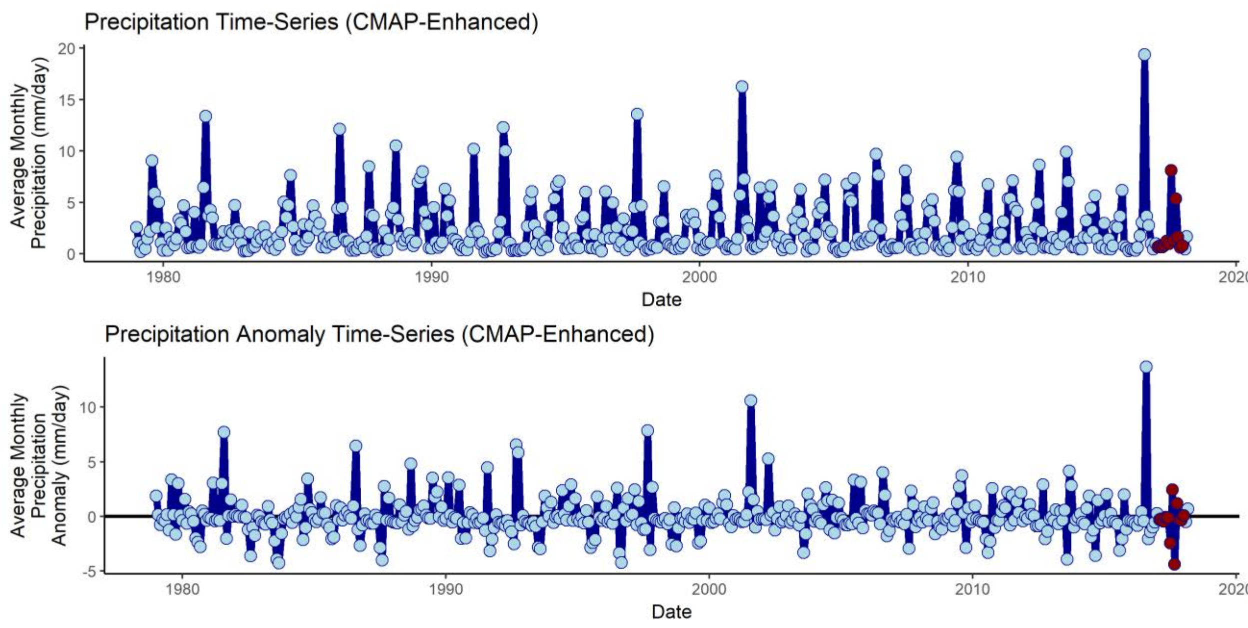


Figure 36. CMAP precipitation across the Wake Atoll Grid. 2017 values are in red.

2.4.3.9 Sea Level (Sea Surface Height and Anomaly)

Description: Monthly mean sea level time series, including extremes

Timeframe: Monthly

Region/Location: Observations from selected sites within the Samoan 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=1770000

Measurement Platform: Satellite and *in situ* tide gauges

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

2.4.3.9.1 Basin-Wide Perspective

This image of the mean sea level anomaly for February 2016 compared to 1993-2013 climatology from satellite altimetry provides a glimpse into how the 2015-2016 El Niño continues to affect sea level across the Pacific Basin. The image captures the fact that sea level continues to be lower in the Western Pacific and higher in the Central and Eastern Pacific (a standard pattern during El Niño events. This basin-wide perspective provides a context for the location-specific sea level/sea surface height images that follow).

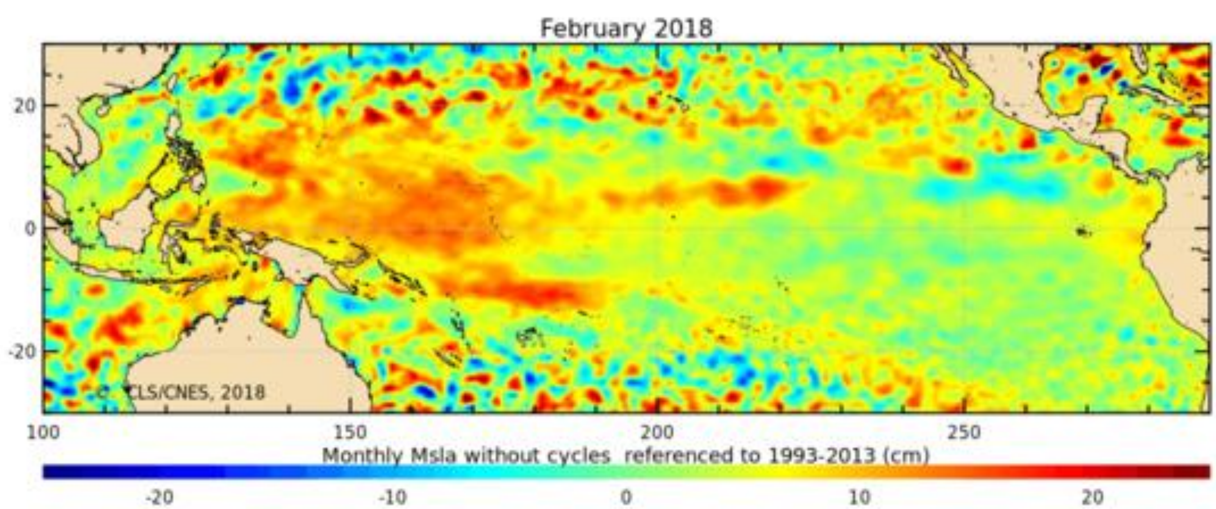


Figure 37a. Sea surface height and anomaly.

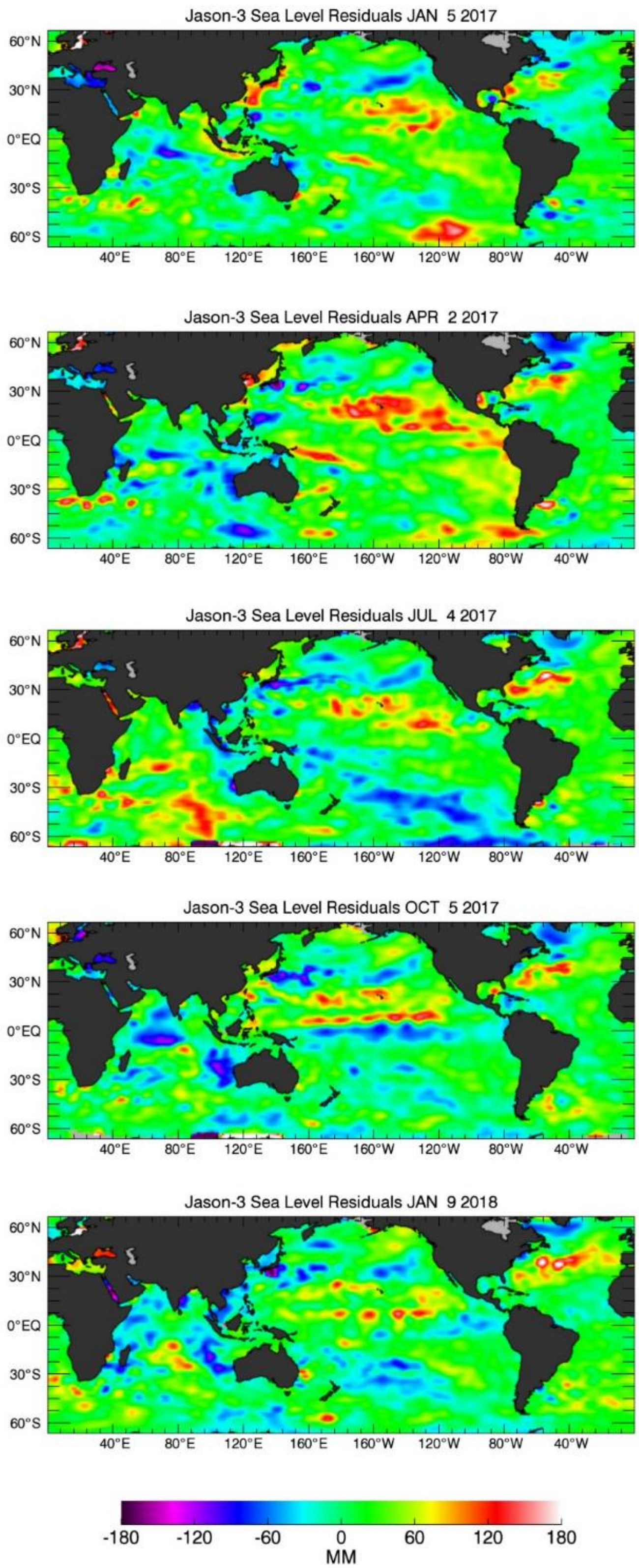
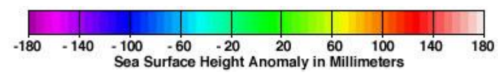


Figure 37b. Quarterly time series of mean sea level anomalies during 2017 show no pattern of El Niño throughout the year according to satellite altimetry measurements of sea level height (unlike 2015).

http://sealevel.jpl.nasa.gov/science/elninopdo/latestdata/archive/index.cfm?y=2017)



2.4.3.9.2 Local Sea Level

These time-series from *in situ* tide gauges provide a perspective on sea level trends within each Archipelago (Tide Station Time Series from NOAA/COOPS).

The following figures and descriptive paragraphs were inserted from https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1619000, & https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1890000.

Figure 38 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.

At Johnston Atoll, water levels include a Mean Sea Level (MSL) trend of 0.75 millimeters/year with a 95% confidence interval of +/- 0.56 millimeters/year based on monthly MSL data from 1947 to 2003 which is equivalent to a change of 0.25 feet in 100 years.

At Wake Island, water levels include a Mean Sea Level (MSL) trend of 2.07 millimeters/year with a 95% confidence interval of +/- 0.43 millimeters/year based on monthly MSL data from 1950 to 2017 which is equivalent to a change of 0.68 feet in 100 years.

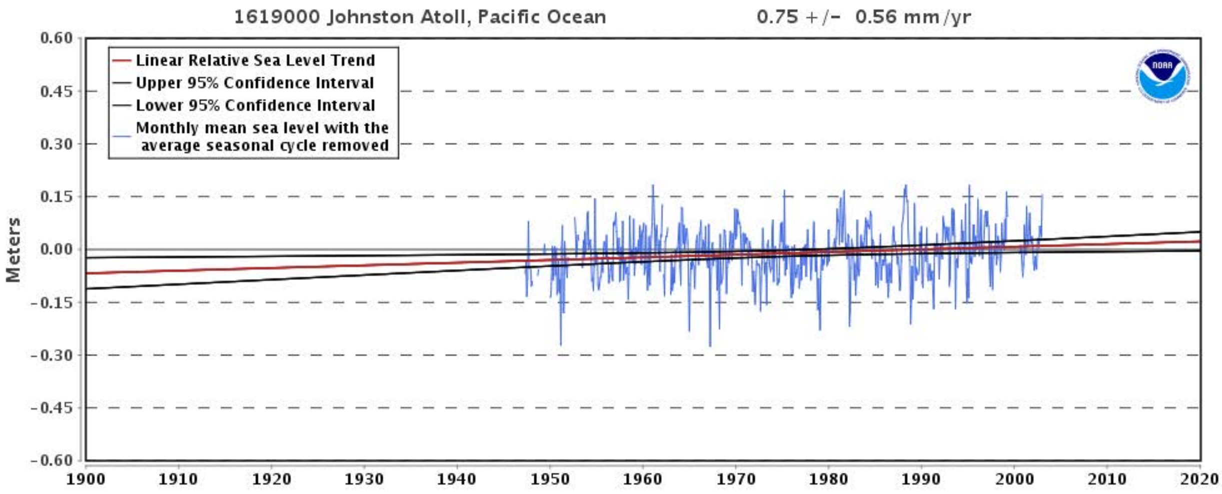


Figure 38. Monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents.

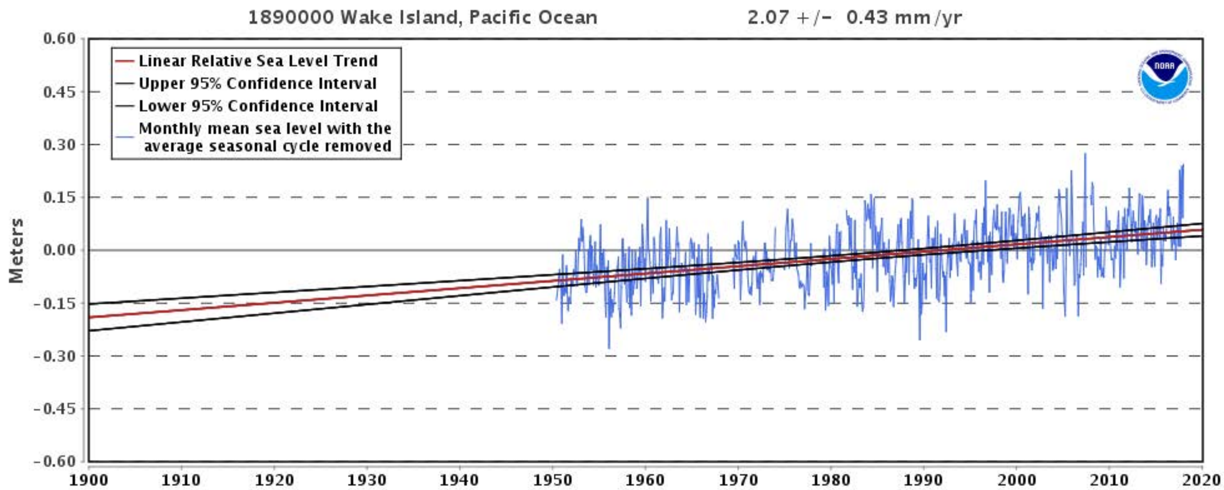


Figure 39. Monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents.

2.5 ESSENTIAL FISH HABITAT

2.5.1 Introduction

The Magnuson-Stevens Fishery Conservation and Management Act includes provisions concerning the identification and conservation of essential fish habitat (EFH), and under the EFH final rule, habitat areas of particular concern (HAPC) (50 Code of Federal Regulations [CFR] 600.815). The Magnuson-Stevens Act defines EFH as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” 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.

2.5.2 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 Pacific Remote Island Area (PRIA) FEP describes EFH for the BMUS, CMUS, CREMUS, and PCMUS.

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

- Updated species descriptions, which can be found appended to the SAFE report. These can be used to directly update the FEP.
- Updated EFH levels of information tables, which can be found in Section 2.5.5.
- Updated research and information needs, which can be found in Section 2.5.6. These can be used to directly update the FEP.
- An analysis that distinguishes EFH from all potential habitats used by the species, which is the basis for an options paper for the Council. This part is developed if enough information exists to refine EFH.

2.5.2.1 Habitat Objectives of FEP

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

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

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

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

2.5.2.2 Response to Previous Council Recommendations

At its 170th meeting, the Council directed staff to develop options for refining precious corals essential fish habitat for the Council's consideration, based on the review in the 2016 SAFE report. The options paper is under development.

At its 170th meeting, the Council directed staff to scope the non-fishing impacts review, from the 2016 SAFE reports, through its advisory bodies. The Plan Team met January 26, 2018 and provided comments on the review.

2.5.3 Habitat Use by MUS and Trends in Habitat Condition

The Pacific Remote Island Areas comprise the U.S. possessions of Baker Island, Howland Island, Jarvis Island, Johnston Atoll, Kingman Reef, Wake Island, Palmyra Atoll, and Midway

Atoll (Figure 40). However, because Midway is located in the Hawaiian archipelago, it is included in the Hawaii Archipelago FEP[1]. Therefore, neither the “Pacific Remote Island Areas” nor “PRIA” include Midway Atoll, for the purpose of federal fisheries management.

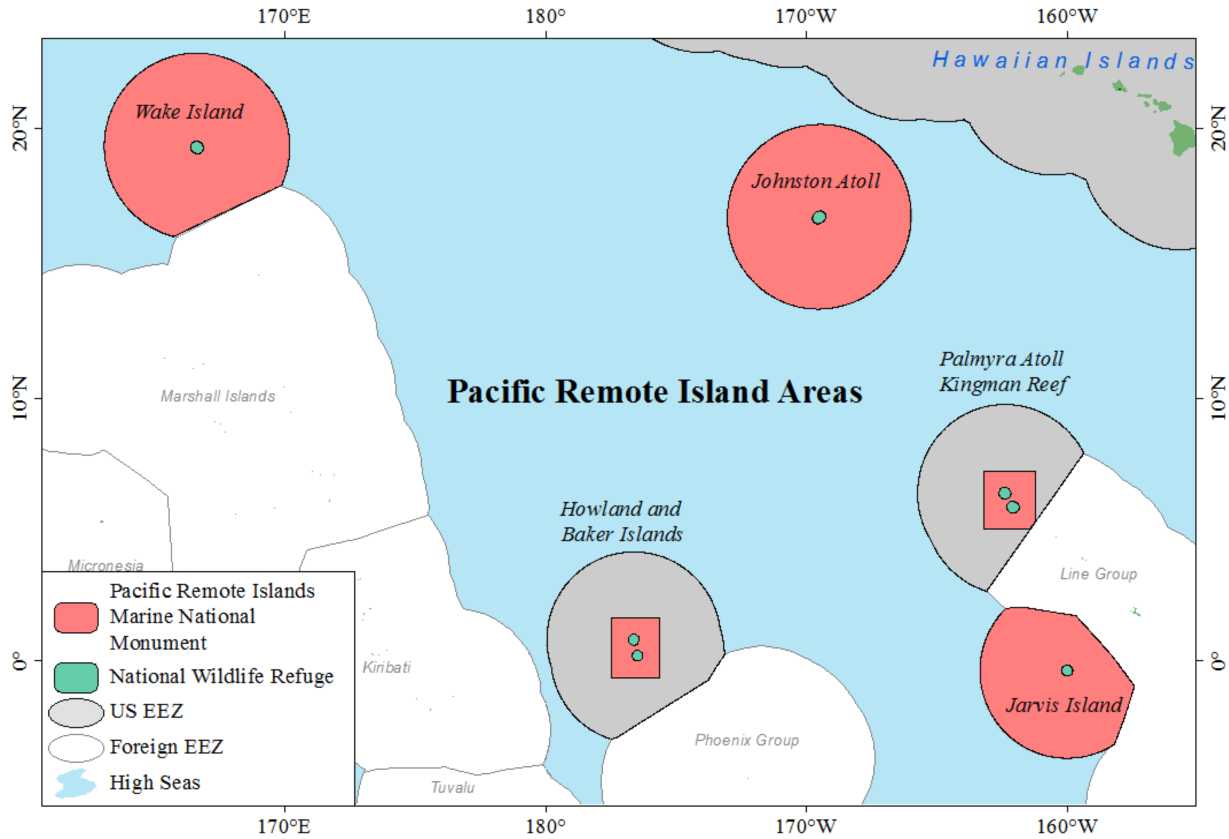


Figure 40. Pacific Remote Island Areas.

