Final Report

Odontocete Studies on the Pacific Missile Range Facility in August 2018: Satellite-Tagging, Photo-Identification, and Passive Acoustic Monitoring

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Cover Photo Credit:

Short-finned pilot whale (*Globicephala macrorhynchus*) with a Fastloc-GPS tag, off Kauaʻi. Photograph taken by Colin J. Cornforth under National Marine Fisheries Service permit no. 20605.

Table of Contents

Acronyms and Abbreviations

BARSTUR	Barking Sands Tactical Underwater Range
BSURE	Barking Sands Underwater Range Expansion
CRC	Cascadia Research Collective
CS-SVM	class-specific support vector machine classifier
FFT	Fast Fourier Transform
GPS	Global Positioning System
kHz	kilohertz
km	kilometer(s)
km^2	square kilometer(s)
m	meter(s)
M3R	Marine Mammal Monitoring on Navy Ranges
MFA	mid-frequency active
PAM	passive acoustic monitoring
PMRF	Pacific Missile Range Facility
SCC	Submarine Command Course
SSSM	switching state-space model
SWTR	Shallow Water Training Range

Executive Summary

As part of a long-term U.S. Navy-funded marine mammal monitoring program, in August 2018 a combination of vessel-based field effort and passive acoustic monitoring was carried out on and around the Pacific Missile Range Facility (PMRF) off Kauaʻi prior to a Submarine Command Course scheduled for mid-August 2018. The purpose of the monitoring effort was to assess the spatial movement patterns and habitat use of cetaceans that are exposed to mid-frequency active sonar and how those patterns influence exposure and potentially responses. The U.S. Navy funded 13 days of small-vessel effort and the National Marine Fisheries Service funded an additional 2 days of effort. Results from this effort were compared with previous Cascadia Research Collective (CRC) survey effort and photo-identification and tag data from Kauaʻi and Niʻihau, based on surveys in 10 different years since 2003. During the survey, the Marine Mammal Monitoring on Navy Ranges (M3R) system was used both to direct the research vessel to potential high-priority species, and to inform the research vessel when only low-priority species were detected on the range, allowing it to survey off the range and thus increasing overall encounter rates with high-priority species.

Over the course of the 15-day project, there were 1,597 kilometers (100.0 hours) of small-vessel survey effort, resulting in 57 sightings of seven species of odontocetes. Of the 57 sightings, 24 were on PMRF representing five of the seven species, and of those, five were directed by M3R acoustic detections. During the encounters, we took 33,452 photographs for individual identification, with photographs added to long-term CRC regional photo-identification catalogs for short-finned pilot whales (*Globicephala macrorhyncus*), bottlenose dolphins (*Tursiops truncatus*), and rough-toothed dolphins (*Steno bredanensis*).

As expected based on previous CRC efforts off Kauaʻi and Niʻihau, rough-toothed dolphins were the most frequently encountered species, with 34 of 57 encounters (59.6 percent) being of this species. Nineteen of the 34 encounters were on PMRF, and three of those groups were found in response to acoustic detections from M3R (60 percent of all responses to acoustic detections). One sighting was of a mixed group of rough-toothed and bottlenose dolphins, only the third sighting of a mixed-species group involving those two species in a combined 780 sightings of the two species in CRC's Hawaiʻi dataset. One location-only tag was deployed on a rough-toothed dolphin. During the five days of location data from the functioning tag, the tagged individual remained off the west coast of Kauaʻi, moving off and on PMRF on four occasions. A social network analysis of photo-identification data of rough-toothed dolphins indicated that the tagged individual was part of the resident, island-associated population.

Short-finned pilot whales were encountered on five occasions over a three-day period, and represented three different social groups. Depth-transmitting satellite tags that included Fastloc-GPS capability were deployed on individuals in two of the three groups, with tag deployments on 17 and 19 August 2018 (the latter group cued by an acoustic detection from M3R). The group tagged on 17 August was linked by association with the main cluster of short-finned pilot whales known to be resident off the island of Hawaiʻi, but re-sighted individuals have only been seen on one occasion off that island, so the group does not appear to exhibit strong fidelity to that area. The group tagged 19 August was linked by association with the western community of short-finned pilot whales known to be resident to Kauaʻi, Niʻihau, and Oʻahu. The third, untagged group (seen both on 17 and 18 August) had been previously tagged off Niʻihau in September 2015 and was thought to be from the resident western community, based on movements from tag data. The Fastloc-GPS tags were programmed to maximize obtaining Fastloc-GPS locations and dive data for a 10-day window spanning the Submarine Command Course scheduled to start on 21 August 2018. These tags produced more than twice as many Fastloc-GPS locations than Argos locations during the 10-day window, and behavior (i.e., dive and surfacing) data coverage during that period ranged from 77.4 to 99.3 percent. This programming regime was successful at producing high resolution information over a shorter-period of time in order to allow a detailed assessment of exposure and response to mid-frequency active sonar. Over a 37-day period the group associated with the eastern community (tagged 17 August) spent most of its time in deep water far offshore (median depth=4,215 meters [m], median distance from shore=73.3 kilometers [km]), with the track ending in slope waters off Hawaiʻi Island. By contrast, the group associated with the western community (tagged 19 August) remained in slope waters (median depth=906 m; median distance from shore=6.9 km) around Kauaʻi over the 23 days the tag transmitted. This group remained in the area during the surface component of the Submarine Command Course, and location and behavior data will be used to assess exposure and response of the tagged individual to mid-frequency active sonar.

There were two encounters with melon-headed whales (*Peponocephala electra*) 10 days apart. Based on a photo-identification match between the two encounters, they appeared to be the same group seen on two different occasions. Two Fastloc-GPS dive satellite tags were deployed during the first encounter, although location data were only obtained from one individual for just over nine days. This is only the third time that melon-headed whales have been satellite-tagged off Kauaʻi or Niʻihau. Over the 9 days of tag data, the individual moved 830 km, with a median depth and distance from shore of 2,220 m and 14.8 km, respectively.

Sperm whales (*Physeter macrocephalus*) were encountered on one occasion, with the vessel directed to the group based on acoustic detections from M3R, as the sperm whale group approached the range from the south. This was only Cascadia's fourth encounter with sperm whales off Kauaʻi or Niʻihau. This group was widely dispersed (>4 km) and included at least one adult male, with long dives of approximately 1 hour in duration. Individuals were not approachable for tagging.

There was one sighting of pantropical spotted dolphins (*Stenella attenuata*), south of PMRF. One individual was satellite-tagged, although only a single location was received from the tag. Four biopsy samples were obtained, and will be analyzed for genetics to further understand population structure of this species in the islands. Bottlenose dolphins were encountered on six occasions, and good quality identifications of 36 distinctive individuals were obtained. Of those, 32 had been previously documented, and all were linked by association with the resident community of bottlenose dolphins from Kauaʻi and Niʻihau. Spinner dolphins (*Stenella longirostris*) were seen on eight occasions but this was a low-priority species so limited efforts were expended to work with them.

Probability-density analyses were undertaken using 12-hour locations from switching state-space models of tag-location data obtained for the three species for which tag data were available from this effort. Core areas (50 percent kernel densities) were identified for the resident populations of rough-toothed dolphins (1,642 square kilometers [km^2]), the Hawaiian

Islands stock of melon-headed whales (82,431 km^2), and the western community of short-finned pilot whales (7,517 km^2). While the core areas for all three populations overlap with at least part of PMRF, the differences in the proportion of the core area that overlaps with PMRF suggests that the likelihood of exposure to mid-frequency active sonar on PMRF varies substantially between populations. Continued collection of photo-identification, movement, and habitat-use data from these species allows for a better understanding of the use of the range and surrounding areas, as well as estimation of abundance and examination of trends in abundance for resident populations.

1. Introduction

The U.S. Navy regularly undertakes training and testing activities on or around the Pacific Missile Range Facility (PMRF) between Kauaʻi and Niʻihau. Vessel-based field studies of odontocetes first began off Kauaʻi and Niʻihau in 2003 (Baird et al. 2003) as part of a long-term, multi-species assessment of odontocetes in the main Hawaiian Islands (Baird et al. 2013a; Baird 2016) being undertaken by Cascadia Research Collective (CRC). As with the other main Hawaiian Islands, the proximity of deep water close to shore provides habitat for a number of odontocete species off Kauaʻi. However, the small size of the island and its orientation relative to prevailing trade winds result in a small area that is typically calm enough to detect, and work with, most species. Thus, considerable survey effort has been needed to learn about all but the most frequently encountered species of odontocetes off the island.

In recent years, most whale and dolphin research off Kauaʻi and Niʻihau has been sponsored by the U.S. Navy. Initially using photo-identification of distinctive individuals and biopsy sampling for genetic analyses, CRC surveys in 2003 and 2005 showed evidence of site fidelity for rough-toothed dolphins (*Steno bredanensis*), bottlenose dolphins (*Tursiops truncatus*), and short-finned pilot whales (*Globicephala macrorhynchus*), as well as provided information on relative sighting rates around the islands (Baird et al. 2006, 2008a, 2009). Sighting rates of a fourth species, pantropical spotted dolphins (*Stenella attenuata*), were low off Kauaʻi and Niʻihau in comparison to other areas (Baird et al. 2013a), and genetic samples obtained from sightings off Kauaʻi and Niʻihau suggest that spotted dolphins in that area are part of a pelagic, open-ocean, population (Courbis et al. 2014).

CRC efforts using satellite tags to assess movements and behavior of individual toothed whales on and around PMRF began in June 2008 in association with the Rim-of-the-Pacific naval training event (Baird et al. 2008b). During that effort, three melon-headed whales (*Peponocephala electra*) and a short-finned pilot whale were tagged and tracked for periods ranging from 3.7 to 43.6 days (Baird et al. 2008b; Woodworth et al. 2011). While the melon-headed whales moved far offshore to the west, the short-finned pilot whale remained around Kauaʻi and moved offshore of western Oʻahu (Baird et al. 2008b). Since 2008 and prior to August 2018, CRC has had 12 additional vessel-based field projects off Kauaʻi, 11 in conjunction with passive acoustic monitoring (PAM) through the Marine Mammal Monitoring on Navy Ranges (M3R) program. M3R, a real-time PAM system capable of fully automated detection and localization of marine mammals, has been implemented at three major Navy undersea training ranges: the Atlantic Undersea Test and Evaluation Center (2002–present; Jarvis et al. 2014), the Southern California Offshore Range (2006–present; Falcone et al. 2009), and most recently at PMRF (2011–present). On PMRF, PAM is used not only to direct the research vessel to vocalizing groups of high-priority species, increasing encounter rates on the range and providing visual verification of vocalizing species, but also to identify times when no high-priority species are vocalizing within the range of the research vessel, allowing it to more effectively search for high-priority species in calm waters south of PMRF.

During the 12 CRC field efforts off Kauaʻi since 2008, 74 satellite tags have been deployed on eight different species of odontocetes (**Table 1**; Baird et al. 2011, 2012a, 2012b, 2013b, 2013c, 2014a, 2015, 2016, 2017a, 2018). Results of field efforts through August 2017 have been previously summarized (Baird et al. 2018; Baird 2016). Combined, efforts through August 2017 accounted for 1,196 hours of boat-based search effort (20,307 kilometers [km]) over 10 different years, providing a strong basis for assessing the relative abundance and population identity of species encountered.

As part of the regulatory compliance process associated with the Marine Mammal Protection Act and the Endangered Species Act, the U.S. Navy is responsible for meeting specific monitoring and reporting requirements for military training and testing activities. In support of these monitoring requirements, the U.S. Navy funded 13 days of field work off Kaua'i to be undertaken prior to a Submarine Command Course (SCC) in August 2018. Two additional days of effort were also undertaken, funded by a grant from the National Marine Fisheries Service to CRC. This report presents findings from this combined effort. The marine mammal monitoring reported here is part of a long-term monitoring effort under the U.S. Navy's Marine Species Monitoring Program. The specific monitoring questions to be addressed during the August 2018 effort, as noted in the contract, were related to the spatial movement patterns and habitat use of multiple species and how those patterns may influence exposure and potentially responses to mid-frequency active (MFA) sonar. In addition to the results of work from August 2018, we incorporate previous efforts, including results where relevant from CRC work elsewhere in the main Hawaiian Islands (Baird 2016). Data obtained through this effort are also contributed to a study examining exposure and response of several species to MFA sonar (Baird et al. 2014b, 2017b); these results will be presented elsewhere.

Table 1. Details of previous field efforts off Kaua'i involving small-vessel surveys, satellite tagging, or M3R passive acoustic monitoring.

Dates	Hours Effort	Odontocete Species Seen[1]	Species Tagged (number tagged)	Odontocete Species Detected on M3R
25-30 Jun 2008	53.8	*Pe, Sb, Sl, Gm,*	*Gm* (1), *Pe* (3)	N/A
16-20 Feb 2011	33.9	*Tt, Sb, Sl, Gm,*	*Gm* (3)	N/A
20 Jul–8 Aug 2011	118.8	*Tt, Sb, Sl, Sa, Oo*	*Tt* (1), *Sb* (3)	*Tt, Sb, Sl*
10–19 Jan 2012	42.2	*Tt, Sb, Sl, Gm, Md*	*Sb* (1), *Gm* (2)	*Tt, Sb, Gm, Sl, Md*
12 Jun–2 Jul 2012	115.7	*Tt, Sb, Sl, Sa, Gm, Pc*	*Tt* (2), *Sb* (3), *Pc* (3)	*Tt, Sb, Gm, Pc*
2–9 Feb 2013	55.9	*Tt, Sb, Sl, Gm*	*Tt* (3), *Sb* (1), *Gm* (2)[2]	*Tt, Sb, Sl, Md, Pm*
26 Jul–2 Aug 2013	36.6	*Tt, Sb, Sl, Pc*	*Sb* (2), *Pc* (1)	*Tt, Sb, Pc, Md, Zc, Pm*
1–10 Feb 2014	66.3	*Tt, Sb, Sl, Gm, Md,*	*Md* (2)[2], *Tt* (2), *Sb* (2), *Gm* (6)	*Tt, Sb, Md, Gm*
7–17 Oct 2014	77.7	*Tt, Sb, Sl, Gm, Fa, Pc, Pm*	*Tt (2),Gm (1), Pc (2), Pm (1)*	*Tt, Pc, Md*
4–16 Feb 2015	63.4	*Tt, Sb, Sl, Gm, Ks*	*Tt (2), Sb (3), Gm (5)*	*Tt, Gm, Pm*
3–11 Sep 2015	65.0	*Tt, Sb, Sl, Gm, Pc*	*Tt (1), Sb (1), Pc (1), Gm (2)*	*Tt, Sb, Pc, Md*
9–15 Feb 2016	49.3	*Tt, Sb, Gm, Sa*	*Gm (6), Sb (2), Sa (1)*	*Pm, Md, Gm, Sb*
6–20 Aug 2017	77.4	*Tt, Sb, Sa, Sl, Pe*	*Sa (2), Sb (2), Pe (2)*	*Sa, Sb, Pe, Oo*
Total	**856.0**		*Gm* (27)[2], *Pe* (5), *Tt* (13), *Sb* (20), *Sa* (3), *Pc* (7), *Md (2)*[2], *Pm (1)*	

[1]Species codes: *Tt=Tursiops truncatus, Sb=Steno bredanensis, Gm=Globicephala macrorhynchus, Pe=Peponocephala electra, Sl=Stenella longirostris, Sa=Stenella attenuata, Oo=Orcinus orca, Pc=Pseudorca crassidens, Pm=Physeter macrocephalus, Md=Mesoplodon densirostris, Zc=Ziphius cavirostris,*

[2]Two tags did not transmit for each species.

M3R=Marine Mammal Monitoring on Navy Ranges

2. Passive Acoustic Monitoring Methods

2.1 PMRF Instrumented Hydrophone Range

The PMRF instrumented hydrophone range is configured with 219 bottom-mounted hydrophones, 132 of which are currently active and available for PAM. The hydrophones were installed in four phases, such that each system has different acoustic monitoring capabilities (**Table 2**). The four range systems are: the Shallow Water Training Range (SWTR), the Barking Sands Tactical Underwater Range (BARSTUR), the legacy Barking Sands Underwater Range Expansion (BSURE), and the refurbished BSURE. The ranges partially overlap, but SWTR is located in the shallow waters of the southeastern part of the range spanning approximately 30 km north to south and varying from approximately 6 to 12 km east to west. BARSTUR is located in the southwestern part of the range and spans approximately 28 km north to south and approximately 18 km east to west. BSURE is located in the northern part of the range and spans approximately 73 km north to south and approximately 30 km east to west. Each range consists of several offset bottom-mounted cables (strings), with multiple hydrophones spaced along each string to create hexagonal arrays. Passive acoustic data pass through the range's operational signal-processing system and the M3R system in parallel. In this way, marine mammal monitoring does not interfere with range use. Many of the SWTR hydrophones and some of the BARSTUR hydrophones are no longer functional, reducing the available data for nearshore cetacean detections.

Table 2. PMRF undersea range characteristics.

Range Area Name	Depth Range (m)	Hydrophone Numbers (string names)	Hydrophone Bandwidth
BARSTUR	~1,000–2,000	2–42 (1–5) 1,10, 21, 24, 37, 41	8–40 kHz 50 Hz–40 kHz
BSURE Legacy	~2,000–4,000	43–60 (A, B)	50 Hz–18 kHz
SWTR	~100–1,000	61–158 (C–H)	5–40 kHz
BSURE Refurbish	~2,000–4,000	179–219 (I–L)	50 Hz–45 kHz

Hz=Hertz; kHz=kilohertz; m=meters; ~=approximately

2.2 M3R System

The M3R system, discussed in detail in Jarvis et al. (2014), consists of specialized signal-processing hardware and detection, classification, localization, and display software that provide a user-friendly interface for real-time PAM. Prior to 2017, the M3R system at PMRF was used on 12 occasions (**Table 1**) in collaboration with vessel-based field efforts, with one or more system operators using the M3R system to direct the research vessel to locations or areas of acoustic detections. This combination approach provides visual species verifications for groups detected acoustically, as well as visual sightings of animals on the range that may not have been acoustically detected. It also increases the encounter rate for vessel-based efforts by using acoustic detections to direct the vessel. Increased encounter rates result in greater opportunities for deploying satellite tags (see below), as well as photo-identifying individuals and collecting biopsy samples for genetic studies.

