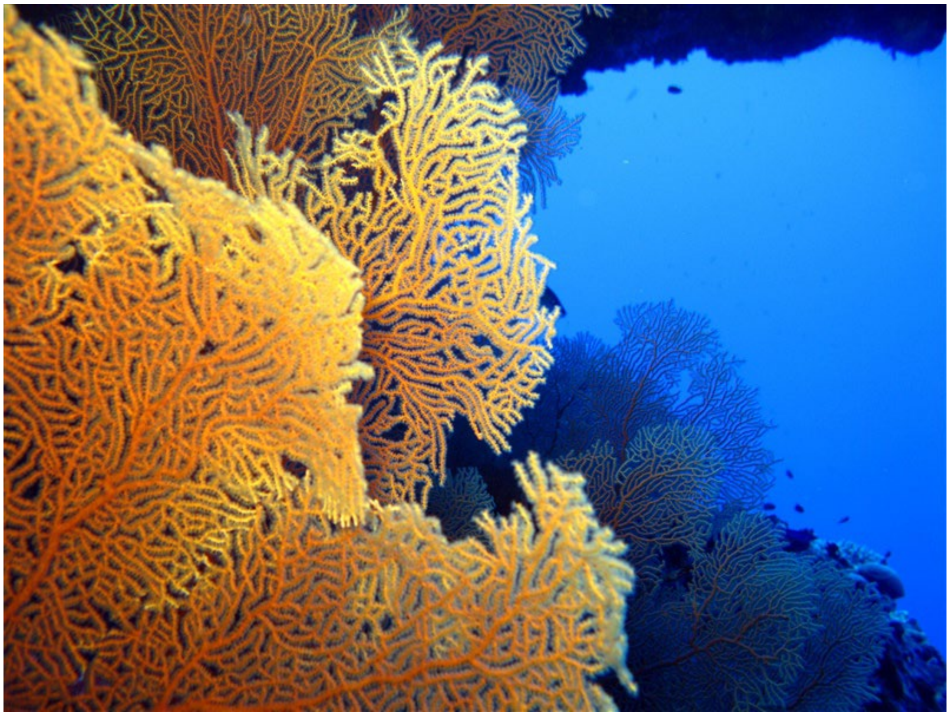
An Overview of Marine Research in the Mariana Archipelago: 1900–2018



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Cover: Orange gorgonian coral bushes in the Commonwealth of the Northern Mariana Islands, 2009.
NOAA Fisheries/Kevin Lino

An Overview of Marine Research in the Mariana Archipelago 1900–2018

Executive Summary

This technical memorandum summarizes "recent" marine research in the Mariana Archipelago, limited here to work conducted from the early 1900s through the end of 2018 (some published as late as 2020). This includes everything from exploratory research and experimental fishing at the end of the European colonial period in the Marianas, up to and including more contemporary marine research, with an emphasis on work conducted since 1970 by the U.S. National Marine Fisheries Service (NOAA Fisheries) and fisheries management agencies of Guam and the Commonwealth of the Northern Mariana Islands (CNMI).

In January 2009, Proclamation 8335 established the Marianas Trench Marine National Monument (MTMNM), under the authority of the Antiquities Act (16 US Code § 431-433), encompassing approximately 95,216 square miles of submerged lands and waters of the Mariana Archipelago (74 FR 1557, 2009). This research overview supports the proclamation's requirement that the management plan for the monument should provide for a program to assess and promote monument-related scientific exploration and research, tourism, and recreational and economic activities and opportunities in the CNMI. It also acknowledges the Mariana Archipelagic Ecosystem in a holistic manner, including Guam and the MTMNM Trench Unit (see Figure 1), consistent with the ecosystem-based fisheries management (EBFM) goals of NOAA Fisheries.

Recognizing that developing such programs should be based on an understanding of information that is already available, in May 2013, resource managers, scientists, and community members from Guam and the CNMI conducted a workshop to gain insight into past, present, and potential marine research in the Mariana Archipelago (Breuer et al., 2014). The workshop identified many completed and ongoing studies in the Marianas and noted the need for an inventory of marine research in and around the MTMNM. Participants said this inventory would ideally include geographic information on regional habitats, species distributions, human impacts, and uses of marine resources. This technical memorandum is designed to provide the background information requested by workshop participants, with geographic references where available. The number of references identified in each of nine general categories, defined through the workshop, is summarized below.

Generalized Research Category *(identified via the workshop)*	**Geographic references**[1]	**Total References**[2]
1) Archaeological and ancient human history	10	28
2) Ecology and ecosystem/fisheries monitoring	11	192
3) Expeditions, deep sea exploration, and geography	35	49
4) Island flora and natural history	17	47
5) Marine biology, life history, and evolutionary biology	16	181
6) Socioeconomic monitoring and human dimensions[3]	6	95

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[1] "Geographic references" may include research in more than one category, depending on the types of work conducted during a given expedition, cruise, or survey. For a more detailed geographic breakdown by research type, see Appendix 1 (p. 75)

[2] "Total references" is not duplicative. A judgement call was made on the primary type for each publication, placing it in a unique category, so the sum of total references equals the total number of entries in the list of Literature Cited (p. 98).

[3] Research on mechanisms of human impact (pollution, toxicity, erosion, sedimentation, etc.) is generally included in Category 6 unless the research is strictly oceanographic or biochemical analysis.

Generalized Research Category *(identified via the workshop)*	**Geographic references[1]**	**Total References[2]**
7) Oceanography, climate, geochemistry, and physical sciences	19	129
8) Population/ecosystem modeling and stock assessment	3	76
9) Legal (laws and legal references)	6	65
Total References	**123**	**862**

In developing a summary of marine research in the region, the United States exclusive economic zone (EEZ) around the CNMI and Guam (including submerged lands) was chosen as the geographic framework. This is in keeping with the life history and range of marine and estuarine species (with the exception of highly migratory species) and fits the jurisdictions of the resource agencies conducting most of the work described in this compendium. Investigations of coastal estuarine ecosystems and fisheries, anadromous fishes, and impacts (e.g., runoff) that transcend jurisdictional boundaries is included, mainly conducted by CNMI and Guam researchers from institutions and agencies that collaborate with NOAA in fisheries, reef, and ecosystem research and monitoring.

In addition to a listing of known marine research in the region, this technical memorandum provides a summary of geological and oceanographic factors that have produced this unique biogeographic setting plus a brief overview of natural and human history in the region. Following this general overview of topics and background, the reference list includes marine-related research spanning the past century and a wide range of disciplines. References with discrete geographic boundaries are also categorized by discipline in Appendix 1.

This is not an exhaustive list of all marine research in the Marianas. It is a compilation of much of the English language marine literature with a focus on research conducted in support of federal and local marine resource management mandates. However, each of its references contains a wealth of other information. Because of our intention to include available marine research references for the region and the practical need to provide this listing in a succinct format, this compendium is simply intended to serve as a link to information for the interested reader. This is what the stakeholders requested during the 2013 workshop, so this report is an effort to make sure this information is readily accessible to the public.

For practical reasons, this review is bookended at 1900 and 2018. Work that was planned or in progress when the authors convened to produce final drafts may be covered in an update. A few additional NMFS references are not directly summarized in the text but were considered relevant enough to include in this compendium. These follow the list of literature cited.

Table of Contents

List of Tables

LIST OF FIGURES

LIST OF ACRONYMS

AGU	American Geophysical Union
BECQ	CNMI Bureau of Environmental and Coastal Quality
BSP	Guam Bureau of Statistics and Plans
CNMI	Commonwealth of the Northern Mariana Islands refers to the period after 1976, when the NMI became a commonwealth.
CFBS	Commercial Fisheries Bio-Sampling (NMFS, PIFSC) program
CPDS	Commercial Purchase Data Systems (Guam DAWR/JIMAR, CNMI DFW data collections and data summaries in association with PIFSC WPacFIN)
CRCP	NOAA, NMFS, Coral Reef Conservation Program
CRED/CREP	PIFSC, formerly Coral Reef Ecosystem Division, now Coral Reef Ecosystem Program
COTs	Crown of thorns starfish *(Acanthaster planci)*
Covenant	Public Law 94-241. ("The Covenant") US Covenant to Establish a Commonwealth of the Northern Mariana Islands in Political Union with the US
DAWR	Guam Division of Aquatic and Wildlife Resources, Department of Agriculture
DFW	CNMI Division of Fish and Wildlife, Department of Lands and Natural Resources
DOC	U.S. Department of Commerce
EBFM	Ecosystem-Based Fisheries Management
EEZ	Exclusive Economic Zone (200 nautical mile international maritime boundaries established under the United Nations Law of the Sea Convention)
ENSO	El Niño Southern Oscillation
FEP	Fishery Ecosystem Plan
FMP	Fisheries Management Plan
FSM	Federated States of Micronesia (Yap, Chuuk, Pohnpei and Kosrae)
FUS	Fisheries of the United States (a NMFS summary of estimated domestic fishery landings)
GovGuam	The Guam Government's popular acronym
GFCA	Guam Fishermen's Cooperative Association (also "the Coop")
HMS	Her Majesty's Ship (British vessel)
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JIMAR	Joint Institute for Marine and Atmospheric Research, Univ. Hawaii at Mānoa, Honolulu
LME	Large Marine Ecosystems, as defined under a NOAA Fisheries' global EBFM project (see https://celebrating200years.noaa.gov/breakthroughs/ecosystems/welcome.html and refer to NOAA LME 2022, an online bibliography, at the end of the reference listing).
MARAMP/RAMP	Marianas Rapid Assessment Monitoring Program, a PIFSC CREP monitoring program
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MPA	Marine Protected Area
MTMNM	Marianas Trench Marine National Monument (also "the Monument")
MUS	Management Unit Species, subject to NMFS and Council fishing limits
NAVFAC	Naval Facilities Engineering Command Pacific
NMFS	National Marine Fisheries Service (also "NOAA Fisheries")
NMI	If capitalized, refers to the CNMI prior to becoming a commonwealth

NOAA	National Oceanic and Atmospheric Administration, U.S. Department of Commerce
OER	NOAA, Office of Ocean Exploration and Research
PFRP	Pelagic Fisheries Research Program, University of Hawaiʻi at Mānoa
PIFSC	(NMFS) Pacific Islands Fisheries Science Center
PIRO	(NMFS) Pacific Islands Regional Office
PIR	U.S. Pacific Islands Region (Guam, CNMI, American Samoa, Hawaiʻi and the PRIA)
PRIA	(U.S.) Pacific Remote Island Areas (Kingman Reef; Palmyra and Johnston Atolls; and Howland, Baker, Jarvis, and Wake Islands)
PSD	PIFSC's Protected Species Division
RAIOMA	Resource Assessment Investigation of the Mariana Archipelago, 1981 NMFS surveys
SOEST	School of Ocean and Earth Science and Technology, Univ. Hawaʻii at Mānoa, Honolulu
WERI	Water and Environmental Research Institute of the Western Pacific, University of Guam
WPacFIN	Western Pacific Fishery Information Network (a NMFS fisheries monitoring data program)
WPRFMC	Western Pacific Regional Fishery Management Council (also “the Council”)
WWII	World War II
UoGML	University of Guam Marine Laboratory
USGS	United States Geological Survey, US Department of the Interior
USFWS	United States Fish and Wildlife Service, U.S. Department of the Interior
USACE	United States Army Corps of Engineers

Acknowledgements and Dedication

This overview is dedicated to the memory of Hokuala Kari Johnson (1978- 2020) in hopes that her tireless efforts to inform the public about the frontiers of marine research and opportunities for marine stewardship that opened up through creation of a marine national monument in the Mariana Archipelago may inspire a new generation to lead the way.

We wish to thank Eric Cruz for his careful review and editorial input to this document, as well as Alexander Gaos and Marie Hill for their detailed reviews and contributions to the sections on marine turtles and cetaceans, respectively.

We also thank Eric Breuer, who put a lot of work into the original drafts when the intent was to deliver a science planning document for the Mariana Trench Marine National Monument. In response to public input in 2013, those drafts evolved into the current document which is intended to provide perspective on marine research to date so that gaps and needs can be identified to aid future science planning. Breuer’s contributions have been incorporated into this report despite its changed objectives.

Last but not least, our sincerest mahalo to Jill M. Coyle for her patience and care reviewing and editing this manuscript.

Introduction and Background

In January 2009, the Marianas Trench Marine National Monument (MTMNM) was established by Proclamation 8335[4]. It encompasses approximately 95,216 square miles of submerged lands and waters of the Mariana Archipelago (74 FR 1557, 2009; see Figure 1). This research overview supports the Proclamation's requirement that the Monument's management plan provide for, among other things, "a program to assess and promote monument-related scientific exploration and research, tourism, and recreational and economic activities and opportunities in the Commonwealth of the Northern Mariana Islands" (CNMI). Although the MTMNM is more geographically limited due in part to the stipulations of the Antiquities Act (see footnote 4), the scope of this compendium includes the U.S. Exclusive Economic Zone (EEZ) and territorial submerged lands around the CNMI and Guam. This broader scope acknowledges the Mariana Archipelago in a more holistic manner consistent with the ecosystem-based fisheries management (EBFM) goals of NOAA Fisheries and is more inclusive of the life history and home range of the marine species it sustains, as well as the jurisdictions of the resource agencies conducting most of the work described.

We should also acknowledge that the perspective of this research overview is driven by the NOAA Fisheries Mission (https://www.fisheries.noaa.gov/about-us). As such, it focuses on research in support of the management of living marine resources. Therefore, this overview is by no means comprehensive, nor is it equally weighted in all scientific disciplines. This is not an exhaustive list of all marine research in the Marianas. Rather, it is a compilation of much of the English language marine literature, with a focus on research conducted in support of federal and local marine resource management mandates. However, each of the references contained herein links to a wealth of more broadly-focused information. In this regard, we hope it may serve as a bridge to a more expansive research perspective.

Recognizing that efforts to develop the research and education programs prescribed in Proclamation 8335 should be founded upon an understanding of available information, resource managers, scientists, and community members from Guam and the CNMI conducted a workshop in May 2013 to gain insight into past, current, and potential marine research in the Mariana Archipelago (Breuer et al., 2014). Participants brainstormed existing and potential research, identifying nine general research categories within which they provided as much information as possible. They identified many completed and ongoing studies in the Marianas, but concluded this inventory would be incomplete if based solely on input from workshop participants. Among their concerns was that though a lot of research had been done, the publications were not easy to find, especially in Guam and the CNMI where the work was conducted.

Participants subsequently requested a systematic inventory of marine research in and around the MTMNM. They wanted that inventory to include geographic information on regional habitats, species distributions, human impacts, and uses of marine resources. This technical memorandum is designed to provide the background information requested, with geographic references where available. The number of references in each of the

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[4] Under the authority of the Antiquities Act (16 US Code § 431-433), which authorizes the President, in his discretion, to declare by public proclamation historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest that are situated upon lands owned or controlled by the Government of the United States to be national monuments, and to reserve as a part thereof parcels of land, the limits of which in all cases shall be confined to the smallest area compatible with the proper care and management of the objects to be protected.

nine categories defined through the workshop is summarized below. Because of our intention to include as much published marine research for the region as possible and the practical need to provide this listing in a succinct format, this compendium is simply intended to serve as a link to the information for the interested reader. This compilation can be used directly to find the reports we were able to locate. Its publication will be followed up with an outreach effort to ensure this information is readily accessible to the public to better inform future research planning efforts.

The temporal scope of this research inventory is limited to the early 1900s through the end of 2018, although some of the research towards the end of this period was published in 2020. It encompasses everything from exploratory research and experimental fishing at the end of the European colonial period in the Marianas, up to and including more contemporary marine research, with an emphasis on work conducted since 1970 by the U.S. National Marine Fisheries Service (NOAA Fisheries) and the fisheries management agencies of Guam (DAWR and BSP, *see acronyms p. ix*) and the Commonwealth of the Northern Mariana Islands (DFW). Additional research, planned or in progress when the final draft of this report was completed, will be covered in an update. A few additional NMFS references are not directly summarized in the text but were considered relevant enough to include in this compendium. These can be found at the end of the literature cited section (p. 156).

In addition to a listing of known marine research and a brief overview of natural and human history in the region, this technical memorandum provides a summary of geological and oceanographic factors that have produced the unique biogeographic setting in the Mariana Archipelago. Following this overview for Guam and the CNMI, a compendium of marine-related research spanning the past century and a wide range of disciplines is provided in the reference list. References with discrete geographic boundaries are also categorized by discipline in Appendix 1.

Generalized Research Category *(identified via the workshop)*	**Geographic references**[5]	**Total References**[6]
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The Mariana Archipelago Marine Ecosystem and its EEZ

The Mariana Archipelago spans about 157 nautical miles of the northern Indo-Pacific, with a combined Exclusive Economic Zone (EEZ) of over 290,000 square nautical miles. The expansive Mariana Archipelago EEZ is the actual geographic framework for this review, although its boundaries are broader than any legal definition of an archipelago[8]. Although the impetus for this overview of marine research was the creation of the MTMNM, the geographic framework of this compendium aligns with the management authority of the primary agencies conducting marine research in the region. This broad scope allows monument managers and the community of the Marianas to explore how past and ongoing research, assessments, and monitoring may inform the development of a program designed for the proper care and management of monument resources, including populations moving freely back/forth across its boundaries.

The MTMNM itself encompasses many unique and highly diverse marine ecosystems. The 95,216-square mile monument is comprised of three "units" (Figures 1 and 3):

- the waters and submerged lands of the three northernmost Mariana Islands (''Islands Unit''),
- submerged lands for designated volcanic sites (''Volcanic Unit''), and
- the Mariana Trench (''Trench Unit'').

Within this region, bounded to the northwest by Japan and the Philippine Sea, and to the south by the Federated States of Micronesia (FSM, Figure 1), lie Guam and the Commonwealth of the Northern Mariana Islands (CNMI). The Archipelago is comprised of sixteen fairly large emergent land masses (including the island of Guam), hundreds of tiny islets, half a dozen shallow banks, and several hundred miles of relatively unexplored marine trenches and canyons. One of the most active volcanic regions on Earth, there are more than 60 undersea volcanoes and at least 20 hydrothermal vent fields, hosting a broad range of marine organisms (NOAA OER, 2016; NOAA PMEL, 2019).

At the tip of the "Coral Triangle", this region lies within one of the most diverse marine biogeographic provinces in the world and a place where currents unite and intersect oceanic regions of high diversity and endemism (DeWitt, 1972; Roberts et al, 2002; Meyer et al., 2007; Spalding et al., 2007; Allen, 2008; Briggs and Bowen, 2011; Belanger et al., 2012; Bowen et al., 2013; Kulbicki et al., 2013; Costello et al., 2017). The Archipelago hosts more than 700 species of corals, 3,000 coral reef fishes (including amphidromous gobies, Lindstrom et al., 2012), and invertebrates, and many wide-ranging pelagic fishes, sea turtles, seabirds, and marine mammals (Springer, 1982; Vermeij et al., 1983; Eldredge, 2003a, b; Randall, 1995, 2003; Steadman, 1999; Richardson and Clayshulte, 2003; Smith 2003; Maison et al., 2010). Over 5,600 marine species have been enumerated for Guam alone, yet little is known about most of them and many more have yet to be described (UoGML, 1981; Mclay, 2001; Paulay, 2003a; Brown et al., 2016).

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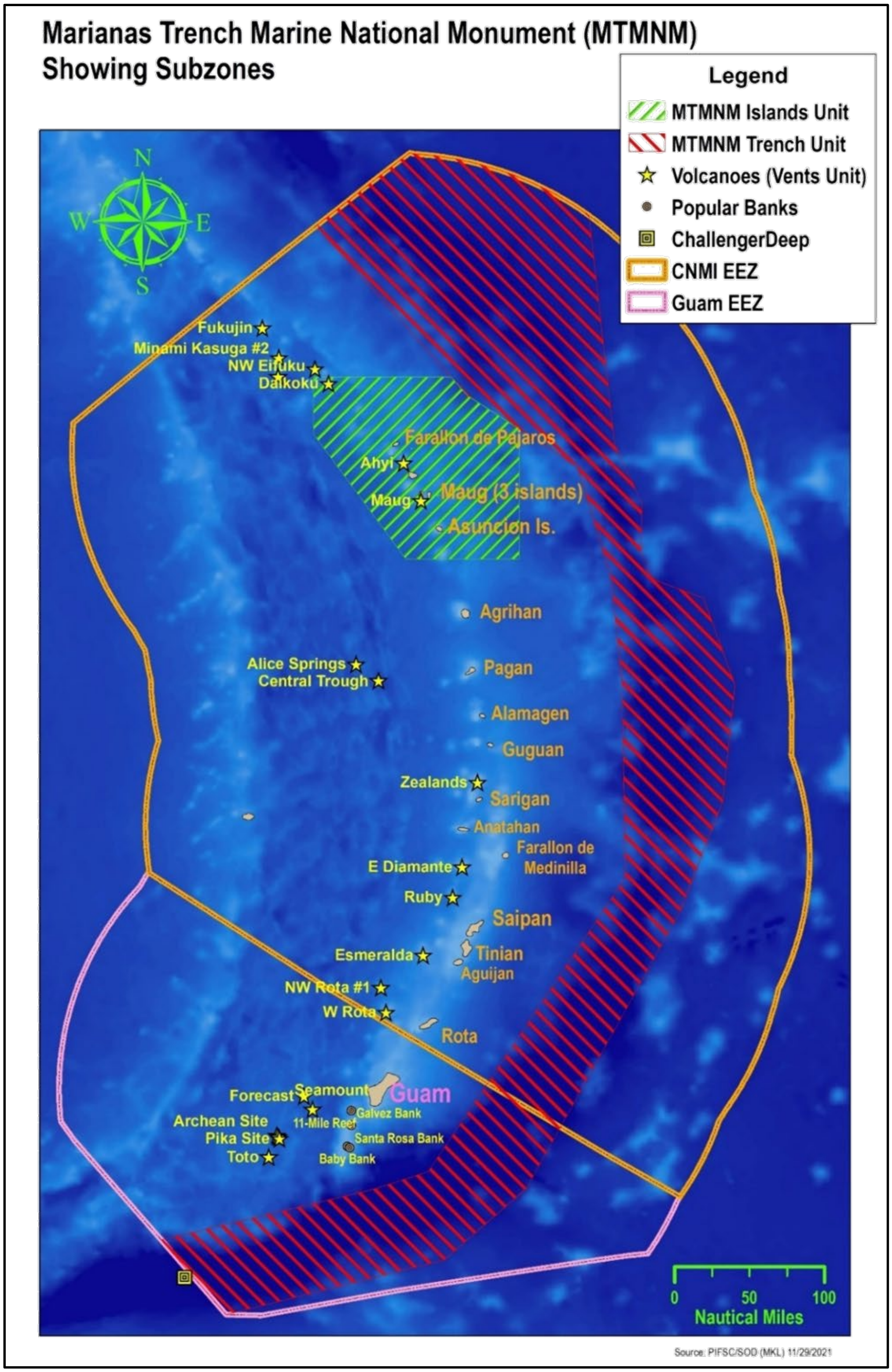
[8] A discussion of topographic and hydrological aspects, or maritime law considerations used in defining archipelago boundaries, is well beyond the scope of this report. We rely simplistically on the 200 nautical mile EEZ, the broadest political boundary accepted by the U.S., CNMI, Guam and the United Nations. Although it is outside the geographic limits of the most insular species, and it transects the migration and home range of many pelagic organisms, through territorial and international agreements, the 200 nmi EEZ allows sustainable management of coastal and highly migratory species. Its use also reflects that this compendium is framed within the context of the NOAA Fisheries Mission.



Source: PIFSC/SOD (MKL) 11/29/2021

Figure 1. Shaded bathymetric map showing the exclusive economic zones of the CNMI and Guam with the Mariana Trench Marine National Monument Trench and Islands Units, as well as submerged volcanic features and location of the Challenger Deep.

Geologic Origins

The geologic origins of the region are complex, characterized by the deep trench created by the tectonic subduction system at the northwestern boundary of the Pacific Plate, where it is thrust beneath the Philippine and Mariana Plates (Figure 2A). Part of the Ring of Fire in the western Pacific, the Indo-Australian Plate also exerts an influence on this zone from the south, creating a region bounded on three sides by volcanic activity and merging flora and fauna from several oceans. The southern islands are limestone formations with level terraces and fringing coral reefs, while the northern islands are steep and emergent volcanic peaks, vents, calderas, and ridges. The diversity of marine habitats that exists in this region, from shallow reefs to deep trenches, is also complex and compounded by the meeting of currents from the South China and Philippine Seas, as well as equatorial and subequatorial gyres and counter currents of the western Indo-Pacific. A brief overview of this ecological setting is provided in this chapter.

Since the discovery of the Challenger Deep in 1875, exploration of the Mariana Islands (including Guam) has been an area of international scientific intrigue (Theberge, 2009). The Mariana Islands are geologically divided into the older Southern Island Arc (Guam, Rota, Aguijan, Tinian, Saipan, Farallon de Medinilla) and the younger Volcanic Arc (Figures 2 and 3), including the northern islands (Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Farallon de Pajaros). The southern islands, along with the western Mariana ridge, are older remnants of the Mariana Arc-Trench system (Stern and Smoot, 1998; Embley et al., 2007). The northern islands are part of the currently active Mariana Volcanic Arc and the Izu-Bonin-Mariana (IBM) subduction system in which the Mesozoic Pacific Plate plunges beneath the Philippine Sea Plate and into the Earth's mantle (Eldredge, 1983b; Stern et al., 2003; Riegl et al., 2008; Lallemand, 2016). Back-arc spreading has caused the West Mariana Ridge to rift and form the Mariana Trough (or "back-arc"), which in turn displaced the fore-arc region farther east (Baker et al., 1996, 2017; Martinez et al., 1995; Martinez et al., 2000; Martinez and Taylor, 2003; Deschamps and Fujiwara, 2003; Deschamps et al., 2005; Anderson et al., 2017). Thus, there are two distinct environments where submarine volcanism occurs in the Mariana region: the Mariana Back-Arc (where plate spreading occurs), and the Mariana Arc (where subduction-related volcanism occurs).

The Mariana subduction system is non-accretionary, meaning that it lacks thick accumulations of oceanic or land-derived sediment in the fore-arc region. This enables scientists to make direct observations and more easily take samples of the lithosphere in the fore-arc near the trench and the subduction plate boundary (Fryer, 1996; Stern and Smoot, 1998). Older parts of the southern fore-arc have also been uplifted above sea level and, along with the southern inhabited Mariana Islands (Guam, Saipan, Tinian, Rota), all are composed of old uplifted marine and volcanic sediments with limestone caps (Farrell et al., 2011). The islands have not seen volcanic activity for about 10 million years which has allowed time for coral reefs to develop around them. The northern islands began forming about 5 million years ago and are still active volcanically. Unlike the southern islands, the northern islands do not have a limestone cap (Riegl et al., 2008). Saipan, Tinian, and southern Guam display emergent mid-Holocene paleoreef flats and paleoshoreline notches standing 1.2–2.0 meters above modern counterparts. Northern Guam and Rota display paleoshoreline emergences implying 0.8 and 1.2 meters of post-mid-Holocene tectonic uplift, respectively (Dickinson, 2000).

Six of the Archipelago's islands have been volcanically active in recent history and numerous seamounts along the Volcanic Arc are volcanically or hydrothermally active (Stern and Smoot, 1998; Embley et al., 2007; Baker et al., 2017). The island of Farallon de Pajaros *(translation "birds' cliff")* is one of the most active volcanoes in the archipelago. Historically known as the "Lighthouse of the Pacific," it has erupted at least 16 times since 1864, with an ash eruption as recently as 1978 (Eldredge, 1983a; Asakura and Furuki, 1994; Brainard et al., 2012). About half of the eruptions have produced lava flows. Eruptions at Farallon de Pajaros between 1975 and 1978 formed a major hydrothermal vent that was emitting an iron and manganese rich plume at the time of Eldredge's study. However, recent volcanic activity on the islands of Pagan and Anatahan may show a shift in volcanic activity in this area. The most recent explosive eruption from one of the Mariana islands was from Anatahan in 2003 (Chadwick et al., 2005; Trusdell et al., 2005). This generated a large ash plume and remained active for more than four years. Pagan volcano was also frequently active in the last century, but at a lower level overall (Lyons et al., 2014).

The island of Maug is composed of three islets East (Higashi-shima), West (Nishi-shima), and North (Kita-shima) that are the rim of an ancient volcano whose central caldera is now flooded by the sea (Eldredge, 1983a). There have been no known eruptions at Maug since 1522, but there are active hydrothermal vents underwater within the present caldera. Depths in the lagoon/caldera are as shallow as 22 m in the center to over 225 m on the caldera floor.

Following World War II, a number of research expeditions including members of the Pacific Vegetation Project were conducted, as described by Eldredge (1983a). American botanists Donald Anderson and F. Raymond Fosberg visited several islands from 1949–1950 and reported on the plants and geography of Pagan, Asuncion, Agrigan, and Guguan (Fosberg, 1958; Fosberg and Corwin, 1958). Geological field work began in 1952, when J.T. Stark and J.I. Tracey, Jr. visited Pagan to investigate the sulfur content of the inner lake. During the summer of 1954, a team of military engineers carried out the study which led to publications regarding the geology of Pagan (Corwin et al., 1957; Tracey et al., 1959). Although primarily a geological study, a number of natural history specimens were collected, including plants, insects, land snails, and other organisms. To date, the Corwin et al. (1957) report is the most extensive for any of the northern islands.

Although its most recent known eruption was in the 1920s, the island of Asuncion is also considered to be an active volcano, as evidenced by its intertidal hot springs (Eldredge, 1983a; Asakura and Furuki, 1994). Asuncion is the steepest of the northern volcanoes and has distinctive landslide scars and sea cliffs. A PIFSC cruise to the area during 2018 bore witness to ongoing landslides at Asuncion (Eric Cruz[9], pers. comm.).

The first deep-sea hydrothermal vents in the Mariana region were discovered by chance in the back-arc in the mid-1980s (Craig, 1987; Fautin and Hessler, 1989). The period of intensive research on vent locations, ecology, and chemistry that followed included discovery of new vents in the southern back-arc and ridge near 13°N (Campbell et al., 1987; Hessler et al., 1988; Hessler and Martin, 1989; Hessler and Lonsdale, 1991; Gamo and Shipboard Scientific Party, 1993; Johnson et al., 1993; Fujikura et al., 1997; Fryer et al., 1998; Mitsuzawa et al., 2000; Masuda et al., 2001; Ishibashi et al., 2004, 2015). The submarine parts of the Mariana Volcanic Arc were poorly known until 2003, when a NOAA-led program began with systematic exploration and surveys of the volcanic arc (Baker et al., 2008, 2017; Embley et al., 2004, 2007). Repeated geological expeditions, each building on the results of its predecessor, were conducted from 2003–2006 by researchers from NOAA,

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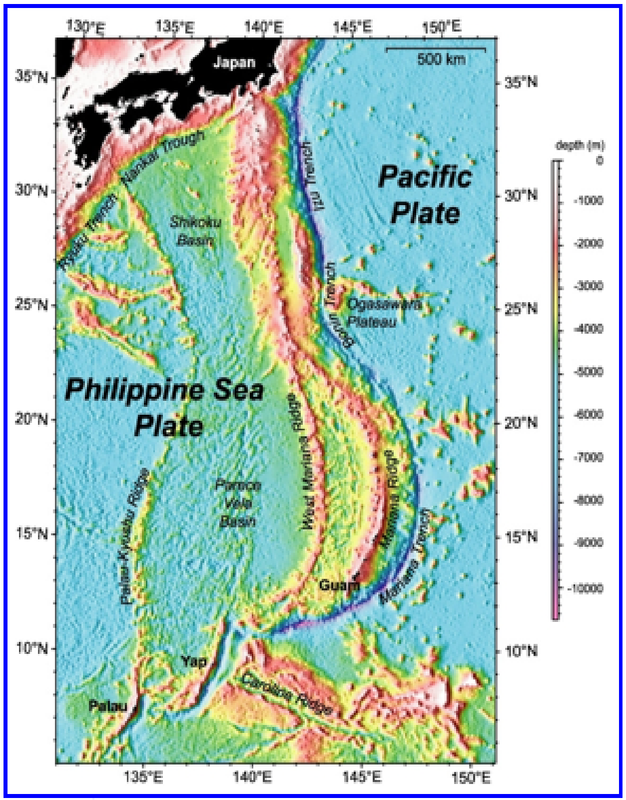
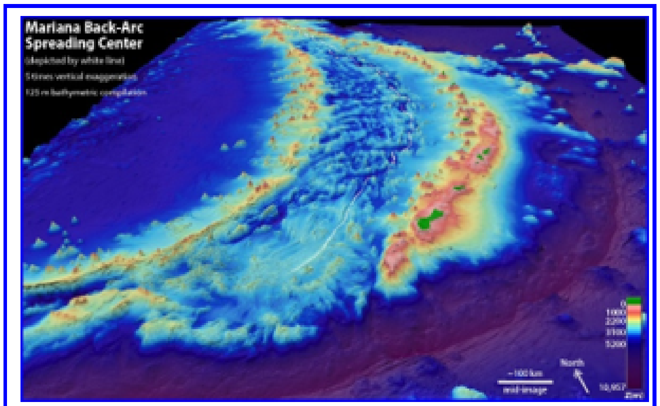
[9] Eric Cruz, Guam Field Operations Liaison, PIFSC Science Operations Division

cooperative institutes at the University of Washington and Oregon State University, and other collaborators (Wheat et al., 2003; Urabe et al., 2004; Baker et al., 2005; Kakegawa et al., 2008). They explored hydrothermally active submarine volcanoes throughout the Mariana Back-Arc using multibeam sonar, remotely operated vehicles (ROV), underwater video, and other instruments (Merle et al., 2003, 2004, 2006).



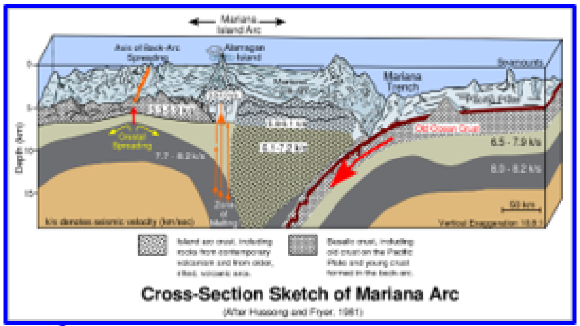
2A *(upper left)*: **Intersection of Phillippine Sea Plate and Pacific Plate showing, the West Mariana Ridge (Volcanic Arc), Mariana Ridge (Southern Arc), and Izu-Bonin and Mariana Trench (subduction zones)**

Source: Pacific Islands Benthic Habitat Mapping Center (PIBHMC), University of Hawaii, School of Ocean and Earth Sciences
http://www.soest.hawaii.edu/expeditions/mariana/images/regional_locator.jpg



2B *(upper right)*: Mariana Back-arc, showing seafloor colored by depth (purple deepest, red shallowest, green are islands above sea-level). White line indicates the back-arc spreading axis. The data are five times vertically exaggerated.

Source: 2015 R/V Falkor Expedition (Image by Susan Merle)
https://www.pmel.noaa.gov/eoi/marianas/images/backarc-5xve-sc-drape-lores.jpg



2C *(lower right)*: **Cross-Section of Mariana Arc**

Source: NOAA Ocean Explorer Gallery
After Hussong and Fryer (1981) Redrawn 2009 by Vanessa Ezekowitz
https://oceanexplorer.noaa.gov/explorations/03fire/background/plan/media/xsection.html

Figure 2. Mariana Archipelago Geologic Zones—Showing the (older, inactive) Southern Arc, (younger, active) Volcanic Arc and Mariana Trough/Trench (Back-Arc/Subduction Zone).

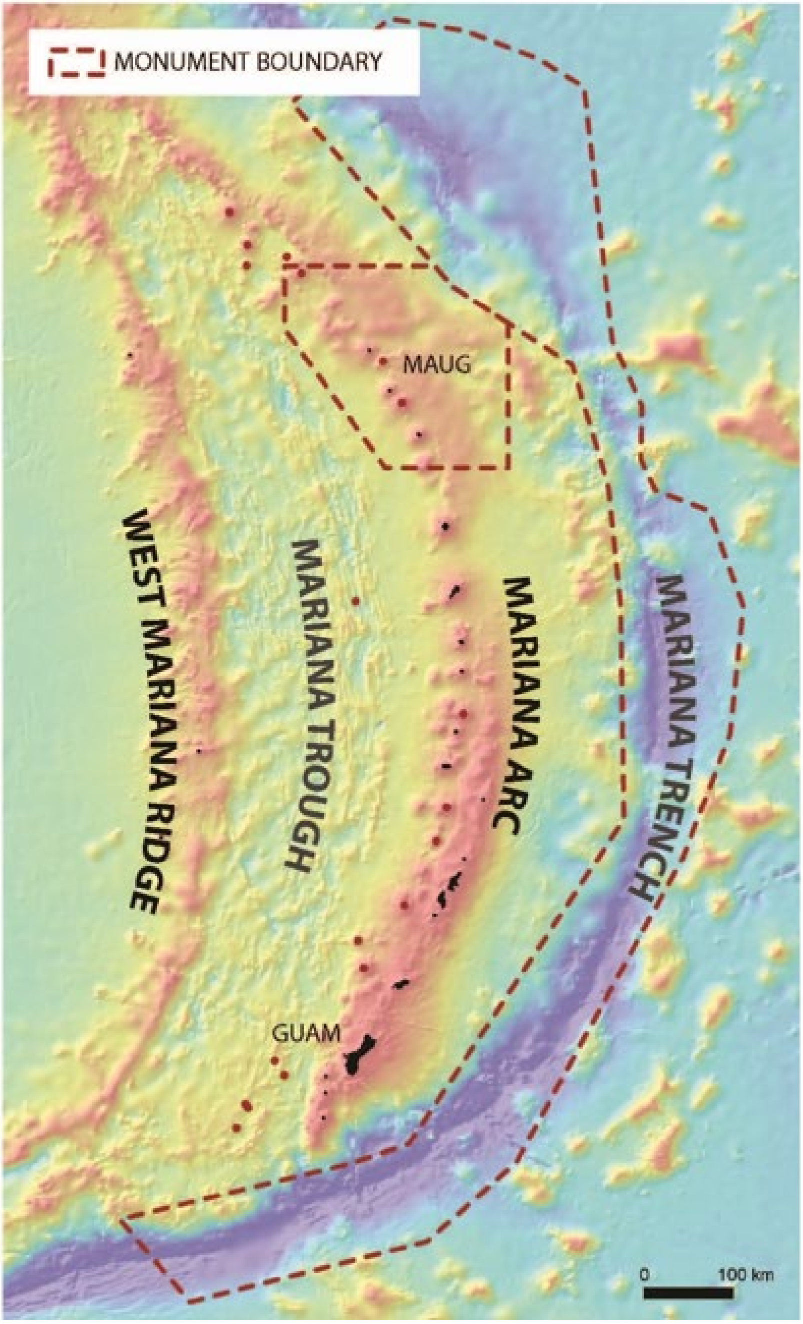


Figure 3. Location of the monument (MTMNM) in relation to major geologic features. **MTMNM includes** Mariana Trench **(Trench Unit),** the 3 northernmost islands of the Mariana Arc **(Islands Unit)**, and volcanic features (**Volcanic Unit**, "Ring of Fire") appearing as red dots between the Mariana Trough and Arc. **Source:** Brainard et al., 2012.