Baker Island is part of the Phoenix Islands archipelago. It is located approximately 1,600 nautical miles to the southwest of Honolulu at 0° 13' N and 176° 38' W. Baker is a coral-topped seamount surrounded by a narrow-fringing reef that drops steeply very close to the shore. The total amount of emergent land area of Baker Island is 1.4 square kilometers.

Howland Island lies approximately 35 miles due north of Baker Island and is also part of the Phoenix Islands archipelago. The island, which is the emergent top of a seamount, is fringed by a relatively flat coral reef that drops off sharply. Howland Island is approximately 1.5 miles long and 0.5 miles wide. The island is flat and supports some grasses and small shrubs. The total land area is 1.6 square kilometers.

Jarvis Island, which is part of the Line Island archipelago, is located approximately 1,300 miles south of Honolulu and 1,000 miles east of Baker Island. It sits 23 miles south of the Equator at

[1] Midway is not administered civilly by the State of Hawaii.

160° 01' W. Jarvis Island is a relatively flat, sandy coral island with a 15–20-ft beach rise. Its total land area is 4.5 square kilometers. It experiences a very dry climate.

Palmyra Atoll is a low-lying coral atoll system comprised of approximately 52 islets surrounding three central lagoons. It is approximately 1,050 nautical miles south of Honolulu and is located at 5° 53' N and 162° 05' W. It is situated about halfway between Hawaii and American Samoa. Palmyra Atoll is located in the intertropical convergence zone, an area of high rainfall.

Kingman Reef is located 33 nautical miles northwest of Palmyra Atoll at 6° 23' N and 162° 24' W. Along with Palmyra, it is at the northern end of the Line Island archipelago. Kingman is actually a series of fringing reefs around a central lagoon with no emergent islets that support vegetation.

Wake Island is located at 19° 18' N and 166° 35' E, and is the northernmost atoll of the Marshall Islands group, located approximately 2,100 miles west of Hawaii. Wake Island has a total land area of 6.5 square kilometers and comprises three islets: Wake, Peale, and Wilkes.

Johnston Atoll is located at 16° 44' N and 169° 31' W and is approximately 720 nautical miles southwest of Honolulu. French Frigate Shoals in the NWHI, about 450 nautical miles to the northwest, is the nearest land mass. Johnston Atoll is an egg-shaped coral reef and lagoon complex comprised of four small islands totaling 2.8 square kilometers. The complex resides on a relatively flat, shallow platform approximately 34 kilometers in circumference. Johnston Island, the largest and main island, is natural, but has been enlarged by dredge-and-fill operations. Sand Island is composed of a naturally-formed island on its eastern portion and is connected by a narrow, man-made causeway to a dredged coral island at its western portion. The remaining two islands, North Island and East Island, are completely man-made from dredged coral.

All commercial activity is prohibited within the Pacific Remote Island Area Marine National Monument, which is 50 nautical miles surrounding Palmyra Atoll and Kingman Reef and Howland and Baker Islands, and the entire US EEZ surrounding Johnston Atoll, Wake, and Jarvis Island.

Essential fish habitat in the PRIA for the four MUS comprises all substrate from the shoreline to the 700 m isobath (Figure 41). The entire water column is described as EFH from the shoreline to the 700 m isobath, and the water column to a depth of 400 m is described as EFH from the 700 m isobath to the limit or boundary of the exclusive economic zone (EEZ). While the coral reef ecosystems surrounding the islands in the PRIA have been the subject of a comprehensive monitoring program through the PIFSC Coral Reef Ecosystem Division (CRED) biennially since 2002, surveys are focused on the nearshore environments surrounding the islands, atolls, and reefs (PIBHMC).

The mission of the PIFSC Coral Reef Ecosystem 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 islands, atolls, 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.

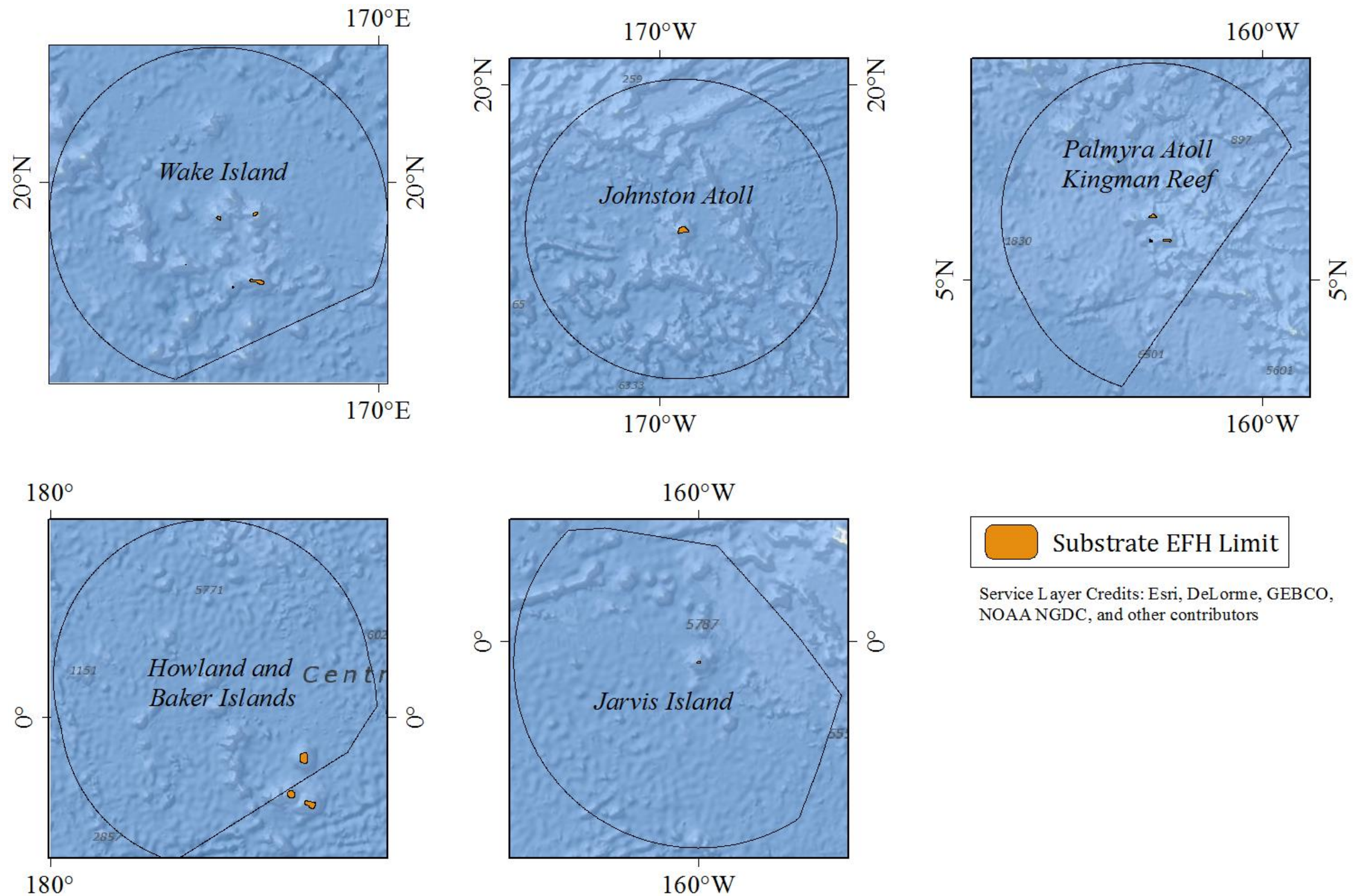


Figure 41. Substrate EFH Limit of 700 meter isobath around the PRIA (from GMRT).

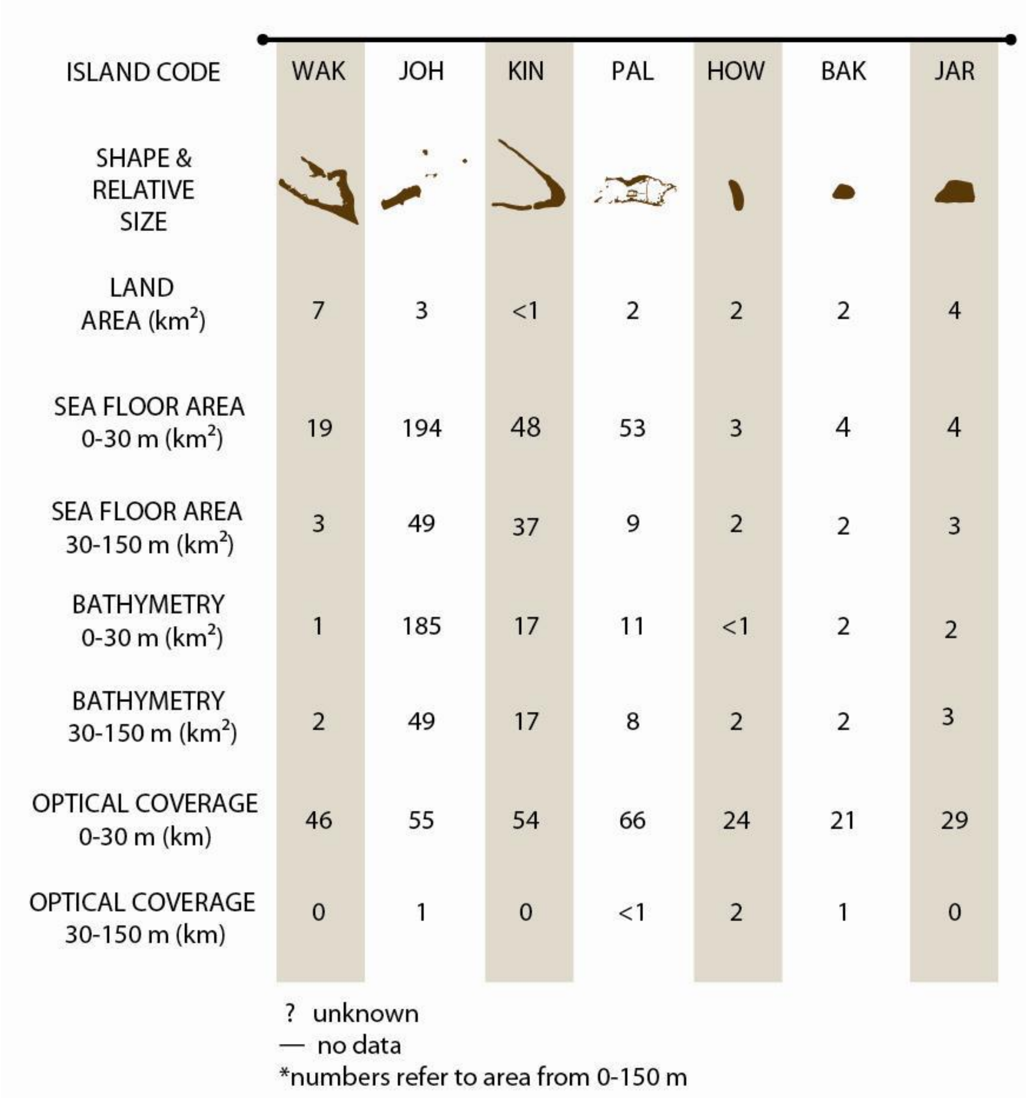
2.5.3.1 Habitat Mapping

Mapping products for the PRIA are available from the Pacific Islands Benthic Habitat Mapping Center and are listed in Table 6.

Table 6. Summary of habitat mapping in the PRIA.

Depth Range	Timeline/Mapping Product	Progress	Source
0-30 m	IKONOS Benthic Habitat Maps	Palmyra only	CRCP 2011
	2000-2010 Bathymetry	67%	DesRochers, 2016
	2011-2015 Multibeam Bathymetry		DesRochers, 2016
	2011-2015 Satellite Worldview 2 Bathymetry	Wake, Baker, and Howland Islands, Johnston and Palmyra Atolls, and Kingman Reef	Pers. Comm. DesRochers, March 19, 2018
30-150 m	2000-2010 Bathymetry	79%	DesRochers, 2016
	2011-2015 Multibeam Bathymetry	Howland and Baker updated with data collected in a few small areas in 2015	Pers. Comm., DesRochers, March 19, 2018
15 to 2500 m	Multibeam bathymetry	Complete at Jarvis, Howland, and Baker Islands	Pacific Islands Benthic Habitat Mapping Center
	Derived Products	Backscatter available for all Geomorphology products for Johnston, Howland, Baker, Wake	Pacific Islands Benthic Habitat Mapping Center

The land and seafloor area surrounding the islands and atolls of the PRIA are reproduced from CRCP (2011) and shown in Figure 42 alongside other physical data.



ISLAND CODE	WAK	JOH	KIN	PAL	HOW	BAK	JAR
SHAPE & RELATIVE SIZE							
LAND AREA (km^2)	7	3	<1	2	2	2	4
SEA FLOOR AREA 0-30 m (km^2)	19	194	48	53	3	4	4
SEA FLOOR AREA 30-150 m (km^2)	3	49	37	9	2	2	3
BATHYMETRY 0-30 m (km^2)	1	185	17	11	<1	2	2
BATHYMETRY 30-150 m (km^2)	2	49	17	8	2	2	3
OPTICAL COVERAGE 0-30 m (km)	46	55	54	66	24	21	29
OPTICAL COVERAGE 30-150 m (km)	0	1	0	<1	2	1	0

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

Figure 42. PRIA Land and Seafloor Area and Primary Data Coverage from CRCP (2011).

2.5.3.2 Benthic Habitat

Juvenile and adult life stages of coral reef MUS and crustaceans including spiny and slipper lobsters and Kona crab extends from the shoreline to the 100 m isobath (64 FR 19067, April 19, 1999). All benthic habitat is considered EFH for crustaceans species (64 FR 19067, April 19, 1999), while the type of bottom habitat varies by family for coral reef species (69 FR 8336, February 24, 2004). Juvenile and adult bottomfish EFH extends from the shoreline to the 400 m isobath (64 FR 19067, April 19, 1999), and juvenile and adult deepwater shrimp habitat extends from the 300 m isobath to the 700 m isobath (73 FR 70603, November 21, 2008). Table 7 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 7. Occurrence of EFH by feature in the PRIA.

Feature	Summit Minimum Depth	Coral Reef/Crustaceans (w/o Deepwater Shrimp)	Bottomfish	Deepwater Shrimp	CRED Long Term Monitoring
Johnston Atoll	Emergent	✓	✓	✓	✓
Palmyra	Emergent	✓	✓	✓	✓
Kingman Reef	Emergent	✓	✓	✓	✓
Extensive banks 80 km SW of Kingman		?	?	?	
Jarvis Island	Emergent	✓	✓	✓	✓
Howland Island	Emergent	✓	✓	✓	✓
Baker Island	Emergent	✓	✓	✓	✓
Southeast of Baker	?	?	?	✓	
Wake Island	Emergent	✓	✓	✓	✓
South of Wake	?	?	?	✓	

2.5.3.3 Oceanography and Water Quality

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

2.5.3.3.1 RAMP Indicators

Benthic percent cover of coral, macroalgae, and crustose coralline algae from CRED are found in the following tables. CRED uses the benthic towed-diver survey method to monitor changes in benthic composition. In this method, "a pair of scuba divers (one collecting fish data, the other collecting benthic data) is towed about one m above the reef roughly 60 m behind a small boat at a constant speed of about 1.5 kt. Each diver maneuvers a tow board 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 sea stars, 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-minute segments, with data recorded separately per segment to allow for later location of observations within the ~ 200-300 m length of each segment. Throughout each survey, latitude and longitude of the survey track are recorded on the small boat using a GPS; and after the survey, diver tracks are generated with the GPS data and a layback algorithm that accounts for position of the diver relative to the boat" (PIFSC Website, 2016).

Table 8. Mean percent cover of live coral from RAMP sites collected from towed-diver surveys in the PRIA.

Year	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2014	2015
Baker	35.37	49.47	38.78		32.95		41.20		47.44		42.10		34.48
Howland	29.06	42.53	36.75		34.69		44.47		50.74		43.26		23.20
Jarvis	24.22	26.19	30.63		28.54		27.70		26.92		25.38		39.75
Johnston			5.01		22.95		18.38		7.94		10.89		7.46
Kingman	39.77	49.51	38.35		24.59		33.13		35.56		37.11		41.92
Palmyra	24.95	31.99	35.07		22.66		25.02		35.35		31.11		42.77
Wake				31.98		19.29		22.56		31.40		32.34	

Table 9. Mean percent cover of macroalgae from RAMP sites collected from towed-diver surveys in the PRIA.

Year	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2014	2015
Baker	12.33	2.11	12.63		9.29		8.09		1.60		8.05		2.15
Howland	2.58	5.34	13.01		3.57		6.14		0.64		6.07		1.08
Jarvis	28.75	10.88	25.03		38.14		24.01		7.35		7.58		3.94
Johnston			25.06		6.90		8.82		1.57		8.49		2.49
Kingman	4.36	5.36	27.04		7.81		7.31		3.97		5.05		2.04
Palmyra	13.28	10.45	23.14		15.17		11.98		4.76		8.94		4.35
Wake				22.88		18.74		12.00		8.30		6.80	

Table 10. Mean percent cover of crustose coralline algae from RAMP sites collected from towed-diver surveys in the PRIA.

Year	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2014	2015
Baker	31.66	37.57	39.61		33.43		23.09		23.40		24.03		32.80
Howland	36.60	27.40	34.26		22.60		22.59		15.73		18.12		21.25
Jarvis	29.11	29.56	34.76		24.23		11.82		30.29		24.20		27.48
Johnston			30.54		19.50		16.07		17.13		17.49		17.45
Kingman	33.04	16.4	17.49		23.50		13.45		9.20		8.45		9.64
Palmyra	38.46	24.46	27.26		26.30		18.02		13.87		17.09		10.28
Wake				1.01		6.43		3.87		4.15		1.13	

2.5.4 Report on Review of EFH Information

One EFH review was drafted this year; the review of the biological components of crustaceans EFH can be found in Appendix C.

2.5.5 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:

- Level 1: Distribution data are available for some or all portions of the geographic range of the species.
- Level 2: Habitat-related densities of the species are available.
- Level 3: Growth, reproduction, or survival rates within habitats are available.
- 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, the 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. A section summarizing the annual review that was performed follows.