Passive acoustic monitoring provides the ability to detect vocalizing animals on the range hydrophones in real-time. Multiple detection algorithms are run, and the data are used to provide localizations where possible. This requires the detection and association of the same vocalization on at least three hydrophones. The ability to localize is highly species dependent. For example, beaked whale foraging clicks have a narrow beam-width. Detecting the same click on three hydrophones is challenging and depends heavily on the whale-hydrophone geometry and the hydrophone spacing. In some cases, only the general area where individuals are vocalizing is known and can be used for attempting at-sea species verifications. Sperm whales (*Physeter macrocephalus*) are more readily localized because the source level of their clicks has been measured at well over 200 decibels referenced to 1 micropascal (Mohl et al. 2000). Therefore, each click is typically detected on multiple range hydrophones allowing localization via multilateration.

The various automated detection algorithms available within M3R are tuned to specific species or types of vocal behavior. Specifically, M3R includes a robust class-specific support vector machine (CS-SVM) classifier that can reliably detect foraging clicks from Blainville's (*Mesoplodon densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales and sperm whales (Jarvis 2012). The CS-SVM also includes a Generic Dolphin class that detects clicks from various small odontocetes and can even detect beaked whale buzz clicks under favorable conditions. M3R also has two frequency-domain detection algorithms, a high-frequency Fast Fourier Transform (FFT) detection algorithm and a low-frequency FFT algorithm. The high-frequency FFT samples the hydrophone data at 96 kilohertz (kHz; for a 48 kHz analysis bandwidth) and forms a 2,048-point FFT with a 50 percent overlap. An adaptive noise variable threshold (exponential average) is run in every bin of the FFT. If energy in the bin is greater than the threshold, the bin level is set to 1; if below, the bin is set to 0. A detection is declared if at least one bin in the FFT is above the threshold. All detections are archived, including the hard-limited (0/1) FFT output. Detections are first differentiated by type (i.e., narrowband "whistle" or broadband "click"). Clicks are then coarsely categorized, based on frequency content, into five descriptive categories: <1.5 kHz, 1.5–18 kHz (representative of sperm whales), 12–48 kHz (representative of delphinid species), 24–48 kHz (representative of beaked whales), and 45–48 kHz. The second FFT-based detector targets low-frequency baleen whale calls. It provides analysis within the band from 0 to 3 kHz with a frequency resolution of 1.46 Hertz and runs in parallel with the high frequency FFT and the CS-SVM classifier. Low-frequency calls received by the LF FFT detector are automatically localized. Lastly, a Naval Information Warfare Center-developed low-frequency (<3 kHz) classifier aimed at minke (*Balaenoptera acutorostrata*) and fin/sei (*Balaenoptera physalus*, *B. borealis*) whales has been integrated and is available to assist the analyst in detection of these mysticete species. All of these algorithms run in parallel and detection reports from each, including species information, are archived. In addition, both the Raven and Ishmael acoustic analysis tool sets have been integrated with M3R data streams to allow for detailed manual analysis of data from individual hydrophones.

The output of M3R automated detection and classification algorithms are displayed to the PAM operator using Worldview and MMAMMAL real-time display software. MMAMMAL displays a color-coded map of the hydrophones indicating the amount of detection activity for each hydrophone, while Worldview overlays whale localizations over a high-resolution bathymetric map of the range. The PAM user can select any hydrophone(s) from the map based on detection activity and display a real-time, hard-limited FFT-based spectrogram of data from that hydrophone. These spectrograms are used by trained PAM personnel to classify the whistles and clicks to species level when possible. Prior to the current effort, detection archives from previous PMRF species verification efforts were reviewed to create a compilation of exemplar spectrograms for visually verified species including: rough-toothed dolphin, spinner dolphin (*Stenella longirostris*), bottlenose dolphin, false killer whale (*Pseudorca crassidens*), short-finned pilot whale, killer whale (*Orcinus orca*), sperm whale, and Blainville's and Cuvier's beaked whales. This compilation provided a reference set for PAM personnel to identify vocalizing species during the effort. Unique frequency characteristics based on the MMAMMAL spectrograms were identified visually and noted to aid in providing initial discrimination between species (**Table 3**). However, because of the small visual-verification sample size for most species and high overlap in signal characteristics between many odontocete species, these characteristics are far from exhaustive for feature characterization. Additional factors such as typical travel speed, habitat depth range, and dispersion of groups based on field studies (e.g., Baird et al. 2013a), were used to help determine species priority for directing the small vessel to groups when multiple groups were present in the area.

Supplementary to MMAMMAL, Worldview software also displays the hydrophone layout, color-coded for detection rate, with the addition of satellite imagery and digital bathymetry as a background. The Worldview display includes the positions of vocalizing animals (each hereafter termed a posit) derived from automated localization software and the species classification from the CS-SVM. However, additional information is provided with each position to help the PAM user determine the accuracy of the automated localization, including the number of neighboring localizations and number of "same" localizations, where "same" is defined as the same position localized by multiple detections. Typically, a higher quantity of "near-neighbor" localizations indicates a more accurate localization. Because of the localization methodology, a single-click position is more likely to be a false positive than a cluster of click positions, each indicating several neighbors. The sub-array on which the detection occurred, referenced by center hydrophone, is also indicated. Overlapping posits from multiple arrays also provides assurance that the posit is accurate. Automated click localizations provide the PAM user a real-time range-wide map for odontocete distribution of click classification type (e.g., beaked whale, sperm whale, small odontocete). In the absence of automatically generated positions, a MMAMMAL tool for semi-manual calculation of positions using hand-selected whistles or low-frequency calls was also used. When the same low-frequency (baleen whale) call or whistle is observed visually on three or more hydrophones, the user can mark the time-of-arrival of the signal on each. These times are then used in a localization algorithm to estimate the animal's position. Typically, when a group of animals is present, a cluster of posits based on multiple vocalizing animals will be plotted around the position of the group. With time, the movement of the group is evident by the track of any one individual within the group. The Worldview display also includes several standard geographic tools such as the ability to measure distance, add points to the map, and include ship navigation data when available.

Table 3. Acoustic features used for species identification and differentiation from passive acoustic monitoring based on prior M3R field efforts.

Species[1]	# Visual Verifications	Whistle Features	Click Features	Distinctive Spectrogram Features	Acoustically Similar Species
Sb	30	8–12 kHz, short sweeps centered at ~10 kHz (typically very few whistles)	12–44 kHz with most energy 16–44 kHz	Short narrowband whistles centered at 10 kHz. Typically very few whistles but lots of dense 12–44 kHz clicks	*Pc* (whistles) *Sa* (clicks)
Sl	5	8–16 kHz, highly variable	8–48 kHz, distinct presence of 40–48 kHz click energy, single animal similar to *Zc*	HF click energy from 40 to 48 kHz. Loses LF click energy first. Long ICI for single species.	*Md, Zc* (clicks) *Tt* (whistles)
Sa	3	Steep 8–20 kHz up sweeps, sometimes 'N' or '^' shaped	12–44 kHz with most energy above 24 kHz	Steepness of the up/down sweeps of whistles. Distinct sets of sweeps, up-down-up 'N' shape or up-down ^ shape	*Gm* (whistles) *Sb* (clicks)
Tt	25	primarily 8–24 kHz, highly variable, lots of loopy curves	16–48 kHz, short ICI	Density of clicks and whistles. Very wideband, long duration loopy whistles.	*Gm* *Sl* (whistles)
Gm	10	Combination of short 6–10 kHz upsweeps with long 10–24 kHz upsweeps	12–44 kHz, repetitive, slowly changing ICI	Very wide band but short duration whistles. Often single up or down sweeps.	*Tt* *Sa* (whistles)
Pc	4	5–8 kHz upsweeps, loopy whistles 8–12 kHz	8–48 kHz, most energy 8–32 kHz, continual presence of energy to 8 kHz	Click energy at 8 kHz, extending upwards to 32–40 kHz.	*Sb* (whistles), need to pay close attention to clicks to differentiate
Md	4	n/a	24–48 kHz, 0.33 s ICI	Consistent ICI and click frequency content.	*Sl* (clicks)

[1]See footnote to **Table 1**.

HF=high frequency; ICI=inter-click interval; kHz=kilohertz; LF=low frequency; n/a=not applicable; ~=approximately

Detection archives were collected from all hydrophones, 24 hours per day, for the entire period. These archives capture all detection reports and automated localizations generated during the effort. Data post-processing is significantly expedited by using the detection archives, which allow rapid evaluation of acoustic detections over long periods. Additionally, raw hydrophone data are recorded using the Naval Information Warfare Center Pacific recorder, allowing for detailed analysis of marine mammal and environmental signals and post-processing of all recorded data to further classify the species that were present, as well as estimate received levels of any mid-frequency active sonar that might occur during or following the tagging effort. The disk recorder is capable of recording precisely time-aligned audio data from all range hydrophones.

Additionally, post-processing software tools have been developed for the automated isolation of Blainville's beaked whale (and other species-specific) click trains from the archived history of CS-SVM classifier reports; a second tool then marks the position of individual foraging dives. These tools have been modified for PMRF. As the mean group size and detection statistics for Blainville's beaked whales on PMRF are determined, estimation of their density and distribution is possible (Moretti et al. 2010).

2.3 Coordination with Small-vessel Efforts

PAM was undertaken for all 15 days of small-vessel research effort. PAM began at 0600 every morning. PAM was used both to direct the research vessel to locations of acoustic detections of high-priority species (e.g., pilot whales, sperm whales), and to assess when only low-priority species (e.g., rough-toothed dolphins, bottlenose dolphins) were acoustically detected on the range, allowing the research vessel to survey in calm areas south of the PMRF. Monitoring continued until the research vessel returned to port or if weather conditions on the range were not suitable for small-boat operations or range access was restricted. A typical visual-verification cycle initiates with a radio communication from the PAM operator to the vessel providing the species and locations (referenced by hydrophone for ease of communication) of all known groups vocalizing within a reasonable travel distance from the vessel. As an example, a communication would detail groups on the SWTR and BARSTUR ranges, but not the BSURE range if the vessel was on the southern end of the SWTR area (see **Figure 1**). The decision of what group to pursue was left to the on-board scientists so that they could prioritize the combination of species preference, weather conditions, and time of day.

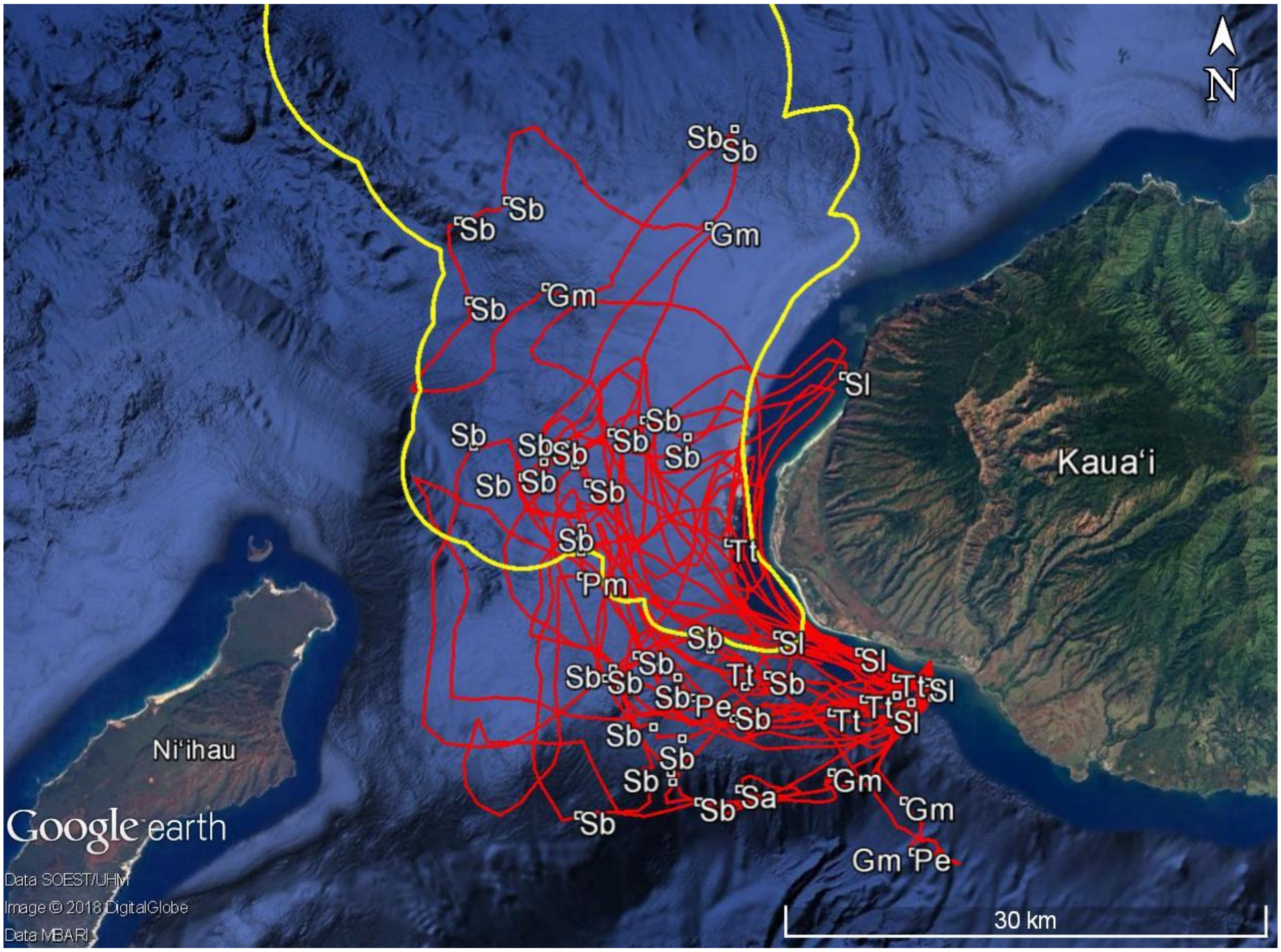


Figure 1. Search effort (red lines) and odontocete sightings (white squares) over 15 days from 6 to 20 August 2018. Species are indicated by two-letter codes (Sb=*Steno bredanensis*, Tt=*Tursiops truncatus*, Gm=*Globicephala macrorhynchus*, Sl=*Stenella longirostris*, Pe=*Peponocephala electra*, Pm=*Physeter macrocephalus*, Sa=*Stenella attenuata*). The PMRF outer boundary is indicated in yellow.

Once selected, the group of interest was radioed back to the PAM team. This group was then followed closely by the PAM team, and attempts were made to provide updated positions to the vessel. Most often the posits were generated automatically by M3R. PAM operators assessed the posit and relayed the coordinates via radio. Sometimes localization involved manually waiting for and selecting distinct whistles to localize. This process was termed a “manual posit.” A best effort was made to also communicate the confidence level of the posit (i.e., the number of solutions at the same location or in the nearby area). Human error can occur when calculating manual whistle localizations, but this is minimal with trained PAM personnel. Using a combination of automatic and manual posits builds confidence in the solutions generated. As the vessel approached the group, additional position updates were communicated by the PAM team, in real time, until receiving confirmation that the on-the-water team had sighted the group. At that time, the PAM team remained on standby until they received additional communication to prevent disruption of tagging and photo-identification activities onboard the vessel. While standing by, the PAM team continued to assess the entire range to provide information for the next encounter cycle.

3. Small Vessel Field Methods

3.1 Tag Types, Programming and Species Priorities

Eight location-dive satellite tags with Fastloc-Global Positioning System (GPS) capability (Wildlife Computers SPLASH10-F) were funded through the Marine Species Monitoring Program, six location-dive (SPLASH10) tags were available from previously funded efforts, and one location-only tag (Wildlife Computers SPOT6) was available from another grant to Cascadia Research Collective. As per the conditions of the contract, SPLASH10-F tags were only to be used with high-priority species, i.e., beaked whales, sperm whales, "blackfish," or baleen whales other than humpbacks. Tags were in the LIMPET configuration, with attachment to the animals with two titanium darts with backward-facing petals, using either short (4.4-centimeter) or long (6.8-centimeter) darts (Andrews et al. 2008), depending on species (e.g., short darts for rough-toothed dolphins, melon-headed whales, or pantropical spotted dolphins, long darts for short-finned pilot whales).

Tags were programmed to maximize the likelihood of obtaining behavior and location information over a 10-day period that spanned the scheduled SCC (3.5 days before and after and the 3 days during the SCC). SPLASH10-F tags were set to transmit up to 900 times per day, over the 17 hours of the day that corresponded to all but 1 hour during which there were Argos satellite overpasses. In terms of transmissions, tags were set with Fastloc-GPS locations as high priority and behavior logs (i.e., dive data) as low priority, with a 6-day buffer. Behavior data and Fastloc-GPS locations were only collected up to 3.5 days past the scheduled end of the SCC, to maximize throughput of both location and behavior data during the period of interest (i.e., before, during, and after the SCC). For tags that remained transmitting after this period, this allowed for prioritization of transmitting existing tag data, rather than collection of new data, in order to minimize gaps in the location and dive record during the period of interest. Tags were programmed to record dives that exceeded 50 meters (m) in depth, with depth readings of 3 m being used to determine the start and end of dives, thus dive durations are slightly negatively biased. Given typical odontocete descent and ascent rates of 1 to 2 m/second, dive durations recorded are likely only 3 to 6 seconds shorter than actual dive durations. Prior to the field effort, satellite passes were predicted using the Argos website to determine the best hours of the day for transmissions given satellite overpasses for the approximately 2-month period starting at the beginning of the deployment period.

