Final Report

Odontocete Studies on the Pacific Missile Range Facility in February 2020: Satellite-Tagging, Photo-Identification, and Passive Acoustic Monitoring

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Cover Photo Credit:

False killer whale (*Pseudorca crassidens*) off Kauaʻi. Photograph taken by Jordan K. Lerma under National Marine Fisheries Service permit no. 20605.

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Acronyms and Abbreviations

~	approximately
#	number
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
HF	high frequency
Hz	Hertz
ICI	inter-click interval
kHz	kilohertz
km	kilometer(s)
km^2	square kilometer(s)
LF	low frequency
m	meter(s)
M3R	Marine Mammal Monitoring on Navy Ranges
MFAS	mid-frequency active sonar
n/a	not applicable
PAM	passive acoustic monitoring
PMRF	Pacific Missile Range Facility
S	seconds
SCC	Submarine Command Course
SWTR	Shallow Water Training Range

Executive Summary

As part of a long-term U.S. Navy-funded marine mammal monitoring program, in February 2020 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-February 2020. 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. Results from this effort were compared with previous Cascadia Research Collective (CRC) survey effort and photo-identification and tag data from Kauaʻi, based on surveys in 11 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 increase overall encounter rates with high-priority species.

Over the course of the 13-day project, there were 1,064 kilometers [km] (71.3 hours) of small-vessel survey effort, 47 sightings of seven species of odontocetes, 23 sightings of humpback whales (*Megaptera novaeangliae*), and one sighting of an unidentified odontocete. Of the 48 odontocete sightings, 20 were on PMRF representing four of seven species, and of those eight were directed by M3R acoustic detections. During the encounters, we took 26,178 photographs for species and individual identification, with photographs added to long-term CRC catalogs for short-finned pilot whales (*Globicephala macrorhynchus*), false killer whales (*Pseudorca crassidens*), pygmy killer whales (*Feresa attenuata*), common bottlenose dolphins (*Tursiops truncatus*), and rough-toothed dolphins (*Steno bredanensis*). Nineteen biopsy samples were taken from five species. Spinner dolphins (*Stenella longirostris*) were seen on 12 occasions, but this was a low-priority species so limited efforts were expended to work with them.

As expected based on previous CRC efforts off Kauaʻi and Niʻihau, rough-toothed dolphins were the most frequently encountered species, comprising 18 of 47 encounters with known species (38.3 percent). Ten of the 18 encounters were on PMRF. A social network analysis of photo-identification data of rough-toothed dolphins indicated that all but two of the identified individuals from this project linked to the main cluster of the resident, island-associated population. In three of the sightings a single melon-headed whale was present, as well as a melon-headed whale x rough-toothed dolphin hybrid, both of which had been previously documented off Kauaʻi during CRC's August 2017 field effort. The melon-headed whale was not approachable for tagging. For two of the three sightings of the hybrid and melon-headed whale, the individuals were not noted at the time of the encounters but were only recognized from later analysis of photographs.

Short-finned pilot whales were encountered only once, and a single SPLASH-10F depth-transmitting satellite tag that included Fastloc®-GPS capability was deployed. The group with the tagged animal had been previously documented in five different years (all off either Kauaʻi or Oʻahu), and was considered to belong to the resident western community of short-finned pilot whales. A crawl model (continuous-time correlated random walk state-space model) of the tag data produced a total of 372 locations at 1-hour intervals compared to 314 total Argos locations, and 277 combined Argos and GPS locations. Behavior (i.e., dive depths and durations of dives and surfacing periods) data coverage during the 12 days that behavior was recorded was 86.8

percent. Over the 16-day period during which the tag transmitted, the group spent most of its time in deep water far offshore (median depth=3,504 meters, median distance from shore=28.1 km), remaining in the area where the Submarine Command Course took place.

Pygmy killer whales were sighted once. This group was not approachable for tagging, but identification photos were obtained for 15 individuals, none of which had been previously identified. This species is among the least likely to be encountered off Kauaʻi or Niʻihau; in previous CRC surveys they have only been documented on two occasions. Neither of these groups have been documented prior or subsequently, providing additional evidence that there is no resident population of this species off Kauaʻi or Niʻihau.