2.5.5.1 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 11. Level of EFH information available for the Western Pacific precious corals management unit species complex. 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
C. regale	0	1	HURL Database
Hemicorallium laauense (prev. C. laauense)	0	1	HURL Database
Gold Coral			
Kulamanamana haumeaae	0	1	Sinniger, *et al.* (2013) HURL Database
Callogorgia gilberti	0	1	HURL Database
Narella spp.	0	1	HURL Database
Bamboo Coral			
Lepidisis olapa	0	1	HURL Database
Acanella spp.	0	1	HURL Database
Black Coral			
Antipathes griggi (prev. *Antipathes dichotoma)*	0	2	Opresko, 2009 HURL Database
A. grandis	0	1	HURL Database
Myriopathes ulex (prev. *A. ulex)*	0	1	Opresko, 2009 HURL Database

2.5.5.2 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 12. Level of EFH information available for the Western Pacific BMUS and seamount groundfish MUS complex.

Life History Stage	Eggs	Larvae	Juvenile	Adult
Bottomfish: (scientific/english common)				
Aphareus rutilans (red snapper/silvermouth)	0	0	0	2
Aprion virescens (gray snapper/jobfish)	0	0	1	2
Caranx ignoblis (giant trevally/jack)	0	0	1	2
C. lugubris (black trevally/jack)	0	0	0	2
Epinephelus faciatus (blacktip grouper)	0	0	0	1
E. quernus (sea bass)	0	0	1	2
Etelis carbunculus (red snapper)	0	0	1	2
E. coruscans (red snapper)	0	0	1	2
Lethrinus amboinensis (ambon emperor)	0	0	0	1
L. rubrioperculatus (redgill emperor)	0	0	0	1
Lutjanus kasmira (blueline snapper)	0	0	1	1
Pristipomoides auricilla (yellowtail snapper)	0	0	0	2
P. filamentosus (pink snapper)	0	0	1	2
P. flavipinnis (yelloweye snapper)	0	0	0	2
P. seiboldi (pink snapper)	0	0	1	2
P. zonatus (snapper)	0	0	0	2
Pseudocaranx dentex (thicklip trevally)	0	0	1	2
Seriola dumerili (amberjack)	0	0	0	2
Variola louti (lunartail grouper)	0	0	0	2
Seamount Groundfish:				
Beryx splendens (alfonsin)	0	1	2	2
Hyperoglyphe japonica (ratfish/butterfish)	0	0	0	1
Pseudopentaceros richardsoni (armorhead)	0	1	1	3

2.5.5.3 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 13. Level of EFH information available for the Western Pacific CMUS complex.

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

2.5.5.4 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 has not been undertaken, as the Council only recently completed its process of re-designating certain CREMUS into the ecosystem component classification. Ecosystem component species do not require EFH designations, as they are not a managed species.

2.5.6 Research and Information Needs

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

2.5.6.1 All FMP Fisheries

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

2.5.6.2 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/CNMI deep-water and shallow-water bottomfish complexes.
- High resolution maps of bottom topography/currents/water masses/primary productivity.
- Habitat utilization patterns for different life history stages and species.

2.5.6.3 Crustaceans Fishery

- Identification of post-larval settlement habitat of all CMUS.
- Identification of "source/sink" relationships in the NWHI and other regions (i.e. 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 CNMI.
- High resolution mapping of bottom topography, bathymetry, currents, substrate types, algal beds, habitat relief.

2.5.6.4 Precious Corals Fishery

- Distribution, abundance, and status of precious corals in the PRIA.

2.5.7 References

DesRochers, A., 2016. "Benthic Habitat Mapping." NOAA Fisheries Center, Honolulu, HI. Presentation. April 6, 2016.

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

PIFSC, 2016. 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.

PIFSC, 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.

PIFSC CREP, 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.

2.6 MARINE PLANNING

2.6.1 Introduction

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

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

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

b. Establish effective spatially-based fishing zones.

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

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

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

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

2.6.1.1 Response to Previous Council Recommendations

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

2.6.1.2 MMAs established under FMPs

Council-established marine managed areas (MMAs) were compiled in Figure 43 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 the Pacific Remote Islands Marine National Monument, are shown in Figure 43.

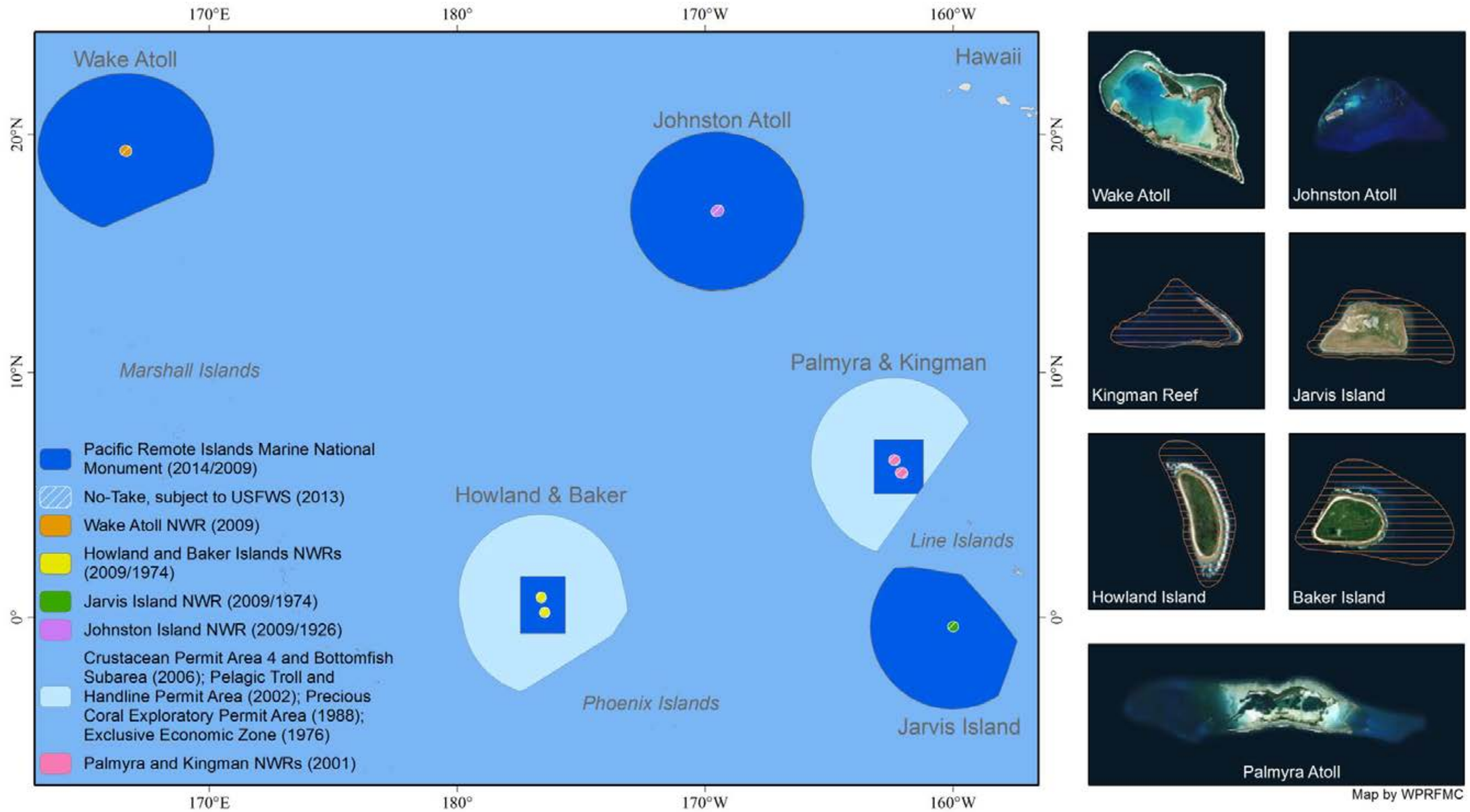


Figure 43. Regulated fishing areas of the PRIA.

Table 14. 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
Other Restrictions								
Howland Island No-Take MPA/PRI Marine National Monument	PRIA/ Pelagic	Howland Island	665.599 and 665.799(a)(1) 69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 PRIA FEP Am. 2	-	All Take Prohibited	Minimize adverse human impacts on coral reef resources; commercial fishing prohibited within 12 nm	2013	-
Jarvis Island No-Take MPA/PRI Marine National Monument	PRIA/ Pelagic	Jarvis Island	665.599 and 665.799(a)(1) 69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 PRIA FEP Am. 2	-	All Take Prohibited	Minimize adverse human impacts on coral reef resources; commercial fishing prohibited within 12 nm	2013	-

Name	FEP	Island	50 CFR /FR /Amendment Reference	Marine Area (km^2)	Fishing Restriction	Goals	Most Recent Evaluation	Review Deadline
Baker Island No-Take MPA/PRI Marine National Monument	PRIA/ Pelagic	Baker Island	665.599 and 665.799(a)(1) 69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 PRIA FEP Am. 2	-	All Take Prohibited	Minimize adverse human impacts on coral reef resources; commercial fishing prohibited within 12 nm	2013	-
Kingman Reef No-Take MPA/PRI Marine National Monument	PRIA/ Pelagic	Kingman Reef	665.599 and 665.799(a)(1) 69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 PRIA FEP Am. 2	-	All Take Prohibited	Minimize adverse human impacts on coral reef resources; all fishing prohibited within 12 nm	2013	-
Johnston Atoll Low-Use MPA/PRI Marine National Monument	PRIA/ Pelagic	Johnston Atoll	69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 PRIA FEP Am. 2	-	Special Permit Only	Minimize adverse human impacts on coral reef resources; superseded by prohibiting fishing within 12 nm in Am. 2	2013	-

Name	FEP	Island	50 CFR /FR /Amendment Reference	Marine Area (km^2)	Fishing Restriction	Goals	Most Recent Evaluation	Review Deadline
Palmyra Atoll Low-Use MPAs/PRI Marine National Monument	PRIA/ Pelagic	Palmyra Atoll	69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 PRIA FEP Am. 2	-	Special Permit Only	Minimize adverse human impacts on coral reef resources; superseded by prohibiting fishing within 12 nm in Am. 2	2013	-
Wake Island Low-Use MPA/PRI Marine National Monument	PRIA/ Pelagic	Wake Island	69 FR 8336 Coral Reef Ecosystem FEP 78 FR 32996 PRIA FEP Am. 2	-	Special Permit Only	Minimize adverse human impacts on coral reef resources; superseded by prohibiting fishing within 12 nm in Am. 2	2013	-

2.6.2 Activities and Facilities

There are no aquaculture, alternative energy facilities, or military training and testing activities occurring in the US EEZ around the PRIAs at this time. The Plan Team will add to this section as new facilities are proposed and/or built.

2.6.3 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 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 14-15, 2018. The RPB's American Samoa Ocean Planning Team has completed its draft Regional Ocean Plan, on which the RPB provided comments and endorsement. CNMI and Guam Ocean Planning Teams have held their kick-off meetings. The RPB, by consensus, adopted the following goals for 2018: finalize the American Samoa Ocean Plan; continue planning in Guam and CNMI including conducting coastal and marine spatial planning training; transfer data portal prototype to permanent site and identify data gaps; and increase funding.

2.6.4 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.

Fisheries off West Coast States and in the Western Pacific; Coral Reef Ecosystems Fishery Management Plan for the Western Pacific, Final Rule. *Federal Register* 69 (24 February 2004): 8336-8349. Downloaded from http://www.wpcouncil.org/precious/Documents/FMP/Amendment5-FR-FinalRule.pdf.

Pelagic Fisheries of the Western Pacific Region, Final Rule. *Federal Register* 56 (18 October 1991): 52214-52217. Downloaded from http://www.wpcouncil.org/pelagic/Documents/FMP/Amendment3-FR-FinalRule.pdf.

Pelagic Fisheries of the Western Pacific Region, Final Rule. *Federal Register* 57 (4 March 1992): 7661-7665. Downloaded from http://www.wpcouncil.org/pelagic/Documents/FMP/Amendment5-FR-FinalRule.pdf.

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/.

3 DATA INTEGRATION

At the 2016 joint meeting of the Archipelagic and Pelagic Fishery Ecosystem Plan Team, the teams recommended that 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, 2016. 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, to be used as the foundation of the data integration chapter ("Chapter 3") of the western Pacific region's (WPR) four archipelagic 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.

Table 15. Participants of the Data Integration Workshop held on November 30th and December 1st, 2016.

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:

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 (Table 16), while the pelagic breakout group developed 11 relationships for pelagic fisheries, including protected species.

Table 16. List of brainstormed potential archipelagic island fishery relationships – scored and ranked. Rank denotes priority level from 3 (highest) to 1 (lowest).

Relationships	FEP	Score	Rank
Bottomfish catch/effort/CPUE/species composition and benthos/substrate (i.e. depth, structure)	All	22	3
Bottomfish catch/effort/ CPUE /species composition and Pacific Decadal Oscillation	All	20	3
Coral reef fish/fishery/biomass and temperature-derived variable	All	20	3
Akule/opelu and precipitation (MHI and Guam)	HI	20	3
Bottomfish catchability and wind speed	All	19	3
Coral reef fish/fishery/biomass and chlorophyll-*a* (with phase lag)	All	19	3
Bottomfish Catch /CPUE and lunar cycle/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 Pacific Decadal Oscillation	All	18	2
Green/red spiny lobster catch/CPUE and vertical relief	HI	18	2
Green/red spiny lobster catch/CPUE and Pacific Decadal Oscillation	HI	18	2
Bottomfish catchability and fishing conditions (i.e. surface, subsurface current, speed, and direction)	All	17	2
Coral reef fish/fishery/biomass and moon phase	All	17	2

Coral reef fish/fishery/biomass and Oceanic Niño Index	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 (e.g. temperature at depth)	All	16	2
Bottomfish catch/effort/ CPUE /species composition and chlorophyll-*a* (with phase lag)	All	16	2
Bottomfish catch/effort/ CPUE /species composition and precipitation	All	16	2
Coral reef fish/fishery/biomass and structural complexity /benthic habitat	All	16	2
Bottomfish catch/effort/ CPUE /species composition and dissolved oxygen	All	15	2
Coral reef fish/fishery/biomass and precipitation	All	14	2
Bottomfish catch/effort/ CPUE /species composition and pH	All	13	2
Bottomfish catch/effort/ CPUE /species composition and predator abundance	All	12	2
Coral reef fish/fishery/biomass and salinity	All	12	2
Coral reef fish/fishery/biomass and dissolved oxygen	All	12	2
Bottomfish catch/effort/ CPUE /species composition and salinity	All	10	1

The continued 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 in 2017 that began exploratory data analysis on different variable combinations to determine which relationships are worth using in the Data Integration chapter. Though the contractor delivered preliminary results for evaluations including data from the MHI, Guam, CNMI, and American Samoa, no explicit analyses were conducted for the PRIA.

APPENDIX A: LIST OF MANAGEMENT UNIT SPECIES

PRIA

The PRIA species list and FSSI status will be made available in subsequent reports as resources allow. Please see the PRIA FEP and implementing regulations for the list of managed species.

APPENDIX B. LIST OF PROTECTED SPECIES AND DESIGNATED CRITICAL HABITAT

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

Common Name	Scientific Name	ESA Listing Status	MMPA Status	Occurrence	References
Seabirds					
Audubon's Shearwater	*Puffinus lherminieri*	Not Listed	N/A	Breeding	Sala et al. 2014
Band-Rumped Storm-Petrel	*Oceanodroma castro*	Not Listed	N/A	Visitor	Sala et al. 2014
Black Noddy	*Anous minutus*	Not Listed	N/A	Breeding	Sala et al. 2014
Black-Footed Albatross	*Phoebastria nigripes*	Not Listed	N/A	Breeding	Sala et al. 2014
Black-Naped Tern	*Sterna sumatrana*	Not Listed	N/A	Visitor	Sala et al. 2014
Black-Winged Petrel	*Pterodroma nigripennis*	Not Listed	N/A	Visitor	Sala et al. 2014
Blue-Gray Noddy	*Procelsterna cerulea*	Not Listed	N/A	Breeding	Sala et al. 2014
Bonin Petrel	*Pterodroma hypoleuca*	Not Listed	N/A	Visitor	Sala et al. 2014
Bridled Tern	*Onychoprion anaethetus*	Not Listed	N/A	Visitor	Sala et al. 2014
Brown Booby	*Sula leucogaster*	Not Listed	N/A	Breeding	Sala et al. 2014
Brown Noddy	*Anous stolidus*	Not Listed	N/A	Breeding	Sala et al. 2014
Bulwer's Petrel	*Bulweria bulwerii*	Not Listed	N/A	Breeding	Sala et al. 2014
Christmas Shearwater	*Puffinus nativitatis*	Not Listed	N/A	Breeding	Sala et al. 2014
Fairy Tern	*Sternula nereis*	Not Listed	N/A	Breeding	Sala et al. 2014
Flesh-Footed Shearwater	*Ardenna carneipes*	Not Listed	N/A	Visitor	Sala et al. 2014
Gould's Petrel	*Pterodroma leucoptera*	Not Listed	N/A	Visitor	Sala et al. 2014
Great Crested Tern	*Thalasseus bergii*	Not Listed	N/A	Visitor	Sala et al. 2014
Great Frigatebird	*Fregata minor*	Not Listed	N/A	Breeding	Sala et al. 2014
Gray-Backed Tern	*Onychoprion lunatus*	Not Listed	N/A	Breeding	Sala et al. 2014
Hawaiian Petrel	*Pterodroma sandwichensis (Pterodroma phaeopygia sandwichensis)*	Endangered	N/A	Visitor	32 FR 4001, Sala et al. 2014
Herald Petrel	*Pterodroma heraldica*	Not Listed	N/A	Visitor	Sala et al. 2014
Kermadec Petrel	*Pterodroma neglecta*	Not Listed	N/A	Visitor	Sala et al. 2014