Two shore-based Argos receiver stations were used to try to increase the amount of dive and surfacing data obtained from the location-dive tags, as well as the Fastloc-GPS locations. This system uses a Wildlife Computers MOTE (see Jeanniard-du-Dot et al. 2017) to record and transmit Fastloc-GPS locations as well as diving and surfacing data to a Wildlife Computers interface for data access. One system was at 456 m elevation on Mākaha Ridge, Kaua'i (22.13°N, 159.72°W), with directional antennas oriented to the north and southwest, and one system was at approximately 365 m elevation on the east side of Ni'ihau (21.95°N, 160.08°W), with one directional antenna oriented to the north and one omnidirectional antenna.

3.2 Vessel, Time and Area of Operations

The field project was timed to occur immediately prior to a Submarine Command Course scheduled for to start 21 August 2018[1]. Thirteen days of effort were funded as part of the Navy's Marine Species Monitoring program, and an additional two days of effort were funded by a grant from the National Marine Fisheries Service to CRC.

The vessel used was a 24-foot (7.3 m) rigid-hulled Zodiac Hurricane, powered by twin Suzuki 140-horsepower outboard engines, and with a custom-built bow pulpit for tagging and biopsy operations. The vessel was launched each morning at sunrise, and operations continued during daylight hours as long as weather conditions were suitable, with a team of five to seven observers scanning 360 degrees around the vessel. The primary launch site was the Kīkīaola small boat harbor. Vessel locations were recorded on a GPS unit at 5-minute intervals.

When weather conditions permitted and there were no range access constraints, the primary area of operations was the PMRF instrumented hydrophone range, with a focus on deep-water areas to increase the likelihood of encountering high-priority species (see below). Coordination with M3R was undertaken for all 15 days. When positions from the M3R system were available, the vessel would transit to specific locations in response to the positions and would survey areas for visual detection of groups. Positions of probable bottlenose dolphins or rough-toothed dolphins, as determined by M3R analysts, were not responded to unless no high-priority species were detected in areas that were accessible. When conditions on PMRF were sub-optimal and there were better conditions elsewhere, or if there was no vocal activity on the range from priority species, or if the range was closed because of Navy activity, the vessel team worked in areas off the range. The vessel team communicated each morning with the PMRF Range Control prior to entering the range and remained in regular contact with Range Control throughout the day as needed to determine range access limitations.

3.3 During Encounters

Each group of odontocetes encountered was approached for positive species identification. Decisions on how long to stay with each group and what type of sampling (e.g., photographic, tagging, biopsy) depended on a variety of factors, including current weather conditions and weather outlook, information on other potentially higher-priority species in the area (typically provided by M3R), and the relative encounter rates. Species encountered infrequently (melon-headed whales, pantropical spotted dolphins) were given higher priority than frequently encountered species (bottlenose dolphins, rough-toothed dolphins, spinner dolphins). Extended work with frequently encountered species was typically only undertaken when no other higher-priority species were in areas suitable for working.

In general, species were photographed for species confirmation and individual identification. For each encounter, information was recorded on start and end time and location of encounter, group size (minimum, best, and maximum estimates), sighting cue (e.g., acoustic detection from M3R, splash, radio call from another vessel), start and end behavior and direction of travel, the group envelope (i.e., the spatial spread of the group in two dimensions), the estimated percentage of the group observed closely enough to determine the number of calves and

[1] The SCC was cut short due to the projected approach of Hurricane Lane.

neonates in the group, the number of individuals bowriding, and information necessary for permit requirements.

For infrequently encountered species (e.g., melon-headed whales, short-finned pilot whales, sperm whales, and pantropical spotted dolphins), if conditions were suitable we attempted to deploy at least one satellite tag per group. When more than one tag deployment was attempted within a single group, the second individual to be tagged was not closely associated with the first. For frequently encountered species (e.g., rough-toothed dolphins), we attempted to deploy one tag per group for the first cooperative group when no other high-priority species were known to be in the area.

Skin/blubber biopsy samples were collected with a crossbow, using an 8-millimeter diameter dart tip with a stop that prevented penetration greater than approximately 15 millimeters. Species targeted for biopsy samples were those where additional samples were needed to help address stock structure questions (e.g., pantropical spotted dolphin, see Courbis et al. 2014), or when behavior of the group and conditions facilitated sample collection. In encounters where tagging was going to be undertaken, biopsy sampling was only undertaken after the cessation of tagging operations.

3.4 Data Analyses

We processed 5-minute effort locations of the research vessel with R (R Core Team 2017) to determine depth first from Hawaiian Island 50 Meter Bathymetry and Topography Grids (www.soest.hawaii.edu/HMRG/multibeam/bathymetry.php), then using GEBCO 30 arc-second grid (www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_30_second_grid/) when the higher resolution data were not available, using package *raster* (Hijmans 2017). Whether locations were inside or outside the PMRF instrumented range boundaries was determined using R package *sp* (Bivand et al. 2013). Photographs were sorted within encounters to identify individuals, and the best photographs of each individual within an encounter were given a photo quality and distinctiveness rating on a four-point scale following methods outlined in Baird et al. (2008a, 2009). Photo quality was categorized as 1) poor, 2) fair, 3) good, or 4) excellent, based on a combination of focus, the size, amount, and angle of the dorsal fin within the frame, and whether other individuals or water were obscuring any of the fin. Individuals were categorized as to distinctiveness as 1) not distinctive, 2) slightly distinctive, 3) distinctive, or 4) very distinctive, based on the size and number of notches on the dorsal fin or the back immediately in front of or behind the fin.

For short-finned pilot whales, rough-toothed dolphins, and bottlenose dolphins, all individuals were compared to individual photo-identification catalogs (Baird et al. 2008a, 2009; Mahaffy et al. 2015) to determine sighting histories. For these species, associations among individuals and groups were assessed with SOCPROG 2.7 (Whitehead 2009), and associations (restricted to photographs that were categorized as fair or better and individuals that were at least slightly distinctive) were visualized using Netdraw 2.158 (Borgatti 2002). With the exception of false killer whales in Hawaiʻi (Martien et al. 2014a), determining population identity of odontocetes is not possible with genetic analyses of a single biopsy sample (Martien et al. 2011; Courbis et al. 2014; Albertson et al. 2017; Van Cise et al. 2016). Thus population identity (insular, pelagic, unknown) was determined based on associations, sighting histories, and movement patterns taken from tagging data, although they are informed by previous genetic analyses of biopsy samples collected from the area (e.g., Martien et al. 2011; Courbis et al. 2014; Albertson et al. 2017). When tagging data were available, population identity of sub-groups recorded in the field was assessed independently. Sub-groups with differing associations, sighting histories, and movement patterns were considered separate groups.

Data obtained from the shore-based Argos MOTE receiver and from the Argos System were processed through the Wildlife Computers portal to obtain diving and surfacing data as well as Fastloc-GPS locations from the SPLASH10-F tags. Fastloc-GPS location data were filtered by removing locations with residual values greater than 35 (Dujon et al. 2014) and those with time errors >10 seconds. Argos locations were estimated using the least-squares methods and were assessed for plausibility using the Douglas Argos-filter v. 8.5 to remove unrealistic locations, following previously used protocols (Schorr et al. 2009; Baird et al. 2010, 2011). Resulting filtered location data were processed with R (R Core Team 2017) to determine depth using package *raster* (Hijmans 2017), and distance from shore and location relative to PMRF boundaries using package *rgeos* (Bivand and Rundel 2017).

From this, the number of times an individual was documented inside the range boundaries was determined and the proportion of time spent within PMRF boundaries was estimated for each individual. For estimating the proportion of time within the range boundaries, when consecutive locations spanned the boundary, the time spent inside the boundary was considered to start at the last location outside the boundary and end at the time of the last location inside the boundary. The number of times an individual was found inside the range boundaries was determined by examining whether consecutive locations were inside or outside of the range boundary.

When more than one tag was deployed on the same species, we assessed whether individuals were acting in concert during the period of overlap by measuring the straight-line distance (i.e., not taking into account potentially intervening land masses) between pairs of individuals when locations were obtained during a single satellite overpass (approximately 10 minutes). We used both the average distances between pairs of individuals and the maximum distance between pairs to assess whether or not individuals were acting independently, following protocols described by Schorr et al. (2009) and Baird et al. (2010).

For the purposes of generating probability-density maps for the three species for which there were new satellite tag tracks from the August 2018 field project, only a single individual from each group was used when pairs of individuals were acting in concert. For individuals tagged with a Fastloc-GPS tag, the GPS positions were used while they were being transmitted, then Argos positions were used after that. Filtered Argos and GPS locations were processed with a switching state-space model (SSSM, R package *bsam* v. 1.1.2) producing one location every 12 hours, to reduce bias associated with tag programming regimes and varying probabilities of Argos satellites being overhead. For example, during some hours the tags were set to transmit there were multiple Argos satellites passing over, increasing the likelihood of having temporally clustered locations, in comparison to hours with at most one satellite overhead. Resultant locations were used in generating probability-density maps. After the tags start duty cycling, SSSM locations were only used on days when Argos positions were recorded for that tag. Locations from the first 24 hours were excluded to reduce any bias associated with the tagging location. Kernel density polygons were generated using the R package *adehabitatHR* v. 0.4.15 (Calenge 2006) and corresponded to the 50, 95 and 99 percent densities. The percentage of overlap of the 50 percent polygon (defined as the core area) with PMRF was determined for each species. Polygons were plotted in Google Earth Pro v. 7.3.2.5776. For melon-headed whales, tag data from 16 individuals from the Hawaiian Islands stock (Aschettino et al. 2012; Baird 2016; Martien et al. 2017) tagged in previous years were included, including individuals tagged off Kauaʻi (n=4), Lānaʻi (n=1), and Hawaiʻi Island (n=11). For rough-toothed dolphins, data from 17 individuals previously tagged off Kauaʻi were included. For short-finned pilot whales, 16 individuals known or thought to be from the western community of insular individuals (Baird 2016) were included.

4. Results

From 6 to 20 August 2018, there were 1,597 km (100.0 hours) of small-vessel field effort (**Figure 1**), with the boat on the water all 15 days (**Table 4**). The research vessel was launched from Kīkīaola small boat harbor on all days. Forecasted winds over the 15 days included east 15 knots (10 days), east 20 knots (two days), northeast 20 knots (two days) and northeast 25 knots (1 day). Strong winds and/or a large short-period swell precluded surveying on the range on some days, and Navy activities were taking place on the northern part of the range for three days, limiting access to the very southern part of the range. Almost 79 percent of the total search effort was in depths less than 1,000 m (median depth=685 m; **Figure 2**).

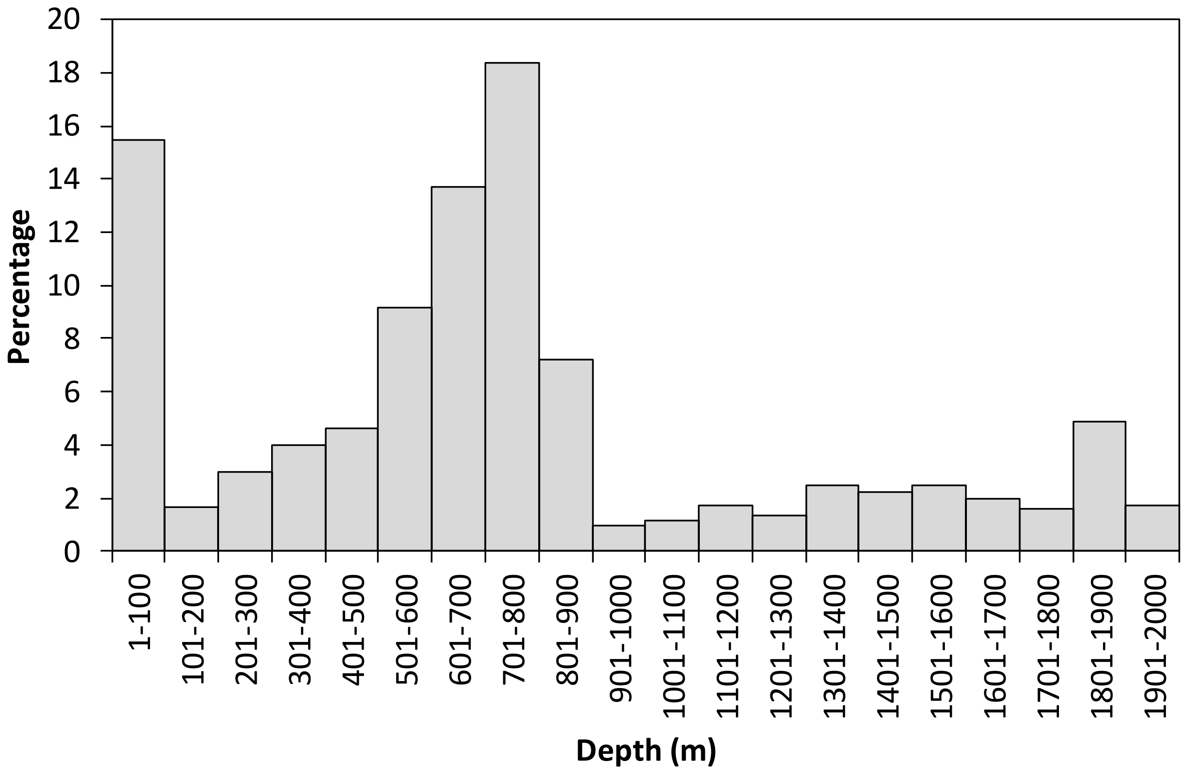


Figure 2. Depth distribution of search effort during 15 days of effort from 6 to 20 August 2018. Note there was a single effort location recorded at a depth >2,000 m (2,140 m), not shown here as it represents only 0.08 percent of the total effort.

Overall, there were 57 sightings of seven species of odontocetes and one sighting of an unidentified odontocete. Five of the seven species (all except melon-headed whales and pantropical spotted dolphins) were documented on PMRF (**Figure 1**, **Table 5**), although the sperm whale sighting was originally off the range and the group moved onto the range during the sighting. Rough-toothed dolphins were encountered on 34 occasions (57.6 percent of all encounters), spinner dolphins on eight, bottlenose dolphins on six, short-finned pilot whales on five (although two of the encounters were of the same group encountered a second time later in the day), melon-headed whales on two, sperm whales on one, and pantropical spotted dolphins on one. Twenty-four of the encounters were on PMRF (19 sightings of rough-toothed dolphins, two sightings of short-finned pilot whales, and one sighting each of spinner dolphins, bottlenose dolphins, and an unidentified odontocete).

Table 4. August 2018 small-boat effort summary.

Date	Total km	Total Hours on Effort	Number of Odontocete Sightings Total	Depart Time HST	Return Time HST	Total km Beaufort 0	Total km Beaufort 1	Total km Beaufort 2	Total km Beaufort 3	Total km Beaufort 4–6
6 Aug 2018	81.60	4.8	1	6:09	10:56	0	11.7	55.1	14.8	0
7 Aug 2018	70.70	5.5	4	6:04	11:33	0	14.8	34.4	17.1	4.4
8 Aug 2018	103.30	5.5	4	6:09	11:36	0	0	79.4	17	6.9
9 Aug 2018	73.70	4.7	5	6:12	10:56	0	0	51.5	16.3	5.9
10 Aug 2018	95.60	6	7	6:04	11:58	0	0	59.4	36.2	0
11 Aug 2018	111.20	6.2	4	6:06	12:15	0	0	74.6	36.6	0
12 Aug 2018	109.00	7.4	1	6:08	13:33	0	0	90	19	0
13 Aug 2018	119.20	7.2	2	6:06	13:19	0	5.6	45.2	60.4	8
14 Aug 2018	128.30	7.2	7	6:04	13:13	0	39	59.5	15.8	14
15 Aug 2018	114.30	6.1	1	6:06	12:14	0	5.7	70.5	38.1	0
16 Aug 2018	126.30	8.4	7	6:09	14:31	0	11.4	67.4	44.9	2.6
17 Aug 2018	74.30	8.9	6	6:13	15:10	0	26	15.1	27.1	6.1
18 Aug 2018	133.00	7.1	4	6:05	13:12	0	24.6	90.4	18	0
19 Aug 2018	135.20	9.1	5	5:58	15:01	1.8	13.5	73.8	24.1	22
20 Aug 2018	121.40	5.9	1	5:58	11:51	0	25.4	86	6	4
Total	1597.10	100.0	59			0	177.7	952.3	391.4	73.9

HST=Hawai‘i Standard Time; km=kilometers.

Table 5. Odontocete sightings from small-boat effort during August 2018.

