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Cover: A spinner dolphin off the west side of Guam. Photo courtesy of Pacific Islands Fisheries Science Center Cetacean Research Program (Marie Hill).

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Executive Summary

The Pacific Islands Fisheries Science Center (PIFSC) Cetacean Research Program has conducted research on cetaceans in the Mariana Archipelago since 2010. A cooperative effort with funding from U.S. Navy Pacific Feet and PIFSC has included summer and winter small-boat surveys off the southernmost islands (Saipan, Tinian, Aguijan, Rota, and Guam); shipboard visual and passive acoustic surveys in portions of the EEZ in 2010, 2015, and 2018; development of photo-identification catalogs; and analyses of collected tissue samples and satellite telemetry tag data. PIFSC has also carried out long-term passive acoustic monitoring on moored recorders off Saipan and Tinian (since 2010) and off Pagan (since 2015) as part of the Pacific Islands Passive Acoustic Network (PIPAN) and deployed drifting acoustic recorders for examination of beaked whale and other cetacean distribution during the 2018 shipboard survey. The goal of these efforts has been to collect the data necessary to conduct the first population assessments for cetaceans within the Mariana Archipelago, including the determination of their occurrence, population structure and abundance, movements, distribution, and habitat use. In addition, these data may be used to evaluate the potential exposure of cetaceans to human-caused stressors within the waters surrounding the Mariana Archipelago including U.S. Navy operations (e.g., sonar, use of explosives), fisheries interactions, and dolphin tourism.

This report summarizes the surveys, data collection, and analyses conducted by PIFSC for cetaceans within the Mariana Archipelago to evaluate the current state of the data with respect to the overall goal of cetacean population assessment. Identification photos and encounter data from surveys conducted by other researchers were contributed by the U.S. Navy for incorporation into the PIFSC data sets for a variety of species and are therefore also represented in the summary reported here. The report is not intended to be an exhaustive review of all cetacean effort conducted in the archipelago, though all significant survey efforts, including those not conducted by PISFC are referenced and, on occasion, discussed in greater detail.

A total of 20 cetacean species have been observed or acoustically detected by PIFSC within the Mariana Archipelago. During small-boat surveys in the southern islands from 2010–2019, 14 species of cetaceans were seen, including spinner dolphin (*Stenella longirostris*), pantropical spotted dolphin (*Stenella attenuata*), bottlenose dolphin (*Tursiops truncatus*), rough-toothed dolphin (*Steno bredanensis*), short-finned pilot whale (*Globicephala macrorhynchus*), sperm whale (*Physeter macrocephalus*), false killer whale (*Pseudorca crassidens*), melon-headed whale (*Peponocephala electra*), pygmy killer whale (*Feresa attenuata*), dwarf sperm whale (*Kogia sima*), Blainville's beaked whale (*Mesoplodon densirostris*), Cuvier's beaked whale (*Ziphius cavirostris*), Bryde's whale (*Balaenoptera edeni*), and humpback whale (*Megaptera novaeangliae*). Risso’s dolphins (*Grampus griseus*) and striped dolphins (*Stenella coeruleoalba*) were observed during PIFSC shipboard visual surveys in 2015 and 2018. Passive acoustic monitoring has provided occurrence data on additional species not yet sighted, including Longman’s beaked whale (*Indopacetus pacificus*), an unknown species of beaked whale (referred to as the Cross Seamount beaked whale, or BWC), blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), and minke whales (*B. acutorostrata*).

Although data are sparse for many species, the aggregate of all data collected to date reveal insights into the distribution and population structure for several species, and adequate data are available to assess abundance and movement patterns for others. The bulk of available data come from surveys near the southern islands, limiting the geographic extent of the conclusions to date. Shipboard visual survey data collected by PIFSC are not currently adequate to conduct abundance analyses for the broader archipelago, though do provide important data on encounter rate and can inform survey design for a dedicated line-transect abundance survey in the future.

Several high-priority analyses could be conducted with the data currently available or with a modest amount of additional data collection. Analyses and activities are considered high priority if they will directly inform National Marine Fisheries Service (NMFS) assessments under the Marine Mammal Protection Act (MMPA) or Endangered Species Act (ESA), they are relatively low cost and may provide focus or direction to future analyses or data collection efforts, or they will inform current Navy monitoring plan questions or consideration of future monitoring efforts in the region. The recommended high-priority analyses or activities include:

- A large-scale visual and passive acoustic shipboard line-transect abundance survey, which is currently planned for 2021 as part of the Pacific Marine Assessment Program for Protected Species (PacMAPPS), a multi-agency rotational cetacean survey plan for the North Pacific.
- Mark-recapture abundance estimation for spinner dolphins, bottlenose dolphins, and short-finned pilot whales within the southern archipelago.
- Genetic analyses of collected samples from spinner dolphins, pantropical spotted dolphins, bottlenose dolphins, rough-toothed dolphins, short-finned pilot whales, false killer whales, and melon-headed whales.
- Examination of habitat preferences of spinner dolphins from environmental and physical features.
- Examination of movements and habitat association of false killer whales and bottlenose dolphins using satellite telemetry data.
- Analysis of the full passive acoustic record for baleen whales, including Bryde’s whales, to examine seasonality and distribution within the archipelago and possible migratory connections to other parts of the Pacific.

Introduction

Study Area

The Mariana Archipelago is made up of 15 islands stretching approximately 890 km in a north-south arc from the northern-most island of Farallon de Pajaros (also known as Uracas) to the southernmost island of Guam (Figure 1). The region is most notably characterized by the Mariana Trench which parallels the archipelago about 150 km to the east, arcing westward to within 120 km south of Guam. The West Mariana Ridge is a series of seamounts paralleling the archipelago 145 to 170 km to the west. The Mariana Archipelago is composed of two U.S. jurisdictions: the territory of Guam and the Commonwealth of the Northern Mariana Islands (CNMI). The CNMI includes all islands within the archipelago with the exception of Guam.

The Mariana Archipelago is home to a large marine protected area—the Mariana Trench Marine National Monument (MTMNM), as well as the U.S. Navy Mariana Islands Testing and Training (MITT) area. The MTMNM consists of the trench unit protecting waters over the Mariana Trench and an islands unit including the 3 northern-most islands in the archipelago. Commercial fishing and other forms of natural resource exploitation are not permitted in Monument waters. The MITT includes the bulk of the U.S. exclusive economic zone (EEZ) around Guam and the CNMI, as well as offshore waters to the west and south to the Federated States of Micronesia and Palau (Figure 1). The MITT was expanded to the west from the Mariana Islands Range Complex (MIRC) in 2015.

Background

Prior to 2007, little information existed on cetaceans in the Mariana Archipelago. Most of what was known at that time came from stranding records (Kami and Lujan 1976; Kami and Hosmer 1982; Donaldson 1983; Trianni and Kessler 2002; Trianni and Tenorio 2012), whaling records (Townsend 1935; Camba 1965; Masaki 1972), and publications of previously undocumented strandings and anecdotal sighting reports (Eldredge 1991; Eldredge 2003; Wiles 2005; Jefferson et al. 2006). A handful of scientific surveys, primarily focused on large whale distribution, were conducted throughout the lower latitude areas of the western North Pacific in the 1990s (Darling and Mori 1993; Yamaguchi 1995; Yamaguchi 1996; Shimada and Miyashita 2001; Ohizumi et al. 2002). These surveys reported low sighting rates of cetaceans in the vicinity of the Mariana Archipelago; however, each of these projects only spent a small amount of time in Mariana Archipelago waters[1].

Two cetacean surveys dedicated to the Mariana Archipelago region were conducted prior to PIFSC beginning work there in 2010. The 2007 Mariana Islands Sea Turtle and Cetacean Survey

[1]Darling and Mori (1993) spent just 1 week on Saipan in February 1990; Shimada and Miyashita (2001) conducted "no effort within 12 nm [of] territorial waters" and only just a few days in the region across 3 survey years; and Ohizumi et al. (2002) spent just 1 day conducting a survey "about 5km off the coast of Pagan and Agrihan Islands in the Northern Mariana Islands." Yamaguchi (1995) spent 10 days surveying nearshore Mariana waters in March–April, 1995, but reported only 5 cetacean sightings (of any species). Although no weather information was given, such a low sighting rate implies that poor sea conditions were likely a factor. No sighting data were reported from Yamaguchi 1996.

(MISTCS) was a large-scale shipboard line-transect survey that covered part of the U.S. EEZ around Guam and CNMI (Fulling et al. 2011) (Figure 1). The MISTCS survey provided encounter and distribution data for 13 cetacean species (Figure S1), and resulted in line-transect abundance and density estimates for 12 cetacean species (Table S1). In August of that same year, a 5-day aerial survey was conducted near the southern islands within the archipelago (Mobley 2007). The aerial survey was designed to monitor for marine mammals during the U.S. Navy "Valiant Shield" training exercises and consisted of circumnavigations of Rota and Guam, as well as approximately 2,300 km of transect lines within the 163,300 km^2 target area to the southeast of the islands (see Figure 1 in Mobley 2007). There were 8 sightings of 7 cetacean species (Mobley 2007).

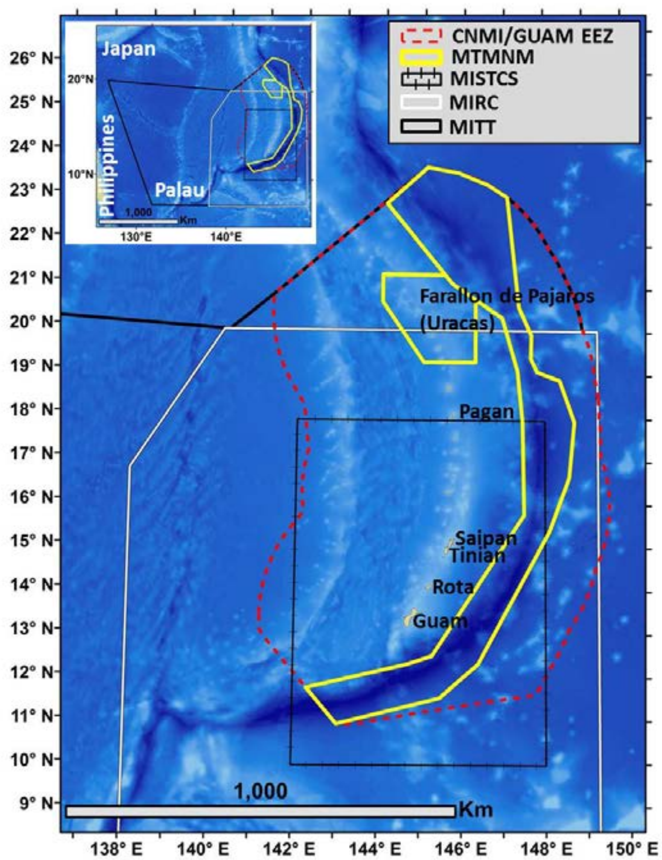

Figure 1. Guam and the Commonwealth of the Northern Mariana Islands (CNMI) Exclusive Economic Zone (EEZ), the Mariana Trench Marine National Monument (MTMNM), the Mariana Islands Range Complex (MIRC), and the Mariana Islands Training and Testing (MITT) area. The 2007 Mariana Islands Sea Turtle and Cetacean Survey (MISTCS) was a U.S. Navy shipboard line-transect survey that covered part of the Guam and CNMI EEZ and the MIRC. Inset–Area zoomed out to show the full extent of the MITT and MIRC.

Following some preliminary (Oleson and Hill 2010; PIFSC 2010a, 2010b) and opportunistic (PIFSC 2010c) survey work in the region, PIFSC began a partnership with the U.S. Navy in 2010 to conduct surveys for cetaceans in the nearshore waters off Guam and the CNMI in an effort to further develop a record of the occurrence, abundance, and structure of cetacean populations in the Mariana Archipelago. PIFSC-led small-boat survey efforts have continued since 2010, and two shipboard visual and passive acoustic surveys were also conducted in 2015 and 2018. Many of the National Marine Fisheries Service (NMFS) assessment goals were supported by the Navy Marine Species Monitoring plans for the MIRC and MITT, primarily focused on occurrence, relative abundance, and population structure for species potentially impacted by Navy activities in the region. The purpose of this report is to summarize the data collected by PIFSC within the Mariana Archipelago and to evaluate the current state of the data and associated analyses with respect to NMFS overall goal of cetacean population assessment. This report primarily details data collected and or analyzed by PIFSC and its partners. Photo-identification and encounter data from other surveys were contributed by the U.S. Navy for incorporation into the PIFSC data sets for various species and are therefore also represented in the summary reported here.

Survey Effort[2]

Small-Boat Surveys

PIFSC has conducted visual surveys for cetaceans in the waters off the southernmost islands of the Mariana Archipelago (Saipan, Tinian, Aguijan, Rota, and Guam) aboard small vessels (5.8–12.2 m) since 2010. Survey tracks did not follow a randomized design, but instead were spread out from day to day to ensure broad survey coverage over a wide range of depths and were also dictated by weather and sea conditions. The survey vessels traveled at a speed of 15–26 km/h, depending on the size of the vessel and sea conditions. Between 4 and 6 observers scanned for marine mammals with unaided eyes or, occasionally handheld binoculars, collectively searching 360-degrees around the vessel.

All cetacean groups encountered were approached for species confirmation, group size estimation, photo-identification, biopsy sampling/sloughed skin collection, and acoustic recording when possible. In 2013, satellite tagging was implemented to investigate movements and spatial use of individuals of some species. Additional data collected during each sighting included the location (latitude/longitude), behavior, and an estimate of the number of calves (neonates and young of the year). Survey conditions (e.g., Beaufort sea state, swell height) and effort status were recorded regularly as conditions changed. A handheld Global Positioning System (GPS) automatically recorded the vessel’s track at 1-minute intervals. Digital SLR cameras with telephoto zoom lenses were used for taking photographs. Photographic efforts were focused on dorsal fin and fluke images (for individual identification purposes) and images of the body and head (for assessments of health and scarring).

Biopsy sampling was conducted using a Barnett RX-150 crossbow and Ceta-Dart bolts with sterilized, stainless steel biopsy tips (25 mm long × 8 mm diameter for small to medium odontocetes and 40 mm long × 8 mm diameter for large odontocetes and baleen whales). Samples were split in half longitudinally with one half of each sample remaining in archival storage at PIFSC and the other half sent either to the Marine Mammal Institute at Oregon State University (OSU) (humpback whales and some stenellids) or to the National Marine Mammal

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[2] Data processing and analyses for visual survey data (e.g., bathymetric, photo-identification, tissue sample, and satellite telemetry) are described in the supplemental material.

and Sea Turtle Research (MMASTR) collection at SWFSC (all other species) for tissue archiving and processing.

Satellite tagging was conducted using a Dan Inject air rifle and deployment arrows designed by Wildlife Computers. Wildlife Computers location-only (SPOT5 and SPOT6) and location-depth (SPLASH10) tags. The tags were attached to the dorsal fin with 2 sterilized, titanium darts with backward facing petals. Two dart lengths were used depending on the species (4.5 cm for small to medium odontocetes or 6.5 cm for large odontocetes) (Andrews et al. 2008). Tag programming varied depending on the species and followed the specifications used by Cascadia Research Collective (CRC) based on the average number of respirations per hour, speed of surfacing, and the likelihood that a tag would remain attached for longer than a month (Baird et al. 2013). Tag IDs were the Platform Terminal Transmitter IDs assigned by Argos.

In 2011–2012, acoustic recordings were made during some PIFSC encounters using a Fostex (model FR-2, Fostex Co., Tokyo, JP) that recorded 24-bit acoustic data sampled at 192 kHz with a hydrophone suspended from 30 m of cable over the side of the survey vessel. The hydrophone was deployed once the boat was positioned (and turned off) within or in front of a group of interest, and recording continued until the group had left the area or the survey team was required to move on to pursue additional survey effort. In 2016, acoustic recordings were made in the vicinity of animals using a Compact Acoustic Recording Buoy designed by Y. Barkley. The free-floating instrument included a hydrophone (HTI-96-MIN, High Tech, Inc., Long Beach, MS) suspended at 30 m depth and a recorder (SM2+ Song Meter, Wildlife Acoustics, Concord, MA) that sampled at 384 kHz, had a pre-amplifier gain of +36 dB and a 1 kHz high pass filter.

In 2015, PIFSC began conducting small-boat surveys targeting humpback whales off Saipan in January–March when the whales were expected to be present based on passive acoustic data collected in the region (Oleson et al. 2015). The field procedures were the same as described above; however, shallow water (≤200 m) areas were targeted based on known humpback whale habitat preferences in other wintering areas (Herman and Antinoja 1977; Frankel et al. 1995).

Across all summer and winter small-boat survey efforts, PIFSC conducted 270 days of surveys for cetaceans off the southernmost islands of the Mariana Archipelago (Saipan, Tinian, Aguijan, Rota, and Guam) between 2010 and 2019 and completed 24,305 km of on-effort trackline (Table S2, Figure 2). A third of the total on-effort survey trackline distance (7,399 km) was inside of the 200 m isobath; 24% (1,766 km) of that was attributed to winter effort targeting humpback whales in shallow water (Figure S2). Most of the survey effort occurred in summer months (May–September) and there was no effort during October–December (Figure 3).

There were 362 groups (excluding within-day re-sights) identified to 14 species including (in order of frequency of occurrence) spinner dolphin, pantropical spotted dolphin, bottlenose dolphin, short-finned pilot whale, rough-toothed dolphin, sperm whale, false killer whale, dwarf sperm whale, pygmy killer whale, Bryde's whale, melon-headed whale, Blainville's beaked whale, and Cuvier's beaked whale (Table 1, Figure 2). Humpback whales were encountered in January–March 2015–2019 when targeted surveys were conducted off Saipan. Across all PIFSC small-boat surveys, there were 19 mixed-species groups, each including 2–3 species. Some groups could not be identified to species, and are indicated as unidentified beaked whales, unidentified whales, and unidentified dolphins. The overall effort resulted in the collection of

130,066 photos and 435 biopsy samples, deployment of 44 satellite tags, and collection of 9 single-species acoustic recordings (Table 1, Table 2).

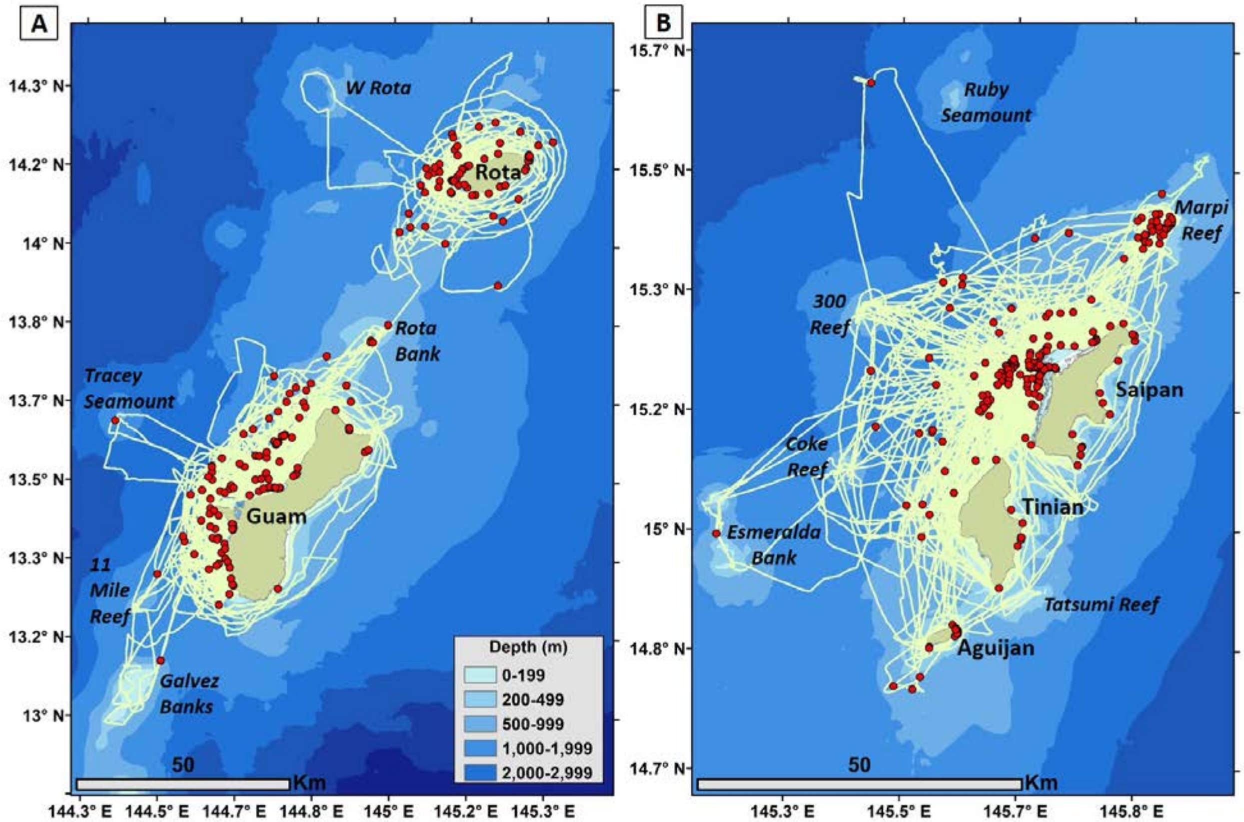

Figure 2. Tracks and cetacean encounters during Pacific Islands Fisheries Science Center small-boat surveys of the southernmost Mariana Archipelago (2010–2019). Panel A–Guam to Rota. Panel B–3-Islands (Saipan, Tinian, Aguijan) area.

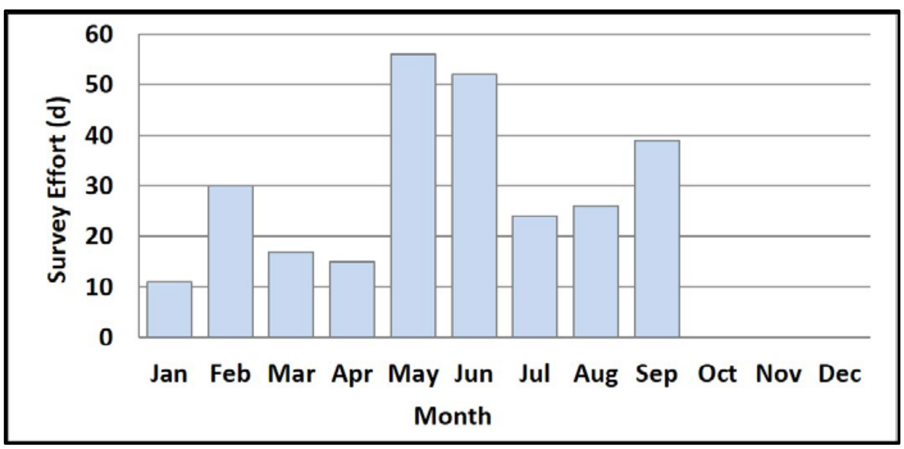

Figure 3. Survey effort (d) across months during Pacific Islands Fisheries Science Center small-boat surveys in the southern Mariana Archipelago (2010–2019).

Table 1. Summary of cetacean encounters during 2010–2019 small-boat surveys conducted by the Pacific Islands Fisheries Science Center within the southern islands of the Mariana Archipelago, including the number of encounters, the median and (range) of group size, the median and range of encounter location depths (m), and the median and range shore distance (km), the number (No.) of photos and biopsy samples collected, satellite tags deployed, and acoustic recordings. Species are listed in order of frequency of occurrence with the exception of humpback whales. Groups that could not be identified to species are shown in gray. Median values are not provided for species with fewer than 3 encounters.

Species	Encounters	Median Grp Size (range)	Median Depth (m) (range)	Median Shore Distance (km) (range)	No. Photos	No. Biopsy Samples	No. Satellite Tags	No. Acoustic Recordings
Spinner dolphin	161	31 (1–135)	41 (2–615)	0.6 (0.1–19)	45,894	101	0	2
Pantropical spotted dolphin	53	35 (4–145)	845 (333–3,000)	6.4 (1.7–53)	12,476	62	1	1
Bottlenose dolphin	40	8 (1–27)	122 (18–1,048)	5.8 (0.3–19)	8,185	37	6	1
Short-finned pilot whale	23	30 (4–48)	720 (51–1,443)	5.1 (0.5–36)	21,453	111	23	3
Rough-toothed dolphin	9	6 (1–25)	479 (65–808)	6.9 (0.4–14)	1,951	4	1	—
Sperm whale	7	9 (6–15)	1,617 (374–2,051	12 (1.1–22)	3,285	17	2	—
False killer whale	6	14 (2–25)	838 (88–2,107)	5.8 (0.7–8.4)	6,707	33	8	—
Dwarf sperm whale	5	3 (1–4)	696 (642–870)	3.3 (1.6–17)	986	1	0	2
Pygmy killer whale	5	8 (6–11)	563 (38–1,978)	6.9 (1.1–10)	1,741	5	0	—
Bryde's whale	5	1	859 (487–1,918)	17.0 (12–24)	846	3	0	—
Melon-headed whale	3	325 (85–380)	1,014 (903–1,975)	6.5 (2.6–15)	7,502	31	3	—
Blainville's beaked whale	2	– (1–5)	– (678–1,200)	– (11–15)	468	1	0	—
Cuvier's beaked whale	1	4	1706	19	230	0	0	—
Humpback whale	42	2 (1–8)	39 (12–624)	8.0 (1.2–18)	18,243	29	0	—

Species	Encounters	Median Grp Size (range)	Median Depth (m) (range)	Median Shore Distance (km) (range)	No. Photos	No. Biopsy Samples	No. Satellite Tags	No. Acoustic Recordings
Mesoplodon beaked whale	5	1 (1–2)	1,078 (1,032–1,614)	20 (5.1–31)	71	0	0	—
Unid. Beaked whale	3	2 (1–2)	1,352 (972–1,815)	7.0 (6.5–12)	0	0	0	—
Unid. medium dolphin	3	1 (1–5)	631 (464–702)	6.2 (2.8–13)	28	0	0	—
Unid. small dolphin	2	– (1–2)	– (26–1,515)	– (2.6–27)	0	0	0	—
Unid. whale / small whale	3	1	447 (343–568)	4.1 (1.3–21)	0	0	0	—
Total	378				130,066	435	44	9

Table 2. Summary of satellite tags deployed during Pacific Islands Fisheries Science Center small-boat surveys and the 2015 Mariana Archipelago Cetacean Survey, including the total number of tags deployed by species with the number of location-only (SPOT) and location-depth (SPLASH) tags, the years in which the tags were deployed, the deployment locations, and the median and range of the tag transmission durations (d).