Common Name	Scientific Name	ESA Listing Status	MMPA Status	Occurrence	References
Laysan Albatross	*Phoebastria immutabilis*	Not Listed	N/A	Breeding	Sala et al. 2014
Lesser Frigatebird	*Fregata ariel*	Not Listed	N/A	Breeding	Sala et al. 2014
Little Shearwater	*Puffinus assimilis*	Not Listed	N/A	Visitor	Sala et al. 2014
Masked Booby	*Sula dactylatra*	Not Listed	N/A	Breeding	Sala et al. 2014
Murphy's Petrel	*Pterodroma ultima*	Not Listed	N/A	Visitor	Sala et al. 2014
Newell's Shearwater	*Puffinus newelli (Puffinus auricularis newelli)*	Threatened	N/A	Visitor	40 FR 44149, Sala et al. 2014
Phoenix Petrel	*Pterodroma alba*	Not Listed	N/A	Former breeder	Sala et al. 2014
Polynesian Storm-Petrel	*Nesofregetta fuliginosa*	Not Listed	N/A	Visitor	Sala et al. 2014
Northern Fulmar	*Fulmarus glacialis*	Not Listed	N/A	Breed and range across North Pacific Ocean.	Hatch & Nettleship 2012
Sooty Shearwater	*Ardenna grisea*	Not Listed	N/A	Breed in the southern hemisphere and migrate to the northern hemisphere.	BirdLife International 2017
Short-Tailed Albatross	*Phoebastria albatrus*	Endangered	N/A	Breed in Japan and NWHI, and range across the North Pacific Ocean.	35 FR 8495, 65 FR 46643, BirdLife International 2017
Sea turtles					
Green Sea Turtle	*Chelonia mydas*	Endangered (Central South Pacific DPS)	N/A	Occur at Wake Island and Palmyra Atoll. Few sightings around Howland, Baker, Jarvis, and Kingman reef.	43 FR 32800, 81 FR 20057, Balazs 1982
Green Sea Turtle	*Chelonia mydas*	Threatened (Central North Pacific DPS)	N/A	Forage around Johnston Atoll.	43 FR 32800, 81 FR 20057, Balazs 1985
Loggerhead Sea Turtle	*Caretta caretta*	Endangered (North Pacific DPS)	N/A	No known sightings. Found worldwide along continental shelves, bays, estuaries and lagoons of tropical, subtropical, and temperate waters.	43 FR 32800, 76 FR 58868, Dodd 1990, NMFS & USFWS 1998
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, Dodd 1990, NMFS & USFWS 1998

Common Name	Scientific Name	ESA Listing Status	MMPA Status	Occurrence	References
Olive Ridley Sea Turtle	*Lepidochelys olivacea*	Threatened (Entire species, except for endangered breeding population on the Pacific coast of Mexico).	N/A	No known sightings. Occur worldwide in tropical and warm temperate ocean waters.	43 FR 32800, Pitman 1990, Balacz 1982
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered[a]	N/A	No known sightings. Occur worldwide in tropical and subtropical waters.	35 FR 8491, Baillie & Groombridge 1996
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered[a]	N/A	No known sightings. Occur worldwide in tropical, subtropical, and subpolar waters.	35 FR 8491, Eckert et al. 2012
Marine mammals					
Bryde's Whale	*Balaenoptera edeni*	Not Listed	Non-strategic	Distributed widely across tropical and warm-temperate Pacific Ocean.	Leatherwood et al. 1982
Blue Whale	*Balaenoptera musculus*	Endangered	Strategic	Extremely rare. Distributed worldwide in tropical and warm-temperate waters.	35 FR 18319, McDonald et al. 2006, Stafford et al. 2001, Bradford et al. 2013, Northrop et al. 1971, Thompson & Friedl 1982
Fin Whale	*Balaenoptera physalus*	Endangered	Strategic	Found worldwide.	35 FR 18319, Hamilton et al. 2009
Humpback Whale	*Megaptera novaeangliae*	Delisted Due to Recovery (Hawaii DPS)	Strategic	Breed in waters around MHI during the winter.	35 FR 18319, 81 FR 62259, Childerhouse et al. 2008, Rice & Wolman 1978, Wolman & Jurasz 1976, Herman & Antinoja 1977,
Humpback Whale	*Megaptera novaeangliae*	Delisted Due to Recovery (Oceania DPS)	Strategic	Breed in Oceania waters during the winter.	35 FR 18319, 81 FR 62259, Guarrige et al. 2007, SPWRC 2008
Humpback Whale	*Megaptera novaeangliae*	Endangered (Western North Pacific DPS)	Strategic	Small population of about 1,000 that breeds in Asian waters during the winter.	35 FR 18319, 81 FR 62259, Eldredge et al. 2003; Barlow et al. 2011; Calambokidis et al. 2001, 2008

Common Name	Scientific Name	ESA Listing Status	MMPA Status	Occurrence	References
Sei Whale	*Balaenoptera borealis*	Endangered	Strategic	Generally found in offshore temperate waters.	35 FR 18319, Barlow 2003, Bradford et al. 2013
Bottlenose Dolphin	*Tursiops truncatus*	Not Listed	Non-strategic	Distributed worldwide in tropical and warm-temperate waters.	Perrin et al. 2009
False Killer Whale	*Pseudorca crassidens*	Not Listed	Non-strategic	Two stocks found in or near PRIA waters: 1) Palmyra Atoll stock found within US EEZ waters around Palmyra Atoll, and 2) Hawaii pelagic stock which includes animals in waters more than 40 km from the MHI. Little known about these stocks. Found worldwide in tropical and warm-temperate waters.	Barlow et al. 2008, Bradford & Forney 2013, Stacey et al. 1994, Chivers et al. 2010
Pygmy Killer Whale	*Feresa attenuata*	Not Listed	Non-strategic	Found in tropical and subtropical waters worldwide.	Ross & Leatherwood 1994
Risso's Dolphin	*Grampus griseus*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide.	Perrin et al. 2009
Rough-Toothed Dolphin	*Steno bredanensis*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide.	Perrin et al. 2009
Common Dolphin	*Delphinus delphis*	Not Listed	Non-strategic	Found worldwide in temperate and subtropical seas.	Perrin et al. 2009
Short-Finned Pilot Whale	*Globicephala macrorhynchus*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters worldwide. Found in waters around Johnston and Palmyra Atolls.	Shallenberger 1981, Baird et al. 2013, Bradford et al. 2013
Spinner Dolphin	*Stenella longirostris*	Not Listed	Non-strategic	Found worldwide in tropical and warm-temperate waters. Occur in shallow protected bays during the day, feed offshore at night.	Norris and Dohl 1980, Norris et al. 1994, Hill et al. 2010, Andews et al. 2010, Karczmarski 2005, Perrin et al. 2009
Spotted Dolphin	*Stenella attenuata attenuata*	Not Listed	Non-strategic	Found in tropical and subtropical waters worldwide. Sighted in waters around Palmyra and Johnston atolls.	Perrin et al. 2009, NMFS PIR unpub. Data

Common Name	Scientific Name	ESA Listing Status	MMPA Status	Occurrence	References
Striped Dolphin	*Stenella coeruleoalba*	Not Listed	Non-strategic	Found in tropical to warm-temperate waters throughout the world.	Perrin et al. 2009
Guadalupe Fur Seal	*Arctocephalus townsendi*	Threatened	Strategic	No known sightings. Little known about their pelagic distribution. Breed mainly on Isla Guadalupe, Mexico.	50 FR 51252, Gallo-Reynoso et al. 2008, Fleischer 1987
Hawaiian Monk Seal	*Neomonachus schauinslandi*	Endangered[a]	Strategic	Endemic tropical seal. Occurs throughout the Hawaiian archipelago. Occasional sightings on Johnston atoll.	41 FR 51611, Antonelis et al. 2006
Northern Elephant Seal	*Mirounga angustirostris*	Not Listed	Non-strategic	Females migrate to central North Pacific to feed on pelagic prey.	Le Beouf et al. 2000
Sperm Whale	*Physeter macrocephalus*	Endangered	Strategic	Found in tropical to polar waters worldwide, most abundant cetaceans in the region.	35 FR 18319, Rice 1960, Lee 1993, Barlow 2006, Mobley et al. 2000, Shallenberger 1981
Blainville's Beaked Whale	*Mesoplodon densirostris*	Not Listed	Non-strategic	Found worldwide in tropical and temperate waters.	Mead 1989
Cuvier's Beaked Whale	*Ziphius cavirostris*	Not Listed	Non-strategic	Occur worldwide.	Heyning 1989
Sharks					
Giant manta ray	*Manta birostris*	Threatened	N/A	Found worldwide in tropical, subtropical, and temperate waters. Commonly found in upwelling zones, oceanic island groups, offshore pinnacles and seamounts, and on shallow reefs.	Dewar et al. 2008, Marshall et al. 2009, Marshall et al. 2011.
Oceanic whitetip	*Carcharhinus longimanus*	Threatened	N/A	Found worldwide in open ocean waters from the surface to 152 m depth. It is most commonly found in waters > 20°C	Bonfil et al. 2008, Backus et al, 1956, Strasburg 1958, Compagno 1984
Scalloped hammerhead	*Sphyrna lewini*	Endangered (Eastern Pacific DPS)	N/A	Found in coastal areas from southern California to Peru.	Compagno 1984, Baum et al. 2007, Bester 2011

Common Name	Scientific Name	ESA Listing Status	MMPA Status	Occurrence	References
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 ranging from 0 to 8 m	Veron 2014
N/A	*Acropora retusa*	Threatened	N/A	Occur in shallow reef slope and back-reef areas, such as upper reef slopes, reef flats, and shallow lagoons, and depth range is 1 to 5 m.	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

[a] These species have critical habitat designated under the ESA. See Table B2.

Table B2. ESA-listed species' critical habitat in the Pacific Ocean[a].

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

North Pacific Right Whale	*Eubalaena japonica*	Endangered	Two specific areas are designated, one in the Gulf of Alaska and another in the Bering Sea, comprising a total of approximately 95,200 square kilometers (36,750 square miles) of marine habitat.	73 FR 19000, 71 FR 38277

[a] For maps of critical habitat, see http://www.nmfs.noaa.gov/pr/species/criticalhabitat.htm.

REFERENCES

Andrews, K.R., Karczmarski, L., Au, W.W.L., Rickards, S.H., Vanderlip, C.A., Bowen, B.W., Grau, E.G., and Toonen, R.J. 2010. Rolling stones and stable homes: social structure, habitat diversity and population genetics of the Hawaiian spinner dolphin (*Stenella longirostris*). Molec Ecol 19:732-748.

Antonelis, G. A., J. D. Baker, T. C. Johanos, R. C. Braun, and A. L. Harting. 2006. Hawaiian monk seal (*Monachus schauinslandi*): Status and Conservation Issues. Atoll Res Bull 543:75-101.

Backus, R.H., S. Springer, and E.L. Arnold Jr. 1956. A contribution to the natural history of the white-tip shark, *Pterolamiops longimanus* (Poey). Deep-Sea Res 3:178-188.

Baillie J. and Groombridge B. 1996. 1996 IUCN Red List of Threatened Animals. IUCN, Gland, Switzerland.

Baird, R.W., A.M. Gorgone, D.J. McSweeney, D.L. Webster, D.R. Salden, M.H. Deakos, A.D. Ligon, G.S. Schorr, J. Barlow and S.D. Mahaffy. 2008. False killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands: long-term site fidelity, inter-island movements, and association patterns. Mar Mamm Sci 24:591-612.

Baird, R.W., D.L. Webster, J.M. Aschettino, G.S. Schorr, D.J. McSweeney. 2013. Odontocete cetaceans around the main Hawaiian Islands: Habitat use and relative abundance from small-boat sighting surveys. Aquatic Mammals 39:253-269

Balazs, G. 1985. Impact of ocean debris on marine turtles: Entanglement and ingestion. *In*: Shomura, R.S. and Yoshida, H.O. [eds.]. Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, HI. U.S Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 574 pp.

Balazs, G.H 1982. Status of sea turtles in the central Pacific Ocean. *In:* Bjorndal, K.A. [ed.]. Biology and Conservation of Sea Turtles. Smithsonian Inst. Press, Washington, D.C. 583 pp.

Barlow, J. 2003. Preliminary Estimates of the Abundance of Cetaceans Along the US West Coast, 1991-2001. [US Department of Commerce, National Oceanic and Atmospheric Administration], National Marine Fisheries Service, Southwest Fisheries Science Center.

Barlow, J. 2006. Cetacean abundance in Hawaiian waters estimated from a summer/fall survey in 2002. Mar Mamm Sci 22(2):446-464.

Barlow, Jay, J. Calambokidis, E.A. Falcone, C.S. Baker, A.M. Burdin, P.J. Clapham, J.K.B. Ford et al. 2011. Humpback whale abundance in the North Pacific estimated by photographic capture-recapture with bias correction from simulation studies. Mar Mamm Sci 27:793-818.

Baum, J., Clarke, S., Domingo, A., Ducrocq, M., Lamónaca, A.F., Gaibor, N., Graham, R., Jorgensen, S., Kotas, J.E., Medina, E., Martinez-Ortiz, J., Monzini Taccone di Sitizano, J., Morales, M.R., Navarro, S.S., Pérez-Jiménez, J.C., Ruiz, C., Smith, W., Valenti, S.V. and Vooren, C.M. 2007. *Sphyrna lewini*. The IUCN Red List of Threatened Species 2007: e.T39385A10190088. Downloaded on 21 Feb 2017.

Bester, C. 2011. Species Profile: Scalloped Hammerhead. Florida Museum of Natural History. http://www.flmnh.ufl.edu/fish/Gallery/Descript/Schammer/ScallopedHammerhead.html.

BirdLife International. 2017. Species factsheet: *Ardenna grisea*. Downloaded from http://www.birdlife.org on 03/05/2017.

BirdLife International. 2017. Species factsheet: *Phoebastria albatrus*. Downloaded from http://www.birdlife.org on 03/05/2017.

Bonfil, R., Clarke, S., Nakano, H., Camhi, M.D., Pikitch, E.K. and Babcock, E.A., 2008. The biology and ecology of the oceanic whitetip shark, *Carcharhinus longimanus*. *In*: Camhi, M.D., Pikitch, E.K., and Babcock, E.A. [eds.]. Sharks of the Open Ocean: Biology, Fisheries, and Conservation, pp.128-139.

Bradford, A.L. and K.A. Forney. 2016. Injury determinations for cetaceans observed interacting with Hawaii and American Samoa longline fisheries during 2009-2013. U.S. Dep. Commer., NOAA Tech. Memo., NOAATM NMFS-PIFSC-50.

Bradford. A.L., K.A. Forney, E.M. Oleson, and J. Barlow. 2013. Line-transect abundance estimates of cetaceans in the Hawaiian EEZ. PIFSC Working Paper WP-13-004.

Calambokidis J., Steiger G.H., Straley J.M. et al. 2001. Movements and population structure of humpback whales in the North Pacific. Mar Mamm Sci 17:769-794.

Calambokidis, J., E.A. Falcone, T.J. Quinn, A.M. Burdin, P.J. Clapham, J.K.B. Ford, C.M. Gabriele, R. LeDuc, D. Mattila, L. Rojas-Bracho, J.M. Straley, B.L. Taylor, J. Urban, D. Weller, B.H. Witteveen, M. Yamaguchi, A. Bendlin, D. Camacho, K. Flynn, A. Havron, J. Huggins, and N. Maloney. 2008. SPLASH: Structure of Populations, Levels of Abundance and Status of Humpback Whales in the North Pacific. Final report for Contract AB133F-03-RP-00078. 58 pp. Available from Cascadia Research (www.cascadiaresearch.org) and NMFS, Southwest Fisheries Science Center (http://swfsc.noaa.gov).

Childerhouse, S., J. Jackson, C. S. Baker, N. Gales, P. J. Clapham, and R. L. Brownell, Jr. 2008. *Megaptera novaeangliae*, Oceania subpopulation. IUCN Red List of Threatened Species (http://www.iucnredlist.org/details/132832).

Chivers, S. J., R. W. Baird, K. M. Martien, B. Taylor, L., E. Archer, A. M. Gorgone, B. L. Hancock, N. Hedrick, M., D. K. Mattila, D. J. McSweeney, E. M. Oleson, C. L. Palmer, V. Pease, K. M. Robertson, J. Robbins, J. C. Salinas, G. S. Schorr, M. Schultz, J. L. Theileking and D. L. Webster. 2010. Evidence of genetic differentiation for Hawai'i insular false killer whales *(Pseudorca crassidens*). NOAA Technical Memorandum, NOAA-TM-NMFS-SWFSC-458. 44pp.

Compagno, L. J. V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the World. An Annotated and Illustrated Catalogue of Shark Species Known to Date. Carcharhiniformes. FAO Fish Synop 124, Vol. 4, Part 2.

Dewar, H., P. Mous, M. Domeier, A. Muljadi, J. Pet,, and J. Whitty. 2008. Movements and site Wdelity of the giant manta ray, *Manta birostris*, in the Komodo Marine Park, Indonesia. Mar Biol 155:121-133.

Dodd, C.K. 1990. *Caretta caretta* (Linnaeus) Loggerhead Sea Turtle. Catalogue of American Amphibians and Reptiles 483.1-483.7.

Eckert, K.L., B.P. Wallace, J.G. Frazier, S.A. Eckert, and P.C.H. Pritchard. 2012. Synopsis of the biological data on the leatherback sea turtle (*Dermochelys coriacea*). U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication BTP-R4015-2012, Washington, D.C.

Eldredge, L.G., 2003. The marine reptiles and mammals of Guam. Micronesica 35(36):653-660.

Fleischer, L. A. 1987. Guadalupe fur seal, *Arctocephalus townsendi*. *In*: Croxall, J.P. and Gentry, R.L. [eds.]. Status, biology, and ecology of fur seals. Proceedings of an international symposium and workshop. Cambridge, England, 23-27 April 1984. U.S. Dept. of Commerce, NOAA, NMFS, NOAA Tech. Rept. NMFS 51. 220pp.

Gallo-Reynoso, J.P., Figueroa-Carranza, A.L. and Le Boeuf, B.J. 2008. Foraging behavior of lactating Guadalupe fur seal females. *In*: Lorenzo, C., Espinoza, E., and Ortega, J. [eds.]. Avances en el Estudio de los Mamíferos de México. Publicaciones Especiales 2:595-614.

Garrigue C, Franklin T, Russell K, Burns D, Poole M, Paton D, Hauser N, Oremus M, Constantine R., Childerhouse S, Mattila D, Gibbs N, Franklin W, Robbins J, Clapham P, Baker CS. 2007. First assessment of interchange of humpback whales between Oceania and the east coast of Australia. International Whaling Commission, Anchorage, Alaska. SC/59/SH15 (available from the IWC office).

Hamilton, T.A., J.V. Redfern, J. Barlow, L.T. Balance, T. Gerrodette, R.S. Holt, K.A. Forney, and B.L. Taylor. 2009. Atlas of cetacean sightings for Southwest Fisheries Science Center Cetacean and Ecosystem Surveys: 1986 – 2005. U.S. Dep. of Commerce, NOAA Technical Memorandum, NOAA-TM-NMFSSWFSC-440. 70 pp.

Hatch, S.A. and Nettleship, D.N. 2012. Northern fulmar (*Fulmarus glacialis*). *In*: Poole, A. [ed.]. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Herman, L. M. and R. C. Antinoja, 1977. Humpback whales in the Hawaiian breeding waters: Population and pod characteristics. Sci Rep Whales Res Inst 29:59-85.

Heyning, J.E. 1989. Cuvier's beaked whale *Ziphius cavirostris* G. Cuvier, 1823. *In*: Ridgway, S.H. and Harrison, R. [eds.]. Handbook of Marine Mammals. Vol. 4. River Dolphins and the Larger Toothed Whales. Academic Press, London and San Diego. 442 pp.