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	# Biopsy Samples Collected	On PMRF (yes/no)	# distinctive individuals photo-identified with good/excellent photos	# distinctive individuals previously photo-identified (excluding within-day)	Visual ID Position	
									Latitude (°N)	Longitude (°W)
06-Aug-18	7:54	*Sb*	4	0	0	yes	0	0	22.06924	159.90525
07-Aug-18	8:20	*Sb*	1	0	0	no	0	0	21.95095	159.84365
07-Aug-18	8:24	*Pe*	140	2	2	no	0	0	21.93958	159.83385
07-Aug-18	9:27	*Sb*	6	0	0	no	9	9	21.92805	159.80994
07-Aug-18	11:04	*Tt*	20	0	0	no	13	10	21.93871	159.73166
08-Aug-18	7:06	*Tt*	20	0	0	no	1	1	21.95679	159.85430
08-Aug-18	7:06	*Sb*	1	0	0	no	0	0	21.95679	159.85430
08-Aug-18	9:16	*Sb*	1	0	0	no	0	0	21.87410	159.90320
08-Aug-18	11:25	*Tt*	1	0	0	no	1	1	21.95046	159.71217
09-Aug-18	6:18	*Sl*	4	0	0	no	0	0	21.93980	159.69048
09-Aug-18	8:44	*Sb*	8	0	2	no	11	10	21.94641	159.87763
09-Aug-18	9:23	*Sb*	4	0	0	no	4	3	21.92330	159.85820
09-Aug-18	9:43	*Sb*	4	1	1	no	4	3	21.91692	159.84096
10-Aug-18	6:36	*Sb*	1	0	0	no	0	0	21.95215	159.78947
10-Aug-18	6:47	*Sb*	10	0	0	no	1	1	21.96671	159.82406
10-Aug-18	9:20	*Tt*	2	0	0	yes	2	2	22.02585	159.81318
10-Aug-18	10:21	*Sb*	3	0	1	no	3	1	21.96331	159.86819
10-Aug-18	10:39	*Sb*	4	0	0	no	3	1	21.95583	159.88256
10-Aug-18	10:50	*Sb*	4	0	0	no	0	0	21.95047	159.88689
10-Aug-18	11:41	*Sl*		0	0	no	0	0	21.96498	159.73445
11-Aug-18	8:08	*Sb*	8	0	0	yes	11	6	22.07907	159.91997
11-Aug-18	9:21	*Sb*	4	0	0	yes	0	0	22.09419	159.86378
11-Aug-18	9:40	*Sb*	2	0	0	yes	1	1	22.08476	159.83771

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	# Biopsy Samples Collected	On PMRF (yes/no)	# distinctive individuals photo-identified with good/excellent photos	# distinctive individuals previously photo-identified (excluding within-day)	Visual ID Position	
									Latitude (°N)	Longitude (°W)
11-Aug-18	10:31	*Sl*	100	0	0	no	0	0	22.11876	159.74394
12-Aug-18	7:02	*Tt*	40	0	1	no	21	20	21.94587	159.80309
13-Aug-18	9:28	*Sb*	9	0	0	yes	0	0	22.25639	159.80920
13-Aug-18	9:36	*Sb*	9	0	0	yes	0	0	22.24902	159.81783
14-Aug-18	6:06	*Sl*	5	0	0	no	0	0	21.94809	159.69338
14-Aug-18	6:11	*Sl*	40	0	0	no	0	0	21.94087	159.71188
14-Aug-18	6:22	*Tt*	15	0	0	no	2	2	21.93125	159.75108
14-Aug-18	10:28	*Sb*	4	0	1	yes	2	2	22.09234	159.85227
14-Aug-18	10:56	*Sb*	2	0	0	yes	0	0	22.08723	159.88338
14-Aug-18	11:31	*Sb*	13	0	1	yes	10	6	22.08040	159.91108
14-Aug-18	11:57	*Sb*	6	0	0	yes	1	1	22.05899	159.89753
15-Aug-18	8:08	*Sb*	9	0	0	yes	7	7	22.07107	159.92403
16-Aug-18	6:13	*Sl*	75	0	0	no	0	0	21.94555	159.68883
16-Aug-18	6:57	*Sa*	40	1	4	no	0	0	21.88875	159.80652
16-Aug-18	10:22	*Pm*	3	0	0	no	0	0	22.00733	159.90158
16-Aug-18	10:28	*Sb*	7	0	0	yes	0	0	22.02102	159.90157
16-Aug-18	10:31	*Sb*	3	0	0	yes	0	0	22.02953	159.90211
16-Aug-18	11:13	*Sb*	1	0	0	yes	0	0	22.03405	159.90132
17-Aug-18	6:42	*Gm*	35	2	2	no	15	10	21.88200	159.70765
17-Aug-18	10:18	*Gm*	26	0	0	no	9	9	21.85346	159.70216
17-Aug-18	10:19	*Pe*	140	0	0	no	0	0	21.85346	159.70216
17-Aug-18	13:01	*Sb*	5	0	0	no	4	3	21.89788	159.84774
17-Aug-18	13:37	*Sb*	9	0	0	no	8	5	21.88160	159.83105
17-Aug-18	15:01	*Sl*	85	0	0	no	0	0	21.93681	159.70329

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	# Biopsy Samples Collected	On PMRF (yes/no)	# distinctive individuals photo-identified with good/excellent photos	# distinctive individuals previously photo-identified (excluding within-day)	Visual ID Position	
									Latitude (°N)	Longitude (°W)
18-Aug-18	6:33	*Gm*	30	0	0	no	8	8	21.89792	159.75107
18-Aug-18	7:44	*Sb*	18	0	0	no	10	9	21.89272	159.84660
18-Aug-18	8:52	*Sb*	4	0	0	yes	0	0	22.06235	159.93659
18-Aug-18	9:10	*Sb*	10	0	0	yes	0	0	22.07968	159.96624
19-Aug-18	7:46	*Gm*	22	2	2	yes	17	15	22.20221	159.82467
19-Aug-18	10:28	*Sb*	5	0	0	yes	0	0	22.21634	159.94630
19-Aug-18	10:45	*Sb*	2	0	0	yes	0	0	22.20515	159.97564
19-Aug-18	11:07	*Sb*	2	0	0	yes	0	0	22.16059	159.9691
19-Aug-18	12:24	*Gm*	26	0	1	yes	8	all within-day	22.16828	159.92298
20-Aug-18	9:39	*Sl*	7	0	0	yes	0	0	21.97453	159.78373

[1]See footnote to **Table 1.** HST=Hawai‘i Standard Time; ID=identification; N/A=not applicable; °N=degrees North; °W=degrees West.

During the encounters, we took 33,452 photographs for individual and species identification, deployed eight satellite tags on four species, and collected 18 biopsy samples from five different species (**Table 6**). The eight encounters with spinner dolphins were short (median=1 minute, maximum=7 minutes), and all in relatively shallow water (range=15–250 m). Photographs were obtained from four of the encounters, but no additional analyses of data from the spinner dolphin encounters were undertaken.

Sperm whales, Blainville's beaked whales, and one baleen whale were detected acoustically, but locations were either far to the north, or on the western edge of the range, and were not reachable given weather conditions at the time. There were large numbers of M3R detections of delphinids thought to be rough-toothed or bottlenose dolphins, but these species were low priorities so the research vessel was not directed to these groups, effectively increasing the size of the area surveyed each day and allowing the vessel to search for higher-priority species in other areas.

4.1 Rough-toothed dolphins

Rough-toothed dolphins were the most frequently encountered species, with 34 of 57 encounters (59.6 percent). Nineteen of the 34 encounters were on PMRF (**Figure 1**), and three of those groups were found in response to acoustic detections from M3R (60 percent of all groups found in response to acoustic detections). Encounter duration ranged from <1 minute to 1 hour and 7 minutes (median=7 minutes), although it should be noted that the longest encounter was a mixed-species sighting including melon-headed whales. One sighting was of a mixed group of rough-toothed and bottlenose dolphins, only the third sighting of a mixed-species group involving those two species in a combined 780 sightings of the two species in CRC's Hawai‘i dataset. Photographs were taken for individual identification in 15 of 34 encounters. During the 15 encounters, we obtained 110 identifications (**Table 5**). Of those, there were 64 identifications of 55 distinctive individuals with good- or excellent-quality photographs. A comparison of the 55 individuals to the photo-identification catalog of this species (Baird et al. 2008a) revealed that 44 of the individuals had been previously photo-identified off Kaua‘i. All of the encounters where more than one distinctive individual was photo-identified included individuals that had been previously documented (**Table 5)**. A social network analysis indicates that almost 92 percent of individual rough-toothed dolphins documented off Kaua‘i and Ni‘ihau link by association in the main cluster of the social network (**Figure 3**).

One tag was deployed on a rough-toothed dolphin, a location-only tag funded by another grant to CRC. The individual tagged (HISb2232 in CRC's photo-identification catalog) had been previously documented off Kaua‘i, twice in September 2015 and once in February 2016 (**Table 7**), and was part of the main cluster of the social network (**Figure 3**). During the five days of location data from the tag, the tagged individual remained to the west of Kaua‘i, moving off and on PMRF on four occasions (**Figure 4**), at a median distance from shore of 12.0 km and a median depth of 1,003 m (**Table 8**). Combined with previous tag deployments on rough-toothed dolphins (Baird et al. 2018), this suggests the tagged group was from the resident, island-associated population. A probability-density map (**Figure 5**) using the 12-hour SSSM results from tag data from this individual and all of the other rough-toothed dolphins previously tagged off Kaua‘i and Ni‘ihau (n=17) indicates their range encompasses both islands and extends to western O‘ahu, and that the core area (1,642 square kilometers [km^2]) for the population broadly overlaps with the southern portion of PMRF (**Table 9**). The overlap of the core area with PMRF was 43.3 percent.

Table 6. Details on satellite tags deployed during August 2018 field effort.

Species[1]	Tag ID	Individual ID	Date Tagged	Sighting #	Duration of Signal Contact (days)	Latitude (°N)	Longitude (°W)	Tag Type	Sex
Gm	GmTag212	HIGm2742	17-Aug-18	2	13.62	21.86	-159.70	SPLASH10-F	Male
Gm	GmTag213	HIGm0926	17-Aug-18	1	37.25	21.85	-159.68	SPLASH10-F	Male
Gm	GmTag214	HIGm0949	19-Aug-18	1	23.05	22.20	-159.84	SPLASH10-F	Male
Gm	GmTag215	HIGm1157	19-Aug-18	1	0	22.20	-159.85	SPLASH10-F	Unknown
Pe	PeTag027	N/A	7-Aug-18	2	9.39	21.94	-159.83	SPLASH10-F	Unknown
Pe	PeTag028	N/A	7-Aug-18	2	0	21.94	-159.81	SPLASH10-F	Unknown
Sa	SaTag009*	N/A	16-Aug-18	2	7.13	21.89	-159.81	SPLASH10	Unknown
Sb	SbTag022	HISb2232	9-Aug-18	3	4.94	21.94	-159.87	SPOT6	Unknown

[1]See footnote to **Table 1**. ID=identification; °N=degrees North; °W=degrees West; #=number; *Only one location was obtained from this tag so data are not considered further.

Table 7. Details on previous sighting histories of individuals satellite tagged in August 2018.

Individual ID	Date First Seen	# Times Seen Previously	# Years Seen Previously	Islands Seen Previously
HIGm2742	17-Aug-18	0	0	N/A
HIGm0926	6-Oct-07	2	2	Hawai‘i
HIGm0949	24-Dec-06	4	3	O‘ahu, Kaua‘i
HIGm1157	26-Jun-08	3	1	O‘ahu, Kaua‘i
HISb2232	7-Sep-15	3	2	Kaua‘i

Gm=Globicephala macrorhynchus; Sb=Steno bredanensis; ID=identification; #=number.

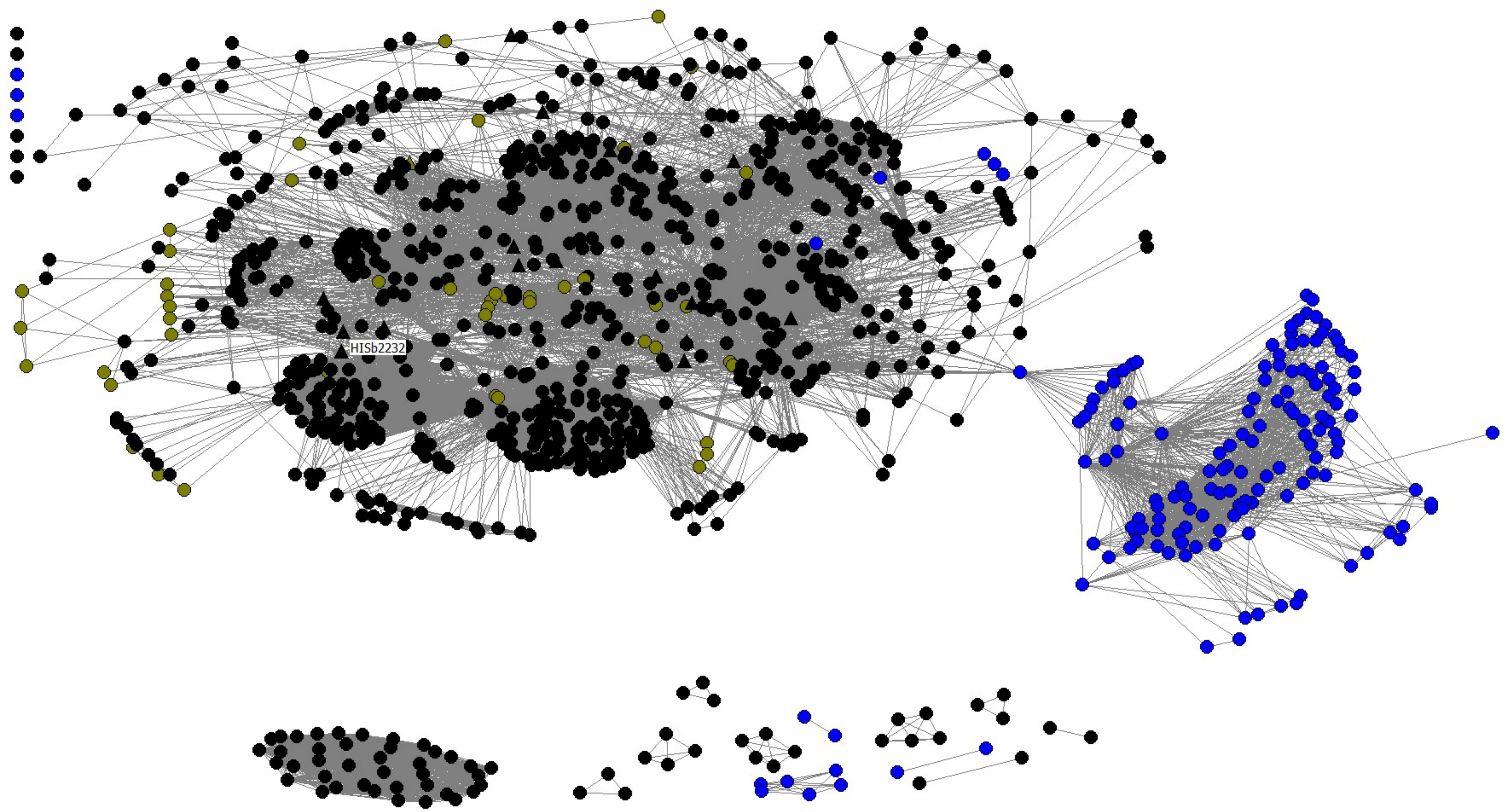


Figure 3. Social network of photo-identified rough-toothed dolphins off Kaua'i, Ni'ihau, and O'ahu. Individuals are color-coded by location first seen: Kaua'i – black; Ni'ihau – green; O'ahu – blue. All individuals tagged off Kaua'i and Ni'ihau (including those tagged in previous efforts) are noted by black triangles. The one individual tagged in August 2018 is indicated with an ID label. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2008a), with a total of 1,014 individuals shown (the main cluster contains 929 individuals, 91.6 percent of all individuals). The lone points in the upper left corner of the figure are individuals that have not been sighted with any others that meet the photo quality and distinctiveness criteria.

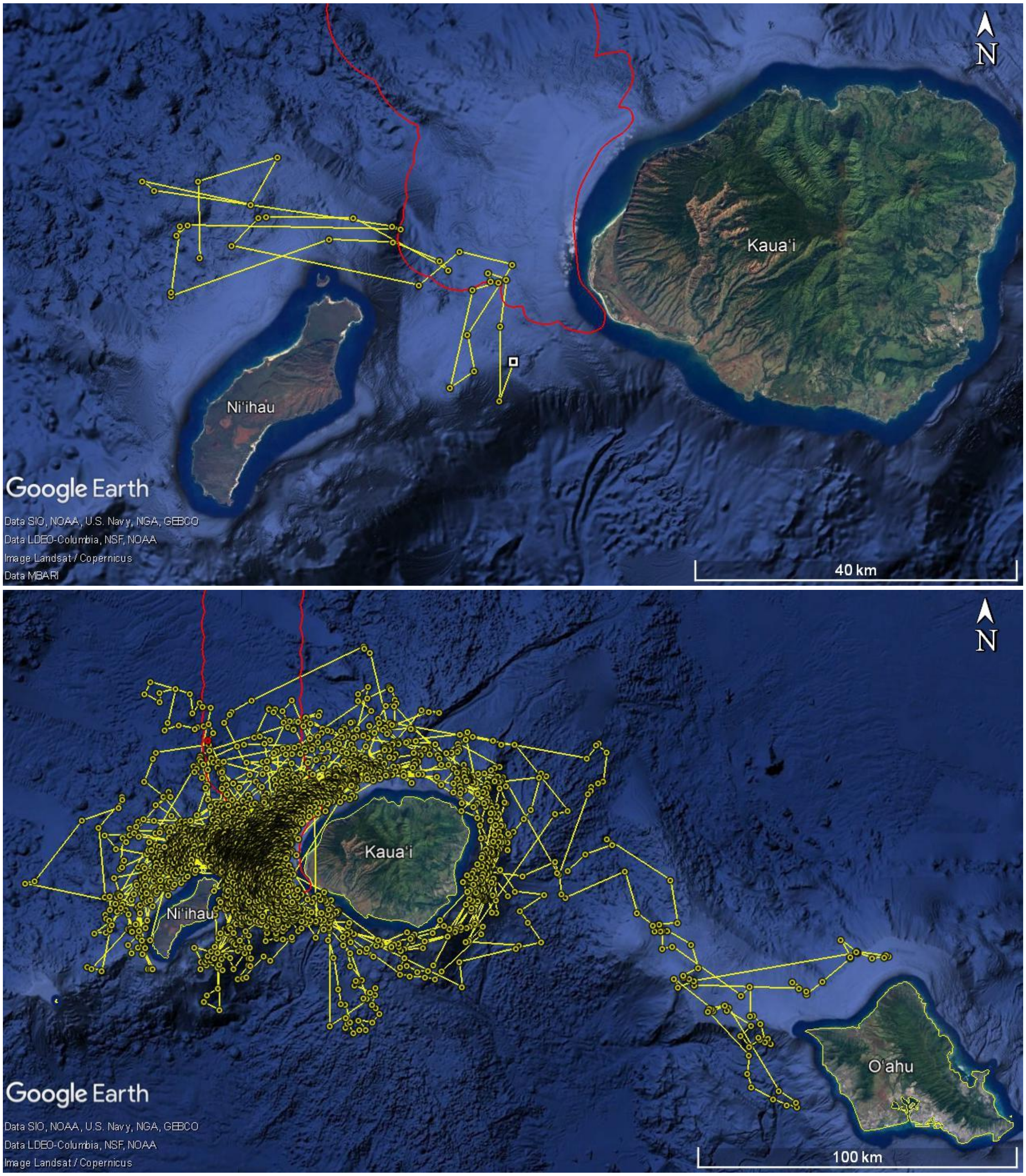


Figure 4. Top. Filtered Argos locations from rough-toothed dolphin HISb2232 (SbTag022) tagged off Kaua'i in August 2018, with the tagging location shown by a white square. Bottom. Locations from all 19 rough-toothed dolphin tag deployments off Kaua'i (2011–2018).Lines connect consecutive locations. The PMRF boundary is shown in red.