The 2006 expedition observed the on-going eruption of NW Rota-1 volcano to be even more active than detected in previous expeditions. Low-level eruptive activity continues to be documented at NW Rota-1 submarine volcano (Embley et al., 2006a; Chadwick et al., 2008; Butterfield et al., 2011; Deardorff et al., 2011; Chadwick et al., 2012). NW Rota-1 is also noteworthy as the first site where an active submarine volcanic eruption was directly observed using a remotely operated vehicle (Fox et al., 2001). The most recent submarine eruption that reached the atmosphere was at South Sarigan Seamount, which experienced a brief explosion and generated an ash plume in May 2010.

Since 2006, most of the sea floor and submarine volcanoes in the volcanic arc have been mapped with multibeam (and some sidescan) sonar. Searches for indices of hydrothermal venting in the water column above each volcano have found that about 30% of the Marianas submarine volcanoes are hydrothermally active (Embley et al., 2006b, 2007; Baker et al., 2008; Starmer et al., 2008a; Resing et al., 2009; Bobbitt, 2010; Gardner et al., 2014). New ecosystems were discovered and characterized, and extraordinary sites from 2004 have been revisited, providing new insights into their remarkable environments (Resing et al., 2016). Sites selected for the Volcano Unit of the MTMNM reflected known vent locations when the Monument was created in 2009 (Baker et al., 2008), but more hydrothermal vents have been and continue to be discovered, especially in the Mariana Back-arc region (Yoshikawa et al., 2012; Nakamura et al., 2013; Ikehata et al., 2014; Anderson et al., 2017; Baker et al., 2017).

Both the Smithsonian Global Volcanism Program[10] and the InterRidge[11] program have put together websites that collate and present information and publications for volcanoes and vents throughout the oceans, including the MTMNM Volcanic Unit. A complete list of known geological and hydrothermal explorations through 2018 plus other research expeditions covering geothermal flora and fauna is included in Appendix 1.

Oceanography and Climate

The Mariana Archipelago as a whole (Guam and the CNMI) is characterized by a hot and humid tropical climate with mean annual air temperatures of 27 °C and a daily fluctuation of about ±6 °C. Relative humidity ranges between 65–80% during the day and 85–100% at night (Riegl et al., 2008). The climate of the northern islands is considered somewhat subtropical, as indicated by a decrease in humidity, temperature, and rainfall heading north from Guam. For example, the more northerly islands of Maug (see Figure 3) have a mean air temperature of 26.4 °C and annual precipitation of 156.7 cm (Eldredge et al., 1977). Located closer to the equator (13.4º N. latitude), Guam's weather is hotter and more humid.

There are distinct wet and dry seasons throughout the Archipelago. About 65–70% of the rainfall occurs during the wet (monsoon) season, from June or July through November or December. The dry season is from roughly January to June (Riegl et al., 2008). About every four years, the islands experience a dry year as a result of the El Niño Southern Oscillation (ENSO). The impacts of weather in the region play an important ecological role, shaping reef and coastal features; driving the distribution, growth, regrowth and species composition of coastal marine assemblages along the prevailing faces of islands within the Archipelago; and influencing seasonal and annual trends in inshore and pelagic fisheries (Randall and Eldredge, 1977; Ogg and Koslow, 1978; Vermeij, 1983; Kerr et al., 1993; Hamnett and Anderson, 2000; Paulay, 2003a; Randall, 2003; Asami et al., 2004, 2005).

The western Pacific is dominated by the east and northeast trade winds. The Archipelago itself is affected by northeast trade winds throughout most of the year, except during the summer months (roughly June–August), when the easterlies often dominate the region (Coast Pilot, 2019). Between latitudes 20–25°N (where the

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[10] Smithsonian website: https://volcano.si.edu/

[11] InterRidge website: https://www.interridge.org

MTMNM Islands Unit is located), northeast and east winds occur about 47% of the time, with a mean velocity of 10.1 knots (Eldredge, 1983a). In the northernmost islands, winds are from the east during May–July, and from the west the rest of the year (Furey, 2006).

Tropical typhoons occur primarily during the wet season throughout the Archipelago. Guam and the CNMI are located in an area commonly known as "typhoon alley," adjacent to a breeding ground for tropical cyclones in the western Pacific. Many cyclonic disturbances form in this region before heading to Asia and can quickly develop into typhoon force winds of 120 miles per hour or greater (CNMI Guide, 2019). On average, the area experiences 1–2 typhoons per year (Eldredge et al., 1977), and a supertyphoon hits one of the islands of the CNMI approximately every 10 years (Furey, 2006). Between 1962 and 1971, five typhoons are thought to have passed either over or very near Maug, based on extrapolations of storms that affected Guam (Eldredge et al., 1977). Whether or not the intensity and frequency of storms is increasing as global weather patterns adapt to climate change is the subject of considerable ongoing research[12].

Storms typically form in the region near the Federated States of Micronesia (or in the Philippines) and track to the north and either west (or east) as they increase intensity. This means that more powerful winds and storm activity, even within the progression of a single storm, will often be seen in the CNMI. For example, an average 7.2 typhoons move within 300 miles of Maug every year (Eldredge et al., 1977) which is well above the average for the whole Archipelago. Guam is east and southeast of the primary area of activity (Crutcher and Quayle 1974) and tends to experience less powerful and direct storm activity than is seen in the CNMI. Its widespread islands and larger EEZ increase the chances for the CNMI to be in the strike zone, and its small, low-lying islands make severe damage more likely if hit.

Several super typhoons have hit the Marianas in recent decades (NOCC/JTWC, 1991; NHC-CPHC, 2019; NOAA NCEI, 2022). Typhoon Soudelor, with reported wind gusts of 105 mph, caused widespread destruction when it hit Saipan on August 2, 2015, knocking out power grids and water supplies and destroying more than 384 homes (Ayers, 2018). Saipan was devastated again on October 24, 2018, when Category 5 Super Typhoon Yutu, the strongest typhoon on record to impact the Marianas, passed over Tinian and Saipan causing catastrophic damage. The storm produced waves approaching 45 feet, blowing considerable debris into nearshore waters and damaging coral reefs on Saipan and Tinian. Guam was last hit by a super typhoon December 8, 2002, when Typhoon Pongsona (Category 4) made landfall with near-peak winds of 175 km/h (109 mph or 94.4 knots), causing over $730 million in damages. The northern end of the island was in the eye of the storm for two hours. Guam was left without power and water, most communication lines were inoperable, and lightening caused fuel tanks to catch on fire, burning most of the island's fuel reserves.

A summary of major tropical cyclones affecting the islands of the Mariana Archipelago is provided in Appendix 2. Increasingly detailed information has been recorded and tracked since the 1950s, so there may have been more untracked storms during the early 1900s. The appendix notes winds registered within the Archipelago where available, but in some cases, higher winds occurred beyond Guam or even beyond the northernmost CNMI. Since storms in this region tend to intensify as they move north, in many cases the maximum category reached

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[12] See, for example: https://climate.nasa.gov/ask-nasa-climate/2956/how-climate-change-may-be-impacting-storms-over-earths-tropical-oceans/ or https://www.gfdl.noaa.gov/global-warming-and-hurricanes/

and greatest landfall impacts were seen somewhere along the coast of Southeast Asia, from the Sea of Japan to the South China Sea.

Climate Change, Ocean Acidification, and other Global and Coastal Human Impacts

Like many tropical marine ecosystems supporting coral reef and other organisms that depend on near-surface conditions such as sunlight, temperature, and pH for their successful growth and development, there are concerns for human impacts that may drastically shape their future. Many of the impacts of key importance relate to the rising concentrations of carbon dioxide (CO_2) in the atmosphere as a result of the consumption and burning of fossil fuels. CO_2 levels are currently higher than have been seen in the past 650,000 years (Petit et al., 1999; Houghton, 2001; Augustin et al., 2004; IPCC, 2001, 2007; Fabry et al., 2008; Guinotte and Fabry, 2008). By 2065, atmospheric CO_2 levels are expected to have doubled in comparison with pre-Industrial Revolution values (Kleypas et al., 1999). As a result, surface pH has dropped 0.1 units since preindustrial days and is projected to drop another 0.3–0.4 units by the end of the century (Mehr et al., 1973; Lueker et al., 2000; Caldeira and Wickett, 2003; Caldeira et al., 2007; Feely et al., 2009). Current trends in atmospheric CO_2 are tracked in near real-time by NOAA's Global Monitoring Laboratory, and summaries for CO_2 and other greenhouse gases can be found at https://gml.noaa.gov/ccgg/trends/.

Numerous researchers have investigated the processes of anthropogenic carbon penetration, ocean acidification, and enhancement of UV-B radiation into the oceans (Brewer et al., 1997; Broecker et al., 1979; Chen and Millero, 1979; Chen and Pytkowicz, 1979; Feely and Chen, 1982; Beardall and Raven, 2003; Doney et al., 2009, 2012; Storlazzi et al., 2013). Evidence suggests that if this trend continues, important marine organisms such as corals and other benthic invertebrates, corraline algae, and plankton with calcareous body parts, will have difficulty maintaining their external skeletons, shells, and tests (Gattuso, et al., 1998, 1999; Sciandra et al., 2003; Delille et al., 2005; Orr et al., 2005; Gazeau et al., 2007; Kuffner et al., 2008; Dupont et al., 2010; Hofmann et al., 2010; Shinjo et al., 2013). Other impacts of concern include changes in photosynthetic processes affecting primary production and symbiosis (Durako, 1993; Hein and Sand-Jensen,1997; Gattuso, et al., 1999; Rost et al., 2003; Langdon and Atkinson, 2005), and changes in physiology and behavior of organisms affecting their growth or survival (Langer et al., 2006; Munday et al, 2011; Domenici et al., 2012; Nowicki et al., 2012). Subsequent changes in species distribution and abundance could have significant impacts on marine food webs and ecosystem processes (Rost and Riebesell, 2004; Barcelos e Ramos et al., 2007; Staudinger et al., 2012; Woodworth-Jefcoats et al., 2017). The implications of climate change for coastal planning in the CNMI are of increasing concern for these low-lying islands (Okano et al., 2015).

Volcanic activity has both direct and indirect impacts on the Mariana's marine biota (Vroom and Zgliczynski, 2011). The submarine volcanoes of the Mariana Arc emit high amounts of CO_2 because it is a magmatic gas (Lupton et al., 2006; Lupton et al., 2008). CO_2 is released as gas bubbles at shallow depths or as liquid droplets at greater depths and pressures. This leads to highly acidic conditions in the vicinity of the vents and volcanoes (Butterfield et al., 2011) that have been shown to have significant impacts on the shells of chemosynthetic mussel communities living nearby (Tunnicliffe et al., 2009). These effects have also been shown for coral reefs, coralline algae, gastropods, and associated reef organisms, in some cases causing enhanced growth of organisms that accelerate reef breakdown (Hall-Spencer et al., 2008; Enochs et al., 2015, 2016). Thus, the submarine volcanoes of the Mariana Back-arc are natural laboratories for the study of the impacts of high-CO_2 environments on marine ecosystems. These and adjacent habitats may also provide a natural laboratory for the study of the global sulfur cycle and other gases that play an important role in climate regulation (Van Alstyne et al., 2006).

Other anthropogenic and natural ecological signals relating to ocean and atmospheric circulation generate research interest in the Marianas. One such beacon has been present worldwide since thermonuclear testing in the Pacific Proving Grounds at Bikini and Enewetak atolls during the 1950s. The radiocarbon (^{14}C) found in coral cores from around Guam (Allen et al., 2016), throughout the Marianas (Konishi et al., 1982), and elsewhere in the Pacific, shows a series of early bomb-produced ^{14}C spikes. These spikes and the variability of other natural isotopes (e.g., isotopic oxygen, $\delta^{18}O$) present in marine organisms including algae can be used, among other things, to estimate reef growth rates, interpret temporal changes in hydrology and ocean-climate (Asami et al., 2004, 2005; Bell et al., 2011), age archaeological deposits (Carson, 2010; Carson and Peterson, 2012), reconstruct paleoceanographic records (Grottoli et al., 2010), and accurately determine the age of fishes.

There is also a considerable amount of literature on marine pollution, its sources, and impacts around the most populous islands of the Archipelago. Trace metals, PCBs, and mercury contamination in nearshore waters of Saipan and Guam has been shown (Denton et al., 2008a, b; Starmer et al., 2008b). Toxic compounds are also seen in sediments (Denton et al., 2001, 2005, 2006), algae (Schaible, 2010), and marine organisms including popular food fishes (Denton et al., 1999, 2006a, b, 2008a, b, 2010, 2011a, b; Starmer, 2005). Human impacts on nearshore water quality and coral reef health, including stormwater runoff, wastewater and sewage discharges, nearshore dumps, species introductions, sedimentation, and damages due to tourism have also been documented (Tsuda, 1971; Paulay, et al., 2002; Porter et al., 2005; Denton and Sian-Denton, 2007; Burdick et al., 2008; Starmer et al., 2008a, b; Denton and Morrison, 2009; Denton et al., 2008b, 2009, 2010, 2011a, b; Whitall et al., 2016; Morrison et al., 2013; Redding et al., 2013; McKinnon, 2015; Montambault et al., 2015; Gailani et al., 2016; Nelson et al., 2016). More subtle ecological effects such as varied resilience and tolerance to nutrients and heavy metals for different algal species, and population interactions relating to fishing, herbivory, and coral recruitment remain an area for research to improve our understanding of anthropogenic impacts (Kuffner and Paul, 2001; Mumby et al., 2012).

Surface Currents

Physical oceanography across the Mariana Archipelago and along its coasts is driven at and near the surface by three major currents; other currents produce large- and small-scale eddies and seasonal effects, some of which return cyclically to insular coasts of Guam and the CNMI (DeWitt, 1972; Wolanski et al., 2003; Furey, 2006; Kobashi and Shang-Ping, 2008; Richmond et al., 2008; Qiu and Chen, 2010; Chang and Oey, 2013; Suntsov and Domokos, 2013). The directions and influences of the main currents affecting marine community structure throughout the Archipelago are summarized in Table 1 and shown in Figure 4 (Spalding et al., 2007).

Like the winds, currents flow predominantly from east to west (“easterly”). They are strongest near to and south of Saipan, gradually weakening as one travels northward (Coast Pilot, 2019). The North Equatorial Current (NEC) circulates clockwise through Guam and the Marianas, transporting water to the west over the Mariana Volcanic Arc where it eventually flows into the Kuroshio Current. The Kuroshio drives north and east along the coast of Japan, helping to distribute surface flora and fauna from Asia and Indonesia. The North Equatorial Counter Current (NECC) heads east along the equator below Guam. The North Pacific Subtropical Counter Current (NPSCC or NPSTCC) and the South Pacific Subtropical Counter Current (SPSCC) head somewhat weakly towards the east, with multiple eddies, bringing diverse species from across the Pacific and Indo-Pacific to the Marianas and other regions (Chang and Oey, 2013).

Table 1. Prevailing Mariana Archipelago Ocean Surface Currents

Name	**Direction**	**Notes**
Kuroshio Current	Heads NE at Marianas then sweeps east towards Japan	Warm semi-tropical
North Equatorial Current (NEC)	Easterly (heading W) near Marianas then sweeps to NW and into the Kuroshio	Warm tropical water eventually joins Kuroshio
North Equatorial Counter Current (NECC)	Westerly (flowing west to east) just above the Equator (south of the NEC)	
North Pacific Subtropical Counter Current (NPSCC)	Westerly, flowing weakly to the east between 17–27°N lat. (seasonal)	Temperate water feeds into N. Pacific Current
South Pacific Subtropical Counter Current (SPSCC)	Westerly, flowing weakly to the east between 17–27°S lat.	Temperate water feeds into S. Pacific Current

Of these, the east to west flowing NEC is the prevailing oceanic circulation pattern influencing the Archipelago from June to December. The NEC surface layer is composed of southern low salinity water (<34.2 psu) and northern high salinity water (> 34.8 psu) with a salinity front at 15° N. lat., which fluctuates with the southern oscillation (Suntsov and Domokos, 2013). The NPSCC seasonally flows west to east around the northern islands (Minagawa et al., 1997; Wolanski et al., 2003; Brainard et al., 2012). Transient eddies form around topographic features of the larger islands, such as those along headlands and embayments of Guam, and larger seasonal eddies generate currents that are suggested to be sufficiently energetic to return fish and coral eggs and larvae to their natal reefs (Wolanski et al., 2003). At the surface, speeds of 30 cm s^{-1} have been recorded for the NEC (Eldredge, 1983a). Recent work has recorded mean flow speeds of 20–25 cm s^{-1} with decreasing flow speeds recorded around the Island Unit (Brainard et al., 2012). Towards the northern end of the Archipelago, the current moves somewhat to the north and turns into the Kuroshio Current (Eldredge, 1983a; Furey, 2006). An excellent summary of ocean circulation (surface to deep) and marine habitats for the region has been provided by DoN (2005, 2013).

The seasonal influence (June–September) of the NPSCC on the northern part of the Archipelago is a result of the weakening trade winds and can have a very significant regional impact, as witnessed by past coral bleaching events (Eldredge, 1983a; Bonjean and Lagerloef, 2002). Seasonal changes in the thermocline off Guam and reduction in the depth of the mixed layer during spring and summer stimulate changes in abundance and catch of important pelagic fishes, eggs, and larvae, among others, a symptom of greater seasonal changes in coastal ecosystems (Amesbury and Babin, 1990; Kawakami et al., 2010). The NEC prevails during the months when the trades remain strong and northeast swells are generated by moving cold fronts from the Asian continent.

Current flow is typically north-northeast around each island, except during tropical storm events which may cause a reversal in direction (Eldredge, 1983a; Richmond et al., 2008). These current patterns have significant impacts on the ecology of the Archipelago. For example, they influence coral composition in the region to resemble more closely that of the Marshall Islands than of Palau, although the Marianas are spatially closer to Palau (Randall, 1995; Richmond et al., 2008). The NECC, flowing west to east just south of the island chain, seems to also influence the southern portion of the Mariana Archipelago (Suntsov and Domokos, 2013). And the interaction of the NEC with island topography generates eddies west of the island chain which may have effects on organisms there (Suntsov and Domokos, 2013).

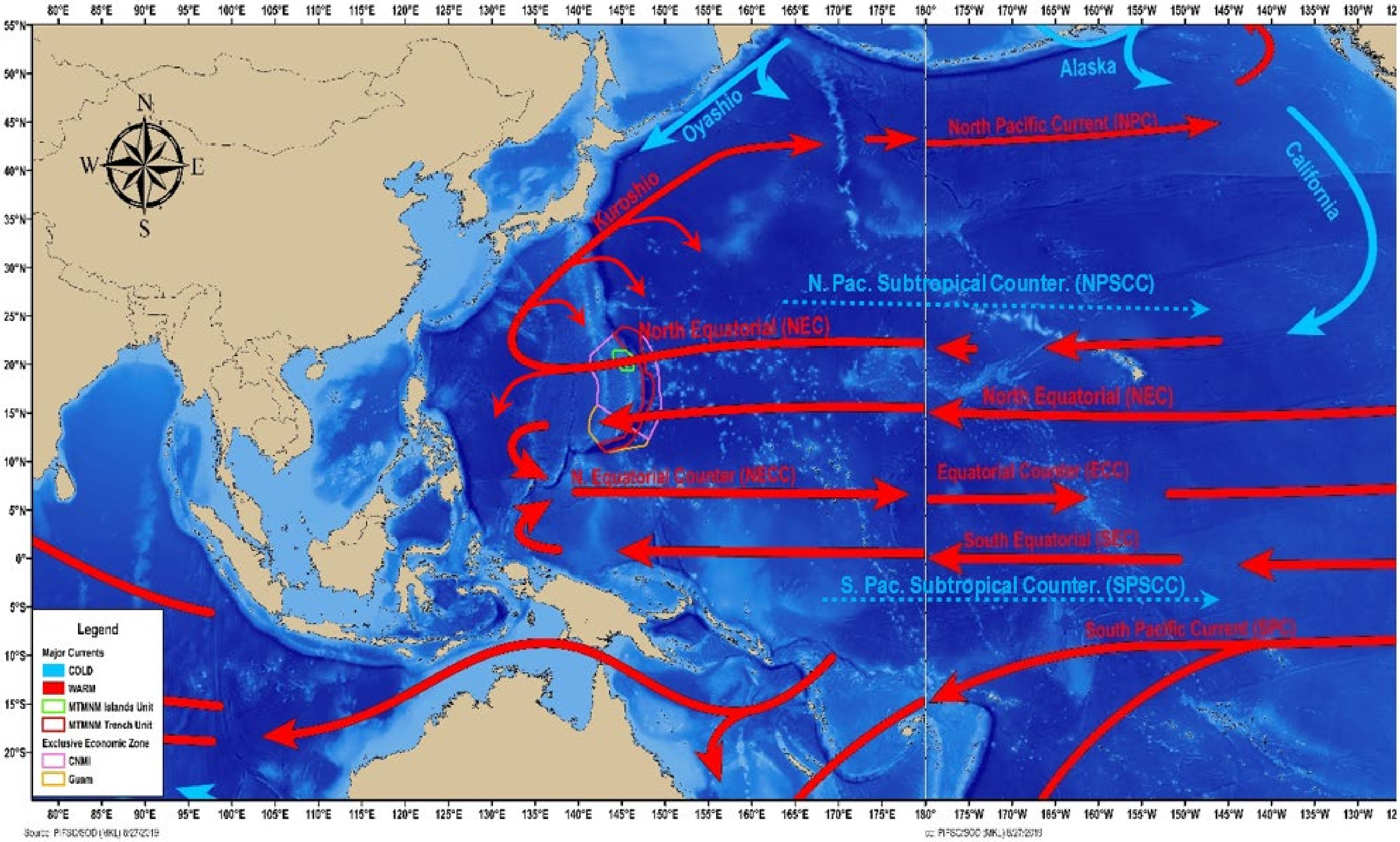

Figure 4. Major Currents Affecting the Mariana Archipelago. Weaker seasonal SCCs also shown (blue dotted lines).

Mid-to-Deep Currents

Deep currents that flow through the Mariana Trench include the Lower Circumpolar Water (LCPW) and the North Pacific Deep Water (NPDW; Siedler et al., 2004). The LCPW propagates westward (Johnson and Toole, 1993; Kawabe and Taira, 1998; Siedler et al., 2004), flowing in through the Eastern Mariana Basin (EMB) and out to the Western Mariana Basin (WMB). As a result of bottom topography blocking its entrance, the LCPW does not flow directly into the Trench from the east (Figure 5). It arrives from the north at 13°N, then flows from the EMB through the Yap- Mariana Junction into the WMB and through the East Fayu Junction on the Caroline Ridge into the EMB (Siedler et al., 2004). The NPDW flows from the east into the EMB, then turns and flows south into the ECB.

Information on currents flowing deeper than 6 km in the trench is limited as a result of the technical and logistic challenges associated with monitoring at these depths (Kawabe et al., 2003; Taira et al., 2004), but 3-D numerical models have helped extend observations in time and space, indicating dynamic and seasonal trends (Lavelle et al., 2010). Taira et al. (2004) collected deep and bottom current information within the Challenger Deep section of the trench and found generally slow current speeds. The fastest currents (8.0 cm/sec) were registered at the deepest station (10,890 m), and there were mean flow rates (0.5–0.7 cm/sec) at the 6600–7000 m depth range.

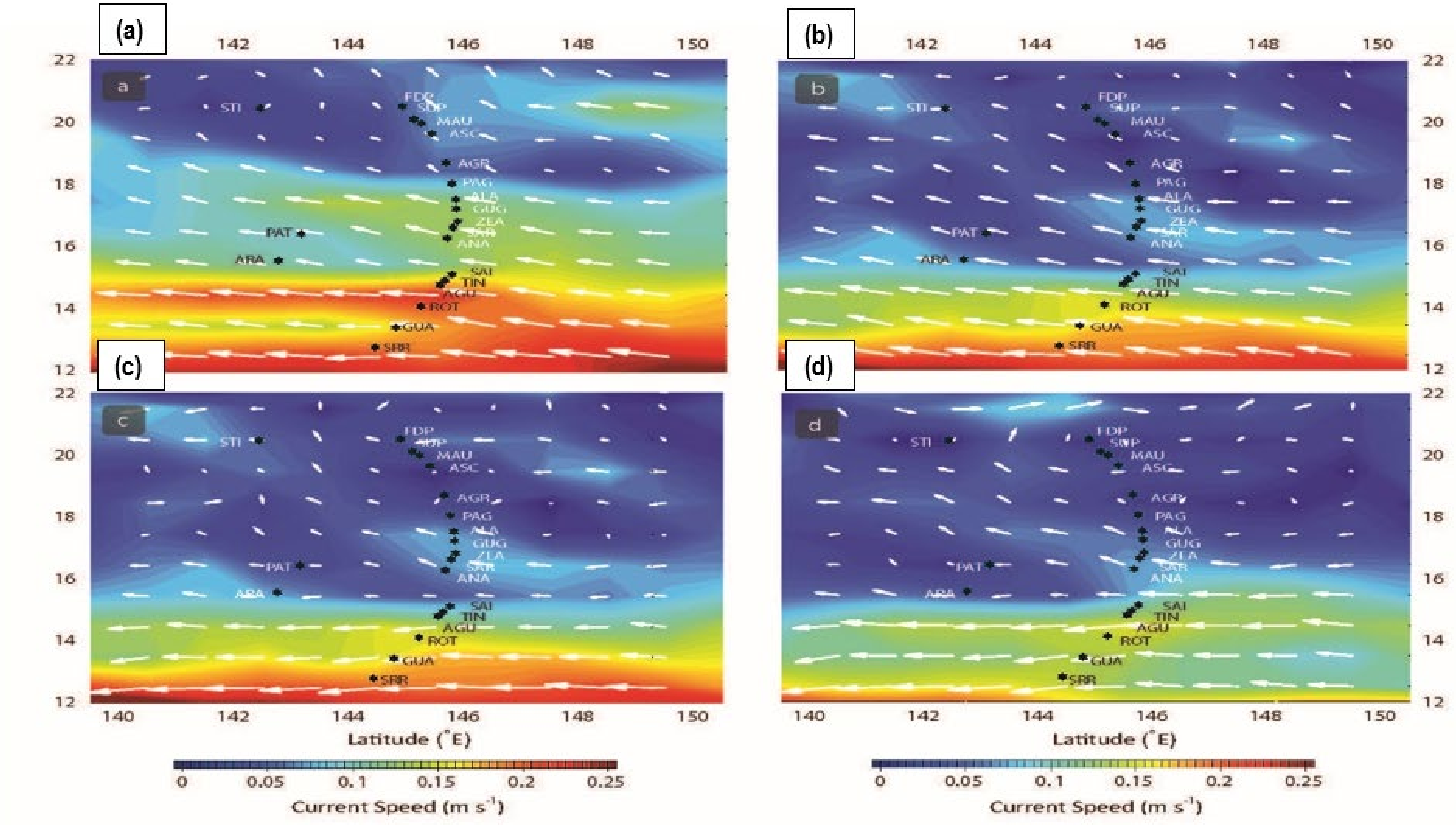

Figure 5. Seasonal ocean surface currents for: (a) fall (October–December), (b) winter (January–March), (c) spring (April–June), and (d) summer (July–September) using NOAA's Ocean Surface Current Analyses (OSCAR) (http://www.oscar.noaa.gov/). Current velocities (m s-1) are color coded, and arrows indicate relative magnitude and direction. Produced using data from 1993 to 2009 (Brainard et al., 2012).

Marine Biogeography

Marine biogeographic provinces surrounding the Archipelago are shaped by the geological, climatic, and oceanographic features outlined above (Becerro et al., 2006; Behrenfeld et al., 2006). In addition to their evolutionary history, surface to deep ocean circulation and topography drive the distribution and seasonality of ocean flora and fauna in the Marianas and worldwide (Amesbury and Babin, 1990; UNESCO et al., 2007; Allen, 2008; Belanger et al., 2012; Spalding et al., 2007, 2012; Oliver and Irwin, 2008). In relation to their genetic and geographic origins, organisms move based on differences in motility, reproductive and developmental strategies, dispersal mechanisms, and many other factors. Migration and successful establishment in new habitats can be modified by the presence or absence of physiological and geographic barriers. Human influences on geographic distribution will be described in following sections. Here we look mainly at other ecological and physical factors.

Early life forms in the Marianas came from the sea and included calcareous algae, corals, mollusks, and crustaceans among other organisms that created layers of limestone and reef shelves over millions of years (Cloud et al, 1956; Fosberg, 1963; Carlquist, 1974; Rogers, 2011; Kirch, 2017). From some time in the Pleistocene (over 10,000 years ago), life other than from the sea began to appear (birds, insects, and other wind born organisms including seeds and resilient plants). In Darwinian fashion, the evolving insular flora and fauna were derived from whatever happened to be carried or excreted by (or managed to hitchhike aboard) migratory birds and marine life, or on items such as floating logs, rafts of flotsam, storm runoff and debris. Thus, prevailing currents, winds, bottom topography, and the physiological resilience of marine flora and fauna have helped broadly define biogeographic realms within and around the Mariana Archipelago.

Various world biogeographic frameworks have been defined, sharing common features, but with different limiting assumptions (UNESCO et al., 2007; Spalding et al., 2007, 2012; Oliver and Irwin, 2008). Figure 6 shows three widely accepted biogeographic classifications as they relate to the Marianas and surrounding regions. The three shown are: (a) Longhurst et al. (1995) and Longhurst (2007), based on the prevailing role of physical forcing as a regulator of phytoplankton distribution; (b) the Marine Ecoregions Of the World (WWF, 2007), which classified coastal and continental shelf waters as a nested hierarchy of realms, provinces, and ecoregions, combined with the Pelagic Provinces Of the World's classification of epipelagic waters of world oceans into 37 pelagic provinces, nested within four broad realms (Spalding et al., 2012); and (c) Costello et al. (2017) based on the worldwide distribution of 65,000 species of animals and plants. Whether shaped by a terrestrial, freshwater, or marine focus, based on comparisons of endemism or shared species composition, or using broad or limited organisms and groups, there is agreement that the Marianas region is a place where unique and diverse biogeographic provinces intersect. The intersection of biogeographic zones in the region, along with the convergence and mixing of currents, drives the Marianas' rich marine biodiversity at various scales and depths of consideration.

The Archipelago is also a key area of the globe for studying hydrothermal vent biogeography, population connectivity, and larval dispersal (Hessler and Lonsdale, 1991; Desbruyeres et al., 2006; Bachraty et al., 2009; Beaulieu et al., 2011). Hydrothermal vents are seafloor hot springs where cold seawater flowing down through the crust is heated, dissolves elements from the rocks it permeates. then reemerges through vents at the seafloor as gas and mineral rich fluids. They develop in areas of active tectonic and volcanic activity such as in the Mariana region.

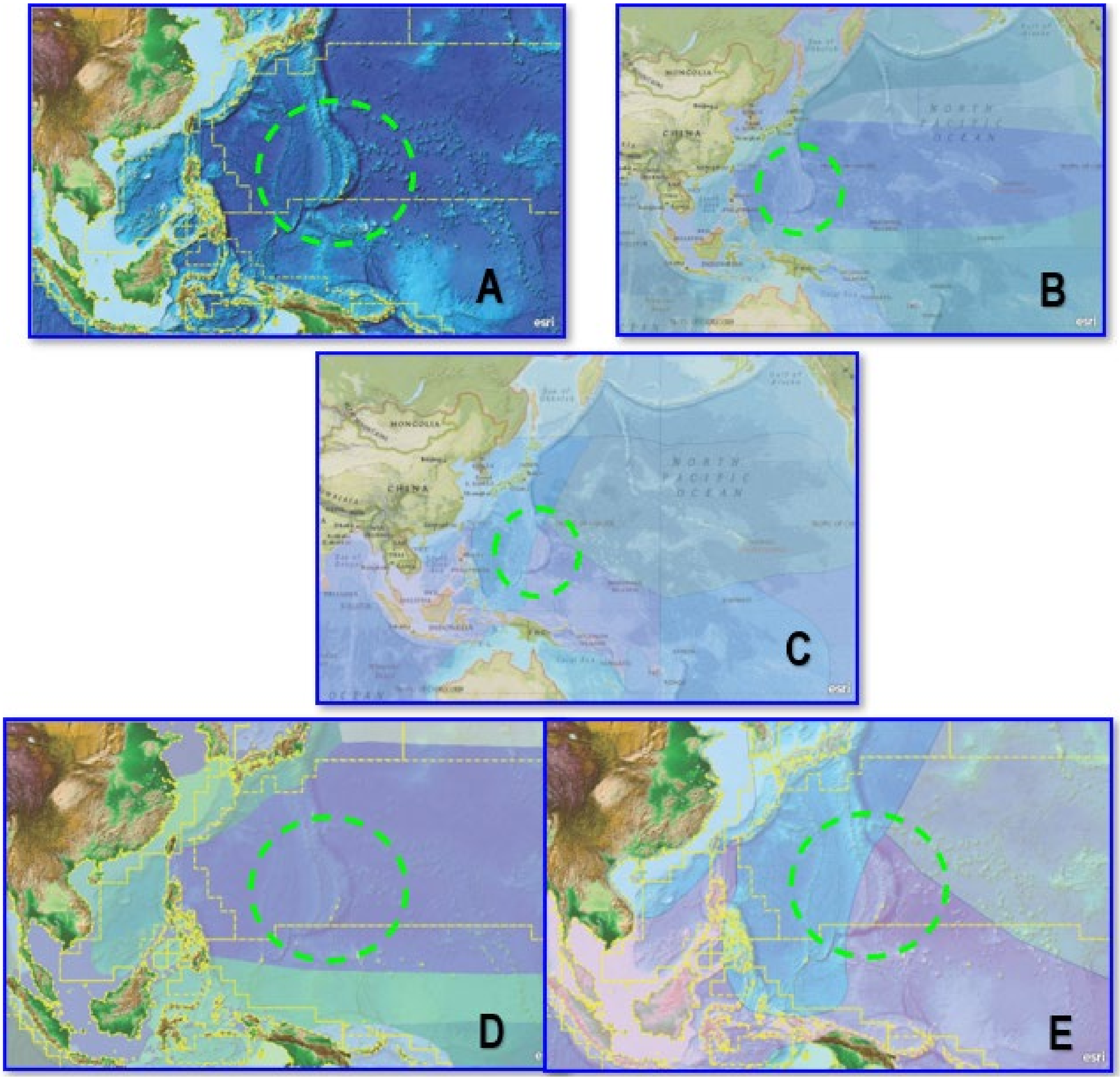

Figure 6. Biogeographic provinces, Mariana region circled in green.

Figure Sources: Online Layers (ESRI ArcGIS Online, NOAA Geoplatform; *most citations see UNEP-WCMC-Global, 2015*)

A) Longhurst Biogeographical Provinces (Longhurst et al.,1995; Zwartjes, 2014; Longhurst, 2007), shown by dashed yellow lines
B) Marine Biogeographic Realms Costello et al. (2017), shown by pastel shading
C) UNEP-WCMC-Global (2015): Marine Ecoregions of the World (Spalding et al., 2007) and Pelagic Provinces of the World (Spalding et al., 2012) are shown by pastel shading. Combined geographic layer in ESRI Geoplatform.
D) Overlap of Longhurst with UNEP-WCMC-Global (yellow dashed lines and pastel shading, respectively).
E) Overlay of Longhurst with Costello et al. (yellow dashed lines and pastel shading, respectively).Base maps: ESRI NOAA: ETOPO1 Global Relief Model Color Shaded Relief (A, D, E) and ESRI National Geographic (B, C).

Within the Archipelago, there are two distinct geologic settings in which active volcanism occurs, the Back-Arc and the Arc. Each has unique chemical processes that have a profound effect on the associated ecology of the local hydrothermal vents. The Back-Arc hydrothermal systems have linear volcanic systems feeding deep and stable hydrothermal circulation that creates high-temperature reaction zones. In contrast, the Arc hydrothermal systems develop around discrete volcanic centers and have shallower hydrothermal circulation with lower temperature reactions. The Arc hydrothermal systems also include high levels of magmatic gases, including SO_2 and CO_2, creating highly acidic environments (Butterfield et al., 2011).