Hill, M.C., E.M. Oleson, and K.R. Andrews. 2010. New island-associated stocks for Hawaiian spinner dolphins (*Stenella longirostris longirostris*): Rationale and new stock boundaries. Pacific Islands Fisheries Science Center Admin Report H-10-04, 12pp.

Karczmarski L, Würsig B, Gailey G, Larson KW, and Vanderlip C. 2005. Spinner dolphins in a remote Hawaiian atoll: social grouping and population structure. Behav Ecol 16: 675-685.

Klimley, A.P. 1993. Highly directional swimming by scalloped hammerhead sharks, *Sphyrna lewini*, and subsurface irradiance, temperature, bathymetry, and geomagnetic field. Mar Biol 117(1):1-22.

Le Boeuf, B.J., Crocker, D.E., Costa, D.P., Blackwell, S.B., Webb, P.M. and Houser, D.S. 2000. Foraging ecology of northern elephant seals. Ecol Monogr 70(3):353-382.

Leatherwood, S., Reeves, R.R., Perrin, W.F., Evans, W.E. 1982. Whales, dolphins, and porpoises of the North Pacific and adjacent arctic waters. NOAA Tech. Rep. NMFS Circ. No. 444.

Lee, T. 1993. Summary of cetacean survey data collected between the years of 1974 and 1985. NOAA Tech.Mem. NMFS 181, 184pp.

Marshall, A., L.J.V. Compagno, and M.B. Bennett. 2009. Redescription of the genus Manta with resurrection of *Manta alfredi* (Krefft, 1868) (Chondrichthyes; Myliobatoidei; Mobulidae). Zootaxa 2301:1-28.

Marshall, A., M.B. Bennett, G. Kodja, S. Hinojosa-Alvarez, F. Galvan-Magana, M. Harding, G. Stevens, and T. Kashiwagi. 2011. *Manta birostris*. The IUCN Red List of Threatened Species 2011: e.T198921A9108067.

McDonald, M.A., Mesnick, S.L. and Hildebrand, J.A. 2006. Biogeographic characterization of blue whale song worldwide: using song to identify populations. J Cet Res Manag 8(1).

Mead, J. G. 1989. Beaked whales of the genus *Mesoplodon*. Pp 349–430. *In*: Ridgeway, S.H., and Harrison, R. [eds.]. Handbook of marine mammals. Volume 4. River dolphins and the larger toothed whales. Academic Press Ltd: London, 452 pp.

Mobley, J. R., Jr, S. S. Spitz, K. A. Forney, R. A. Grotefendt, and P. H. Forestall. 2000. Distribution and abundance of odontocete species in Hawaiian waters: preliminary results of 1993-98 aerial surveys Admin. Rep. LJ-00-14C. Southwest Fisheries Science Center, National Marine Fisheries Service, P.O. Box 271, La Jolla, CA 92038. 26 pp.

National Marine Fisheries Service and U.S. Fish and Wildlife Service. 2007. Recovery Plan for U.S. Pacific Populations of the Loggerhead Turtle (*Caretta caretta*). National Marine Fisheries Service, Silver Spring, Maryland. 72 pp.

Norris, K. S. and T. P. Dohl. 1980. Behavior of the Hawaiian spinner dolphin, *Stenella longirostris*. Fish Bull 77:821-849.

Norris, K. S., B. Würsig, R. S. Wells, and M. Würsig. 1994. The Hawaiian Spinner Dolphin. University of California Press, 408 pp.

Northrop, J., Cummings, W.C. and Morrison, M.F. 1971. Underwater 20-Hz signals recorded near Midway Island. J Acoust Soc Am 49:1909-10.

Perrin, W.F., Wursig, B., and Thewissen J.G.M. [eds.]. 2009. Encyclopedia of marine mammals. Academic Press.

Pitman, R.L. 1990. Pelagic distribution and biology of sea turtles in the eastern tropical Pacific. *In*: Richardson, T.H., Richardson, J.I., and Donnelly, M. [eds.]. Proc. of the Tenth Annual Workshop on Sea Turtle Biology and Conservation. U.S. Dep. of Comm., NOAA Tech. Memo. NMFS-SEFC-278. 286 pp.

Rice, D. W., and A. A. Wolman. 1984. Humpback whale census in Hawaiian waters—February 1977. *In:* Norris, K.S., and Reeves, R.R. (eds.). Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. Final report to the Marine Mammal Commission, U.S. Department of Commerce, NTIS PB-280-794.

Rice, D.W. 1960. Distribution of the bottle-nosed dolphin in the leeward Hawaiian Islands. J Mammal 41(3):407-408.

Ross, G.J.B. and Leatherwood, S. 1994. Pygmy killer whale *Feresa attenuata* (Gray, 1874). Handbook of marine mammals 5:387-404.

Sala, E., Morgan, L., Norse, E., and Friedlander, A. 2014. Expansion of the U.S. Pacific Remote Islands Marine National Monument. Report to the U.S. Government, 35 pp.

Sanches, J.G. 1991. Catálogo dos principais peixes marinhos da República de Guiné-Bissau. Publicações avulsas do I.N.I.P. No. 16. *In:* Froese, R. and Pauly, D. [Eds.]. 2000. FishBase 2000: concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines. 344 pp.

Schulze-Haugen, M. and Kohler, N.E. [eds.]. 2003. Guide to Sharks, Tunas, & Billfishes of the U.S. Atlantic and Gulf of Mexico. RI Sea Grant/National Marine Fisheries Service.

Shallenberger, E.W. 1981. The status of Hawaiian cetaceans. Final report to U.S. Marine Mammal Commission. MMC-77/23. 79pp.

Stacey, P. J., Leatherwood, S., and Baird, R.W. 1994. *Pseudorca crassidens*. Mamm Spec 456:1-6.

Stafford, K.M., S.L. Nieukirk and C.G. Fox. 2001. Geographic and seasonal variation of blue whale calls in the North Pacific. J Cet Res Mgmt 3:65–76.

Strasburg, D. 1958. Distribution, abundance, and habits of pelagic sharks in the Central Pacific ocean. Fish Bull 138(58):335-361.

Thompson, P. O., and W. A. Friedl. 1982. A long-term study of low frequency sounds from several species of whales off Oahu, Hawaii. Cetology 45:1–19.

Veron, J.E.N., 2014. Results of an update of the Corals of the World Information Base for the Listing Determination of 66 Coral Species under the Endangered Species Act. Report to the Western Pacific Regional Fishery Management Council, Honolulu.

Wolman, A. A. and Jurasz, C.M. 1977. Humpback whales in Hawaii: Vessel Census, 1976. Mar Fish Rev 39(7):1-5.

APPENDIX C: CRUSTACEAN LIFE HISTORY AND HABITAT REVIEW

OVERVIEW

This report presents a literature review of the life history and habitat requirements for each life stage for four species of reef-associated crustaceans that are landed in commercial fisheries Western Pacific region: two species of spiny lobster (*Panulirus marginatus* and *Scyllarides squammosus*), scaly slipper lobster (*Scyllarides squammosus*), and Kona crab (*Ranina ranina*).The most up to date information on the species distribution, fisheries in the Western Pacific Region, and life history is summarized. Tables summarizing the multiple dimensions of habitat use for each life stage (egg, larvae, post-larvae, juvenile, and adult) are also provided. The purpose of this report is to provide guidance in reviewing and updating essential fish habitat for reef associated crustaceans in the Western Pacific region.

1. HAWAIIAN SPINY LOBSTER (*PANULIRUS MARGINATUS)*

1.1. GENERAL DESCRIPTION AND DISTRIBUTION

Spiny lobsters are non-clawed, decapod crustaceans with slender walking legs of roughly equal size (Uchida, 1986; FAO, 1991).The Hawaiian spiny lobster (*Panulirus marginatus*), also known as ula and banded spiny lobster, is endemic to the Hawaiian Archipelago and Johnston Atoll (Brock, 1973; Polovina and Moffitt, 1995). The highest abundances of spiny lobster are found in the Northwestern Hawaiian Islands (NWHI; Uchida and Tagami, 1984). A single male spiny lobster has been collected in the shallow waters of Johnston Atoll, but it is unknown if an established reproducing population exists here (Brock, 1973).

Although *P. marginatus* has a long pelagic larval duration, the spiny lobster exhibits significant population structure across the Hawaiian Archipelago with regional differentiation between the NWHI and main Hawaiian islands (MHI; Lacchei *et al.,* 2014). Larval exchange between populations in the MHI and NWHI is minimal and if it does occur, it is more likely larvae are transported from the MHI to NWHI than vice versa (Lacchei *et al.,* 2013).

From the mid-1970s to 1999 spiny lobsters were targeted in a commercial trap fishery in the NWHI (O'Malley, 2004). The NWHI commercial fishery was composed of 9-14 vessels, setting about 80 traps per day and taking 3, approximately 8 week trips per year (Polovina and Mitchum, 1992). Total effort in the commercial fishery was approximately 1 million trap hauls per year (Polovina *et al.,* 1995). Necker Island and Maro Reef accounted for over 60% of all lobster landings (Polovina and Mitchum, 1992).

1.2. FISHERIES

In 1983, a requirement for NWHI commercial lobsters fishers to submit logbooks was implemented and the fishery was managed with a minimum size of 5 cm tail-width (7.5 cm carapace length or CL) and no trapping in areas < 18 m. The depth restriction was to minimize disturbance to the Hawaiian monk seal (Parrish and Polovina, 1994). In 1996, a retain all regulation was implemented and replaced the 5 cm tail width (TL) minimum size due to the high discard mortality rate.

The NWHI commercial spiny lobster fishery peaked in 1985 with total landings exceeding 2.5 million pounds. After 1985, CPUE began to steadily decline, which has been attributed to a number of causes. In 1990, there was a recruitment collapse, which was attributed to climate change and shifts in the ecosystem's productivity (Polovina *et al.,* 1995). After this recruitment collapse, fishing continued and reduced the spawning stock biomass to low levels (Polovina *et al.,* 1995). In 2000, NMFS closed the NWHI spiny lobster fishery due to increasing uncertainty in the assessment of the population; area-based commercial closures from the NWHI Coral Reef Ecosystem Reserve in 2001 and the complete prohibition on commercial fishing in the Papahānaumokuākea Marine National Monument in 2006 have maintained the closure. Since the closure of the commercial fishery in 2000, there has been no evidence that the NWHI spiny lobster population has recovered (O'Malley, 2011; Lacchei *et al.,* 2014).

Currently, fewer than three commercial fishers in the MHI land spiny lobster with traps (NOAA Fisheries, 2017a), and approximately 19 commercial dive fishers land spiny lobsters (NOAA Fisheries, 2017b). In 2015, 5,744 lbs. of spiny lobster where landed commercially in the MHI fishery (DAR, 2015). Spiny lobsters are also targeted and landed by recreational and subsistence fishers in the MHI, but the extent of this fishery is unknown (MacDonald and Thompson, 1987). Management for the spiny lobster in the MHI includes a closed season from May-August, no taking of female lobsters, no spearing, and a minimum size of 3.25 inch CL.

1.3. LIFE HISTORY

1.3.1. GROWTH, MATURITY, MOVEMENT, AND NATURAL MORTALITY

Hawaiian spiny lobsters exhibit sexual dimorphism in growth with males growing faster than females (O'Malley, 2009). While temporal and spatial variation in growth rates for *Panulirus sp*. is uncommon, the temporal, spatial, and individual growth rates of spiny lobsters found in the NWHI is the highest that has ever been reported for any *Panulirus* species (O'Malley, 2009). The cause of the large variation in growth rates is unknown, but may be attributed to variability in prey regimes and/or environmental conditions (O'Malley *et al.,* 2012).

Growth in spiny lobsters is stepwise as they get larger by molting and difficult to describe with a continuous von Bertalanffy relationship (O'Malley and MacDonald, 2009). The molting process consists of 8 discrete stages (Lyle and MacDonald 1983). Mean annual growth rates of tagged male lobsters with a 75 mm CL varied between 3.55 to 15.85 mm, and the annual average growth rate of 70 mm CL tagged female lobsters varied between 1.866 mm to 15.84 mm (O'Malley and MacDonald, 2009).

Size at which female lobsters reach sexual maturity also varies spatially and temporally, and may be associated with density dependence (Polovina, 1989; DeMartini *et al.,* 2003). Estimates of onset of sexual maturity for females range between 57.99 mm CL and 74.8 mm CL (Polovina, 1989). The onset of female maturity was reportedly lower in banks after 10 years of heavy exploitation, which Polovina hypothesizes may be a compensatory response (Polovina, 1989).

Although the longevity of this species is not known, other tropical spiny lobster species live up to 20 years (Butler and MacDiarmid 2011). Annual natural mortality likely varies with size but is estimated on average to be 0.456 (Haight and Polovina, 1993)

1.3.2. REPRODUCTION

Female fecundity increases with both carapace length and tail-width (Honda, 1980; DeMartini *et al.,* 2003). Female lobsters have between 114,000 and 782,000 eggs per brood, and may have multiple broods per spawning season (DeMartini *et al.,* 2003). A 36% increase in average fecundity and a 5% increase in egg diameter was observed over a 30-year period and attributed to a compensatory response to decreased lobster densities and increased per capita food resources as a result of either natural cyclic declines in productivity and/or high exploitation rates from the commercial fishery (DeMartini *et al.,* 1993; DeMartini *et al.,* 2003). This increase in fecundity and egg size coincided with compensatory declines in size at maturity (DeMartini *et al.,* 2003).

Hawaiian spiny lobsters are dioecious and fertilization occurs externally (Uchida, 1986). Mature males will deposit a spermatophore on a mature females' abdomen (Uchida, 1986). Females then release the ova from the oviduct and simultaneously scratch and break the spermatophore open to release spermatozoa, which fertilize the eggs (WPRFMC, 1983). Females attach the fertilized eggs to setae of the female's pleopod. The eggs are visible and females carrying fertilized eggs on the pleopod are referred to as 'berried'. Females carry fertilized eggs for 30-40 days until they hatch into planktonic, pelagic larvae (Morris, 1968). Brooded eggs are orange when first extruded and change to a brown color before hatching (DeMartini *et al.,* 2003).

The spawning season of *P. marginatus* appears to vary within the NWHI chain. Around Nihoa, Necker Island, and French Frigate Shoals, ovigerous females occur in late summer and early winter; toward the northwestern end of the chain, ovigerous females are more abundant in early summer (Uchida *et al.,* 1980). Off O'ahu spawning has been throughout the year and peak activity is concentrated in May-August and low activity is apparent in November-January (McGinnis, 1972).

1.3.3. LARVAE AND RECRUITMENT

After hatching, pelagic phyllosoma larvae, drift in the ocean currents for 12 months and pass through 11 stages of development (MacDonald, 1986; Polovina and Moffitt, 1995). Larval phyllosoma make diurnal movements from 80-100 m during the day, to 10-20 m at night, and are found in high abundance on the surface at night during the new moon (Polovina and Moffitt 1995). Abundance of late stage phyllosomes are higher offshore (up to 25 nmi from 200 m contour) relative to the 200-m contour, which may be explained by either oceanographic currents and nearshore topography pushing larvae offshore and/or higher predation in nearshore areas (Polovina and Moffitt 1995). Although spiny lobsters have a long pelagic duration, banks differ substantially in the proportion of larvae they retain from resident spawners, as well as the portion of larvae they receive from other banks (Polovina *et al.,* 1999). Oceanographic processes such as the strength of the Subtropical Counter Current (SCC) at 26° N latitude, where it intersects with the Hawaiian Ridge and sea level height, play a large role in determining larval retention rates and survival of the pelagic phyllosoma. A high abundance of late stage larvae are found at 26° N suggesting recruitment is linked to the strength of the SCC (Polovina and Moffit, 1995).

This relationship is especially clear at Maro Reef in the NWHI, where a clear trend exists between sea level height and recruitment to the fishery 4 years later (Polovina *et al.,* 1995).

After 12 months, phyllosoma metamorphose into free swimming post-larval pueruli (Polovina and Moffitt, 1995). Pueruli actively swim to shallow, nearshore waters in preparation for settlement (MacDonald, 1986). Settlement is generally higher at the center of the Hawaiian Archipelago relative to the ends, and higher in the NWHI than the MHI (MacDonald, 1986). Other species of spiny lobster pueruli are capable horizontal, directed swimming of up to 40-60 km, but it is unknown how far pueruli of Hawaiian spiny lobster are able to move horizontally before settling (Pearce and Phillips, 1994). Large pulses in larvae settlement occur during new moon and first quarter lunar phase (MacDonald, 1986). However, seasonal, interannual, and geographic patterns of recruitment vary, which are determined to some extent by larval availability resulting from oceanographic conditions such as the strength of the subtropical counter current (MacDonald, 1986; Mitchum and Polovina, 1992; Polovina and Mitchum, 1994; Polovina and Moffitt, 1995; Polovina *et al.,* 1999).

Pueruli settle in depths between 1 and 30 m, and at low densities relative to other spiny lobster species (MacDonald, 1989; Polovina and Moffitt, 1995). While other *Panulirus* sp. use shallow nearshore algal, seagrass, and mangrove roots as nurseries, these types of habitats are poorly represented in Hawaii (MacDonald and Stimson, 1980). In the NWHI, there was no correlation found between shallow habitat and fishery production, suggesting that lobster pueruli may recruit directly to deeper waters from the pelagic habitat relative to other tropical lobster species (Parrish and Polovina, 1994). Upon settling, puerulus molts into the postpuerulus stage, typically around the time of the full moon (Macdonald, 1986).

1.3.4. JUVENILE STAGE

Although post-larval recruitment is influenced by the abundance of pueruli in the banks surrounding waters, differences in adult production between banks in the NWHI is also driven by availability of juvenile habitat (Parrish and Polovina, 1994; Polovina *et al.,* 1995). The habitat requirements of juvenile spiny lobsters are believed to be the bottleneck for adult lobster abundance (Parrish and Polovina, 1994). Observations of small lobsters between 1 and 30 m provide evidence that 30 m is the deepest that lobster larvae are able to settle (Polovina and Moffit, 1995). The highest abundances of juveniles are found in benthic habitat with intermediate (5-30 cm) vertical relief (Parrish and Polovina, 1994). Lower densities of juvenile lobster are found in habitats with low vertical relief (< 5 cm) and high vertical relief (>30 cm) (Parrish and Polovina, 1994). Intermediate vertical relief is provided by scattered coral colonies and algal fields, which are common habitats in the 2 most historically productive fishing grounds at Necker Island and Maro Reef (Parrish and Polovina, 1994). The intermediate vertical relief benthic habitat likely represents a compromise between shelter and abundance of predators; it is enough relief to provide some shelter, but in habitats with relief > 30 cm predatory reef fish such as sharks and jacks that prey on juvenile lobsters are more abundant.