False killer whales were encountered on three occasions over two days (14 and 15 February 2020), with all sightings on PMRF and two in response to acoustic detections. None of the groups were approachable for tagging, but identification photos were obtained for the two encounters on 14 February 2020. Eight identifications were obtained from the first encounter on 14 February 2020, four of which had been previously documented and linked by association to the Northwestern Hawaiian Islands population of false killer whales. Only a single identification was obtained from the second encounter on 14 February 2020. While the individual had not been previously documented, it was most likely also from the Northwestern Hawaiian Islands population, given the proximity to the first encounter. Three biopsy samples were obtained, from individuals in both of the encounters on 14 February 2020. The 15 February 2020 encounter was brief (<1 minute), with a single individual lost shortly after being sighted.

Common bottlenose dolphins (hereafter bottlenose dolphins) were encountered on nine occasions, and 46 good-quality identifications of 24 distinctive individuals were obtained. Of those, 23 had been previously documented, and all were linked by association with the resident community of bottlenose dolphins from Kauaʻi and Niʻihau. Two SPLASH10 depth-transmitting satellite tags were deployed onto bottlenose dolphins during the project, on 15 and 17 February 2020. Both individuals tagged are known members of the resident Kauaʻi and Niʻihau community, and one of the two individuals had been previously tagged during a 2013 CRC field project. The tags produced 223 and 383 Argos locations over 13.9 and 20.0 days, respectively, and generally remained close to the islands (median depth=119 m and 180 m, median distance from shore=3.1 km and 3.7 km, respectively). Behavioral data (i.e., dive and surfacing) coverage during deployment was 100 percent for both tags.

Probability-density analyses were undertaken using 12-hour locations from crawl state-space models of tag-location data obtained for the two species for which tag data were available from this effort, incorporating data from all previous tag deployments on individuals from these populations. Core areas (50 percent kernel densities) were identified for the resident populations of bottlenose dolphins (1,852 square kilometers) and the western community of short-finned pilot whales (8,736 square kilometers). While the core areas for both 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*), common bottlenose dolphins (*Tursiops truncatus*, hereafter bottlenose dolphins), 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 other species, for example false killer whales (*Pseudorca crassidens*), pygmy killer whales (*Feresa attenuata*), and pantropical spotted dolphins (*Stenella attenuata*), were low off Kauaʻi and Niʻihau in comparison to other areas (Baird et al. 2013a). Genetic samples obtained from pantropical spotted dolphin sightings off Kauaʻi and Niʻihau suggest that spotted dolphins in that area are part of a pelagic, open-ocean, population (Courbis et al. 2014). For false killer whales, Kauaʻi and Niʻihau is known to be an overlap area for all three recognized populations (main Hawaiian Islands insular, Northwestern Hawaiian Islands insular, and pelagic) in Hawaiian waters (Bradford et al. 2015).

CRC efforts using satellite tags to assess movements and behavior of odontocetes 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 February 2020, CRC has had 13 additional vessel-based field projects off Kauaʻi, 12 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 calls from several species of marine mammals, has been implemented at four 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), PMRF (2011–present; Jarvis et al. 2019), and most recently at the Jacksonville Shallow-Water Training Range (2019-present). While automated species classification is not always possible through the M3R system, real-time classifiers have been developed for some of the high priority species (e.g., beaked whales), and other species are able to be discriminated by trained M3R operators based on spectral characteristics. 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.