Research and exploration of hydrothermal vents has uncovered a myriad of life in and around hydrothermal vent structures (Craig, 1987; Hessler et al., 1988; Fautin and Hessler, 1989; Hessler and Martin, 1989; Vandover et al., 1989; Hessler and Lonsdale, 1991: Kojima et al., 2001; DFO, 2010; NOAA OER 2019). Microbial communities associated with hydrothermal vents have been termed “extremophiles” as a result of their harsh living conditions. These communities, which are the base of the food chain in chemosynthetic ecosystems, live at extreme depths. They have unique metabolisms, such as the use of hydrogen sulfide (toxic to most animals) as an energy source, and flourish at elevated temperature and pressure (Davis and Moyer, 2008; Bartlett, 2009; Huber et al., 2010; Kelley et al., 2002; Kelley et al., 2004; Stevens et al., 2016). Hydrothermal microbes have novel molecules and enzymes that interest the biotechnology industry and offer a research frontier for understanding bioactive compounds that could lead to new drug discoveries and many other important applications (Lutz and Falkowski, 2012; Ramirez-Llodra et al., 2010; Thornburg et al., 2010).

The complex topic of marine life will be further explored in the section on fisheries trends, relative abundance, and ecology by functional groups (p. 46). But first we must examine the presence of humans in the Mariana Archipelago. In recent history, the human element has driven many changes in coastal ecology, and we will continue to play an important role in shaping the future of this dynamic marine ecosystem.

Historical Setting: A History of Human Presence in the Mariana Archipelago

Prehistoric Period (1500 BC–1521 AD)

The Marianas were among the first islands settled in Micronesia (Paulay, 2003a). The first inhabitants of the Archipelago, known as Chamorros today, arrived approximately 3300–4300 years ago (Allen and Amesbury, 2012; Kirch, 2017; Petchey et al., 2016, 2018; Reith and Athens, 2019; Petchey and Clark, 2021). They migrated to the Marianas as a series of small groups over many generations. Coming from Southeast Asia, they populated the islands of the Philippines and Micronesia, traveling more than 2000 km (1080 nmi) by oceangoing outrigger canoes over 40 feet long sewn together with *sennit*, caulked with *lemmai* gum, and powered by woven *akgak* sails (Thomas, 1987; Cunningham, 1992; Petchey et al., 2016). They brought common Pacific food plants (e.g., taro, yams, breadfruit) but apparently few domestic animals besides poultry (Thompson, 1945; Reed, 1952). At that time, they possessed polished stone implements, a complex culture and language, and knowledge among other things of navigation, fishing, coastal gleaning, and pottery-making.

The prehistoric period in the Mariana Islands lasted from roughly 1500 BC–1521 AD. The period can be broken into a Pre-Latte phase and Latte Phase (Spoehr, 1957). It has also been subdivided further (Moore and Hunter-Anderson, 1999). The onset of the Latte phase was approximately 800-1000 AD and is characterized by megalithic features called latte sets (Allen and Amesbury, 2012; Herman, 2019). A clan-based society arose that included villages characterized by impressive latte houses, one-story houses set atop rows of two-piece stone columns. These were still in use as late as 1668. Archaeological evidence indicates rice cultivation and pottery making prior to European arrival in the 16th century. By then, the Chamorros had developed a complex, class-based matrilineal society based on fishing and agriculture, supplemented by occasional trade visits from Caroline Islanders (Herman, 2019).

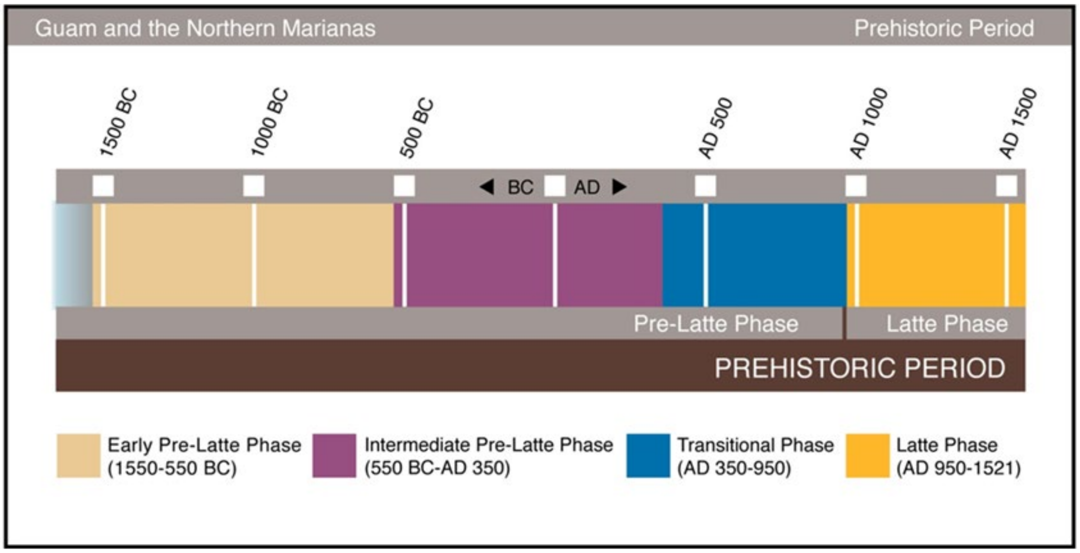

Figure 7. Guam and the Northern Marianas prehistoric period (Amesbury, 2013).

Latte sets are still found along coastlines and the interior of the Mariana Islands. Archaeological work at Pagan and Sarigan (Athens, 2011) found abundant remains dating to the latte period. Settlements on Guam also demonstrated the preference for areas near a beach or estuary, with access to coastal marine resources (Kurashina, 1991). The occupation of the islands north of Saipan may have begun late in the prehistoric period, but populations on some islands remained relatively high until the Spanish "*reducción*" in 1697–1698. This Spanish term refers to the drastic reduction in population that began with the Spanish occupation.

Spanish Period (1521–1899)

By the time the Spanish arrived, there were anywhere from 50,000 to over 100,000 people. The first European documented to have seen the island group was the Portuguese explorer, Ferdinand Magellan. On March 6, 1521, during a Spanish expedition of world circumnavigation, Magellan observed a string of islands and sailed between two of them landing on Guam (Nowell, 1962). Gayle and Taitano (1974) estimated the pre-Spanish population of the Marianas Islands (Guam and today's CNMI) at approximately 100,000.

The Spanish occupation began slowly. A single Franciscan priest and a few Spanish soldiers are reported to have stayed about a year on Guam from 1596–1597, and there were various accounts of Spanish ships wrecked or stranded among the islands of Saipan and Tinian throughout the early decades of the 1600s (McKinnon et al., 2016). With Magellan's arrival, the Spaniards established missions in the Marianas, but there was conflict between the Spanish and indigenous Chamorro people. Actual Spanish occupation of Guam began in 1668 with the arrival of Father Diego Figure Luis de San Vitores and other Jesuit priests, accompanied by a guard of 33 soldiers (Reed, 1952). By early 1669, they had established a mission at Agana (Hagåtña). A Spanish-Chamorro war was waged from 1670–1695, at the end of which the Chamorro people were forced to move a great deal between different islands within the Marianas, increasing and decreasing various islands' populations (Evans-Hatch and Associates, 2004). By the end of the Spanish period, the population of the Marianas (including Guam) had been reduced to less than 5,000 through a combination of war, disease epidemics, and other factors.

The Carolinians (*Refaluwasch* or "people of the deep sea") traveled frequently to and from the Marianas during the pre-historic period, but travel slowed during the war. After the war, trade between the Chamorros and Carolinians was renewed (Amesbury et al., 1989). In 1815, Carolinians began to settle in the Marianas. Generally, people throughout the Marianas fished for food. No land mammals were established in the Marianas until Spaniards brought them to the islands.

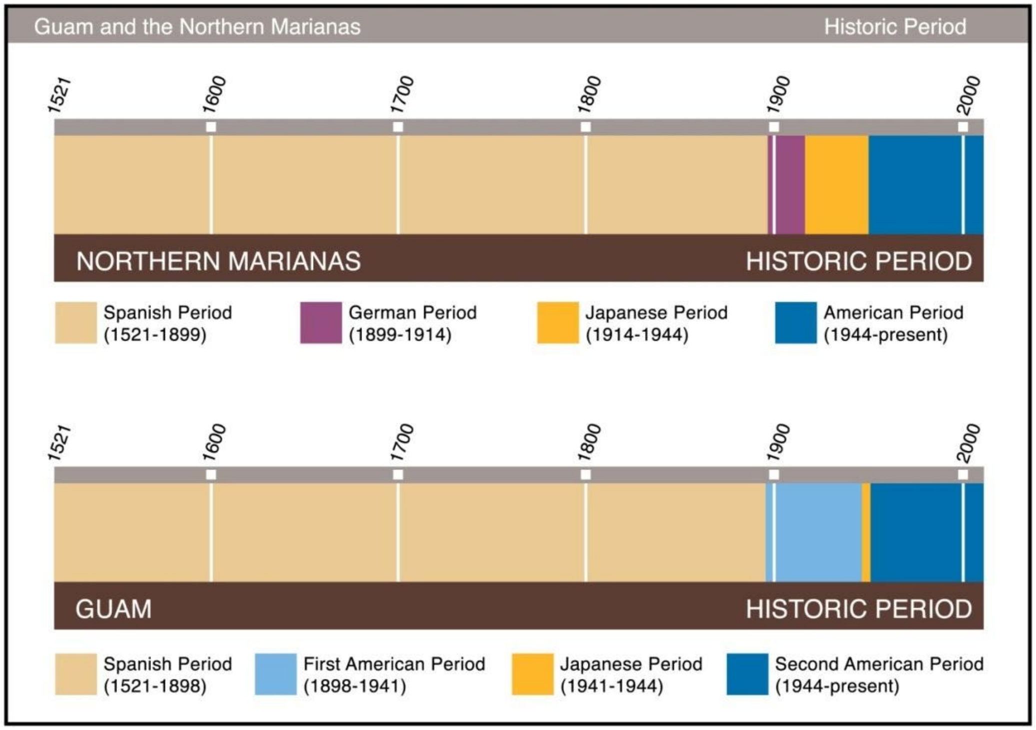

Figure 8. Guam and the Northern Marianas (Amesbury, 2013*)*

Scientific collections were not a compelling reason for travel among the islands during the earliest Spanish era. Diego Luis de San Vitores first arrived on Guam in 1665. He traveled north throughout the Archipelago to Maug during 1668 and 1669 (Garcia, 1683) and discovered the remaining northern islands, claiming them for Spain. British explorer George Anson visited Tinian in 1742 and described some of the island's features, including the wells and archaeological remains (Anson and Walter, 1845). La Pérouse and de Milet (1797) stopped briefly at Asuncion in 1786 and made some notes regarding the vegetation. The first scientific expedition in the Marianas was led by Alessandro Malaspina in 1792. He visited only Guam, and reports from his expedition were never fully completed. Beechey (1831), visited Asuncion in 1827 aboard H.M.S. *Blossom*, and further described the vegetation in a general manner.

Otto von Kotzebue, a Russian navigator, and several botanists and naturalists visited Guam aboard the *Rurick* for six days in November 1817 (Von Kotzebue, 1821). In March 1819, Louis Claude de Saulces de Freycinet stopped at Guam and remained there for several months (de Saulces de Freycinet et al., 1824, 1826; de Saulces de Freycinet, 2003, in: Allen and Amesbury, 2012). French zoologists Jean René Constant Quoy and Joseph Paul Gaimard, and botanist Charles Gaudichaud-Beaupré collected extensively. German explorer and geographer Friedrich Benjamin Graf von Lütke and ornithologist Friedrich Heinrich Freiherr von Kittlitz landed at Guam briefly in March 1828 aboard the *Astrolabe*, under the command of Jules-Sébastien-César Dumont d'Urville. They also visited Rota and Tinian (von Lütke et al., 1835).

It was not until the late 1880s that definitive efforts were made to collect scientific information about the northern islands. Don Eugenio Sanchez y Zayas sailed throughout the islands with the Governor of the Marianas in early 1866 aboard the *Narvaez*. He prepared a detailed study of the islands which was published soon after the trip (Sanchez y Zayas, 1866). In the early 1870s, Governor Don Luís de Ibáñez y Garcia visited the islands and wrote a description and history (de Ibáñez y Garcia, 1886). Alfred Marche travelled throughout the islands between April 1887 and March 1889, and collected information and specimens. He went as far north as Agrihan and visited most of the islands (Marche, 1890, 1891). His collections resulted in additional publications on fishes (Pellegrin, 1898), birds, mammals (Oustalet, 1895), and land snails (Quadras and von Moellendorff, 1894).

German Period (CNMI, 1899–1914)

Control of the Northern Marianas and Guam took separate paths following the Spanish period. Guam was ceded to the U.S. after the Spanish-American War in 1898. Spain entered into the German-Spanish Treaty of February 12, 1899, selling the Northern Marianas and its other remaining islands to Germany for 837,500 German gold marks (about $4,100,000 U.S. at the time) (Purcell, 1976). The Northern Marianas and other island groups were incorporated by Germany as a small part of the larger German Protectorate of New Guinea. The total population in the Northern Marianas portion of these islands was only 2,402 inhabitants around this time according to the 1902 U.S. Census Bureau (Allen and Amesbury, 2012). Because the ten most northerly islands were actively volcanic, they were mostly uninhabited.

German District Commissioner on Saipan, Georg Fritz, travelled to all the northern islands during May 1901 (Fritz, 1902, 1904). He described their general geology, flora and fauna, and commented on archaeology, history, and ethnography. He also planted coconuts, ironwood trees (*Casuarina*), and other plants on Guguan and Uracas. In describing the anchorage at Tinian, Fritz observed that the island's surface was of coralliferous limestone and deep-red clays and he noted the presence of potable ground water (Cloud et al., 1956). On Rota, he observed that the terraced limestones enclosed a volcanic core which he thought might be intrusive. He commented on the perennial streams of the south and east coasts, mentioned the useful plants and animals, described the early history and archaeological ruins, and presented a sketch of the island and its anchorage. Fritz's careful observations on the topography, vegetation, fauna, rock types, mineral products, water resources, and archaeology of all the islands he encountered lead him to note that the Mariana Islands were divisible into two groups (Fritz, 1902). He recognized that the limestone peaks of the islands from Medinilla south distinguished them from the wholly volcanic islands north of there. These observations provided a foundation for researchers who, in following decades, began putting together the geology and natural history of the region (Cloud et al., 1956). One of the most extensive works pertains to all the German islands of the Marianas. Von Prowazek (1913) described Rota, Tinian, and Saipan and provided an extensive list of the terrestrial flora; however, much of the natural history is drawn from Fritz' earlier work.

First American Period (Guam, 1899–1941)

On June 20, 1898, a fleet of American ships, led by Captain Henry Glass, pulled into Apra Harbor to capture the Spanish garrison on Guam. The Spanish leaders were not prepared to defend the island as news of the Spanish-American war had not yet reached Guam. The Spanish surrendered the following day. The Americans left to support other battles in the Pacific, taking the island's highest-ranking officials as prisoners, while leaving no one in charge of the island. It would take more than a year for Americans to designate a Governor, who also served as the Commanding Officer of the U.S. Naval Station Guam.

Alexander Agassiz, aboard the *Albatross*, led the first American expedition to Guam in 1900. Numerous reports resulted, including ones on fishes, birds, crustaceans, and sea cucumbers (Agassiz 1903). Alvin Seale from the Bernice Pauahi Bishop Museum also visited Guam in 1900 and collected a number of birds and fishes (Seale, 1901). One of the first general accounts of the Marianas was that of Costenoble (1905).

The first American occupation of Guam ended when Japanese bombers from Saipan attacked Guam's Naval Station at Apra Harbor. On December 8, 1941, while island residents were preparing to celebrate the Feast of the Immaculate Conception, Japanese troops seized control and began an occupation that lasted three years (Camacho, 2011; Herman, 2019). This well-planned attack happened four hours after the bombing of Pearl Harbor that decimated the U.S. Pacific Fleet.

Japanese Period (CNMI, 1914–1944)

In 1914, Japan seized all of Germany's colonial possessions in East Asia and Micronesia, including the Northern Mariana Islands (NMI), and held them through the end of World War I. When the war ended, the NMI, Palau, Caroline, and Marshall Islands were assigned to Japan under the Treaty of Versailles (1919). The Northern Marianas became a Japanese mandate from the League of Nations after 1919, until it was seized by the United States in World War II. Historical uses of the waters of the northern islands included shipping and fishing. From 1920-1944 (also referenced as the "Japanese mandate"), the Japanese operated a pole and line fishery out of Saipan, which was the first large-scale commercial fishery in the Marianas. Higuchi (2007) referred to the years from 1922–1931 as the "experimental period" and 1931–1941 as the "rise of fishing industries." By 1936, a thriving fishing industry had developed, as well as a sugar industry occupying most of the arable land on Saipan, Tinian, and Rota.

Modest population growth took place on a few of the islands under Japanese rule. Japan used some of the islands for sugarcane production during this time, and they mined phosphate on Rota (Stewart, 2019). The resident population grew to 23,800 on Saipan, of which only 3,222 were originally from the islands. Tinian's population reached 1,530 (25 Chamorro), and Rota's reached 5,600 (791 Chamorro). Small numbers of people also lived on the islands of Asuncion and Maug.

Prior to World War II, a Japanese military boat traveled along the island chain from Saipan to Asuncion, moving people and supplies between islands. Oral histories from residents of Asuncion, and islands between there and Saipan, describe trade between the populated northern islands. The more populated and developed southern islands would send canned goods, coffee, and clothes to residents as far north as Asuncion. Asuncion and other northern islanders returned fresh produce and dried fish in trade to Saipan, Tinian, and Rota (Kotowicz and Richmond, 2013).

The NMI became one of six Japanese naval districts in Micronesia. Several families moved to Asuncion to grow coconuts for copra production during the period when the Japanese governed the Mariana Islands. Residents practiced agriculture and fishing in Asuncion for personal consumption and to supply the Japanese government. Interviews and oral histories with residents of Asuncion have provided some information about residential life and natural resource use on the island, but this information is limited, and many questions remain. Additionally, there is evidence of limited military residence on Maug during the Japanese period, including oral histories and photographic evidence that Okinawans working for the Japanese military processed fish while living on Maug (Kotowicz and Gionfriddo, 2014).

During the Japanese administration of the NMI, a number of surveys and reports were published pertaining to botany and geology. Tayama (1936a, b, 1937, 1938, 1939a, b, 1952) and Tayama and Ota (1940) dealt extensively with the geology and coral reefs of the islands, and Yoshii (1936) described the noncalcareous rocks of Pagan and other islands. Tanakadate (1940) visited Pagan and wrote a detailed description of the volcanos of that island. Botanical collections were made at many of the islands (Kanehira 1934, 1935; Hosokawa 1934). Only one marine animal was included in reports made during this time (Nishiyama, 1942).

American Period (CNMI and Guam: Post World War II, 1944 to present)

Government

In 1941, the United States became involved in World War II and the Governor of Guam surrendered the island to Japan. However, all of the Northern Marianas remained under Japanese control until U.S. forces gained control in 1944.

CNMI

At the end of World War II, in July 1944, American forces gained control of Saipan and construction of bases and airfields began. The U.S. Naval Military Government administered the Northern Mariana Islands from 1944 to 1947, when the NMI became part of the Trust Territory of the Pacific Islands, established pursuant to United Nations Security Council Resolution 21. During this time, many Chamorro returned to the NMI from other parts of Micronesia; nearly 50,000 Asian civilians present in the NMI at the end of the war returned to their home countries.

Much of the geology and natural history exploration of the northern islands is linked to its military occupation (Cloud, 1959; Tracey et al., 1959; Doan and Blumenstock, 1960; Corwin, 1961). The population of the NMI grew relatively slowly during this time, and foreign investment and economic development were somewhat restricted (Allen and Amesbury, 2012). This lasted until 1976, when the Northern Marianas Islands became a U.S. commonwealth. The airfields on Tinian are now largely abandoned (Stewart, 2019).

Between 1975 and 1976, the Northern Mariana Islands chose to join the United States of America (U.S.) and was accepted via the Covenant to Establish a Commonwealth of the Northern Mariana Islands in Political Union with the U.S. ("The Covenant," Public Law 94-241; Tamanaha, 1989.). The Covenant was fully implemented in 1986 (Presidential Proclamation 5564; Horey, 2011). In entering the Covenant, the U.S. fulfilled its United Nations

Trusteeship obligation to have the people of the Northern Mariana Islands exercise their inherent right to self-determination. Section 301 of the Covenant conferred U.S. citizenship to the people in the Northern Mariana Islands, and section 304 guaranteed the citizens of the Northern Mariana Islands would be entitled to all the privileges and immunities of citizens in all of the United States of America.

The Commonwealth Constitution was drafted in 1976 and ratified in 1977. The new government and Constitution came into effect on January 9, 1978 (CNMI Law Revision Commission, 2019). The first CNMI delegate to the House of Representatives took office in 2009. That delegate has a non-voting seat in the U.S. Congress.

Because it became law in 1974, two years before the NMI became a U.S. Commonwealth, the Territorial Submerged Lands Act (Public Law 93-435) did not include submerged lands within the CNMI. Until the U.S. Congress amended that statute (Public Law 113-34 on Sept. 18, 2013), the CNMI was the only populated territory in that part of the U.S. Territorial Sea that did not have title to its submerged lands (Clement et al., 2005). When the MTMNM was designated on January 15, 2014, submerged lands adjacent to the islands of Farallon de Pajaros (Uracas), Maug and Asuncion (the MTMNM "Island Unit." see Figure 1) permanently covered by tidal waters (up to the mean low water line and 3 statute miles seaward from the mean high tide line) were excepted from conveyance to the CNMI by Presidential Proclamation 9077 ("Excepted Lands"). Proclamation 9077 included a provision allowing the Secretary of the Interior to subsequently transfer the Excepted Lands to the CNMI at such time as the Secretary of the Interior, the Secretary of Commerce, and Government of the CNMI had entered into an agreement for the coordination of management ensuring the protection of the Monument within the area to be conveyed.

A Memorandum of Agreement (MOA) among all parties was signed in 2016, with the purpose of providing a cooperative framework for the coordination of resource management to ensure the comprehensive long-term conservation and protection of the Monument within the Northern Islands Submerged Lands. The MOA established functional relationships, processes, and general terms and conditions under which the signatories would cooperate to effectively coordinate management (CNMI et al., 2016; U.S. FWS et al., 2017; Richmond et al., 2019). In December 2016, the CNMI Government received a patent for the submerged lands, providing the local government authority over the seabed, mineral rights, subsoil, water column, and surface water resources in the three-mile coastal zone (Jewell, 2016).

Guam

Since the 1898 Treaty of Paris (between Spain and the U.S.), Guam has remained a U.S. territory under a series of naval authorities (Rogers, 2011; Herman, 2019). After World War II, Guam was converted to a forward-operations base for the US Navy and Air Force (Camacho, 2011). The island's pre-World War II Naval Station was expanded, and numerous facilities and supply depots were built across the island, including Anderson Air Force Base on the northern portion of the island.

The Guam Organic Act of 1950 (48 U.S. Code § 1421a) established Guam as an Unincorporated Organized[13] Territory of the United States and resulted in Guam's Bill of Rights (48 U.S. Code § 1421b) and a civilian government. This act conferred U.S. citizenship to the people of Guam and established local self-government. Despite its long history as a U.S. territory, Guam remains on the United Nations list of 17 non-self-governing territories (UN, 2023). Although one is a commonwealth and the other a territory, similar to the CNMI, Guam has three branches of government and has a non-voting delegate appointed to the U.S. House of Representatives. Both Guam and CNMI citizens can serve in the U.S. military, but neither can vote in U.S. presidential elections.

A strong local government, responsive and responsible to the local electorate, characterizes both Guam and the CNMI. The Mayors' Council of Guam, established through the enactment of Public Law 14-27 (Organic Act of Guam, 1977) is an important part of Guam's governance structure. Comprised of nineteen mayors and seven vice mayors, it is an independent entity (not a line office) of the Government of Guam under the Executive Branch. The mayors are elected by local communities every four years, not appointed, creating a strong civil coalition that closely represents its constituents' concerns and opinions. Article VI of the Northern Mariana Islands Constitution (CNMI Constitution,1978) establishes standards for the voters from Rota, Tinian and Aguiguan, Saipan, and the islands north of Saipan to elect a mayor for each island (or group of islands). Each of these insular governments has its own municipal council which presides over "all local matters of a predominately local nature not pre-empted by the Commonwealth Legislature." Each has a role in establishing the annual budget, approving any reprogramming of funds, approving department heads on the island (or group of islands), and serving as stand in mayor in the event the mayor is incapacitated.

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[13] Organized is defined as land under the sovereignty of the federal government (but not part of any state) that is given a measure of self-rule by the U.S. Congress through an Organic Act.

Population and Cultural Heritage: Mariana Archipelago (Guam and the CNMI)

The Marianas' original inhabitants, known today as the Chamorros or Chamorus (derived from *Chamorri* or *Chamoli*; the upper class in ancient Chamoru society[14]) are believed to have come from Southeast Asia as early as 2000 B.C. and have cultural and linguistic similarities with people from Malaysia, Indonesia, and the Philippines (Hensley and Sherwood, 1993; Allen and Bartram, 2008). Chamorro and English are the official languages of Guam today. Carolinian, Chamorro, and English are the official languages of the CNMI. Both areas include a large Filipino population, speaking a wealth of dialects, unified by Tagalog ("Filipino"). Chinese is also widely used in the CNMI, where about 90% of the population speaks a language other than English at home (Foster and Ballendorf, 2020). The Spanish culture, which influenced the Chamorros for nearly four centuries, is still present today and is evident in much of the Chamorro language. Chamorro spoken on Guam has distinct pronunciation, even spelling, compared with the CNMI. Japanese is also spoken in many of the hotels and shops, and some Japanese words are commonly used by locals while speaking the Chamorro language, reflecting the influence of the tourism industry.

The population of U.S. citizens throughout Guam and in the CNMI to a lesser extent is predominantly of Chamorro cultural extraction. There are also significant numbers of Carolinians (Chuukese, Kosraeans, Pohnpeians, Yapese, and Palauans), along with immigrants from other areas of Micronesia and East Asia (especially the Philippines). The non-citizen population in the CNMI is made up primarily of Filipino and Chinese, with some representation from several other Asian countries (US DI, 2019). Table 2 shows estimated proportions of ethnic groups in the CNMI and Guam, as registered in the 2010 Census (Goworowska and Wilson, 2015; US CIA, 2020). Corresponding 2010 population estimates can be found in Table 3.

Gayle and Taitano (1974) conducted an analysis of social, cultural, and historical factors bearing on the political status of Guam for the 1973–1974 Political Status Commission. They described the importance of culture and self-determination for Guam's people and how these were impacted by Spanish and later American colonial interests. Despite racial changes and changing governance, they noted that a distinct Chamorro culture still prevails that clearly traces itself back to pre-Spanish days. Characteristics of this culture include an extended family with mutual obligations and privileges; a system of matrilineal descent with a high position and importance of women in society; a love for musical expression (singing, dancing, and other creative expression); respect for authority, traditions, and the elders; and many cooperative economic, religious, and social activities connecting communities and groups (Hensley and Sherwood, 1993).

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[14] https://www.guampedia.com/matao-and-achaot/

Table 2. Ethnicities reported in 2010 census of Guam and the CNMI.

Ethnic Group	**Guam**	**CNMI**
Chamorro	37.3%	23.9%
Filipino	26.3%	35.3%
Carolinian*	10.0%	4.6%
• Chuukese (FSM)	*(7.0%)*	* *
• Pohnpeian (FSM)	*(1.4%)*	* *
• Palauan	*(1.6%)*	* *
Mixed	9.4%	12.7%
Caucasian	7.1%	* *
Korean	2.2%	4.2%
Other Pacific Islander	2.0%	6.4%
Other Asian	2.0%	3.7%
Chinese	1.6%	6.8%
Japanese	1.5%	* *
Other	0.6%	2.5%

Table legend

* The Caroline Islands include modern FSM (see acronyms) and Palau. Percentages of Carolinians on Guam were reported separately for three of these island areas (Chuuk, Pohnpei, and Palau), totaling 10%. These statistics were reported as a group for the CNMI. Other Carolinians may be included as well in “Other Pacific Islanders”

* * Statistics for these groups not reported or included in another group.

In 1980 the CNMI population was just 16,780, while on the much larger island of Guam the population was more than six times greater (Table 3). A period of rapid growth followed for the CNMI and the population more than doubled by 1990, due in part to the expansion of the tourism and garment industries (described p. 26). Guam’s population increased by about 25% during the same period.

Between 1990 and 2000, the CNMI population increased by almost 60%. However, it decreased from 2000-2010 on all three populated islands (Saipan, Tinian, and Rota). This accompanied a drastic reduction in tourism and the travel industry in the CNMI (MVA, 2012). Guam’s population had 133,152 residents in 1990 and increased by 20,000 (16.3%) over the next 10 years. From 2000 to 2010, Guam’s population increased by roughly 3%, and has continued to see slow but consistent growth. The following sections describe the very different economic, immigration, and tourism trends that have played a role in the changing populations of each insular area.

Table 3. Population of the Mariana Archipelago by major island (1950–2018).

Year	Rota	Tinian	Saipan	Northern Islands	Total CNMI	Guam	Total Archipelago
1950					6,286	58,754	65,040
1958	969	405	6,654	262	8,290	66,700	74,990
1960					8,861	66,900	75,761
1967	1,078	610	9,035	263	10,986	81,400	92,386
1970					12,359	86,470	98,829
1973	1,104	714	12,382	133	14,333	105,550	119,883
1980	1,261	866	14,549	104	16,780	106,869	123,759
1985					21,386	120,615	142,001
1990	2,295	2,118	38,896	36	43,345	133,152	177,189
1995	3,509	2,631	52,698	8	58,846	144,190	203,036
2000	3,283	3,540	62,392	6	69,221	155,324	224,545
2005					67,737	159,581	227,318
2010	2,527	3,136	48,220	0	53,883	159,358	213,241
2015					52,779	166,404	219,183
2018					51,994	167,772	219,766
2020					57,446	168,485	

Sources: U.S. Bureau of Census Mid-year Population Estimates (2/25/2019) and 1950* Guam U.S. DOC Bureau of Census preliminary estimates (6/30/1950).CNMI 2020 value based on United Nations estimate.

https://www.census.gov/data/tables/time-series/dec/cph-series/cph-t/cph-t-8.html

https://www2.census.gov/library/publications/decennial/1950/pc-04/pc-4-03.pdf

https://www.worldometers.info/world-population/northern-mariana-islands-population/

(Note: Direct census with detailed island counts are performed only periodically.)

Economic Growth, Immigration, and Tourism

CNMI (1976–present)

The CNMI's economy and major industries have changed since becoming a Commonwealth in 1976. The transition from a subsistence economy dominated by farming and fishing at the beginning of this period, to an economy dominated by tourism-related industries and government employment has been abrupt at times to say the least (Dela Cruz, 2010). In the early years, the Commonwealth regulated its own immigration. During that period, foreigners were allowed to enter the CNMI for travel purposes, including transit to the United States. The Covenant also allowed products made in the CNMI to enter the U.S. duty free. Local control of immigration, a low minimum wage, and this duty-free status allowed the CNMI to utilize low-cost labor from Asia and to return a substantial profit on clothing produced for export.

A complex set of international economic, social, and political factors led to a spike in population and dramatic growth in the apparel industry in Saipan during the 1980s and 1990s, followed by a downward trending economic rollercoaster stretching through the first decade of the new millenium (King, 1991; Franzel, 2007; US Senate, 2007; Dela Cruz, 2010). The number of jobs in the apparel industry climbed from almost none in 1980, to over 7,710 in 1995 (Allen and Amesbury, 2012). During the same period, the number of tourists and other travelers to the CNMI rose to nearly 700,000, boosting visitor industry employment to an estimated 9,570 jobs (McPhee Associates and Conway, 2008). CNMI employment levels increased by nearly 13% annually, one of the highest growth rates in the world (CEDSPC-CNMI, 2009). Visitor arrivals increased steadily from 1990, reaching a high of 726,690 in 1997.

During this time, tourism joined the garment industry as a major economic driver for the Commonwealth. The impact of tourism extended beyond airlines, hotels, and restaurants. It partially supported the Commonwealth's retail trade, especially in the core urban area. The effect rippled through many segments of the economy (Bank of Hawaii, 2003). In 1999, tourism and the garment industry were responsible for 85% of total economic activity and 96% of exports from the CNMI (Allen and Amesbury, 2012).

The Asian economic crisis of 1997 had a clear impact on visitor arrivals in the late 1990s, leading to the eventual withdrawal of Japan Airlines, a major source of flights to the CNMI. In 2005, the U.S. eliminated quotas on textile and apparel imports from other textile-producing countries in accordance with World Trade Organization agreements. This was a blow to the CNMI garment industry which did not survive the lower-cost competition (Heidebrecht, 2001). The last Saipan garment factory closed its doors in 2009 (McPhee Associates and Conway, 2008), and from 2005 to 2011, visitor arrivals declined from 506,846 to 338,646 (MVA, 2012).

Gambling casinos became legal on Tinian in 1989 and on Rota in 2007. The first Tinian casino opened in a small, converted office building in May of 1995, and closed in December of the same year (US N, 1999). While numerous other companies have announced plans and even broken ground for development over the years, the only casino that endured for a while was the Tinian Dynasty Hotel and Casino, which opened in 1998 and closed in 2015 (MVA, 2012; Ayers, 2018). Saipan voters rejected a Saipan casino initiative in 1979 and again in 2007. However, in 2014, the CNMI Legislature legalized gambling casinos on Saipan (Erediano, 2014), and the Imperial Pacific Resort and Casino (IPRC) opened in Garapan in 2017. This controversial and opulent venture shows the potential to dramatically affect the future character of the Garapan area and its coastal ecology (Ayers, 2018).

In 2007, U.S. Public Law 110-28 increased the CNMI minimum wage incrementally to meet the U.S. federal minimum wage (DoL, 2008). In 2008, U.S. Public Law 110-229 re-federalized the CNMI immigration policy and control. In June 2009, the U.S. Department of Homeland Security took over the CNMI's immigration and border controls, lowering the number of CW-1 Visas[15] granted for foreign workers. By 2016, the quota for CW-1 visas was reached. The cap on CW-1 visas is Commonwealth-wide, so the high demand for skilled foreign casino construction workers also affects the ability to hire skilled foreign labor in other industries, including the commercial fisheries and seafood sectors (Ayers, 2018).

Gross domestic product (GDP) is a key economic indicator that measures the value of all the goods and services produced in an area in a given year. CNMI's GDP hit its low point in 2011 at $751 million, presumably from the closing garment industry, slumping tourism, and the minimum wage and immigration issues described above. It began to rebuild from that point, and increased each year thereafter through 2015, when it reached $922 million (Ayers, 2018). Ayers surmised that the increases in GDP are linked to increases in private fixed investment that occurred in 2014 and 2015, following the legalization of gambling on Saipan.

Government employment is extremely important in the CNMI and has been since the beginning of the Commonwealth (Dela Cruz, 2010). An estimated 10% of residents are employed in government. About a third of the remaining private businesses (and 40–45% of private employment) are in ocean-related jobs, industries, and services (ERG, 2018).

Guam (post-World War II)

The U.S. military has had a presence on Guam since 1898 (Rogers, 2011; Herman, 2019). It is difficult to separate this colonial, followed by territorial, control from modern economic issues in Guam. Since World War II, Guam's economy has been dominated largely by tourism and the U.S. military (Douglas, 2008; Camacho, 2011). Among economic and cultural concerns raised by Gayle and Taitano (1974) in describing the need for local sovereign control were the management of shipping, immigration, and air traffic; the development and exploitation of lands, beaches, and other resources; and the protection and harvest of Guam's fishing resources.

Guam's economy depends on military spending, followed closely by tourism and other services. In 2002, Guam's economic activity was locally calculated at $3.4 billion (non-inflation adjusted) (First Hawaiian Bank, 2006 in Allen and Bartram, 2008). In 2015, excluding the military, the Guam government (GovGuam) employed about 30% of the labor force (ERG, 2018). Guam's 2016 GDP was estimated at about $5.8 billion. During the same year, total federal spending (defense and non-defense) amounted to almost $2 billion, or 34.2% of Guam's GDP (US CIA, 2019). The ocean is also an important part of Guam's economy. In 2015, ERG (2018) estimated that a third of Guam's private businesses were ocean related, encompassing 1,078 establishments, and employing 19,500–21,300 people.

Over the past 20 years, the tourist industry on Guam has grown rapidly, creating a construction boom for new hotels, golf courses and other tourist amenities. For the first time, in 2016, service exports, mainly spending by foreign tourists in Guam, amounted to over $1 billion, or 17.8% of GDP (US CIA, 2019). Guam's peak tourist years were between 1995 and 1997, when approximately 1.4 million tourists arrived annually, primarily from Japan (Allen and Bartram, 2008). Today, more than 1.1 million tourists visit Guam each year, including about 1,000,000 from Japan and 150,000 from Korea.