Not only do benthic algae provide shelter, it may also play a role in the trophic ecology of lobsters (MacDiarmid *et al.,* 1991). Macroalgae that provide intermediate vertical relief found in the NWHI include *Dictopterus* sp., *Sargassum* sp., and *Padina* sp. Algal presence and growth is closely associated with temperature, thus northerly banks may be more susceptible to cooling and loss of algae cover resulting in reduced recruitment, increased natural predation, and potentially a reduction in food available to lobsters (Parrish and Polovina, 1994).

1.3.5. ADULT STAGE

Adult lobsters recruit to the fishery approximately 3 years after settling on to benthic habitat, which is slightly larger than the onset of sexual maturity (MacDonald 1985; Polovina and Mitchum, 1992). Generally adult lobsters are found in depths between 20 and 150 m at banks with summits less than 30 m deep, and do not move between banks, which can have depths over 4,000 m (Parrish and Polovina, 1994; Polovina *et al.,* 1995). The depth with highest abundance of lobsters varies with latitude and is likely a result of temperature (Uchida and Tagami, 1984). In the southern portion of the NWHI highest abundances were found in depths from 37 and 64 m, but north of Gardener Pinnacles higher abundances were found in depths of 10 to 36 m. Commercial fishers frequently fish in depths between 20 and 70 m (Polovina, 1993).

Vertical relief of habitat is not found to be correlated with adult lobster abundance (Parrish and Polovina, 1994). Perhaps this is because adult lobsters are less vulnerable to predators (Parrish and Polovina, 1994). Adult lobsters are often found in cracks and crevices of reefs, have been observed moving across open sandy areas between reef patches in pairs (MacDonald 1984), and are also found on the banks of deep slopes that are characterized by 'heavy seas, strong bottom surge, and swift currents' (Parrish and Kazama, 1994).

Unlike other *Panulirus* sp., adult lobsters do not undergo significant migrations. Tag and recapture studies in the NWHI found that the majority of lobsters moved < 1 km after over a year at liberty (O'Malley and Walsh, 2013). Limited movement patterns are likely because juvenile and adult lobster habitats are the same, offshore currents are within reach of newly hatched larvae, and the NWHI do not experience large seasonal shifts in water temperature (O'Malley and Walsh 2013).

P. marginatus are nocturnal predators (FAO, 1991) and are regarded as omnivorous, opportunistic scavengers (Pitcher, 1993). Food items reported from the diets of *Panulirus sp*. include echinoderms, crustaceans, mollusks (primarily gastropods), algae, and seagrass (Pitcher 1993). Catchability of spiny lobsters does not appear to be related to seasonal or lunar changes (MacDonald and Stimson, 1980)

1.4. SUMMARY OF HABITAT USE

Stage	Stage Duration	Diet	Depth Distribution	General Distribution	Benthic Habitat	Oceanographic Features
Egg	30-40 days (Morris,1968)	N/A	benthic (brooded by females)	N/A	N/A	N/A
Larvae (phyllosoma)	12 months (Polovina and Moffit, 1995)	N/A	80-100 m (daytime) 10- 20 m (night) (Polovina and Moffit, 1995).	Offshore (25 nmi from 200 nm contour) (Polovina and Moffit, 1995)	N/A	strength of the Subtropical Counter Current (SCC) at 26° N latitude and sea level height (Polovina, 1999)
Post-pueruli and Juvenile	~3 years (Polovina and Moffit, 1989)	N/A	1-30 m (Polovina and Moffit, 1995)	Settlement higher at center of Archipelago and in NWHI (MacDonald, 1986)	benthic habitat with intermediate (5-30 cm) vertical relief (Parrish and Polovina, 1994)	Temperature** (Polovina and Parrish, 1994)
Adult	Up to 20 years (Butler and MacDiarmid, 2011)*	echinoderms, crustaceans, mollusks, (primarily gastropods) algae, and seagrass (Pitcher, 1993)	between 20 and 150 m at banks with summits < 30 m deep (Polovina *et al.*, 1995)	Highest abundances in NWHI Maro Reef and Necker Island (Lacchei *et al.*, 2014)	Slopes of banks with rocky substrate or found in cracks and crevices in coral reef habitat (Polovina, 1989; Pitcher, 1993)	High abundance found in areas with heavy seas (4-6 ft.), strong bottom surge, and swift currents (1-2 knots) (Parrish and Kazama 1994) Also found in calm lagoon areas in the NWHI(Lacchei and Toonen, 2013)

*Based on other species of spiny lobster.
**Algal cover that provides intermediate relief habitat utilized by juveniles is impacted by temperature.

1.5. REFERENCES

Brock, R.E., 1973. A New Distributional Record for *Panulirus Marginatus* (Quoy and Gaimard, 1825). *Crustaceana*, *25*(1), pp. 111-112. https://doi.org/10.1163/156854073X00588.

DAR, 2015. *Commercial marine landings summary trend report* (p. 16). Honolulu, HI.

DeMartini, E.E., DiNardo, G.T., and Williams, H.A., 2003. Temporal changes in population density, fecundity, and egg size of the Hawaiian spiny lobster (*Panulirus marginatus*) at Necker Bank, Northwestern Hawaiian Islands. *Fishery Bulletin*, *101*(1), pp. 22-31. Retrieved from http://fishbull.noaa.gov/1011/03demart.pdf.

DeMartini, E.E., McCracken, M.L., Moffitt, R.B., and Wetherall, J.A., 2005. Relative pleopod length as an indicator of size at sexual maturity in slipper (*Scyllarides squammosus*) and spiny Hawaiian (*Panulirus marginatus*) lobsters. *Fishery Bulletin*, *103*(1), pp. 23-33. Retrieved from http://fishbull.noaa.gov/1031/dema.pdf.

DeMartini, E., Parker, D., and A. Honda, V., 1993. Comparisons of spiny lobster Panulirus marginatus fecundity, egg size, and spawning frequency before and after exploitation. *Fisheries Bulletin*, *91*.

Gooding, R.M., 1985. Predation on released spiny lobster, *Panulirus marginatus*, during tests in the northwestern Hawaiian Islands. *Marine Fisheries* Review, *47*(1), pp. 1-27.

Haight, W.R. and Polovina, J.J., 1993. Status of lobster stocks in the Northwestern Hawaiian Islands. *Southwest Fisheries Science Center National Marine Fisheries Service, Honolulu Laboratory*. Honolulu, HI.

Holthuis, L.B., 1991. *Marine lobsters of the world: an annotated and illustrated catalogue of species of interest to fisheries known to date*. Rome: Food and Agriculture Organization of the United Nations.

Honda, V.A., 1980. *Preliminary results of studies on the fecundity of the spiny lobster, Panulirus marginatus, in the Northwest Hawaiian Islands*.

IUCN, 2009. *Panulirus marginatus:* Butler, M., Cockcroft, A. and MacDiarmid, *A.: The IUCN Red List of Threatened Species 2013: e.T170067A6724412* [Data set]. International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.UK.2011-1.RLTS.T170067A6724412.en.

Lacchei, M., O'Malley, J.M., Toonen, R.J., 2014. After the gold rush: population structure of spiny lobsters in Hawaii following a fishery closure and the implications for contemporary spatial management.

Lyle, W.G. and MacDonald, C.D., 1983. Molt Stage Determination in the Hawaiian Spiny Lobster *Panulirus Marginatus*. *Journal of Crustacean Biology*, *3*(2), pp. 208-216. https://doi.org/10.2307/1548257

Macdonald, C., Jazwinski, S.C., and Prescott, J.H., 1984. *Queuing Behavior of the Hawaiian Spiny Lobster Panulirus Marginatus* (Vol. 35).

MacDonald, C.D., 1986. Recruitment of the Puerulus of the Spiny Lobster, *Panulirus marginatus*, in Hawaii. *Canadian Journal of Fisheries and Aquatic Sciences*, *43*(11), pp. 2118-2125. https://doi.org/10.1139/f86-260

Macdonald, C.D. and Thompson, B.E., 1987. Characteristics of a Recreational Fishery for Hawaiian Spiny Lobsters at the Midway Islands. *North American Journal of Fisheries Management*, *7*(2), pp. 194-201. https://doi.org/10.1577/1548-8659(1987)7<194:COARFF>2.0.CO;2.

NOAA Fisheries, 2017a. Hawaii Lobster Diving : Retrieved January 4, 2018, from http://www.nmfs.noaa.gov/pr/interactions/fisheries/table1/pir/hi_lobster_diving.html.

NOAA Fisheries, 2017b. Hawaii lobster trap : Retrieved January 4, 2018, from http://www.nmfs.noaa.gov/pr/interactions/fisheries/table1/pir/hi_lobster_trap.html.

O'Malley, J.M., 2004. Trap-weight influence on catches of Hawaiian spiny lobsters *(Panulirus marginatus*) and scaly slipper lobster *(Scyllarides squammosus)* from the Northwestern Hawaiian Islands (Administrative Report No. H-04-06). Retrieved from https://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_04-06.pdf.

O'Malley, J.M., 2008. Evaluations of Tag Retention and a Device for Releasing Discarded Hawaiian Spiny Lobsters *Panulirus marginatus*. *North American Journal of Fisheries Management*, *28*(3), pp. 619-624. https://doi.org/10.1577/M07-102.1.

O'Malley, J.M., 2009. Spatial and Temporal Variability in Growth of Hawaiian Spiny Lobsters in the Northwestern Hawaiian Islands. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, pp. 325-342. https://doi.org/10.1577/C09-031.1.

O'Malley, J.M. and MacDonald, C.D., 2009. Preliminary Growth Estimates of Northwestern Hawaiian Islands Spiny Lobster (*Panulirus marginatus*): Indications of Spatiotemporal Variability (Administrative Report No. H-09-01) (11 p.). Pacific Island Fisheries Science Center.

O'Malley, J.M. and Walsh, W.A., 2013. Annual and Long-Term Movement Patterns of Spiny Lobster, *Panulirus Marginatus*, and Slipper Lobster, *Scyllarides Squammosus*, in the Northwestern Hawaiian Islands. Bulletin of Marine Science, 89(2), pp. 529-549. https://doi.org/10.5343/bms.2012.1047.

Parrish, F.A. and Kazama, T.K., 1992. Evaluation of ghost fishing in the Hawaiian lobster fishery. *Fisheries Bulletin*, *90*, pp. 720-725.

Parrish, F.A. and Martinelli-Liedtke, T.L., 1999. Some preliminary findings on the nutritional status of the Hawaiian spiny lobster (*Panulirus marginatus*). *Pacific Science*, *53*(4), 6 p. Retrieved from http://pubs.er.usgs.gov/publication/70021198.

Parrish, F.A. and Polovina, J.J., 1994. Habitat Thresholds and Bottlenecks in Production of the Spiny Lobster (*Panulirus Marginatus*) in the Northwestern Hawaiian Islands. *Bulletin of Marine Science*, *54*(1), pp. 151-163.

Phillips, B.F. and Booth, J.D., 1994. Design, use, and effectiveness of collectors for catching the puerulus stage of spiny lobsters. *Reviews in Fisheries Science*, *2*(3), pp. 255-289. https://doi.org/10.1080/10641269409388559.

Phillips, B. and Kittaka, J., 2008. *Spiny Lobsters: Fisheries and Culture*. John Wiley and Sons.

Pitcher, C.R., 1993. Spiny lobster. In "Nearshore marine resources of the South Pacific". *Singapore National Printers*. Chapter 17, pp. 541-581

Polovina, J.J., 1989. Density Dependence in Spiny Lobster, Panulirus marginatus, in the Northwestern Hawaiian Islands. *Canadian Journal of Fisheries and Aquatic Sciences*, *46*(4), pp. 660-665. https://doi.org/10.1139/f89-084.

Polovina, J.J., 1993. The Lobster and Shrimp Fisheries in Hawaii. *Marine Fisheries Review*, *55*(2), pp. 28-33. Retrieved from http://spo.nmfs.noaa.gov/mfr552/mfr5525.pdf

Polovina, J.J., 1999. Application of TOPEX/POSEIDON satellite altimetry to simulate transport dynamics of larvae of spiny lobster, *Panulirus marginatus*, in the northwestern Hawaiian Islands, 1993-1996. Fish. Bull., 97, pp. 132-143. Retrieved from https://ci.nii.ac.jp/naid/10025315369/

Polovina, J.J., Haight, W.R., Moffitt, R.B., and Parrish, F.A., 1995. The Role of Benthic Habitat, Oceanography, and Fishing On the Population Dynamics of the Spiny Lobster, *Panulirus Marginatu*s (Decapoda, Palinuridae), in the Hawaiian Archipelago. *Crustaceana,* 68(2), pp. 203-212. https://doi.org/10.1163/156854095X00106

Polovina, J.J. and Mitchum, G.T., 1994. Spiny lobster recruitment and sea level: results of a 1990 forecast. *Fishery Bulletin*, *92*, pp. 203-205.

Polovina, J.J. and Mitchum, G.T., 1992. Variability in spiny lobster Panulirus marginatus recruitment and sea level in the Northwestern Hawaiian Islands. *Fishery Bulletin*, 90(3), pp. 483-493.

Polovina, J.J. and Moffitt, R.B., 1995. Spatial and Temporal Distribution of the Phyllosoma of the Spiny Lobster, *Panulirus Marginatus*, in the Northwestern Hawaiian Islands. *Bulletin of Marine Science, 56*(2), pp. 406-417.

Seeb, L.W., Seeb, J.E., and Polovina, J. J., 1990. Genetic Variation in Highly Exploited Spiny Lobster *Panulirus marginatu*s Populations from the Hawaiian Archipelago. *Fisheries Bulletin*, *88*, pp. 713-718. Retrieved from https://swfsc.noaa.gov/publications/cr/1990/9054.pdf.

Shaklee, J.B., 1984. Genetic variation and population structure in a spiny lobster, *Panulirus marginatus*, in Hawaiian archipelago. *Fisheries Bulletin*, *82*, pp. 693–701. Retrieved from https://ci.nii.ac.jp/naid/10026984355/.

Uchida, R.N., and Tagami, D.T., 1984. Biology, distribution, population structure, and pre-exploitation abundance of spiny lobster, *Panulirus marginatus* (Quoy and Gaimard 1825), in the Northwestern Hawaiian Islands. In: *Proceedings of the second symposium on resource investigations in the northwestern Hawaiian Islands*, *1*, pp. 157-198.

Uchida, R.N., and Uchiyama, J.H., 1986. Fishery Atlas of the Northwestern Hawaiian Islands *NOAA Technical Report* No. NMFS 38. NOAA.

Uchida, R.N., and Uchiyama, J.H., 2001. Fishery Management Plan for Coral Reef Ecosystems of the Western Pacific Region: Environmental Impact Statement. *Western Pacific Regional Fishery Management Council,* 3 p.

2. RED SPINY LOBSTER (*PANULIRUS PENCILLATUS*)

2.1. SPECIES DESCRIPTION AND DISTRIBUTION

Panulirus pencillatus also known as the ula, red spiny lobster, and proghorn spiny lobsters, is found from the Indo-West to the Eastern Pacific, the widest known geographic distribution of any spiny lobster species (Cockcroft *et al.,* 2011). Two genetically distinct populations have been identified between the western/central and eastern Pacific (Abdullah *et al.,* 2014). The common name of the species comes from the body color of individuals found in the eastern Pacific, which is less fitting for *P. pencillatus* with a greenish body color that are found in the western/central Pacific (Abdullah *et al.,* 2014).

2.2. FISHERIES

Red spiny lobster is targeted by lobster fisheries throughout its range, and is considered overexploited in many regions (Cockcroft *et al.,* 2011). Due to its relatively shallow depth preference, it most typically is targeted using hands from spearfishers, or fishers who walk along the reef flat at night (Coutures, 2003). In the Western Pacific region, fisheries exist for the red spiny lobster in American Samoa, CNMI, Guam, and the MHI (McGinnis, 1972; Coutures, 2003; Porter *et al.,* 2005). It is the most abundant lobster species in American Samoa, one of the top landed invertebrate species in CNMI and has been heavily exploited in the MHI. Although not targeted in the NWHI lobster fishery, red spiny lobsters were landed in low numbers (DiNardo and Moffit, 2007).

2.3. LIFE HISTORY

2.3.1. GROWTH, MATURITY, NATURAL MORTALITY, AND MOVEMENT

Like other lobster species, *P. pencillatus* growth is step-wise and body size increases by molting (Coutures, 2003). Reported growth rates vary substantially by region and are likely affected by local factors such as temperature and growth. Growth rates are generally high in juveniles and decrease with age, specifically at the onset of maturity, when more energy is devoted towards reproductive growth and molting becomes less frequent (Courtes, 2003).

P. pencillatus are sexually dimorphic, males reach larger sizes and grow faster than females (Coutures, 2003). Size at 50% sexual maturity in the Western Pacific region is estimated at 6 cm CL, approximately 2-3 years after settling in benthic habitat (Ebert and Ford, 1986; Coutures, 2003). The largest male is reported as 16 cm carapace length (Richer de Forges and Laboute, 1995).

Although natural mortality rates (*M*) vary with size and age, an average *M* of 0.25 per year was estimated for lobsters in CNMI (Ebert and Ford, 1986). Large males may be more vulnerable to predation due to difficulty finding large dens (Coutures, 2003). Large males may be absent on reefs where large dens are not available due to high predation rates. Although specific mortality rates have not been reported for this species, other spiny lobsters lived up to 20 years (Butler and MacDiarmid, 2011).

2.3.2. REPRODUCTION

Spawning season varies by location. For example, Enewetak Atoll in the Marianas has a peak in berried females during the spring, while the presence of berried females in another nearby atoll peaked in the fall (Ebert and Ford, 1986). In Hawai‘i, berried females are found throughout the year (MacDonald, 1971). The drivers behind seasonality of spawning are not known, but may be related to environmental factors such as temperature (Ebert and Ford 1986).

The relationship between size and fecundity of females is exponential, and females may spawn 2-3 times per year (MacDonald, 1971; Pitcher, 1992). Like other spiny lobster species, fertilization is external and occurs when the male deposits a spermatophore on the abdomen of the female which she scratches off to fertilize extruded eggs. Eggs are brooded for approximately one month before hatching as pelagic larvae (Chubb, 1994). Females release eggs in areas that allow the pelagic larvae to quickly drift offshore (Coutures, 2000).

2.3.3. LARVAE AND RECRUITMENT

Phyllosoma larvae drift in the pelagic environment for up to 8-9 months before settling (Matsuda *et al.,* 2006) where they are carried up to 3,700 km by ocean currents and gyres (Johnson, 1974). In larval tows across the Hawaiian archipelago, *P. pencillatus* phyllosoma were found in high abundance near O‘ahu, but were not present in any tows east of French Frigate or off of Midway Atoll (Johnson, 1968).