Species	# Tags (SPOT/SPLASH)	Deployment Years	Deployment Locations	Median (range) Transmission Duration (d)
Short-finned pilot whale	23 (16/7)	2013, 2014, 2016, 2017, 2018	Guam, Rota, Marpi Reef, Tinian	54 (7–235)
False killer whale	9 (7/2)	2013, 2014, 2015	Guam, Rota, Tinian, Asuncion	31 (4–198)
Bottlenose dolphin	6 (4/2)	2013–2015, 2017	Rota, Saipan, Tinian, Aguijan	10 (4–21)
Melon-headed whale	3 (3/0)	2014, 2017	Saipan, Guam	3 (2–16)
Sperm whale	2 (1/1)	2016	Saipan, Guam	– (10–42)
Pantropical spotted dolphin	1 (1/0)	2016	Guam	11
Rough-toothed dolphin	1 (1/0)	2013	Aguijan	12

Shipboard Surveys

2015 Mariana Archipelago Cetacean Survey

From 8 May–5 June 2015, PIFSC conducted the Mariana Archipelago Cetacean Survey (MACS), a shipboard survey around all islands in the Mariana Archipelago north of Farallon de Medinilla (FDM) in waters out to 92.6 km (50 nmi) from shore. MACS 2015 consisted of both systematic and non-systematic line-transect effort from the ship and additional survey effort from a small boat. Non-systematic effort occurred when the visual observers maintained established line-transect data collection protocols when the ship was not on a systematic trackline.

A continuous watch for cetaceans was carried out by a team of 6 cetacean observers from the flying bridge of the ship (approximately 15 m above the sea surface) during daylight hours (sunrise to sunset). The observer team rotated through 3 on-effort roles (port and starboard observers and a center observer/data recorder), searching for cetaceans ahead of the vessel from the starboard beam (90° right) to the port beam (90° left) using 25×150 mounted binoculars (port and starboard observers) and 7×50 handheld binoculars or unaided eyes (center observer). The ship followed the survey tracklines at a speed of 10 kt (18.5 km/h). Most cetacean groups within a 5.6 km (3 nmi) perpendicular distance from the transect line were approached for group size estimation and, if time permitted, additional data collection including photo-identification and biopsy sampling from the ship. During some encounters, a small boat was launched for photo-identification, biopsy sampling, and satellite tagging. The sampling and tagging methods were the same as described above for small-boat surveys. In addition, at some of the northern islands, the small-boat was launched to conduct an independent nearshore survey while the ship worked further offshore.

Passive acoustic towed array surveys were conducted during all daylight hours. The towed array consisted of 7 hydrophones (HTI 96-MIN) within 2 array segments (3 hydrophones within an inline array and 4 within an end array) separated by 30 m of cable and towed 300 m behind the ship. All incoming acoustic data, as well as depth data, were sampled at 500 kHz using National Instruments A/D card and recorded to a computer hard drive. Data were aurally and visually monitored for the occurrence of dolphin whistles and echolocation clicks using Ishmael software (Cooperative Institute for Marine Resources Studies, Oregon State University, Newport, OR), and bearing angles to detected groups were plotted using WhalTrak software (Dr. Jay Barlow, Southwest Fisheries Science Center, La Jolla, CA). In some cases, the vessel was directed toward detected groups if they were within 3 nmi of the trackline and passed the beam without being sighted by the visual team.

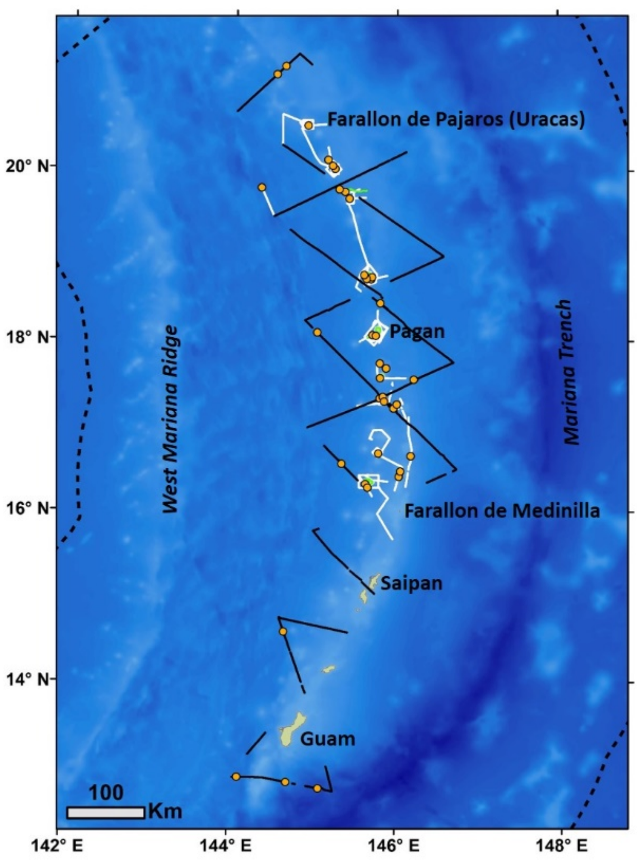

Figure 4. Systematic effort tracks (solid black lines), non-systematic effort tracks (white solid lines), small-boat tracks (green solid lines), and cetacean encounters (orange dots) during the Pacific Islands Fisheries Science Center 2015 Mariana Archipelago Cetacean Survey (8 May–5 June). Dashed black line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone.

During MACS 2015, systematic effort was conducted along 1,996 km of trackline, non-systematic effort from the ship was conducted along 1,924 km of trackline, and small-boat effort was conducted along 317 km of trackline (Figure 4). The survey tracklines covered a wide range of depths from shallow (<100 m) nearshore waters to nearly 7,000 m depth offshore, but most (75%) of the effort was in 1,400–3,800 m depth (Figure S2). There were 35 sightings of 9 species including spinner dolphin, rough-toothed dolphin, bottlenose dolphin, Risso's dolphin, melon-headed whale, false killer whale, sperm whale, Blainville's beaked whale, and Bryde's whale, as well as several groups that could not be identified to species, including unidentified dolphins, whales, and beaked whales. A total of 6,616 photos and 51 biopsy samples were collected, and a single satellite tag was deployed on a false killer whale (Table 2, Table 3). From the towed array, there were single-species acoustic recordings during 21 visual encounters of identified species (Table 3), as well as real-time detection of 3 groups of sperm whales, one group of beaked whales, and 12 groups of unidentified dolphins not observed by the visual survey team.

Table 3. Summary of cetacean encounters during the 2015 Mariana Archipelago Cetacean Survey conducted by the Pacific Islands Fisheries Science Center, including the total number of encounters (S = systematic effort; N = non-systematic effort), the median and range of the group size, the median and range encounter location depth (m), and the median and range shore distance (km), the number (No.) of photos and biopsy samples collected, satellite tags deployed, towed array acoustic detections, and single-species acoustic recordings. Species are listed in order of frequency of occurrence. Groups not identified to species are shown in gray. Median values are not provided for species with fewer than 3 encounters.

Species	Total Encounters (S/N)	Median (range) Grp. Size	Median (range) Depth (m)	Median (range) Shore Distance (km)	No. Photos	No. Biopsy Samples	No. Tags	No. Towed Array Acoustic Detections	No. Single Species Acoustic Recordings
Spinner dolphin	12* (–/8)	22 (6–47)	27 (14–416)	0.2 (0.1–0.8)	467	12	0	7	7
Melon-headed whale	4 (2/2)	167 (90–268)	2,500 (1,562–3,383)	40 (18–71)	2,462	27	0	4	4
Rough-toothed dolphin	4 (1/3)	16 (12–27)	559 (30–1,955)	2.1 (0.4–16)	1,072	6	0	2	2
Bottlenose dolphin	3 (–/3)	10 (9–20)	671 (98–961)	2.9 (1.1–35)	45	2	0	2	2
Bryde's whale	3 (2/1)	2 (1–4)	3,198 (844–3,762)	46 (9.0–71)	785	0	0	0	2†
Sperm whale	3 (2/1)	1 (1–9)	2,594 (1,578–2,975)	32 (14–75)	461	1	0	3	2
Blainville's beaked whale	2 (1/1)	– (3–4)	– (267–1,290)	– (0.5–3.5)	23	0	0	1	1
False killer whale	2 (–/2)	– (6–31)	– (2,457–2,461)	– (13–40)	1,285	3	1	1	1
Risso's dolphin	2 (1/1)	– (1–5)	– (2,594–4,398)	– (75–95)	8	0	0	2	1
Mesoplodon beaked whale	5 (1/4)	1	1,294 (914–1,699)	3.5 (0.8–13)	8	0	0	1	1

Species	Total Encounters (S/N)	Median (range) Grp. Size	Median (range) Depth (m)	Median (range) Shore Distance (km)	No. Photos	No. Biopsy Samples	No. Tags	No. Towed Array Acoustic Detections	No. Single Species Acoustic Recordings
Unid. large whale	2 (1/1)	1	– (1,883–3,585)	– (6.7–73)	0	0	0	—	—
Unid. rorqual	1 (1/–)	1	2,047	80	0	0	0	—	—
Unid. small dolphin/dolphin	2 (1/1)	– (2–17)	– (399–6,298)	– (38–67)	0	0	0	—	—
Total	45* (13/28)				6,616	51	1	23	23

*Includes 4 small-boat-only encounters

†Sonobuoys were deployed during 2 Bryde's whale encounters, but the data have not been processed to determine if vocalizations were recorded.

2018 Mariana Archipelago Cetacean Survey

From 9 July to 1 August 2018, PIFSC conducted MACS 2018, a shipboard survey off the islands of Guam to Pagan and west to the West Mariana Ridge approximately 278 km (150 nmi) from shore. The effort consisted of both systematic line-transect effort within a pre-determined survey grid and non-systematic offshore and nearshore tracks from the ship plus additional survey effort from a small boat. Dedicated small-boat and ship surveys were conducted at FDM and Pagan to better assess nearshore species distribution at both locations. All visual and towed array data collection methods were the same as those used during MACS 2015 except as noted below.

Passive acoustic towed array data were collected simultaneously from 6 hydrophones (HTI 96-MIN), 3 within an inline array and 3 within an end array, with the arrays separated by 30 m of cable. Data were digitized at 500 kHz sample rate using a 12-channel SA Instrumentation SailDAQ and recorded. PAMGuard software (pamguard.org) was used to manage data recording, real-time acoustic detection and tracking, and manage acoustic metadata. Several click detectors and a single whistle/moan detector were run in real-time, and bearing angles were computed for all detected sounds.

Drifting Acoustic Spar Buoy Recorders (DASBRs) were deployed to collect passive acoustic data independent of the ship's operations. DASBRs included 2 hydrophones in a vertical array at 150 m depth, with the hydrophones spaced 10 m apart and simultaneously sampled at 576 kHz using a SoundTrap (HF ST4300, Ocean Instruments, Auckland, NZ). Acoustic data collection was duty-cycled, recording for 2 of every 5 minutes. Tilt was measured using an accelerometer integrated within the SoundTrap. Depth was collected through an additional Lotek time-depth recorder (LAT1400-64kB). A surface float contained an Iridium transmitter that reported the buoy location.

During MACS 2018, systematic effort was conducted along 2,164 km of trackline, non-systematic effort was conducted along 1,124 km of trackline, and small-boat effort was conducted along 74 km of trackline (Figure 5). Survey effort covered depths from 10 m to 4,700 m, but more than half (57%) of the overall survey trackline was in water depths greater than 3,000 m (Figure S2). There were 64 cetacean sightings of 13 species including spinner dolphin, pantropical spotted dolphin, striped dolphin, rough-toothed dolphin, bottlenose dolphin, Risso's dolphin, melon-headed whale, pygmy killer whale, short-finned pilot whale, sperm whale, Cuvier's beaked whale, dwarf sperm whale, Bryde's whale, and several groups that could not be identified to species, including sei or Bryde's whales, *Kogia* sp., unidentified dolphins, and unidentified whales. A total of 6,816 photos and 20 biopsy samples were collected (Table 4).

A total of 94 acoustic encounters were identified in real-time using the automated detectors within PAMGuard, including acoustic detections during 30 sightings. In addition to those groups seen by the visual team, the passive acoustic team encountered 4 groups of false killer whales, 7 groups of sperm whales, 5 groups of Blainville's beaked whales, 2 groups of Cuvier's beaked whales, 1 group of Longman's beaked whales, and 45 groups of unidentified dolphins.

Eight DASBRs were deployed and recovered during MACS 2018 (Table 5, Figure 6). To date, the acoustic data from the DASBRs have been analyzed for beaked whale and *Kogia* species occurrence, and include detections of Blainville's, Cuvier's, Longman's beaked whales, the Cross Seamount beaked whale (BWC), and *Kogia* species.

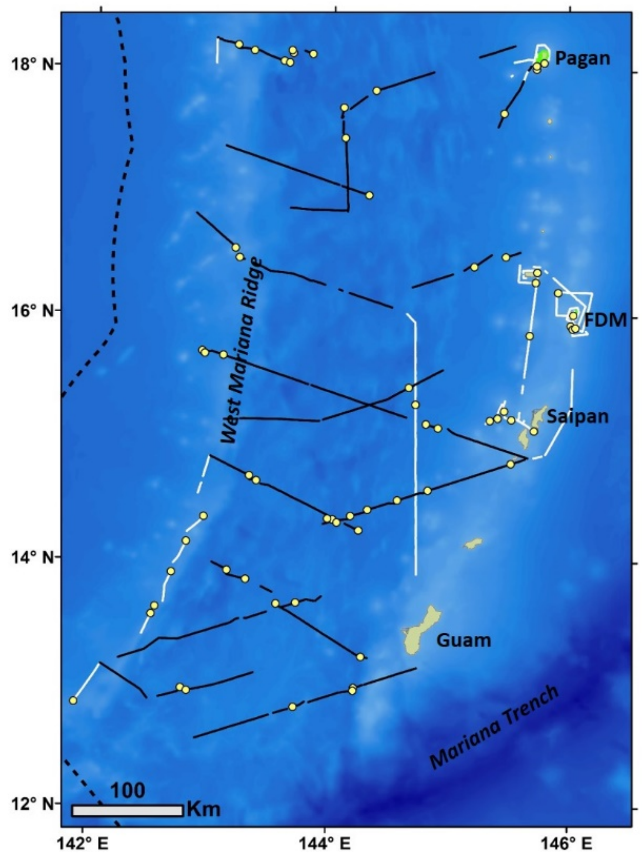

Figure 5. Systematic effort tracks (solid black lines), non-systematic effort tracks (solid white lines), small-boat tracks (solid green lines), and cetacean encounters (yellow dots) during the Pacific Islands Fisheries Science Center 2018 Mariana Archipelago Cetacean Survey (9 July–1 August). Dashed black line—Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone.

Table 4. Summary of cetacean encounters during the 2018 Mariana Archipelago Cetacean Survey conducted by the Pacific Islands Fisheries Science Center including the number of encounters (S = systematic effort; N = non-systematic effort), the median and range of the group size, the median and range of encounter location depth (m), and the median and range shore distance (km), the number (No.) of photos and biopsy samples collected, towed array acoustic detections, and single-species acoustic recordings. Species are listed in order of frequency of occurrence. Groups not identified to species are shown in gray. Median values are reported only for species with 3 or more encounters.

Species	Total Encounters (S/N)	Median (range) Grp. Size	Median (range) Depth (m)	Median (range) Shore Distance (km)	No. Photos	No. Biopsy Samples	No. Towed Array Acoustic Detections	No. Single Species Acoustic Recordings
Bryde's whale	10 (6/4)	2 (1–4)	3,044 (1,045–4,295)	177 (24–302)	1,905	2	0	10†
Pantropical spotted dolphin	9 (7/2)	27 (13–112)	3,621 (93–3,935)	58 (4.6–188)	242	8	7	6
Spinner dolphin	7* (3/3)	10 (1–62)	3,805 (17–4,237)	93 (0.2–112)	360	0	4	4
Short-finned pilot whale	3/3	27 (17–41)	2,544 (93–4,476)	94 (1.6–221)	2,273	2	6	3
Bottlenose dolphin	4* (2/1)	5 (2–24)	2,207 (17–4,476)	192 (0.2–262)	237	4	3	1
Rough-toothed dolphin	3 (1/2)	12 (7–13)	2,210 (1,084–4,163)	120 (3.4–227)	348	0	3	3
Sperm whale	2 (1/1)	– (3–13)	– (2,166–4,276)	– (29–157)	0	0	2	2
Cuvier's beaked whale	1 (1/–)	2	3,517	226	90	0	0	0
Dwarf sperm whale	1 (1/–)	1	1,854	267	0	0	0	0

Species	Total Encounters (S/N)	Median (range) Grp. Size	Median (range) Depth (m)	Median (range) Shore Distance (km)	No. Photos	No. Biopsy Samples	No. Towed Array Acoustic Detections	No. Single Species Acoustic Recordings
Melon-headed whale	1 (1/–)	399	2,054	258	903	4	1	1
Pygmy killer whale	1 (1/–)	22	3,956	219	345	0	1	1
Risso's dolphin	1 (1/–)	8	3,751	92	13	0	1	1
Striped dolphin	1 (1/–)	20	3,904	58	97	0	0	0
Sei/Bryde's whale	2 (1/1)	1	– (1,754–4,067)	– (200–206)	3	0	0	1†
Pygmy/dwarf sperm whale	1 (1/–)	1	4,211	117	0	0	0	0
Unid. small dolphin	7 (4/3)	17 (6–50)	2,330 (87–3,734)	39 (10–276)	0	0	2	-
Unid. dolphin	3 (3/–)	5 (4–5)	3,497 (3,068–4,278)	183 (84–294)	0	0	1	1
Unid. large whale / rorqual	6 (2/4)	1	1,840 (1,369–3,605)	44 (14–200)	0	0	0	1†
Unid. small whale	2 (2/–)	– (2–80)	– (3,035–3,714)	– (196–291)	0	0	0	0
Unid. cetacean	1 (1/–)	1	3,949	41	0	0	0	0
Total	69 (43/24)				6,816	20	31	35

*Includes 1 small-boat-only sighting. †Sonobuoy detections and recordings.

Table 5. Summary of Drifting Acoustic Spar Buoy Recorder (DASBR) deployments during the 2018 Mariana Archipelago Cetacean Survey (MACS) including the deployment location (latitude/ longitude), deployment date/time (UTC), recording end date/time (UTC) and the duration of the recording.

	Deployment			Recording	
DASBR ID	Latitude	Longitude	Time (UTC)	Recorder End Time (UTC)	Recording Duration (hh:mm)
DS1	13.596	144.427	7/9/2018 08:13	7/20/2018 08:55	264:41
DS2	14.897	145.132	7/9/2018 18:10	7/20/2018 21:00	266:49
DS3	16.292	145.545	7/11/2018 12:14	7/22/2018 23:40	275:25
DS4	17.260	145.398	7/12/2018 14:34	7/24/2018 06:25	279:50
DS5	16.984	144.380	7/14/2018 16:12	7/22/2018 21:23	197:10
DS6	16.172	144.474	7/15/2018 06:47	7/23/2018 20:59	206:11
DS7	13.236	144.357	7/18/2018 09:12	7/27/2018 02:44	209:32
DS8	15.583	144.979	7/21/2018 09:04	7/25/2018 20:10	107:06

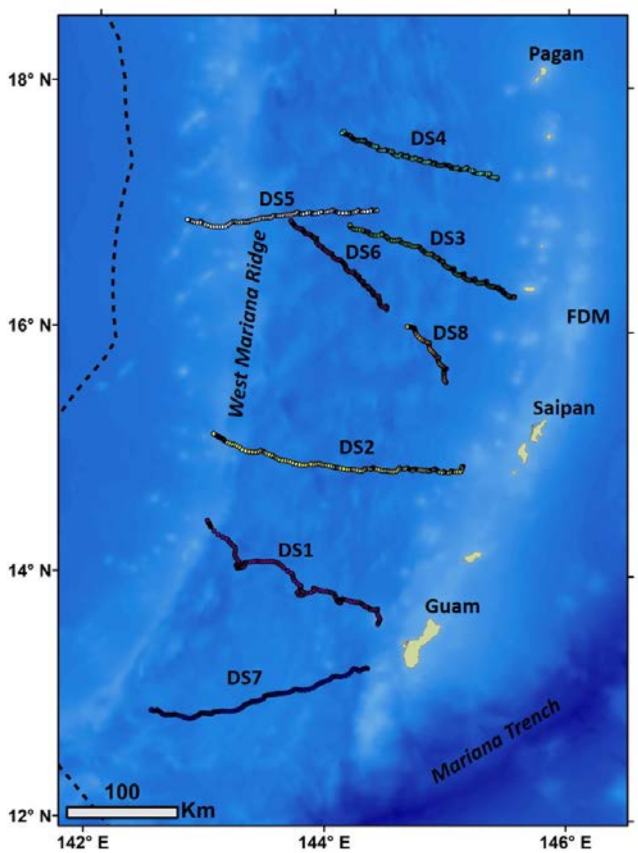

Figure 6. Drifting Acoustic Spar Buoy Recorder tracks during the 2018 Mariana Archipelago Cetacean Survey. Dashed black line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone.

Long-term passive acoustic monitoring

In addition to opportunistic recordings obtained during small-boat surveys and towed array or DASBR recordings collected during MACS 2015 and 2018, PIFSC has maintained 3 long-term passive acoustic monitoring sites within the Mariana Archipelago as part of the Pacific Islands Passive Acoustic Network (PIPAN). Monitoring sites at Saipan and Tinian have been occupied since 2010 and 2011, respectively, and at Pagan for 2 years from 2015 to 2017. The Pagan site was re-occupied in summer 2018. High-Frequency Acoustic Recording Packages sampling at 200 kHz were deployed at each site annually and provided cetacean and noise data from 10 Hz to 100 kHz. All recordings were duty-cycled to maintain recording for the full year, though the length of the off-period of the duty cycle was reduced over time as battery life increased. Several analyses have been conducted with the PIPAN data including examination of baleen whale occurrence, beaked whale occurrence, and other species or time-specific analyses. Acoustic analysis methods for each species or call type have been described in detail in relevant reports cited for each species and are not repeated here. Insights into species occurrence, distribution, and seasonality from the PIPAN data are incorporated into the species summaries below.

Species Summaries

The following species summaries are listed in order of frequency of species occurrence across all PIFSC surveys of the Mariana Archipelago (2010–2019) (Table S3), and include information on species encountered during other vessel surveys since 2010 funded by the U.S. Department of Defense (Table S4). A special case is the humpback whale, which is listed last because it occurs only seasonally in the Mariana Archipelago during “winter” months (December–April).

Available data and analyses to date are summarized by species (with beaked whale species combined). Species summaries include a discussion of what is known or may be assessed with available data relative to population structure, abundance, distribution and habitat use, and exposure to human stressors. Known potential human stressors include activities by the U.S. and cooperating Navies (e.g., sonar, underwater explosives detonations), fisheries interactions, vessel strikes, and dolphin-directed tourism. There are three nearshore U.S. Navy training areas off Guam where underwater detonations and explosive ordnance use occur, all near Apra Harbor and in water depths between 38 m and 1,750 m (Figure S3). Dolphin–directed tourism activities have been observed off Guam, particularly within and just outside of bays along the west coast (e.g., Tumon, Piti, Hagatna, Agat).

Spinner Dolphin

Spinner dolphins were the most frequently sighted species during PIFSC surveys (n = 180) (Figure 7, Table S3). On 3 occasions spinner dolphins were seen with other species including bottlenose dolphins, rough-toothed dolphins, and humpback whales. Spinner dolphin group sizes ranged from 1 to 135 individuals (median = 29). A total of 46,721 photos, 113 biopsy samples, and 13 acoustic recordings have been collected (Table S3).

The spinner dolphin photo-identification catalog currently includes encounters from 2010 to 2013 and contains 307 individuals from 91 encounters off Saipan, Tinian, Aguijan, Rota, and Guam. Forty-three percent of individuals have been seen in more than one year. There are no matches between Guam and the other islands, but there are re-sights between Rota and the 3-Islands area of Saipan, Tinian, and Aguijan. Photos collected during 45 encounters since 2013 have gone through initial processing, matching, and checking, and await grading and cataloging before they can be used in further analyses. Through 2013, the cumulative number of distinctive individuals is still increasing relative to the cumulative number of individuals sighted over all years (Figure 8), indicating that the photo-identification catalog is still growing steadily.

To date, 95 biopsy samples collected during small-boat surveys off Saipan (*n* = 43), Tinian (*n* = 6), Aguijan (*n* = 8), Rota (*n* = 11), and Guam (*n* = 27) have been genetically sexed and sequenced at the mitochondrial control region by SWFSC (Martien et al. 2014a). These samples represent 41 females, 53 males, and 1 dolphin of unknown sex. Twenty-four haplotypes were identified from 93 samples, with 11 of those known from the Central Pacific (Oremus et al. 2007; Andrews et al. 2010). Martien et al. (2014) found that Mariana Archipelago spinner dolphins are not evolutionarily distinct from other Pacific populations and concluded that a larger sample size, sampling from the northern islands, or microsatellites may reveal genetic population structure. OSU conducted an analysis of 18 microsatellite loci from 76 spinner dolphin samples and found weak but significant differentiation between Guam and the 3-Islands area/Rota (Table S5). There are 17 samples from the northern Mariana Archipelago and 6 samples from Guam for which processing by SWFSC is planned.