From the 14 CRC field efforts off Kauaʻi since 2008, data have been obtained from 82 satellite tags deployed on eight different species of odontocetes (**Table 1**; Baird et al. 2011, 2012a, 2012b, 2013b, 2013c, 2014a, 2015, 2016, 2017a, 2018, 2019a). Results of field efforts through August 2018 have been previously summarized (Baird et al. 2019a; Baird 2016). Combined, CRC efforts off Kauaʻi and Niʻihau from 2003 through August 2018 accounted for 1,296 hours of boat-based search effort (21,904 kilometers [km]) over 11 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 Kauaʻi to be undertaken prior to a Submarine Command Course (SCC) in February 2020. 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 February 2020 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 sonar (MFAS). In addition to the results of work from February 2020, we incorporate results from previous efforts where relevant from CRC work off Kauaʻi and elsewhere in the main Hawaiian Islands (Baird 2016). Data obtained through this effort have also contributed to a study examining exposure and response of several species to MFAS (Baird et al. 2014b, 2017b, 2019b); 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*
6–20 Aug 2018	100.0	*Tt, Sb, Gm, Sl, Sa, Pe, Pm*	*Gm* (4)[3], *Pe* (2)[3], *Sa* (1), *Sb* (1)	*Pm, Md, Tt, Sb*
Total	**956.0**		*Gm* (32)[4], *Pe* (7)[3], *Tt* (13), *Sb* (21), *Sa* (4), *Pc* (7), *Md* (2)[3], *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.

[3] One tag did not transmit.

[4] Three tags did not transmit.

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, which overlaps with the legacy BSURE. The ranges partially overlap (**Figure 1**), 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. The majority of the SWTR hydrophones and some of the BARSTUR (along the southern and southwestern part of BARSTUR) and BSURE hydrophones are no longer functional, reducing the available data for cetacean detections in nearshore areas and on the southern part of the range.

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)	8–40 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 2020, the M3R system at PMRF was used during 12 CRC field projects (**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 Section 3.2), as well as photo-identifying individuals and collecting biopsy samples for genetic studies.