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[15] CW-1 is a non-immigrant visa allowing temporary workers to travel to the U.S. for employment in the CNMI

Other Marine Related Human Dimensions Research

Since much of its cultural heritage comes from coastal and insular countries, fishing and seafood are integral to life in Guam and the CNMI (Hensley and Sherwood, 1993). Chamorro and Carolinian people identify themselves as having an ancestral connection with the sea that they continue to maintain to this day McKinnon et al. (2014). Most archaeological sites are found near the coast and provide evidence of this long heritage, including fish remains and implements (fishhooks, gorges, nets ocean-going canoes, etc.). Historical accounts of fishing practices also substantiate this legacy. Olmo (2013) used modern fisheries catch data, combined with knowledge of fish midden sites, to expand our understanding of prehistoric fishing strategies and behaviors on Guam. Amesbury et al. (1989) and Amesbury (2008, 2013) described pelagic and bottomfishing throughout the Archipelago from the prehistoric period to the present and provided a recap of some of the human impacts on indigenous fisheries and fishing rights throughout European, Japanese, and American history. Amesbury et al. (1989) provided an extensive description of evidence from linguistics, archaeological and anthropological studies, isotopic analyses, ethnographic accounts, and other historical records of early fishing practices, fishing gears and methods, indicating long term use of inshore and offshore pelagic and bottomfish resources by indigenous people throughout the Archipelago.

Van Beukering and colleagues studied the economic value of Saipan's (Van Beukering, et al., 2006) and Guam's coral reefs and associated resources (Van Beukering et al., 2007). The results were derived from a household survey, discrete choice experiment, total economic value calculation, spatial analysis, and evaluation of sustainable financing for each island. Results of the survey showed residents of Saipan are still strongly connected to the ocean and coral reefs and rely heavily on the coastal marine environment for fishing and recreational activities. The biggest threat to the marine environment perceived by Saipan residents was water pollution due to runoff and sewage operations. The study estimated the economic importance of Saipan's entire marine environment ("Total Economic Value" or TEV) at U.S. $61.16 million per year, and concluded that the more valuable the reef, the poorer its condition and the greater its perceived threats (Van Beukering et al., 2006).

Results of their survey on Guam showed most households consume fish about twice a week. At the time the survey was conducted (January-March 2005), more than half of fish consumed came from stores or restaurants and about 40% from immediate or extended family and friends. About 35-45% of respondents were active fishers who went fishing about once a week. The average cost of fishing was estimated at $165 (U.S.) per month. Only a few fishers on Guam reported selling part of their catch. From the small percentage of fisher-respondents that sold their catch, average earnings from fishing were estimated at $250 (U.S.) per month, Thus, fishing on Guam was neither a subsistence nor a commercial activity. Most fishers said they fish for enjoyment and to strengthen social bonds. The study estimated the TEV of Guam's marine environment at $127 million (U.S.) annually (Van Beukering et al., 2007).

A cost earning survey of the Guam fishing fleet was conducted in 2011 (Hospital and Beavers, 2012). The 147 fishers that participated mainly identified themselves as Chamorro and were statistically somewhat more educated and affluent than the general population. Respondents reported that the catch was an important family food source and that fishing was an important cultural practice that was also valued for subsistence, recreational, and quasi-commercial purposes. Trolling was the most popular fishing method, but they used many gears and targeted many species. Participants averaged 39 fishing trips during the year, and most (70%) sold a portion of their catch. Fisher-respondents reported most of their catch (42%) was given away. Slightly more of the remaining catch was consumed at home (29%) as opposed to being sold (24%). A small portion was exchanged for goods/services (3%) and the rest (2%) was released.

Studies of the CNMI small-boat fishery also demonstrated its importance to residents for food security, to build and maintain social networks, and to perpetuate fishing traditions. A cost earning survey of the fleet was conducted in 2011 with participation from 112 fishers—80% from Saipan, 10% from Tinian, and 10% from Rota (Hospital and Beavers, 2014). An average of 37 fishing trips per year were made by respondents. Trolling was the most popular fishing method, followed by deepwater bottomfishing, shallow bottomfishing, and spear fishing. Trips were evenly distributed between inshore (within 3 nm) and offshore (3–200 nm). The results showed fishing was predominantly for subsistence. Nearly all fishermen supplemented their income elsewhere. Most respondents (74%) sold at least part of their catch, mainly for trip cost-recovery. Interestingly (like Guam), most of the catch was given away (38%), with about equal amounts sold (29%) versus consumed at home (28%). A small amount was exchanged for goods and services (3%), and the rest (2%) was released. The catch was an important food source for families, but (like Guam) social and cultural motivations to fish outweighed economic reasons. The survey also documented attitudes and perceptions about fishing conditions, establishment of the Monument, impacts of military exercises, and other topics.

Chan and Pan (2019) studied economic performance indicators for small-boat fisheries in the CNMI (Saipan, 2009–2017) and Guam (2011–2017). They were able to track the trends of cost and potential net revenue per trip and examine the components (e.g., fuel, ice, bait, gear costs) contributing to observed variations. The 2011 average trip cost (all gear types, adjusted for inflation) on Guam was $110. Trip cost decreased to $92 by 2017, with annual (up/down) variation, peaking at $119 in 2012. The average trip cost in the CNMI was lower, but was also more variable, ranging from $56–$72 from 2009–2017, with a peak of $88 in 2013. The major trip cost was fuel for both insular areas. With trip costs of around $100, fishers in the Guam small-boat fishery had negative potential net revenue per trip in 2011 and 2016. In the CNMI, the average potential sales value per trip ranged from its lowest value of $117 in 2009, to $200–300 from 2012–2017. With trip costs under $90, fishermen in the CNMI had positive potential net revenue for all years of the study period.

The potential sales value of Guam's bottomfish fishery was negligible according to the study, because almost none of the catch was intended for sale. Instead, bottomfish were kept for home consumption and given away to friends and relatives. Guam's pelagic fishery had the highest potential sales value among its fisheries, but potential net revenue per pelagic trip was similar to that for Guam's reef fishery because the reef fishery had the lowest trip costs (closer to shore with low fuel costs). In contrast, the CNMI reef fishery had the lowest potential net revenue due to the smaller volume of reef catches on Saipan. This may be partially a function of the limited market venues available to fishers on Saipan. The differences in size structure and resulting value of these two reef fisheries may also be influenced by the fact that most commercial reef fishing on Guam was done through SCUBA spearfishing in deeper waters, whereas most reef fishing on Saipan was conducted within the lagoon (and without SCUBA).

In 2011, during the study described above, Chan and Pan estimated that 66% of the small-boat catch on Saipan was intended for sale. In the same year, Hospital and Beavers estimated that only 38% of this catch was actually sold. A comparison of potential revenue versus actual fish sales on Guam, as expected, was more comparable (given the better market conditions on Guam, which has a fishing cooperative and numerous small markets). In fact, Chan and Pan's study estimated that 38% of the catch on Guam was intended for sale in 2011, which is comparable to Hospital and Beavers' finding that 35% of the catch was actually sold by Guam small-boat fishers. These findings indicate some of the complexities of the commercial fishing industries in the CNMI and Guam, as well as the importance of markets and why fishery trends are so difficult to predict and monitor throughout the Marianas (see Fisheries Monitoring, Assessment and Management section, p.31).

Grace-McCaskey (2014) examined the potential for using secondary human and social data to better understand the complexities of relationships between humans and coral reef ecosystems across 70 islands, reefs, and atolls in the Pacific, including the Marianas. She evaluated data including population and demographics, reef fishing pressure, land and watershed alterations, economic development, and marine resource governance. Her results showed a lack of sufficiently fine-scale data for these indicators, which precluded meaningful comparison across insular areas.

When the Magnuson Fishery Conservation and Management Act was reauthorized in 1996, it was amended with the Sustainable Fisheries Act, and renamed to Magnuson-Stevens Fishery Conservation and Management Act MSA). The MSA established a new "National Standard 8" (NS8) that required Fishery Management Councils to pay more attention to human fishing communities. NS8 states:

> *"Conservation and management measures shall, consistent with the conservation requirements of this Act, take into account the importance of fishery resources to fishing communities in order to (A) Provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities (MSA Section 301(a) (8))."*

As part of its Fisheries Management Plan (FMP) for the Mariana Archipelago, the Western Pacific Regional Fisheries Management Council (WPRFMC or "the Council") proposed that each of the major island areas under its jurisdiction be identified as a fishing community (WPRFMC, 1998, 2002, 2005, 2008). Among others, NMFS approved recognition of the CNMI and Guam as fishing communities (64 FR 19067, 1999). The description of the fishing communities in the original amendments, as incorporated into the Mariana Archipelago Fishery Ecosystem Plan (FEP), defines these fishing communities as the analysis unit required for social impact assessment in fishery impact statements under the MSA. PIFSC social scientists researched and developed fishing community profiles for Guam (Allen and Bartram, 2008) and the CNMI (Allen and Amesbury, 2012; Ayers, 2018). In addition to historical aspects of community dependence on fishing and seafood, and trends in reef, inshore, and commercial fishing, these reports provide details of political history, governance, population, economy, and the social and economic roles of fishing. They also recommend key cultural and economic indicators be tracked through time as indices of social impacts of fisheries management. The community profiles help inform these analyses.

Designation of the MTMNM was accompanied by contentious social debate within the CNMI and Guam over the pros and cons of designation, increased federal management in the Archipelago, possible economic benefits, impacts to fishers and fishing communities, and other issues. This initial conflict prior to designation, itself a socioeconomic impact, was not studied systematically. A retrospective review indicated that the community response would have been more positive had the initial designation process been more broadly participatory (Richmond et al., 2019). MTMNM designation had the support in the CNMI of then Governor Benigno R. Fitial. Some of the reasons for his support included that: (1) the Monument prohibited commercial fishing only in the Island Unit, which is already protected by the CNMI Constitution, (2) it ensured local government could determine what traditional indigenous fishing could occur, and (3) it did not conflict with exploration of undersea mineral deposits (Allen and Amesbury, 2012), although commercial exploitation could only occur in areas of the EEZ located outside the Monument boundaries.

In early 2011, PIFSC social scientists conducted 40 interviews with people in Guam and Saipan to learn about traditional fishing patterns in waters within the Mariana Archipelago, including areas designated as part of the Monument. The research documented past and contemporary fishing trips to the lands and waters of the MTMNM

Islands Unit, described perspectives and experiences of the participants on these trips, and explored the historical and cultural importance of this area to residents of the CNMI and Guam (Kotowicz and Richmond, 2013). The authors found that trips to the Islands Unit area were rare because of its distance from populated islands, but these few trips were culturally significant events that provided residents from CNMI and Guam with connections to their indigenous roots. The same authors used insights from this research to support a recommendation for planners to include social context and equity issues in considering location and regulation of future marine protected areas (Richmond and Kotowicz, 2015).

In 2013, NMFS established requirements for fishing in the Islands Unit of the MTMNM. Proclamation 8336 directed the Secretary of Commerce, in consultation with the Secretary of the Interior, to take action under the MSA to regulate fisheries and ensure proper care and management of the monuments, including allowing for traditional indigenous fishing practices. The Council recommended incorporating the fishery management provisions into its Mariana Archipelago FEP. The amendment to the FEP and its implementing regulations codified the boundaries of the monument, prohibited commercial fishing in the Islands Unit of the MTMNM, and established management measures for non-commercial and recreational fishing consistent with the proclamation. The new rule provided a definition of “noncommercial” fishing that encompassed traditional indigenous fishing and stated that “customary exchange of fish harvested within the Islands Unit under a noncommercial permit is allowed.” It further provided that “monetary reimbursement under customary exchange shall not exceed actual fishing trip expenses related to ice, bait, fuel, or food” (78 FR 32996, 2013).

The MTMNM requirement to obtain a permit could present an impediment to indigenous fishing, since many trips were made spontaneously. The regulations also “prohibit the conduct of commercial fishing outside the Monument and noncommercial fishing within the Monument during the same trip,” which could further hinder fishing activity since 99% of commercial trips involved returning with fish to share, a type of noncommercial fishing (Richmond and Kotowicz, 2015). Additionally, MTMNM rules do not permit recreational charter and noncommercial fishing during the same trip, a practice that sometimes does happen. According to Richmond and Kotowicz’s (2015) findings, these regulations could disproportionately affect local and indigenous people.

Following designation of the MTMNM, PIFSC social scientists also completed a telephone survey of Guam and CNMI residents to lay a foundation for exploring potential and anticipated socioeconomic effects of the Monument (Kotowicz and Allen, 2015; Kotowicz et al., 2017). They interviewed 500 Guam and 500 CNMI residents in early 2012, to provide MTMNM managers with baseline information about residents’ awareness of its designation, management preferences, perceptions of the effects of the designation, and interest in Monument activities, including research. Their findings suggested:

- public awareness of the Monument was low prior to the survey,
- residents generally supported designation of the Monument,
- most residents did not believe that the Monument would affect them or their community, and
- knowledge and perceptions of the Monument varied between fishing and non-fishing households.

The National Coral Reef Monitoring Program conducts socioeconomic monitoring of indicators in all U.S. coral reef territories and jurisdictions. Researchers conducted random-dial telephone surveys and in-person interviews in conjunction with a review of secondary sources. By tracking ecosystem services via composite indicators of human well-being (adapted from Dillard et al., 2013) alongside coral reef ecosystem condition, this monitoring effort provides a better understanding the ecosystem as a whole. These composite indicators for human well-being and ecosystem condition include survey questions on governance, health, safety, education, social connectedness, access to social services and basic needs. In their summary findings for Guam's 2016 report, Gorstein et al. (2018) stated that Guam residents reported swimming and beach recreation as the most common coral reef-related human recreational activity. Thirty percent of residents indicated that they participate in fishing or gathering of marine resources. Perceptions concerning marine resource condition differed in some respects between respondents based on their village of residence. The authors surmised that this may correlate with varying resource quality in different regions. Similarly, in the summary findings for the CNMI's 2016 report, Gorstein et al. (2019) reported swimming and beach recreation as the most common human participation in recreational coral reef-related activities in the CNMI. Thirty-eight percent of residents indicated that they participate in fishing or gathering of marine resources and their perceptions concerning the change in condition of marine resources over the last 10 years were mostly negative.

Kleiber et al. (2018) applied the national community social vulnerability indicators, originally designed for the east coast of the United States by Jepson and Colburn (2013), to fishing communities in the U.S. Pacific islands. These indices describe factors of social cohesion in communities that have been associated with greater adaptive capacity to abrupt or gradual changes (Cutter et al., 2003). Kleiber et al. (2018), had thought these indices might provide information about relative vulnerability of fishing communities to a given threat, disruption, or proposed policy change in the Pacific, but found that some of the data types used in the Cutter et al. (2003) study were not applicable, of questionable validity, or unavailable for this region. They concluded that with more data and more iterations of this analysis, these indicators might be further refined and improved over time for use in the Pacific.

Fisheries Monitoring, Assessment and Management

Background

Total fisheries catch and effort around the CNMI and Guam can only be roughly estimated for many reasons. Prior to July 2019, neither Guam nor the CNMI had catch or sales reporting requirements by individuals or vessels, with few exceptions (Lowe et al., 2024a). However, the CNMI implemented mandatory licensing and reporting requirements for commercial fishers and vendors (all species) in July 2019. CNMI rules require commercial harvesters and vendors to obtain licenses and to record and report, regardless of whether other data collection programs are collecting similar data. Mandatory reporting is generally uncommon for most insular Pacific fisheries, especially if the catch is not being sold. Submerged portions of the EEZ dwarf areas of emergent land by almost three orders of magnitude. With a large area where fishing is possible and a small domestic fleet of small outboard troll and bottomfish vessels[16], at-sea-monitoring is difficult. The great distances between populated islands and fishable locations, including submerged banks and atolls outside the Monument, add to this difficulty.

The vast high seas area outside the EEZ is fished by large, mainly longline vessels from many nations, some of which had until recently transshipped through Guam's port where monitoring is more practical. However, the last remaining company handling transshipment operations at the Commercial Port of Guam closed on December 31, 2020 (O'Connor, 2021). There has also been transshipment through the CNMI at times, but this was without offloading in port (air-to-air freight), and the contribution to local jobs and economic opportunities was minimal (Hamnett and Pintz, 1996). Transshipments are not included in commercial landings data summarized here but are registered in multinational high seas stock assessments.

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[16] CNMI boats 12–24 ft.; Guam vessels 12–48 ft. (Moffitt et al., 2007; Lowe et al., 2024a)

Several federal permitting programs exist for vessels operating in the EEZ of the CNMI and Guam. In 1991, NMFS implemented Amendment 2 to the FMP for Pelagic Fisheries of the Western Pacific Region, requiring longline and transshipping vessel owners to obtain permits for their vessels, and vessel operators to maintain and submit logbook data on their fishing and transshipment activities (56 FR 24731, 1991). Provisions of the FMP for Coral Reef Ecosystems of the Western Pacific Region, implemented in 2004, included permitting and reporting requirements for fishing with gears not specifically authorized or for transshipment of coral reef species not “previously harvested” from marine protected areas (69 FR 8336, 2004[17]). In 2006, the U.S. EEZ around CNMI was incorporated into the Council’s former FMP for crustaceans, bottomfish and seamount groundfish, and precious corals. The final rule implementing these amendments applied federal permit and reporting requirements to vessel operators targeting crustacean and precious coral species around the CNMI (71 FR 69495, 2006). The requirements are still in effect for these species (84 FR 2767, 2019). In 2006, NMFS implemented a final rule, requiring federal permitting and reporting for large bottomfish vessels (50 feet or longer) fishing in waters around Guam (71 FR 64474, 2006). In 2008, federal permitting and reporting requirements were implemented for CNMI commercial bottomfish fishers through Amendment 10 to the bottomfish and seamount groundfish FMP (73 FR 75615, 2008), and for squid jig fishing vessels over 50 feet in length through Amendment 15 to the Pelagics FMP (73 FR 70600, 2008). Finally, the 2013 permit requirement for the Islands Unit of the MTMNM applies to all non-commercial and recreational charter fishing and includes provisions for reporting (78 FR 32996, 2013). All these programs have had sparse participation over the years and have resulted in minimal reporting.

Guam Fisheries Monitoring

Fishery data collection and management programs in Guam are administered by GovGuam’s Department of Agriculture, Division of Aquatic and Wildlife Resources (DAWR). Its Bureau of Statistics and Plans (BSP), Business and Economic Statistics Program (Governor’s Office) monitors seafood import/export data. This includes the international transshipment industry for large pelagic species, mainly tunas, destined to south Pacific canneries through the Port of Guam (Hamnett and Pintz, 1996). BSP’s Coastal Management Program, DAWR, and the Guam Environmental Protection Agency all participate in programs relating to fishery-independent monitoring, protection, and management of coastal marine habitats under Guam’s Coral Reef Initiative (Hoot et al., 2018; NOAA CRCP, 2018a).

CNMI Fisheries Monitoring

CNMI fisheries data collection and management programs are administered by the CNMI Government’s Department of Lands and Natural Resources, Division of Fish and Wildlife (DFW). In 2013, the CNMI Divisions of Coastal Resources Management (DCRM) and Environmental Quality (DEQ) merged under the Bureau of Environmental and Coastal Quality (BECQ) to conduct fishery-independent monitoring and management of coastal marine habitats (NOAA CRCP, 2018b). The CNMI (DFW) and Guam (DAWR and BSP) also monitor and manage insular, coastal, and archipelagic resources through their collaboration with various U.S. programs (e.g., NOAA, USFWS) and their participation in the Council (WPRFMC, 2005, 2008, 2016, 2018). In addition, they provide data to organizations such as the United Nations and the Secretariat of the Pacific Community in support of international fisheries monitoring, assessment, and management (Liske-Clark, 2015; NOAA CRCP, 2018c).

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[17] In 2019 many reef species were reclassified from “management unit” to “ecosystem component” species, with less detailed reporting requirements (84 FR 2767, 2019).

Fishery-dependent Data

Fishery data presented in this section have been estimated by three primary methods. Two of these provide an estimate of total catch and effort (Jasper et al., 2016a, b). The other method estimates only commercial seafood sales/purchases ("commercial landings," a subset of the total catch). Most fishery-dependent surveys were funded by the U.S. Fish and Wildlife Service, with additional funding and database/programming support through NOAA Fisheries (Hamm, 1993, 1998). Three main types of monitoring have been conducted:

1. **Shoreline (or "shore-based") creel surveys** utilize a roving method. Surveyors traverse the coast in a vehicle or on foot conducting interviews and hourly tallies of fishing activity by gear type and shoreline area to estimate the ***total inshore catch*** (commercial and non-commercial).
2. **Boat-based creel surveys** use a stationary (access/intercept) method, counting daily fishing trips (by gear) and interviewing incoming captains or crew to estimate ***total offshore catch***.
3. The **commercial purchase data** (collection) system (CPDS) is essentially a survey of seafood vendors on the islands of Guam and Saipan, using a government provided purchase receipt form to get data on ***direct purchases from fishers***.

All three methods rely on voluntary cooperation, and each has different coverage, biases, and gaps (Myers, 1993; Bak, 2012; Bak-Hospital, 2015; Trianni et al., 2018a). A comparison of results from these surveys has been used over the years to estimate total seafood landings for the CNMI and Guam. Most surveys have been done only on Guam and Saipan. A few surveys have been conducted briefly on Tinian and Rota (McKagan, 2017; WPRFMC, unpublished).

Shore-based creel surveys provide a fairly detailed picture of the catch within lagoons, estuaries, fringing reefs, and close to shore, where gleaning (by hand, with or without a knife), and gears such as hook and line, talaya (thrownet), and spears are used. The surveyors see inshore fishers, whether swimming, in small vessels, or on foot. Activity taking place offshore is not included and the surveys are usually not conducted at night for safety reasons. Shore-based creel surveys, including an aerial gear count component, began on Guam in 1963 (CIC Research, 1983; Hamm and Kassman, 1986; Hensley and Sherwood, 1993). Shore-based creel surveys in the CNMI have been operative over two time periods, from 1984 to 1994, and from 2005 to present, mainly on Saipan. CNMI shore-based surveys do not include aerial reconnaissance.

Boat-based creel surveys are a good way to estimate the catch by small offshore fishing vessels as long as they leave and return from accessible docks and landing sites at times of day/night when survey staff is available. Hidden landing sites and night fishing are seen on all populated islands. Local agencies (DFW and DAWR) do their best to cover a representative sample of fishing trips, including odd hours and locations (e.g., weekdays/weekends, different gears, landing sites) when funding is available. Staffing surveys during evenings and on weekend/holidays is the most challenging aspect of this work. Boat-based surveys, which began in 1982 on Guam and 2000 on Saipan, are ongoing. They estimate total catch based on the average trip-level catch and number of trips (Myers, 1993; Bak, 2012; Bak-Hospital, 2015). With a significant investment of staff time and funding, creel surveys provide important insights into fishing on the most populated islands, mainly in areas with sufficient infrastructure to allow surveyors to view and monitor fishing activity. Fishing outside visible areas is estimated or ignored in hopes these trips can be intercepted at boat ramps and other landing sites.

Commercial purchase monitoring also has its biases which are different for Guam versus the CNMI. Guam's commercial purchase data collection is voluntary, but participation has been exemplary over the past four decades, providing excellent insight into local fisheries. Guam has had a successful fishing cooperative for decades through which 60–80% of commercial sales are processed. The Guam Fishermen's Cooperative Association (GFCA or "the Coop") helps commercial fishers sell their catch centrally, reduce their fuel and ice costs, and comply with safe food handling requirements. In addition, the Coop contributes in many ways to community functions, small businesses, fishing derbies, and charitable activities (Allen and Bartram, 2008). The proportion of commercial landings going through the GFCA varies annually and by major fishing category (pelagic, reef/inshore, and deep bottomfishing). The GFCA collaborates actively with PIFSC to help estimate commercial sales on Guam (Lowe et al., 2024a). Other commercial markets on Guam also collaborate to varying extents and are included in commercial landings estimates reported in the NMFS publication, “Fisheries of the United States” (NMFS, 2019).

The CNMI has few seafood markets, mainly on Saipan. Although there have been several efforts to develop a centralized market or cooperative, none has passed the test of time. Other venues such as roadside vendors, restaurants, hotels, and, more recently, casinos play a large role in seafood distribution on Saipan (Lowe et al., 2024a; Ayers, 2018). Sales are mainly door to door on the islands of Tinian and Rota. In 2012, the CNMI Government enacted legislation (CNMI H.B. 17-282, 2012) requiring both commercial catch and commercial seafood sales/purchases reporting. As previously mentioned, in February 2019, regulations developed by the DFW were published in the Commonwealth Register (CNMI DLNR, 2019). The system of data collection and compliance monitoring being implemented in the CNMI includes bi-weekly reporting of the harvest, purchase, and/or sale of marine life caught within the EEZ by fishers or businesses.

Seafood sales occur at locations that are widely dispersed around island coasts and within hard-to-reach neighborhoods, particularly in the CNMI. Each vendor or market prefers a different range of species and sizes suitable to their customers’ preferences and budgets. These venues change, so having an active outreach effort to identify and adapt the sampling program accordingly is important. Even different fishers using the same gear provide very different catches due to differences in fishing locations, experience levels, and habits. It is challenging to conduct a representative market survey across islands, vessels, and venues (roadside, markets, restaurants, hotels, etc.), even when vendors cooperate willingly. Ayers (2018) provided a breakdown of 2015 seafood purchases under the CNMI Nutrition Assistance Program, demonstrating the range of market preferences evident in a fairly large sample of pelagic, reef and bottomfish purchases. That report also identified some of the challenges associated with monitoring species composition through a passive survey instrument, such as written invoices/receipts or vendor-generated reports, since these mainly register large multi-species categories (e.g., “reef fish”) unless there are significant differences in pricing.

Since 2009, PIFSC’s Commercial Fisheries Bio-Sampling (CFBS) program has been collecting life history data on reef and bottomfishes, and invertebrates such as crabs, lobsters, and octopus sold in local markets and pre-market settings on Guam and Saipan (Kamikawa et al., 2015; NOAA PIFSC, 2016; Matthews et al., 2019). The CFBS began collecting data on Guam in October 2009, and on Saipan in January 2011. Although not designed to estimate total landings, the program does sample the whole commercial catch of fishers that agree to participate. However, not all catch comes to market and the take home catch often eludes the monitoring effort. A few species are targeted each year for developing complete life history information (e.g., age, growth, size at maturity), including size-frequency data. The CFBS has provided the most detailed species breakdown available for the broad market categories seen in passive data collections. CFBS data represent a subsample of the commercial purchase data, which are a subset of the total catch. Some gears are better represented than others in this subsample. As such, trends will not be further described for this data set.

Fishery-independent surveys are conducted routinely by natural resource agencies on Guam and in the CNMI. There have also been estimates of abundance and catch of reef and inshore fisheries species within three miles of fringing reefs in the CNMI as part of monitoring for development permitting or in response to concerns with overharvesting by new fisheries (Graham, 1994a, b; Gourley, 1997; Green, 1997). There is a long term monitoring program on Guam that looks at overall coral health, which includes a component of associated biological communities. Additionally, the PIFSC Coral Reef Ecosystem Program (CREP) has conducted bi- and triennial fishery-independent surveys throughout the Mariana Archipelago since 2003 (Heenan et al., 2015; McCoy et al., 2018).

Total Catch versus Commercial Purchase Data

The fishery-dependent monitoring programs described above document significant annual catches of fishes, invertebrates, and marine algae in and around Guam and the CNMI (Hamm and Kassman, 1986; Hamm and Quach, 1988a, 1989; Hamm et al., 1986, 1990, 1991, 1992a, 1992b, 1993, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012; Myers, 1993; Radtke and Davis, 1995; Kikkawa, 1994, 1997; Gutierrez, 2003; Lowe et al., 2013, 2014, 2016, 2024a, 2024b, 2024c). These fisheries are harvested for sale as well as for recreation and home consumption. Figure 10 shows estimated commercial seafood purchases for Guam and Saipan, monitored by DAWR, DFW, and JIMAR, and compiled by NMFS PIFSC (WPacFIN Data Portal, 2019). These estimates indicate commercial purchases of seafood on Guam from 2000–2018 ranged from 77–308 (U.S.) tons, valued from $378 thousand to $1.4 million (U.S.) annually. During the same years, commercial purchases on Saipan (where > 90% of CNMI seafood purchases take place), ranged from 100–275 tons, valued at $503 thousand to $1.2 million annually. It should be noted these are estimated commercial purchases, based upon the local data collection systems in place during this time period. The data used for stock assessment or other analyses may vary from those available via the data portal and SAFE reports (WPRFMC, 2018, 2020) due to differences in quality control, species groupings, and other factors.

Commercial seafood sales ("commercial landings") are estimated each year as part of the NMFS publication Fisheries of the United States (NOAA NMFS FUS, 2017). However, a significant portion of commercial purchases go undetected; this varies by fishing method and "functional" (taxonomic) group (Zeller et al., 2005, 2007a; Trianni, et al., 2018a). Figure 11 shows the estimated combined commercial value of direct seafood purchases from fishers on Guam and Saipan which ranged from $946 thousand to over $2.3 million annually from 2000–2018[18]. This does not include door to door sales. Wholesale purchase prices are monitored (direct sales to buyers) as opposed to market (retail) price. The value of the commercial seafood industry, including sales through restaurants, hotels, markets, food stands, etc., is of course considerably higher.

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[18] **Data Sources Figures 10-14**: WPacFIN Data Portal, 2019. Figs. 10–11 & 13 use the commercial purchase data (COM), Figs. 12 & 14 use the combined boat-based (BBS) and shore-based (SBS) creel survey data.

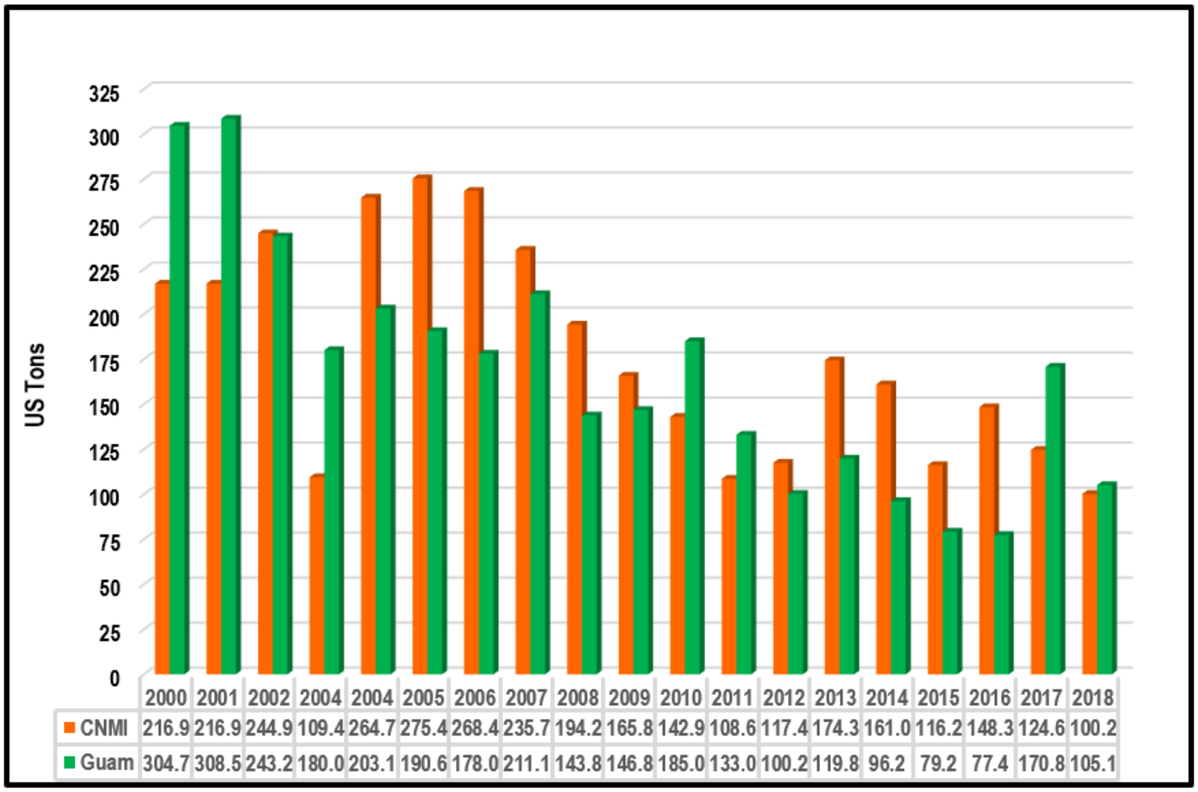


Figure 9. Annual estimated commercial seafood purchases: 2000–2018.

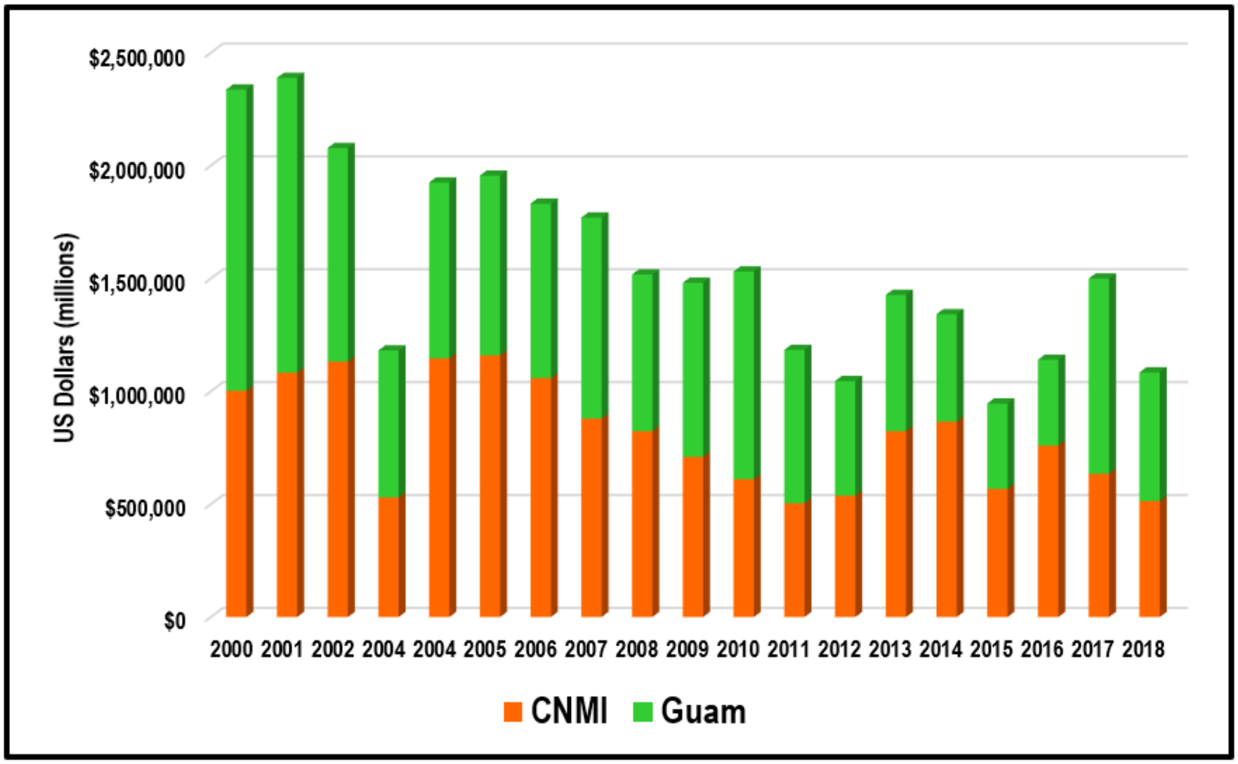
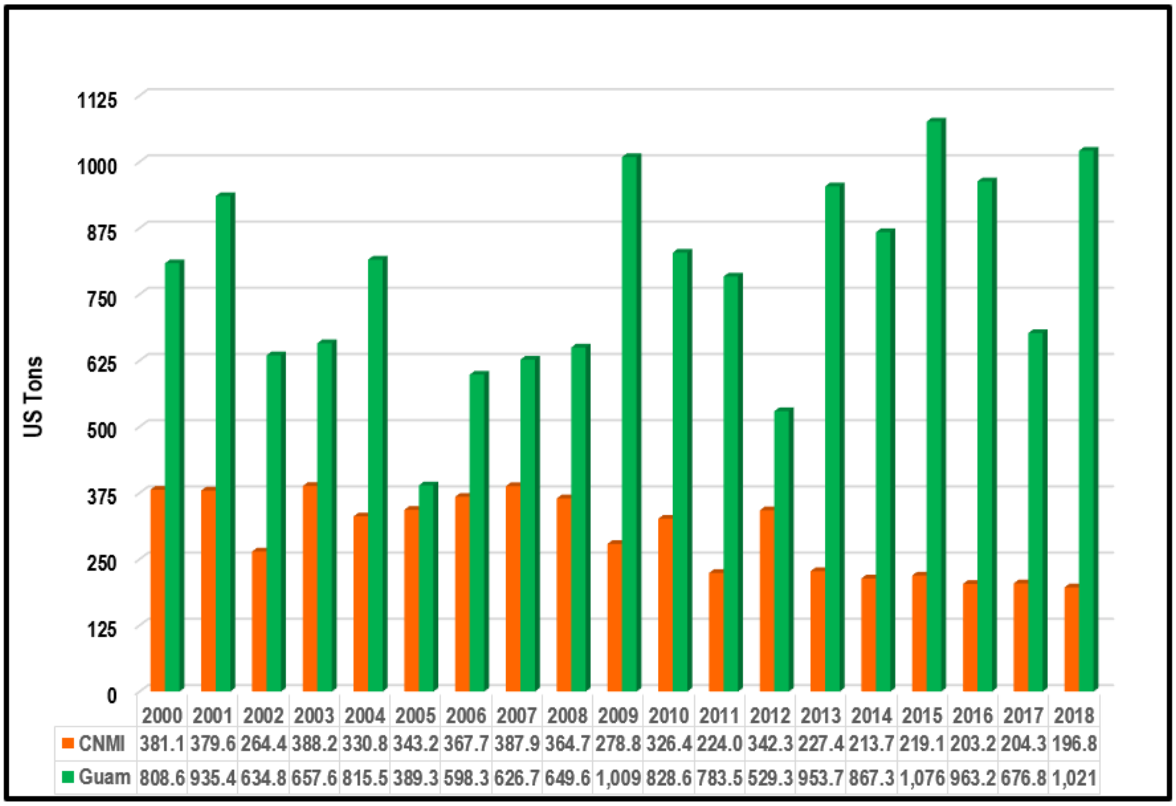


Figure 10. Estimated commercial value seafood purchases, Mariana Archipelago: 2000–2018.