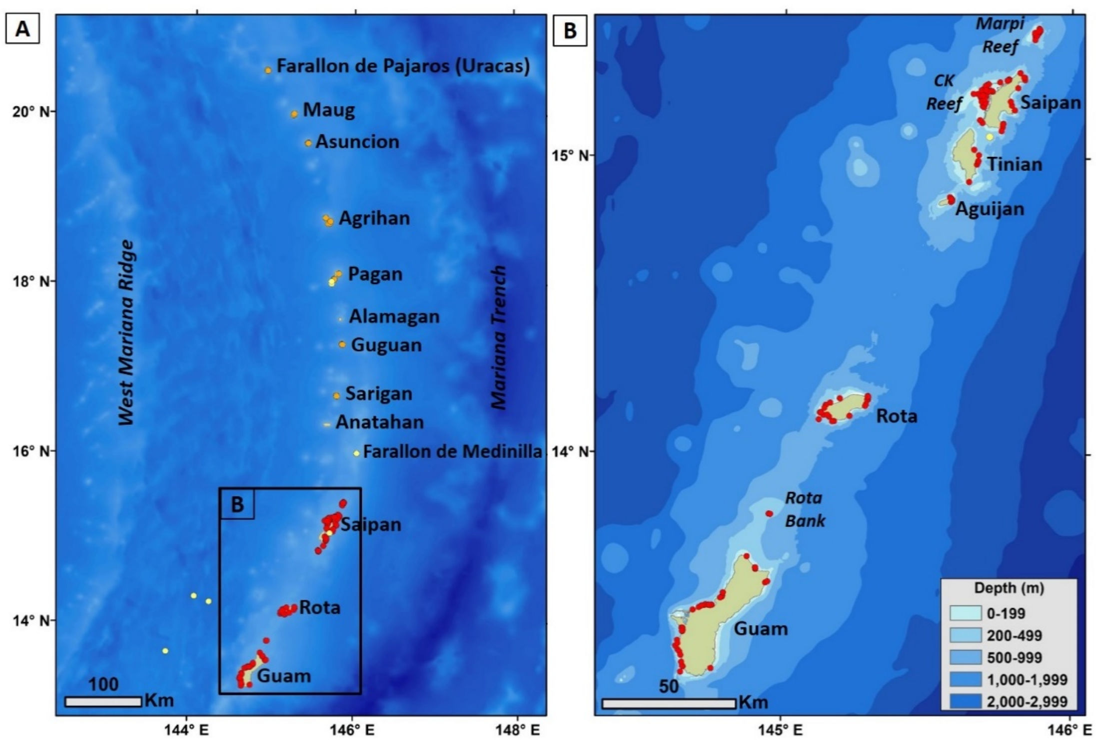

Figure 7. Spinner dolphin encounters during the Pacific Islands Fisheries Science Center surveys. Panel A – spinner dolphin encounters across the archipelago during the 2010–2019 small-boat surveys (red dots) and the Mariana Archipelago Cetacean Surveys in 2015 (orange dots) and 2018 (yellow dots). Panel B – spinner dolphin encounters in the southern portion of the archipelago (Guam to Saipan).

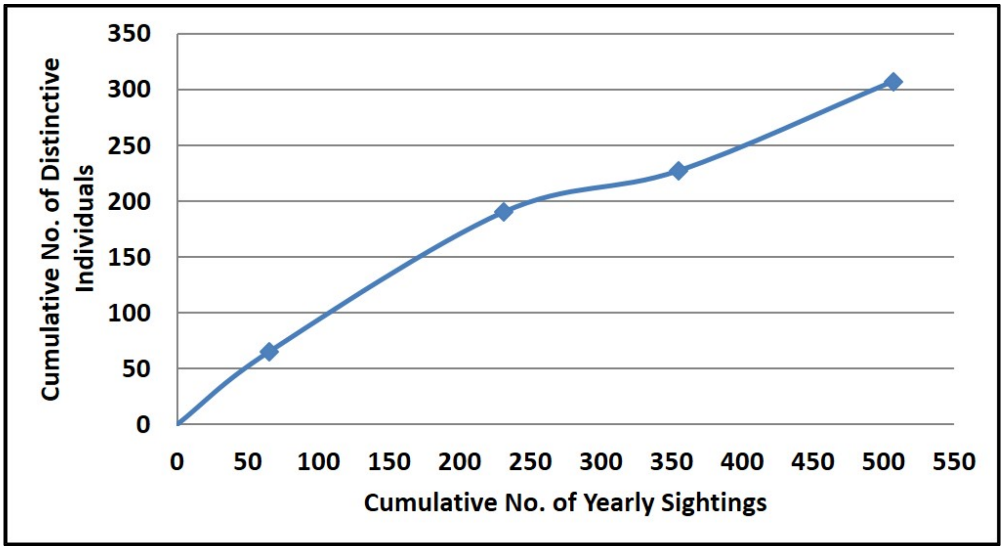

Figure 8. The cumulative number of individual spinner dolphins sighted over all years (2010–2013, with each year represented as a point) versus the cumulative number of distinctive individuals.

Population Structure

The photo-identification and genetic data together appear to support designation of 2 demographically-independent populations, 1 that includes the 3-Islands area and Rota and the other around Guam. Such designation would be supported by significant microsatellite genetic differentiation between these regions and the lack of photo-identification matches, suggesting lack of movement between Guam and the Rota/3-Islands area. Photo-identification cataloging of the remaining photos since 2013 should be concluded before such a designation is finalized. Processing of existing identification photos and samples from the northern islands, while a small sample, may be adequate to suggest a northern boundary for a putative Rota/3-Islands group, as well as for other island-associated populations further north. Three sightings of spinner dolphins in offshore waters during MACS 2018 suggest a pelagic population is also likely within this region. Additional biopsy sampling off Guam, the northern islands, and offshore is recommended due to the smaller number of samples collected from those areas.

Abundance

Given the high percentage of photo-identified individuals that have been seen in more than 1 year, mark-recapture abundance estimation for populations around southern islands of the archipelago is promising. More than 50% of cataloged individuals off Guam and more than 36% of cataloged individuals off Rota and the 3-Islands area were photographed in multiple years. Before proceeding, photo cataloging through 2018 should be completed and population structure within the southern islands resolved.

Distribution and Habitat Use

PIFSC surveys suggest spinner dolphins are primarily island-associated year-round. Spinner dolphins were seen in all months with survey effort and at most islands within the Mariana

Archipelago, as well as at some offshore reefs (e.g., Rota Bank, Chalan Kanoa (CK) Reef, Marpi Reef) (Figure 7). With the exception of encounters at offshore reefs and 3 encounters within the Mariana Trough (>100 km from shore and in water depths >3,800 m), most of the spinner dolphin encounters were within 1 km from shore (median = 0.6 km) where water depths were less than 100 m (median = 44 m) (Table S3).

Of particular interest is the repeated use of areas by spinner dolphins that are atypical from what is observed in other locations around the tropical Pacific. Spinner dolphins in Hawai‘i and French Polynesia are found in calm, sheltered locations (typically bays) during the day (Norris et al. 1994; Poole 1995). While some spinner dolphins do follow this pattern off Guam and the west side of Saipan, others are regularly encountered in both winter and summer at Marpi Reef, 18 km north of Saipan and fully exposed to wind and swell. Spinner dolphins also use areas where currents and swell backwash off cliff faces and create extremely dynamic conditions, as was seen at all northern islands during MACS 2015 and at Pagan and FDM during MACS 2018.

Martin et al. (2016) examined the nearshore distribution of “small cetacean” sightings around Guam from 1963 to 2012 based on aerial surveys conducted semimonthly by the Guam Department of Agriculture Division of Aquatic and Wildlife Resources (DAWR). Based on notes provided by the survey teams and discussion with the surveyors, the authors suggested that the vast majority of the small cetacean sightings were spinner dolphins. The highest density of small cetacean sightings was along the southwestern coast from Facpi Pt. to the west edge of Cocos Lagoon and on the east side from Pago Bay to Pati Pt., though dolphins were seen in all 12 geographic zones except inside of Cocos Lagoon, on the east side from Talofofo Bay to Pago Bay, and on the west side inside of Agana Bay and Apra Harbor (see Figure 4 in Martin et al. 2016).

Exposure to Human-caused Stressors

There have been no spinner dolphin encounters within 4 km of any of the U.S. Navy underwater detonation sites off Guam; however, photo-identification matches between encounters demonstrate that individuals move between northern and southern locations along the west side of Guam and could pass through these areas, particularly at the Piti Mine Neutralization Area (Figure S3).

The regular occurrence of spinner dolphins in the coastal waters and bays off Guam make them easy targets for the tourism industry. Such activities have the potential to affect spinner dolphins by displacing them from preferred habitat, leading to shorter resting periods as has been observed in Hawaiian waters (Delfour 2007, Ostman-Lind 2008, Courbis and Timmel 2009). The long-term effects of such disturbance could be a reduction in the overall health and abundance of individuals in the population (e.g., Tyne et al. 2014).

Pantropical Spotted Dolphin

Pantropical spotted dolphins were the second most frequently sighted species (n = 62) during PIFSC surveys (Figure 9, Table S3). They were seen mixed with bottlenose dolphins during 2 encounters and with sperm whales during a single encounter. Pantropical spotted dolphin group sizes ranged from 4 to 145 animals (median = 35). A total of 12,718 photos, 70 biopsy samples, and 7 acoustic recordings were collected, and 1 satellite tag was deployed (Table S3).

Pantropical spotted dolphin photos collected off Guam (2010–2014) were analyzed to assess whether it would be worthwhile to create a photo-identification catalog for the purpose of mark-recapture abundance estimation. Twelve group encounters from Guam were evaluated. On average, only 30% of discernible individuals in a group had fin photos of sufficient quality. The combination of spotted dolphin behavior (moving rapidly and creating water spray) coupled with poor sea conditions during many encounters resulted in poor quality photos with dorsal fins being partially obscured by water. Within the subset of individuals with usable fin photos, only about 30% were adequately marked to be included in a photo-identification catalog. The likelihood of re-sighting marked individuals was assessed by comparing 21 very distinctive fins across encounters with the assumption that all individuals (very distinctive and less distinctive) would have the same re-sight potential. Of that group, 2 individuals were re-sighted. Given the combination of poor photo quality, low proportion of marked individuals, and low re-sight potential, the creation of a photo-identification catalog for pantropical spotted dolphins was not pursued.

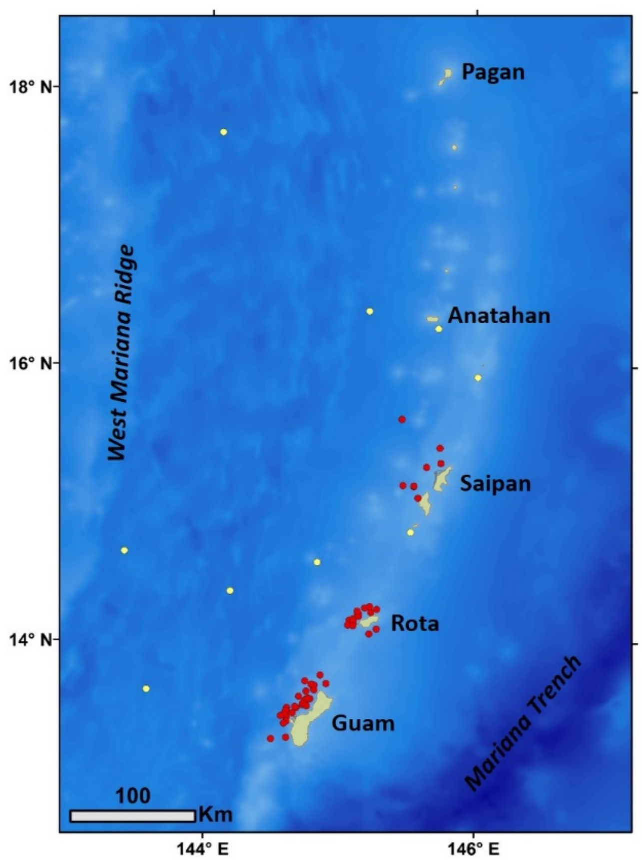

Figure 9. Pantropical spotted dolphin encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the 2018 Mariana Archipelago Cetacean Survey (yellow dots).

There were 62 biopsy samples collected from pantropical spotted dolphins in the southern portion of the Mariana Archipelago since 2010 (Table 1; Saipan, $n = 6$; Tinian, $n = 7$; Rota, $n = 21$; Guam, $n = 28$) and 8 samples collected during MACS 2018 (Table 4) off FDM ($n = 1$) and Anatahan ($n = 7$). OSU has processed 54 southern islands samples, including mtDNA sequencing and genotyping at 12 microsatellite loci. Both data sets showed significant differentiation between Guam and Rota (Table S6). No differentiation was found between the 3-Islands and Guam or Rota, which may have been related to sample size. Pantropical spotted dolphins from the Mariana Archipelago are significantly differentiated from those in Hawai‘i, the Marquesas, and the Solomon Islands (the only other areas with sufficient sample size) (Table S7, Baker 2015).

A single location-only satellite tag was deployed on a pantropical spotted dolphin off Guam in June 2016 (Table 2, Figure 10). The tag transmitted for 11 d during which the dolphin spent most of the time off the west side of the island.

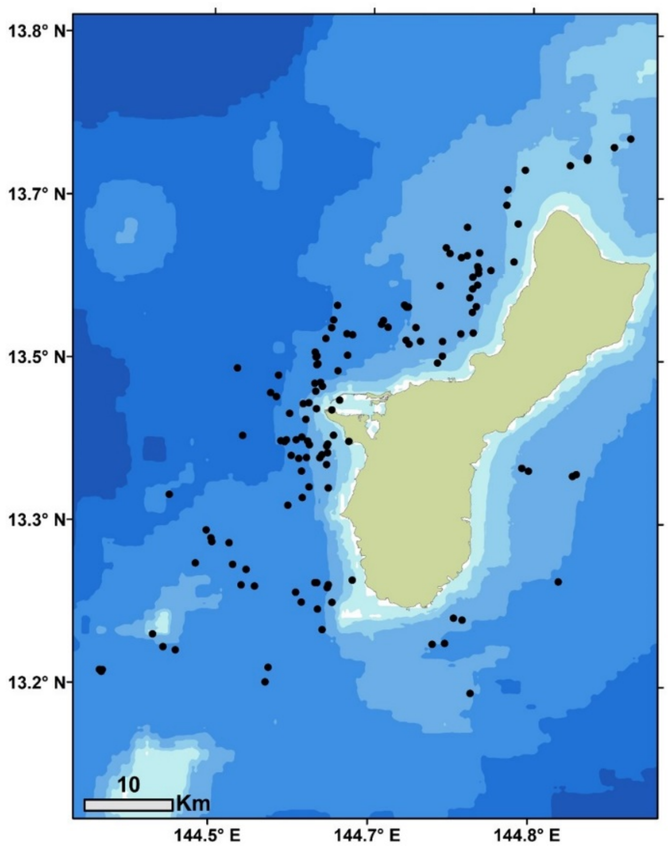

Figure 10. Satellite telemetry locations from a tag deployed on a pantropical spotted dolphin in June 2016 off Guam during the Pacific Islands Fisheries Science Center small-boat surveys. Tag duration was 11 d.

Population Structure

There are not enough data on pantropical spotted dolphin genetics or movements to assess population structure at this time. Significant differentiation in the mitochondrial DNA (mtDNA) sequences and microsatellite loci between Guam and Rota do suggest there may be structure within the archipelago, though a larger genetic sample size or corroborating data from another line of evidence (e.g., photo-ID or movement data) are needed to confirm that spotted dolphins at these 2 islands represent separate demographically independent populations.

Abundance

Analysis of pantropical spotted dolphin photo quality, distinctiveness, and re-sighting rates suggest that development of a photo-identification catalog is not worthwhile at this time and as such, pursuit of mark-recapture abundance estimation is infeasible. Pantropical spotted dolphin abundance will likely be better assessed using larger-scale line-transect surveys that can provide assessment of the broader distribution of spotted dolphins and their archipelago-wide abundance.

Distribution and Habitat Use

Encounter data demonstrate that pantropical spotted dolphins are distributed in offshore and nearshore areas. During PIFSC surveys, pantropical spotted dolphins were encountered off all of the southernmost islands (Guam to Saipan), as well as off FDM and Anatahan, and offshore as far west as the West Mariana Ridge (Figure 9). Encounters were 1.7–128 km from shore in a broad range of depths (93–3,935 m) (Table S3). Pantropical spotted dolphins were the most frequently sighted small dolphin during MISTCS (Fulling et al. 2011), with 15 of 17 encounters in offshore areas (6 outside of the EEZ) and few encounters associated with significant bathymetric features (3 over the west Mariana Ridge and 1 over the Mariana Trench) (Figure S1). Fulling et al. (2011) reported depths 114–5,672 m for pantropical spotted dolphin encounters (Table S1). The single location-only tag deployed off Guam (Figure 10) may offer some additional information on nearshore spatial use but is limited because of the short tag duration.

Exposure to human-caused stressors

Pantropical spotted dolphins do occur within U.S. Navy detonation areas off Guam, with 1 group encountered within 1 km from the Piti Floating Mine Neutralization Area, and the single satellite tagged animal passing within 0.6 km of the Agat Bay UNDET Area and within 0.3 km of the Outer Apra Harbor UNDET Area (Figure S3).

Off the west side of Guam, pantropical spotted dolphins were encountered repeatedly near fish aggregating devices (FADs); specifically, FAD-1 and FAD-2. When assessing the Mariana Archipelago spotted dolphin photos for suitability for photo-identification, some dolphins were found to have signs of fisheries interactions with dorsal fin or peduncle scarring that is characteristic of fishing line entanglement (Figure S4; e.g., Baird & Gorgone 2005; Kiska et al. 2008; Baird et al. 2015). To estimate the proportion of individuals with entanglement scars, a full assessment of the existing pantropical spotted dolphin photos would be necessary.

Bottlenose Dolphin

There were 47 bottlenose dolphin encounters during PIFSC surveys (Figure 11, Table S3). Bottlenose dolphins were encountered multiple times in mixed-species groups and were seen with short-finned pilot whales (*n* = 6), false killer whales (*n* = 3), rough-toothed dolphins (*n* = 5), spinner dolphins (n = 3), pantropical spotted dolphins (n = 2), and humpback whales (n = 1). Group sizes of bottlenose dolphins ranged from 1–27 individuals (median = 8). A total of 8,467 photos, 43 biopsy samples, and 4 acoustic recordings were collected, and 6 satellite tags were deployed during bottlenose dolphin encounters (Table S3).

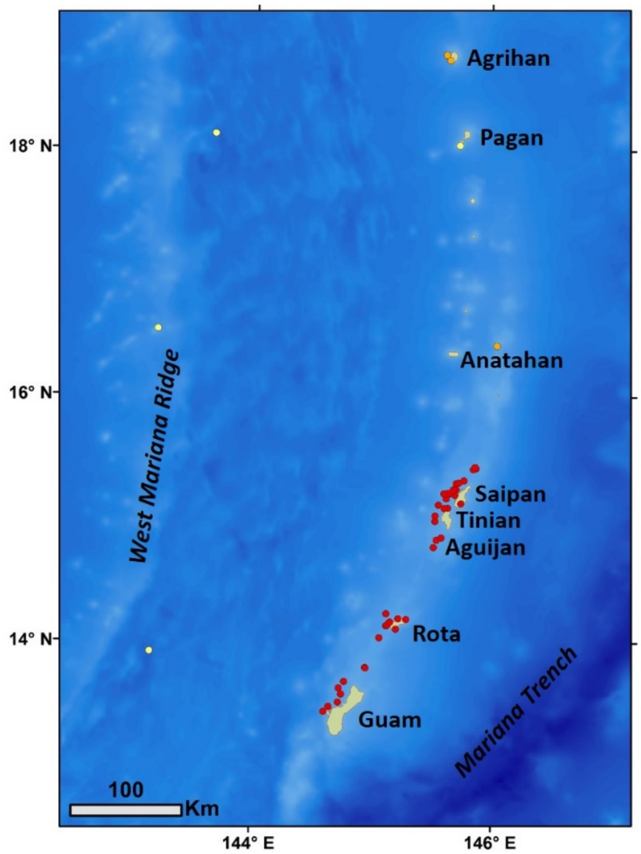

Figure 11. Bottlenose dolphin encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the Mariana Archipelago Cetacean Surveys in 2015 (orange dots) and 2018 (yellow dots).

The bottlenose dolphin photo-identification catalog currently includes photos collected from 2010 through 2016 by PIFSC and Navy contractors and contains 61 individuals from 32 encounters off Saipan, Tinian, Aguijan, Rota, and Guam (Table 1, Table S4). Of these individuals, 62% were seen in more than 1 year and 41% were seen in 3 or more years. There were re-sights among all islands. The cumulative number of distinctive individuals is starting to level off relative to the cumulative number of individuals sighted across all years (Figure 12), indicating that the growth of the photo-identification catalog is slowing. Photos from MACS 2015 and small-boat surveys in 2017 and 2018 have undergone initial processing and matching, but individuals are not yet cataloged. Photos from 2 encounters outside of the Guam and CNMI EEZ collected during MISTCS in 2007 (Fulling et al. 2011) and from 1 encounter off Pagan in 2013 (TetraTech 2014) (Table S4) have revealed no matches to other regions.

Fifteen biopsy samples collected from bottlenose dolphins from 2011 to 2013 (Saipan, n = 7; Tinian, n = 1; Aguijan, n = 1; Rota, n = 3; Guam, n = 3) were genetically sexed and sequenced at the mitochondrial control region (Martien et al. 2014a). SWFSC will process the remaining 22 biopsy samples collected during PIFSC small-boat surveys, 2 samples collected from Agrihan and offshore of Anatahan during MACS 2015, and 4 samples collected from Pagan and offshore locations during MACS 2018.

Of the 15 bottlenose dolphin biopsy samples that have been processed, there were 10 males, 4 females, and 1 dolphin of unknown sex. Four haplotypes were identified, including the Lh1 haplotype that most closely matches a haplotype from Fraser's dolphins sampled in the Philippines (Martien et al. 2014a). Comparing the nuclear microsatellite genotypes of the Mariana Archipelago samples to those of 'pure' bottlenose dolphins and Fraser's dolphins revealed that all 15 Mariana Archipelago samples exhibited evidence of Fraser's dolphin ancestry, with individuals deriving on average 14% of their nuclear ancestry from Fraser's dolphins. Evidence of nuclear introgression in all processed Mariana bottlenose dolphin samples, together with evidence of a single Fraser's dolphin haplotype among all samples, suggests that there was a single hybridization event far enough in the past to allow Fraser's dolphin nuclear DNA to permeate the population. The Mariana Archipelago samples exhibited low genetic diversity compared to other bottlenose dolphin populations, suggesting that they represent a small, demographically independent population.

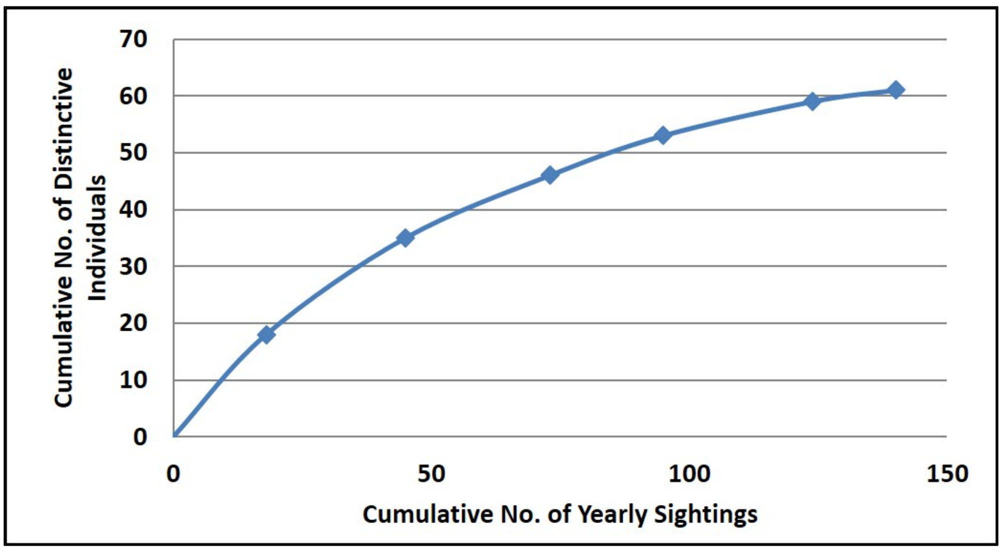

Figure 12. The cumulative number of individual bottlenose dolphins sighted over all years (2011–2016, with each year represented as a point) versus the cumulative number of distinctive individuals.

Satellite tags were deployed on 6 bottlenose dolphins (4 location-only, 2 location-depth) during PIFSC small-boat surveys (2013–2015, 2017) (Table 2, Figure 13). Five of 6 satellite tags were deployed within the 3-Islands area and the dolphins primarily stayed within the area, however 2 went north to East Diamante Seamount west of FDM and a third individual went almost as far north as Sarigan. A single tag was deployed on a male bottlenose dolphin off Rota in 2015 (tag ID 141720). During the 10-d duration of the tag, he traveled between Rota and Guam. The same individual had been previously tagged off Saipan in 2013 (tag ID 128898), and did not leave the 3-Islands area during the 9 d tag transmission (Figure 13).