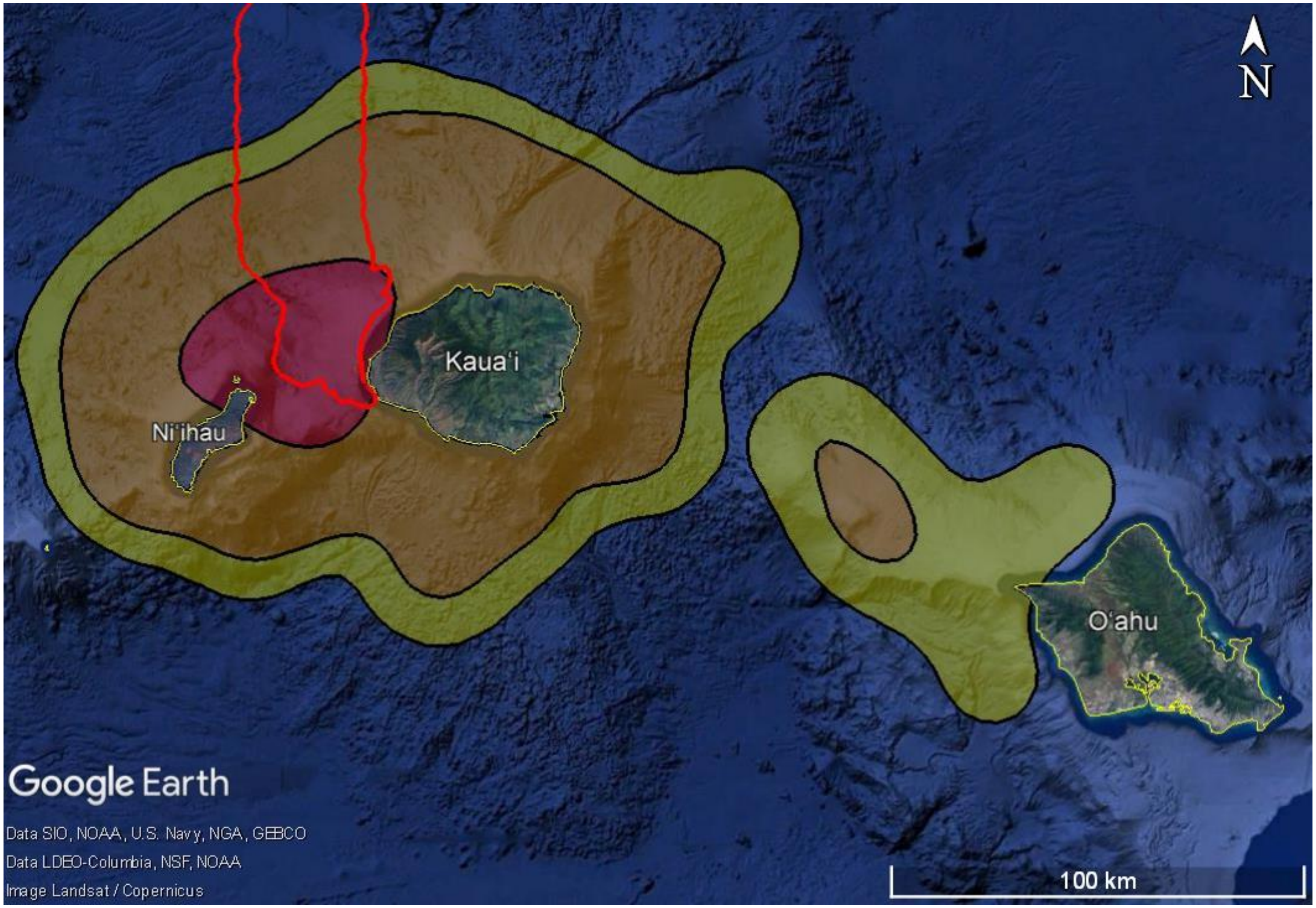


Figure 5. Probability-density representation of rough-toothed dolphin 12-hour locations generated by a switching state-space model of data from 18 satellite tag deployments off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50 percent density polygon (the "core range"), the orange represents the 95% polygon, and the green represents the 99 percent polygon. The PMRF boundary is shown as a solid red line.

Table 9. Areas within 50 percent ("core range"), 95 percent, and 99 percent isopleths based on kernel-density analyses of 12-hour switching state-space model locations from satellite-tag data, excluding the first day of locations and using only a single individual from any pair when individuals were acting in concert.

Species/population	Area (km^2) within selected isopleths based on kernel density		
	50%	95%	99%
Rough-toothed dolphin	1,642	13,516	21,771
Melon-headed whales – Hawaiian islands population	82,431	463,668	694,857
Short-finned pilot whale – western community	7,517	47,816	77,716

4.2 Short-finned pilot whales

Short-finned pilot whales were encountered five times over three days from 17 to 19 August 2018, with three of the encounters south of PMRF, and two on PMRF (**Figure 1**). The first sighting on PMRF (on 19 August 2018) was in response to an acoustic detection from M3R, and that group was re-located later in the same day using information from a satellite tag deployed on an individual in the group during the first encounter. Group sizes ranged from 22 to 35 individuals (median=26). This was a high-priority species, so encounter durations were extended (median=55.8 minutes, maximum=3.3 hours), and attempts were made to deploy satellite tags during all encounters. From the five encounters 11,723 photos were taken and compared to CRC's photo-identification catalog for this species (Mahaffy et al. 2015). From these there were 140 identifications representing 85 individuals, and the five sightings represented three different groups, with two of the three groups each seen twice (one on two consecutive days and the aforementioned group seen twice within the same day on PMRF). Individuals in the group seen on two consecutive days (17 and 18 August 2018) could not be approached close enough for tagging. Overall four satellite tags (all SPLASH10-F) were deployed, with two tags deployed in each of the other two groups, one south of PMRF on 17 August 2018, and one on PMRF on 19 August 2018. Argos location data were obtained from three of the four tags, for periods of 13.6 and 37.2 days for the group tagged 17 August 2018, and for 23.0 days for the group tagged 19 August 2018. The one tagged individual for which no locations were obtained was re-sighted post-tagging with the tag still attached over three hours post-tagging, but no transmissions were received, suggesting the tag failed on or shortly after attachment. Five biopsy samples were collected from short-finned pilot whales, two from the first group encountered on 17 August 2018, and three from the group encountered on 19 August 2018.

Of the 85 photo-identified individuals, 63 were previously documented, including individuals from all three groups (**Table 5**). Twenty-one individuals were photo-identified in the group tagged on 17 August 2018, and of those 12 had been previously documented, all off the island of Hawai‘i. Of the 12, four had been documented almost 11 years earlier (in October 2007), and eight had been documented 14 months prior (in June 2017). This group has been linked by association with individuals from the resident eastern community of short-finned pilot whales (**Figure 6**).

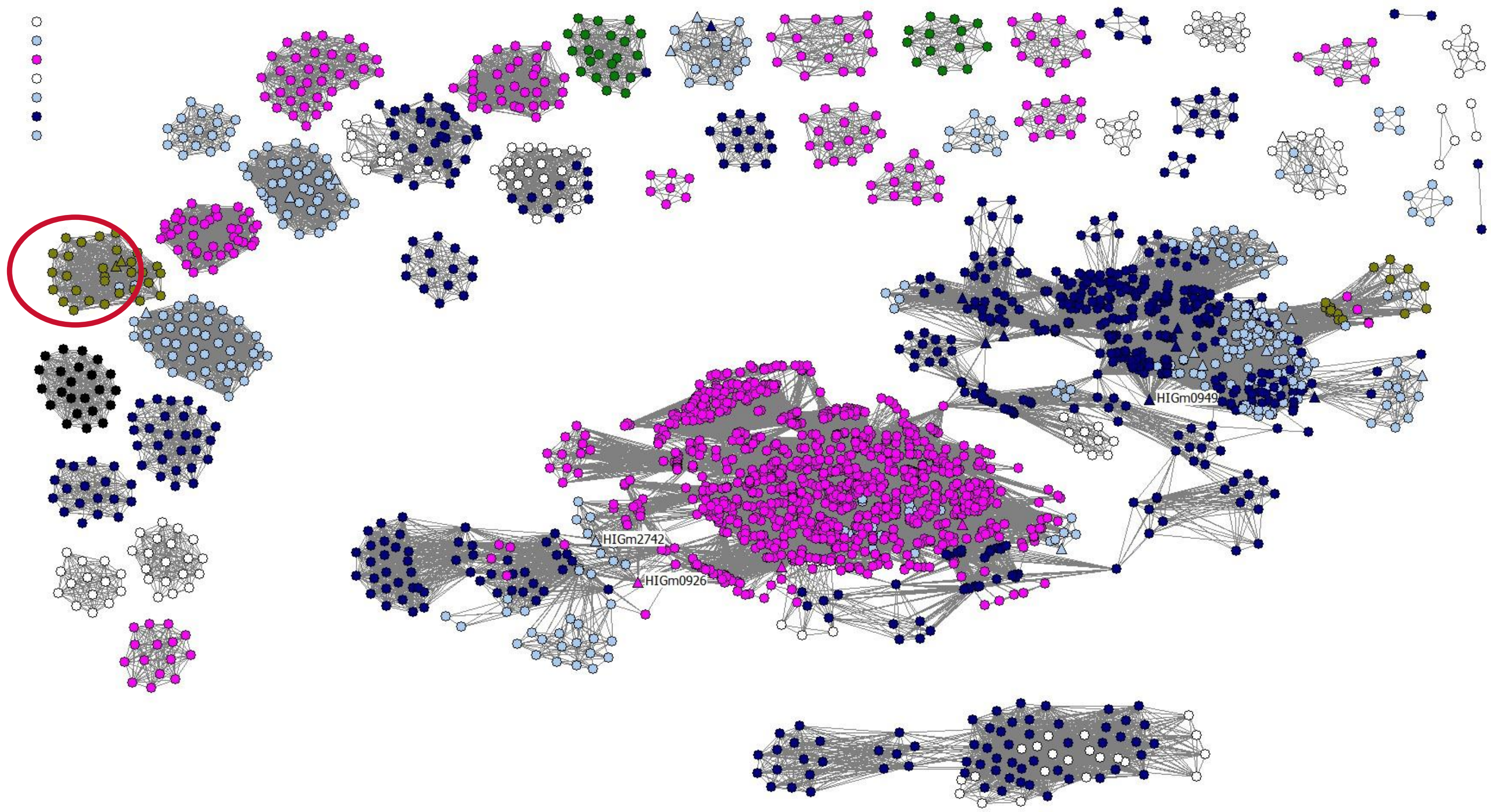


Figure 6. Social network of photo-identified short-finned pilot whales from the main Hawaiian Islands. Individuals are color-coded by island first documented: Kaua‘i – light blue; Ni‘ihau – light green; O‘ahu – dark blue; Molokai – dark green; Lanai – white; Hawaii Island – pink. All individuals tagged off Kaua‘i and Ni‘ihau (including those tagged in previous efforts) are noted by triangles. The three individuals with location data tagged in August 2018 are indicated with ID labels, two individuals linked by association with the main cluster identified off Hawaii Island (HIGm2742 and HIGm0926) and one individual (HIGm0949) linked to the main cluster from Kaua‘i and Ni‘ihau. The group encountered 17 and 18 August 2018 that was not tagged is indicated by a red circle. This figure includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Mahaffy et al. 2015), with a total of 1,795 individuals shown (the main cluster contains 1,608 individuals, 89.5 percent of all individuals).

Based on the Fastloc-GPS locations, the two tagged individuals in this group remained closely associated over the period the tags were attached (**Figure 7**). The tagged individuals spent most of their time offshore (filtered Argos locations, median distance from shore=73.3 km, maximum=204.2 km), at a median depth of 4,215 m. This group moved from south of Kauaʻi to north of Oʻahu, between Oʻahu and Molokaʻi and then into deep water to the southwest of Oʻahu, before moving to off Hawaiʻi Island (**Figure 8**). This group was far to the southeast of Kauaʻi when the SCC started, thus it will not be possible to assess MFA sonar exposure and response of this group. From the two tags deployed on individuals in this group, 278 (GmTag212) and 308 (GmTag213) Fastloc-GPS locations were obtained that met filtering criteria. We compared the resolution of data from Argos and the Fastloc-GPS for GmTag213 for the period of overlap of these two data streams. After filtering, there were 114 Argos locations (median interval=1 hr, 25 min, max=9 hr, 5 min) versus 308 Fastloc-GPS locations (median interval=37 minutes, maximum=4 hr, 19 min).

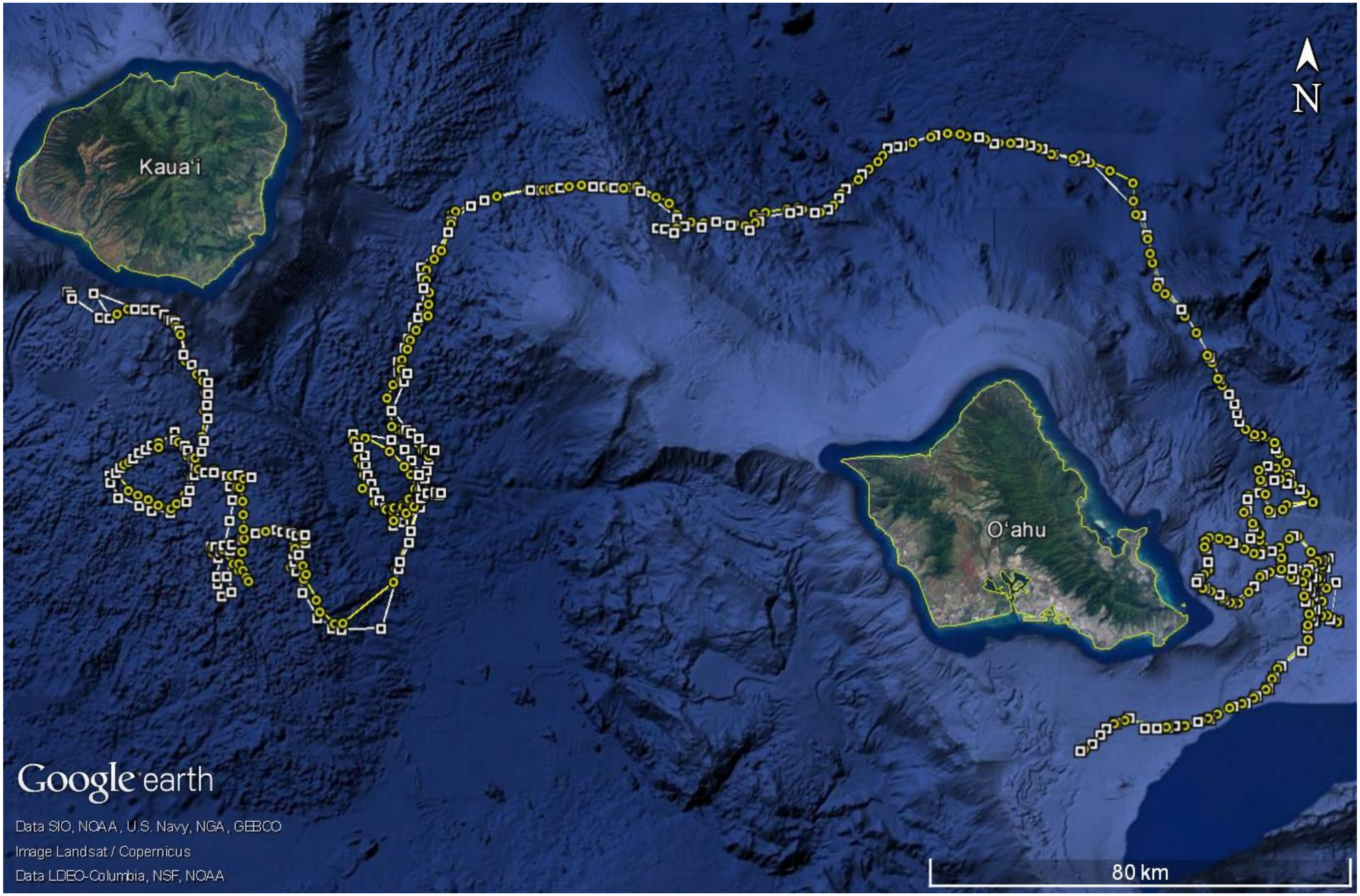


Figure 7. Fastloc-GPS locations from HIGm2742 (GmTag212; white squares, n=278) and HIGm0926 (GmTag213; yellow circles, n=308) over an 11-day period from 17 to 27 August 2018, showing the two individuals remained closely associated during this period.