To illustrate the difference between commercial purchases and total catch, Figure 12 shows estimated total catch for the CNMI (Saipan) and Guam fisheries from 2000–2018. These are combined annual estimates from DFW's and DAWR's boat-based and shore-based creel surveys. When compared with Figure 10, total catch is about 2–3 times the amount purchased by vendors. For many cultural and traditional reasons, up to two-thirds of the catch either goes to home consumption, is shared with friends and neighbors, and/or may be sold or bartered via nonstandard commercial outlets (e.g., door-to-door sales, roadside stands, pop-up vendors), particularly in the CNMI (Severance et al., 2013).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
🟧 CNMI	381.1	379.6	264.4	388.2	330.8	343.2	367.7	387.9	364.7	278.8	326.4	224.0	342.3	227.4	213.7	219.1	203.2	204.3	196.8
🟩 Guam	808.6	935.4	634.8	657.6	815.5	389.3	598.3	626.7	649.6	1,009	828.6	783.5	529.3	953.7	867.3	1,076	963.2	676.8	1,021

Figure 11. Annual estimated total catch: 2000–2018.

Although the breakdown of estimated total catch data by major fishery/habitat groups (e.g., pelagics, bottomfish, reef species) shows that fisheries around Guam and Saipan are quite similar (Figure 13), the proportions of these groups in commercial purchase data are distinct and vary from year to year (Figure 14). The proportion of reef species in sales data is higher than in the total catch. This is also true for bottomfish and invertebrates (see legend at the bottom of the figure), particularly on Guam. Guam's commercial markets also include nosnos/squid (multi-family group), some of which may have come from landings at the Port of Guam during this time period (high seas imports). Inshore species, including invertebrates, appear to be more abundant in markets on Guam than in the CNMI, where they are sold at the side of the road or may be sold directly to hotels and restaurants. Lobsters and certain crabs are more likely to be seen in Guam markets too, as are deep bottomfish. Much of the highly valued invertebrate catch may be sold at the side of the road, in neighborhoods, or by other methods in the CNMI. This also occurs at times on Guam. Weather, particularly wind, may be another reason CNMI markets have a lower proportion of bottomfish.

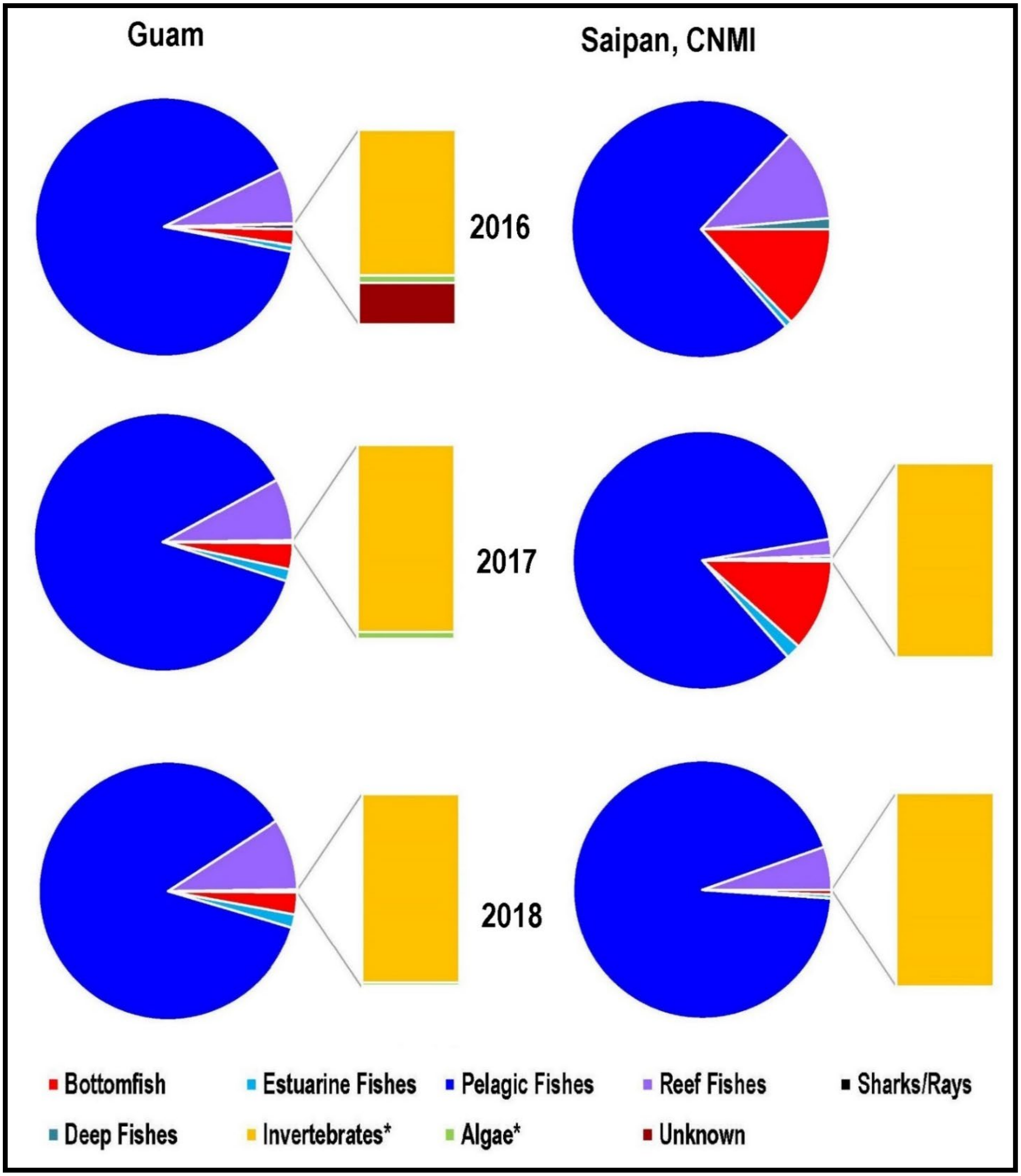


Figure 12. Proportion (% weight) of total fishery landings by major groups.

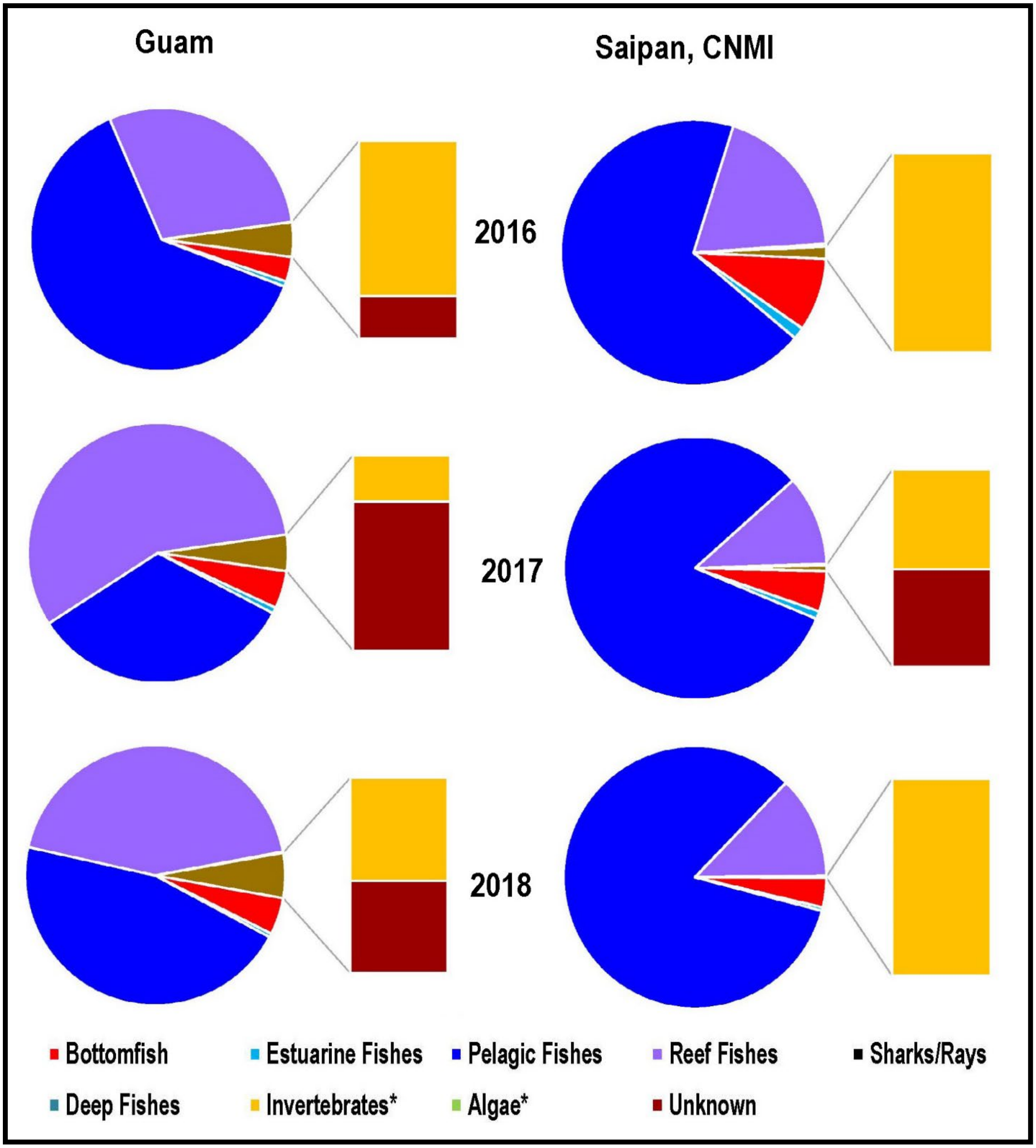


Figure 13. Proportion (% weight) of estimated commercial fishery landings by major groups.

It should be noted that the weight of invertebrates and algae is often underestimated in creel survey data because these species may be omitted or listed without weight. Reef or bottom fisheries taking place at night or in remote locations may also be missed by the surveys. Market data tend to be reliably weighed but poorly detailed as to species. Differences in fishing regulations, customer preferences, sales venues, and other factors may account for the differences in Guam's versus Saipan's buyer/market data. Without speculating too much about the causes, it is noted that sales data show different trends from total catch. It can also be confirmed that markets on Saipan are different than on Guam. Trends in data for specific groups are further described in the sections listed by major "functional groups" (beginning p. 53).

Both Guam and Saipan's total catch is dominated by pelagics, such as skipjack tuna (*Katsuwonus pelamis*), toson/wahoo (*Acanthocybium solandri*), mahimahi (*Coryphaena equiselis and C. hippurus*), and some yellowfin tuna (*Thunnus albacares*). Billfish catches are rare in the CNMI and because it is hard to sell large fish, they are not targeted. However, on Guam during the marlin/billfish season, most fishermen actively target those fish. Additionally, it is easier to sell larger fish on Guam because of the Coop, allowing the growth of this market and support of a popular billfish fishing derby season.

Bottomfish catches include deep slope eteline snappers (Lutjanidae), emperors (Lethrinidae), and a wide variety of groupers (Serranidae). All three of these families also have shallow water representatives that show up in reef fish catches. Other elements of reef fisheries are too diverse to describe, but include wrasses (Labridae), goatfishes (Mullidae), parrotfishes (Scaridae), squirrel and soldierfishes (Holocentridae), tangs and surgeons (Acanthuridae), rabbitfishes (Siganidae), jacks (Carangidae), invertebrates (octopus, snails, other mollusks, lobsters, crabs, etc.), and algae. For detailed information on Guam and CNMI commercial fish sales by species, see the NMFS publication "Fisheries of the United States" (FUS: NOAA NMFS FUS 1995–2019) or "Fisheries Statistics of the Western Pacific" (FSWP: Hamm et al., 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012; Lowe et al., 2013, 2014, 2016, 2024a, 2024b, 2024c).

Many factors limit the export of fresh, locally caught seafood from the CNMI, and to a lesser extent Guam. Even same-island sales can be challenging. One of the greatest challenges, especially for the CNMI, is the availability of fresh water for ice. The low water table, permeable limestone cap, and small size of Saipan all contribute to making its groundwater slightly brackish, except at higher elevations (Carruth, 2003: Stafford et al., 2013). Large fishing ventures have a hard time getting sufficient ice for fishing vessels, let alone packaging and shipping seafood off island. The larger size and presence of a successful fishing cooperative on Guam that can provide ice is a great boon to fishermen on that island. Shipping logistics, such as flight schedules, distances, costs, and transfer times to reach commercial markets present additional challenges. There is some export of locally caught fish from Saipan and Guam to the Federated States of Micronesia (FSM). Some of this is by immigrants or visitors from the FSM, and there may be well-developed networks of fishers and buyers that feed these markets.

The CNMI maintains a market industry comprised of small vendors (ERG, 2018). Fishing cooperatives have not done well and there are records of failed cooperatives on Saipan from the early 1950s (Amesbury, 1989). Instead, it is the small-scale markets and door-to-door sales that thrive, mainly on Saipan. For example, in 2013, unaccounted for door-to-door sales on Saipan were estimated to comprise about 30% of commercial pelagic landings (WPRFMC, 2013). Since the fish/seafood species and sizes sold to restaurants, hotels, markets, and other commercial venues is different than what is gifted/bartered with friends or family, door-to-door, at community functions, etc., the best measure of species composition in the catch is creel survey data (total catch). Zeller et al. (2007b) suggested that the contributions of small-scale fisheries to GDP for the CNMI (and American Samoa) may have been underestimated by more than a factor of five and indicated that the "non-commercial" sector plays a more significant role as contributors to the GDP than assumed.

Fisheries Management and Other Marine Resource Conservation Measures

Many marine resources management measures in place in the CNMI today stem from the Japanese period. For example, the use of explosives, electricity, and poisons was forbidden during the Japanese mandate and has remained illegal. Licensing requirements for certain types of commercial harvest put in place during the mandate also remain in place in some form today. These and other management measures are now found either in the

CNMI Public Law (2-51) that created the DFW under the Department of Lands and Natural Resources (DLNR), or in DFW regulations.

The seasonal restriction on harvest of the topshell (formerly*Trochus niloticus*, currently *Rochia nilotica)* also stems from when the mandate was enforced throughout the CNMI and other parts of Micronesia. The topshell closed season, along with a 3-inch size limit for this species, is still in force within the Commonwealth Code. Introduced in 1938 (see marine taxa section, p. 67), these snails have been managed in a state of moratoria in the CNMI, with open seasons during periods with adequate biomass, as recommended by Adams et al. (1994), following an SPC-led survey of their distribution and abundance on Saipan, Tinian, and Rota. An open season was declared by the DLNR in 1996, monitored by the DFW, and documented by Trianni (2002b). No commercial open season has since been declared, but non-commercial harvest is believed to occur.

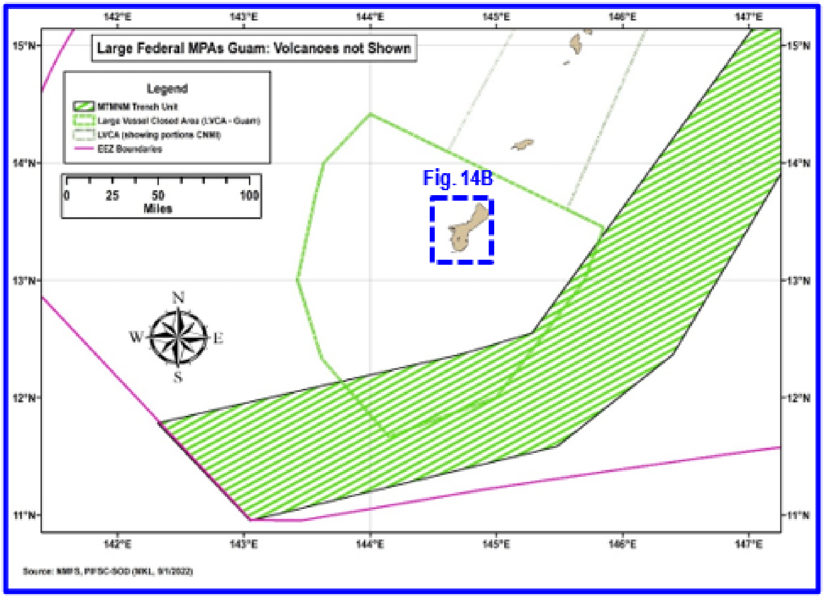
Guam fishing regulations, including seasonal restrictions, size and bag limits, and gear restrictions are managed under the Department of Agriculture's Administrative Rules and Regulations (Guam Government, 2020). Some permitting requirements and catch limits for activities within federal wildlife refuges are managed by the U.S. Fish and Wildlife Service (USFWS, 2020). Although it was under American influence (not subject to mandate regulations), similar seasonal and commercial harvest restrictions for *Trochus* also exist in Guam, as well other species-based limits, such as those on the harvest and export of giant clams (various species and subspecies of tridacnid clams). Giant clam regulations include a minimum size, a ban on commercial harvest, non-commercial bag limits, and restrictions on the export of giant clams (maximum number). Other fishing regulations found under the Guam Administrative Rules and Regulations (GARR) include gear and size restrictions, bag limits, and fee/penalty schedules for violations.

Both the CNMI and Guam governments have established a network of marine protected areas (MPAs or marine preserves; Figures 14-15 and Table 4) around the most populated islands with varied fishing restrictions (e.g., no take, limited gears, species specific). For a recap of the diverse coastal MPAs established in Guam (from 1978) and in the CNMI (from 1981 forward), see Wusinich-Mendez and Trappe (2007). CNMI DFW (2015), provides a more recent overview of the CNMI's MPAs. Federal MPAs are described and inventoried on a NOAA website, which also provides downloadable geographic data (NOAA National Marine Protected Areas Center, 2019). A summary of the largest federal CNMI and Guam MPAs, with closure of the EEZ to purse seining and addition of a CNMI closure to longlining within 30 nmi of shore can be found in 76 FR 17811 (2011) and 71 FR 10869 (2006; Guam longline closure to 50 nmi). The rules within MPAs can be quite complex, involving a combination of gear and species restrictions (e.g., Schroer, 2005, 2007; Wusinich-Mendez and Trappe, 2007; CNMI DFW, 2015). For example, the preserve at Tumon Bay on Guam only allows fishing from shore using cast net (*talaya*) or hook and line, and the catch is limited to rabbitfishes (various *Siganus* spp.), juvenile goatfish (Mullidae), juvenile jacks (Carangidae), and the convict tang *(Acanthurus triostegus)*. Furthermore, talaya fishers along the reef margin at Tumon Bay are only allowed to take two species/groups, rabbitfishes and convict tangs. As the depth and distance from shore increase (evidenced by the location of the reef margin), an increasing number of gears and fishing methods are allowed. Trolling may be conducted from the reef margin seaward, but only for pelagic fishes. Bottomfishing may be conducted from the 100-foot contour seaward.

Baseline studies have been made for the CNMI Mañagaha Marine Conservation Area (Trianni, 1999a), the Tinian Marine Sanctuary (Trianni, 1999b), and in the Sasanhaya Bay Fish Reserve on Rota (Trianni and Moots 2000). The existence of a military closed zone at Farallon de Medinilla (FDM) has required annual marine surveys as part of mitigation to assess damage to nearshore coral reef habitat due to training exercises (Trianni 1998d, 1999). Several internal reports from the U.S. Navy have been produced that highlight the positive benefits of the closed zone, most of which have been summarized by Smith and Marx (2016).

The first recommendation to designate a marine protected area within the greater Archipelago was made by the international biological program held in Koror, Palau, in November 1968 (Doty et al., 1969). This was seconded by the research crew from the Lindblad Explorer expedition which took place August 13, 1976 (Eldredge, 1983a). Their report to the Saipan commissioner, published by the University of Guam (UoG), included a recommendation that Maug Island be designated as a protected research area.

The MTMNM was first advanced as a fisheries reserve. It was supported in part because the proposed reserve (Islands Unit) was so far away it would likely not negatively impact local fishing opportunities. Tupper (2007), Taylor and McIlwain (2010), and Taylor et al. (2012) found positive spillover effects near marine reserves around Guam, and benefits within Guam's MPAs including age structure and biomass responses. The implementation of a SCUBA-spearfishing ban in the CNMI in 2002, in effect creating a large-scale MPA, has also had a positive impact on coral reef fisheries resources in comparison with Guam, where this practice was not illegal until recently (Lindfield et al., 2014, 2016). The use of SCUBA to harvest fish on Guam was banned in March 2020. CNMI restrictions on the use of nets in Saipan Lagoon also resulted in apparent increases in abundance of certain reef fish families (Trianni et al., 2018).



Source: NMFS, PIFSC-SOD (MKL, 9/1/2022)

Figure 14A: Geographic perspective Guam Large MPAs

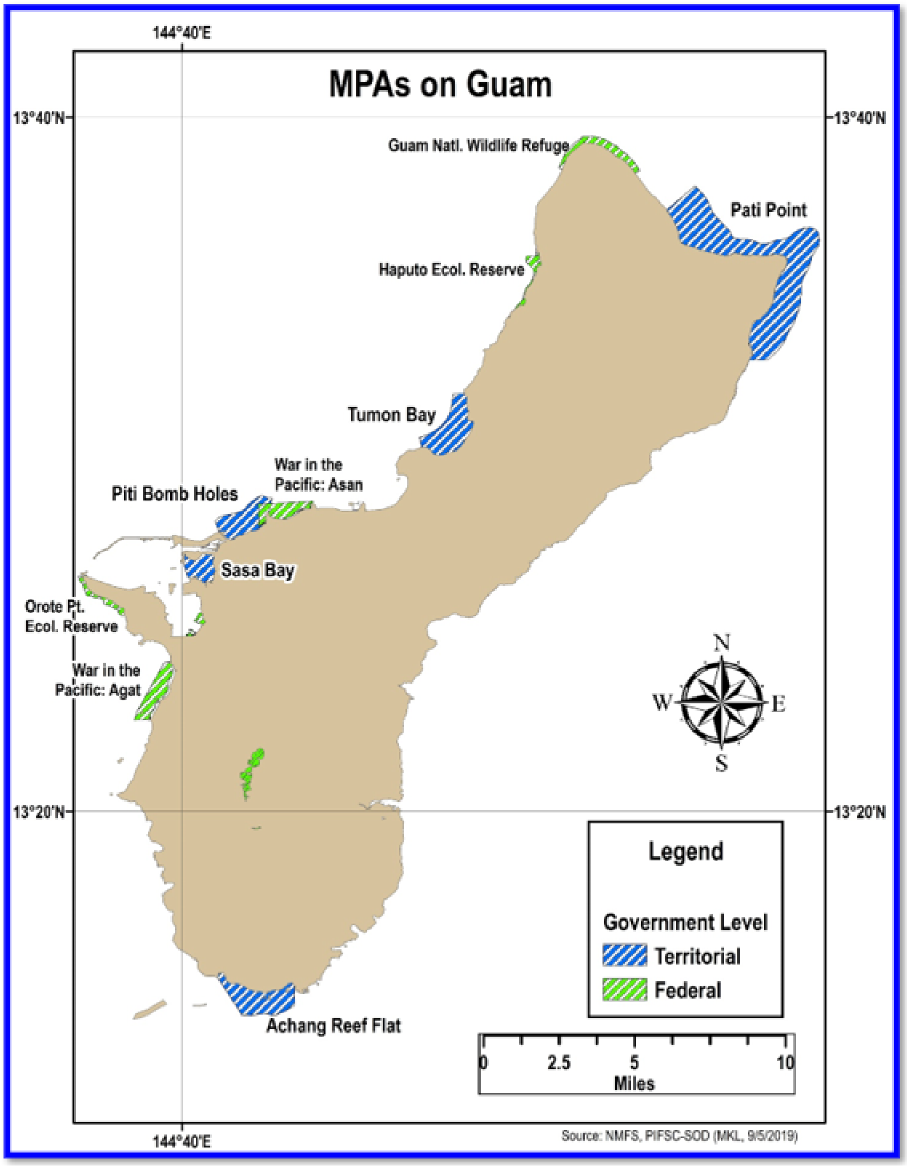


Figure 14B: Map of MPAs on Guam. For more information on Guam MPAs, see: https://pipap.sprep.org/country/gu MPA Shapefiles Source**:** Reefbase.org (2011).

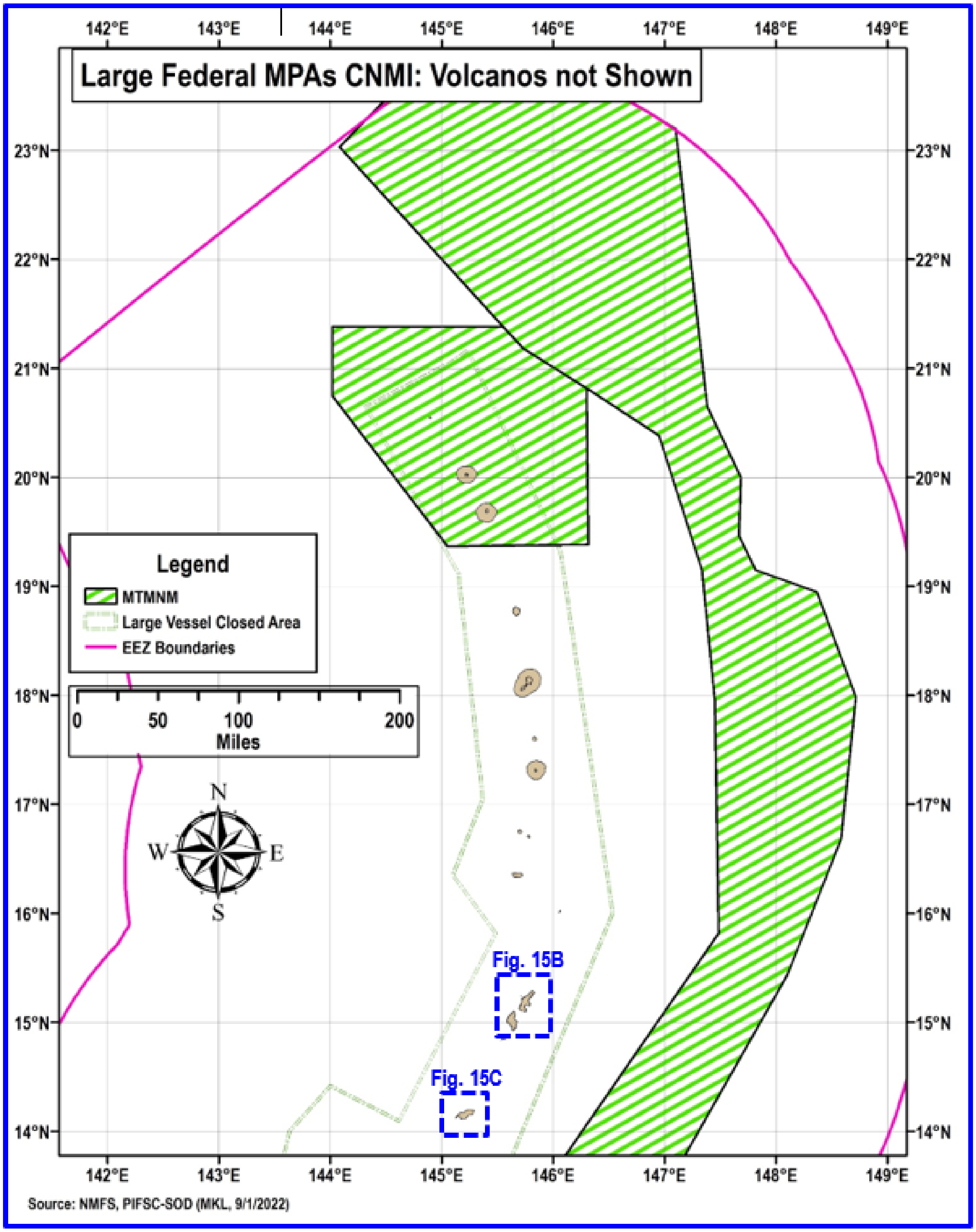


Figure 15A: Geographic perspective: CNMI large MPAs.

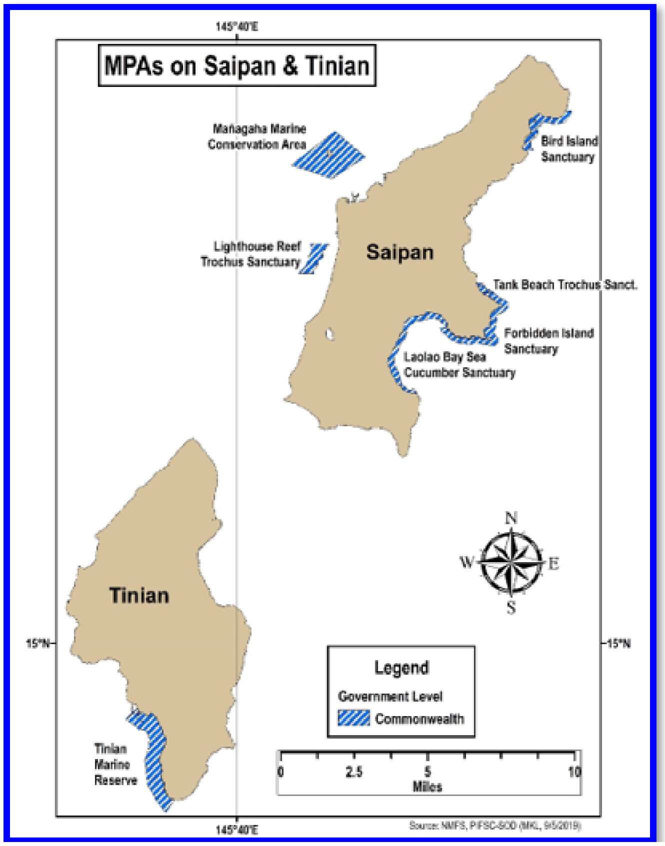


Figure 15B. MPAs on Siapan and Tinian.

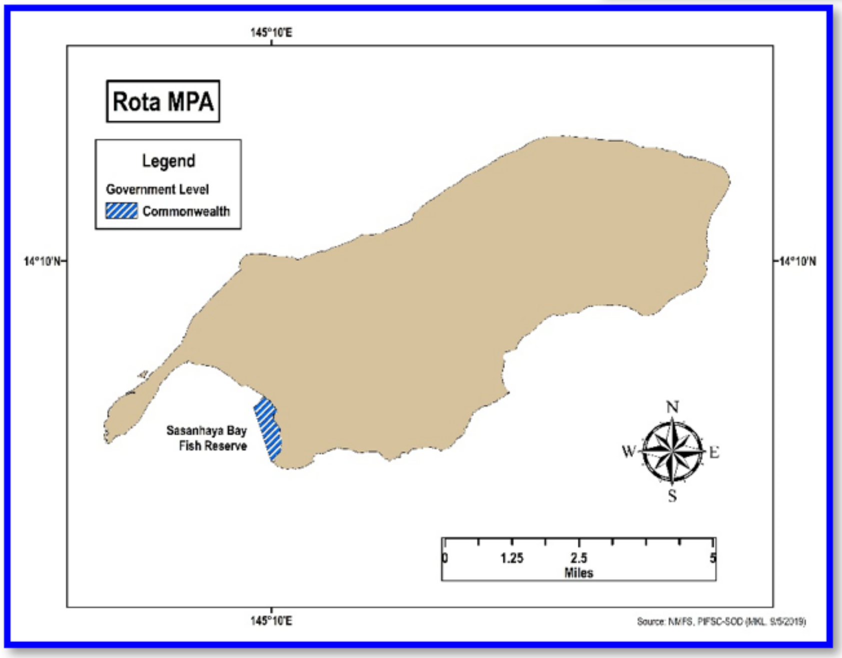


Figure 15C. MPAs on Rota

For more information on CNMI MPAs see:

- https://dcrm.gov.mp/our-programs/marine-monitoring-program/marine-protected-areas/
- https://pipap.sprep.org/country/mp

MPA Shapefiles Source: CNMI Bureau of Environmental & Coastal Quality (4/22/2018) https://becq-dcrm.opendata.arcgis.com/datasets/cnmi-marine-protected-areas/explore?location=14.686730%2C145.495075%2C10.36

Table 4. Marine Protected Areas in the Mariana Archipelago (chronological order).

Territory	**Island**, Place/Regulation Name	Designation	Enacting Law	Year
CNMI	**Uracas**	Uninhabited Island	CNMI Constitution	1977
	Maug	Uninhabited Island	CNMI Constitution	1977
	Asuncion	Uninhabited Island	CNMI Constitution	1977
	Saipan, Mañagaha Island	Uninhabited Island	CNMI Constitution	1977
	Saipan, Tank Beach Trochus Reserve	No-take species specific reserve	CNMI DFW Regulation	1981
	Saipan, Lighthouse Trochus Reserve	No-take species specific reserve	CNMI DFW Regulation (85-30.1-415)	1981
	Rota, Sasanhaya Bay Fish Reserve	No-take marine reserve	Senate Local Bill 9-2	1994
	Sea Cucumber Moratorium	***CNMI-wide***	CNMI PL 11-63	1998
	Saipan, Lau Lau (or Laolao) Bay and Bird Island Sea Cucumber Sanctuaries	No-take taxa/group reserve	CNMI Administrative Code § 85-30.1-420, Public Law 11-63	2000
	Saipan, Mañagaha Marine Conservation Area	No-take marine reserve	CNMI PL 12-12	2000
	Saipan, Bird island Marine Sanctuary	No-take marine reserve	CNMI PL 12-46	2001
	Saipan, Forbidden Island Marine Sanctuary	No-take marine reserve	CNMI PL 12-46	2001
	(CNMI-wide) Fair Fishing Act	Banned use of SCUBA or other assisted breathing apparatus to take fish	CNMI PL 12-87 (amended PL 12-77 which had amended PL 12-14)	2002
	CNMI-wide (later exceptions Tinian and Rota) Net Use Restrictions	Restricted the use of certain nets to catch fish in the CNMI. Modifications made through Public Law for allowance under certain circumstances on Tinian and Rota.	CNMI DFW Regulation	2003
	Tinian, Marine Reserve	Partial-take marine reserve	CNMI PL 15-90; amended by PL 17-14	2007; amended 2010
	Longline Vessel Closed Area	Within 30 nm of the CNMI	76 FR 17811 76 FR 37287	2011 2011

Territory	**Island**, Place/Regulation Name	**Designation**	**Enacting Law**	**Year**
Guam	War in the Pacific National Historical Park	National Historical Park (fishing and diving allowed)	National Park History Division, 1978 (land acquisition, undetermined)	1978
	Haputo Ecological Reserve Area	Ecological Reserve	USN: Ch. 15 OPNAVINST 5090.1; Ch 17 NAVFAC P-73 Real Estate Manual; 36 CFR 251.23; 40 FR 38; and US HR 5602	1984
	Orote Ecological Reserve Area	Ecological Reserve		
	Guam National Wildlife Refuge	National Wildlife Refuge (zoned no-take areas, restricted non-commercial fishing only permitted)		1993
	Pati Point	Marine Preserve, limited fishing allowed (hook-and-line only)	Guam P.L. 24-21	1997
	Achang Reef Flat	Marine Preserve, limited cultural fishing allowed	Guam P.L. 24-21	1997
	Tumon Bay	Marine Preserve, limited species and gears allowed (cast net, hook-and-line)	Guam P.L. 24-21	1997
	Piti Bomb Holes	Marine Preserve (no-take)	Guam P.L. 24-21	1997
	Sasa Bay	Marine Preserve (no-take)	Guam P.L. 24-21	1997
	Guam offshore to 50-nm	Longline closed area created • coordinates corrected • consolidated with error • final coordinate correction	57 FR 45989 59 FR 46933 61 FR 34578 71 FR 10869	1992 1994 1996 2006
CNMI and Guam	Purse Seining Closed Area	EEZ Guam and CNMI	CNMI and Guam	2011
CNMI and Guam	Marianas Trench Marine National Monument	Trench Unit	Presidential Proclamation 8335	2009
CNMI		Vents, Volcanoes Unit		
		Islands Unit (no commercial fishing, restricted non-commercial fishing permitted)		

Stock Assessments

Stock assessments for the U.S.-associated Pacific islands, including Guam and the CNMI, are addressed in various detailed historical reports that need not be recounted here. Annual and quarterly summaries covering the period from 2011–2020 can be found at https://www.fisheries.noaa.gov/stock-assessments-quarterly-reports-archive. New information posted on NOAA's website (https://www.fisheries.noaa.gov/national/population-assessments/fish-stock-assessment-report) can be explored by region and species using the link found in the footnote[19] for region "Pacific Islands."

A summary of recent stock assessments, including data quality issues and methods for Guam and the CNMI, can also be found at https://www.fisheries.noaa.gov/pacific-islands/population-assessments/western-pacific-stock-assessment-review. Of particular interest during the period covered by this compendium are the recently developed methods and assessments for reef fish using the challenging data collections that exist for this region (Nadon and Ault, 2016; Nadon, 2019). Earlier reviews of stock assessments from 2005–2013 are available online at https://www.fisheries.noaa.gov/pacific-islands/about-us/independent-peer-reviews-science-pacific-islands.