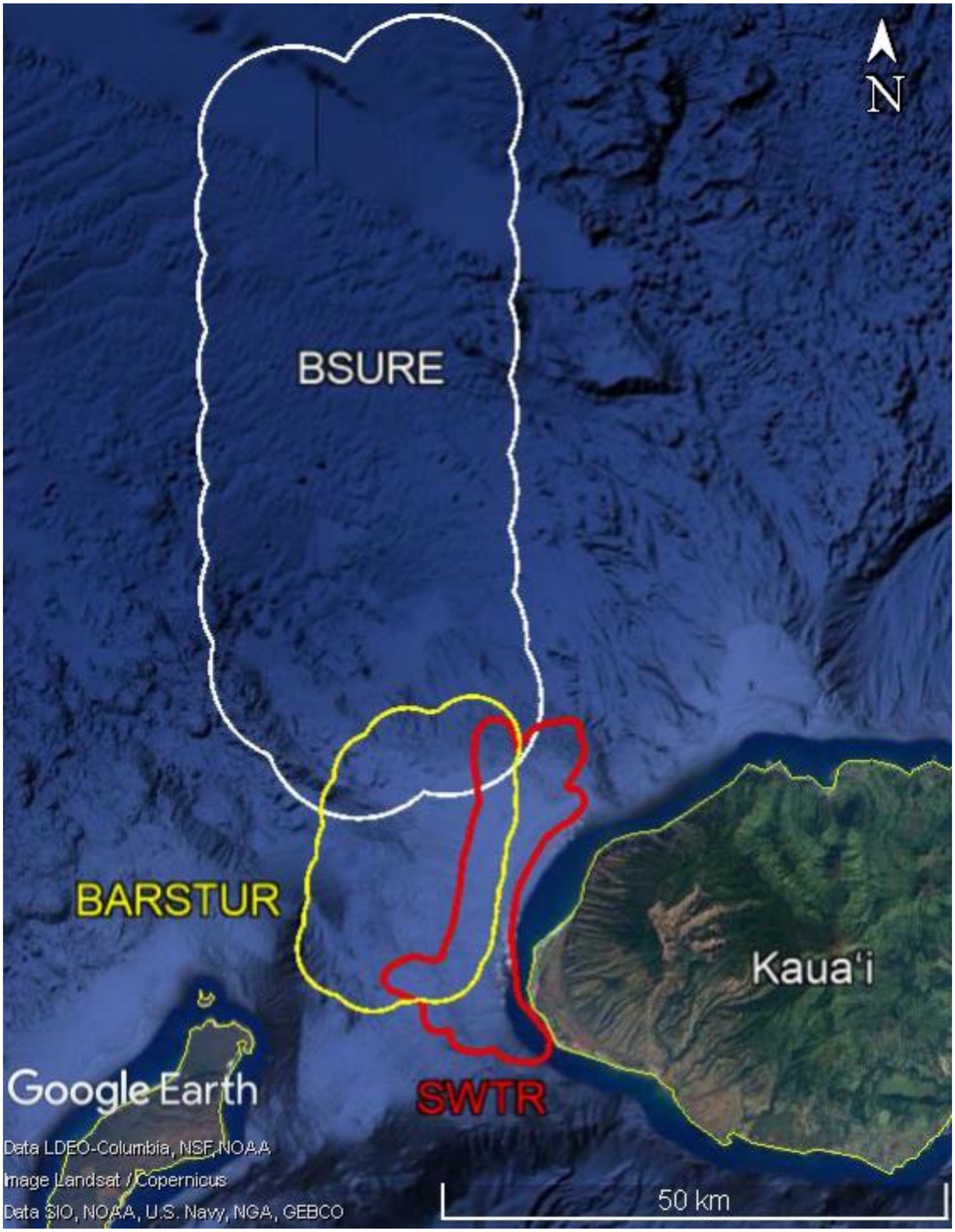

Figure 1. The PMRF hydrophone system showing range systems: Shallow Water Training Range (SWTR), the Barking Sands Tactical Underwater Range (BARSTUR), and Barking Sands Underwater Range Expansion (BSURE).

M3R 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. During combined boat- and M3R field efforts, detection and localization data are parsed and interpreted by M3R operators and relayed to the boat via radio. Localization 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 (Møhl 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 both foraging and buzz clicks from Blainville’s (*Mesoplodon densirostris*) and Cuvier’s (*Ziphius cavirostris*) beaked whales (Jarvis 2012). The CS-SVM also detects sperm whales and includes a Generic Dolphin class that detects clicks from various small odontocetes. In addition to the CS-SVM classifiers, M3R 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 overlapping 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 for 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 low-frequency 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 into M3R 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 is displayed to the PAM operator using Worldview and MMAMMAL real-time display software. MMAMMAL displays a color-coded map of the hydrophones indicating the level 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, 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 field 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 posit 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[1]
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] Species codes: *Tt=Tursiops truncatus, Sb=Steno bredanensis, Gm=Globicephala macrorhynchus, Sl=Stenella longirostris, Sa=Stenella attenuata, Pc=Pseudorca crassidens, Md=Mesoplodon densirostris,*

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

Detection archives were collected from all hydrophones, 24 hours per day, for almost 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 to estimate received levels of any MFAS 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.

2.3 Coordination with Small-vessel Efforts

PAM was undertaken for all 12 days of small-vessel research effort. PAM began between 0600 and 0630 every morning. PAM was used both to direct the research vessel to locations of acoustic detections of high-priority species (e.g., false killer 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 calmer areas south of the range. Monitoring continued until the research vessel returned to port or if weather conditions on the range were not suitable for small-vessel 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.

Once selected, the identity of 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

Ten 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 eight location-only tag (Wildlife Computers SPOT6) were available from another grant to CRC. 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 humpback whales (*Megaptera novaeangliae*). SPLASH10 tags were only to be deployed on lower-priority species (e.g., bottlenose dolphins, rough-toothed dolphins) during the latter half of the field effort, depending on the availability of tags. Tags were in the LIMPET configuration, with attachment to the animals via 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 bottlenose dolphins, long darts for short-finned pilot whales).

Tags were programmed to maximize the likelihood of obtaining behavior and location information over a 12-day period that spanned the scheduled SCC (3 days before, 3 days after and the 6 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 Argos satellite overpasses. In terms of transmissions, tags were set with GPS locations as high priority and behavior logs (i.e., dive data) as low priority, with a 6-day buffer. Behavior data and GPS locations were only collected up to 3 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 longer than 30 seconds and exceeding 50 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 per 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 and location.