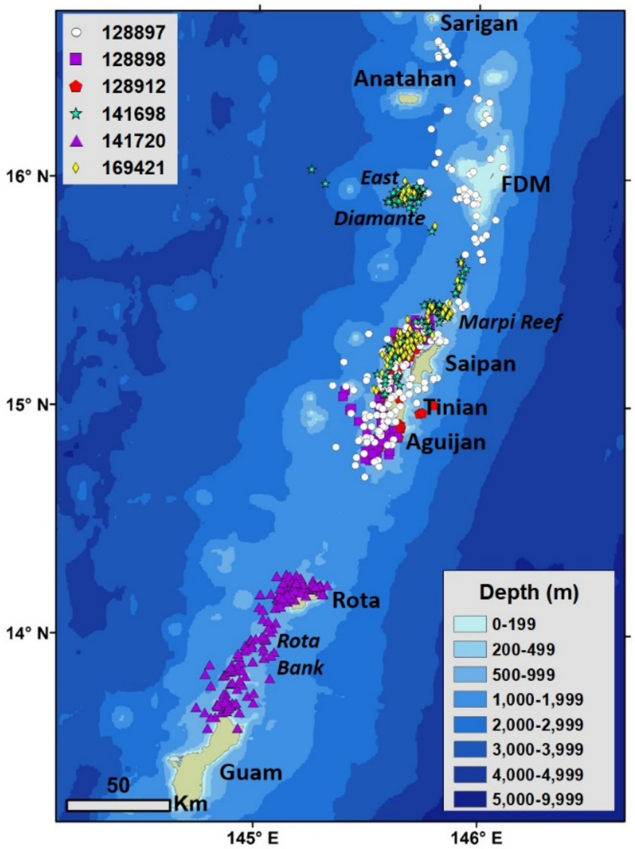

Figure 13. Satellite telemetry locations from tags (displayed by tag ID) deployed on bottlenose dolphins during the Pacific Islands Fisheries Science Center small-boat surveys (2013–2017). Tag durations ranged 4–21 d.

Population Structure

Available genetic analyses, photo-identification, and satellite telemetry data do not provide evidence of population structure within bottlenose dolphins in the southern Mariana Archipelago. It is unlikely that sequencing the remaining 22 biopsy samples from the southern islands alone would contribute significant new information toward examination of population structure, given that the existing genetic data set likely already contains a large fraction of the total population from the southern islands. Collection and analysis of available samples from dolphins in the northern islands and offshore would be valuable for assessing structure more broadly within the region.

It is possible that Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) could occur within the Mariana Archipelago. None have been identified from the 15 processed samples to date. The remaining samples will be sequenced by SWFSC to determine if any of the dolphins are Indo-Pacific bottlenose dolphins.

Abundance

Abundance estimation using mark-recapture methods may be feasible. Although the bottlenose dolphin photo-identification catalog is small (n = 61 individuals), 62% of the individuals were seen in more than 1 year and 41% were seen in 3 or more years. Such an estimate would apply to the southern islands only. Bottlenose dolphin abundance throughout the archipelago may be better assessed using line-transect methods from a shipboard survey of the broader area.

Distribution and Habitat Use

Bottlenose dolphins were encountered during PIFSC surveys off all of the southernmost islands (Guam to Saipan), as well as off Anatahan, Pagan, and Agrihan in the north (Figure 11). They were also encountered in offshore waters of the West Mariana Ridge. PIFSC encounters ranged 0.2–262 km from shore and had water depths 17–4,476 m, but more than half had depths less than 200 m (Table S3). There were 5 encounters with bottlenose dolphins during MISTCS, all offshore with a range of depths 4,241–5,011 m, including 2 outside of the EEZ boundary (Table S1, Figure S1; Fulling et al. 2011).

Data from the satellite tags could be used to more fully characterize habitat use, including associations with islands, bathymetric features, and oceanographic conditions. Such an analysis would benefit from additional tag data, given the low number of tags (*n*=6) and relatively short tag durations for those deployments. Patterns or changes in space use of the individual tagged in multiple years may be informative. Two of the satellite tags deployed on bottlenose dolphins were location-depth tags and could be used to look at the dive behavior of the individuals, including geographic variation in dive depth.

Exposure to human-caused stressors

It is possible that bottlenose dolphins are exposed to underwater detonations off Guam. A group of bottlenose dolphins was seen approximately 1.2 km from the Piti Floating Mine Neutralization Area (Figure S3) in 2013, and the median depth of all small-boat bottlenose dolphin encounters overlaps that of 2 of the 3 detonation areas.

Short-finned Pilot Whale

Short-finned pilot whales were encountered 29 times during PIFSC surveys (Figure 14, Table S3). They were found in mixed-species groups during a third of the encounters, and were seen with bottlenose dolphins (n = 6), rough-toothed dolphins (n = 2), pantropical spotted dolphins (n = 1), and humpback whales (n = 1). Short-finned pilot whale group sizes ranged from 4 to 48 individuals (median = 30). A total of 23,726 photos, 113 biopsy samples, and 6 acoustic recordings were collected, and 23 satellite tags were deployed during short-finned pilot whale encounters (Table S3).

The photo-identification catalog for short-finned pilot whales includes all encounters during small-boat surveys through 2018 and contains 209 individuals from 26 encounters off Saipan, Tinian, Aguijan, Rota, and Guam including 2 encounters in 2011 and 2012 by HDR and 1 encounter during MISTCS (Table S4). The U.S. Navy contributed photos from 3 additional encounters during MISTCS. Although there were a few very distinctive fins, no matches were found in the existing catalog. The cumulative number of individuals sighted over all year versus the cumulative number of distinctive individuals appears to be leveling off (Figure 15). However, photos from 5 short-finned pilot whale encounters during MACS 2018 have been initially processed and only a small number of individuals matched to the existing catalog. Once new individuals are added to the catalog, the cumulative number of distinctive individuals will increase relative to the cumulative number of yearly sightings.

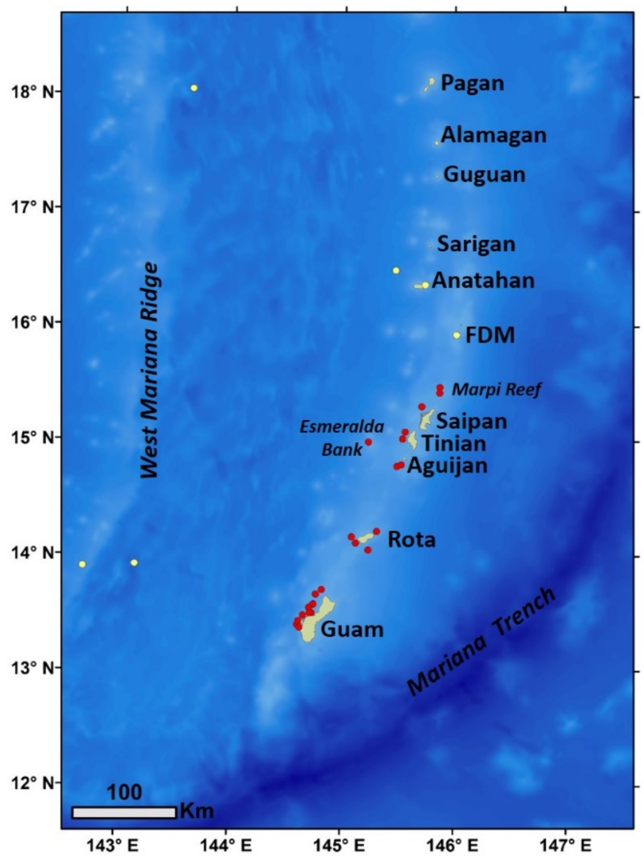

Figure 14. Short-finned pilot whale encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the 2018 Mariana Archipelago Cetacean Survey (yellow dots).

During 2011–2016, biopsy samples (n = 96) were collected from 81 individuals; 78 individuals sampled during the PIFSC small-boat surveys and 3 individuals sampled in 2012 by HDR operating under the PIFSC permit. These samples represent 43 females, 34 males, and 4 whales of unknown sex (Hill et al. 2018). Five haplotypes (A1, A2, C, 17, 18) were found, 2 of which are unique to the Mariana Archipelago (17 and 18) (Martien et al. 2014a; Hill et al. 2018). Haplotype A1 and A2 were identified based on the use of longer sequences (962 bp versus 345 bp) and when truncated were identical to haplotype A identified by Oremus et al. (2009).

Between 2013 and 2018, 23 satellite tags (16 location-only, 7 location-depth) were deployed on short-finned pilot whales during PIFSC small-boat surveys (Table 2, Figure 16). Seventeen tags were deployed off Guam and Rota in May–June 2013–2016. In February 2017, a single tag was deployed at Marpi Reef. In August 2018, 3 tags were deployed at Marpi Reef and 2 tags were deployed off Tinian.

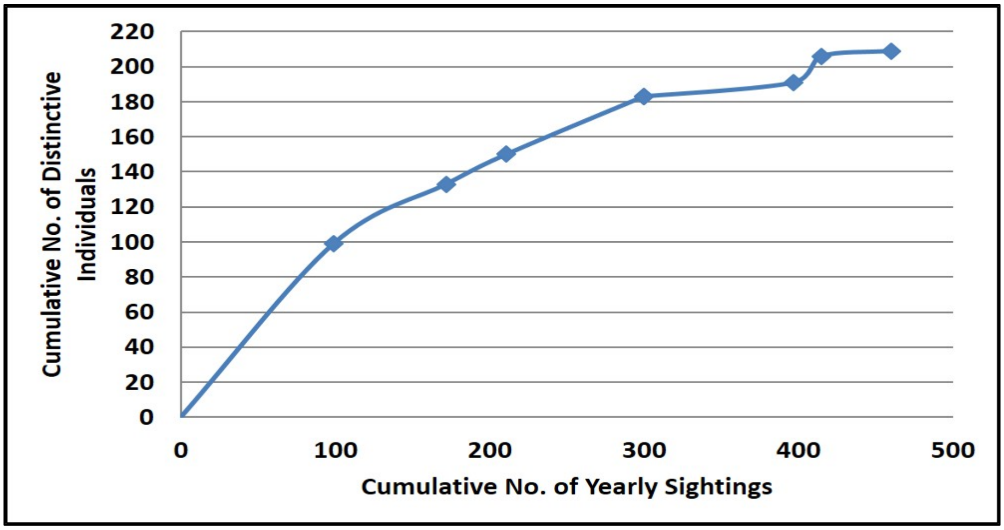

Figure 15. The cumulative number of individual short-finned pilot whales sighted over all years (2011–2014, 2016–2018, with each year represented as a point) versus the cumulative number of distinctive individuals.

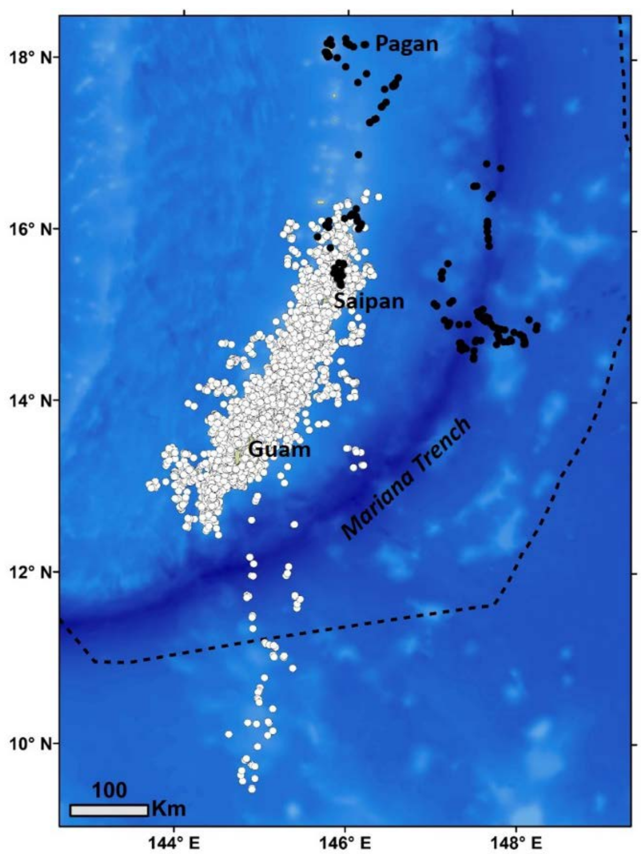

Figure 16. Satellite telemetry locations from 23 satellite tags deployed on short-finned pilot whales during the Pacific Islands Fisheries Science Center small-boat surveys (2013–2018). Tag durations ranged 7–235 d. All tags except 1 were deployed on individuals within the main social cluster (white dots). The only tag deployed in 2017 was on an individual outside of the main social cluster (black dots).

Population Structure

Photo-identification, satellite tag, and genetic data provide a complicated picture of potential population structure within short-finned pilot whales in the Mariana Archipelago. Photo-identification data through 2016 were used by Hill et al. (2018) to create a preliminary social network diagram for 196 individuals. The network diagram demonstrated that most of the photo-identified individuals were part of 1 main social cluster, while 3 other groups had been observed only once and were not connected.

Satellite tag data from the main social cluster also indicate a restricted home range within the southern portion of the archipelago and submerged reefs to the south. Hill et al. (2018) suggested that short-finned pilot whales in the Mariana Archipelago may be similar to other archipelagic populations in which some individuals are resident and island-associated, while others may be occasional visitors and have more offshore distributions. The collection of movement data since Hill et al. (2018) supports the potential for overlapping populations of short-finned pilot whales within the archipelago. A satellite tag was deployed on a short-finned pilot whale in February 2017 at Marpi Reef, with the resulting track demonstrating movements different from all previously tagged whales that belonged to the main social cluster (Figure 16). Over the 27 d duration of the tag, the whale traveled north to Pagan and then moved out over the Mariana Trench where it spent 12 days before the tag stopped transmitting. None of the whales at Marpi Reef in 2017 were connected to the main social cluster, although 3 individuals had been observed in 2012 off Aguijan.

Genetic analyses have focused primarily on a broader question of the relatedness of short-finned pilot whales in the Mariana Archipelago to those in other parts of the Pacific. Using mitogenomes and nuclear SNP loci, Van Cise et al. (2019) determined that there are two subspecies of short-finned pilot whales, which were termed Shiho and Naisa. Shiho short-finned pilot whales are found in the eastern Pacific Ocean and northern Japan. Naisa short-finned pilot whales are found throughout the Atlantic and Indian Oceans, as well as the central and western Pacific Ocean including the Mariana Archipelago.

Three mitochondrial haplotypes identified in Mariana Archipelago short-finned pilot whales are distributed broadly in the South Pacific, southeast Asia, the Indian Ocean, the western North Atlantic, and the Caribbean (Oremus et al. 2009; Téllez et al. 2014; Van Cise et al. 2016a; Morin et al. 2015), while 2 haplotypes appear to be unique to the region (Martien et al. 2014a), indicating that the Mariana Archipelago is an area of unusually high diversity. Within samples collected in the Mariana Archipelago, Martien et al. (2014a) found strong mitochondrial differentiation between short-finned pilot whales encountered in the waters off the 3-Islands area and those encountered off Rota and Guam, suggesting a lack of female-mediated gene flow between these island groups, although the differentiation between the areas may reflect familial or social structure rather than population differentiation (Martien et al. 2014a). No significant nuclear differentiation has yet been found between island groups in the Mariana Archipelago, suggesting that there is male-mediated gene flow between among sampled individuals, though lack of differentiation could be due to small sample size (Van Cise et al. 2016b).

In order to better assess the population structure of short-finned pilot whales in the Mariana Archipelago, samples from new groups and new areas (offshore and northern islands) are needed. An additional 12 biopsy samples from short-finned pilot whales will be analyzed by SWFSC, which includes 2 samples from offshore encounters during MACS 2018 and 1 sample from an encounter with a group on Marpi Reef in 2017 that is not part of the main social cluster.

Abundance

Photo-identification data from the main social cluster are adequate to conduct a mark-recapture analysis for an abundance estimation of short-finned pilot whales within that cluster. Of the 157 individuals in the photo-identification catalog that are part of the main social cluster, 127 (81%) were seen in more than 1 year and 62 (40%) were seen in 3 or more years.

Distribution and Habitat Use

Short-finned pilot whales are found in nearshore and offshore areas of the Mariana Archipelago, and were seen off each of the southernmost islands and nearby offshore locations including Marpi Reef and Esmeralda Bank during PIFSC surveys (Figure 14). They were also encountered off FDM and Anatahan and multiple times on the West Mariana Ridge. PIFSC encounters were 0.5–221 km from shore in a wide range of depths (51–4,476 m), although most were close to shore (median = 6.9 km) with a median depth of 724 m (Table S3). All but 1 of the 5 MISTCS encounters were offshore; including 1 that was south of Guam and outside of the EEZ boundary (Figure S1, Fulling et al. 2011).

Hill et al. (2018) used satellite telemetry data from short-finned pilot whales within the main social cluster from 2013 to 2016 to determine the home range, core area, and highest use area of the whales in summer months (June–August). They found that the highest use area was off the northwest side of Guam and extended north toward Rota. The home range of the whales spanned an area south of Santa Rosa Reef and north of FDM, and the core area centered on Guam and Rota, extending south to Santa Rosa Reef and north beyond Rota (see Figure 3 in Hill et al. 2018). Although individual whales made occasional longer distance trips away from the islands, including 1 that traveled 417 km south of Guam before returning to the Mariana Archipelago within 10 d, the telemetry data suggested that the tagged whales primarily associated with nearshore waters. More recent deployments, including 5 from August 2018 on individuals from the main social cluster, suggest the space use may have shifted in recent years. Whales tagged in 2018 spent all or most of their time off Saipan and Tinian, in contrast to the highest use areas originally identified off Guam and Rota in previous years. One short-finned pilot whale has been tagged twice, originally off Rota in 2014 and again off Marpi Reef in 2018, providing a limited data set to examine inter-annual variability in space use. Analysis of data from 5 location-depth tags deployed in 2014–2016 revealed that short-finned pilot whales were primarily diving to intermediate depths (101–499 m) at night. Hill et al. (2018) suggested that the whales may follow the deep scattering layer to feed. Two location–dive tags deployed in 2018 have not been similarly analyzed, but could be used to further examine diving behavior in Mariana Archipelago short-finned pilot whales.

Exposure to human stressors

Satellite telemetry data from short-finned pilot whales suggest they may be exposed to underwater explosive events at all three U.S. Navy sites off Guam (Figure S3). Telemetry locations fall within the exclusion zones for UNDET areas on days with scheduled detonation activities, as well as at other times without scheduled operations.

Mariana Archipelago short-finned pilot whales have shown signs of potential fisheries interactions, including dorsal fin scarring or mutilation (Figure S5) similar to that observed on false killer whales near Hawaiʻi (Baird & Gorgone 2005, Baird et al. 2015). Fishing activity within the archipelago has not been well characterized for assessing which fisheries are most likely to interact with short-finned pilot whales.

While the dolphin-directed tourism off Guam is primarily focused on spinner dolphins, tour vessels have been observed during short-finned pilot whale encounters outside of Agat Bay.

Beaked Whales

There were 19 encounters of beaked whales during PIFSC surveys (Figure 17, Table S3). Of these encounters, 6 were identified to species; 4 were Blainville's beaked whale and 2 were Cuvier's beaked whale. The remaining beaked whale sightings were recorded as *Mesoplodon* beaked whales (n = 10) or unidentified beaked whales (n = 3) due to insufficient view of the animals to confirm species identity. It may be possible to determine species for 1 *Mesoplodon* beaked whale sighting that was recorded on the towed array during MACS 2015, though the data processing has not yet been carried out. Beaked whale group sizes ranged from 1–5 individuals. A total of 890 photos, 1 biopsy sample, and 11 acoustic recordings were collected during beaked whale encounters (Table S3).

In addition to Blainville's and Cuvier's beaked whales, a group of Longman's beaked whales were acoustically detected on the hydrophone array but were not seen during MACS 2018. An automated click detector was run through the acoustic data collected during DASBR deployments. Detected clicks were then examined by an analyst to assign a species identification based on species-specific click characteristics. The number of detections was based on the positive identification of a beaked whale species within a 2-min analysis period. This approach resulted in 534 detections of 4 species of beaked whales (Table 6, Figure 18).

PIPAN data from Saipan, Tinian, Pagan, as well as from other sites in the central and western Pacific have been partially analyzed for beaked whale occurrence. Blainville's beaked whales are the most commonly detected beaked whale at all Mariana Archipelago PIPAN sites, though Cuvier's and the unidentified beaked whale currently known as the Cross Seamount beaked whale (BWC) have also been heard sporadically at all 3 locations (Figure 19; Baumann-Pickering et al. 2014, 2018; Oleson et al. 2015; Hill et al. 2015). Large differences in detection across the 3 monitoring locations, and especially at Tinian relative to the other 2 locations, may be due to the specific monitoring area, with the Tinian recorder deployed on a steep slope relatively close to the island, while the other 2 sites are on flatter seafloor further from the islands.

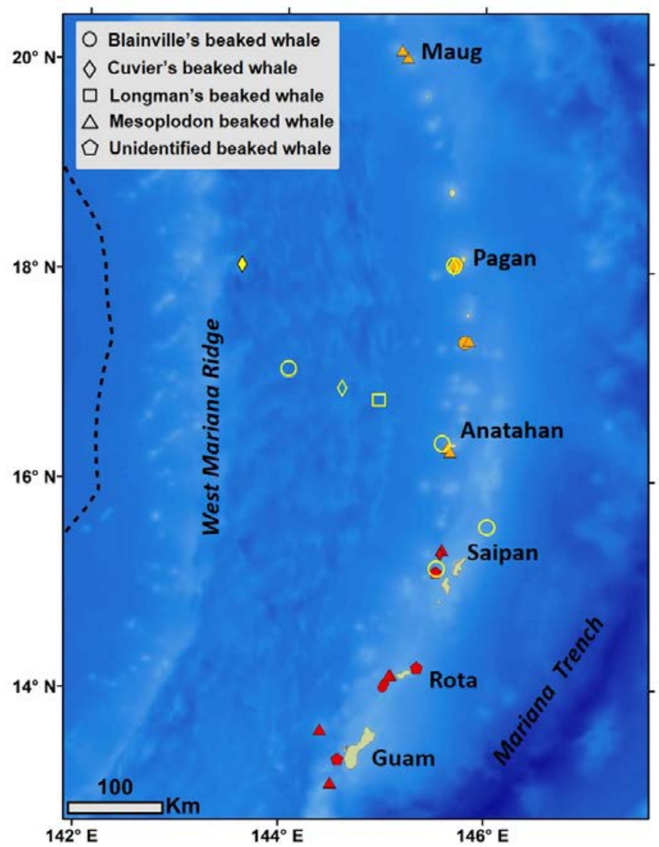

Figure 17. Beaked whale encounters by species during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red symbols) and the Mariana Archipelago Cetacean Surveys in 2015 (orange symbols) and 2018 (yellow symbols). Solid symbols represent visual encounters and hollow symbols represent acoustic-only detections of beaked whales on the towed array.

Table 6. Number of 2-min files with detections of beaked whales on Drifting Acoustic Spar Buoy Recorders deployed during the 2018 Mariana Archipelago Cetacean Survey.

Species	# Detections
Blainville's beaked whale	203
Cuvier's beaked whale	175
Longman's beaked whale	117
Cross Seamount beaked whale	37
Unidentified beaked whale	2

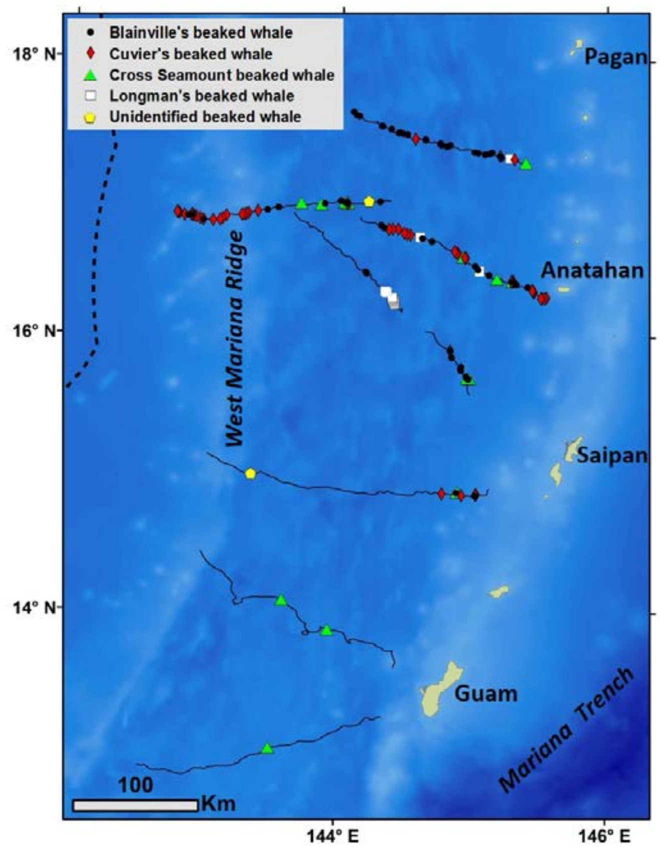

Figure 18. Drifting Acoustic Spar Buoy Recorder tracks (solid black lines) and acoustic detections of beaked whales during the 2018 Mariana Archipelago Cetacean Survey. Dashed black line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone.