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[19] Link to stock assessments by region and species: https://www.fisheries.noaa.gov/species-directory

Fisheries and Ecological Research Highlights by Major Functional Groups

Functional Groups (Marine Taxa)

The following section is presented within the framework of major marine taxa to provide a foundation for collaboration that integrates basic monitoring to track ecosystem changes with fundamental research to understand the driving biological, ecological, environmental and socio-economic forces. It is our hope that this framework will make it easier for marine scientists to identify areas of shared interest in the Archipelago that can inform the broader topics of global and local marine ecology and resource management. Cooperative research has long been the goal of agencies, individuals, organizations, and learning institutions throughout the Pacific. Supporting this effort would be a valuable legacy for the Monument. That is why we adopted this approach for our research review which was undertaken at the request of Monument stakeholders.

Figure 16 provides a perspective on how major marine taxa ("functional groups") fit into the known biological kingdoms. The taxonomy is complex and under constant revision. All living kingdoms (animals, plants, fungi, unicellular organisms, and variously nourished bacteria) are represented in the Archipelago. Ancient and distinct lines of marine microbes (mainly bacteria) have a complex and important role in deep trench and volcanic food chains (Kato et al., 1997; Hutchins et al., 2007; Bartlett, 2009; Tarn et al., 2016; Peoples et al., 2018), as well as in shallow habitats (Lobban et al., 2002, 2011b; Cruz-Rivera and Paul, 2006; Rivera-Posada et al., 2011). Research on Guam (Lobban et al., 2011a, b, 2014, 2015) indicates a diverse community of tiny prokaryotes and their complex ecological relationships with marine macrofauna is waiting to be unveiled throughout the Archipelago. Although they are "extremely"[20] diverse and abundant in trench and volcanic vents, and even shallow habitats, we only mention these tiny organisms briefly in this broad overview.

Even within the most visible taxa, rare and cryptic species with complex ecological roles are constantly being discovered, (Donaldson, 1989; Kensley, 2001; Castro, 2003; Ng and Ng, 2003; Ng and Takeda, 2003; Tan and Ng, 2003; Becerro and Paul, 2004; Faucci, et al., 2006; Anker, 2010). This report cannot do justice to this rich and complex floral and faunal tapestry which continues to be unfolded and explored in the Marianas. Because of their importance to fisheries, this review will focus on the three most prominent groups of macro flora and fauna (shown in Table 5 and illustrated in Figure 16), which make up over 99% of the biomass in marine fisheries:

1. **Marine Algae and Flowering Plants:** large and small plants, including edible seaweeds and those living within coral reefs, in addition to the seagrasses and mangroves that form essential coastal habitat
2. **Invertebrates:** echinoderms, crustaceans, mollusks, corals, worms, planktonic animals, etc.
3. **Vertebrates:** fishes, marine mammals, sea turtles, etc.

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[20] Shameless pun, referencing their colonization of "extreme" habitats

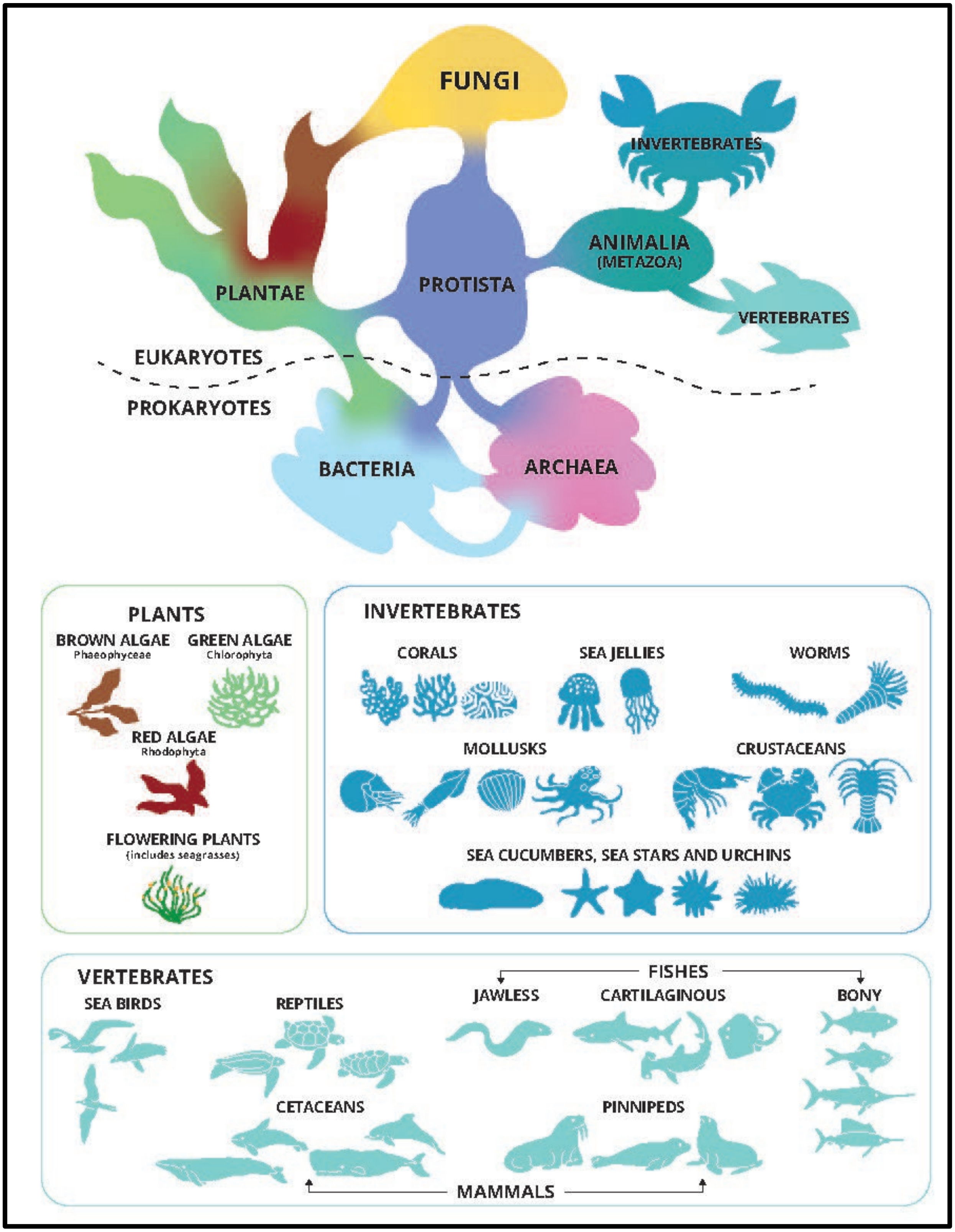

Figure 16. Perspective on living kingdoms and marine fisheries taxa. Figure by Kathleen Uno-NOAA Affiliate, Lynker Technologies.

Table 5. Major fisheries taxa and functional groups

Kingdom: Major Division	**Infra Phyla** *(for kingdoms not shown in detail various levels above phylum)*	**Group name(s)**	**Marine and Coastal Examples**	**Notes/Comments**
Archaebacteria	Prokaryotic, unicellular	Ancient bacteria	Hydrothermal vent fauna in deep marine habitats of the Marianas, able to harvest chemical energy from hot minerals and gases	Ancient intermediate between bacteria and eukaryotes
Eubacteria	Prokaryotic, unicellular	True bacteria	Bacteria and cyanobacteria	Simple cells, rigid cell walls, often flagellated
Protista (including Chromista[21])	Eukaryotic, unicellular, and multicellular	One-celled organisms, mostly (some with plant-like features)	Foraminiferans, radiolarians, diatoms, etc.	Cells have DNA in chromosomes within a nucleus
Plantae	Eukaryotic, multicellular	Flowering Plants	Sea grasses, mangroves *(most representatives are terrestrial)*	Largest, most diverse group with varied and unique reproductive strategies including vivipary
		Algae	Various edible marine algae, food for humans and many other species	Marine algae represent a small fraction of the world's plant taxa. They reproduce both sexually and asexually.
Fungia	Eukaryotic, multicellular	Fungi	Marine fungi are found on coral reefs, in sediments at the bottom of the ocean, at many levels in between (and within) with metabolic superpowers forming vital elements of food webs.	Some taxonomists place fungi within plants.
Animalia	Eukaryotic, multicellular			
	Major Marine Phyla	**Major Functional Groups (phyla, etc.)**		
Invertebrates	Cnidaria	Phylum with stinging cells (nematocysts)	Jellyfish, corals, sea pens, sea fans, etc.	
	Annelids	Polychaetes, Serpulids	Segmented worms: feather dusters, *Palolo*, serpulids	Many worm-like creatures not listed, including other phyla
	Echinoderms	Sea stars, brittle stars, sea cucumbers, sea urchins, sand dollars...		
	Mollusks	Cephalopods, gastropods, bivalves...	Octopus, squids, snails, clams, limpets, nautilus	
	Arthropods	Crustaceans: multiple orders, suborders, etc., many families	Lobsters, shrimps, mantis shrimps, crabs, many small planktonic species	
Vertebrates	Chordata, Vertebrates (subphylum)	Boney fishes (several orders, suborders, etc. and many families)	Bonefish, lizardfishes, silversides, needlefish, eels, halfbeaks, flying fishes, mullets, most pelagic, reef, and bottom fishes.	Too many familiar forms to mention. *Note: Tunicates (top p.56) are also in this subphylum, but are not of interest to fisheries.*
		Cartilaginous fishes	Sharks and rays	
		Turtles	Marine, brackish, and freshwater turtles	
		Marine mammals	Dolphins, porpoises, whales	

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[21] Chromista (Kingdom) includes all protists with plastids contain chlorophyll c (these definitions are continuously evolving).

Marine and Coastal Aquatic Vegetation

Jarzen and Dilcher (2009) indicate there was extensive mangrove vegetation on Saipan, predating the arrival of humans, but these forests were impacted by human presence after World War II. Woodroffe (1987) noted the presence of seven species of mangroves on Guam. More recently, up to ten species have been observed (https://www.guampedia.com/mangroves-the-forest-between-land-and-sea/). Woodroffe (1987) indicated there were two mangrove species present in the 1980s on Saipan, but as of 2018, only the oriental mangrove (*Bruguiera gymnorrhiza*) had significant abundance. Ellison (2009) described wetlands, and Bhattarai and Giri (2011) mapped mangrove distributions in the Pacific, including the Mariana islands. Gilman et al. (2006, 2016) commented on the potential impacts of sea level rise on the distribution and abundance of Pacific mangroves, again with specific notes on the CNMI and Guam.

Records of 90 marine benthic algal species from Farallon de Pajaros south to Anatahan, CNMI, were first published in 1977 (Tsuda and Tobias, 1977a,b). An unpublished technical report on the natural history of Maug included a list of 35 species of benthic algae, with percent cover for each, in the undersea volcanic crater (Eldredge et al., 1977). Subsequently, the University of Guam Marine Lab (UoGML) produced a bibliography (Tsuda, 1981) and checklists (Tsuda, 1972, 2003) for benthic marine algae. CREP biennial and triennial MARAMP surveys record percent cover of major benthic groups, including macroalgae, encrusting algae, turf algae, and hard corals. From 2009–2014, turf algae was the most abundant benthic substrate recorded, with at least 40% cover on each island surveyed (Heenan et al., 2015). Marine algal coverage found during 2003, 2005, and 2007 MARAMP surveys is documented in Brainard et al. (2012).

During the 2003 and 2005 MARAMP cruises, benthic algae collected from the Mariana Arc and West Mariana Ridge seamounts revealed 10 new species of red algae, and documented the presence of 67 species throughout the Archipelago (Tsuda et al., 2015). Lobban and Tsuda (2003) provided an updated checklist of benthic marine macroalgae and seagrasses of Guam (and Micronesia). Tribollet and Vroom (2007) described the distribution and relative abundance of algae throughout the Archipelago, and Vroom et al. (2006) described the health of many of the algal species that dominated reefs relative to each other. A survey at Santa Rosa Reef, south of Guam, found new occurrences of green and brown algae (Tsuda et al., 2012). Volcanic ash deposits affect crustose coralline red algae and macroalgae on the reefs (Vroom and Zgliczynski, 2011), and volcanic activity may promote the growth of cyanobacteria and microalgae (Schils, 2012).

Lobban and Tsuda (2003) and Tsuda (2003) provided updated checklists for macroalgae and seagrasses of the Marianas. Research on seagrasses in the Marianas has focused on biochemical processes (McMillan and Smith, 1982; Pinkerton et al., 2015), as well as on long term monitoring of seagrass meadows (LaRouche et al., 2019). Houk and Camacho (2010) reported competitive interactions between macroalgae and seagrasses in Saipan Lagoon. Vargas-Ángel (2010) provided an overview of the distribution of occurrences of crustose coralline algal (CCA) diseases across the U.S.-assoicated Pacific Islands, noting CCA diseases were “common to abundant” with detectable “hot spots” around Guam and the southern Mariana Islands (as well as other regions). Kendall et al. (2017) mapped the distribution of benthic habitats in Saipan Lagoon, including seagrasses. LaRoche et al. (2019) described decadal changes in a seagrass bed on Guam.

Invertebrates

The acquisition of fishery-dependent data in the Marianas is notably limited, particularly for most invertebrates harvested. There are a number of invertebrate fisheries for which data are not collected systematically, or for which the resolution of data collection is poor. Fisheries monitoring issues in the CNMI and Guam have been described in earlier sections (see p.31). Until the last decade, CNMI commercial purchase (CPDS) data showed sales of “unspecified invertebrates,” including octopus, spiny and slipper lobsters, shrimp, and squid. Guam commercial purchase data show similarly broad, slightly different categories including “unspecified invertebrates” (octopus, crabs, spiny and slipper lobsters, and squids). This makes it nearly impossible to detect long term trends at the species level for most invertebrates.

Some invertebrate fisheries are current, and others are more historical in nature since the resource may have been harvested to a level where fishing is no longer considered worthwhile. Available fishery-dependent information stems from short-term harvests of select economically important species. Oddly enough, some of the most complete records of invertebrate fisheries available are from decades ago.

Some of the largest fishery harvests in the Marianas took place during the period of the Japanese mandate (1920–1944). Although also limited in its detail, information from the mandate provides sufficient data to establish the scope of fishing activity that was occurring, especially regarding highly valued sea cucumber resources (another multi-species group). Smith (1947) provided comprehensive documentation of the breadth of marine fisheries in Micronesia during the Japanese period. The post-war survey included Japanese records from 1941, and indicated significant harvests of sea cucumbers and shellfish, as well as sharks and other fishes.

Other recent monitoring programs, such as the Guam and CNMI shore- and boat-based creel surveys, provide more insight into the extent of invertebrate fisheries than commercial purchase monitoring. These surveys collect both commercial and non-commercial data, including gleaned catches of lobster, octopus, squid, other mollusks, and shellfish. Additionally, on Saipan, the CFBS (“Bio-sampling”) program focuses on fish vendor purchases from the nighttime commercial coral reef fish spear fishery, which includes species of lobsters, octopus, and squid. This has brought to light significant catches that are not registered in the commercial purchase data and may be missed by creel surveys. On Guam, with active collaboration from the Coop and some other markets, there has been time to sort invertebrate sales and quantify relative abundance (and more recently size structure) by species. This information indicates there are significant fisheries for marine invertebrates, both in the CNMI and Guam, which are not well understood based on historical data.

Information on the distribution of invertebrates in the Mariana Archipelago has been primarily obtained from research excursions to the northern islands of the CNMI. Survey work by the UoGML (Eldredge et al., 1977) and the Chiba Natural History Museum Expedition (Asakura and Furuki, 1994) focused on identification of invertebrate species from Anatahan to Uracas. In 2003, the University of Guam journal, Micronesica published a special volume that summarized existing knowledge of marine biodiversity for the Archipelago (Paulay, 2003a, 2003b). The report recognized over 4,000 species of invertebrates present in the Mariana Archipelago and noted that this number is high relative to comparably sized areas, although it is lower than locations in southern Micronesia.

The UoGML has served as the premier research institute in Micronesia, producing an abundance of work pertaining to coral reef ecosystems and functions, including numerous studies directed at the biology and ecology of coral reef invertebrates. The UoGML website lists peer-reviewed and technical publications generated from research by its academic staff and graduate students. This information can be found at https://www.uog.edu/ml, where there is a chronological listing with online access to downloadable technical reports UoGML (1971–2020).

Since 2003, PIFSC has conducted biennial or triennial coral reef ecosystem research cruises in the Mariana Archipelago under the Coral Reef Ecosystem Program's Resource Assessment and Monitoring Program (RAMP). The RAMP cruises collect data on macroinvertebrate species of management interest, such as the potentially destructive crown-of-thorns starfish *(Acanthaster planci)*, and economically desirable groups such as sea cucumbers (class Holothuroidea), sea urchins (class Echinoidea), giant clams (*Tridacna* spp.), and the top shell *(Rochia nilotica)*. The SCUBA surveys generally take place on outer reef slopes to depths of 30 m. Additionally, RAMP cruises have incorporated the collection of cryptobiota (organisms that are hard to find or see) using collecting plates left in situ between cruises ("autonomous reef monitoring structures" or ARMS). Since 2006, the U.S. National Park Service has also monitored the benthic marine community (and fishes), at the War in the Pacific National Historical Park (Guam), with sufficient species and abundance resolution to register changes in crown-of-thorns starfish (Brown et al., 2016).

The majority of invertebrate research has been restricted to the shallower depths in the MTMNM Islands Unit or in the southern islands of the Mariana Archipelago. However, limited information has been published for the invertebrate species inhabiting hydrothermal vents in the Monument's Volcanic Unit (Kojima et al., 2011; Kojima and Watanabe, 2015). Species lists have been published for Alice Springs Field, one of the Northern Back-Arc vents (Hessler and Lonsdale, 1991), for one of the arc seamounts (Fujikura et al., 1997), and individual species have been studied at arc vents (Fautin and Hessler, 1989; Tunnicliffe et al., 2009).

Preliminary species lists for hydrothermal vents at several of the arc seamounts are available in cruise reports from the NOAA Submarine Ring of Fire cruises to the Mariana Arc in 2004 and 2006, and for southern Mariana back-arc vents from a Japan Agency for Marine-Earth Science and Technology (JAMSTEC) cruise in 2010. Many new invertebrate species have been discovered in the Islands, Volcano, and Trench Units of the MTMNM from underwater video that is still being mined for information collected during the 2016 Deepwater Exploration of the Marianas completed by NOAA's *Okeanos Explorer*. An extensive benthic invertebrate key is available online (see links to cruise reports in Appendix 1).

Forams (Phylum Foraminifera: Shelled Protista)

Forams are found from shallow to extremely deep areas throughout the world. For example, large calcareous foraminiferans are abundant in coral reefs in the Marianas (Pochon et al., 2001, 2007). More than 100 species of foraminifera have also been collected and reported in the Marianas from hadal depths below 6000 m (Akimoto, et al., 2001; Kitazato et. al., 2009). However, the difficulties with collection methodologies and technologies at these depths appear to cause an underestimation in comparison with other evaluations of the foraminifera in the world's oceans, which are at depths of around 2140 m (Kitazato et al., 2009). This important group, and the equally diverse and abundant (yet tiny) radiolarians, will receive minimal coverage in this overview, which is focused on major fisheries taxa and issues affecting their habitat and macro food items/prey. Suffice it to say that, like everywhere, another entire world can be seen beneath the microscope.

Sponges (Phylum Porifera)

Considerable new sponge fauna has been found in the Marianas within the past 15 years, including 124 species of siliceous sponges (class Demospongiae) and four species of calcareous sponges (class Calcarea), described by Kelly et al. (2003). Thirty percent of the sponges encountered were undescribed. The actual diversity of sponge fauna is considerably higher, since many species remain to be collected and identified (Kelly et al., 2003). Among other things, the new taxa represent a rich source of metabolites possessing novel structural features and biological activities, and a wealth of potential in the fields of biochemistry and medicine (Lee et al., 2001; Aknin et al., 2010). Despite their high diversity and abundance, studies of ecology, age, and growth of marine sponges are in their infancy in the Mariana Archipelago and worldwide (Rohde and Schupp, 2011). Quinn and Kojis (1999) described ecological aspects of mixed coralline sponge colonies (demospongids) at depths up to 39 meters around Saipan. There is also evidence of the spread of at least one marine sponge from the Philippines across the Pacific, including Guam, as the likely result of centuries of trans-Pacific shipping (Carballo et al., 2013). Many more introductions likely occur as a result of ballast and hull encrusting organisms.

The 2016 Deepwater Exploration of the Marianas completed by NOAA's *Okeanos Explorer* observed many potentially new species of sponges at various taxonomic levels (NOAA OER, 2019). This diversity is difficult to catalogue since several high-level sponge taxa are under revision or review (in part due to recent discoveries). For example, the 2016 *Okeanos* exploration uncovered:

- 61 potentially new species of siliceous sponges of the (new) class Demospongiae (formerly an order) were found (36 Demospongiae, 22 Cladorhizidae, 2 Dendoricellidae and 1 Myxillidae);
- 15 potentially new species in the order Tetractinellida (2 Corallistidae, 6 Geodiidae, 4, Vulcanellidae, and 3 family yet unknown);
- 28 potentially new species of glass sponges (order Amphidiscosida), including 14 Hyalonematidae and 14 Pheronematidae;
- 5 potentially new species in the order Hexactinellida;
- 67 potentially new species in the (new) order Lyssacinosida, including 44 Euplectellidae and 23 Rossellidae; and
- 26 potentially new species in the (new) order Sceptrulophora, including 5 Euretidae, 8 Farreidae, 2 Auloplacidae, 3 Tretodictyidae and 8 Uncinateridae).

Sponge communities of the class Calcarea in the Mariana Archipelago, in shallow-water, mesophotic, and deep benthic habitats have not yet been well described. No published information is available for the glass sponges (class Hexactinellida) from the Marianas. Research on deep-sea coral and sponge ecosystems throughout the U.S. Pacific Islands region is an area wide open for discovery (Hourigan et al., 2017), to which further exploration of the Mariana Trench will add a wealth of new information.

The encrusting cyanobacteriosponge *Terpios hoshinota* was first reported from the Mariana Archipelago on Guam by Bryan (1973). This sponge competes for space in the reef environment and was found to grow fastest on clean substrates in Guam. After clean substrate habitat, this species grows faster on live coral, reef rock, and red calcareous algae, respectively (Plucer-Rosario, 1987). Outbreaks of this sponge can result in considerable damage to corals. However, research from southern Japan suggests these outbreaks may occur at irregular intervals and may not necessarily result in an irreparable climax state (Reimer et al., 2010).

Corals (Phylum Cnidaria, Class Anthozoa)

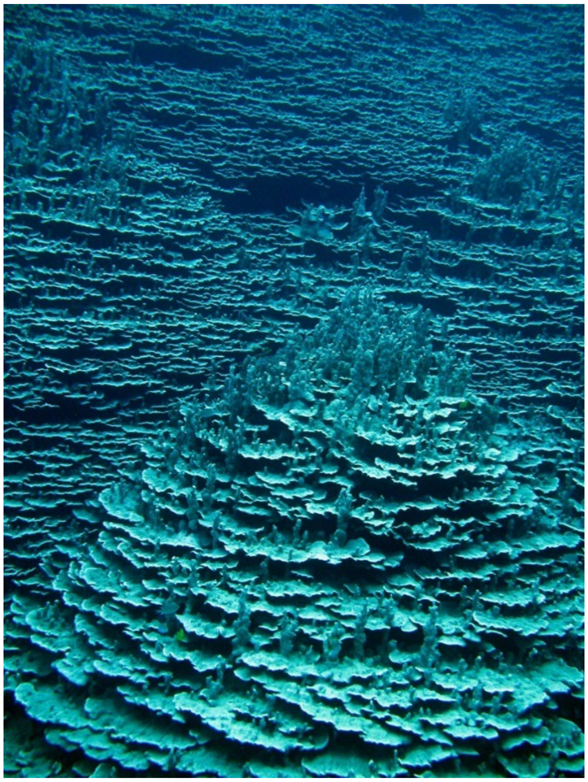

Figure 17. Magnificent scleractinian coral structures from the CNMI. Photographer: Kevin Lino (2009)

The hermatypic (hard type) coral reefs of the Mariana Archipelago are considered to be the most diverse of the U.S. Pacific Islands (Randall, 1995; Randall, 2003; Brainard et al. 2012). They are also among the most spectacular. For example, enormous scleractinian coral structures have been identified throughout the CNMI (Figure 15). The large differences in land area and slope have been identified as major factors that have shaped the coral reef ecosystems of the Archipelago (Riegl et al., 2008; Houk and Van Woesik, 2010; Brainard et al., 2012). Symbiotic relationships (Gochfeld, 2010) and settlement substrate preferences (Golbuu and Richmond, 2007; Slattery and Gochfeld, 2016) are among other ecological factors shown to affect the distributions of Marianas scleractinia. Although live coral collection in the CNMI is prohibited except for scientific purposes, dead coral can be collected for traditional uses.

The importance of coral reefs throughout the Archipelago has been brought to light through various studies aimed at understanding recruitment and ecological structure (Kojis and Quinn, 2001; Quinn and Kojis, 2003; Houk and Van Woesik, 2010; Brainard et al. 2012). Rooney et al. (2005) undertook characterization of reef and other benthic habitat in Saipan Harbor, but much work remains to be done. Houk and Van Woesik (2006) explored sampling design to optimize CNMI benthic video surveys to better detect long term changes in coral cover and other benthic diversity. Recent studies have highlighted threats to to coral reefs including bleaching events (Reynolds et al., 2014; Raymundo et al., 2017), ocean acidification (Enochs et al., 2015, 2016), effects of climate change on larval transport (Kendall and Poti, 2014; Kendall and Poti, 2015; Kendall et al., 2016), pesticide and heavy metal contamination (Whitall et al., 2016), invasive species and diseases (Vargas-Ángel, 2010), and changes in overall resilience of coral and associated algal communities due to climate change and other anthropogenic effects (Birkeland, 2000; Belliveau and Paul, 2002; Houk et al., 2014; Maynard et al., 2015a, b, 2018). Recent research also holds promise of identifying biomarkers that can be used to monitor disease and stress in coral communities in the Marianas and other regions (Gochfeld et. al, 2015).

Non-scleractinian Anthozoa (soft corals) of the Marianas are also quite diverse and abundant. Paulay et al. (2003a) reviewed these taxa, based on literature and surveys registering six zoanthids, eight corallimorpharians, 26 actiniarians, three ceriantharians, 10 antipatharians, and 79 octocorals. They indicated that zoanthid, corallimorpharian, and shallow water gorgonian fauna of Guam are relatively well characterized, but that many locally recognized forms have yet to be identified to species. The same authors noted that a rich deep-water octocorallian fauna has been collected but had yet to be catalogued at that time. The cover of the present report shows dense orange gorgonian coral bushes in the CNMI, which are equally as remarkable as hard coral assemblages in the region (Puglisi-Weening et al., 2000, 2002).

The WPRFMC (the Council) is the only U.S. fisheries management council with a deep-sea coral FMP. The Council and NMFS have regulated deep sea coral harvest to prevent overfishing since the Precious Corals FMP was finalized and implemented in the early 1980s (WPRFMC, 1979; 48 FR 39229, 1983). In recent years, deep-coldwater coral habitats have received increasing attention because of their unique biodiversity and the ecological communities they support (Roberts et al., 2006). A growing concern for the protection of deep-sea coral and sponge habitat resulted in an amendment to the MSA that provided a mechanism by which regional fishery management councils can protect deep-sea corals in U.S. waters and established a deep-sea coral research and technology program within NMFS (Hunter, 1995; Hourigan, 2009; NOAA CRCP, 2010; Parrish et al., 2014). The FMP was amended in 2006 to include federal waters around the CNMI Rota Bridled White-eye Unit (USFWS) management area and to extended existing requirements for federal permits and logbooks to include all harvests of precious corals in EEZ waters of this management area (71 FR 53605, 2006). Additional detailed information can be found on the Council website[22].

The *Okeanos Explorer* "Deep Water Exploration of the Marianas" conducted remote observation vehicle (ROV) dives during 2016. This exploration was the first to discover and document deep-sea coral and sponge communities in the waters of the Mariana region. The surveys also confirmed the presence of precious coral (pink, red, gold, and bamboo) in the Archipelago. Previous anecdotal reports noted a fishery of the precious coral *Corallium* harvested north of Pagan (Takahasi, 1942). Other sources have noted the existence of precious corals in several locations throughout the CNMI EEZ (Grigg, 1993, 2010; Hein et al., 2005).

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[22] Council Precious Corals FMP website: https://www.wpcouncil.org/former-fishery-management-plans/precious-corals-fishery-management-plan/

Echinoderms (Phylum Echinodermata: Sea Stars, Sea Cucumbers, Sand Dollars, Brittle Stars, etc.)

The most prominent echinoderms in the Marianas are sea urchins and sea cucumbers, both of which provide important "ecosystem services" on coral reefs at a wide range of depths. Sea urchins are primarily herbivores, feeding on algae, although some can be predatory. Sea cucumbers are generally omnivorous detritivores, feeding on benthos-associated organic matter, although some are also filter feeders. Kerr et al. (1993) described the distribution and abundance of sea cucumbers on a fringing reef in Guam. Research in the Mariana Trench observed elpidiids at depths of 10.9 km, extending the maximum known depth record for holothurians (Gallo et al., 2015).

Many other echinoderms have also been identified throughout the Archipelago. Irimura et al. (1994) recorded 15 species of non-holothurian echinoderms from rocky inter- and sub-tidal habitats in the northern islands of the CNMI. Paulay (2003c) included 202 species of echinoderms from the Archipelago as a whole. Paulay (2003c), produced a summary of sea stars, urchins, and sea cucumbers for the Mariana Islands. Starmer (2003) produced a checklist of ophiuroids from Guam. Kirkendale and Messing (2003) provided an annotated checklist for crinoids including 21 species from throughout the Archipelago (17 on Guam and 10 from the CNMI). Studies by Michonneau et al. (2013) and Michonneau and Paulay (2014) examined echinoderm diversity and identified new species.

During the Spanish period, thousands of pounds of sea cucumbers were harvested and exported to China. This was noteworthy since, at the time, sea cucumbers were not eaten by islanders (Amesbury and Hunter-Anderson, 2003). During the German period, there was minimal documentation of fisheries activity. However, a German district officer on Guam noted that Carolinians from Saipan dove for trepang (sea cucumbers) at Aguijan Island (also spelled Aguigan) off Tinian and sold them to Japanese merchants (Amesbury et al., 1989). This was one of the first observations of fisheries commerce in the CNMI after the Spanish period, documenting one of the effects of the 19th century Carolinian migration to the Mariana Islands.

Although common on Saipan during the immediate post-war era (Cloud, 1959), the short spine (or collector) sea urchin *(Tripneustis gratilla)* may have been overharvested as it is no longer common. The gonads of *T. gratilla* are favored by the Palauan community on Saipan. One directed, spatially restricted survey for *T. gratilla* focused on areas in the central part of Saipan Lagoon, including locations visited during the Cloud survey (Yuknavage, 2001). The purpose was to assess the potential use of *T. gratilla* gametes as a biomonitoring indicator. This was referred to as the Sea Urchin Fertilization Toxicity (SUFT) test which is still under consideration by the U.S. Environmental Protection Agency. Another urchin, *Diadema savignyi*, was also assayed and showed relatively high sensitivity to nickel and lower copper toxicity rates in embryonic long-spined urchins collected on Guam (Rosen et al., 2015).

Goreau et al. (1972) surveyed the abundance of the crown of thorns starfish (COTs, *Acanthaster planci)* as a regulator of coral reef structure on Saipan in response to the major outbreak of COTs throughout Micronesia during the late 1960s (Marsh and Tsuda, 1973). Houk et al. (2007) theorized that the transition zone chlorophyll front triggers COTs outbreaks. Timmers et al. (2012) found that COTs outbreaks were regionally derived.

There have been important but short-lived fisheries for sea cucumbers throughout history. During the Japanese mandate, significant sea cucumber harvests took place throughout Micronesia, including in the NMI. Richmond

(1995) indicated that more than 5,000 tons of sea cucumber may have been harvested throughout Micronesia during that period (1914–1944). Smith (1947) reported over 119,000 lb were harvested from the Saipan District during 1941. In the fall of 1995, a sea cucumber fishery began on Rota, targeting the surf redfish (*Actinopyga mauritiana*), with secondary harvests of the black teatfish *Holothuria whitmaei* (Trianni, 2002a). The first such fishery since the Japanese period, there was active fishing for several months on Rota. Fishing activity moved to Saipan in 1996, following a depletion of surf redfish around Rota. The Saipan fishery was halted in 1997 due to intensive exploitation. A post-fishery survey and depletion model analysis showed a 78–90% reduction of surf redfish populations from their original biomass in harvested areas (Trianni, 2000). A survey of surf redfish populations was conducted on Tinian in 1997 to provide data that could be used to set a quota to prevent overfishing in the event harvesting shifted to Tinian (Trianni, 2004).

In 1998, a moratorium was placed on the harvest of sea cucumbers in the CNMI as a result of research and management decisions. In 2006, areas where sea cucumbers were harvested on Saipan during 1996 were re-surveyed to evaluate their regrowth/recovery status. Surveys from other parts of Micronesia indicated that recovery to sustainable levels had not occurred since the Japanese mandate (Richmond, 1996). In 2011, a population assessment reported that harvested areas on Saipan had fully recovered to pre-harvest levels (Trianni and Tenorio, 2011).

A sea cucumber fishery driven by the beche-de-mer industry of Asian markets was also set up on Guam in the mid-nineteenth century, during the period of Spanish control (Olive y Garcia, 2006). More recently, there have been a few cases of illegal harvesting of sea cucumbers, including the confiscation of over 11,000 specimens, which were being processed for export to China. Because of the increase in sea cucumber harvesting, DAWR is looking to reduce the daily harvest bag limit from 100 individuals per person to five (5) individuals.

Underwater visual surveys undertaken by CNMI natural resource agencies and the PIFSC CREP MARAMP since 2003, routinely collect data on sea urchins and sea cucumbers (Brainard et al., 2007). Thus, information on distribution and abundance of echinoderms should be widely available. However, many of these surveys do not consistently document echinoderm fauna to the species level.

Polychaetes (Segmented worms: Phylum Annelida, Class Polychaeta)

Although most polychaetes identified from the Marianas have been from shallow reef systems, the group remains highly diverse and taxonomically challenging. Considerable work remains to be completed describing new species and understanding their functional roles in marine ecosystems of the Archipelago. Early research provided limited data on polychaetes from an intertidal reef platform on Guam (Kohn and White, 1977). Pettibone (1989) described four new species of polynoid polychaetes collected by the R/V *Alvin* during the 1987 Mariana Back-Basin Expedition. Several polychaete species were observed in the northern islands of the Archipelago during the Chiba Natural History Museum Expedition (Chiba Expedition) in 1992 (Sato-Okoshi and Yokouchi, 1994). Evaluation of recent collections, primarily from nearshore coral reef ecosystem habitats, has increased the number of known polychaete species from Guam (104 species in 30 families) and Saipan (51 species in 20 families) (Bailey-Brock 1999; Bailey-Brock, 2003). New species have recently been described from Guam (Magalhães and Rizzo, 2012; Magalhães and Baily-Brock, 2015) and Saipan (Magalhães and Baily-Brock, 2013).

The known deep-sea habitats polychaetes occupy in the Marianas range from cold abyssal plain environments to hydrothermal vents, where heat tolerant species such as the Pompeii worm (*Alvinella pompejana)* are found. In 2009, a yet unidentified species was found in the Challenger Deep by the hybrid unmanned autonomous underwater vehicle *Nereus* (http://ns.gov.gu/geography.html**)**. Gallo et al. (2015) summarized and compared epibenthic and scavenging communities, including polychaetes, in the Mariana and New Britain trenches. During 2016, NOAA's *Okeanos Explorer* observed many new deepwater polychaetes including one potential species in the subclass Hirudinea, one in the order Phyllodocida, one broadly characterized polychaete, and for each of the following families (number of species in parentheses): Acrocirridae (4), Flabelligeridae (1), Polynoidae (1), Siboglinidae (3), Sabellidae (1), and Chaetopteridae (1).

Crustaceans (Phylum Arthropoda: Subphylum Crustacea)

A variety of crustaceans occur throughout the Mariana Archipelago. At least 805 species have been identified. Not surprisingly, knowledge of this group in the region is heavily biased toward macro-crustaceans. Decapods account for 84% of known species and 50% of these are crabs (Hamano 2003; Paulay et al., 2003b). However, a fairly diverse stomatopod fauna is present representing nine families. The Guam DAWR recognizes three families of barnacles which may have been introduced and spread as encrusting organisms on vessels and pier pilings (Paulay and Ross, 2003). There are also several known amphipods, but many small and cryptic species remain to be enumerated or discovered. Only the major functional groups will be briefly mentioned.

Crabs

A comprehensive Archipelagic inventory of brachyuran crabs has not been undertaken, but 62 species from 13 families were identified in the northern CNMI during the 1992 Chiba Expedition (Takeda et al., 1994). This included *Ocypode* specimens on the upper shores of sandy beaches on the northern islands of Pagan and Agrihan. The abundance of soft-sediment crabs is well established in the populated southern islands of the Archipelago (Cloud, 1959; Paulay, 2003a; Paulay et al., 2003b), though the full extent of their distribution is not known. Ghost crabs (*Ocypode* spp.) and fiddler crabs *(Uca* spp*.)* are harvested for food in Guam and the CNMI.

Crabs in the superfamily grapsoidea, locally known as "agaaf," are also commonly harvested in populated islands of the Archipelago. The species composition of rock crab communities in the Marianas has not been fully described. Conclusions are complicated by taxonomic revisions that are still in progress. For example, seven genera of grapsoid crabs (*Grapsus, Geograpsus, Pachygrapsus, Cyclograpsus, Plagusia, Percnon,* and *Metopograpsus)* were found throughout the Archipelago, including on the islands of Maug and Farallon de Pajaros (Takeda et al., 1994; Paulay et al., 2003a). However, *Plagusia* has now been redefined into three genera. Several new species in the genus *Chiromantes* have also been described recently from Guam, Taiwan, and Christmas Island (Davie and Ng, 2013).