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 GPS locations. This system uses a Wildlife Computers MOTE (see Jeanniard-du-Dot et al. 2017) to record and transmit 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, Kauaʻi (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 Niʻihau (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 over a 13-day span immediately prior to and during the first three days of the SCC scheduled for February 2020. It should be noted that MFAS is not used during the first approximately three days of the SCC, and tagging efforts continued during that non-MFAS period.

The vessel used was a 24-foot (7.3 m) rigid-hulled inflatable, powered by twin Yamaha 150-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. Launch sites were either Kīkīaola small boat harbor or Port Allen, depending on strength and direction of prevailing winds and anticipated areas for suitable working conditions. 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 days when weather conditions allowed access to the range or areas near the range. 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. Humpback whales were generally not approached unless they were associated with odontocetes, or in cases when weather conditions precluded working with other higher-priority species. When more than one species was present in a group they were recorded as separate sightings, and details were noted on spacing and interactions among the species. Decisions on how long to stay with each group and the 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, false killer whales, pygmy killer whales, short-finned pilot whales) 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 neonates in the group, the number of individuals bowriding, and information necessary for permit requirements.

For infrequently encountered species (e.g., false killer whales, short-finned pilot whales, pygmy killer whales), 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 samples could be used to assess stock identity (e.g., false killer whale, see Martien 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. Biopsy samples were sub-sampled for a number of ongoing studies. Skin sub-samples were submitted to the Southwest Fisheries Science Center for archiving for genetic analyses, as well as to Florida International University for a study of stable isotopes. In addition, skin and blubber sub-samples from most samples were submitted to University of California San Francisco for developing cell lines. Blubber samples were archived at the University of Hawai‘i for hormone chemistry and/or toxicology analyses.

3.4 Data Analyses

Five-minute effort locations of the research vessel were processed with R v4.0.2 (R Core Team 2020) to determine bathymetric depth from Hawaiian Island 50 Meter Bathymetry and Topography Grids (www.soest.hawaii.edu/HMRG/multibeam/bathymetry.php) using the package, *raster* (Hijmans 2020). When data were not available through this higher resolution grid, then depth was determined using the GEBCO 30 arc-second grid (www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_30_second_grid/). We determined whether effort and sightings locations were inside or outside the PMRF instrumented range boundaries using the package *sf* (Pebesma 2018).

For short-finned pilot whales, rough-toothed dolphins, pygmy killer whales, false killer whales, melon-headed whales, and bottlenose dolphins, 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, 2008c, 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. Humpback whale fluke photos were submitted to www.happywhale.com.

For the above-noted odontocetes, with the exception of melon-headed whales, all individuals were compared to individual photo-identification catalogs (Baird et al. 2008a, 2008c, 2009; Mahaffy et al. 2015; McSweeney et al. 2009) to determine sighting histories. Catalogs include photographs obtained from dedicated CRC field efforts where attempts were made to photograph all individuals in groups, as well as opportunistic photos contributed by citizen scientists or other researchers. For these species, associations among individuals and groups were assessed with SOCPROG 2.7 (Whitehead 2009). Social networks were generated using Netdraw 2.158 (Borgatti 2002) to illustrate associations, restricted to individuals that were at least slightly distinctive and with photographs that were categorized as fair or better. Associations within social networks have previously been used with several species of Hawaiian odontocetes to inform population identity and examination of genetic structuring of populations (e.g., Aschettino et al. 2012; Baird et al. 2008c; Martien et al. 2014; Van Cise et al. 2017a). With the exception of false killer whales in Hawai‘i (Martien et al. 2014), determining population identity of odontocetes is not possible with genetic analyses of a single biopsy sample (Albertson et al. 2017; Courbis et al. 2014; Martien et al. 2011; 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., Albertson et al. 2017; Courbis et al. 2014; Martien et al. 2011). 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 streams 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 time series data as well as GPS locations from the SPLASH10-F tags. Any additional messages detected by the goniometer onboard the research vessel were decoded using the package *parsegonio* (Cioffi 2020) and incorporated into datasets where applicable.