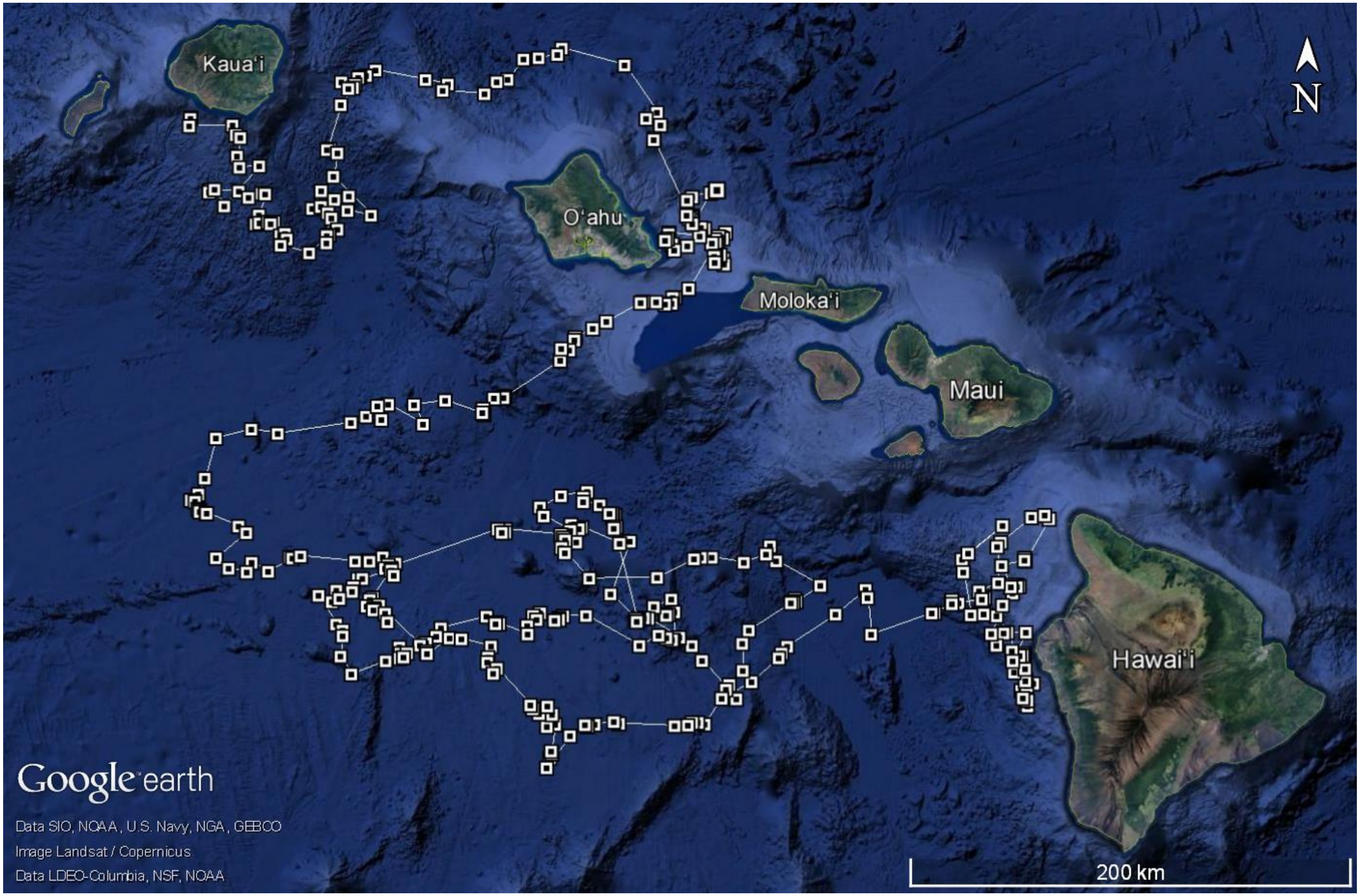


Figure 8. Filtered Argos locations from satellite-tagged short-finned pilot whale HIGm0926 (GmTag213) over a 37-day period from 17 August to 24 September 2018. The individual was off the southwest side of Kaua'i when tagged.

Thirty-seven individuals were photo-identified in the group tagged on 19 August 2018, 30 of which had been previously documented off either Kaua‘i, O‘ahu, or both islands. Individuals from this group had been previously documented in up to four different years and up to five previous times, and were linked by association with the western community of short-finned pilot whales (**Figure 6**). Tag data were received from one of the two individuals (GmTag214) for a period of 23 days. We compared the resolution of data from Argos and the Fastloc-GPS for GmTag214 for the period of overlap of these two data streams (**Figure 9**). After filtering there were 91 Argos locations (median interval=1 hour, 4 minutes; max=11 hours, 11 minutes) versus 196 Fastloc-GPS locations (median interval=45 minutes, maximum=5 hours, 24 minutes). Over the entire 23 days the individual remained associated with Kaua‘i and Ni‘ihau (**Figure 10**, filtered Argos locations median distance to shore=6.9 km, median depth=906 m). This individual was on or near PMRF from 21 to 22 August 2018, the period of the SCC, so data are being used to assess exposure and response to MFA sonar (reported elsewhere). Data from this individual were combined with data from 16 other individuals from the western community of short-pilot whales tagged off Kaua‘i to produce a probability-density map (**Figure 11**), showing that the core area for this community (7,517 km^2) is centered around Kaua‘i and Ni‘ihau and broadly overlaps the southern half of PMRF (**Table 9**). The overlap of the core area with PMRF was 19.9 percent.

Behavior data (dives and surfacing periods) from the short-finned pilot whales were obtained for 8.1 days (GmTag212), 10.2 days (GmTag213), and 8.3 days (GmTag214) representing 77.4 percent, 98.8 percent and 99.3 percent coverage for the three individuals, respectively, for the period that behavior data were collected (**Figure 12; Table 10**). The relatively high number of Fastloc-GPS locations and behavior coverage reflects that these tags transmitted well after the period that Fastloc-GPS locations and behavioral data were being collected (4, 28, and 15 days, respectively), thus allowing for the transmission of data stored in the buffer for extended periods.

No tags were deployed on individuals in the group seen on both 17 and 18 August 2018. During these two encounters, a combined 27 individuals were photo-identified, and of those 21 had been previously documented, all off the island of Ni‘ihau during a CRC research effort there in September 2015. This group has not been previously documented associating with any other group of pilot whales (**Figure 6**). During the 2015 effort, two individuals in the group were satellite tagged, and movement data were obtained for 18 days. Tag data from those individuals showed they remained on the slopes of Kaua‘i and Ni‘ihau during the duration of tag attachments (unpublished data).

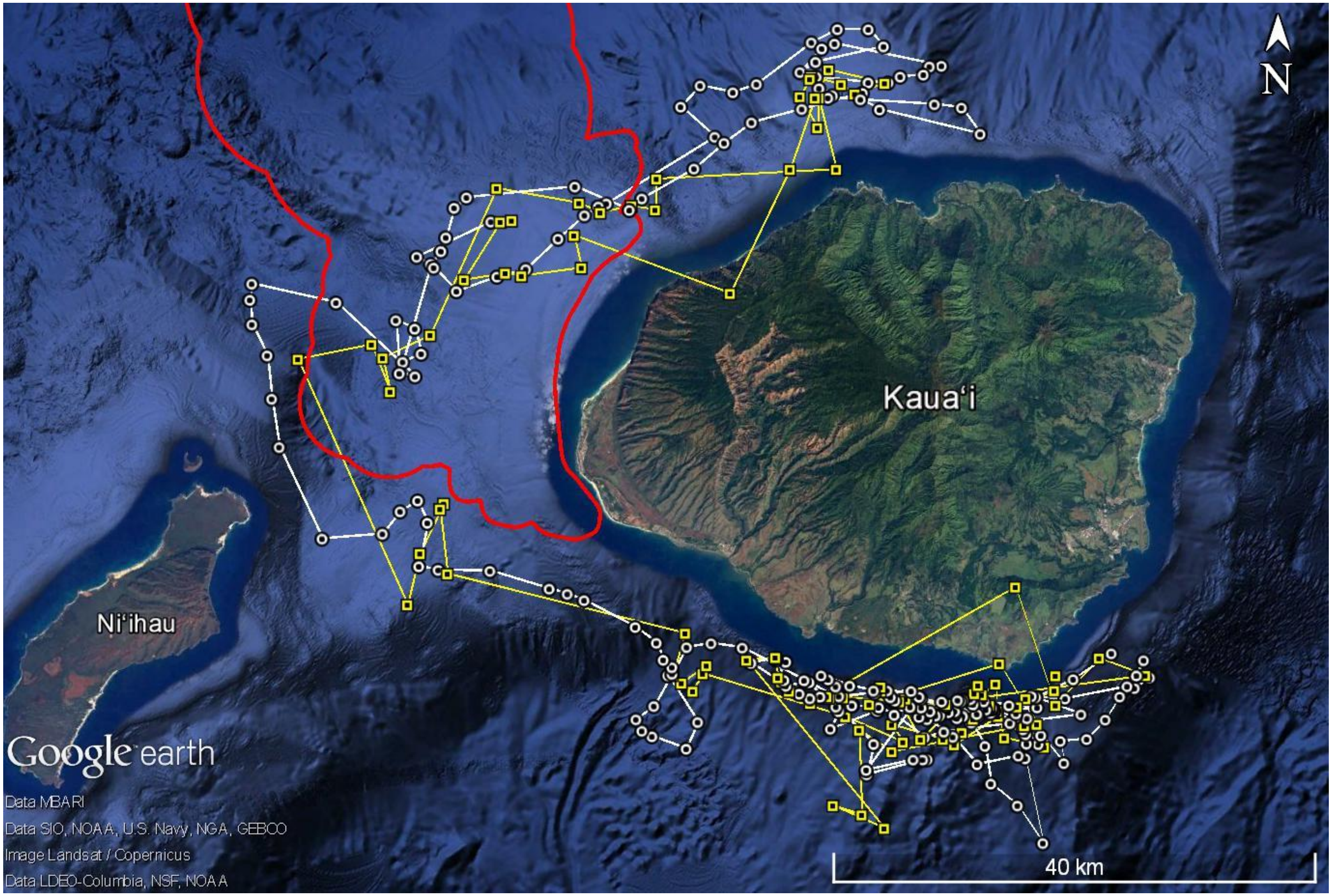


Figure 9. Filtered Argos locations (yellow squares) and Fastloc-GPS locations (white circles) from satellite tagged short-finned pilot whale HIGm0949 (GmTag214) for the period where both location types were received, over a nine-day period from 19 to 27 August 2018. Consecutive locations are joined by lines. The PMRF boundary is outlined in red.

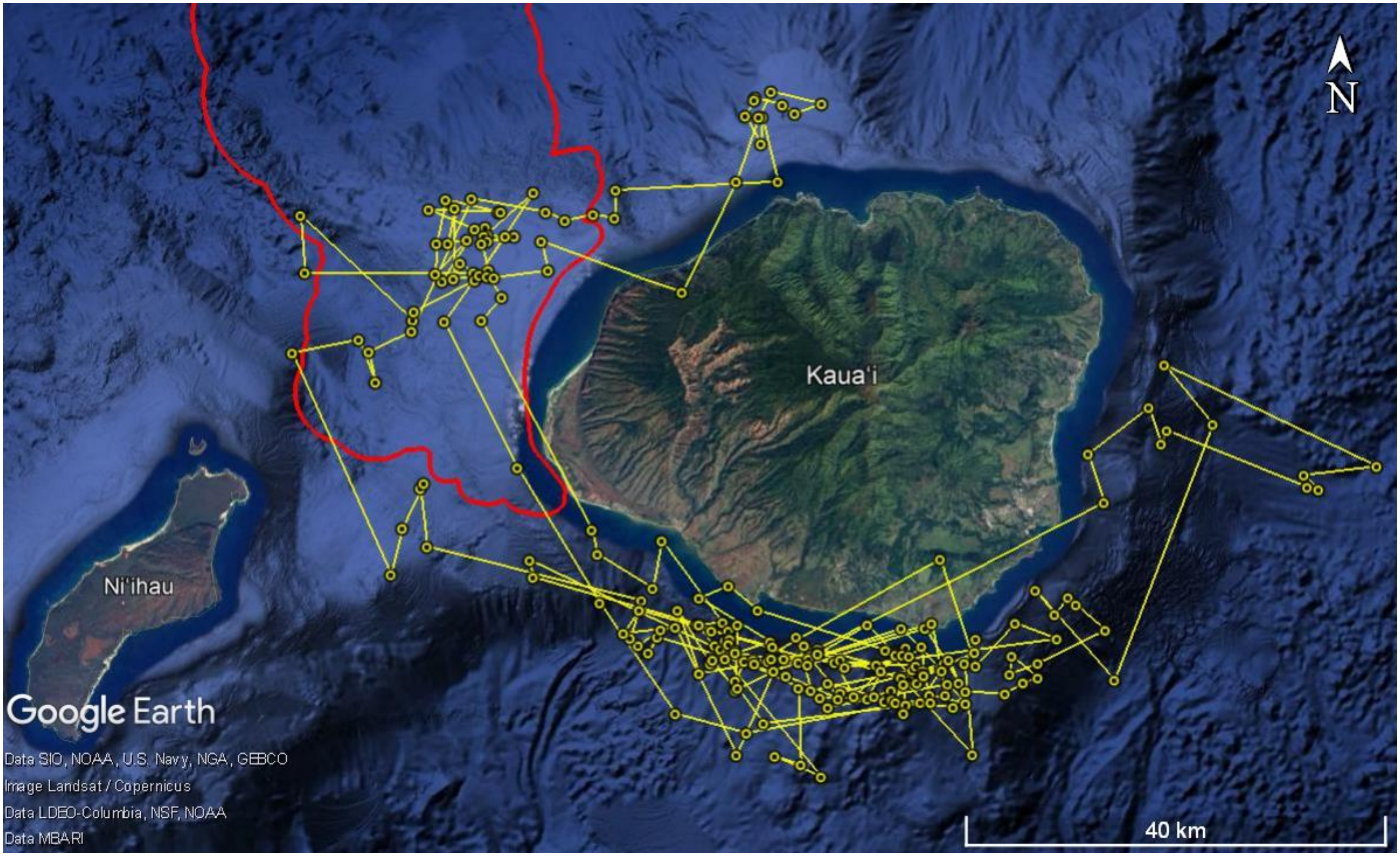


Figure 10. Filtered Argos locations (yellow circles) from satellite tagged short-finned pilot whale HIGm0949 (GmTag214) over a 23-day period from 19 August to 11 September 2018. Consecutive locations are joined by lines. The PMRF boundary is outlined in red.

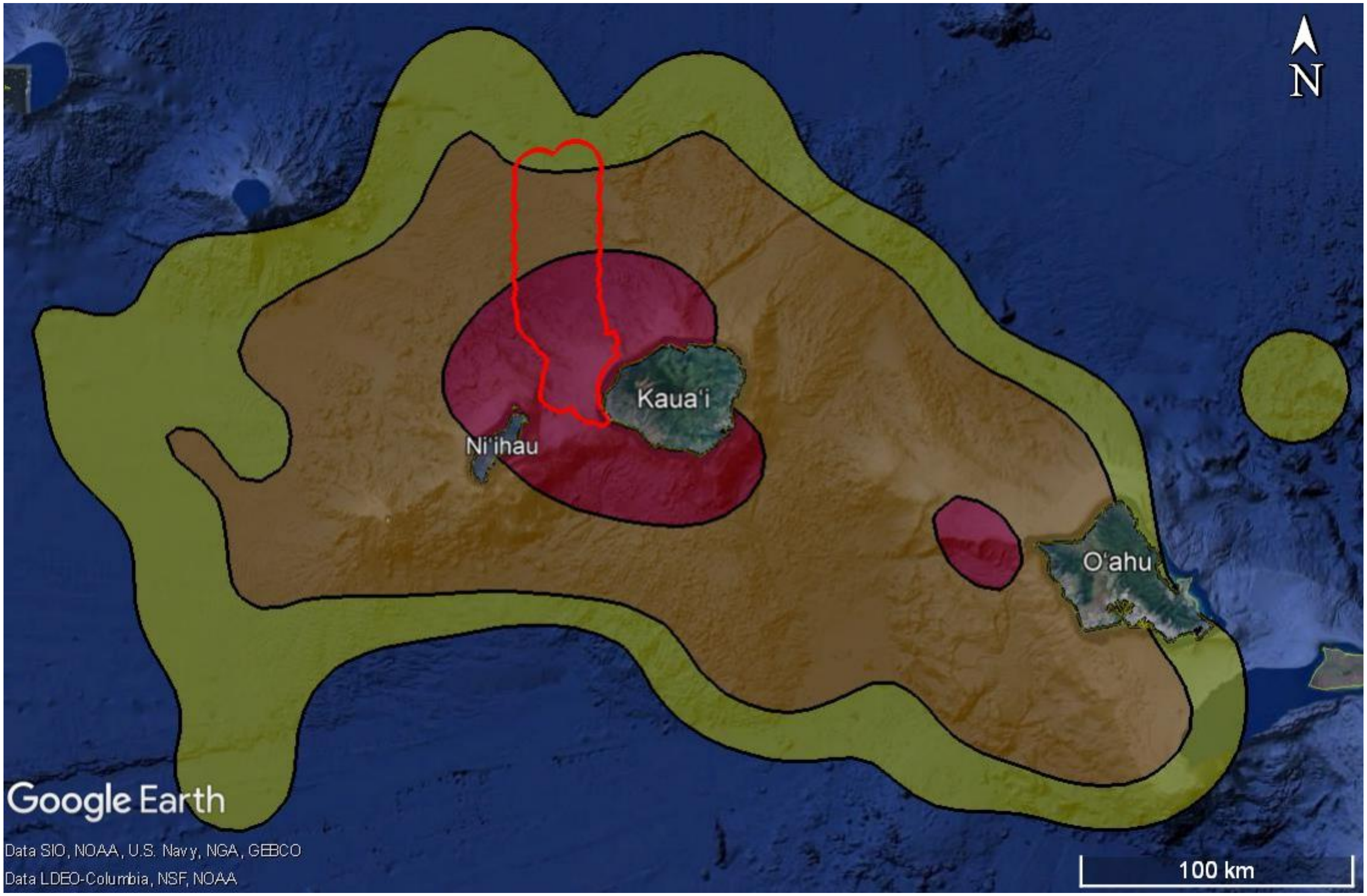


Figure 11. Probability-density representation of short-finned pilot whale 12-hour switching state-space model locations from satellite tag deployments on 17 individuals from the western main Hawaiian Islands insular community. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50 percent density polygon (the "core range"), the orange represents the 95 percent polygon, and the green represents the 99 percent polygon. The PMRF boundary is outlined in red.