Much research remains to be done on crabs, as well as other diverse crustaceans in the Marianas. There is currently no formal approach to describing the diversity of crab fauna in the Marianas or its fishery potential. Liske-Clark (2015) included an overview of conservation measures for several species of crabs throughout the CNMI. In 2015, a NOAA fisheries research cruise (SE-15-03) under the MTMNM program set traps throughout the northern islands in an attempt to evaluate the distribution and abundance of Kona crab (*Ranina ranina)* for which Allowable Catch Limits (ACL) had been set by the Council and NOAA Fisheries. The catch of Kona crab from that cruise did not indicate the likelihood of a viable fishery in the region. The one Kona crab seen on video was clearly avoiding shark predation. At least one juvenile Kona crab was also found in fish stomach contents during a 2018 Marianas life history research cruise (SE-18-02; Eric Cruz, pers. comm.). Experimental commercial fishing off the island of Rota during the same period produced no catch and resulted in significant gear loss.

Lobsters

Like crabs, there have been no formal fishery-independent assessments of lobster distribution and abundance throughout the Archipelago. The economically valuable spiny lobster *(Panulirus* spp.) is routinely caught and sold on Guam and all the populated southern islands of the CNMI. Spiny lobsters are assumed to be found throughout the Marianas. However, they have not been documented entering lobster traps.

Five species have been identified around Guam: *Panulirus penicillatus*, *P. femoristriga, P. longipes, P. ornatus, and P. versicolor*. Smith (1947) noted that spiny lobsters were fished at night close to shore on Saipan and were common on the reef near Mañagaha Island. *Panulirus* spp. are also documented around Maug, in the Monument Islands Unit (Hayashi et al., 1994). The most common species of spiny lobster landed in Guam and the CNMI is *Panulirus penicillatus*, which has comprised the bulk of identified commercial and non-commercial catches. Two other spiny lobster species have been identified from commercial markets, *P. femoristriga* and *P. longipes*. The presence of *P. ornatus* and *P. versicolor* in the CNMI has not been formally established. In addition, the slipper lobster, *Parribacus antarcticus* is fairly common in markets on Saipan, though not as common on Guam.

The primary source for published data on lobster landings in the CNMI has been the DFW and in Guam the DAWR CPDS (NMFS, 1995-2015; Lowe et al., 2024a). Annual commercial purchases have been estimated since 1981. Lobster landings estimates have also been made from creel survey data by both agencies, although not with the same consistency as in the CPDS. The best source of detailed information on lobster fisheries for Guam and Saipan has been the NMFS Commerical Fisheries Bio-Sampling Program (CFBS), where lobsters were identified to species and measured individually. Although it does not represent the total harvest, this program has provided additional information about relative abundance of spiny lobster species in catches sampled and has identified slipper lobster species not registered at all in commercial purchase data.

Deepwater Shrimp

Scientific exploration of deepwater shrimp and other resources throughout the Mariana Archipelago began in the early 1980s (Moffitt, 1983; Polovina et al., 1985; Emerson and Moffitt, 1988). In addition to diverse, often undescribed species, three of the most popular fishery species were quickly found: *Heterocarpus laevigatus, H. ensifer,* and *H. longirostris* and some of their unique life history characteristics were explored (King and Moffitt, 1984). Surveying all of the major banks and seamounts at depths from 90–990m, a total of 12 pandalid species were registered throughout the Marianas (four species of *Plesionika* and eight of *Heterocarpus*), and two other deepwater shrimps (*Acanthephyra eximia* and *Plesiopenaeus edwardsianus*). Moffitt and Polovina (1987) estimated an equilibrium yield of 161.5 metric tons per year for the entire Archipelago, with the highest yields around Saipan, Rota, Tinian, Galvez and Santa Rosa Banks, and Farallon de Medinilla. From 1980–1985, NMFS undertook a 5-year survey program with the purpose of estimating sustainable harvest levels for potential fisheries resources throughout the Archipelago. Ralston (1986) conducted an intensive fishing experiment for

Heterocarpus laevigatus at Alamagan Island as part of these research cruises, conducted under the name "Resource Assessment Investigation of the Mariana Archipelago" (RAIOMA; Polovina et al., 1985).

In 1994, a Saipan-based company began harvesting *H. laevigatus* in the southern islands of the CNMI, primarily Saipan and Tinian, with limited fishing effort near the northern island of Anatahan (Ostazeski, 1997). A second Saipan-based company entered the fishery in December 1995, harvesting *H. laevigatus* near Saipan, Aguijan, and Rota. Although both companies targeted *H. laevigatus*, incidental catches of *H. ensifer*, a species found at shallower depths, were also observed. These fishing ventures both ended by 1997, and no subsequent efforts at harvest have been successful.

Mollusks (Phylum Mollusca: Octopuses, Squids, Cuttlefishes, Marine Snails, Clams, Nudibranchs, etc.)

The earliest archaeological evidence indicates shellfish were an integral part of both the pre-latte and latte periods indigenous cultures of the Mariana Islands and Guam (Amesbury and Hunter-Anderson, 2003). According to Szabó and Amesbury (2011), "The importance of molluscs across this region, as a consistent source of food as well as providing raw materials for artefacts, can hardly be overestimated." Cultural deposits dating to the pre-latte phase in Tumon Bay and East Agana Bay on Guam yielded mostly bivalves, while the latte phase deposits yielded mostly gastropods, especially *Strombus*. However, in the latte phase, shell assemblages from southern Guam, bivalves consistently outweighed gastropods, and changes in the relative abundance of bivalve species were noted.

An extensive review of archaeological shell deposits on Guam and southern Saipan found evidence of an overall decline in mangrove habitat, resulting from decreasing sea level (Amesbury, 1999, 2007). Amesbury (1999) also acknowledged that differences in the geology of Guam probably accounted for some of the differences in shell assemblages from Tumon Bay and East Agana Bay compared with sites farther south. A change from shell harvest in mangrove habitats to coral reefs was identifiable through changes in archaeological shell deposit composition (Amesbury, 2007). Changes in shell deposit composition were also thought to be attributable to decreasing sea level, human harvesting, or some combination of both (Amesbury and Hunter-Anderson, 2003).

Smith (1947) documented Saipan landings of "other shells" from 1941 Japanese mandate records, but there was no information on species, nor were there data from prior harvests. This harvest category would mainly be comprised of gastropods and bivalves, the primary groups mentioned in following sections. A great deal remains to be explored and uncovered at the species level for marine mollusks throughout Guam and the CNMI. SeaLifeBase (2020) lists only 188 species of mollusks in the CNMI and 868 in Guam, based mainly on information provided by Smith (2003). The following sections document much higher numbers in the CNMI. The discrepancy in numbers is noted here as an opportunity for improving future collaboration. To jumpstart this process, the present report with its links to other references will be made available to SeaLifeBase as soon as it is published.

Cephalopods (octopuses, squids, cuttlefishes and nautiluses)

A review of the cephalopod fauna of Guam by Ward (2003) identified 21 species, along with an unidentified species from Pagan. Of the 21 species identified, 19 were octopuses, three of which were tentatively identified to the species level (*Octopus abaculus, O. ornatus,* and *O. cyanea)*. The broadclub cuttlefish, *Sepia latimanus*, has been identified from Guam (Corner and Moore, 1980). Cuttlefish have also been observed from Saipan, as well as the bigfin reef squid (*Sepioteuthis lessoniana)*. No other cuttlefishes or squids have been identified to species in the Marianas, and no assessment of cephalopods has been undertaken. Octopuses are common in many restaurants and markets in the Marianas and are also harvested for home consumption.

Chambered nautiluses are found in the western Pacific Ocean and coastal areas of the Indian Ocean, and there have been direct observations in the Philippines and other areas adjacent to the Mariana Archipelago. However, reports within the Archipelago are anecdotal. The region is included in the distribution for five species of *Nautilus*, including the emperor (or "chambered") nautilus *(Nautilus pompilius)*, and at least two *Argonauta* species. In 2018, NOAA Fisheries listed *Nautilus pompilius* as a threatened species under the Endangered Species Act because of their low reproductive rates, slow growth, late maturity, and specialized depth and temperature requirements. More information can be found at: https://www.fisheries.noaa.gov/species/chambered-nautilus. With so many deep and diverse habitats throughout the Marianas and the existence of the MTMNM, this should be an ideal place to learn more about this group.

Gastropods

The Archipelago harbors a rich diversity of marine gastropods that has yet to be fully described (Kurozumi and Asakura, 1994). Vermeij et al. (1983) could already list over 300 species of shelled mollusks in the CNMI, noting that at least 18 of these (mainly limpets) were rare or unknown from the southern islands. Conversely, at least 22 gastropods that were common in the southern Marianas were absent in the northern Marianas, indicating the existence of distinct biogeographic provinces consistent with the geologic zones described in earlier sections. Fine-scale endemism is also documented throughout the Archipelago (and Indo-west Pacific) from mitochondrial DNA sequencing (Meyer et al., 2007). Geographic analysis of nudibranch nuclear ribosomal RNA also indicates the presence of larger-scale regional differences ranging from Guam to the coast of Japan, shaped by changing climatic zones and ocean currents (Yorifuji et al., 2012).

Information pertaining to gastropods in the Marianas is typically limited to species of commercial, subsistence, or curio interest. However, Carlson and Hoff (2003) listed 485 species of Marianas opisthobranch gastropods from collections at the University of Guam. A similar listing for prosobranch gastropods by Smith (2003) found 895 species. Marine species found primarily in shallow reef habitats comprised the vast majority of both gastropod listings. Intricacies of life history and ecological relationships for this rich fauna (and other gastropod taxa) remain ripe for exploration, even without verging into the deep (Ginsburg and Paul, 2001; Pola et al., 2005; Ritson-Williams and Paul, 2007; Ritson-Williams et al., 2009; Rosenberg and Salisbury, 2014).

The humpbacked conch or *dogas* in Chamorro, *Gibberulus gibberulus* (family Strombidae), made up a significant proportion of Mariana shell midden deposits from 1,500 B.P. until European contact (Amesbury, 2007). Anecdotal information suggests the spider conch snail (*Lambis lambis*, another strombid) was common on Saipan during the 1970s, although archaeological evidence does not indicate that this species was common in shell middens examined from the Mariana Islands. The species is not commercially harvested today, but it is collected by non-commercial (subsistence/"recreational") fishers for its shell and meat, as is the horned helmet snail, *Cassis cornuta*, family Cassidae (Roth, 1980).

Tapestry turban snails are also commonly harvested by non-commercial fishers in the southern islands of the Archipelago. The three most common species harvested are *Turbo petholatus, T. setosus,* and *T. argyrostomus* (family Turbinidae). They are also all found on Asuncion and Maug, within the MTMNM Island Unit (Kurozumi and Asakura, 1994; Vermeij et al., 1983). *T. setosus* has the greatest known distribution within the CNMI and has also been documented from Farallon de Pajaros (Kurozumi and Asakura, 1994; Vermeij et al., 1983).

The trumpet triton snail, *Charonia tritonis* (family Charoniidae), is also consumed on Guam and in the CNMI (Roth, 1980), and they are highly sought after by curio and shell collectors. Very little is known about the distribution of this species throughout the Archipelago, but it is uncommonly observed in the southern islands of the CNMI. The branched murex, *Chicoreus ramosus* (family Muricidae), is also harvested by curio and shell collectors.

In 1938, the top shell snail *Rochia nilotica* (family Tegulidae, then *Trochus niloticus* or *Tectus niloticus*), was the first recorded marine introduction to the Archipelago (Asano 1938). It became established on Saipan in 1938 and was brought to Tinian by 1939. Saipan provided seed stock to Guam and the northern islands of the CNMI, where the species also became established. Smith (1987) examined the growth rates, distribution, and abundance of *[Rochia]* on Guam. The establishment of this species throughout the Archipelago prompted an extensive resource survey (Adams et al., 1994). There has been little economic yield from this introduction and an assessment of its ecological impacts has never been made (Trianni, 2002).

Bivalves

A total of 339 species of bivalves have been identified in the Marianas (Paulay, 2003b) within four taxonomic groups (subclass, Protobranchia; infraclass, Pteriomorphia; subterclass, Heterodonta; and superorder, Anomalodesmata). As with other groups, but particularly with mollusks within the past decade, taxonomic revisions date many references shortly after publication. New species remain to be described throughout the Archipelago and will fall under or determine the future organization of major taxa.

The most prominent bivalves in the Marianas are the giant clams (family Cardiidae, subclass Autobranchia) (Neo et al., 2017). It has been suggested by Paulay (2003b) that at least 10 bivalve species are no longer found on Guam, including two species of giant clam, *Tridacna gigas* and *Hippopus hippopus*. While *Tridacna squamosa* and *Tridacna maxima* are believed to be native to the Archipelago, *Tridacna derasa* and *Hippopus hippopus* are believed to have been introduced from southern Micronesia and may recently have become locally extinct on some islands (Wells, 1996). Reintroduction attempts on Saipan in the 1990s and 2000s by the CNMI DFW, using broodstock produced by the Palau Mariculture Demonstration Facility, have not been evaluated. Fishery-independent data on giant clams have been collected in the Marianas since 2003 as part of monitoring by the PIFSC MARAMP. Giant clams have been observed throughout the Archipelago based on a report summarizing data collected from 2003–2007 (Brainard et al., 2012).

In August 2016, a petition to list ten species of giant clams under the Endangered Species Act (16 U.S.C. §1531 et seq., 1973) was made to NMFS. This included all the species referenced above as occurring in the CNMI. A subsequent 90-day finding determined that seven species would undergo status reviews. A comprehensive review of the giant clams was completed in response to this petition (Neo et al., 2017) indicating, among other findings, that many unanswered questions should be addressed to determine the need for conservation measures at specific locations (e.g., issues of connectivity, phylogenetic relationships, minimum number, and density needed to ensure a viable population).

The comb venus *Gafrarium pectinatum* (family Veneridae) occurs in intertidal-to-submerged sands and suitable back-reef habitats and was commonly found in Marianas archaeological deposits (Amesbury, 2007). In the CNMI today, it is harvested by gleaning coarse sands at low tide. This species has also been found on Pagan, but very little is known about its modern distribution throughout the Archipelago (Vermeij et al., 1983).

Chordates (Phylum Chordata: Tunicates and Fishes)

Tunicates (subphylum)

Ascidians (also referred to as sea squirts or tunicates) were collected in Guam from 1998 through 2000. At least 117 species were found within 32 genera. Of these, 87 species were described as colonial and 30 were solitary. Eighty-six species were considered indigenous to Guam and 31 species (16 colonial; 15 solitary) were considered to be either introduced or cryptogenic (missed in prior surveys). Some of the ascidians collected remain to be fully identified (Lambert, 2003).

The 2016 Deepwater Exploration of the Marianas completed by NOAA's *Okeanos Explorer* (see Appendix 1) found several species of tunicates. These included carnivorous tunicates of the families Octacnemidae and Pyuridae. Several others were identified only to the subphylum level.

Cartilaginous Fishes (Class/subclass Elasmobranchii: Sharks and Rays)

Pre-latte and latte period archaeological deposits from the southern islands of the CNMI have been found to contain remains of Elasmobranchii, identified merely as sharks and rays, but specifically including mackerel sharks (order Lamniformes) (Amesbury and Hunter-Anderson, 2008). Jorgensen et al. (2009) conducted genetic and electronic tagging studies which indicated their homing behavior has maintained a separate northeastern coastal Pacific population of white sharks *(Carcharodon carcharias)* that persistently returns to a network of coastal hotspots, following distant oceanic migrations. There are no direct reports of the harvest of sharks and rays during the Spanish period. However, referencing Rodrigue Lévesque's (1992–2002) compilation of historical source documents pertaining to Micronesia, Amesbury and Hunter-Anderson (2008) stated that the indigenous Chamorros did not fish for sharks, but did have interactions with sharks while fishing.

There were significant landings of sharks, and shark fins were being extracted for export from the NMI to Japan during the mandate (Japan and League of Nations, 1924; Smith, 1947; Amesbury and Hunter-Anderson, 2008). Details regarding the species harvested or targeted were not provided. Nor was there any specific mention of the harvest of rays or skates during that period (Smith, 1947), but such activity may have been included under one or more of the following three reported categories: sharks, shark fins, or other fish. Shimada (1951) noted from post-WWII Japanese equatorial fisheries surveys that dorsal, pectoral, and caudal fins were retained for the shark fin markets, and most of the shark was also retained (including the liver, which was important worldwide for vitamins before these could be synthesized). Other than shark fins, it is not known whether or not other parts of sharks were similarly retained during the mandate.

Sonu (1998) noted that shark products were exported from Guam from 1991–1997. No record of the export of shark products from the CNMI was registered during that same period. In 2000, there was one attempt at harvesting sharks as a resource in the CNMI when a local fishing company and a Korean company formed a joint venture. The two companies obtained an experimental fishing permit from NMFS granting them approval to harvest sharks using a drift gillnet.

Nadon et al. (2012) analyzed towed-diver data for reef sharks from PIFSC's (former) CRED underwater surveys (2004–2010 data). This included MARAMP data from 2005, 2007, and 2009. The results of the analysis indicated that reef shark population densities around the inhabited southern islands of the Archipelago were up to 97% lower than the more lightly exploited northern islands and the banks and reefs of the West Mariana Ridge.

In 2008, the CNMI passed legislation (Public Law 15-124) that prohibited the feeding and taking of sharks and rays. This was superseded in 2011 by Public Law 17-27, prohibiting the taking, possession and sale of shark-fins, while allowing possession of whole sharks for subsistence and non-commercial purposes. A bill specifically banning the possession, sale, offer for sale, trade, or distribution of shark fins on Guam (Bill 44-31, Guam Legislature, 2011: 1st Regular Session) became law in 2011.

Bony Fishes (Osteichthyes)

The distribution of reef fish resources in the Marianas was described by Donaldson (1995) and expanded upon by Brainard (2012). Coastal fishes around Guam are included in Amesbury and Myers (1982). Over 1,100 species were identified by Myers (1988, 1991, 1999) and Myers and Donaldson (2003). That number is expected to increase as marine research in the Marianas expands to greater depths and explores finer spatial scales. Meso-pelagic and deep-sea fishes have also been examined, but considerable information remains to be uncovered (Polovina et al., 2009; Nielson and Moller, 2011; Miller et al., 2012; Tunnicliffe et al., 2010, 2013; Linley et al., 2016; Newman et al., 2016; Smith-Vaniz and Johnson, 2016; Stevens et al., 2016; Mundy et al., 2018). The CNMI Division of Fish and Wildlife maintains a checklist of fishes of the CNMI that is periodically updated (Trianni and Ostazeski, 1996; Moots et al., 2000; Tenorio, 2013, 2014). Both the Guam DAWR and CNMI DFW also maintain a database of marine species (including algae and invertebrates), for fisheries monitoring purposes, supported by PIFSC's Fisheries Research and Monitoring Division (FRMD).

Archaeological examination of fish bone deposits from sites on Guam, Tinian, and Saipan assembled by Amesbury and Hunter-Anderson (2003) showed the presence and consumption of reef and deep slope fish families similar to those harvested today, including the families Scaridae (parrotfishes), Acanthuridae (tangs and surgeonfishes), Mullidae (goatfishes), Lethrinidae (emperors), Nemipteridae (threadfin breams), and Serranidae (groupers). The above authors and Amesbury (2008) also found diets included some of the typical pelagic fishes, such as Scombridae (mackerels, tunas, bonitos, including wahoo), Coryphaenidae (mahimahi), and Istiophoridae (marlins, spearfish, and sailfishes). These findings were similar to descriptions of fish and fisheries recorded during the Spanish period as noted by Amesbury and Hunter-Anderson (2003) and mentioned in previous sections.

The first detailed observations on fishing during the German period were recorded by German Government District Officer Georg Fritz[23], as documented in Amesbury and Hunter-Anderson (2003). The Japanese period in

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[23] See references to Fritz's observations (p. 20) under historical German Period (CNMI, 1899–1914)

the Northern Mariana Islands saw considerable development of nearshore (Smith, 1947) and offshore (Uchida and Sumida, 1975; Uchida 1983) fisheries. The primary fishes targeted were pelagic tunas, especially skipjack (*Katsuwonus pelamis)*, for which landings peaked near 3,698 metric tons in 1937. Other tuna landings peaked at around 151 metric tons in 1936 (Amesbury and Hunter-Anderson 2008). Because of the long distance from Saipan to Japan (even longer travel times in those days) skipjack and other tunas were dried into jerky sticks for storage and transport (Smith, 1947). Other fish groups targeted during the Japanese mandate included mackerels and mullet. No evidence has been found of deep bottomfishing during this period. The use of reef fisheries appears to have been limited to local consumption. The highest annual landings documented of (unspecified, presumably reef) fishes were the 315 metric tons, reported on Saipan during 1941 (Smith, 1947). It should be noted that this is within the estimated range of total CNMI (Saipan) landings for all species from 2000–2018 creel survey data (Figure 11, p. 36).

During the CNMI U.S. trust territory period (1944–1947) following WWII, fisheries landings were not consistently recorded. Those landings that were documented were much lower than the amounts seen during the Japanese mandate. Polovina and Shippen (1983) estimated catch and effort by Japanese longliners and bait boats around the Archipelago which would not have been included in the record. The highest annual landings of all fish recorded during that period were about 180 metric tons in 1977. Total fisheries landings since the CNMI became a commonwealth reached a maximum in 1989 at about 280 metric tons. Hamm et al. (1989b) provided a review of the pelagic fisheries for Guam and the CNMI for the year directly preceding that peak.

In 1981, NMFS RAIOMA surveys were conducted with the purpose (among others) of providing estimates of sustainable harvest levels for the deep bottom fishery throughout the Archipelago (Polovina, 1981; Polovina and Roush, 1982; Polovina, 1985; Polovina et al., 1985; Polovina and Ralston, 1986; Polovina, 1987; Ralston, 1988; Ralston and Williams, 1988). A growth in bottomfishing for the CNMI and Guam ensued (Kikkawa, 1994, 1997). Hamm and Quach (1988b) and Hamm et al. (1989a) provided a record of commercial bottomfish landings for the CNMI (1982–1988) and Guam (1979–1988). Bottomfish landings from the CNMI peaked in the mid to late 1990s, when several large Saipan-based commercial vessels and at least one vessel based in Guam were actively harvesting bottomfish from the northern islands of the CNMI (Trianni 1998b; Trianni 1999c).

In 2006, NMFS implemented Amendment 9 to the Fishery Management Plan (FMP) for bottomfish and seamount groundfish fisheries of the western Pacific Region that prohibited large vessels (50 feet or longer) from fishing for bottomfish in federal waters within 50 nautical miles around Guam and established federal permitting and reporting requirements for these large vessels (71 FR 64474, 2006). In 2007, an assessment update for Guam's and the CNMI's bottomfish resources was published (Moffitt et al., 2007). Amendment 10 to the bottomfish and seamount groundfish FMP was implemented in 2008 establishing federal permitting and reporting requirements for all commercial bottomfish vessels fishing in the waters around the CNMI. The final rule also closed certain waters around the CNMI to bottomfish fishing by vessels over 40 feet in length and required vessel monitoring system units on these vessels (73 FR 75615, 2008). The closed areas were repealed in 2016 via Amendment 4 to the Mariana Archipelago FEP (81 FR 61625, 2016).

The CNMI coral reef fish fishery also reached its peak in the mid-1990s, when scuba-spearfishing was at its zenith. This included a scuba-spearfishing venture that harvested coral reef fish in the CNMI's northern islands from Anatahan to Maug. The use of assisted air breathing (SCUBA and hookah) to harvest marine resources was banned throughout the CNMI in 2002. In 2003, restrictions were placed on the use of gill, drag, and surround nets throughout the CNMI. Evaluations of the effectiveness of these management measures have been made[24] for scuba (Linfield et al. 2016) and nets (Trianni et al. 2018). Scuba-spearfishing dominated the commercial catch of reef fish on Guam until it was banned in 2020.

Dalzell and Lewis (1988) and Dalzell et al. (1996) summarized landings from the Pacific Islands, including Guam and the CNMI. Sampling and assessment of nearshore commercial coral reef fisheries was first undertaken by Graham (1994a). This work included estimating landings from fishing using surface-generated assisted air ("hookah") (Graham, 1994b). Trianni (1998a) reported on landings from the CNMI scuba-spear fishery. Zeller et al. (2005) estimated total (commercial and non-commercial) coral reef and bottomfish catches from 1950–2000 for the CNMI and Guam (also Hawaiʻi and American Samoa). Houk et al. (2012) described the nighttime commercial free-dive spear fishery, based on limited seasonal sampling. This description was clarified and updated by Trianni et al. (2018a), using a multi-year data set derived from the Saipan CFBS. Cuetos-Bueno and Houk (2018) also estimated historical reef fish abundance in the CNMI.

Fish research in the Marianas has taken place on various taxonomic, geographic, and bathymetric scales. Highlights include the long-term research and surveys that eventually identified the spawning area of the Japanese eel, *Anguilla japonica*, in the West Mariana Ridge (Tsukamoto, 1992; Tsukamoto, 2006; Kurogi et al., 2011; Yoshinaga et. al., 2011; Tsukamoto et al., 2013; Otake et al., 2019), and dietary studies on the notorious-yet-poorly-known mesopelagic lanternfishes (Van Noord, 2013). Large coral reef fish surveys throughout the Archipelago in 2003, using three different underwater visual methods (Schroeder et al., 2006), indicated that large fish (all taxa pooled) occurred in relatively higher densities around the northernmost islands (i.e., Uracas, Maug, Asuncion). NOAA's 2016 deepwater exploration of the Marianas aboard the *Okeanos Explorer* identified new species and extended the range of various fishes, including the first in situ observation of an aphyonid (Mundy et al. 2018). Other observations from that expedition are available by taxa in an online photo guide (NOAA OER, 2019). Research on diet of fishes in the region have been limited to studies on two bottomfish species (Seki and Callahan, 1988), a few reef fishes on Guam (Tsuda and Bryan, 1973; Priest et al., 2016), and a mesophotic reef fish and popular commercial species *(Lethrinus rubrioperculatus)* in the southern islands of the CNMI (Trianni and Tenorio, 2012a). Marshell et al. (2011) and Taylor and Mills (2013) utilized passive telemetry to study the movements of reef fish targeted by fisheries around Guam. Holdsworth et al. (2009) conducted high-resolution satellite tracking of striped marlin *(Kajikia audax)* from New Zealand through the region to the central Pacific.

Genetic research has yielded interesting evolutionary and ecological information on fishes for the Archipelago. Studies on six acanthurids and one zanclid from around Guam confirmed phylogenetic inferences from morphological data, supporting hypotheses that single-plated unicornfishes form a monophyletic group (Dayton, 2001). Genetic studies of *Siganus spinus* (Priest et al., 2012) and *Naso unicornis* (Horne et al., 2013) in the southern islands of the Archipelago found those populations to be genetically homogeneous. Analysis of tissue samples collected from three coral reef fish species (*Scarus rubroviolaceous*, *Naso lituratus*, and *Acanthurus lineatus*) indicated that weak population structure may exist for *Scarus rubroviolaceus* but found no genetically

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[24] See Fisheries Management and Other Marine Resource Conservation Measures (p. 39)

identifiable population structure for the other two species (Carson, 2015). Carson's research suggested that southern populations of *S. rubroviolaceus* may contribute more to genetic variation in the northern CNMI due to the direction of prevailing currents.

Data from PIFSC MARAMP surveys support ongoing monitoring and assessment needs for coral reefs and reef-associated fish populations on both regional and global scales. Analyzing data from PIFSC MARAMP, Williams et al. (2011) found the density of reef fish assemblages was greatest at uninhabited islands in the Archipelago and generally increased in a south to north direction. However, Williams et al. (2012) also indicated that species composition differed sharply between northern and southern islands. Williams et al. (2015) substantiated this; despite regional differences, total reef fish biomass in the absence of humans was predicted to be depleted by 61–69% at populated islands in the Mariana Archipelago. Surveys of nearshore reef fishes and their habitat are also a regular part of monitoring of marine reserves by fisheries agencies throughout the CNMI and Guam (Trianni, 1998a-d, 1999a-d; Trianni and Moots, 2000; Tenorio, 2008a, b; Plass-Johnson, 2011a, b; Williams et al., 2012, 2015). Richards et al. (2012) found the abundance of large-bodied coral reef fishes was negatively correlated with human population density in the Marianas. In addition to human population density, Williams et al. (2015) found oceanic productivity to be an important driver of coral reef fish biomass. Weijerman et al. (2014, 2015, 2016a, b) developed reef ecosystems models and used fishery-dependent and fishery-independent data to evaluate the relative effects of climate and ocean changes, land-based sources of pollution, and fishing. This work has shown promise for the use of modelling to explore the potential value of various management strategies (Weijerman et al., 2016a).

Stock assessments of bottom and coral reef fishes around Guam and the CNMI are conducted periodically by PIFSC researchers (Moffitt et al., 2007; Brodziak et al., 2012; Yau et al., 2016; Nadon, 2019). The Western and Central Pacific Fisheries Commission conducts stock assessments on highly migratory species, particularly tunas and billfishes (https://www.wcpfc.int/home). Although catch data from the Archipelagic EEZ do not contribute significantly to these stock assessments for highly migratory species, weight-frequency data from high seas vessels that transship through the Port of Guam (provided by the Guam BSP) may be more important, particularly for skipjack tuna.

Fish life history and behavioral research in the Marianas was initially supported by the UoGML (Paul et al., 1990; McIlwain et al., 2009; Taylor and McIlwain, 2010; Taylor and Choat, 2014; Taylor et al., 2012, 2014, 2015) and the CNMI DFW (Trianni 2011; Trianni, 2016). More recently, in addition to sampling reef fish (and invertebrate) landings from Saipan's nighttime commercial spear fishery and Guam's commercial fishery in general, the PIFSC CFBS program has supported work on reef fish life history (Sundberg et al., 2015; Taylor et al., 2015, 2016; Newman et al., 2016; Taylor and Cruz, 2017). The PIFSC biosampling program has also provided data used to develop length-weight relationships for reef and bottomfish species on Guam (Kamikawa et al., 2015) and in the CNMI (Matthews et al., 2019).

Protected Species

The first well-documented cetacean research observations in the Marianas were found following WWII, although there is anecdotal information from ships of exploration and conquest (Polack, 1838; Ibáñez del Carmen et al., 1846-1899; Couper, 2009; Beattie et al., 2023; Goetzfridt, 2023). Whaling records (Townsend, 1935; Camba,

1965) and surveys focused on broader regions (Shimada and Miyashita, 2001; Ohizumi et al., 2002) provide evidence of occasional occurrence of large whales in waters of the Mariana Archipelago. Nishiwaki (1966) summarized whale distribution and migration based on Japanese whaling records, including post-WWII information from the Mariana Islands. Masaki (1972) reported on whale tagging in the Ogasawara and Mariana Islands. Miyazaki and Wada (1978) further documented cetacean observations during a whale marking cruise.

Kami and Lujan (1976), Kami and Hosmer (1982), and Donaldson (1983) all recorded strandings of cetaceans on Guam. DFW staff summarized cetacean strandings in the CNMI (Trianni and Kessler, 2002; Trianni and Tenorio, 2012b). The latter reference includes records of the stranding of two Cuvier's beaked whales (*Ziphius cavirostris*), which are susceptible to impacts from ocean noise (Taylor et al., 2004; D'Amico et al., 2009; Filadelfo et al., 2009).

Eldridge (1991) summarized published and unpublished reports on occurrences of marine mammals within Micronesia, including the Marianas. Darling and Mori (1993) and Yamaguchi et al. (1995, 2002) summarized humpback whale observations in the western North Pacific, including anecdotal sightings in the Mariana Archipelago. Eldridge (2003) summarized the reports of marine mammals around Guam and the CNMI, including those listed in Eldridge (1991). Jefferson et al. (2006) reported their observations of a mixed school of melon-headed whales (*Peponocephala electra*) and rough-toothed dolphins (*Steno bredanensis*) at Rota. Fulling et al. (2011) reported on the distribution and abundance of cetacean species from a 2007 large-vessel line-transect survey within the southern portion of the CNMI and Guam EEZ (including the islands from Guam to Pagan). HDR (2011, 2012) conducted small-boat surveys for cetaceans and turtles around Guam in the winters of 2011 and 2012. Tetra Tech et al. (2014) conducted a large-vessel line-transect marine mammal survey in 2013 around Pagan in the CNMI, which included a nearshore small-boat non-systematic survey, photo-identification of individuals, and a variety of passive acoustic monitoring techniques. Uyeyama (2014) and HDR (2014) summarized previously unpublished incidental sightings of cetaceans within the Mariana Islands Range Complex.

Between 2010 and 2019, PIFSC's Cetacean Research Program (CRP, Protected Species Division) conducted annual small-boat cetacean surveys around Saipan, Tinian, Rota, and Guam (Hill et al., 2020a). In 2015–2019, the CRP conducted directed humpback whale small-boat surveys during winter months (Hill et al., 2020a, b). Additionally, the CRP conducted visual and passive acoustic line-transect surveys throughout the Mariana Archipelago in 2010, 2015, and 2018 aboard NOAA ships (Oleson and Hill, 2010; Hill et al., 2020). PIFSC data collection methods during small-boat and large-vessel surveys, including individual photo-identification, satellite tagging, and biopsy sampling of cetaceans, resulted in species-specific studies on their distribution, movements, spatial use, population structure, and genetic diversity (Martien et al., 2014; Hill et al., 2018, 2020b).

PIFSC cetacean research also includes the deployment of **H**igh-frequency **A**coustic data **R**ecording **P**ackages (HARPs) at various locations in the Marianas, including Tinian, Saipan, and Pagan (Oleson et al., 2015). HARP recordings are used in combination with vessel survey data to identify cetacean species and assess their distribution and year-round occurrence (Oleson et al., 2015; Hill et al., 2020a).

Research and conservation efforts for sea turtles have also increased in recent decades. Pritchard (1977, 1982a, b), Hirth (1993), Gyuris (1999), Martin et al. (2019), Becker et al. (2019), and Gaos et al. (2020) have described turtle distributions for the region. Three of the world's seven species of marine turtles have been reported from Guam waters (Eldredge, 2003b). Green *(Chelonia mydas)* and hawksbill *(Eretmochelys imbricata)* turtles are the only species consistently seen in nearshore waters of Guam, Tinian, and Sapian and are relatively common, with the former species outnumbering the latter by a ratio of approximately 10:1. The CNMI DLNR has led monitoring of sea turtle nesting sites since the early 1990s (Pultz et al., 1999; Summers et al., 2017, 2018). Similarly, the Guam DAWR Sea Turtle Recovery Program was formed in 2000 to conduct baseline population studies and minimize threats to turtles and their nesting sites.

Sea turtle surveys were first conducted around Saipan by Kolinski et al. (2001). Subsequent surveys covered first Tinian and Aguijan (Kolinski et al., 2004), and then Rota (Kolinski et al., 2006). Only green turtles are known to nest in the Archipelago, with no records of nesting hawksbills within the past 10 years. Dutton et al. (2015) explored the genetic stock structure of green sea turtles throughout the Archipelago and elsewhere in the Pacific, indicating that the green turtles nesting in the Marianas are part of the central west Pacific distinct population segment (Seminoff et al. 2015). Recent genetic work on juvenile green turtles in the Marianas suggests foraging individuals likely originate primarily from the Federated States of Micronesia and the Republic of the Marshall Islands (PIFSC, unpublished data). Work et al. (2015) included sea turtle necropsies from the Mariana Archipelago in a pan-Pacific comparison with turtles from Hawaiʻi, Johnston and Palmyra Atolls, and American Samoa and did not find any of the fibropapillomatosis that is fairly common in Hawaiʻi. Most Mariana turtles in that study had died from fishing-induced or boat strike trauma, followed by infectious/inflammatory diseases, nutritional problems, and an array of physiologic problems. However, in 2020, fibropapilloma was detected in Guam and it has been observed in multiple turtles in the Piti Bomb Holes area since that time.

Since 2013, sea turtle survey and tagging efforts have been undertaken annually by PIFSC's Marine Turtle Biology and Assessment Program (MTBAP) in collaboration with local authorities (Jones et al., 2015; Martin and Jones, 2017a, b; Martin et al., 2018, 2019; Gaos et al., 2020). MTBAP surveys have focused on Saipan, Tinian, and Guam (with a large effort within Apra Harbor) but have sought to include all the islands (Martin et al. 2019, Gaos et al., 2020). Martin et al. (2018) summarized surveys for marine megafauna, including sea turtles, throughout Micronesia.

These studies indicate the green and hawksbill turtles inhabiting the Marianas consist primarily of juveniles whose movements and habitat use are highly neritic. Most of their time is spent within a less than 1 km^2 core area, demonstrating limited movements and high foraging site fidelity. Notwithstanding this perspective, more vagile movement patterns are sometimes observed, including shifts in intra-island foraging areas, transitions between inter-island foraging areas, and long-range migration departures outside the Mariana Islands (Martin et al., 2019; Gaos et al., 2020). Dive patterns suggest that both juvenile green and hawksbill turtles spend most of their time in waters shallower than 25 meters (Gaos et al., 2020). Recent research involving the deployment of satellite tags on post-nesting green turtles on Guam and Saipan indicates nesting females rarely remain around the Marianas and typically undertake westward migrations to foraging grounds around the Philippines, Indonesia, and Japan (PIFSC unpublished data).

Appendix 1: References with Geographic Information by Major Disciplines

To aid the reader in locating information within this index, the topics are organized by the following **major research categories** gleaned from discussions and workshops with stakeholders from 2011–2013 (Breuer et al., 2014). These are listed below with a few subtopics and examples (in no particular order) that fit within each category.