For quality control measures, we removed GPS locations with residual values greater than 35 (Dujon et al. 2014) and/or with time errors longer than 10 seconds; resulting locations were subsequently filtered through a general speed filter accessed via Movebank (Kranstauber et al. 2011). We set the maximum plausible speed to 5 m per second (18 km per hour) and maximum location error to 1000 m. Argos location data were processed through the Kalman smoothing algorithm (Lopez et al. 2015) accessed through Argos CLS. Kalman-smoothed positions were then filtered through the Distance, Angle, Rate filter of the Douglas-Argos Filter (Douglas et al. 2012) via Movebank (Kranstauber et al. 2011) to remove unrealistic locations. User-defined filter settings were specified as follows: maximum sustainable rate of movement (MINRATE) was set to 15 km per hour for short-finned pilot whales and 20 km per hour for bottlenose dolphins; maximum distance between consecutive locations (MAXREDUN) was set to 3 km; the tolerance level for turning angles (RATECOEF) was set to 25, the default for marine mammals; and positions with an Argos location-quality class of 2 or 3 were exempt from filtering (KEEPLC).

Where multiple tags were deployed on the same species, we assessed whether individuals were moving synchronously during the period of overlap by calculating the straight-line distance between pairs of individuals for locations transmitted during a common satellite pass (approximately 15 minutes). Following Schorr et al. (2009) and Baird et al. (2010), we used both the mean distances and maximum distances between pairs of individuals to inform whether individuals were acting independently.

After applying quality-control measures, we fitted location data to a continuous-time correlated random walk model (state-space model) using the package, *crawl* v.2.2.3 (Johnson et al. 2008; Johnson and London 2018), which allows for direct incorporation of positional uncertainty (i.e., location error ellipse measures) into state (i.e., location) estimation. To reduce bias associated with varying tag programming regimes and satellite coverage probabilities, we used fitted crawl models to predict locations at a 1-hour time step. In addition, where segments of predicted trajectories occurred on land, we applied the *fix_path* function within *crawl* (Johnson et al. 2008; Johnson and London 2018) to re-route segments around land. Briefly, this function identifies segments intersecting with land (polygon), and then uses a least-cost algorithm and model-fitted parameters to generate segments around land. For SPLASH10-F tags, GPS locations were used in place of Argos locations where applicable in the time series of the deployment.

Hourly locations were then processed in R to determine bathymetric depth using the same procedure as described above via *raster* (Hijmans 2020), and distance from shore and whether or not locations were inside or outside the PMRF instrumental range boundary via the package, *sf* (Pebesma 2018). For segments occurring within the range, we estimated the proportion of time spent within range boundaries by summing the total amount of hourly positions that occurred within the range boundary.

Prior to analysis of dive behavior data, we examined behavior time series and tag status files to ensure the tags operated as intended and to check for any indication of pressure transducer failures that may have occurred during the deployment. Specifically, we reviewed the depth value recorded for each status message; this value represents the last depth value recorded immediately prior to the tag transmitting a location. Because the animal must surface for a location to be transmitted, this value is usually within 1 to 2 m of zero, although some cases of extreme linear drift have been observed where a range of up to 10 m may be considered acceptable (R.D. Andrews, Marine Ecology and Telemetry Research, pers. comm.). Therefore, we considered depth values exceeding +/-10 m as a possible indication of pressure transducer failure. In addition, we assessed values reported in the ZeroDepthOffset column, which represents the offset value the tag applies to the depth sensor readings. We deemed values that exceeded +/- 9 m as possible transducer failures. Lastly, we calculated minimum rates of ascent and descent, where extreme ascent/descent rates may be indicative of a pressure transducer failure. Ascent/descent rates were calculated by dividing twice the dive depth by the dive duration, and an average value of 2 m per second was used as a proxy for potential transducer issues. Where possible pressure transducer failure was evident, behavior data were truncated to exclude records following the suspected occurrence of failure as reported in the status file. Behavior data are transmitted in blocks that include five dives and five surfacing periods. Gaps in the behavior record occur when a block is not received and are of variable durations depending on the durations of the dives and surfacing periods within each block. We calculated the proportion of coverage of behavior data obtained by comparing the summed duration of dives and surface periods to the total period that behavior data were expected, given tag programming and when they were deployed relative to the start of the SCC.