Table 10. Dive information from satellite tags deployed during August 2018 field efforts.

Tag ID	# Days Data	% of Total Record	# Dives ≥ 50 m	Dives per hour	Median Dive Depth (m) for Dives ≥ 50 m	Maximum Dive Depth (m)	Median Dive Duration[1] (min)	Maximum Dive Duration[1] (min)
GmTag212	8.11	77.4	375	1.9	271.5	1,103.5	10.5	20.3
GmTag213	10.22	98.8	541	2.2	247.5	831.5	12.1	23.0
GmTag214	8.31	99.3	361	1.8	359.5	943.5	11.7	18.7

[1]Duration of dives underestimated because time spent in top 3 m not included. Typical rates of ascent/descent are in the 1 to 2 m/second range, so durations are likely only underestimated by 3 to 6 seconds. No dive data were available for SaTag009, SbTag022, or PeTag027.

m=meters; min=minutes; #=number; ≥=greater than or equal to

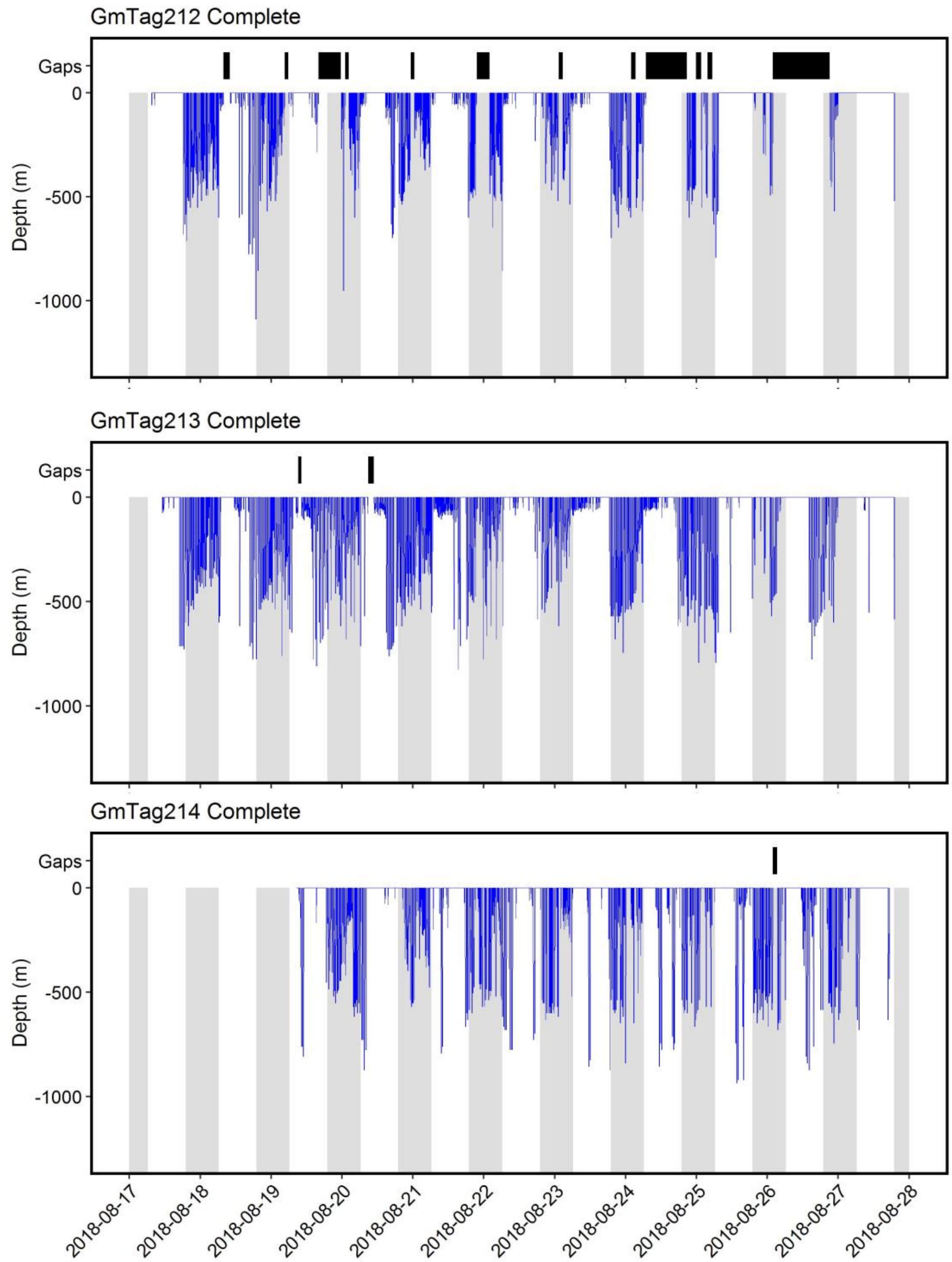


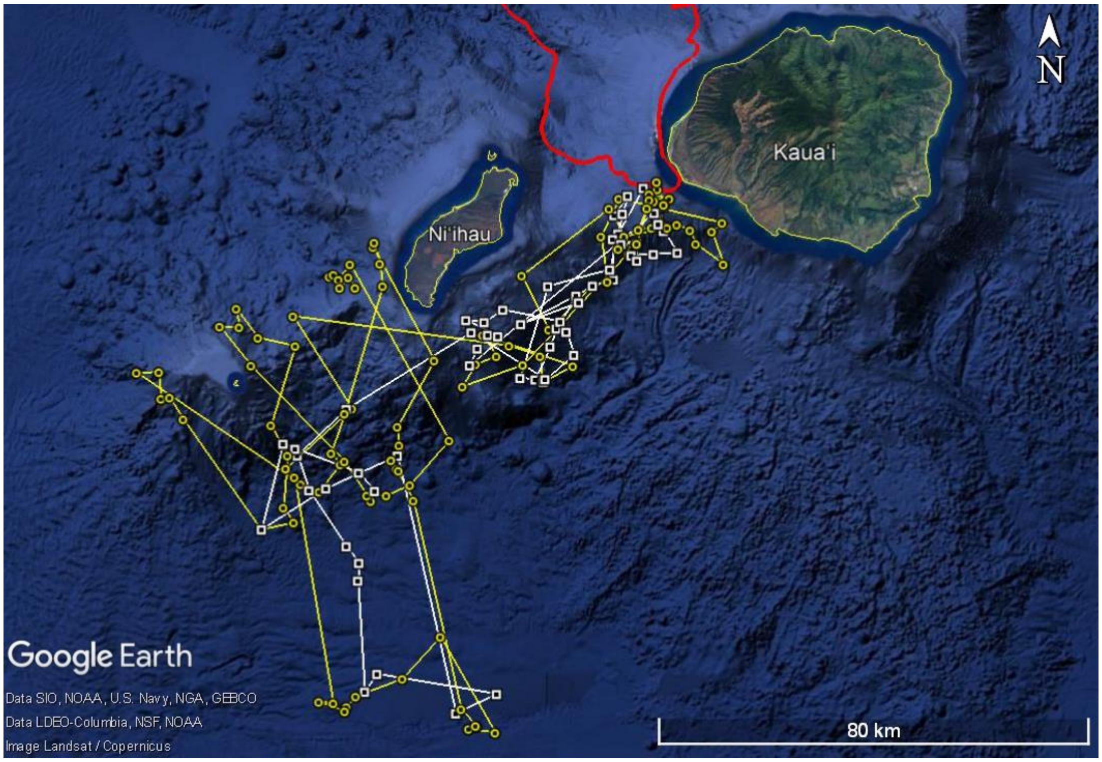
Figure 12. Behavior data from three satellite-tagged short-finned pilot whales: GmTag212 (top), GmTag213 (middle), and GmTag214 (bottom). Dives deeper than 50 m are shown; when the whales were <50 m the tag records "surface" periods, indicated by a line at 0 m. The x- and y-axis scales are the same for comparison. The alternating vertical bars represent night (gray) and day (white). Black lines at the top represent gaps in dive and surface data.

4.3 Melon-headed whales

Melon-headed whales were encountered on two occasions, both of large groups, estimated at 140 individuals in both sightings. Both of the sightings were south of PMRF (**Figure 1**). Two biopsy samples were collected from melon-headed whales from the group encountered 7 August 2018. The second sighting, on 17 August 2017, was a mixed group with short-finned pilot whales. Efforts during this encounter were focused on the pilot whales, thus limited information was collected from this group. A total of 4,136 photographs was taken from these two encounters for future inclusion into CRC’s melon-headed whale photo-identification catalog (Aschettino et al. 2012). Although photographs have not been compared to CRC’s photo-identification catalog for this species, a comparison of a small number of individuals among the two encounters revealed one individual matching between the two, indicating that the same group was encountered on the two different days.

During the sighting on 7 August 2018 two SPLASH10-F satellite tags were deployed, although transmissions were received from only one tag. The tag for which no transmissions were received was attached to the leading edge of the fin, with one dart only partially embedded. This animal as not re-sighted post-tagging, thus it is unknown whether the tag failed on impact or came off shortly after deployment. The other tag transmitted for a 9.4-day period, during which time the tagged individual remained associated with Kauaʻi, Niʻihau, and the area to the south and southwest of Niʻihau (**Figure 13**). Using Argos locations, the tagged individual was found at a median depth of 2,220 m and at a median distance offshore of 14.8 km. Sixty Fastloc-GPS locations and 105 Argos locations were received from this tag. The greater number of Argos locations relative to Fastloc-GPS locations likely reflected the tag stopping transmissions prior to the cessation of Fastloc-GPS location acquisitions. This tag stopped transmitting five days prior to the scheduled start of the SCC. No behavioral (i.e., dive and surfacing) data were recorded for this individual as it was programmed to begin collecting and transmitting behavioral data three days prior to the start of the SCC.

These groups are expected to be part of the Hawaiian Islands stock as the Kohala resident stock has not been recorded away from Hawaiʻi Island (Baird 2016; Carretta et al. 2017). For context, location data are shown for individuals known or thought to be from the Hawaiian Islands stock tagged by CRC from 2008 through 2018 (**Figure 13**), including individuals previously tagged off Kauaʻi (n=5), Lānaʻi (n=1), and Hawaiʻi Island (n=11). A probability-density map using 12-hour SSSM locations from tag data (**Figure 14**) shows that the core area for this population is large (a combined 82,431 km^2), with one portion around Kauaʻi and Niʻihau and overlapping with the southern part of PMRF, and one around Maui, Lanai, Kahoʻolawe, and Hawaiʻi Island (**Table 9**). The overlap of the core area with PMRF was 0.7 percent.



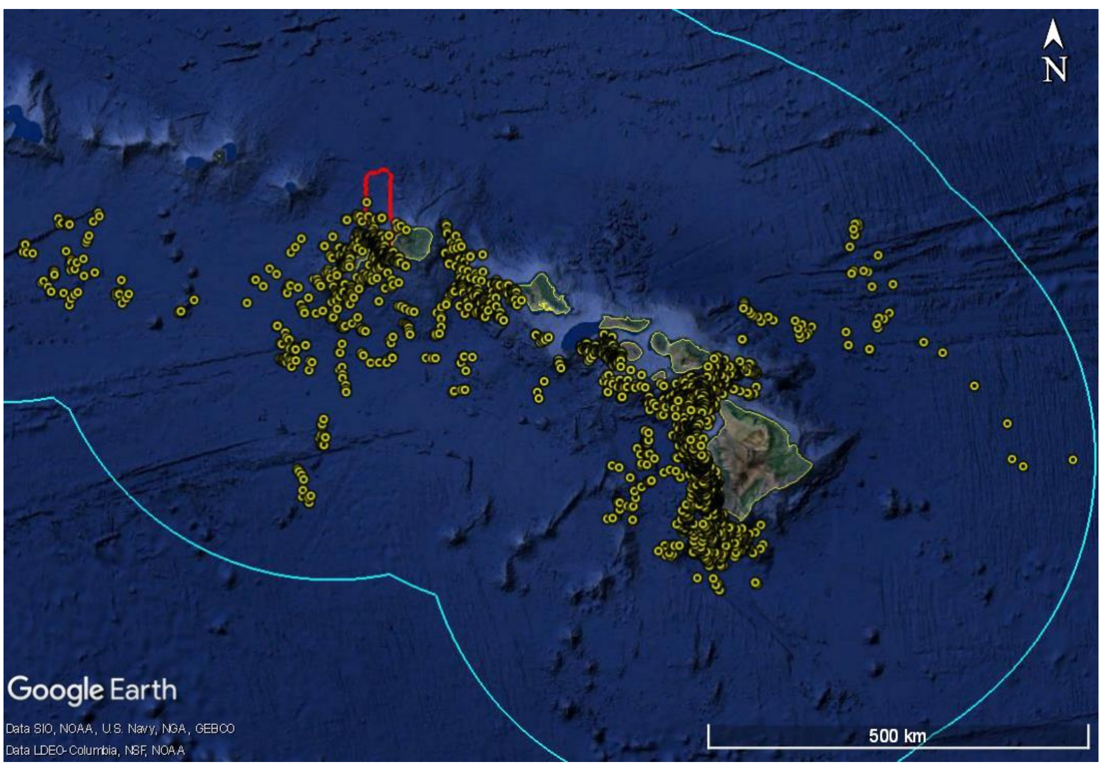


Figure 13. Top. Locations of melon-headed whale PeTag027 satellite tagged in August 2018. Argos locations are shown in yellow circles with consecutive locations joined by a yellow line, while Fastloc GPS locations are shown with white squares with consecutive locations joined by a white line. Bottom. Locations of all melon-headed whales satellite tagged in Hawai‘i that are known or thought to be from the Hawaiian Islands stock (n=17), including individuals tagged off Kaua‘i (n=6), Lāna‘i (n=1), and Hawai‘i Island (n=10). The boundary of PMRF is shown as a solid red line and the boundary of the Exclusive Economic Zone is shown in blue.

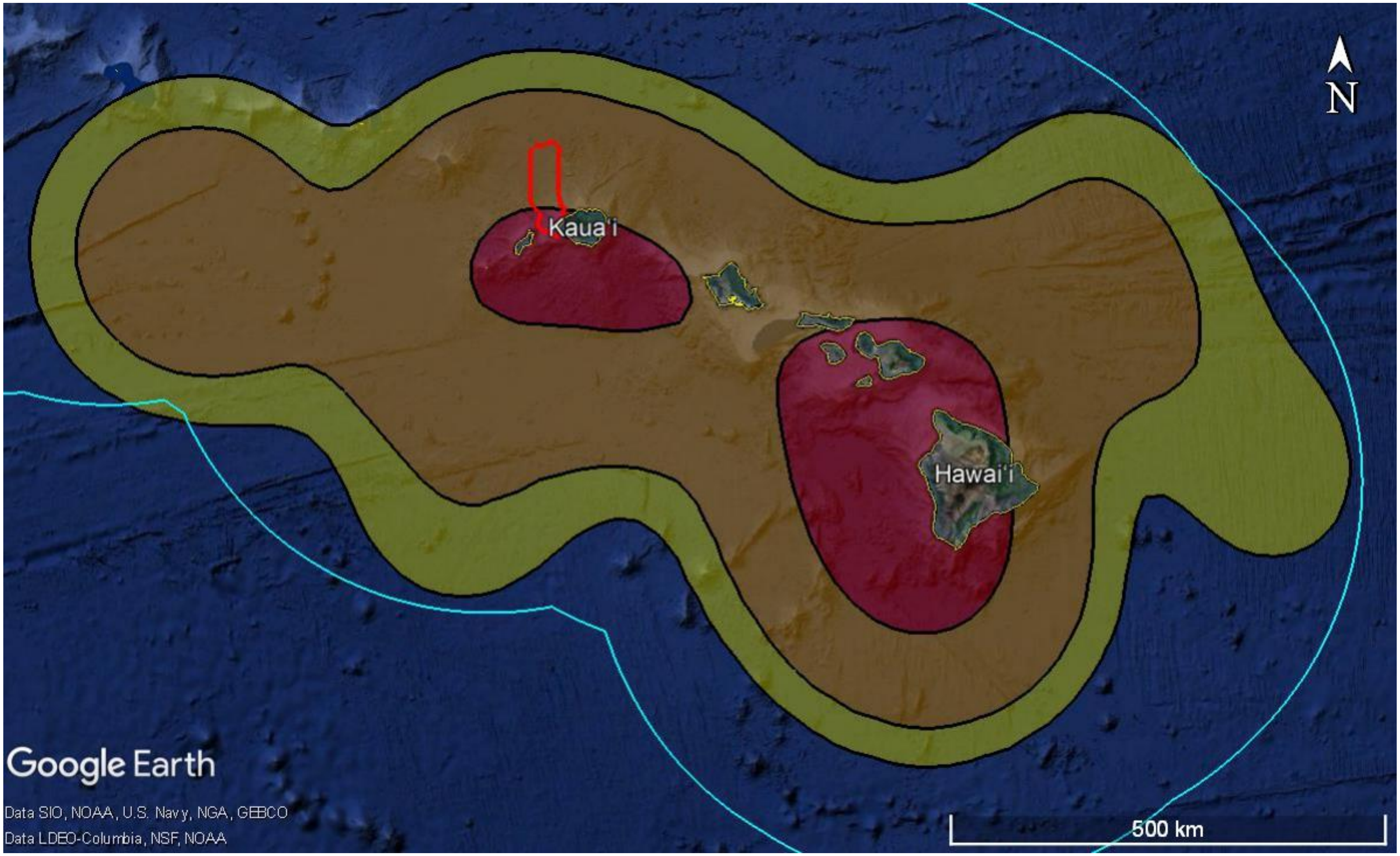


Figure 14. Probability-density representation of melon-headed whale 12-hour switching state-space model locations from individuals from the Hawaiian Islands stock. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50 percent density polygon (the "core range"), the orange area represents the 95 percent polygon, and the green represents the 99 percent polygon. The PMRF boundary is indicated by a solid red line and the boundary of the Exclusive Economic Zone is shown in blue.