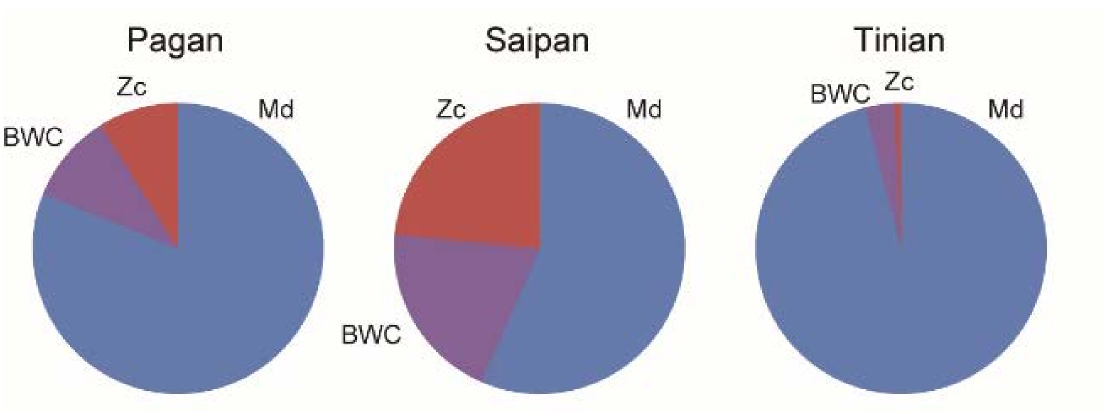

Figure 19. Relative frequency of occurrence of beaked whale species in the passive acoustic data from Pacific Islands Passive Acoustic Network sites from 2010 through 2017. BWC–Cross Seamount beaked whale; Zc–Cuvier's beaked whale; Md–Blainville's beaked whale.

Population structure

It is not possible to assess population structure of either Blainville's or Cuvier's beaked whales in the Mariana Archipelago with the available tissue samples or photographic data. Acoustic analysis of geographic variation in Blainville's beaked whale echolocation click characteristics suggests that while characters such as center frequency and inter-click interval are fairly stable across the species range, geographic variation in peak frequency is evident (Baumann-Pickering et al. 2018), though it is not yet clear if this variability is correlated with population boundaries or other ecological or behavioral factors, such as differences in prey choice or prey size.

Abundance

Beaked whale abundance may be best assessed acoustically using a combination of towed array and drifting acoustic sensors. Towed array data from MACS 2015 have not been processed to classify beaked whale encounters to species. DASBR data collected during MACS 2018 or future efforts across the entire EEZ may provide the best insights into distribution and abundance.

Distribution and Habitat Use

Beaked whales were encountered or acoustically detected throughout the archipelago from Guam to Maug, and in offshore waters within the Mariana Trough and out to the West Mariana Ridge (Figure 17, Figure 18). Most of the PIFSC beaked whale visual encounters were nearshore (median = 7.0 km from shore) with the exception of the Cuvier's beaked whale encounter during MACS 2018 that was greater than 225 km from shore near the West Mariana Ridge (Figure 17, Table S3). The median depth of PIFSC beaked whale encounters was 1,202 m (Table S3). During the DASBR deployments of MACS 2018, the highest number of beaked whale detections was along the 3 tracks north of Anatahan, with detections occurring through the Mariana Trough out to the West Mariana Ridge (Figure 18). Only a small number of beaked whales were detected within the Mariana Trough south of Saipan and the 2 southernmost DASBRs detected only Cross Seamount beaked whales. During MISTCS, there were 2 *Mesoplodon* beaked whale encounters that were on or near the West Mariana Ridge, and 1 unidentified beaked whale encounter that was close to Alamagan (Figure S1; Fulling et al. 2011). Depths of the MISTCS beaked whale encounters ranged from 2,122 to 3,984 m (Table S1, Fulling et al. 2011). There is no clear seasonality in the occurrence of any beaked whale species within the acoustic data, with detections of each species occurring year-round (Simonis et al. 2020).

Exposure to human stressors

Nine Cuvier's beaked whales have been found stranded on Guam, Rota, or Saipan since 2007. A stranding of 2 whales in August 2011, 1 on Guam in March 2015, and another on Guam in 2016 were temporally associated with use of military mid-frequency sonar (Simonis et al. 2020). Beaked whales are known to be sensitive to military sonar (e.g., Filadelpho et al. 2009; Tyack et al. 2011; DeRuiter et al. 2013), other high intensity anthropogenic sounds, including air guns and oceanographic echosounders (Cholewiak et al. 2017), and other sources (e.g., Carretta and Barlow 2011) in certain circumstances. Military sonar is infrequently detected at Mariana Archipelago PIPAN sites (Simonis et al. 2020), such that beaked whales in this region may be more likely to respond given their relative naiveté to the sound source. A randomization test relating stranding dates to dates of known military sonar use within the Mariana region suggested a less than 1% probability that 3 of the 8 strandings occurred within several days of sonar use by chance (Simonis et al. 2020). Follow on analysis by Navy using the full classified data set revealed many additional days of sonar use and accordingly, a higher probability (10%) that strandings were related to sonar usage based on chance alone.

Bryde's Whale

Bryde's whales were first encountered during PIFSC surveys in 2015 and were seen a total of 18 times over subsequent years (Figure 20, Table S3). Group sizes ranged from 1 to 4 individuals (median = 1). A total of 3,536 photos, 5 biopsy samples, and 12 acoustic recordings were collected during Bryde's whale encounters. "Biotwang" sounds (Neuikirk et al. 2016) were detected in association with at least 10 encounters, providing strong evidence that this sound type previously unassociated with a specific species is produced by Bryde's whales.

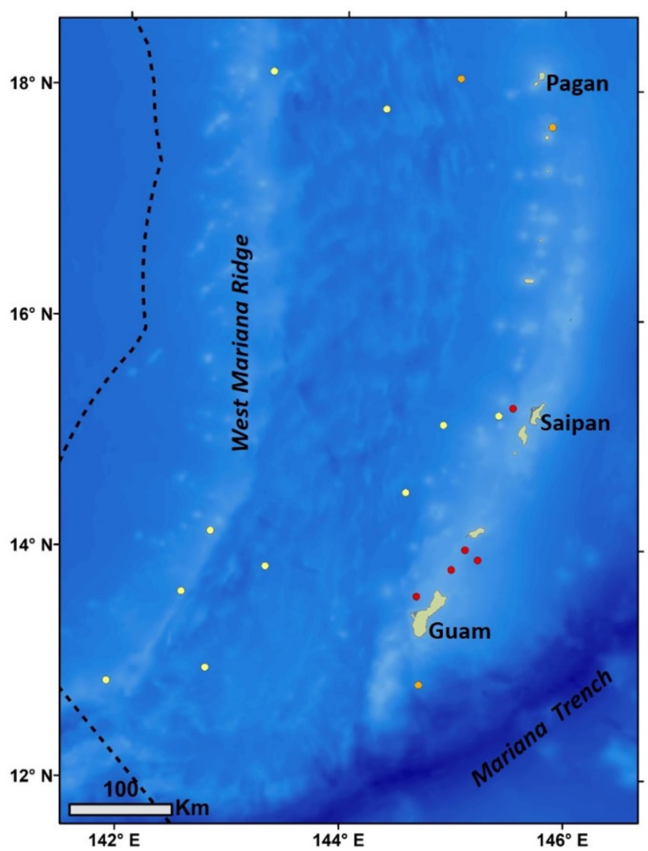

Figure 20. Bryde's whale encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the Mariana Archipelago Cetacean Surveys in 2015 (orange dots) and 2018 (yellow dots). Dashed black line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone.

A photo-identification catalog has not been created for Bryde's whales due to poor photo quality and lack of distinctive dorsal fins in the photos collected during small-boat surveys. Photos collected during 10 encounters from MACS 2018 (Table 4) and 10 encounters from MISTCS (Table S4) have not been processed.

Genetic analysis of the 3 Bryde's whale biopsy samples collected through 2016 revealed all to be males. Mitochondrial sequences from the biopsies were compared to data from a genetic study of Bryde's whales in the western Pacific and Indian Ocean (Kanda et al. 2007), with all 3 Mariana Archipelago whales sharing haplotypes detected in the earlier study. The 2 biopsy samples collected from Bryde's whales during MACS 2018 have not been processed.

Population structure

Identification of Bryde's whale call types in this region may provide an opportunity to assess the distribution of these whales in other regions, including within PIPAN sites at Hawaiʻi and Wake Atoll and within long-term acoustic monitoring locations in other parts of the western Pacific. Though not detected among the 3 biopsy samples collected during this study, it is possible that the recently-described Omura's whales (*Balaenoptera omurai*) may occur in the Mariana Archipelago, as its range is not yet fully described.

Abundance

Current population size of Bryde's whales will be best assessed using a large-scale ship-based survey of the broader region.

Distribution and Habitat Use

Bryde's whales were encountered near islands from Guam to Alamagan, as well as offshore within the Mariana Trough and on the West Mariana Ridge during PIFSC surveys (Figure 20). The PIFSC encounters had a broad range of distances from shore (9–302 km) and depths (487–4,295) (Table S3). Eight of 18 MISTCS encounters were south of the Mariana Trench and outside of the EEZ (Figure S1; Fulling et al. 2011). Eight of the remaining 10 MISTCS encounters that were within the EEZ boundary were far offshore. The MISTCS encounters with Bryde's whales generally occurred in areas of steep bathymetric relief including the West Mariana Ridge and the Mariana Trench where depths ranged from 2,549 to 7,373 m (Table S1, Figure S1; Fulling et al. 2011). During a PIFSC small-boat encounter at Rota Bank, the Bryde's whale was visibly skim feeding, but its prey could not be determined.

It is likely that Bryde's whales are in the Mariana Archipelago year-round. They were seen in all months of the January–April MISTCS survey (Fulling et al. 2011), in May during MACS 2015, in July during MACS 2018, and in August–September during small-boat surveys. Association of the biotwang with Bryde's whales will provide the capability to assess the seasonality and relative abundance of Bryde's whales at PIPAN sites, as well as the spatial distribution of animals heard on DASBRs during MACS 2018.

Exposure to human stressors

There are insufficient data to fully assess the exposure of Bryde's whales to human activities in the Mariana Archipelago, however during MACS 2018 a female (with a calf) was observed approximately 250 km west of Guam with a line tightly wrapped overtop of her blow hole causing deep abrasions (Figure S6). The extent of the entanglement and the source of the line could not be determined.

Rough-toothed Dolphin

Rough-toothed dolphins were encountered 16 times during PIFSC surveys (Figure 21, Table S3) and were found in mixed-species groups with bottlenose dolphins (*n* = 6), spinner dolphins (*n* = 1), and short-finned pilot whales (*n* = 2). Group sizes of rough-toothed dolphins ranged from 1 to 27 individuals (median = 12). A total of 3,371 photos, 10 biopsy samples, and 5 acoustic recordings have been collected, and 1 satellite tag deployed during rough-toothed dolphin encounters (Table S3).

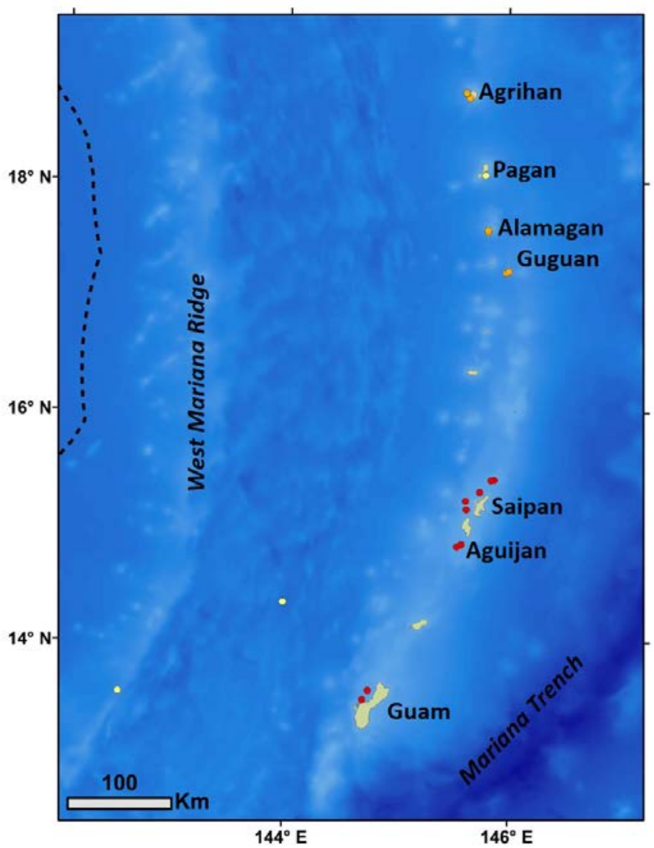

Figure 21. Rough-toothed dolphin encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the Mariana Archipelago Cetacean Surveys in 2015 (orange dots) and 2018 (yellow dots).

The current rough-toothed dolphin photo-identification catalog contains 7 individuals from 4 encounters between 2013 and 2016 off Saipan and Aguijan during PIFSC small-boat surveys. In addition, a single very distinctive individual photographed off Guam in 2016, and 7 distinctive individuals photographed off Guguan in 2015 did not match any of the individuals in the catalog. None were added to the photo-identification catalog because they did not meet the photo quality criteria. Photos from 3 additional MACS 2015 encounters, as well as those from 2018 small-boat encounters and MACS 2018 have not been fully processed.

A total of 10 biopsy samples were collected from rough-toothed dolphins during PIFSC surveys. Two of these samples have been processed and were both female with the same haplotype (KA_01), a haplotype common in animals sampled off Kaua‘i in the Hawaiian Archipelago. These samples were also included in an analysis of the worldwide phylogeography of rough-toothed dolphins conducted at OSU (Albertson et al. in prep). The analysis included both full mitochondrial genomes and nuclear introns to examine structure from the species level to the population level. The Mariana Archipelago samples were included in a western Pacific/Indian Ocean stratum. Albertson et al. (in prep) found significant differences in the metagenomes of the western Pacific/Indian Ocean stratum versus the central/eastern Pacific and Atlantic, but did not find significant nuclear differentiation. They did not examine structure within the Mariana Archipelago. The remaining 8 Mariana Archipelago samples will be analyzed by SWFSC.

A single location-only satellite tag was deployed on a rough-toothed dolphin off Aguijan in 2013. The tag transmitted for 12 d, during which the dolphin remained off the west sides of Saipan, Tinian, and Aguijan (Table 2, Figure 22).

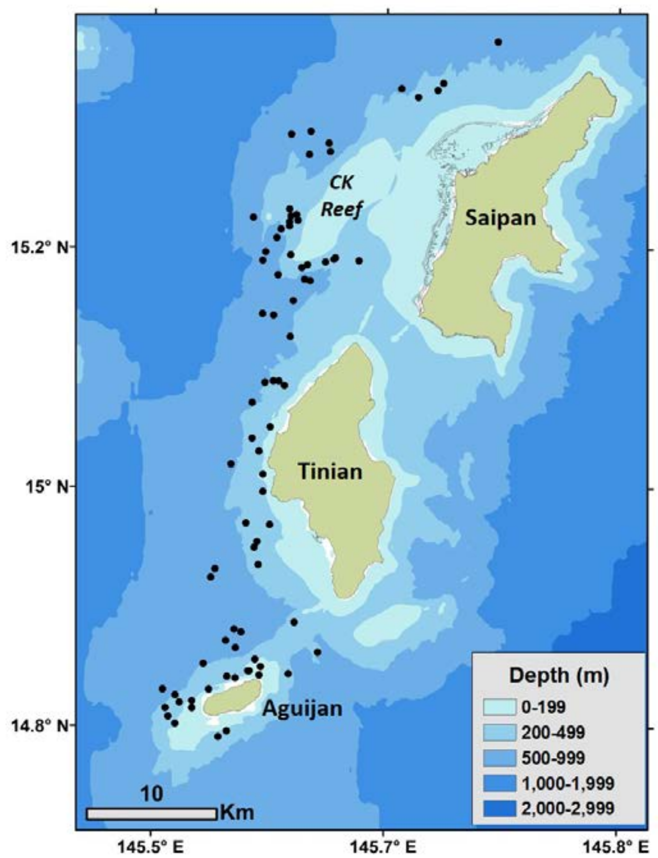

Figure 22. Satellite telemetry locations from a tag deployed on a rough-toothed off Aguijan during the Pacific Islands Fisheries Science Center small-boat surveys in 2013. The tag transmitted for 12 d.

Population Structure

Processing of the remaining 8 biopsy samples is planned but is unlikely to be immediately informative. Assuming levels of differentiation similar to that found among stocks of rough-toothed dolphins in Hawaiʻi (Albertson et al. 2017), a minimum of 20 to 40 samples per stratum would likely be necessary to detect structure within the Mariana Archipelago, if it exists. More identification photos, biopsy samples, and movement data are needed to determine if there is structure at any scale.

Abundance

There are currently too few individuals within the photo-identification catalog to conduct a mark-recapture analysis for abundance estimation. A large-scale line-transect survey may be better suited to assessing the abundance of rough-toothed dolphins within the archipelago.

Distribution and Habitat Use

Most PIFSC rough-toothed dolphin encounters were near islands from Guam to Agrihan, but there was an offshore encounter within the Mariana Trough and another on the West Mariana Ridge during MACS 2018 (Figure 21). During PIFSC surveys, the median shore distance of rough-toothed dolphin encounters was 6.7 km and the median depth was 616 m, but the dolphins were seen as far as 227 km from shore and in depths that ranged from 30 to 4,163 m (Table S3). There were 3 rough-toothed dolphin encounters during MISTCS (Figure S1, Fulling et al. 2011). One was south of Guam and outside of the EEZ boundary. One was nearshore of Guguan, and the third was a mixed-species encounter with bottlenose dolphins offshore of Saipan. The MISTCS encounter locations were in a range of depths 1,019–4,490 m (Table S1). In addition to the encounter location data, telemetry data from a single tag deployment in 2013 (Figure 22) could be used to characterize habitat use.

Exposure to human stressors

Rough-toothed dolphins have not been observed within the U.S. Navy detonation areas off Guam, though they do use overlapping water depths in this area. Within the Mariana Archipelago, rough-toothed dolphins have shown signs of potential fisheries interactions including dorsal fin scarring or mutilation that is characteristic of fishing line entanglement (Figure S7).

Sperm Whale

During PIFSC surveys, there were 12 sperm whale encounters (Figure 23, Table S3). On two occasions sperm whales were seen with other species; once with pantropical spotted dolphins and once with Risso's dolphins. Sperm whale group sizes ranged from 1–15 individuals (median=9). A total of 3,746 photos, 18 biopsy samples, 8 sloughed skin samples, and 4 acoustic recordings were collected, and 2 satellite tags deployed.

The sperm whale photo-identification catalog currently contains 11 individuals with full fluke images, representing all sightings from 2010–2016. Two individuals have been encountered twice, together off Guam in 2010 and again in 2016 off Saipan. Photos from six encounters during MISTCS and one encounter during PIFSC 2018 small-boat surveys have not been processed.

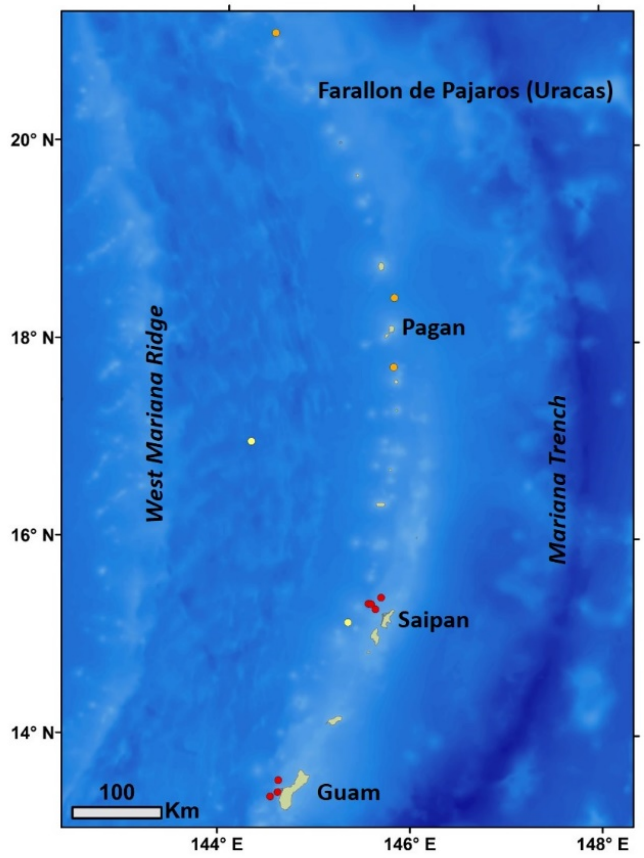

Figure 23. Sperm whale encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the Mariana Archipelago Cetacean Surveys in 2015 (orange dots) and 2018 (yellow dots).

Of the 26 tissue samples that were collected from sperm whales in the Mariana Archipelago, 5 (1 biopsy and 4 skin) collected during a 2013 encounter off Saipan were sequenced by SWFSC for a global phylogeography study of sperm whales using mitogenome haplotypes (Morin et al. 2018). All of the samples had the same mitogenome haplotype (mtGen08) and sex (female). The remaining 17 biopsy samples and 4 sloughed skin samples have not been processed.

Two satellite tags (1 location-only, 1 location-depth) were deployed on sperm whales during small-boat surveys off Saipan and Guam in 2016 (Table 2, Figure 24). The individual tagged off Saipan traveled north almost as far as Guguan, while the individual tagged off Guam moved offshore and went north as far as Tinian during the life of the tag.

Population Structure

Based on the existing samples and photo-identification and movement data, no conclusions can be made about the population structure of sperm whales in the Mariana Archipelago. Sperm whales have low mtDNA diversity globally, and a recent study of global phylogeography (Morin et al. 2018) concluded that existing sperm whales descended from a reduced population of whales in the Pacific, such that genetic selection and hitchhiking are not solely responsible for the low mtDNA diversity in this species. Because of this low diversity, and relatively small sample size from within the Mariana Archipelago, it would not be worthwhile to sequence the remaining 17 biopsy samples at this time. Based on prior studies, more than 25 samples are needed to assess the relation of Mariana Archipelago sperm whales to other locations in the Pacific.

Abundance

The sperm whale photo-identification catalog is too small conduct a mark-recapture analysis for abundance estimation. Current sperm whale abundance in the Mariana Archipelago will be better assessed using a large-scale line-transect survey of the broader region.

Distribution and Habitat Use

All available sperm whale encounter and satellite telemetry data demonstrate that sperm whales use both offshore and nearshore waters within the Mariana Archipelago (Figure 23, Figure 24). Sperm whales were encountered near islands from Guam to Pagan, as well as offshore within the Mariana Trough and north of Uracas (Figure 23). The PIFSC encounter locations were 1.1–157 km from shore, and depths ranged from 374 to 4,276 m (Table S3). During MISTCS, sperm whales were the most frequently encountered species and location depths ranged 809–9,874 m (Table S1, Figure S1, Fulling et al. 2011). The encounter and satellite telemetry data could be used to characterize the habitat use of sperm whales in the Mariana Archipelago, including associations with islands, bathymetric features, and oceanographic conditions.

Sperm whales were the most common large whale detected within the PIPAN data set from Saipan and Tinian. At the Saipan site, sperm whales were heard during all months with recording effort with the exception of April 2011, when only 4 days of recording effort occurred during that month (Oleson et al. 2015). A large-scale assessment of temporal and geographic patterns in the occurrence of sperm whales throughout the central and western Pacific based on the PIPAN data set, including the sites at Saipan and Tinian, suggests that sperm whales peak in occurrence in spring and fall and are detected less often in summer within the Mariana Archipelago (Merkens et al. 2019). Examination of the Pagan data may provide greater insight into movements north and south within the archipelago and on the relative occurrence of whales further to the north. Analysis of DASBR data collected during MACS 2018 will also provide a broad picture of sperm whale occurrence within the study area.

Exposure to human stressors

There are inadequate data to assess exposure to human-caused stressors for sperm whales in the Mariana Archipelago, but satellite telemetry locations from a tagged sperm whale and sightings of sperm whales during PIFSC small-boat surveys were at similar depths as the Navy’s Agat Bay underwater detonation site (Figure S3). Satellite telemetry locations were within 10 km and sighting locations were 3–6 km from the Agat Bay site.

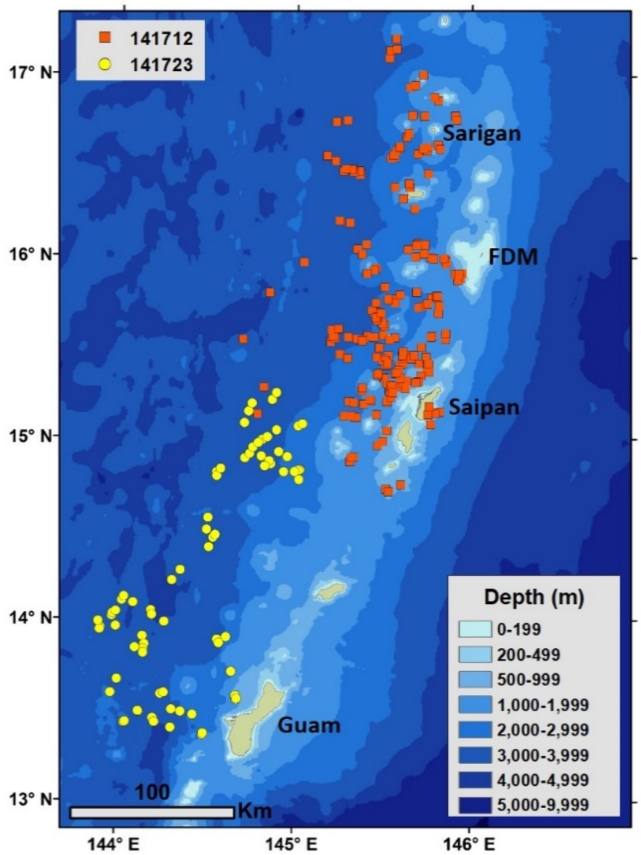

Figure 24. Satellite telemetry locations from tags (displayed by tag ID) deployed on sperm whales off Saipan and Guam during the Pacific Islands Fisheries Science Center small-boat surveys in 2016. The tags transmitted for 42 d and 10 d, respectively.