Probability-density distribution analysis was undertaken for the two resident populations/communities tagged during the February 2020 effort. For this analysis, we used location data from previous tag deployments on individuals belonging to these communities in addition to the location data obtained from the February 2020 effort. Locations for each population were pooled, and only a single individual from each synchronous pair was used where applicable. Positions from the first 24 hours of each deployment were excluded from analysis to reduce potential bias associated with the deployment region. Crawl-fitted models were used to predict locations at 12-hour intervals in order to reduce spatial autocorrelation, which can lead to overconfidence in probability distribution estimates (Fleming et al. 2015). Kernel density polygons were generated using adehabitatHR (Calenge 2006), from which 50, 95, and 99 percentile ranges were estimated. The percentage of overlap between the 50 percent polygon (i.e., “core area”) with the PMRF boundary was calculated for each species/population. For bottlenose dolphins, 13 additional individuals tagged off Kauaʻi were included. For short-finned pilot whales, 18 additional individuals tagged off Kauaʻi and known or thought to belong to the western community of insular individuals were included.

4. Results

From 6 to 18 February 2020, there were 1,064 km (71.3 hours) of small-vessel field effort (**Figure 2**), with the boat on the water for 12 of the 13 days (**Table 4**). Due to unworkable sea conditions off the west side of Kauaʻi, the research vessel was launched from Port Allen small boat harbor during the first half of the project (6 to 11 February 2020). During the latter half of the project (12 to 18 February 2020) the vessel was launched from Kīkīaola small boat harbor. Forecasted winds over the 12 days of fieldwork included east 20 knots (four days), east 25 knots (one day), north 20 knots (four days), northeast 20 knots (two days), and north-northwest 20 knots (one day). On 10 February 2020 forecasted winds were north gales reaching 35 knots and easing to 25 knots, and the research vessel did not go out on the water as a result of the unworkable sea conditions. Strong winds and/or a large short-period swell precluded surveying on PMRF on some days, and Navy activities periodically limited access to parts of the range. A majority of search effort was in depths less than 1,000 m, with almost 35 percent of effort spent in waters less than 100 m deep (median depth=445 m; **Figure 3**). Search effort in shallower depths primarily reflects transiting back to the harbor when there are unworkable conditions offshore.

Overall, there were 71 cetacean sightings: 23 of humpback whales and 48 of odontocetes (one of which was unidentified). Twenty encounters with four of the seven species of odontocetes (rough-toothed dolphins, bottlenose dolphins, false killer whales, and a melon-headed whale) were documented on PMRF (**Figure 2**, **Table 5**). Rough-toothed dolphins were encountered on 18 occasions (38.3 percent of all encounters with known species), spinner dolphins on 12 (25.5 percent), bottlenose dolphins on nine (19.1 percent), false killer whales on three (6.4 percent), melon-headed whales on three (6.4 percent), short-finned pilot whales on one (2.1 percent), and pygmy killer whales on one (2.1 percent).

During the encounters, we took 26,178 photographs for individual and species identification. Humpback whale identification photographs were obtained from eight out of the 23 encounters, representing as many as 16 individuals. Identification photos from these encounters were submitted to www.happywhale.com. Spinner dolphin photographs were obtained from eight out of the 12 encounters, but photographs for this species were not analyzed and are not discussed further. Results from photo-identification of other species are discussed below. During encounters three satellite tags were deployed on two species, and 19 biopsy samples were collected from five different species, including four species of odontocetes (**Table 5** and **Table 6**).