4.4 Sperm whales

Sperm whales were acoustically detected on the southernmost hydrophones on PMRF on 16 August 2018, with the group moving north onto the range (**Figure 1; Table 5**). The research vessel was directed to the group, and located one individual in 800 m water depth. Over the approximately 2-hour encounter we observed three widely dispersed sperm whales, spread over at least four kilometers, making long dives (e.g., approximately 1 hour) and moving north onto PMRF. The research vessel was only able to get close to one individual on two occasions, an adult male based on size, but the individual was not approachable close enough to deploy a satellite tag.

4.5 Pantropical spotted dolphins

A group of an estimated 40 pantropical spotted dolphins was sighted on 16 August 2018 south of PMRF (**Figure 1, Table 5**). One location-only satellite tag was deployed on an individual in this group (Table 6), but only a single location was received (approximately 7 days after deployment), thus information from this tag is not considered further. A total of 2,029 photographs was obtained for eventual incorporation into a spotted dolphin photo-identification catalog. Four biopsy samples were collected from individuals in the group for genetic analyses at Portland State University (following protocols outlined by Courbis et al. 2014), and sub-samples were sent to the tissue archive at the Southwest Fisheries Science Center.

4.6 Bottlenose dolphins

Bottlenose dolphins were sighted on six occasions (**Figure 1, Table 5**). No funding was available for tagging bottlenose dolphin groups so encounter durations were short (median=11 minutes, range=5 minutes to 2 hours 11 minutes). Photographs were obtained from all six encounters, representing 73 identifications. Good- or excellent-quality photographs were available from 56 of the 73 identifications, representing all six encounters. Restricting analyses to good-quality photographs of distinctive individuals, there were 40 identifications representing 36 individuals. A comparison to the long-term photo-identification catalog (Baird et al. 2009) indicated that 32 of the 36 individuals were previously documented, all off Kauaʻi and/or Niʻihau. Of those 32 that were previously documented, three had been seen in one previous year, three had been seen in two previous years, nine had been seen in three previous years, four had been seen in four previous years, three had been seen in five previous years, seven had been seen in six previous years, two had been seen in seven previous years, and one had been seen in eight previous years. Nine of the individuals were first documented off Kauaʻi and Niʻihau over 10 years earlier (maximum span of years=15.2), three during CRC's first field project off Kauaʻi in 2003 (Baird et al. 2003). Individuals from all encounters were linked by association to the main cluster of the Kauaʻi/Niʻihau social network (**Figure 15**), which includes almost 90 percent of all bottlenose dolphins photo-identified off the islands, indicating they were all from the island-associated population. Excluding 18 individuals photographed off Kaʻula Island, 93.9 percent of the individuals photo-identified off Kauaʻi and Niʻihau since 2003 have been linked by association within this social network, suggesting that non-resident bottlenose dolphins rarely visit the area.

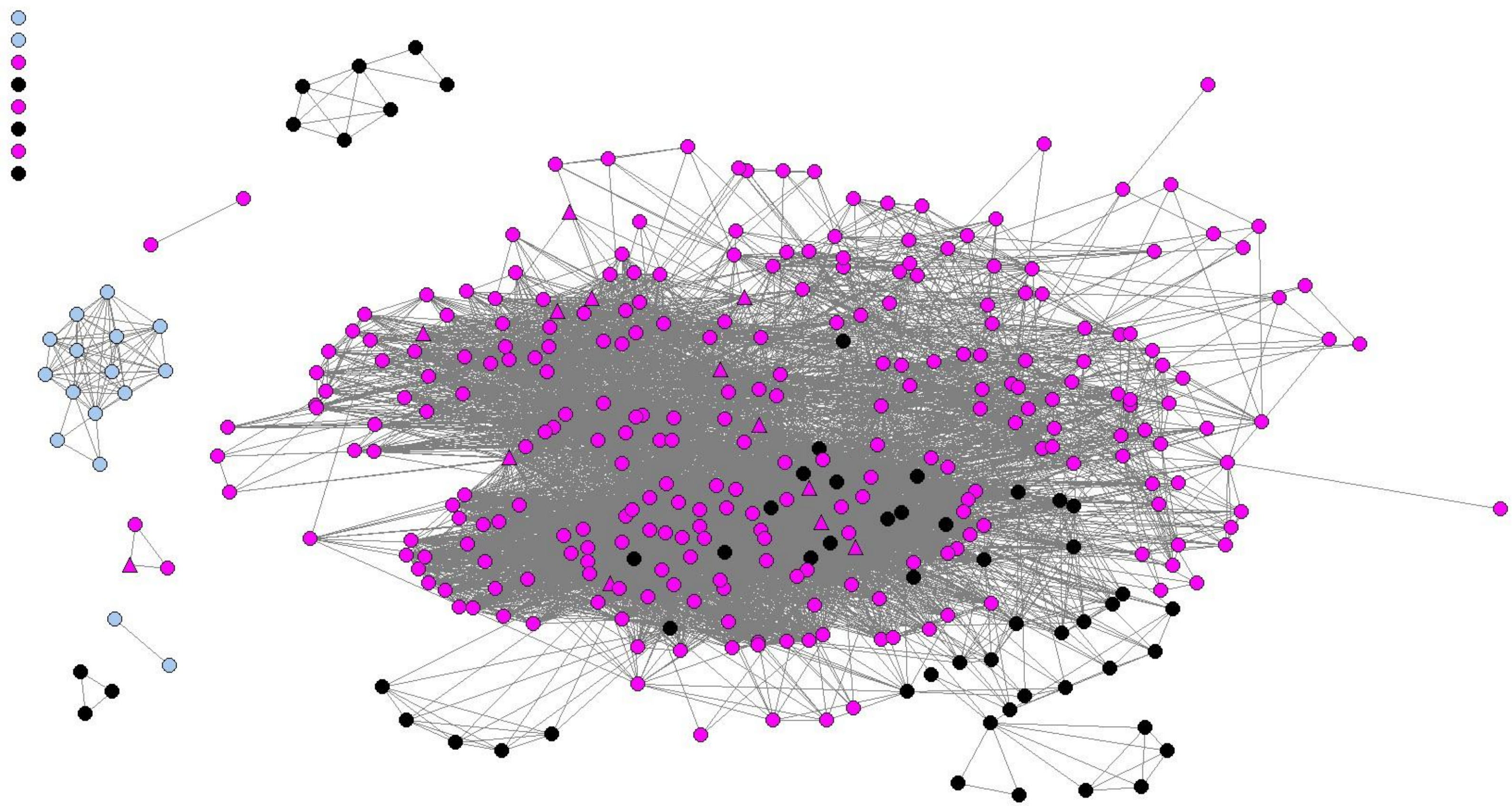


Figure 15. Social network of bottlenose dolphins photo-identified off Kaua'i, Ni'ihau, and Ka'ula including all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2009). Individuals that have been tagged in previous efforts are noted by triangles. A total of 363 individuals is shown, 324 (89.3 percent) in the main cluster. Individuals are color-coded based on the island first seen: Kaua'i – pink; Ni'ihau – black; Ka'ula – blue. The lone points in the upper left corner of the figure are individuals that have not been sighted with any others that meet the photo quality and distinctiveness criteria.

5. Discussion and Conclusion

Over the 15-day field effort in August 2018 information was obtained on seven species of odontocetes off Kaua‘i, four of which (short-finned pilot whales, rough-toothed dolphins, spinner dolphins, and bottlenose dolphins) are regularly seen off the island, and three (sperm whales, melon-headed whales, pantropical spotted dolphins) which are rarely seen there (Baird et al. 2013a; Baird 2016). Our sightings of short-finned pilot whales represent the first CRC sightings of pilot whales from the month of August off Kaua‘i or Ni‘ihau, despite 132 hours (1,996 km) of prior CRC research efforts there (in August 2013, August 2015, and August 2017).

We deployed eight satellite tags on four species prior to the SCC. The satellite-tag data obtained from three of these species, when interpreted in the context of the association and re-sighting data, increased our understanding of how these species use the area and potentially overlap with naval activities. These results directly address the monitoring question in the scope of work “what are the spatial movement patterns and habitat use of marine mammal species that are exposed to mid-frequency active sonar and how do these patterns influence exposure and potentially responses.”

Six of the tags were programmed to include Fastloc-GPS locations in addition to Argos locations and dive behavior. These were the first Fastloc-GPS tags deployed on odontocetes off of Kaua‘i, and we programmed the tags to maximize high-temporal-resolution data for a period of time around the SCC. While sacrificing longer-term data (both behavioral and Fastloc-GPS locations), overall this programming regime was extremely successful in terms of the high-resolution behavioral information and Fastloc-GPS locations received. While no locations were received from two of the Fastloc-GPS tags (at least one of which appeared to fail on impact), three of the remaining four tags performed extremely well, all deployed on short-finned pilot whales. In these three cases, for the periods that the tags were programmed to provide dive data and Fastloc-GPS locations (i.e., the time period surrounding the SCC), all three tags provided almost a complete record of dive data and higher resolution location data than is available from Argos alone (**Figures 7, 9, 11; Table 9**). One Fastloc-GPS tag deployed on a melon-headed whale produced more Argos locations than Fastloc-GPS locations, although this likely was due to the tag stopping transmissions prior to the cessation of collection of Fastloc-GPS locations. One of the tagged individuals, a short-finned pilot whale with high-resolution dive and location data (GmTag214, **Figures 9, 11**) was on the range at the start of the SCC and thus available for analyses of exposure and response. Data from this individual are included in analyses following methods of previous exposure analyses (Baird et al. 2017b) that will be available later in 2019.

As has been the case with previous CRC efforts off Kaua‘i, rough-toothed dolphins are the most frequently encountered species of cetacean on PMRF. Although encounters with this species were relatively short (median=7 minutes), based on Navy priorities, we were able to obtain both photo-identification (**Table 6**) and satellite tag data (**Figure 4**), providing additional evidence that that there is a resident population around Kaua‘i and Ni‘ihau. Combined with individuals previously tagged off Kaua‘i or Ni‘ihau, the probability density mapping from satellite tag data indicate that a large portion of the core area for this population (43.3 percent) overlaps with PMRF, and these individuals are thus likely regularly exposed to MFA sonar. Given the high encounter rates, ease of working with this species, and overlap of their core area with PMRF, this species would be an ideal candidate for detailed assessment of exposure and response to MFA sonar, as well as determining population consequences of such exposure.

Photo-identification data from the five encounters with short-finned pilot whales indicated they represented three different social groups (two of which were encountered twice) from two different communities. Sighting histories and social network analyses revealed that two of the groups appear to be part of the western community of resident pilot whales, which range primarily from Niʻihau to Oʻahu, with core areas around Kauaʻi and Niʻihau as well as off western Oʻahu (**Figure 11**). The remaining group is linked by association with the main cluster in the eastern community of short-finned pilot whales (**Figure 6**), whose range primarily centers off Hawaiʻi Island (Baird 2016). However, this group has only been seen on two prior occasions off Hawaiʻi Island, and thus does not appear to show strong fidelity to the area. Based on the satellite-tag data (**Figure 8**), this group appeared to act similarly to how some tagged pelagic short-finned pilot whales have used offshore waters. This variability reflects that, despite intensive research on pilot whales in the islands (e.g., Abecassis et al. 2015; Mahaffy et al. 2015; Baird 2016; Van Cise et al. 2016, 2017a, 2017b, 2018), there is still much remaining to be learned about their population structure and spatial use.

In CRC's previous work off Kauaʻi and Niʻihau, melon-headed whales had only been encountered on nine previous occasions representing four or possibly five different groups: a sighting in June 2003 north of Kauaʻi (Baird et al. 2003), sightings in June 2008 on three different days over a 5-day span in the Kaulakahi Channel (CRC unpublished), and four sightings in August 2017, representing two repeat sightings of a large group and two sightings of a lone individual traveling with a melon-headed whale x rough-toothed dolphin hybrid (Baird et al. 2018). We had two encounters with melon-headed whales during the August 2018 effort that appeared to be the same group seen twice, representing only the fifth or sixth group of melon-headed whales documented in CRC's efforts off Kauaʻi and Niʻihau. Tag data from this group over a 9-day period showed they remained generally associated with Kauaʻi and Niʻihau (**Figure 13**), although the individuals are almost certainly part of the Hawaiian Islands stock of melon-headed whales, which broadly uses offshore waters in Hawaiʻi with movements among the islands (**Figure 14**; Aschettino et al. 2012; Baird 2016; Carretta et al. 2017; Martien et al. 2017). To confirm population identity comparisons of photographs taken during these encounters with the CRC photo-identification catalog would be required[2]. The sightings and associated satellite tag data from this and prior efforts illustrate that melon-headed whales are rarely seen in the area. However, when they are seen, they may remain in the area for short periods (e.g., a week or more), and they broadly range among and offshore of the main Hawaiian Islands.

Two other rarely-encountered species were documented during the August 2018 field effort. In our prior work off Kauaʻi, pantropical spotted dolphins have only been sighted off the island on 11 occasions (Baird et al. 2013a): four times in 2003, once in 2005 (a single individual associating with spinner dolphins), three times in 2011 (all of the same lone individual documented in 2005, and all three times associating with spinner dolphins), and once each in 2012, 2016, and 2017. Overall they represent only approximately 2 percent of odontocete sightings off Kauaʻi and Niʻihau, compared to between approximately 23 and 26 percent of odontocete sightings off other islands

[2] No funding has been available for upkeep of CRC's melon-headed whale photo-identification catalog for several years so a large backlog of photographs needs to be assessed to update the catalog.

(Baird et al. 2013a). Based on a combination of low sighting rates (particularly in comparison to the other main Hawaiian Islands) and genetic information (Courbis et al. 2014), pantropical spotted dolphins are not thought to be resident to Kaua‘i or Ni‘ihau (Baird 2016), and thus groups that may be in the area during MFA sonar use are likely naïve to such exposure. The sample size of genetic samples from this species off Kaua‘i in the Courbis et al. (2014) study was small, however (n=8), and only three additional samples had been collected from spotted dolphins around the island subsequent to that study. Although we did not obtain any useful data from the single tag deployed during our August 2018 encounter, we did obtain four skin/blubber biopsy samples, and they will contribute to a better understanding of the population structure of this species in Hawaiian waters.

Sperm whale sightings in CRC’s previous field work off the island are even less common, with the sighting of a single animal in June 2003 (Baird et al. 2003) and two groups of adult females and juveniles on the same day in October 2014 (Baird et al. 2017c). While sperm whales are regularly recorded acoustically on PMRF (Martin et al. 2018), they primarily spend their time in deep water (Baird et al. 2013a; Rone et al. 2015) and thus are usually found outside of the normal range of the research vessel. A satellite-tag deployment on one individual in October 2014 revealed wide-spread movements away from the islands over a 14-day period. Combined with the low sighting rates, this evidence suggests sperm whales are not resident to the islands (Rone et al. 2015; Baird 2016), and thus individuals that are exposed to MFA sonar on PMRF are likely naïve to such exposure. Our sperm whale sighting in August 2018 was only our fourth off the island; unfortunately, the long distance (>2 km) traveled on the long (approximately 1 hour) dives limited our ability to approach close enough to tag. As with other rarely encountered species, continued field efforts will be required to obtain additional information to assess spatial use in relation to exposure to mid-frequency active sonar.

Although few encounters were cued by acoustic detections from M3R, this reflects that on most days there were no high-priority species acoustically detected on portions of the range that were accessible to the research vessel. Such monitoring allowed the research vessel to survey in relatively calm areas south of PMRF, effectively increasing the area that could be covered on any particular day, and resulting in encounters and successful tagging of high-priority species such as short-finned pilot whales and melon-headed whales south of the range. In addition, the value of M3R in directing the research vessel to groups that would not otherwise be encountered was illustrated by the short-finned pilot whale encounter on 19 August 2018; it was only one of the individuals tagged in this group that remained around PMRF during the SCC, thus providing additional location data for assessment of exposure and response to MFA sonar.

The Navy’s monitoring goals relate broadly to questions of marine mammal occurrence, their exposure to MFA sonar (and other Navy activities), their responses to sonar, and the consequences of exposure and responses. This research broadly addresses occurrence questions and has also provided data to address exposure and response questions (Baird et al. 2014b, Baird et al. 2017b). As photo-identification sample sizes increase, the ability to directly assess consequences improves, through the estimation of survival rates and abundance of the respective populations, as does the potential for using these datasets to examine age and sex structure as well as trends in abundance for these populations. The presence of island-associated resident populations of these species off the island of Hawai‘i (Baird 2016), an area with less frequent exposure to MFA sonar, will also provide a useful comparison of age and sex structure of populations with varying levels of exposure of MFA sonar, which may provide a strong basis for assessing consequences to exposure.

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