1) **Archaeological and ancient human history**
   - Marine archaeology
   - Ethno-historic research
2) **Ecology and ecosystem/fisheries monitoring**
   - Environmental monitoring
   - Species and ecosystem monitoring
   - Marine ecology
   - Ecological interactions
   - Ecosystem studies
   - Climate change studies
   - Biogeography and population genetics
   - Bio-indicators and ecological indicators
3) **Expeditions, deep sea exploration, and geography**
   - Basic exploration (including historical surveys and descriptions of the Marianas)
   - Mapping (all types including e.g., benthic, shallow-water, slope/shelf, deep sea, habitat mapping)
4) **Island flora and natural history**
5) **Marine biology, life history, and evolutionary biology**
   - Fish life history
   - Evolutionary biology
   - Basic genetic studies
   - Taxonomy
   - Behavioral studies
6) **Socioeconomic monitoring and human dimensions**
   - Economics
   - Traditional cultural practices
   - Governance
   - Human impacts
   - Human population growth
   - Collaboration and capacity building
   - Other human dimensions
7) **Oceanography, geochemistry, and physical sciences**
   - Monitoring
   - Modeling
   - Studies of nutrient cycles
8) **Population/ecosystem modeling and stock assessment**
   - Stock assessments
   - Probability susceptibility indices

Table A 1. References with well-defined geographic location

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference(s)**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Magellan, Ferdinand			1521	Mariana Islands	Portuguese explorer on a Spanish expedition to circumnavigate the globe	Nowell (1962)			X					
Luis de Sanvitores, Diego			1683 *1665,1668 –1669*	Guam, Maug, Northern Islands	Exploration "discovered" northern islands and claimed them for Spain	In: Garcia (1683)			X					
Anson, George			1742	Tinian	Island features (e.g., wells, archeological remains)	Anson and Walter (1845)	X		X					
Malaspina, Alessandro			1792	Guam	Natural history	Reports never completed.				X				
de Galaup comte de Lapérouse ("La Pérouse"), Jean François			1797	Asuncion	Botany	La Pérouse and de Milet (1797)				X				
de Saulces de Freycinet, L.C.			1819	Guam, Tinian, and Rota	French scientific expedition provided detailed account of tools, fishing techniques and traditional practices, zoology, and botany in the Marianas.	de Freycinet, et al. 1824,1826); de Freycinet (2003)	X		X	X				
von Kotzebue, O.		*Rurick*	1821 *1817*	Guam	Natural history	von Kotzebue (1821)			X	X				
Friedrich Benjamin Graf von Lütke (captain) and Heinrich von Kittlitz (artist, explorer, and naturalist)		*le Séniavine, Astrolabe*	1835 *1826–1829*	Guam, Rota, and Tinian	Ornithology and illustrated natural history	von Lütke et al. (1835)				X				

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference(s)**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Beechey, F.W.		*H.M.S. Blossom*	1831 *1827*	Asuncion	Plants	Beechey (1831)				X				
Sanchez y Zayas, E.		*Narvaez*	1866	Northern Islands	Discovery and population estimates	Sanchez y Zayas (1866)	X							
de Ibáñez y Garcia, L.		*Narvaez*	1886 *1866*	All Islands	History and description	de Ibáñez y Garcia (1886)	X							
Marche, A.			1890, 1891 *1887–1889*	Most islands as far north as Agrihan, Pagan	General botanical collections; also, fishes, birds, mammals, land snails (held in the Museum d'Histoire Naturelle, Paris). Most identifications began around 1958. No comprehensive report on plants was published.	Marche (1890, 1891); Pellegrin (1898); Oustalet (1895); Quadras and von Moellendorff (1894)				X	X			
Seale, Alvin Bernice Pauahi Bishop Museum, Honolulu			1901 *1900*	Guam	Visited Guam; collected a number of birds and fishes	Seale (1901)			X					
Fritz, G. (German Governor)			1902, 1904 *1901*	Northern Islands: Pagan, Guguan, Farallon de Pajaros	General geology and flora (prominent plants, especially cultivated ones). Planted several types of trees on Guguan and Farallon de Pajaros (e.g., coconuts, ironwood). Records not supported by specimens. History and ethnography of Chamorro people.	Fritz (1902, 1904)				X		X		

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Agassiz, Alexander		*Albatross*	1903 *1899–1900*	Guam	Expedition's extensive collections led to various reports (e.g., on fishes, birds, crustaceans, and sea cucumbers)	Agassiz (1903)			X					
Costenoble, H.L.W.			1905	Mariana Archipelago	General natural history overview; one of the first general accounts of the islands.	Costenoble (1905)			X					
von Prowazek, S.J.			1913	All Islands	Natural history	von Prowazek (1913)				X				
Tayama, R.			1936–1952	All Islands	Geology and coral reefs	Tayama (1936a, b,1937,1938, 1939a,b, 1952); Tayama and Ota (1940)					X		X	
Yoshii, M.			1936	Pagan and other islands	Noncalcareous rocks	Yoshii (1936)							X	
Tanakadate, H.			1940	Pagan	Volcanologist	Tanakadate (1940)							X	
Kanehira, R.			1934, 1935 *1933*	Pagan	Collected botanical specimens	Kanehira (1934, 1935)				X				
Hosokawa, T.			*1934*	Pagan,	(2 short visits in July and August). Gathered 42 plants. Listed his own and previous records from Marianas by island for each species	Hosokawa (1934)				X				
Nishiyama, S.			1942	Northern islands	Marine mammals	Nishiyama (1942)					X			

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Anderson, D.	Pacific Vegetation Project		1949	Pagan	Collected species were deposited in the U.S. National Herbarium, Bernice P. Bishop Museum (Oahu, Hawaii) and New York Botanical Garden.	In: Fosberg (1958)				X				
Fosberg, F.R. and G.L. Corwin	Pacific Vegetation Project		1949–1950	Pagan	Flora: Collected species deposited in the U.S. National Herbarium, Bernice P. Bishop Museum (Oahu, Hawaii), and New York Botanical Garden.	Fosberg (1958); Fosberg and Corwin (1963)				X				
Bonham, L.D. and G.L. Corwin	Pacific Vegetation Project		1957 *1954*	Pagan	Collected 40 specimens of plants mentioned in Bonham's account of the vegetation. Also: insects, land snails, other organisms. Specimens deposited in the U.S. Natl. Herbarium.	Fosberg and Corwin (1958); Corwin et al. (1957)				X				
Cloud, P.E., Jr., R.G. Schmidt, and H.W. Burke			1956, 1959 *1955*	Saipan	Geology and natural history. Submarine topography	Cloud et al. (1956); Cloud (1959)							X	
Corwin, G., D. Bonham, J. Terman, and G.W. Viele			1957, 1961	Pagan	Geology and natural history	Corwin et al. (1957); Corwin (1961)							X	
Spoehr, A.			1957	Objan, Saipan	Archaelogical evidence of J-shaped Latte Phase fishhook of Isognomon shell from Objan, Saipan.	Spoehr (1957)	X							

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
USGS, Dept. Interior and USACE Pacific Geological Mapping Prog.			1959 1952–1954	Guam	Geology and natural history: terrain, geography, soils, vegetation, climate, rock, soil, field observations	Tracey et al. (1959)							X	
Doan, D.B. and D.I. Blumenstock			1960	Tinian	Geology and natural history	Doan and Blumenstock (1960)				X			X	
J. Villagomez			1970	Pagan	Algae and invertebrate collections	Villagomez (1970) *Unpublished, but specimens are catalogued and available online.*			X					
R.S. Jones, R.H. Randall, H. Kami, R. Struck		U.S. Navy ship *Grasp*	1971	Maug, Agrihan, Anatahan	Fishes, corals, algae, and invertebrate collections	Collections (UoGML) described in Eldredge 2003a			X	X	X			
R. Hervin			1971–1972	Pagan, "other islands"	Algae, terrestrial plants, invertebrates, fishes	In: Eldredge (1983a)			X					
DeWitt, P.W.		NOAA *Townsend Cromwell*	1972	All islands	Depth and temperature measurement	DeWitt (1972)			X				X	
Wernhart, Karl R.			1972	Micronesia	A pre-missionary manuscript record of the Chamorro, Micronesia	Wernhart (1972)	X							
Tomoko, E., and F. Saito			1973	Pagan	Archaeological excavation on Pagan found probable coral files, shell adzes, fishhooks of bone and shell, radiocarbon dated blue and white trade porcelain, other unworked animal and fish bones (e.g., turtle, parrot fish). Estimated latte age A.G. 1300–1700.	Egami and Saito (1973)	X							

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
L.G. Eldredge, S. Amesbury, E.A. Kay, C. Lamoureux, M. Falanruw (Univ. Guam, Univ. Hawaii, Yap Inst. Natural Science)			1975	All islands	Broad-based marine survey	Eldredge (1983a; 2003a, b); Algae in Tsuda and Tobias (1977a, b) and Tsuda (2003)			X					
Sir Peter M. Scott		*Linblad Explorer*	1976, 1977	Maug	Reef fish	Eldredge (1983a) Summary. Originals at UK National Archives [25]			X					
R.T. Tsuda, L.G. Eldredge, P. Moore, M. Chernin, and S. Neudecker			1976	Maug	Natural history survey	Eldredge et al. (1977) In: Eldredge (1983a)			X					
Japan Marine Fishery Research Center	No. 20	*Akitsu Maru*	1975–1977	All islands	Skipjack tuna survey, temperature depth profiles	In: Eldredge (1983a)			X					
Micronesian Coordinated Development Co. Ltd.		*Daikatsu-Maru*	1976	Pagan, Agrihan, Asuncion, Maug, and southern islands	Bottom-handline fishing survey	In: Eldredge (1983a)			X					
Kohn and White, 1977			1977	Intertidal polychaetes reef platform on Guam		Kohn and White (1977)		X						

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[25] Catalogue of the papers and correspondence of Sir Peter Markham Scott. Cambridge University Library: Dept. Manuscripts & University Archives. Unpublished. Section D. Travel. See: https://discovery.nationalarchives.gov.uk/details/r/4270dcda-fa04-4dd8-aeeb-22bf281d7370

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
NMFS, SWFSC, Honolulu Laboratory		*Townsend Cromwell*	1978	All islands	Survey	NMFS PIFSC (1978)			X					
Hosmer and Kami		F/V *Typhoon*	19801981	All islands, banks, seamounts	Exploratory fishing	In: Eldredge (1983a)			X					
University of Guam biologists			1981	Pagan	General natural history survey including marine studies	In: Eldredge (1983a)			X		X			
University of Guam Marine Laboratory		F/V *Pution Ta'se*	1983	Pagan, Guguan, Anatahan, Saipan, Aguijan, Rota	Inshore environmental assessment, plankton survey, preliminary precious coral dredging	In: Eldredge (1983a)			X					
NMFS, Southwest Fisheries Science Center, Honolulu Laboratory	Resource Assessment Investigation of the Mariana Archipelago (RAIOMA)	*Townsend Cromwell*	1982–1985	All islands	Resource Assessment Investigation of the Mariana Archipelago (RAIOMA). Quantify the distribution and sustainable yield of insular fishery resources (deepwater bottomfish and shrimps) with commercial potential in the Mariana Archipelago	Polovina (1981); Moffitt (1983); Polovina et al. (1985); Ralston (1986); Moffitt and Polovina (1987); Emerson and Moffitt (1988). *Data see Townsend Cromwell NMFS PIFSC (1989)*		X	X		X			X

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
McGovern-Wilson			1989	Afetna, Saipan.	Archaeological evidence of human bone spear points found in association with burial 6 at Afetna, Saipan.	McGovern-Wilson, (1989) <u>*In:*</u> Allen and Amesbury 2012	X							
NMFS, Southwest Fisheries Science Center, Honolulu Laboratory	Resource Assessment Investigation of the Mariana Archipelago (RAIOMA)	*Townsend Cromwell*	1982–85	All islands	Resource Assessment Investigation of the Mariana Archipelago (RAIOMA). Quantify the distribution and sustainable yield of insular fishery resources (deepwater bottomfish and shrimps) with commercial potential in the Mariana Archipelago	Polovina (1981); Moffitt (1983); Polovina et al. (1985); Ralston (1986); Moffitt and Polovina (1987); Emerson and Moffitt (1988). *Data see Townsend Cromwell NMFS PIFSC (1989)*		X	X		X			X
Chiba Natural History Museum Expedition			1992	Mariana Islands		Sato-Okoshi and Yokouchi (1994)		X		X				
Japan Agency Marine-Earth Sci. Tec.		*Shinkai 6500* (submersible)	1993	Mid-Mariana Trough	Survey hydrothermal vents	Gamo et al. (1993)			X					

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Leach, Foss and Janet Davidson of the Museum of New Zealand Te Papa Tongarewa			1990; 2012	Mochong, Rota	Analysts calculated the minimum number of individuals (MNI) in archaeological fish bone collections identifying 313 fishes from the archaeological collections from Mochong, Rota. The families are grouped by probable fishing methods. They also suggest methods that were used for catching the fishes based on the technology of the time period, the habits and habitats of the fishes, and ethnographic comparison.	Leach et al. (1990)	X							
Butler			1995	Achugao, Saipan	Archaelogical evidence of U-shaped hook possibly of Turbo shell, from an early Pre-Latte context at Achugao, Saipan	Butler, B. M. (ed.) (1995)	X							
Japan Agency Marine-Earth Sci. Tec.		*Shinkai 6500*	1997	Mariana back-arc basin	Submersible survey deep-sea hydrothermal vents and lithosphere	Fujikura et al. (1997)			X					
Ogden Environmental and Energy Services, Inc.			1998	U.S. Naval Ordnance Annex on Guam	Archaeological studies	In: Dixon et al. (2012)	X							
Moore and Hunter-Anderson			1999		Archaeological studies	Moore and Hunter-Anderson (1999)	X							

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Moore and Hunter-Anderson			1999		Archaeological studies	Moore and Hunter-Anderson (1999)	X							
Pacific Consulting Services, Inc. (PCSI; formerly Ogden Environmental and Energy Services, Inc. of Honolulu, Hawaii)			2002	U.S. Naval Ordnance Annex on Guam; northeast of Fena Reservoir	Archaeological studies	In: Dixon et al. (2012)	X							
NOAA/OAR /PMEL /EOI (Earth-Ocean Interactions Prog.)	TN 153	R/V *Thomas G Thompson*	2003	Submarine Ring of Fire Expedition	First systematic survey of 60 submarine volcanoes in the Mariana Arc. Submarine Ring of Fire Expedition. 2003–Mariana Arc.	Merle et al. (2003).			X				X	
University of Tokyo, Ocean Research Institute		R/V *Hakuho Maru*	2003	West Mariana Ridge; North Pacific	Search for and found spawning area of Japanese Eel *(Anguilla japonica)*	Tsukamoto (1992, 2006), Tsukamoto et al. (2013), Kurogi et al. (2011)		X			X			
Amesbury, J.R. and R.L. Hunter-Anderson			2003; 2008	Rota, Afetna, Saipan, and Unai Masalok and Tachongna, Tinian	Archaeological fishbone analysis. Sites on Rota yielded pelagic fish and sea turtle remains; sites in CNMI yielded pelagic fish remains dating to the Prehistoric Period.	Amesbury and Hunter-Anderson (2003, 2008) in Allen and Amesbury (2012)	X							

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
NOAA NMFS PIFSC	MARAMP (See reference for cruise numbers)	*Oscar Elton Sette; Hi'ialakai*	2003-2018	Mariana Archipelago	Surveys to monitor coral reef fish and invertebrate species throughout the Archipelago, with bathymetry and oceanographic data.	See cruise reports: NOAA Ship *Hi`ialakai* HI-07-03 (2007), HA-11-01 (2011) NOAA Ship *Oscar Elton Sette* SE-10-02 (2010); SE-10-03/SE-79 (2010); SE-14-04 (2014); SE-14-05 (2014); SE-15-02 (2015); SE-15-03 (2015)		X			X		X	X
NOAA/OAR /PMEL / EOI (Earth-Ocean Interactions Program)	TN 167	R/V *Thomas G Thompson*	2004	Submarine Ring of Fire	Used ROV to explore some of the hydrothermally active sub-marine volcanoes mapped during 2003 expedition.	Merle et al. (2004).		X	X				X	
Ocean Res. Inst., Univ. Tokyo and Hokkaido University		ROV and towed camera	2004	Southernmost Mariana Arc (Nakayama Field;12°43'N , 143°32'E)	Light transmission and temperature, with deep-tow camera surveys of hydrothermal vents	Gamo et al. (2004)			X				X	

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
NOAA NMFS PIFSC	OES-05-10 and 11	*Oscar Elton Sette*	2006 *(2005)*	CNMI: (Saipan Guguan, Pagan, Asuncion, Uracas, Maug, Supply Reef, Agrihan, Alamagan, Zelandia Bank Sarigan, Anatahan, Pathfinder, Arakane, Tinian, Aguijan, and Rota)	MARAMP	NMFS PIFSC CRCP (2006a, b: Cruise 05-10 = OES-32; Cruise 05-11 = OES-33)		X						
NOAA/OAR /PMEL / EOI		*Thompson* and *Southern Surveyor*	2005	Mariana Trough, Lau Basin	Conductivity-temp-depth-optical tows, plume surveys	Baker et al. (2005)			X					
NOAA NMFS PIFSC	OES-05-12	*Oscar Elton Sette*	2005	Guam, Santa Rosa Reef, and Galvez Bank	MARAMP	NMFS PIFSC CRCP (2005: Cruise SE-05-12 = OES-34)		X						
NOAA/OAR /PMEL / EOI	TN 167	R/V *Thomas G Thompson*	2006	Submarine Ring of Fire, Rota eruptions and Mariana Back-Arc	Observed the on-going eruption of NW Rota-1 volcano to be even more active than previous expeditions. New ecosystems were discovered and characterized and extraordinary sites from 2004 were revisited.	Merle et al. (2006); Embley et al. (2004, 2006b, 2007)			X				X	

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
NOAA/OAR /PMEL / EOI		Ship and ROV	2003, 2004, 2006	Mariana arc, 76 volcanoes	Monitoring hydrothermal vents, 26 active and 50 inactive	Baker et al. (2008)			X					
NOAA NMFS PIFSC	HA-07-02	*Hi'ialakai*	2007	Guam and CNMI: Rota, Aguijan, Tinian, Saipan	MARAMP	NMFS PIFSC CRCP (2007a) Cruise HI-07-02		X						
NOAA NMFS PIFSC	HA-07-03	*Hi'ialakai*	2007	CNMI: Anatahan, Sarigan, Zealandia Bank, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, Supply Reef, Uracas (Farallon de Pajaros)	MARAMP	NMFS PIFSC CRCP (2007b) Cruise HI-07-03		X						
Dept. Zoology, UH Mānoa		n.a.	2002-2003	Guam: Gun Beach (13°32'N; 144°47'E)	Monthly sampling soritid foraminifera on the reef	Pochon et al. (2007)					X			
NOAA NMFS PIFSC	HA-09-02	*Hi'ialakai*	2009	Guam and CNMI: Rota, Aguijan, Tinian	MARAMP	NMFS PIFSC CRCP (2009a) Cruise HA-09-02		X						
NOAA NMFS PIFSC	HA-09-03	*Hi'ialakai*	2009	CNMI: Saipan, Sarigan, Pagan, Asuncion, Supply Reef, Uracas (Farallon de Pajaros), Maug, Agrihan, Alamagan, Guguan, Zealandia Bank, Anatahan	MARAMP	NMFS PIFSC CRCP (2009b) Cruise HA-09-03		X						
NOAA/OAR /PMEL / EOI	TN 232, J2-396 to J2-412	R/V *Thomas G Thompson* and associated *ROV Jason*	2009	Guam and NW Rota	Expedition to NW Rota-1 discovered that the volcano had grown a new cone. ROV dives made observations of the eruptive activity, collected geologic, chemical, and biological samples, and deployed instruments.	Bobbitt (2009)			X				X	

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Fisheries Agency, Japan		R/V *Kaiyo Maru* & *Hokko Maru*	2008-2009	West Mariana Ridge; North Pacific	Evaluation otolith stable isotope ratios to help identify juvenile growth areas for Japanese eels collected from the West Mariana Ridge spawning area. Cone noted over the eruptive vent since 2006.	Otake et al. (2019)		X			X			
JISAO, PMEL U Washington		Sea Bird 911	2009	Mariana Arc 1200 km from 13.5° - 23.2°N	Surveyed 50 submarine volcanoes (Seabird, CTD, LSS, ORP sensors)	Resing et al. (2009)							X	
NOAA NMFS PIFSC	SE-10-02 (SE-78)	*Oscar Elton Sette*	2010	Guam: Galvez Bank, 11-mile Bank and CNMI: Saipan, Rota, Farallon de Medinilla, banks north of FDM	MARAMP, FMSD, Bathymetric surveys, BRUVs, AUV	Rooney (2010) Cruise SE-10-02		X			X		X	
NOAA NMFS PIFSC	SE-10-03 (SE-79)	*Oscar Elton Sette*	2010	CNMI, Guam (+Wake and Micronesia)	Midwater trawl. Acoustics and oceanography. Cetacean surveys using High-Frequency Acoustic Recording Packages (HARPs): Saipan, Tinian (and Wake).	NMFS PIFSC (2010: Cruise SE-10-03 = SE-79)		X			X		X	
NOAA/OAR /PMEL / EOI	KM-1005, J2-486 to J2-495	*R/V Kilo Moana* and associated *Jason*	2010	Guam and NW Rota		Bobbitt (2010)			X				X	
NOAA NMFS PIFSC	HA-11-01	*Hiʻialakai*	2011	Guam, Saipan, Rota, Aguijan, Tinian, Sarigan, Pagan, Asuncion, Supply Reef, Uracas (Farallon de Pajaros), Maug, Agrihan, Alamagan, Guguan, Zealandia Bank, Anatahan	MARAMP	Brainard (2011) Cruise HA-11-01		X						
Athens, J.S.			2011	CNMI: Pagan, Sarigan	Archaeology	Athens (2011)	X							
Allen, S.D. and J.R. Amesbury			2012	Mariana Archipelago	CNMI Fishing Community Profile	Allen and Amesbury (2012)	X					X		

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Carson, M.T. and J.A. Peterson			2012	Ritidian Archaeological Site, Northern Guam	Radiocarbon chronology with marine reservoir correction for the ritidian archaeological site, northern Guam	Carson (2010); Carson and Peterson (2012)	X							
NOAA/OAR /PMEL / EOI	Submarine Ring of Fire	*Jason* (ROV) and R/V *Revelle*	2014	Submarine Ring of Fire	ROV dives: Snail and Urashima vent sites (Mariana back-arc), NW Rota and NW Eifuku seamounts (Mariana arc)	Baker et al. (2017)			X				X	
NOAA NMFS PIFSC	SE-14-04	*Oscar Elton Sette*	2014	Mariana Archipelago	Select species of reef fish and deep bottomfish caught by spear and electronic reel to collect life history tissues for analysis (age, growth, size/ age at maturation). Nearshore surveys reef habitat. Ocean-ographic data. Archaeological team deployed at Alamagan.	NMFS PIFSC (2014a) Cruise SE-14-04		X			X			
NOAA NMFS PIFSC	SE-14-05	*Oscar Elton Sette*	2014	Guam	Guam insular reef and bottomfish, BRUVS, bio-sampling and shark depredation	NMFS PIFSC (2014b) Cruise SE-14-05		X			X			

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
NOAA NMFS PIFSC	SE-15-02	*Oscar Elton Sette*	2015	CNMI and Guam to 50nmi: including Uracas, Maug, Asuncion, Farallon de Medinilla, Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Saipan, Guam	Ship-board, line-transect visual and acoustic surveys for cetaceans	NMFS PIFSC (2015a) Cruise SE-15-02		X						
NOAA NMFS PIFSC	SE-15-03	*Oscar Elton Sette*	2015	CNMI Northern Islands	Kona crab surveys. Oceanographic data. Nearshore coral reef surveys.	NMFS PIFSC (2015b) Cruise SE-15-03		X			X		X	
NOAA/OAR /PMEL/EOI Coop. Inst. Univ. Washington and Oregon State University	FK151121	R/V *Falkor* (Schmidt Ocean Institute)	2015	Mariana back-arc	EOI scientists explored the Mariana back-arc spreading center and found four new hydrothermal vent sites. Extensive imagery, soundings, and mapping.	Merle and Chadwick (2015); Resing et al. (2016)			X				X	
NOAA OER PMEL EOI w/Okeanos *(below)*	FK151121	*ROV SuBastian* aboard the *R/V Falkor* (Schmidt Ocean Institute)	2016	Mariana back-arc	EOI scientists explored the Mariana back-arc following up 2015 discoveries new hydrothermal vent sites and lava flows.	NOAA OER (2016) NOAA PMEL (2019)			X				X	

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
NOAA OER	Deepwater Exploration Mariana Archipelago	*Okeanos Explorer*	2016	Mariana Archipelago	Survey of deepwater biological communities and geophysical environments.	NOAA OER (2016)		X	X		X		X	
US Navy	Annual Marine Survey	USN	2016	Farallon de Medinilla	Marine surveys from 1997-2012. Rapid Environmental Assessment of fish and invertedrate species, including assessment of damage to island and nearshore waters from DOD training activities.	Smith and Marx (2016)		X			X			
SIO and UC San Diego; Global Ocean Design; Avatar Alliance			2016	Challenger Deep, Sirena Deep and Ulithi Atoll	Water samples, chemical data collected, DNA extraction and sequencing microbial communities	Tarn et al. (2106)					X			
NOAA/OAR /PMEL/EOI	FK151121 and EX1605L1–2	*R/V Falkor* and *Okeanos Explorer*	2016	Mariana back-arc 12.7°-18.3°N	Multibeam bathymetric surveys. Synthesis of new surveys and data collected previously	Anderson et al. (2017)							X	
Rieth, T.M. and J.S. Athens			2019 *2017*	Marianas Islands and Bismark Archipelago	Conducted Bayesian model using site specific radiocarbon data, estimating first inhabitants of the Mariana Islands may have been 3230-3085 cal BP.	Reith and Athens (2019)	X							
Petchey, F. and G. Clark			2016 2021	Unai Bapot, Saipan.	Used radiocarbon dating to analyze hardwater to explain 3500 cal. BP results from culturally significant shells recovered from the site of Unai Bapot on the island of Saipan.	Petchey and Clark (2021)	X							

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel(s)**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Ayers, A			2018	CNMI	CNMI fishing community profile (2017 update), including political history, governance, population, economy, social and economic role of fishing; historical reliance on fishing and seafood; trends in reef, inshore, and commercial fishing; and recommendations for cultural and economic indicators.	Ayers (2018)						X		
NOAA NMFS PIFSC	SE-18-02	*Oscar Elton Sette*	2019	CNMI: Uracas (Farallon de Pajaros), Maug, Asuncion, Pagan, Guguan, Sarigan, Anatahan	Life history cruise. Operations included hook-and-line specimen sampling of deep-slope (200–400-m depths) demersal fishes; collection of reef-associated fishes via snorkel-spearfishing; surface to 200 m depth CTD casts to collect vertical depth-profile oceanographic data; and water and sediment sampling for environmental DNA (eDNA) analyses.	NMFS PIFSC (2018a) Cruise SE-18-02		X			X		X	
NOAA NMFS PIFSC	SE-18-03	*Oscar Elton Sette*	2018	Mariana Archipelago	Cetacean surveys	NMFS PIFSC (2018b) Cruise SE-18-03		X					X	X

							Research Category							
Researcher(s) /Organization	**Cruise Name or #**	**Vessel**	**Year** Published *Conducted*	**Location(s)**	**Description**	**Reference**	**1) Archaeological and ancient human history**	**2) Ecology and ecosystem/ fisheries monitoring**	**3) Expeditions, deep sea exploration and geography**	**4) Island flora and natural history**	**5) Marine biology, life history and evolutionary biology**	**6) Socio-economic monitoring and human dimensions**	**7) Oceanography, geochemistry and physical sciences**	**8) Population or ecosystem modeling and stock assessment**
Petchey, F., G. Clark, I. Lindeman, P. O'Day, J. Southon, K. Dabell and O. Winter			2018		Used tri-isotope approach to radiocarbon dating to identify carbon sources and date archaeological middens, using three shellfish taxa that are more prone to erroneous ages.	Petchey et al. (2018)	X							
NOAA NMFS PIFSC	Insular Reef and Bottomfish Life History Survey	*Oscar Elton Sette*	2018	Mariana Archipelago	Select species of reef fish, and deep water bottomfish, were obtained by spear fishing and electronic reel to collect life history tissues for analysis of age and growth and size/age at maturation. Oceanographic data.	See: SE-18-02 report		X			X		X	
NOAA NMFS PIFSC	Mariana Archipelago Cetacean Survey (MACS)	*Oscar Elton Sette*	2021	Mariana EEZ (Guam and CNMI)	Line-transect surveys for cetaceans and seabirds	Yano et al. (2022)		X						

Appendix 2

Table A 2. Major cyclonic disturbances in the Mariana Archipelago 1900–2018.

Year	Name	**Most affected territory and island(s)** *at nearest approach or landfall*[26]	Maximum Category (SSHWS)[27]	Maximum Winds (knots)*	
				Sustained (kt)	Gusts (kt)
1923	No name	Guam	4		122
1924	No name	Guam (center passed S of Guam, extreme rains)	TS		60
1930	No name	Guam (center passed NE of island)	TS		36
1935	No name	Guam (center passed SW of island)	TS		60
1940	No name	Guam (tropical cyclone passed SW of island)	TS		53
1940	No name	Guam (eye passed near S end of island)	4	110	130
1941	No name	Guam (eye passed N end of island)	3		108
1946	Querida	Guam, Rota (eye passed misway between islands)	2		82–85
1948	Agnes	Guam, Rota (center developing TS passed S of Rota)	TS		55
1949	Allyn	Guam (eye passed 60 nm S of island)	3		>110
1950	Doris	Guam (135 nm SW of Agaña)	TS		63
1951	Marge	Guam (25 nm S of Agaña)	TS		55
1952	Hester	Guam (passed 120 nm S of the island)	1		70
1953	Irma	Guam (center passed 90 nm S of Agaña)	TS		55
1953	Nina	Guam (center developing cyclone passed N tip of Guam)	TS		57
1953	Alice	Guam (developing cyclone passed/lingered offshore)	TS		56
1954	Lorna	Guam (center developing typhoon passed S of Guam)	TS		50
1957	Lola	Guam (reach modern day Cat 5 just S of Guam)	5	84	>100
1961	Nancy	Guam (formed and grew quickly; extensive damage to S of Guam as ~Cat 3-4, winds S Guam provided)	5	59	188
1962	Karen	Guam (landfall, winds 175mph)	5	135	150–165
1963	Olive	Guam (approached Guam from S), CNMI (eye crossed Saipan w/winds 130kt)	4	87-90	130
1963	Wendy	Guam (65 nm SW of Agaña)	TS		50

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[26] Closest approach/landfall location does not include anything outside the Mariana Archipelago, which in some cases may be where the storm reached its highest wind speed and category. Wind speeds shown for Marianas where available. (Sources: NOCC/JTWC, 1991; NHC-CPHC, 2019; NOAA NCEI via WorldData.Info, 2022)

[27] Saffir–Simpson Hurricane Wind Scale (SSHWS), as described by Saffir (1973), Simpson (1974), Schott et al. (2019).

Year	Name	**Most affected territory and island(s)** *at nearest approach or landfall*[26]	**Maximum Category (SSHWS)**[27]	**Maximum Winds (knots)***	
				Sustained (kt)	**Gusts (kt)**
1963	Susan	CNMI (Saipan, Tinian, eye just N of Rota), Guam	1	70	
1964	Sally	Guam (center of developing typhoon landfall S tip)	1	70	
1967	Gilda	CNMI (eye/landfall on Rota), Guam (N end winds shown)	TS	60	
1968	Jean	Guam (eye passed 95 nm NW of Agaña, winds 54 kt), CNMI (Saipan devastated)	5		150
1968	Irma	CNMI (Saipan, center passed S Rota), Guam (50 nm N of Agaña)	TS	56	
1968	Judy	Guam (eye passed 100 nm S of Agaña)	TS		50
1968	Ora	Guam (N portion)	1	75	77
1971	Amy	Guam (eye passed 90 nm SW of Agaña)	5	60	
1971	Phyllis	Guam (landfall as weakening TS)	TS		50
1974	Mary	Guam (NE of Guam as TS, with wide band of gales)	TS		55
1975	June	Guam (eye of super typhoon 215 nm W-SW)	5		70
1976	Fran	Guam (intensifying TS near Guam)	4		131
1976	Pamela	Guam (eye passed over w/winds >73mph), Saipan	4	120	138–145
1977	Kim	Guam (eye landfall N Guam)	1		77
1978	Rita	Guam (center passed 82 nm S of Agaña)	1	72	
1978	Judy	Guam (rapidly developing TS made landfall)	TS	40	60
1979	Tip	Guam (strengthened after passing Guam as TS)	5		68
1979	Abby	Guam (center of TS passed 108 nm S of Agaña)	TS		55
1979	Alice	Guam (weakening to TS before passing S of Guam)	3	96	109
1980	Betty	Guam (center developing typhoon 25 nm S of Agaña)	1	55	79
1980	Dinah	CNMI	4	113	
1984	Bill	Guam (eye passed 20 nm S of island)	2		84
1984	Ike	Guam (began SE of Guam and strengthened to TD), CNMI	4	92	127
1986	Kim	CNMI	5	137	
1987	Lynn	Guam (passed NW), CNMI (no landfall)	5	120	160
1988	Roy	Guam, Rota (brushed both as weakening Cat 4 to 3)	4	87	98
1989	Andy	Guam (approached from S-SW)	5	135	
1990	Russ	Guam (near miss, winds up to 150mph)	4	120	125

Year	Name	**Most affected territory and island(s)** *at nearest approach or landfall*[26]	**Maximum Category (SSHWS)**[27]	**Maximum Winds (knots)***	
				Sustained (kt)	**Gusts (kt)**
1991	Yuri	Guam (passed S-SW of Guam as ~Cat 3-4)	5	122	153
1992	Gay	Guam (landfall with 100mph winds)	5	109	161
1992	Omar	Guam (landfall with 120mph winds)	4	100	131
1997	Isa	Guam (severe rains), Rota	5	87	144
1997	Ivan	Guam	5	105	161
1997	Joan	Guam, CNMI (passed between Anatahan - Saipan)	5	105	161
1997	Keith	Guam, CNMI (passed between Rota - Tinian)	5	109	157
1997	Paka	Guam, CNMI (struck Guam and Rota, winds 145 mph)	5	100	161
2002	Higos	CNMI (passed just north of)	4	96	135
2002	Pongsona	Guam, CNMI (passed through both, winds 110-183mph)	4	92-94	131
2002	Chataan	Guam (eye passed just N, island w/in the eyewall, Guam winds 75-106mph), Rota (46-75mph)	4	96	131
2002	Halong	Guam (passed just S as a TS, high wind and waves)	4	87	135
2004	Chaba	Rota, lesser extent Guam	5	125	180
2005	Nabi	Guam, CNMI (passed ~55km N of Saipan)	5	96	140
2007	Kong-rey	Guam, CNMI	3	79	100
2008	Dolphin	Guam (passed south of Guam as TD)	2	65	87
2009	TD 18W	Guam	TD	31	31
2009	Melor	CNMI	5	109	153
2011	Ma-On	CNMI	4	96	113
2013	Francisco	Guam and to a lesser extent the CNMI (as TD with heavy rainfall)	5	105	140
2014	Phanfone	CNMI	4	96	135
2014	Rammasun	Guam (passed directly over as a TD w/weaker winds, heavy rains), CNMI	5	92	140
2015	Bavi	Saipan, Rota, Tinian	TS	85	95
2015	Chan-hom	Rota, Guam (rainfall)	4	105	140
2015	Dolphin	Guam, Rota (passed between)	5	106-115	160
2015	Goni	Marianas (pass thru)	4	100	122
2015	Nangka	CNMI (passed directly over Alamagan)	4	100	135
2015	Soudelor	CNMI (landfall on Saipan and Tinian), Guam also affected	5	113	157
2018	Maria	Guam (landfall, 50 kt winds on Guam as TS)	5	105	140

Year	Name	**Most affected territory and island(s)** *at nearest approach or landfall*[26]	**Maximum Category (SSHWS)**[27]	**Maximum Winds (knots)***	
				Sustained (kt)	**Gusts (kt)**
2018	Mangkhut	Guam, Rota (87 kt sustained winds Rota as Cat 2)	5	100-105	177
2018	Yutu	CNMI (landfall on Tinian and southern Saipan)	5	113	157
2019	Wutip (Betty)	Guam (passed SW of Guam w/winds shown)	5	100	135

Storm Abbreviations used per Saffir–Simpson Hurricane Wind Scale *(Saffir, 1973; Simpson, 1974; Schott et al., 2019)*

		1-minute sustained wind speed		
Abbreviation	**Description**	**Knots (kt)**	**Mph**	**km/h**
TD	Tropical depression	≤ 33	≤ 38	≤ 62
TS	Tropical storm	34–63	39–73	63–118
1	Category 1–Typhoon	64–82	74–95	119–153
2	Category 2–Typhoon	83–95	96–110	154–177
3	Category 3–Typhoon	96–112	111-129	178–208
4	Category 4–Super Typhoon	113–136	130–156	209–251
5	Category 5–Super Typhoon	≥ 137	≥ 157	≥ 252

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NOAA's Marianas Trench Marine National Monument internet site, located at https://www.fisheries.noaa.gov/pacific-islands/habitat-conservation/marianas-trench-marine-national-monument has additional information and video links regarding the research and accomplishments in the Mariana Islands and MTMNM.