False Killer Whale

There were 8 false killer whale encounters during PIFSC surveys (Figure 25, Table S3) and during 3 encounters false killer whales were accompanied by bottlenose dolphins. Group sizes of false killer whales ranged from 2–31 individuals (median = 14). A total of 6,707 photos, 36 biopsy samples, and 1 acoustic recording have been collected, and 9 satellite tags deployed (Table S3).

The current false killer whale photo-identification catalog contains 58 individuals representing all PIFSC small-boat encounters and 1 encounter during MISTCS. Nine of these individuals were seen in 2 different years. Six other very distinctive individuals were photographed during MISTCS encounters, but no matches were found in the existing catalog and the individuals were not added to the catalog because the photos did not meet the quality criteria. Individuals identified during MACS 2015 do not match any individuals within the existing catalog; these individuals will be added to the catalog once the quality grading is complete.

Sixteen biopsy samples from a single false killer whale encounter off Rota in 2013 were genetically sexed and sequenced at the mitochondrial control region by SWFSC. They represent 12 females and 4 males. Nine have haplotypes that are also found in the central and eastern

Pacific (haplotypes 7 and 9; Martien et al. 2014b), while 7 have a haplotype that has only been found in the Mariana Archipelago (haplotype 34), but is similar to other pelagic haplotypes. There are 20 additional samples from false killer whales that will be analyzed by SWFSC.

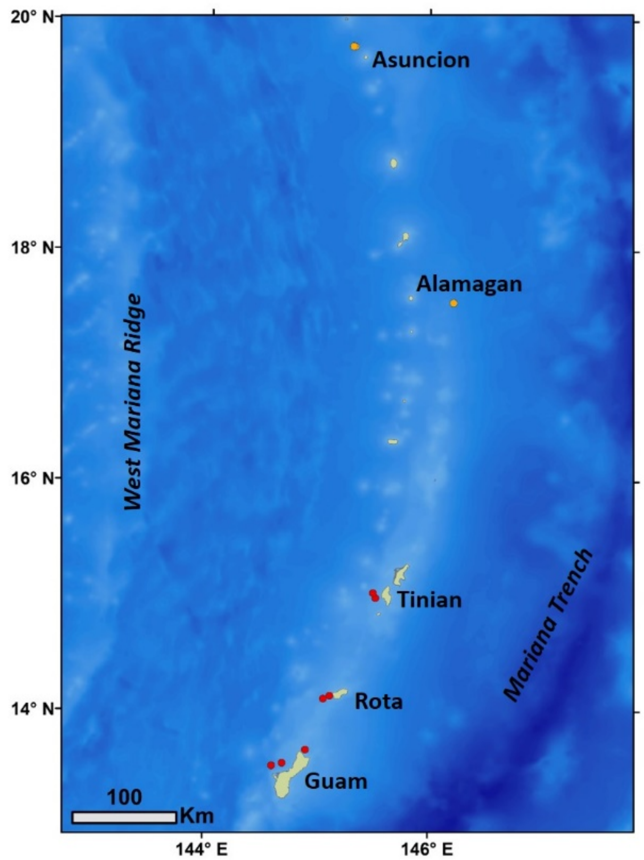

Figure 25. False killer whale encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the 2015 Mariana Archipelago Cetacean Survey (orange dots).

A total of 9 satellite tags (7 location-only, 2 location-depth) were deployed on false killer whales in the Mariana Archipelago between 2013 and 2015 (Table 2, Figure 26). With the exception of 2 individuals, most of the tagged false killer whales remained within the Guam and CNMI EEZ boundary. One individual tagged off Asuncion during MACS 2015 traveled more than 1,500 km west of the EEZ to the boundary of the MITT before turning back east.

Population Structure

Population structure of Mariana Archipelago false killer whales remains uncertain given the genetic, photo-identification, and movement data available to date. One observed haplotype is unique to the Mariana Archipelago, but is similar to other pelagic false killer whale haplotypes observed in the central and eastern Pacific. The remaining 20 biopsy samples, 3 of which were collected from individuals off Asuncion at the northern end of the island chain, will be sequenced by SWFSC. Satellite telemetry data from most tagged animals suggest affinity to the islands. Tag records show long excursions away from the island chain with repeated returns to the islands over the course of several weeks to months. Additional genetic samples and satellite tags will likely be required to resolve false killer whale population structure in this region.

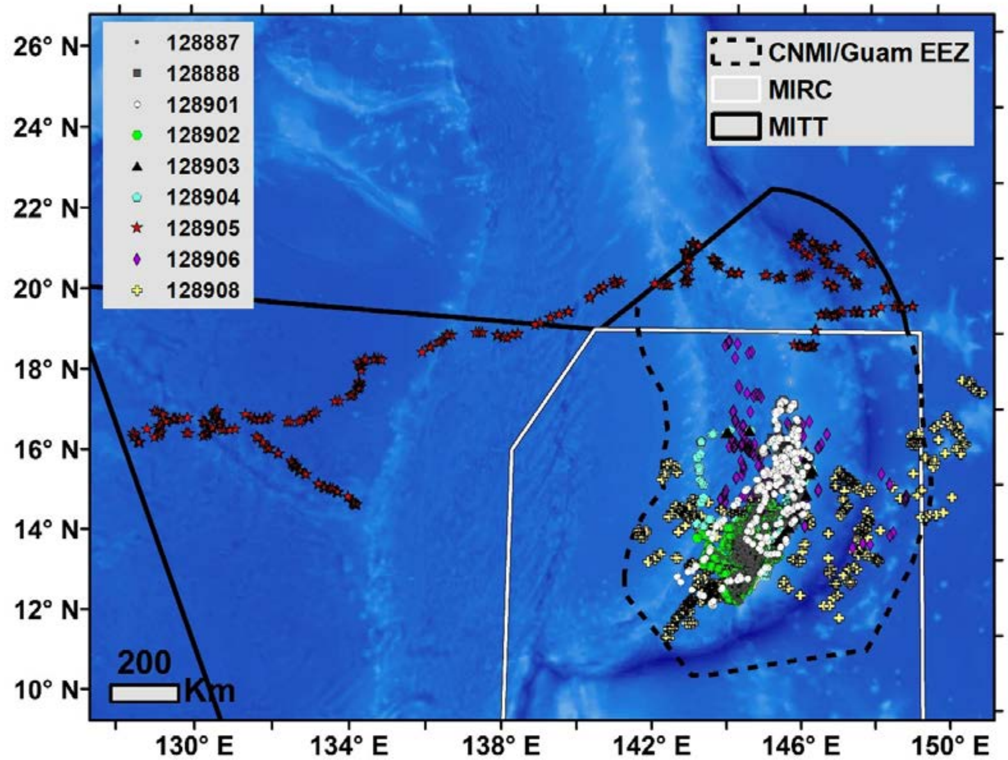

Figure 26. Satellite telemetry locations from tags (displayed by tag ID) deployed on false killer whales in the Mariana Archipelago. Eight of 9 tags were deployed during the Pacific Islands Fisheries Science Center small-boat surveys off Guam, Rota, and Tinian. The ninth tag (tag ID 128905; red stars) was deployed on a false killer whale during the 2015 Mariana Archipelago Cetacean Survey off Asuncion. Tag durations ranged 4–198 d. Dashed line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone (EEZ). White line–Mariana Islands Range Complex (MIRC) boundary. Black solid line–Mariana Islands Training and Test (MITT) area.

Abundance

Nine of 58 individuals within the false killer whale photo-identification catalog have been seen in more than 1 year. Given the small catalog size and low resight rate, it is unlikely that a mark-recapture analysis would provide a robust assessment of population size. Additional encounter and photo-identification effort is needed, particularly within the northern islands and offshore waters.

Distribution and Habitat Use

All available encounter and satellite telemetry data on false killer whales demonstrate that the whales occur in both nearshore and offshore waters with a broad range of depths in the Mariana Archipelago (Figure 25, Figure 26). False killer whales were encountered as far south as Guam and as far north as Asuncion during PIFSC surveys (Figure 25). They were within 40 km from shore (median = 6.9 km) and in a range of depths from 88 to 2,461 m (Table S3). Eight of 9 encounters during MISTCS were offshore and in waters as deep as 8,058 m (Table S1, Figure S1; Fulling et al. 2011).

Kernel density estimates of home range, core area, and highest use area could be pursued using the satellite tag data. The encounter location and satellite tag data could be used to look at false killer whale associations with islands, bathymetric features, and oceanographic conditions. Two of the satellite tags were location-depth tags, which could provide information on the dive behavior of the tagged false killer whales.

Exposure to human stressors

Multiple satellite tag locations from false killer whales occurred within and around the exclusion zones of U.S. Navy denotation areas off Guam (Figure S3), suggesting potential exposure to denotation activities in that region. False killer whales photographed during PIFSC small-boat surveys show signs of potential fisheries interactions, including dorsal fin scarring or mutilation that is characteristic of fishing line entanglement (Figure S8) similar to those on false killer whales observed in Hawaiʻi (Baird & Gorgone 2005; Baird et al. 2015).

Melon-headed Whale

Melon-headed whales were encountered 8 times during PIFSC surveys (Figure 27, Table S3). Group sizes ranged from 85 to 399 individuals (median = 229). A total of 10,867 photos, 62 biopsy samples, and 5 acoustic recordings were collected, and 3 satellite tags were successfully deployed during melon-headed whale encounters.

The current melon-headed whale photo-identification catalog contains 401 individuals from 11 encounters including all PIFSC encounters, a 2012 HDR encounter off Guam, and 2 MISTCS encounters in 2007 (Table S4). Comparisons among all encounters resulted in 16 resights. Individuals seen during PIFSC encounters off Guam and Saipan were also seen off Guguan and Sarigan, as well as on the West Mariana Ridge. One individual encountered off Sarigan in 2015 was photographed during a MISTCS encounter approximately 100 km north of Challenger Deep (Mariana Trench).

Three location-only satellite tags were deployed on melon-headed whales (Table 2, Figure 28). Two were deployed off Saipan in 2014, and the third was deployed off Guam in 2017. The individual with the longest duration tag (16 d) primarily stayed within the 3-Islands area but moved as far south as Rota and as far north as East Diamante Seamount, west of FDM.

Population structure

Martien et al. (2017) found only moderate genetic differentiation between melon-headed whale populations within and between ocean basins and suggested that connectivity between island-associated populations may be maintained through occasional long-distance dispersal or gene flow with larger pelagic populations. Two Mariana Archipelago melon-headed whale samples collected by HDR off Guam (Table S4) were used in the Martien et al. (2017) study. Detecting population structure within Mariana Archipelago melon-headed whales using genetic data would require analysis of both mitochondrial and nuclear data and sample sizes in excess of 20 samples per stratum, assuming levels of genetic differentiation between populations comparable to that found by Martien et al. (2017). Genetic analysis by SWFSC of the 62 biopsy samples collected during PIFSC melon-headed whale encounters is planned, but given that individuals within the photo-identification catalog were re-sighted between island and offshore locations, delineation of population structure is unlikely. As well, the movement data are insufficient to determine population structure.

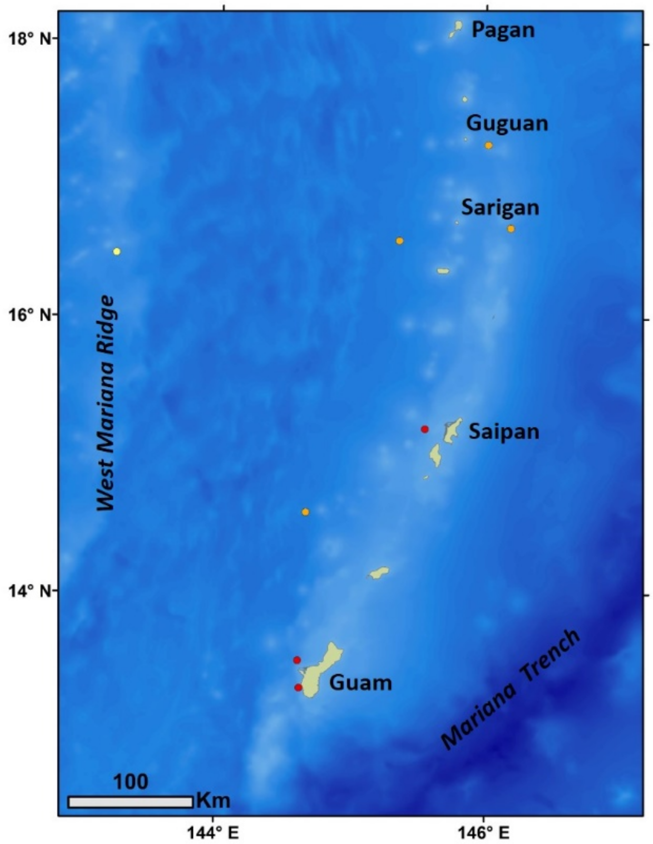

Figure 27. Melon-headed whale encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the Mariana Archipelago Cetacean Surveys in 2015 (orange dots) and 2018 (yellow dot).

Abundance

Given that only 16 individuals of 401 (4%) within the photo-identification catalog have been re-sighted, a mark-recapture analysis for abundance is not possible. The photo-identification catalog number, or an appropriate subset that considers the annual rate at which population additions and losses may occur, may be used as a proxy for the minimum abundance of melon-headed whales in the Mariana Archipelago. Melon-headed whales will be better assessed using a large-scale shipboard survey of the broader region.

Distribution and Habitat Use

Melon-headed whales have been encountered in both nearshore and offshore locations in the Mariana Archipelago. During PIFSC surveys, they were encountered off Guam, Saipan, Sarigan, and Guguan, as well as within the Mariana Trough and on the West Mariana Ridge (Figure 27). The PIFSC encounters ranged 2.6–258 km from shore and had depths 903–3,383 m (Table S3). During MISTCS, 1 melon-headed whale encounter was nearshore to Guam, while the other was close to the Mariana Trench and the EEZ boundary (Figure S1, Fulling et al. 2011). The photo data suggest that individuals roam over large areas within the Mariana Archipelago. The locations from satellite tags deployed on melon-headed whales indicate some associations with submerged reefs and seamounts (Figure 28).

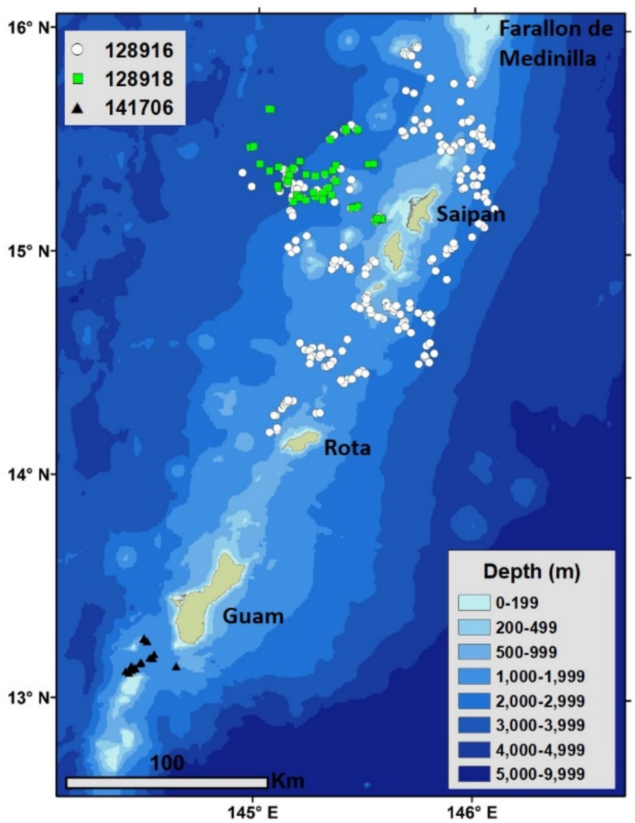

Figure 28. Satellite telemetry locations from tags (displayed by tag ID) deployed on melon-headed whales during the Pacific Islands Fisheries Science Center small-boat surveys in 2014 and 2017. The tags transmitted for 2–16 d.

Exposure to human stressors

There are insufficient data to assess the exposure of melon-headed whales to human activities in the Mariana Archipelago.

Pygmy Killer Whale

Pygmy killer whales were encountered 6 times during PIFSC surveys (Figure 29, Table S3). During 1 encounter, pygmy killer whales were seen with humpback whales. A single group of pygmy killer whales was encountered off Guam each year from 2013 to 2015, and included new calves in 2014 and 2015. Group sizes ranged from 6–12 individuals (median=9). A total of 2,086 photos, 5 biopsy samples, and 1 acoustic recording were collected during pygmy killer whale encounters.

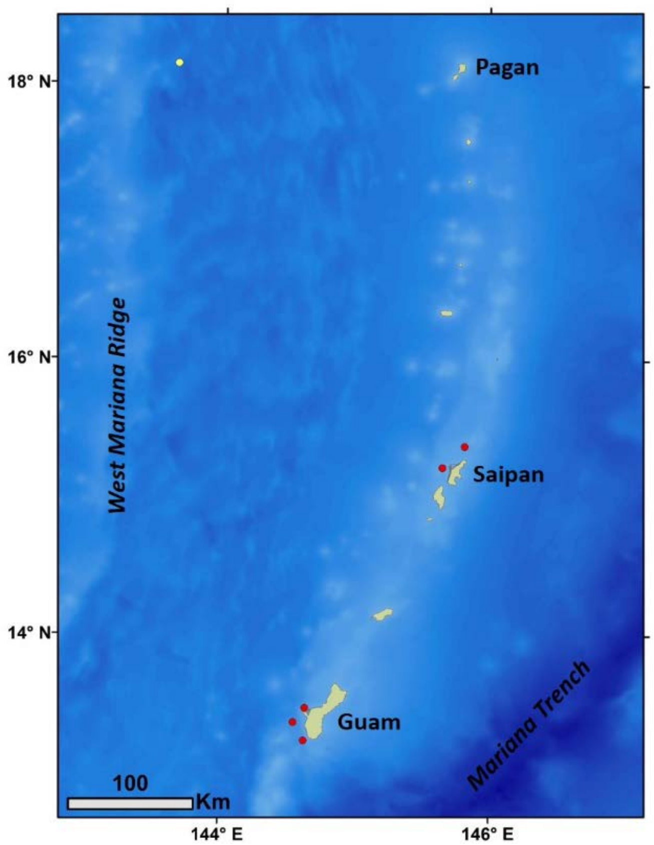

Figure 29. Pygmy killer whale encounter locations during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the 2018 Mariana Archipelago Cetacean Survey (yellow dot).

All photographs of pygmy killer whales collected during PIFSC small-boat encounters have been processed, and the photo-identification catalog contains 8 individuals. All 8 individuals were part of the same group seen off Guam in 3 consecutive years, and 6 of the individuals were seen in all 3 years. Photos collected during an offshore encounter during MACS 2018 have not been processed.

The 5 biopsy samples collected during PIFSC small-boat encounters have not been analyzed, but photos collected during the sampling events show that 2 individuals were each sampled twice resulting in a total of 3 sampled pygmy killer whales.

Population structure

Repeated encounters of the same group of individuals off Guam suggest that some pygmy killer whales may be island-associated and demonstrate extreme site-fidelity. Satellite telemetry data would be useful in determining the range of individuals in this group. Other than this single group with apparent fidelity to Guam, there are insufficient data to assess population structure for pygmy killer whales in the Mariana Archipelago. With only 3 sampled individuals, there is little value in processing the biopsy samples from pygmy killer whales at this time.

Abundance

With only 8 individuals in the photo-identification catalog, a mark-recapture analysis for abundance estimation is not possible. This species may be better assessed using a large-scale ship-based survey of the broader archipelago.

Distribution and Habitat Use

Pygmy killer whales were encountered in both nearshore and offshore waters and across a broad range of depths. During PIFSC surveys, most of the encounter locations were close to shore (median = 8.1) and in waters less than 600 m deep (Figure 29, Table S3). There was a single encounter of pygmy killer whales during MACS 2018, which was far offshore west of Pagan near the West Mariana Ridge where the depth was 3,956 m (Table 4, Figure 29). There was a single encounter of pygmy killer whales during MISTCS; south of Guam and just north of the Mariana Trench in 4,439 m deep water (Table S1, Figure S1; Fulling et al. 2011). An assessment of habitat use is limited by the low number of sightings.

Exposure to human stressors

Although there are insufficient data to fully assess the exposure of pygmy killer whales to human activities in the Mariana Archipelago, there is potential for the Guam group to be exposed to detonation activities off Guam. Pygmy killer whales were encountered 2.5 km from the Piti Floating Mine Neutralization Area and 3 km from the Agat Bay UNDET Area (Figure S3).

Dwarf Sperm Whale

There were 6 dwarf sperm whale encounters during PIFSC surveys (Figure 30, Table S3). Two encounters off Guam in 2016 included the same 2 mom-calf pairs. Dwarf sperm whale group sizes ranged from 1 to 4 individuals (median = 3). A total of 986 photos, 1 biopsy sample, and 3 acoustic recordings were collected during dwarf sperm whale encounters. There were 8 detections of *Kogia* species on DASBRs deployed during MACS 2018 (Figure 31).

Passive acoustic recordings were made during 2 encounters with 2 mom-calf pairs seen together off Guam and were only the second confirmed-species recordings in the wild (Merkens et al. 2018). These recordings were used to characterize dwarf sperm whale clicks and make comparisons to other dwarf sperm whale acoustic recordings and previously described clicks of pygmy sperm whales (*K. breviceps*) (Merkens et al. 2018). The authors concluded that although dwarf sperm whale clicks cannot yet be distinguished from those of pygmy sperm whales, the detailed description of the clicks will provide genus identification and the ability to monitor these cryptic species using passive acoustics.

There is no photo-identification catalog for dwarf sperm whales, as photos are generally of low quality and dorsal fins are not distinctive.

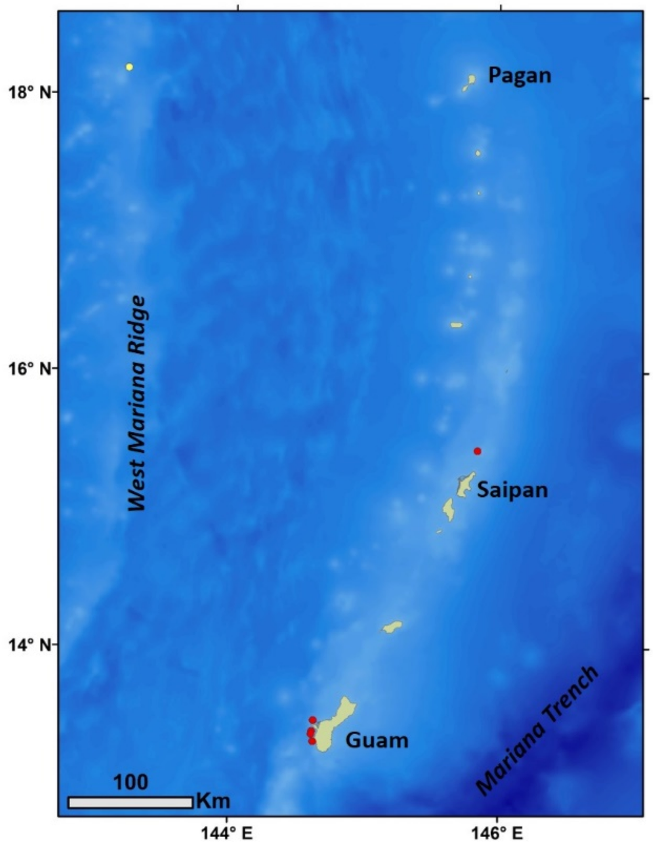

Figure 30. Dwarf sperm whale encounters during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys (red dots) and the 2018 Mariana Archipelago Cetacean Survey (yellow dot).

Population Structure

It is not possible to assess population structure of dwarf sperm whales with the available data.

Abundance

There is no photo-identification catalog for dwarf sperm whales in the Mariana Archipelago, precluding mark-recapture abundance estimation. Abundance of this species in the Mariana Archipelago would be better assessed using large-scale ship-based surveys or passive acoustic surveys utilizing drifting buoys (e.g., Griffiths and Barlow 2016), such as the DASBRs used during MACS 2018.

Distribution and Habitat Use & Exposure to human stressors

The low sighting rate of dwarf sperm whales limits an assessment of habitat use and exposure to human-caused stressors.

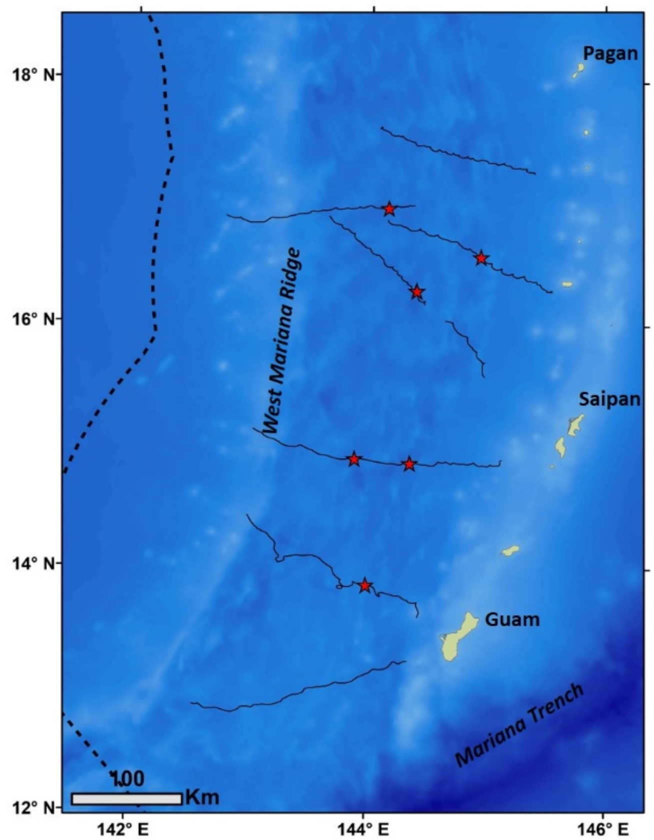

Figure 31. Drifting Acoustic Spar Buoy Recorder tracks (solid black lines) and acoustic detections of *Kogia* sp. (red stars) during the 2018 Mariana Archipelago Cetacean Survey. Dashed black line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone.