Limited information is available about *P. pencillatus* recruitment in the Western Pacific region, but they are believed to settle in the same benthic habitat utilized by adults, near the outer reef break (Coutures, 2003). In French Polynesia, *P. pencillatus* post-larvae make active settlement choices, with highest preference towards dead coral (Lecchini *et al.,* 2010). Recruitment also occurred on live coral, macroalgae, and sand (Lecchini *et al.,* 2010).

2.3.4. JUVENILE STAGE

No juvenile specific information was found in the literature, but they are thought to inhabit the same areas as adult lobster (Coutures, 2003).

2.3.5. ADULT STAGE

Red spiny lobsters occupy relatively shallow depths from 1-16 m deep on small islands or near arid coasts (Holthuis, 1991). In the Western Pacific adults are found in clear waters near fringing or reefs slopes that are exposed to high wave energy, habitat that is typically found on the windward exposure of islands in depths up to 5 m (George, 1992; Ebert and Ford, 1986). *P. pencillatus* are nocturnal, hiding in protected caves and corals, or under boulders during the day that are present in lagoons and the outer reef slope (George, 1972; MacDonald, 1979; Coutures, 2003). At night, lobster move up the spurs and grooves of surge channels at the reefs edge and into shallow reef flats to forage (Coutures, 2003).

P. pencillatus have a robust pereiopod, which may be an advantageous adaption that allows foraging in shallow, high energy wave environments where rates of foraging competition and predation may be lower (MacDonald, 1988). Spiny lobster feed on algae, crustaceans, echinoderms, polychaets, and mollusks found in reef flats (Graham, 1993). Females migrate further up the reef flat (closer to shore) than males at night, which may make them more susceptible to fishers walking on reef flats (Ebert and Ford, 1986).

In Hawaii, historical exploitation rates are higher in the MHI than in the NWHI due to the >18 m depth restriction that was used to manage the NWHI lobster fishery (Lacchei *et al.,* 2014). However, in general, abundances of spiny lobster are much higher in the MHI compared to the NWHI because of the larger area of available shallow habitat (Lacchei *et al.,* 2014). In Tutuila, American Samoa the total area of *P. pencillatus* habitat is small, a narrow ban that has a 20-25 m width around the reef edge. In CNMI the estimated density of lobsters per linear km is on average 126 (Ebert and Ford, 1986).

2.4. SUMMARY OF HABITAT USE

Stage	Stage Duration	Diet	Depth Distribution	General Distribution	Benthic Habitat	Oceanographic Features
Egg	1 month (Chubb, 2000)	N/A	Benthic (brooded by females)	N/A	N/A	Eggs hatched in areas accessible to currents (Coutures, 2003)
Larvae	8-9 months (Matsuda *et al.*, 2006)	N/A	Pelagic	Offshore	N/A (pelagic)	Oceanic gyres and currents (Johnson, 1997)
Juvenile	2-3 years (Ebert and Ford, 1986)	N/A	N/A	N/A	Dead coral, live coral, macroalgae, sand (Lecchini *et al.*, 2010)	N/A
Adult	Up to 20 years (Butler and MacDiarmid, 2011)*	Algae, crustaceans, echinoderms, polychaetes, mollusks (Hothuis, 1991)	0-5 m (George, 1972)	Most common on outer reef slopes of fringing reefs moving at night up surge channels at the reef edge and onto shallow reef flats (Coutures, 2003)	Reef or rocky areas with high vertical structure (Coutues, 2003)	Clear oceanic waters and high energy wave action typical of windward exposure (Holthuis, 1991)

*Based on other species of spiny lobster.

2.5. REFERENCES

Abdullah, M.F., Chow, S., Sakai, M., Cheng, J.H., and Imai, H., 2014. Genetic Diversity and Population Structure of Pronghorn Spiny Lobster *Panulirus penicillatus* in the Pacific Region. Pacific Science, *68*(2), pp. 197–211. https://doi.org/10.2984/68.2.3

Chow, S., Jeffs, A., Miyake, Y., Konishi, K., Okazaki, M., Suzuki, N., and Sakai, M., 2011. Genetic Isolation between the Western and Eastern Pacific Populations of Pronghorn Spiny Lobster *Panulirus penicillatus*. *PLOS ONE*, *6*(12), e29280. https://doi.org/10.1371/journal.pone.0029280.

Chubb, C.F., 2000. Reproductive Biology: Issues for Management. In B. F. Phillips and J. Kittaka (Eds.), Spiny Lobsters (pp. 243–275). Blackwell Science Ltd. https://doi.org/10.1002/9780470698808.ch14.

Cockcroft, A., MacDiarmid, A., and Butler, M., 2011. *Panulirus penicillatus*. The IUCN Red List of Threatened Species 2011: e.T169951A6691002. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T169951A6691002.en. Downloaded on 05 January 2018.

Courtes, E., 2003. The biology and artisanal fishery of lobsters of American Samoa (DMWR Biological Report Series No. 103) (p. 66). Pago Pago, American Samoa: Department of Marine and Wildlife Resources.

Coutures, E. and Chauvet, C., 2001. Growth and minimum suitable catch size of spiny lobsters *Panulirus pencillatus* (Olivier,1791) and *Panulirus Longipes* (Decapoda, Palinuridae) in the Southern Lagoon of New Caledonia. *Crustaceana*, *74*(11), pp. 1189–1199. https://doi.org/10.1163/15685400152885174.

Ebert, T.A. and Ford, R.F., 1986. Population ecology and fishery potential of the spiny lobster *Panulirus penicillatus* at Enewetak Atoll, Marshall Islands. *Bulletin of Marine Science*, *38*(1), pp. 56-67.

George, R.W., 1972. South Pacific islands rock lobster resources. Rep. South Pac. Is. Fish. Dev. Agency, Rome. UN/FAO WS/C7959. 42 pp.

Graham, T., 1993. Reef fish resources of the CNMIL a review of the fisheries, research, and management (DFW Technical Report No. 94-03). Lower Base, Saipan, MP: CNMI, Dept. of Natural Resources, Div. of Fish and Wildlife.

Graham, T., 1994. Biological analysis of the nearshore reef fishery of Saipain and Tinian (DFW Technical Report No. 94-02) (p. 134). Commonwealth of the Northern Mariana Islands, Division of Fish and Wildlife.

Hearn, A., and Murillo, J.C., 2008. Life History of the Red Spiny Lobster, *Panulirus penicillatus* (Decapoda: Palinuridae), in the Galápagos Marine Reserve, Ecuador. *Pacific Science*, *62*(2), pp. 191-204. https://doi.org/10.2984/1534-6188(2008)62[191:LHOTRS]2.0.CO;2.

Holthuis, L.B., 1996. Marine lobsters of the world of interest to fisheries [CD-ROM]. World Biodiversity Database CD-ROM Series. Retrieved from http://www.vliz.be/en/imis?refid=6030.

Johannes, R.E., 1979. Improving shallow water fisheries in the Northern Marianas Islands.

Johnson, M.W., 1968. Palinurid Phyllosoma Larvae from the Hawaiian Archipelago (Palinuridea). *Crustaceana*, Supplement, (2), pp. 59-79. Retrieved from http://www.jstor.org/stable/25027388.

Juinio, M.A.R., 1987. Some Aspects of the Reproduction of *Panulirus Penicillatus* (Decapoda: Palinuridae). *Bulletin of Marine Science*, *41*(2), pp. 242-252.

Lacchei, M., O'Malley, J.M., and Toonen, R.J., 2014. After the gold rush: population structure of spiny lobsters in Hawaii following a fishery closure and the implications for contemporary spatial management.

Lecchini, D., Mills, S.C., Brié, C., Maurin, R., and Banaigs, B., 2010. Ecological determinants and sensory mechanisms in habitat selection of crustacean postlarvae. *Behavioral Ecology*, *21*(3), pp. 599-607. https://doi.org/10.1093/beheco/arq029.

MacDonald, C.D. 1979. Management aspects of the biology of the spiny lobsters, *Panulirus marginatus, P. penicillatus, P. versicolor*, and *P. longipes femoristriga* in. Hawaii and the Western Pacific. Final Report to the Western Pacific Regional Fishery Management Council, Honolulu, HI. 46 p.

Matsuda, H., Takenouchi, T., and Goldstein, J. S. (2006). The Complete Larval Development of the Pronghorn Spiny Lobster Panulirus Penicillatus (Decapoda: Palinuridae) in Culture. *Journal of Crustacean Biology*, *26*(4), pp. 579-600. https://doi.org/10.1651/S-2630.1.

Porter, V., Leberer, T., Gawel, M., Gutierrez, J., Burdick, D., Torres, V., and Lujan, E., 2005. The State of Coral Reef Ecosystems of Guam.

3. SLIPPER LOBSTER (*SCYLLARIDES SQUAMOSUS*)

3.1. SPECIES DESCRIPTION AND FISHERIES

The scaly slipper lobster (*Scyllarides squamosus*), or ulu papapa, is found throughout the Indo-Pacific from east Africa to Japan, Hawai‘i, Melanesia, and Australia (Butler *et al.,* 2011). In the NWHI *S. squamosus* is assumed to make up a single meta-population (DiNardo and Moffit, 2007).

S. squamosus made up a minor portion of catch in the NWHI from the 1970s to 1996 in fishers primarily targeting *P. marginatus*. From 1997-1999 several commercial vessels began targeting slipper lobster at Maro Reef (DeMartini and Kleiber, 1998), During the time that the NWHI lobster fishery was active, because little was known about the life history of the scaly slipper lobster, life history parameters were borrowed from the spiny lobster species that was also targeted in the fishery (O’Malley, 2011). However, recent studies on *S. squamosus* reveal life history characteristics between the two species are very different than previously thought (O’Malley, 2011). The NWHI was closed in 2000 due to uncertainty in assessment results and population status of both lobster species. Recent fishery independent surveys indicate that abundance of scaly slipper lobsters has not increased since that time (O’Malley, 2011).

In the MHI, the slipper lobster is managed with 7 cm tail width minimum size regulations.

3.2. LIFE HISTORY

3.2.1. GROWTH, MATURITY, NATURAL MORTALITY, AND MOVEMENT

Growth of *S. squammosus* varies by location. Growth is best described by the Schnute model; juveniles experience faster growth rates, which decline with the onset of maturity (O’Malley, 2011). In the NWHI, growth rates vary by bank; however, individual variation in growth at each bank is minimal (O’Malley, 2011).

Size at sexual maturity also varies by location, but has been reported occurring around 6.6-6.7 cm (Hearn *et al.,* 2007, Lavalli *et al.,* 2009). Adults can reach sizes up to 20 cm CL (Holthuis, 1991). Natural mortality varies by location and year (O’Malley, 2009), and adults do not move large distances (< 1 km; O’Malley and Walsh, 2013).

3.2.2. REPRODUCTION

In Hawai‘i, ovigerous females are found throughout the year and peak in abundance during May and July when water is warmer (O’Malley 2011). Fecundity increases with size and ranges between 54,000 and 227,000 eggs per female (DeMartini and Williams, 2001; DiNardo and Moffitt 2007; Sekiguchi *et al.,* 2007).

3.2.3. LARVAE AND RECRUITMENT

The pelagic larvae duration of *S. squamosus* is between 3 - 6 months (DiNardo and Moffitt, 2007). Larvae have been found up to 20 km of coast of southwest O‘ahu (Phillips and McWilliam, 1989) and in midwater trawls around the Marianas (Sekiguchi, 1990).

3.2.4. JUVENILE STAGE

There is no information on the juvenile stage of *S. squammosus*.

3.2.5. ADULT STAGE

S. squammosus are found in reefs and rocky areas (Holthuis, 1991). The reported depth range of this species varies by location. In Hawai‘i, the reported depth range is 30 – 120 m (DiNardo and Moffit, 2007). In other areas it is reported as 5-80 m with highest abundances at 20-50 m (Chan, 1998). Adult *S. squammosus* are found in very high densities in banks making them very vulnerable to trap fisheries (Clarke and Yoshimoto, 1990).

The scaly slipper lobster reaches sexual maturity between a 66-67 mm carapace length (DeMartinit and Kleiber, 1998) and can reach a maximum size of 15 cm carapace length (Holthuis, 1991) shelters during the day, and forages at night where it feeds mainly on bivalves (Chan, 1998; Lavalli and Spanier, 2007). Adults are known to feed on bivalves (Chan, 1998; Lavalli and Spanier, 2007).

3.3. SUMMARY OF HABITAT USE

Stage	Stage Duration	Diet	Depth Distribution	General Distribution	Benthic Habitat	Oceanographic Features
Egg			benthic (brooded by females)			
Larvae	3-6 month (DiNardo and Moffit, 2007)		pelagic	Offshore (at least 20 km) (Phillips and McWilliam, 1989)	N/A (pelagic)	Optimal temperature 25-29 C (Minagawa, 1990)
Juvenile						
Adult		Bivalves (Chan 1998, Lavalli *et al.*, 2007)	1-120 m (DiNardo and Moffit, 2007)	Most common on outer reef slopes of fringing reefs moving at night up surge channels at the reef edge and onto shallow reef flats (Courtes, 2003)	Reef and rocky areas (Holthuis, 1991)	

3.4. REFERENCES

Butler, M., Cockcroft, A. and MacDiarmid, A., 2011. *Scyllarides squammosus*. The IUCN Red List of Threatened Species 2011: e.T170008A6704714. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T170008A6704714.en. Downloaded on 05 January 2018.

Clarke, R.P. and Yoshimoto, S.S., 1990). Application of the Leslie Model to Commercial Catch and Effort of the Slipper Lobster, *Scyllarides squammosus*, Fishery in the Northwestern Hawaiian Islands. *Marine Fisheries Review, 52*(2), pp. 1-7. Retrieved from http://spo.nmfs.noaa.gov/mfr522/mfr5221.pdf.

Coutures, E., 2000. Distribution of phyllosoma larvae of Scyllaridae and Palinuridae (Decapoda: Palinuridea) in the south-western lagoon of New Caledonia. *Marine and Freshwater Research*, *51*(4), pp. 363–369. https://doi.org/10.1071/mf98108.

DeMartini, E.E., 2006. Compensatory reproduction in Northwestern Hawaiian Islands lobsters (Vol. 543).

DeMartini, E.E., Kleiber, P., and DiNardo, G.T., 2002. Comprehensive (1986-2001) characterization of size at sexual maturity for Hawaiian spiny lobster (*Panulirus marginatus*) and slipper lobster (*Scyllarides squammosus*) in the Northwestern Hawaiian Islands (NOAA Technical Memorandum NMFS No. NOAA-TM-NMFS-SWFSC-344).

Holthuis, L.B., 1996. Marine lobsters of the world of interest to fisheries [CD-ROM]. World Biodiversity Database CD-ROM Series. Retrieved from http://www.vliz.be/en/imis?refid=6030.

Johnson, M.W., 1971. The Phyllosoma Larvae of Slipper Lobsters from the Hawaiian Islands and Adjacent Areas (Decapoda, Scyllaridae). *Crustaceana*, *20*(1), pp. 77-103.

Lau, C.J., 1987. Feeding Behavior of the Hawaiian Slipper Lobster, Scy*llarides Squammosus,* with a Review of Decapod Crustacean Feeding Tactics on Molluscan Prey. Bulletin of *Marine Science*, *41*(2), pp. 378-391.

Lavalli, K.L., and Spanier, E., 2007. The Biology and Fisheries of the Slipper Lobster. CRC Press.

O'Malley, J.M., 2004. Trap-weight influence on catches of Hawaiian spiny lobsters (*Panulirus marginatus*) and scaly slipper lobster (*Scyllarides squammosus*) from the Northwestern Hawaiian Islands (Administrative Report No. H-04-06). Retrieved from https://www.pifsc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_04-06.pdf.

O'Malley, J.M., 2011. Spatiotemporal variation in the population ecology of scaly slipper lobsters <Emphasis Type="Italic">Scyllarides squammosus</Emphasis> in the Northwestern Hawaiian Islands. *Marine Biology*, *158*(8), pp. 1887–1901. https://doi.org/10.1007/s00227-011-1701-z.

O'Malley, J.M., Drazen, J.C., Popp, B.N., Gier, E., and Toonen, R.J., 2012. Spatial variability in growth and prey availability of lobsters in the northwestern Hawaiian Islands. *Marine Ecology Progress Series*, *449*, pp. 211–220. https://doi.org/10.3354/meps09533.

O'Malley, J.M. and Walsh, W.A., 2013. Annual and Long-Term Movement Patterns of Spiny Lobster, *Panulirus Marginatus*, and Slipper Lobster, *Scyllarides Squammosus*, in the Northwestern Hawaiian Islands. *Bulletin of Marine Science, 89*(2), pp. 529–549. https://doi.org/10.5343/bms.2012.1047.

Phillips, B.F. and McWilliam, P.S., 1989. Phyllosoma larvae and the ocean currents off the Hawaiian Islands. *Pacific Science*, *43*(4), pp. 352–361. Retrieved from https://scholarspace.manoa.hawaii.edu/bitstream/10125/1232/1/v43n4-352-361.pdf.

Phillips, B. and Kittaka, J., 2008. Spiny Lobsters: Fisheries and Culture. John Wiley and Sons.

Sekiguchi, H., 1990. Four species of phyllosoma larvae from the Mariana waters. *Bulletin Japan. Soc. Fish. Oceanography.*, *54*(3), pp. 242–248. Retrieved from http://jsfo.jp/contents/pdf/53-2816.pdf.

Spanier, E., 1994. What Are the Characteristics of a Good Artificial Reef for Lobsters? *Crustaceana*, *67*(2), pp.173–186. https://doi.org/10.1163/156854094X00549.

Spanier, E., Lavalli, K., and Edelist, D., 2010. Artificial habitats for benthic dwelling lobsters - analysis of 5 decades of research (Vol. 52).

Trianni, 1998. Summary and further analysis of nearshore reef fishery of the Northern Mariana Islands (p. 72).

Williams, H.A. and DeMartini, E.E., 2001. Fecundity and Egg Size of *Scyllarides Squammosus* (Decapoda: Scyllaridae) at Maro Reef, Northwestern Hawaiian Islands. *Journal of Crustacean Biology*, *21*(4), pp. 891–896. https://doi.org/10.1163/20021975-99990180.