Risso's Dolphin

Risso's dolphins were encountered 3 times during PIFSC surveys (Figure 32, Table S3). During a 2015 encounter north of Uracus, a single Risso's dolphin was associated with 2 sperm whales. A total of 21 photos and 1 acoustic recording were collected. No biopsy samples were collected and there is no photo-identification catalog.

Population structure

There are no genetic, photographic, or movement data with which to assess population structure for Risso's dolphins in the Mariana Archipelago. An acoustic analysis of geographic variation in Risso's dolphin echolocation clicks in the central and eastern North Pacific and the western Atlantic revealed potential patterns in the spectral peaks and troughs that may be indicative of population structure (Soldevilla et al. 2017), though additional examination will be required to determine whether that variation is tied to prey preference or other factors rather than population structure. Acoustic recordings of Risso's dolphins in the Mariana Archipelago may provide additional information about the utility of acoustic data for assessing population structure and the similarity between Risso's dolphins echolocation clicks there versus elsewhere in the central Pacific.

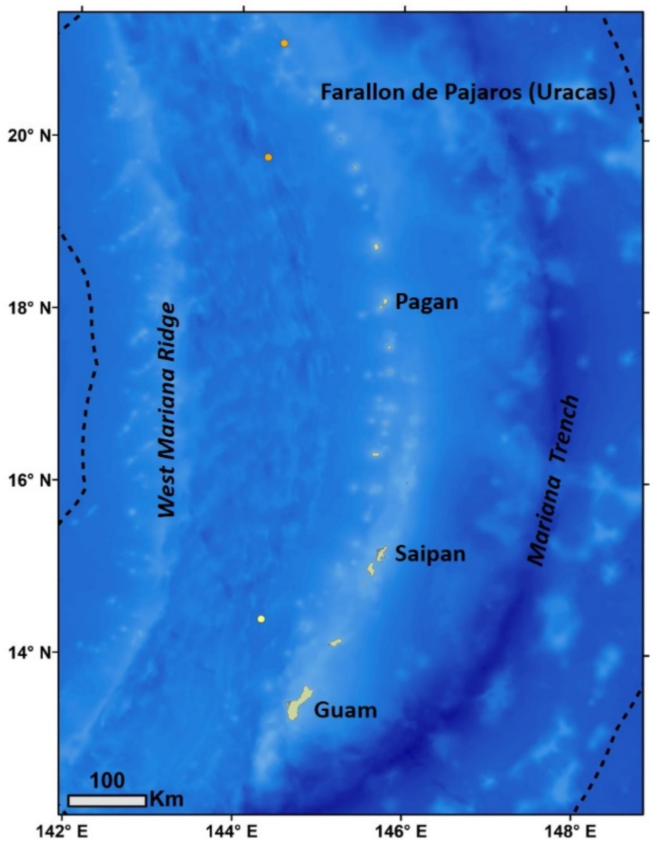

Figure 32. Risso's dolphin encounters during the Pacific Islands Fisheries Science Center Mariana Archipelago Cetacean Surveys in 2015 (orange dots) and 2018 (yellow dot). Dashed black line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone.

Abundance

There are inadequate data to assess Risso's dolphin abundance in the Mariana Archipelago. A large-scale ship-based survey will likely be the best approach for determining Risso's dolphin abundance in the region.

Distribution and Habitat Use

Risso's dolphin encounters during PIFSC surveys were in offshore waters in depths greater than 2,500 m (Figure 32, Table S3). Passive acoustic data from PIPAN and other autonomous recorders may provide additional information about Risso's dolphin occurrence in the region, as the species does produce distinctive species-specific clicks (Soldevilla et al. 2008, 2017).

Exposure to human stressors

There are insufficient data to assess the exposure of Risso's dolphins to human activities in the Mariana Archipelago.

Striped Dolphin

Striped dolphins were encountered once during PIFSC surveys (Figure 33, Table S3). A total of 97 photos were collected. No biopsy samples were collected, and there is no photo-identification catalog.

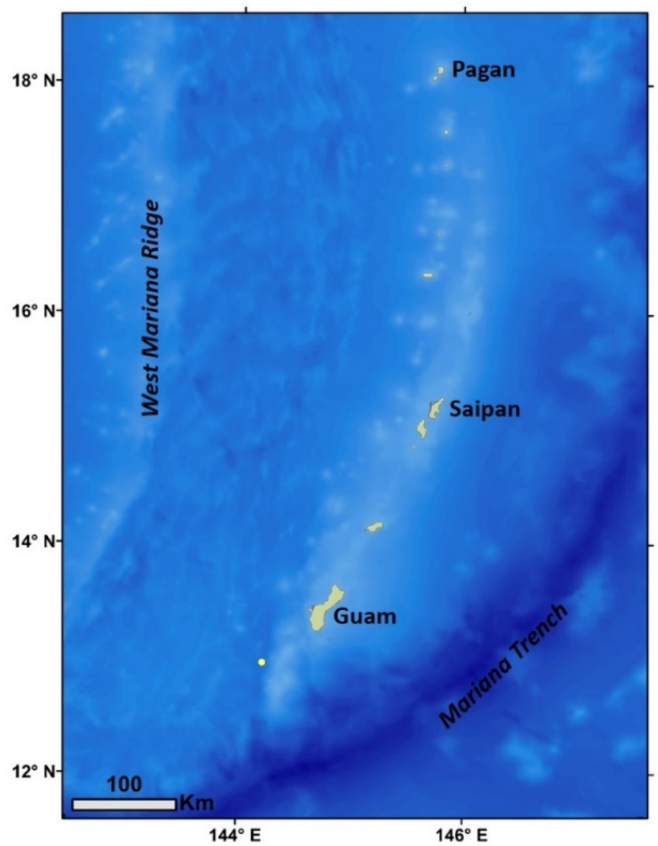

Figure 33. Striped dolphin encounter during the Pacific Islands Fisheries Science Center 2018 Mariana Archipelago Cetacean Survey (yellow dot).

Population structure

There are no genetic, photographic, or movement data with which to assess population structure for striped dolphins in the Mariana Archipelago.

Abundance

Currently, there are inadequate data to assess striped dolphin abundance in the Mariana Archipelago. A large-scale ship-based survey will likely be the best approach for determining striped dolphin abundance in the region.

Distribution and Habitat Use

Striped dolphin encounters during MISTCS (Table S1, Figure S1; Fulling et al. 2011) and MACS 2018 (Figure 33, Table S3) were primarily offshore and ranged from 54–342 km from shore where depths were greater than 2,300 m.

Exposure to human stressors

There are insufficient data to assess the exposure of striped dolphins to human activities in the Mariana Archipelago.

Humpback Whale

Between 2015 and 2019, PIFSC conducted targeted humpback whale surveys off the 3-Islands area. There were 42 encounters with humpback whales during which photos were collected (Table 1, Figure 34). During 4 encounters humpback whales were seen with other species including bottlenose dolphins, spinner dolphins, pygmy killer whales, and short-finned pilot whales. Humpback whale group sizes ranged from 1–8 individuals (median = 2). Mother-calf pairs were seen in all years except 2019, and there were a total of 14 pairs across years. A total of 18,243 photos and 29 biopsy samples were collected during humpback whale encounters. Small-boat surveys in February–March 2010 and April 2014 off the 3-Islands area and Guam did not target humpback whales but did include survey effort in waters less than 200 m (33% of trackline distance) including some offshore reefs, but no humpback whales were observed.

The humpback whale photo-identification catalog includes 44 non-calf individuals and 13 calves. Of the non-calf individuals, 4 were photographed at Marpi Reef during MISTCS. There are full fluke images for 30 individuals. Eight individuals were encountered in more than 1 year, and the cumulative number of distinctive individuals relative to the cumulative number of individuals sighted over all years is still increasing (Figure 35), indicating that the photo-identification catalog is still growing.

Twenty-eight humpback whale biopsy samples collected from 2015 to 2018 were sequenced at OSU (Hill et al. 2020a). They represented 24 individuals (14 females, 10 males), and 7 mtDNA haplotypes were identified.

Population structure

Five of the haplotypes (A-, A+, A3, E1, F2) found in the Mariana Archipelago humpback whale samples are common throughout the North Pacific. Two haplotypes (E5, E6) are more localized to the western North Pacific but are also present in the eastern and central North Pacific. Comparisons of mtDNA from Mariana Archipelago humpback whale samples to those collected during the 2004–2006 North Pacific study of humpbacks (Baker et al. 2013) revealed a significant difference ($p < 0.05$) between the mtDNA haplotype frequencies of the Mariana Archipelago samples and those from 4 of 8 breeding grounds (Hill et al. 2020a). In the western North Pacific, the Mariana Archipelago differed significantly from the Philippines and Okinawa but not from Ogasawara. Comparisons of mtDNA haplotype frequencies also suggested strong connections between the Mariana Archipelago and the feeding grounds of the Commander Islands, western Gulf of Alaska, and western Aleutians (Hill et al. 2020a).

Fluke images from the photo-identification catalog have been compared to existing catalogs from the Philippines, Japan, and Russia. These comparisons have found matches to some breeding areas in Japan (*n* = 10) and the Philippines (*n* = 1), as well as to Russian feeding areas (*n* = 3), suggesting Mariana Archipelago humpback whales are part of the western North Pacific distinct population segment (Hill et al. 2020a), which is listed as endangered under the U.S. Endangered Species Act. The current catalog and biopsy sample sizes from the Mariana Archipelago are small, and additional data are necessary to better assess migratory routes and connectivity to other breeding and feeding grounds.

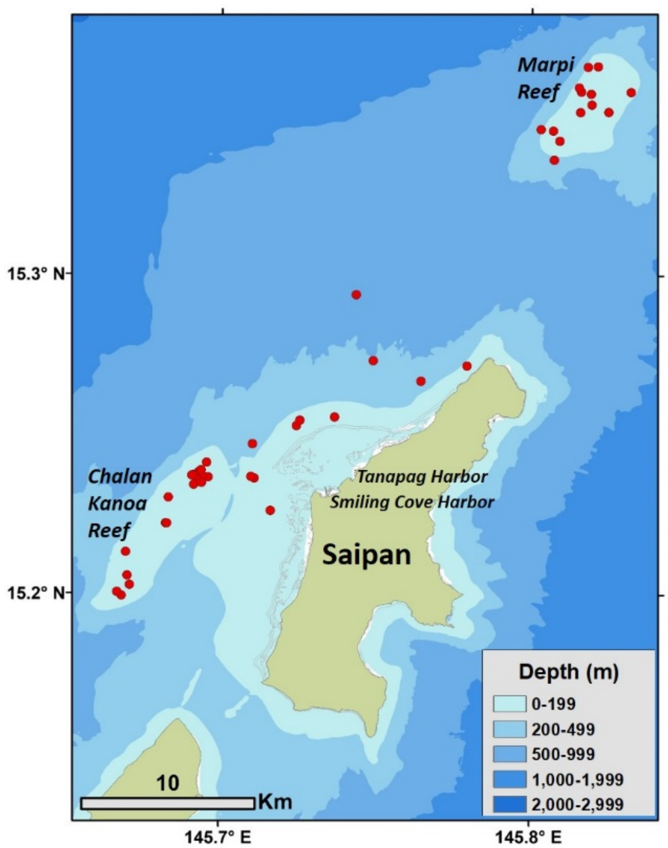

Figure 34. Humpback whale encounters during the Pacific Islands Fisheries Science Center small-boat humpback whale focused surveys (January–March 2015–2019). Tanapag and Smiling Cove Harbors are the only vessel ports on the island.

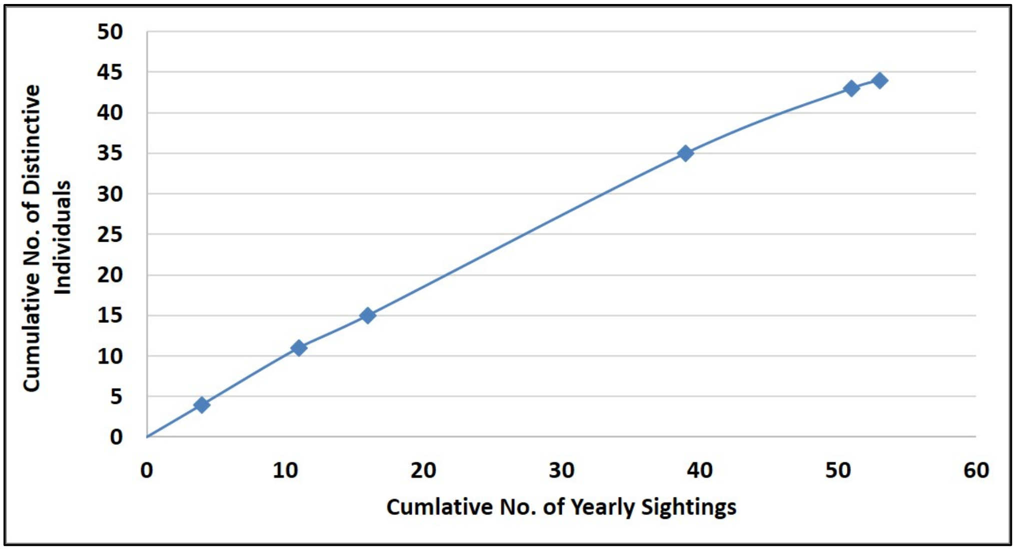

Figure 35. The cumulative number of individual non-calf humpback whales sighted over all years (2007, 2015–2019, with each year represented as a point) versus the cumulative number of distinctive individuals.

Abundance

Preliminary annual mark-recapture abundance estimates of humpback whales within the PIFSC study area were obtained using photo-identification data collected during the 2015–2019 winter surveys (Hill et al. 2020b). Using an open population mark-recapture model (the POPAN generalization of the Jolly-Seber model), Hill et al. (2020b) estimated yearly abundances that ranged from 34 (SE, 19; 95% CI, 12–92) whales in 2019 to 126 (SE, 44; 95% CI, 65–246) whales in 2017, with an average of 61 (SE, 13; 95% CI, 41–91) whales across all years. The sampling periods in each year were short relative to the length of the winter breeding season; therefore, the annual abundances potentially underestimate the numbers of whales associated with the study area throughout each winter. Although some whales do appear to remain within the study area over periods of at least several days, others likely move in and out. The effects of whale movement in and out of the study area along with sampling variability and bias are not well understood but are important to consider in the application of these estimates (Hill et al. 2020b).

Distribution and Habitat Use

The occurrence of humpback whales in the Mariana Archipelago was evident from whaling records (Townsend 1935), opportunistic sightings (Eldredge 1991, 2003; Darling and Mori 1993; Yamaguchi et al. 2002; Uyeyama 2014), and passive acoustic records (DoN 2007; Oleson et al. 2015), but it was not clear whether this area served as a migratory route or a winter breeding ground. The PIFSC winter small-boat surveys that targeted humpback whales confirmed that the whales are using the Mariana Archipelago as a breeding ground (Hill et al. 2020). Multiple mother-calf pairs (including a neonate and very small calves) and competitive groups have been encountered off Saipan. In addition, several individuals were re-sighted between years, including females with different calves in different years, demonstrating individual site fidelity to the Mariana Archipelago as a wintering area.

Humpback whales were acoustically detected within the PIPAN data from Saipan and Tinian in December–April in all years analyzed to date (2010–2015) (Oleson et al. 2015). The full data set, including new data from Pagan in the northern portion of the archipelago, is being evaluated for humpback whale song using deep machine learning approaches (Allen et al. in review), and additional analyses could be carried out to assess trends in the number of singers present in the region since recording effort began in 2010.

Studies on humpback whales around the world demonstrate that on breeding grounds the whales use warm, shallow water areas (<200 m) that are typically close to shore (Whitehead & Moore 1982; Martins et al. 2001; Ersts and Rosenbaum 2003; Rasmussen et al. 2007; Félix and Botero-Acosta 2011), and the PIFSC and the MISTCS (Fulling et al. 2011) encounters reflected the finding. Most (88%, n = 37) of the humpback whale encounters occurred in depths less than or equal to 100 m and approximately half of those (n = 22) had depths less than or equal to 50 m. All of the humpback whale encounters were within 18 km of the Saipan shore (median = 8.0 km) and most were on either CK Reef or Marpi Reef (Figure 34). Semi-monthly aerial surveys conducted by the Guam DAWR did not report humpback whales from 1963 to 2012 (Martin et al. 2016), suggesting humpback whales are not common in the nearshore waters around Guam. In addition, small-boat surveys conducted off Guam by PIFSC in February 2010 and April 2014 did not result in any humpback whale encounters.

A study of humpback whales in New Caledonia found that the whales used shallow offshore seamounts intensively within the breeding season and during their migration away from the breeding area (Garrigue et al. 2015). There are numerous seamounts and submerged reefs within the Mariana Archipelago. In March 2018, the PIFSC partnered with the U.S. Coast Guard Sector Guam to survey 2 offshore locations for humpback whales. Neither Santa Rosa Reef (60 km south of Guam) nor Galvez Banks (30 km south of Guam) is accessible with a small-boat in winter. During the single-day surveys, no humpback whales were observed in those areas.

Visual surveys or use of passive acoustic devices at other shallow water locations and seamounts in the Mariana Archipelago may reveal additional humpback whale wintering locations. Examination of 2 years of PIPAN data from Pagan may be particularly enlightening with regard to whether humpbacks are distributed further north into the archipelago and whether the timing of their occurrence there suggests migratory movements along the archipelago.

Exposure to human threats

Although there are insufficient data to fully assess the exposure of humpback whales to human threats in the Mariana Archipelago, vessel collision is a potential threat to humpback whales off Saipan. Humpback whales occur off the west side of Saipan where the only harbors (Tanapag and Smiling Cove) on the island are located (Figure 34), and vessel traffic is heavy. Cargo ships and other large commercial vessels, smaller commercial vessels (e.g., diving, fishing, parasail), government vessels (e.g., Navy, Coast Guard, CNMI), and private vessels all use or transit through the waters where humpback whales are found. Four to six Navy Prepositioning Ships are typically anchored in the waters between the outer reef of the island and CK Reef or on CK Reef. Crew transport vessels move back and forth between the harbor and the ships multiple times a day. In 2014, there was a preliminary report of a crew transport vessel striking a large whale (Pacific Islands Regional Office, unpublished data). No photos were taken of the whale and it was recorded in the report as a possible humpback or sperm whale, but given the shallow-water location of the incident it was likely a humpback whale. Personnel from the CNMI Department of Fish and Wildlife responded to the report and found a group of 4 humpback whales within the immediate area, however none showed signs of recent vessel strike.

Other Baleen Whales

No baleen whales other than humpback and Bryde's whales have been observed in the Mariana Archipelago during PIFSC surveys, though several are known to occur across the western Pacific, including blue (*B. musculus*), fin (*B. physalus*), sei (*B. borealis*), and minke (*B. acutorostrata*) whales. Sei whales were the third most frequently sighted species during the MISTCS (Figure S1, Fulling et al. 2011). PIFSC PIPAN acoustic data sets have been analyzed to annotate occurrence of sounds consistent with those known or likely to be produced by these species. Blue and fin whale calls were rarely detected in the Saipan and Tinian data sets, and minke whale boings were detected on a few occasions off Saipan only (Oleson et al. 2015).

Blue whale 20 Hz tonal calls produced by central Pacific blue whales and downswept D calls, produced by all blue whale populations and not identifiable to population, were each detected on less than 1% of monitoring days. Blue whale 20 Hz calls were heard only in fall and winter (September, November–January) and downswept D calls were heard only in summer (May, June, and August). Other calls similar to those produced by blue whales elsewhere in the world (i.e., long duration and very low frequency, tonal calls) have also been detected at the Mariana Archipelago PIPAN sites, though to date cannot be confirmed as being produced by blue whales.

Fin whale 20 Hz calls were detected on 4 days off Saipan (April 2010–2 days; May 2011–2 days) and 2 days in April 2011 off Tinian. Minke whale boings were detected during 6 days in March and April 2010 off Saipan.

Priority Analysis and Data Collection Needs

Large-scale visual and passive acoustic survey

It is clear from the data collected and analyses conducted to date that there are inadequate data to assess population structure, abundance, or distribution for many species throughout the Guam and CNMI EEZs, in both nearshore and offshore waters of the archipelago. The greatest research need for most cetacean species in the Mariana Archipelago is a large-scale ship-based abundance survey. The full suite of available visual survey and passive acoustic data should be used to develop a line-transect survey that is capable of providing adequate data for assessing abundance, as well as adequate time for the deployment of satellite tags and the collection of tissue samples in offshore and northern island waters where data are sparse. Both autonomous and towed passive acoustics will be a necessary component of the survey effort in order to accumulate adequate data to assess beaked whale and *Kogia* species.

The Pacific Marine Assessment Program for Protected Species (PacMAPPS) includes a Mariana Archipelago survey within the 5-year rotation. The Mariana survey is currently scheduled for 2021.

Analyses of Existing Survey Data and Continuation of Data Collection Efforts

Although data are sparse for many species, there are high priority analyses that could be conducted with the data currently available or with a modest amount of additional data collection. We attempt to summarize here, by species, what analyses could be pursued given staff and resources to dedicate to examining these questions. We also include potential analyses of passive acoustic data sets that may be particularly valuable for examining structure, abundance, or distribution of Mariana Archipelago cetaceans. Analyses are considered high priority if one or more of the following criteria apply:

- They will directly inform NMFS assessments under MMPA or ESA.
- They are relatively low cost and may provide focus or direction to future analyses or data collection efforts.
- They will inform current Navy monitoring plan questions or future Navy monitoring efforts in the region.

High priority analyses or data collection are not identified for all species observed in the region. Analyses and data collection needs by species are listed in the same order as the species summaries. Within each species, analyses are listed in priority order, though many analyses can or should occur concurrently.

Spinner dolphins

- **Photo-identification grading and cataloging for 2014–2018 encounters**. Completing the processing and cataloging of photos from the southern and northern islands will provide needed insight into the extent of animal movement and therefore population range.
- **Generate mark-recapture estimates of abundance for Guam and for Rota/3-Islands area**. Once photo-identification processing and matching is complete and population structure within the southern islands resolved, spinner dolphin abundance within the 2 southern island regions is feasible.
- **Genetic analyses of samples collected in the northern islands**. Although the number of samples available from the northern islands is relatively few compared to the southern islands, processing those samples for haplotype and microsatellites may reveal the northern extent of the population occurring around Rota and the 3-Islands. This population includes animals that have been identified outside of traditional shallow water daytime spinner dolphin habitat, such as at Marpi Reef, suggesting these animals have the potential to roam further north along the island chain. Such analyses may also inform the extent of future sampling efforts in the northern islands.
- **Characterize spinner dolphin habitat use based on environmental and physical features.** Such characterization may reveal unique habitat preferences to this region and provide context for examining exposure to human-caused threats in the nearshore environment.

Bottlenose dolphins

- **Generate mark-recapture abundance estimation for the southern islands**. The available photo-identification catalog includes a large proportion of re-sighted individuals, enabling pursuit of mark-recapture estimates for nearshore areas.
- **Genetic analysis to determine occurrence of Indo-Pacific bottlenose dolphins**. Examination of genetic sequence data for all remaining unprocessed samples would prove valuable for assessing if this species occurs in the region.
- **Deploy additional location-only and location-depth tags to assess movements and habitat association**. A modest number of additional location-only tags deployed in the southern islands could provide insight into population boundaries for a population occurring within the southern islands. Additional location-depth tags could provide insight into variability in foraging behavior throughout the day and in association with other environmental features, including bathymetry and satellite-sensed variables.

Short-finned pilot whales

- **Additional tissue sample collection and satellite tagging off the 3-Islands area and northern islands.** Additional samples may help determine if there is population structure between the northern and southern islands and provide focus for future efforts aiming to examine the potential impact of Navy activities, fisheries interactions, or other human impacts to short-finned pilot whales.
- **Generate mark-recapture estimate for the southern islands main social cluster.** Photo-identification data are adequate to carry out mark-recapture estimation for the main social cluster found in the southern islands.

False killer whales

- **Sequence remaining genetic samples**. This processing would allow us to better assess occurrence of unique haplotypes and evaluate differences between northern and southern animals, particularly those with broader offshore movements.
- **Examine movements and habitat preferences using satellite telemetry data.** Telemetry data from 9 whales are currently available and relatively long duration deployments provide information over 6–9-month timeframes for some individuals. The apparent affinity for the island archipelago may be better assessed in relation to various habitat variables.

Melon-headed whales

- **Evaluate use of catalog size as minimum population size.** Only 16 re-sights between groups over 8 years suggest catalog size or more likely an appropriate subset may be a reasonable proxy for minimum population size.

Humpback whales

- **Continue winter surveys off Saipan and other parts of the Mariana Archipelago.** The collection of identification photographs and tissue samples from the Mariana

Archipelago would allow for a more robust estimation of the number of animals using this breeding ground and for continued examination of their connections to other North Pacific breeding and feeding grounds.

Analysis of Passive Acoustic Data sets

Available passive acoustic data sets, including long-term fixed site monitoring within PIPAN, towed array data from shipboard surveys, and autonomous drifting recorder data from MACS 2018 may be useful for evaluating questions of population structure, abundance, distribution and habitat, and exposure to human-stressors. The same criteria were applied to determine analyses that were highest priority. Analyses are listed in order of species occurrence within the Species Summaries.

False killer whales & short-finned pilot whales

- Examine all visually-verified or satellite tag-concurrent acoustic detections to assess vocal characteristics of false killer whales and short-finned pilot whales in the region relative to those from Hawai‘i or other areas. Validation of current false killer whales and short-finned pilot whale acoustic classifiers for the Mariana Archipelago would provide the opportunity for assessing occurrence and movements from PIPAN and DASBR data and the potential for acoustic abundance estimates from future systematic acoustic surveys.

Bryde's whales

- **Describe species-specific call types** using available sonobuoy and array data concurrent with sightings of Bryde's whales.
- **Examine seasonality and distribution** of Bryde's whales within PIPAN and DASBR data sets using call type descriptions from sonobuoy data. Seek data sets from other monitoring networks in the western Pacific to better assess the range of the Bryde's whale population.

Beaked whales

- **Re-process towed array data from MACS 2015** to assess distribution of beaked whale species in the northern Mariana Archipelago. Such analyses could aid in design of future large-scale ship-based or autonomous drifting recorder surveys in the region.

Humpback whales

- **Assess song structure** from Marianas PIPAN data sets and others in the North Pacific to evaluate possible migratory routes, and relatedness to humpback song in other regions of the western Pacific and Aleutians.

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Supplemental Material – Data Processing and Analyses

Bathymetry Data

For visualization and analysis of spatial data, bathymetric data sets of varying resolutions were used, which included high-resolution multibeam color-shaded bathymetry for nearshore waters from the Pacific Islands Benthic Habitat Mapping Center[3]. A Global Multi-Resolution Topography (GMRT)[4] custom bathymetric grid encompassing the U.S. EEZs of CNMI and Guam was referenced for offshore areas not covered by the other data sets. All bathymetry data sets were processed using ArcCatalog 10.3 (ESRI, Redlands, CA). The ASCII files were first converted into raster grids, projected in the World Geodetic System (WGS) 1984 Universal Trans Mercator (UTM) Zone 55N coordinate system and imported into ArcMap 10.3.

Surveys and Encounters

Vessel GPS tracks and encounter locations were processed in ArcCatalog 10.3, projected in the WGS 1984 UTM Zone 55N coordinate system, and then overlaid onto the bathymetric data sets within ArcMap 10.3. Depths of the encounter and on-effort trackline locations were determined by extracting the depth values from each relevant bathymetric raster data set. Small boat search effort was summarized in depth bins of 200 m intervals. In addition, the distances from the closest shoreline for each encounter location were determined.

Photo-Identification

Photo-identification catalogs were created using photos collected during small-boat surveys from 2010 to 2018, MACS 2015, and MACS 2018. Additional photos were contributed by the U.S. Navy from the 2007 MISTCS, the 2011 and 2012 HDR, and the 2013 TetraTech surveys (Table S2). Initial matches of individuals were made within each sighting by a photo-identification analyst and were then checked by a second analyst. Individually identified fins were also compared with all others within the sighting to look for missed matches. Marks along the leading and trailing edges of the dorsal fins were used as the primary identifiers. Marks or scars on the body, dorsal fin surface, and peduncle; and coloration patterns on the body and dorsal fin were used as secondary identifiers. Each individual fin in each photo was rated for quality based on numeric scores within 4 categories (focus/clarity, contrast/lighting, angle, extent visible) and was assigned an overall quality rating (Q-1 = high, Q-2 = moderate, Q-3 = poor). Distinctiveness ratings were assigned to each individual based on the number, size, and shape of the features located on the leading and trailing edges of the dorsal fin (D-1 = high, D-2 = moderate, D-3 = low, D-4 = clean fin and no marks on the peduncle directly behind the dorsal fin). After the completion of matching and rating within sightings, identified individuals were compared between sightings by both analysts. Only those fins with a distinctiveness of D-1 or D-2 and a quality rating of Q-1 or Q-2 were initially entered into the catalog. Images of D-1 and D-2 individuals that did not meet the quality criteria for the catalog were kept for future comparisons.

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[3] School of Ocean and Earth Science and Technology (University of Hawaiʻi at Manoa) http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm

[4] Ryan et al. 2009; Marine Geoscience Data System http://www.marine-geo.org/portals/gmrt

Tissue Sample Analysis

Sample Analysis at SWFSC

DNA was extracted from biopsy samples and used for genetic sex determination, mitochondrial control region sequencing, and microsatellite genotyping using standard laboratory methods. Methods used for control region sequencing and sex determination are as described in Martien et al. (2012, 2014b). Microsatellite genotyping methods for bottlenose dolphins are as described in Martien et al. (2012). Full mitochondrial genome sequencing methods for sperm whales are described in Morin et al. (2018).

Sample Analysis at OSU

Total genomic DNA was extracted following methods described in Olavarria et al. (2007). For humpback whales, spinner dolphins, and spotted dolphins, a genetic profile was created for each sample which contained sex, mitochondrial DNA (mtDNA) control region haplotype, and 12 to 18 previously published microsatellite loci depending on species. Replicate samples were identified with the program CERVUS (Marshall et al. 1998) requiring a minimum of 8 matching microsatellite loci, supported by sex and control region haplotype where available. All replicate samples were removed before population level analyses.

Satellite Telemetry

Argos Doppler locations of the satellite-tagged cetaceans were determined by the Argos system using Kalman filtering (Lopez and Malardé 2011). The Argos raw DIAG files were uploaded to Movebank[5] where the Douglas Argos Filter (DAF) was run on the satellite tag locations using the distance angle rate filtering method (Douglas et al. 2012). The DAF was set to automatically retain location classes (LC) of LC2 and LC3; LC1, LC0, LCA, LCB, and LCZ locations were retained if they met certain criteria. Locations of those classes had to be separated from the next location by less than a maximum redundant distance of 3 km. The maximum sustainable rate of movement was set to 15 km/h for short-finned pilot whales, melon-headed whales, and sperm whales and 20 km/h for false killer whales, bottlenose dolphins, rough-toothed dolphins, and spotted dolphins based on maximum travel speeds noted during observations in Hawai‘i (Baird et al. 2013, Baird pers. comm.). The filtered satellite tag locations were plotted in ArcMap 10.3.

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[5] https://www.movebank.org

Supplemental Tables

Table S1. Summary of cetacean sightings during the Mariana Islands Sea Turtle and Cetacean Survey (MISTCS, Fulling et al. 2011) including the total number of encounters, group-size range, depth range (m), the number of groups (n) used for abundance estimation, the mean group size (S) and coefficient of variation (CV) for n groups, the abundance estimate (N) and CV for the MISTCS survey area (see Figure S1). Note: information within this table was excerpted from Tables 2, 3, 5 in Fulling et al. 2011, and the species listed are only those that were also encountered during the Pacific Islands Fisheries Science Center (PIFSC) surveys and are listed in the same order as Table S3.

Species	Encounters	Group Size Range	Depth Range (m)	n	S (CV)	N (CV)
Spinner dolphin	1	98	426	1	98	1,803 (0.96)
Pantropical spotted dolphin	17	1–115	114–5,672	11	64.2 (0.58)	12,981 (0.70)
Bottlenose dolphin	4	3–10	4,241–5,011	3	2.2 (0.81)	122 (0.99)
Short-finned pilot whale	5	5–43	927–4,490	4	17.5 (0.50)	909 (0.68)
Beaked whales	3	1	2,122–3,984	—	—	—
Bryde's whale	18	1–3	2,549–7,373	10	1.4 (0.12)	233 (0.45)
Rough-toothed dolphin	2	7–15	1,019–4,490	1	9	166 (0.89)
Sperm whale	23	1–25	809–9,874	11	5.1 (0.40)	705 (0.60)
False killer whale	10	2–26	3,059–8,058	5	9.8 (0.43)	637 (0.74)
Melon-headed whale	2	80–109	3,224–3,935	2	94.5 (0.15)	2,455 (0.70)
Pygmy killer whale	1	6	4,439	1	6	78 (0.88)
Striped dolphin	10	7–44	2,362–7,570	7	27.4 (0.34)	3,531 (0.54)
Humpback whale	1	8	148	—	—	—

Table S2. Summary of small-boat surveys for cetaceans conducted by the Pacific Islands Fisheries Science Center off of the southernmost islands of the Mariana Archipelago including the month(s) during which surveys were conducted, the number of survey days (No. Surveys), and the distance of on-effort trackline (km). The 3-Islands refer to Saipan, Tinian, and Aguijan.

Year	Location	Month(s)	No. Surveys	Distance (km)
2010	3-Islands	Feb–Mar	6	559
	Rota	—	0	0
	Guam	Feb	10	681
		Total	16	1,240
2011	3-Islands	Aug	15	1,424
	Rota	Sept	6	605
	Guam	Aug–Sep	9	949
		Total	30	2,978
2012	3-Islands	Jun	14	1,539
	Rota	May–Jun	6	500
	Guam	May; Jul	11	1,292
		Total	31	3,331
2013	3-Islands	Jul	14	1,493
	Rota	Jul	6	493
	Guam	Jun–Jul	10	1,062
		Total	30	3,048
2014	3-Islands	Apr; May–Jun	23	2,223
	Rota	Jun	5	471
	Guam	Apr; May	17	1,363
		Total	45	4,058
2015	3-Islands	Feb–Mar	8	511
	Rota	Aug–Sep	6.5	668
	Guam	Aug–Sep	15	1,373
		Total	29	2,552
2016	3-Islands	Mar; May	20	1,730
	Rota	May	5	304
	Guam	May–Jun	8	709
		Total	33	2,744
2017	3-Islands	Feb; May	15	1,306
	Rota	—	0	0
	Guam	May	8	688
		Total	23	1,994
2018	3-Islands	Feb; Aug–Sep	17	1,241
	Rota	—	0	0
	Guam	Sep	5	448
		Total	22	1,689
2019	3-Islands	Jan	11	671
	Rota	—	0	0
	Guam	—	0	0
		Total	11	671

*In September 2015, a 1-day survey was conducted between Rota and Guam.

Table S3. Summary of cetacean encounters during Pacific Islands Fisheries Science Center small-boat and ship surveys in the Mariana Archipelago 2010–2019 including species common name, total number of encounters, median group size and range, median depth (m) and range, median shore distance (km) and range, the number (No.) of photos and biopsy samples collected, No. of satellite tags deployed, and No. of acoustic recordings. Species are listed in order of frequency of occurrence with the exception of humpback whales that occur only seasonally within the Mariana Archipelago.

Species	Encounters	Median Group Size (range)	Median Depth (m) (range)	Median Shore Distance (km) (range)	No. Photos	No. Biopsy Samples	No. Satellite Tags	No. Acoustic Recordings
Spinner dolphin	180	29 (1–135)	44 (2–4,237)	0.6 (0.1–112)	46,721	113	0	13
Pantropical spotted dolphin	62	35 (4–145)	895 (93–3,935)	6.5 (1.7–188)	12,718	70	1	7
Bottlenose dolphin	47	8 (1–27)	146 (17–4,476)	5.8 (0.2–262)	8,467	43	6	4
Short-finned pilot whale	29	29 (4–48)	724 (51–4,476)	6.9 (0.5–221)	23,726	113	23	6
Beaked whales	19	1 (1–5)	1,202 (267–3,517)	7.0 (0.5–226)	890	1	0	11
Bryde's whale	18	1 (1–4)	2,238 (487–4,295)	72 (9.0–302)	3,536	5	0	12
Rough-toothed dolphin	16	12 (1–27)	616 (30–4,163)	6.7 (0.4–227)	3,371	10	1	5
Sperm whale	12	9 (1–15)	1,809 (374–4,276)	19 (1.1–157)	3,746	18	2	4
False killer whale	8	14 (2–31)	1,097 (88–2,461)	6.9 (0.7–40)	7,992	36	9	1
Melon-headed whale	8	229 (85–399)	1,848 (903–3,383)	28 (2.6–258)	10,867	62	3	5
Pygmy killer whale	6	9 (6–22)	569 (38–3,956)	8.1 (1.1–219)	2,086	5	0	1
Dwarf sperm whale	6	2 (1–4)	747 (642–1,854)	3.6 (1.6–267)	986	1	0	3

Species	Encounters	Median Group Size (range)	Median Depth (m) (range)	Median Shore Distance (km) (range)	No. Photos	No. Biopsy Samples	No. Satellite Tags	No. Acoustic Recordings
Risso's dolphin	3	5 (1–8)	3,752 (2,594–4,398)	92 (75–95)	21	0	0	1
Striped dolphin	1	20	3,904	58	97	0	0	0
Humpback whale	42	2 (1–8)	39 (12–624)	8.0 (1.2–18)	18,243	30	0	0

Table S4. Summary of data contributed by the U.S. Navy from other survey efforts in the Mariana Archipelago. MISTCS–Mariana Islands Sea Turtle and Cetacean Survey in 2007 (Fulling et al. 2011); HDR–small-boat surveys conducted off Saipan and Guam in 2011 and 2012 (HDR 2011, 2012); TetraTech–ship and small-boat survey off Pagan, Saipan, and Tinian in 2013 (TetraTech 2014). All biopsy samples were collected under the Pacific Islands Fisheries Science Center's Cetacean Research Program permit. TBD–to be determined.

	MISTCS		HDR			TetraTech		
Species	No. Encounters for Photo Analysis	No. Photos	No. Encounters for Photo Analysis	No. Photos	No. Biopsy Samples	No. Encounters for Photo Analysis	No. Photos	No. Biopsy Samples
Spinner dolphin	1	22	7	1,786	—	4	TBD	5
Pantropical spotted dolphin	1	55	1	TBD	4	—	—	—
Bottlenose dolphin	2	24	2	222	—	1	1,094	—
Short-finned pilot whale	4	196	2	1,232	3	—	—	—
False killer whale	6	175	—	—	—	—	—	—
Sperm whale	6	327	1	—	—	—	—	—
Bryde's whale	10	589	—	—	—	—	—	—
Melon-Headed Whale	2	202	1	543	2	—	—	—
Humpback whale	1	199	—	—	—	—	—	—
Total	33	1,789	12	3,489	9	5	1,094	5

Table S5. Spinner dolphin mtDNA F_{ST} (p-value) above diagonal (calculated using Arlequin) and microsatellite (18 loci) F_{ST} (p-value) calculated using Genepop with Exact test for p-value. Values are significant at p<0.05. Numbers in parentheses after location in column headers are the sample sizes used for mtDNA comparisons. Numbers in parentheses after row location names are the sample sizes used for microsatellite comparisons. Differentiation is measured by conventional F_{ST} index, which ranges from F_{ST} = 0, where there is no difference in compared frequencies, to F_{ST} = 1 if there are fixed differences in alternate frequencies. As a general rule of thumb, values of F_{ST} <0.05 suggest moderate levels of genetic isolation and F_{ST} >0.20 represent nearly complete isolation (i.e., less than one migrant per generation) (Baker 2015). The 3-Islands refer to Saipan, Tinian, and Aguijan.

	Guam (25)	Rota (10)	3-Islands (55)
Guam (23)	–	0.000 (0.947)	0.017 (0.123)
Rota (10)	0.004 (0.084)	–	0.000 (0.584)
3-Islands (53)	0.004 (0.009)	0.000 (0.037)	–

Table S6. Pantropical spotted dolphin mtDNA F_{ST} (p-value) above diagonal (calculated using Arlequin) and microsatellite (12 loci) F_{ST} (p-value) below diagonal (calculated using Genepop with Exact test for p-value). One individual from Guam had a poor quality microsatellite genotype and was excluded from microsatellite comparisons. Values are significant at p<0.05. Numbers in parentheses after location in column headers are the sample sizes used for mtDNA comparisons. Numbers in parentheses after row location names are the sample sizes used for microsatellite comparisons. Differentiation is measured by conventional F_{ST} index, which ranges from F_{ST} = 0, where there is no difference in compared frequencies, to F_{ST} = 1 if there are fixed differences in alternate frequencies. As a general rule of thumb, values of F_{ST} <0.05 suggest moderate levels of genetic isolation and F_{ST} >0.20 represent nearly complete isolation (i.e., less than one migrant per generation) (Baker 2015). The 3-Islands refer to Saipan, Tinian, and Aguijan.

	Guam (28)	Rota (20)	3-Islands (6)
Guam (27)	–	0.029 (0.025)	0.048 (0.072)
Rota (20)	0.009 (0.037)	–	0.012 (0.340)
3-Islands (6)	0.000 (0.891)	0.000 (0.832)	–

Table S7. Pantropical spotted dolphin mtDNA F_{ST} (p-value) (calculated using Arlequin) for the Mariana Archipelago compared to other Archipelagos in the Pacific Ocean. Numbers in parentheses following location names are the sample sizes.

	Marianas (54)
Marquesas (50)	0.0260 (<0.0001)
Solomons (31)	0.0302 (0.0001)
Hawaiʻi (100)	0.2841 (<0.0001)

Supplemental Figures

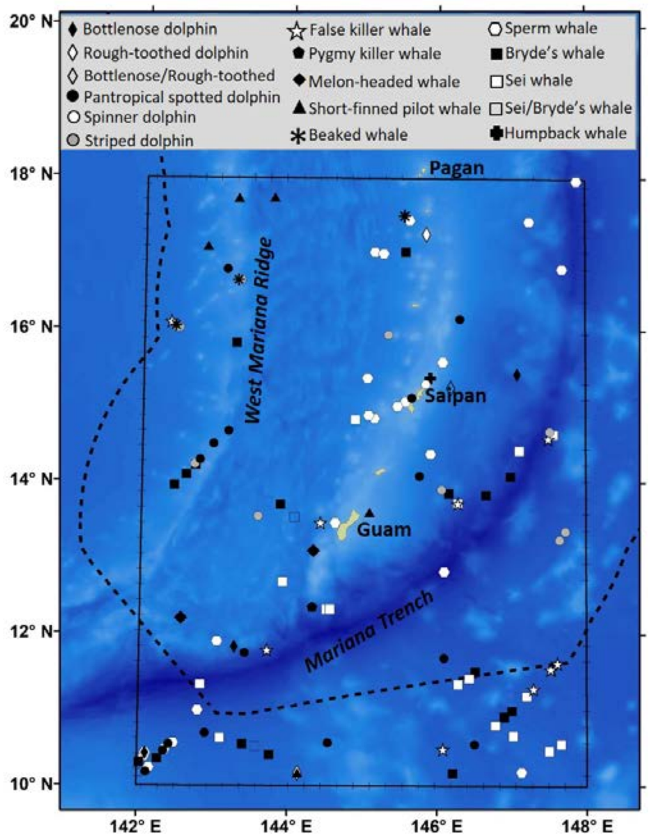

Figure S1. Cetacean encounters during the 2007 Mariana Islands Sea Turtle and Cetacean Survey (MISTCS, Fulling et al. 2011). Beaked whales were listed as either *Mesoplodon* sp. or unidentified beaked whale. Dashed black line–Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone. Hashed black line–MISTCS study area. Note: sei whales were not included within this summary document because they were not observed during Pacific Islands Fisheries Science Center surveys nor detected in the Pacific Islands Passive Acoustic Network data sets.

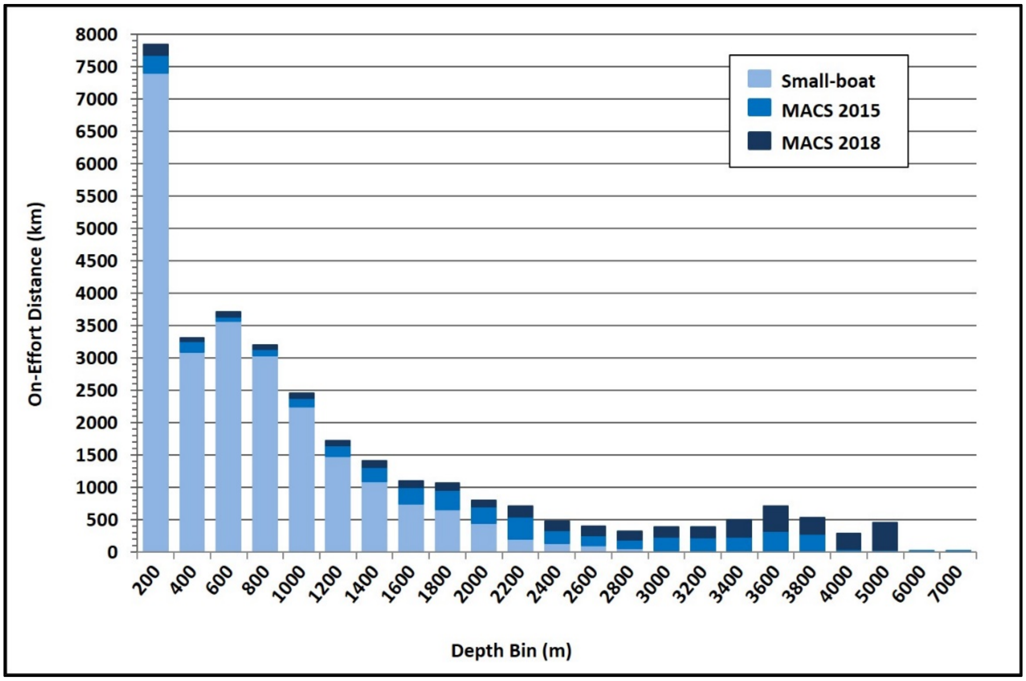

Figure S2. Survey effort (km) by depth (m) during the Pacific Islands Fisheries Science Center cetacean surveys in the Mariana Archipelago. Total survey trackline distance was 24,305 km for the 2010–2019 small-boat surveys, 4,237 km for the 2015 Mariana Archipelago Cetacean Survey (MACS), and 3,362 km for the 2018 MACS.

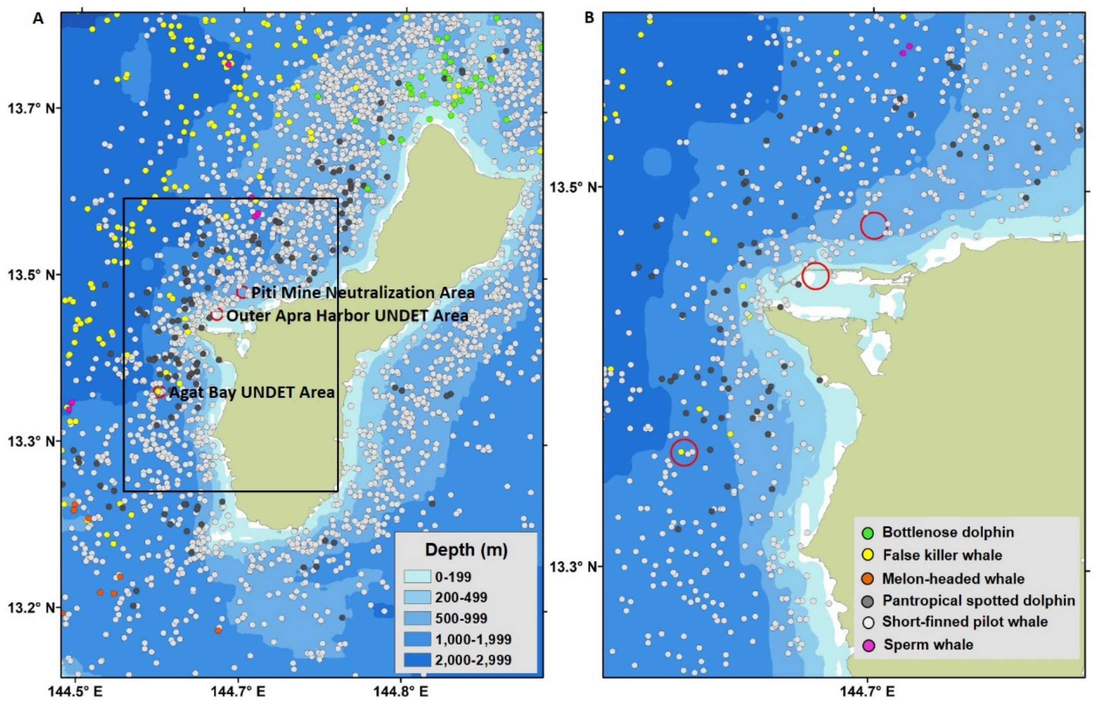

Figure S3. U.S. Navy underwater explosive operation sites and satellite telemetry locations of tagged cetaceans off Guam. Panel A–Wide-area view. Panel B–Zoomed-in view of the boxed area within panel A. Circles represent the 640 m exclusion zones. Piti Mine Neutralization Area = 750 m depth, 1.9 km shore distance; Outer Apra Harbor UNDET Area = 38 m depth, 0.3 km shore distance; Agat Bay UNDET Area = 1,750 m depth, 6.7 km shore distance.

Figure S4. Pantropical spotted dolphins, with scarring and dorsal fin disfigurements consistent with potential entanglement in hook-and-line fishing gear, photographed during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys.

Figure S5. Short-finned pilot whales, with dorsal fin scarring and mutilation suggestive of line entanglement, photographed during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys and 2018 Mariana Archipelago Cetacean Survey.

Figure S6. Bryde's whale, with line wrapped over its blow hole, photographed during the Pacific Islands Fisheries Science Center 2018 Mariana Archipelago Cetacean Survey.

Figure S7. Rough-toothed dolphins, with dorsal fin disfigurements consistent with potential entanglement in hook-and-line fishing gear, photographed during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys and 2015 Mariana Archipelago Cetacean Survey.

Figure S8. False killer whales, with scarring and dorsal fin disfigurements consistent with potential entanglement in fishing gear, photographed during the Pacific Islands Fisheries Science Center 2010–2019 small-boat surveys.