4. KONA CRAB (*RANINA RANINA*)

4.1. GENERAL SPECIES DESCRIPTION AND DISTRIBUTION

The kona crab (*Ranina ranina*), also known as frog crab, red frog crab, papa'i kua loa, krab ziraf, and spanner crab is a large marine brachyuran which is targeted by both commercial and recreational fishers in Hawai'i. While Hawai'i represents the easternmost point of the Kona crab's range (Brown, 1985) commercial fisheries also exist in Australia, Japan, Philippines, Thailand, Seychelles Islands and Hawai'i (Brown, 1985; Tahil, 1983; Boulle, 1995; Krajangdara and Watanabe, 2005). The largest fishery for Kona crabs is found in Queensland, Australia where annual landings can reach over six million pounds making it the largest single species fishery in the State (Dichmont and Brown, 2010). No genetic information is currently available to determine the connectivity of Kona crabs across the Hawaiian Archipelago.

4.2. FISHERIES

A small commercial fishery for Kona crabs has operated continuously in the MHI since 1938, with an annual peak in landings of 70,000 lbs. occurred in 1972 (Vansant 1978). Additionally, a small number of crabs were landed in the NWHI and Kona crab were taken incidentally in the NWHI spiny lobster fishery (closed in 2000) (Brown 1985). Historically, the majority of Kona crab landings in Hawai'i have come from either Penguin Bank, located off the southwest coast of Moloka'i, or from the northwest coast of Ni'ihau (Onizuka, 1972). Several fishermen also operate off the north coast of O'ahu (Onizuka, 1972). Kona crab is thought to be a popular target for recreational fishers (Smith, 1993) however, the extent of the recreational fishery is not known.

Currently the State of Hawai'i Department of Aquatic Resources (HDAR) manages the MHI Kona crab stock as one management unit. The fishery is currently managed using four regulations: (1) seasonal closure May-August, (2) a minimum legal size of 4 inch carapace length, (3) no taking/killing of female crabs and (4) no spearing of crabs. The same regulations apply to recreational fishers. The WPRFMC does not have species-specific management measures applicable to federal waters.

4.3. LIFE HISTORY

4.3.1. GROWTH, MATURITY, MOVEMENT, AND NATURAL MORTALITY

Definitive growth rates of Kona crabs are not known but some partial information is available. In Australia two opposing hypotheses for the growth rates of Kona crabs have been proposed. The fast growth hypothesis estimates that crabs will reach a minimum legal size (4 inches) within 18 months will be 5.5 inches in 4 years and will attain maximum size within 8 to 9 years (Brown, 1986; Boullé, 1995). The slow growth hypothesis estimates that male crabs would take 4 years to reach minimum legal size (4 inches), nine years to attain 5.51-inch size and 14 - 15 years to attain maximum size found in this species (de Moussac, 1988; Chen and Kennelly, 1999; Brown *et al.,* 1999; Kirkwood *et al.,* 2005). Aquarium-reared Kona crabs were found to grow approximately 0.25 inches per week from the time they settle, until the time they have reached the ninth instar (Brown *et al.,* 2008).

The growth rates of Kona crabs are difficult to assess as their hard parts are lost during molting, and growth rates are stepwise between molts (Brown *et al.,* 1999). Catch and recapture methods to determine growth provide an overestimation of time between molts as time since last molt of recaptured crabs cannot be determined (Chen and Kennelly, 1999) and tagging can negatively affect growth rates (Brown *et al.,* 1999). An attempt at analyzing lipofuscin in the brain and eyestalks of the crabs to determine age was unsuccessful (Brown *et al.,* 2008) although this technique has been successful in other crustaceans (Sheehy and Prior, 2008). Due to high mortality rates of Kona crabs in captivity future attempts using this technique must begin with a larger sample size (Brown *et al.,* 2008). Overall, male Kona crabs grow faster than females and grow more per molt (Chen and Kennelly 1999; Brown *et al.,* 1999). Smaller crabs molt much more often than larger crabs. However, larger crabs experience more growth per molt (Chen and Kennelly, 1999). In Hawai‘i males grow on average 0.39 inches per molt and females grown an average of 0.30 inches per molt (Onizuka, 1972). The growth rates found in Kona crabs vary by region, as is typical for many crustaceans (Kruse, 1993). Factors such as temperature and food availability are correlated with the number of molts a crab experiences and how quickly a crab is able to grow (Brown *et al.,* 1999).

The size at which Kona crabs reach sexual maturity varies by region and sex. Color of Kona crabs may be a general indicator of their sexual maturity; immature crabs are white and turn orange as they mature (Fielding and Haley, 1976). In Hawai‘i, the majority of males were found to have mature spermatozoa at a 2.9 inch carapace length (Fielding and Haley, 1976). In Hawai‘i, over 87% of females were sexually mature with a 2.6 inch carapace length (Onizuka, 1972).

Natural mortality rates for Kona crabs in Hawai‘i are unknown (Onizuka, 1972). A preliminary estimate of natural mortality using the length converted catch curve was completed in the Seychelles Islands in the Indian Ocean. Natural mortality rates (M) in the Seychelles were estimated to be 0.8-0.9 yr^{-1} for female crabs and 1.0 yr^{-1} for males (de Moussac, 1988).

4.3.2. REPRODUCTION

Berried females (i.e., crabs that are bearing eggs) are found from May through September (Onizuka, 1972). The highest frequency of egg bearing females occurs in June and July. Ovarian growth for female Kona crabs occurs from February to May resulting in increased feeding during these months (Fielding and Haley, 1976). Feeding rates and thus emergence time in females has been found to be greatly correlated with their reproduction cycle (Kennelly and Watkins, 1994). Berried females rarely emerge from the sand causing catch rates for females to drop dramatically during certain times of the year (Skinner and Hill, 1987; Kennelly and Watkins, 1994). In months prior to breeding, emergence of females increases, as they search for food (Skinner and Hill, 1986).

In Kona crabs fertilization is external (Onizuka, 1972). Large brachyuran male crabs may be able to fertilize multiple females (Kruse, 1993). However, small male crabs may not be all of a female's eggs. A unique characteristic of brachyuran crabs is the ability of females to store sperm in the abdominal receptacle and successfully fertilize their eggs up to two years after copulation (Kruse, 1993). Male Kona crabs must be large enough to dig female crabs out of the sand and copulate (Skinner and Hill, 1986; Minagawa, 1993). The eggs are orange in color until a few days before hatching, when they turn brown (Onizuka, 1972). Eggs are brooded until they hatch 24 to 35 days after being fertilized (Onizuka, 1972).

4.3.3. LARVAE AND RECRUITMENT

Newly settled Kona crabs have been observed in the shallow waters of the surf break on a beach in west Maui (Layne Nakagawa, pers. comm.). Kona crab larvae spend several weeks as planktonic larvae which is their primary mechanism for dispersal (Brown, 1985). The first molt, when the larvae develop into a zoea I stage, is typically 7-8 days after the larvae hatch (Fielding, 1974). Six to seven days later a second molt occurs and the larvae develop into the zoea II stage. Prey density greatly affects the time between molts and the growth of these larval crabs (Minagawa and Murano, 1993a). Larvae begin to settle on the bottom 5-6 weeks after they have hatched (Brown *et al.,* 2008). The newly settled crabs typically have around a 0.40 inch carapace length (Brown *et al.,* 2008). The settlement cue for the larvae is unknown but they are presumed to settle in sandy substrata (Brown *et al.,* 2008). Larvae feed mostly during the day but little is known about the food preference of the larvae making aquaculture-rearing attempts unsuccessful to date (Minagawa and Murano, 1993b). Changes in temperature will affect the feeding habits of the larvae as water temperature is correlated with feeding rates (Minagawa and Murano, 1993b).

4.3.4. JUVENILE STAGE

The habitat of small juveniles is unknown but assumed to be similar to the adult habitat (Brown, 2001).

4.3.5. ADULT STAGE

Adult Kona crabs can reach up to 5.5-10.4 inches in length, and live up to 10 years (Pecl *et al.,* 2011). Adult Kona crabs are found in sandy substrata adjacent to coral reefs in areas subject to strong currents across the tropical and subtropical Indo-Pacific in depths ranging from 6 to 650 feet (Vansant, 1978). Most commercial Kona crab fishing in Hawaiʻi occurs from 50 to 150 feet (Vansant, 1978)

The crabs spend a majority of time buried in the sand to avoid predators which include sharks, rays, loggerhead turtles, large fish, and occasionally marine mammals (Skinner and Hill, 1986; Kennelly *et al.,* 1990). Kona crabs emerge from the sand to feed and mate (Skinner and Hill, 1986). Kona crabs are opportunistic scavengers but also feed on small fish and invertebrates (Onizuka, 1972).

4.4. SUMMARY OF HABITAT USE

Stage	Stage Duration	Diet	Depth Distribution	General Distribution	Benthic Habitat	Oceanographic Features
Egg	24-35 days (Onizuka, 1972)	N/A	benthic (brooded by females)	N/A	N/A	
Larvae	5-6 weeks (Brown *et al.*, 2008)		pelagic	Offshore	N/A (pelagic)	Temperature* (Minagawa and Murano, 1993b)
Juvenile		Similar to adults (Brown *et al.*, 2008)	Shallower than juveniles (pers. comm.)		Sandy substrata adjacent to coral reefs (Brown, 2008)	
Adult		Opportunistic scavengers but also feed on small fish and invertebrates (Onizuka, 1972)	2 – 200 m (Vansant, 1978)	Wide islands shelves (Thomas *et al.*, 2013)	Sandy substrata adjacent to coral reefs (smooth soft bottoms) (Brown, 2008)	Areas subject to strong currents (Vansant, 1978)

4.5. REFERENCES

Boullé, D.P., 1995. Seychelles krab ziraf (*Ranina ranina*) fishery: the status of the stock. *Unpublished report to the Seychelles Fishing Authority*, pp. 1-39.

Brown, I.W., 1985. The Hawaiian Kona crab fishery. *Unpublished report to Queensland Department of Primary Industries*, Brisbane, pp. 1-18.

Brown, I.W., 1986. Population biology of the spanner crab in south-east Queensland. *Fishing Industry Project* 87/71, pp. 1-145.

Brown, I.W., Kirkwood, S., Gaddes, C., Dichmond C.M., and Oveneden, J., 1999. Population dynamics and management of spanner crabs (*Ranina ranina*) in southern Queensland. FRDC Project Report Q099010. Deception Bay, *Queensland Department of Primary Industries and Fisheries*, pp. 1-145.

Brown, I.W., Dunning, M.C., Hansford, S., and Gwynn, L., 2001. Ecological Assessment Queensland Spanner Crab Fishery. *Report to Queensland Department of Primary Industries, Brisbane*, pp. 1-36.

Brown, I.W., 2004. Spanner crab (*Ranina ranina*) stock assessment and TAC-setting review for the quota period 1/6/04-5/31/06. *Southern Fisheries Center, Deception Ba, project Report* QI03064, pp. 1-14.

Brown, I.W., Scandol, J., Mayer, D., Campbell, M., Kondyias, S., McLennan, M., Williams, A., Krusic-Golub, K., and Treloar, T., 2008. Reducing uncertainty in the assessment of the Australian spanner crab fishery. *Queensland Department of Primary Industries and Fisheries, Brisbane, Project Report* PR07-3314, pp. 1-129.

Brown, I.W., 2010. Queensland Spanner Crab Annual Status Report and TAC review for TAC period June 2010- May 2012. Southern Fisheries Centre, Deception Bay, *Crab Scientific Advisory Group Report* 2010/01, pp. 1-15.

Chen, Y. and Kennelly, S.J., 1999. Probabilistic stepwise growth simulations to estimate the growth of spanner crabs, *Ranina ranina*, off the east coast of Australia. *Marine and Freshwater Research*, *50*(4), pp. 319-325.

de Moussac, G., 1988. Le crabe girafe *Ranina ranina*, auz Seychelles: biologie et exploitation. *Technical Report Seychelles Fishing Authority*, *8*, pp. 1-23.

Dichmont, C.M. and Brown, I.W., 2010. A case study in successful management of data-poor fishery using simple decision rules: the Queensland Spanner crab fishery. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, *2*, pp. 1-13.

DiNardo, G.T., Haight, W.R., and Wetherall, J.A., 1998. Status of lobster stocks in the North – West Hawaiian Islands, 1995-97, and outlook for 1998. *Administrative report* H-98-05. Southwest Fisheries Science Center, pp. 1-35.

Fielding, A., 1974. Aspects of the biology of the Hawaiian Kona crab, *Ranina ranina* (Linnaeus). *Thesis for the degree of Master of Science* (*University of Hawaii*). Zoology, 16 p.

Fielding, A. and Haley, S.R., 1976. Sex ratio, size at reproductive maturity and reproduction of the Hawaiian Kona crab *Rainina ranina* (Linnaeus)(Brachyura, Gymnopleura, Raninidae). *Pacific Science*, 30, pp. 131-145.

Friedlander, A.M. and Parrish, J.D., 1997. Fisheries harvest and standing stock in a Hawaiian Bay. *Fisheries Research*, 32(1), pp. 33-50.

Gooding, R.M., 1985. Predation on released Spiny Lobster, *Panuliurs marginatus*, during tests in the Northwestern Hawaiian Islands. *Marine Fisheries Review*, 47, pp. 27-45.

Hill, B.J. and Wassenberg, T.J., 1999. The response of spanner crabs (*Ranina ranina*) to tangle nets- behaviour of the crabs on the nets, probability of capture and estimated distance of attraction to bait. *Fisheries Research*, 41(1), pp. 37-46.

Kennelly, S.J. and Craig, J.R., 1989. Effects of trap design, independence of traps and bait on sampling populations of spanner crabs *Ranina ranina*. *Marine Ecology Progress Series*, *51*, pp. 49-56.

Kennelly, S.J., Watkins, D., and Craig, J.R., 1990. Mortality of discarded spanner craps *Ranina ranina* in a tangle-net fishery laboratory and field experiments. *Journal of Experimental Marine Biology and Ecology*, *140*, pp. 39-48.

Kennelly, S.J. and Watkins, D., 1994. Fecundity and reproductive period and their relationship to catch rates of spanner crabs, *Ranina ranina*, off the east coast of Australia. *Journal of Crustacean Biology*, *24*, pp. 146-150.

Kennelly, S.J. and Scandol, J.P., 2006. Using a Fishery-Independent Survey to Assess the Status of a Spanner Crab *Ranina ranina* Fishery: Univariate Analyses and Biomass modeling. *Crusaceana*, *75*(1), pp. 13-39.

Kirkwood J.M., Brown, I.W., Gaddes, S.W., and Holye, S., 2005. Juvenile length-at-age data reveal that spanner crabs (*Ranina ranina*) grow slowly. *Marine Biology*, *147*, pp. 331-339.

Kirkwood, J.M. and Brown, I.W., 1998. The effect of limb damage on the survival and burial time of discarded spanner crabs, *Ranina ranina* Linnaeus. *Marine Freshwater Research*, *49*, pp. 41-45.

Krajangdara, T. and Watanabe, S., 2005. Growth and reproduction of the red frog crab, *Ranina ranina* (Linnaeus, 1758), in the Andaman Sea off Thailand. *Fisheries Science*, *71*, pp. 20-28.

Kruse, G.H., 1993. Biological Perspectives on crab management in Alaska: an oral report to the Alaska Board of Fisheries. Div. of Commercial Fisheries, Dept. of Fish and Game, Regional Information Report, Juneau, Alaska, pp. 1-10.

Minagawa, M., 1993. Relative Growth and Sexual Dimorphism in the Red Frog Crab (*Ranina ranina*.) *Nippon Suisan Gakkaishi*, *59*, pp. 2025-2030.

Minagawa, M., Chiu, J.R., Kudo, M., Ito, F., and Takashima, F., 1993. Female reproductive biology and oocyte development of the red frog crab, *Ranina ranina*, off Hachijojima, Izu Islands, Japan. *Marine Biology*, *115*, pp. 613-623.

Minagawa, M and Murano, M., 1993a. Effects of prey density on survival, feeding rate, and development of zoeas of the red frog crab *Ranina ranina* (Crustacea, Decapoda, raninidae). *Aquaculture*, *113*, pp. 91-100.

Minagawa, M. and Murano, M., 1993b. Larval feeding rhythms and food consumption by the red frog crab *Ranina ranina* (Decapoda, Raninidae) under laboratory conditions. *Aquaculture*, *113*, pp. 251-160.

Minagawa, M., Chiu, J.R., Kudo, M., and Takashima, F.,1994. Male reproductive biology of the red frog crab, *Ranina ranina*, off Hachijojima, Izu Islands, Japan. Marine Biology, *118*, pp. 393-401.

Onizuka, E.W., 1972. Management and development investigations of the Kona crab, *Ranina ranina* (Linnaeus). Div. Fish and Game, Dept. Land and Nat. Res. Report, Honolulu, Hawaii, pp. 1-11.

Pecl, G.T., Ward, T., Doubleday, Z., Clarke, S., Day, J., Dixon, C., Frusher, S., Gibbs, P., Hobday, A., Hutchinson, N., Jennings, S., Jones, K., Li, X., Spooner, D., and Stoklosa, R., 2011. Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia. Part 1: Fisheries and Aquaculture Risk Assessment. Fisheries Research and Development Corporation, Project 2009/070.

Power, M. and Power, G., 1996. Comparing Minimum size and slot limits for Brook Trout management. *North American Journal of Fisheries Management*, *16*, pp. 49-62.

Sheehy, M.J. and A.E. Prior, 2008. Progress on an old question for stock assessment of the edible crab *Cancer pagurus*. *Marine Ecology Progress Series*, *353*, pp. 191-202.

Skinner, D.G. and B.J. Hill, 1986. Catch rate and emergence of male and female spanner crabs (*Ranina ranina*) in Australia. *Marine Biology*, *91*, pp. 461-465.

Skinner, D.G. and Hill, B.J., 1987. Feeding and Reproductive behavior and their effect of catch-ability of the spanner crab *Ranina ranina*. *Marine Biology*, *94*, pp. 211-218.

Smith, K.S., 1993. An ecological perspective on inshore fisheries in the Main Hawaiian Islands. *Marine Fisheries Review*, *55*, pp. 34-49.

Sumpton, W.D., Brown, I.W., and Kennelly, S.J., 1993. Fishing gears that minimize the damage incurred by discarded spanner crab (*Ranina ranina*): Laboratory and field experiments. *Fisheries Research*, *22*, pp. 11-27.

Tahil, A.S., 1983. Reproductive period and exploitation of the red frog crab, *Ranina ranina* (Linnaeus, 1758) in central Tawi-Tawi, Philippines. *The Philippine Scientist*, *20*, pp. 57-72.

Uchida, R.N. and Uchiyama, J.H., 1986. Fishery atlas of the Northwestern Hawaiian Islands. NOAA Technical Report NMFS, 38, pp. 70-71.

Vansant, J.P., 1978. A survey of the Hawaiian Kona crab fishery. Thesis for the degree of Master of Science (University of Hawaii). *Oceanography*, pp. 1-59.