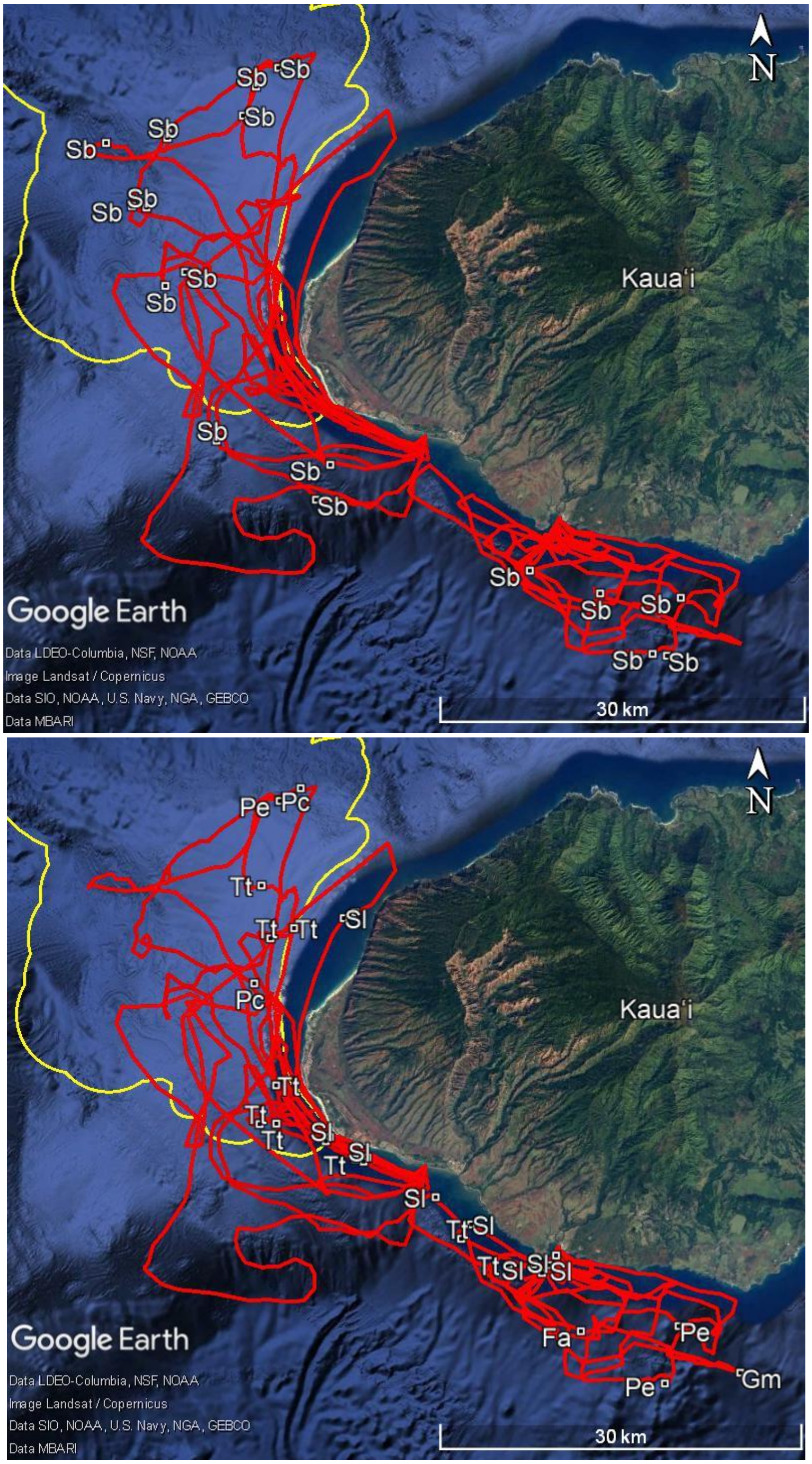

Figure 2. Search effort (red lines) and odontocete sightings (white squares) over 13 days from 6 to 18 February 2020. Top – rough-toothed dolphins. Bottom – other species. Species are indicated by two-letter codes (Sb=*Steno bredanensis*, Tt=*Tursiops truncatus*, Gm=*Globicephala macrorhynchus*, Sl=*Stenella longirostris*, Pe=*Peponocephala electra*, Pc=*Pseudorca crassidens*, Fa=*Feresa attenuata*). The PMRF outer boundary is indicated in yellow. Note the northernmost melon-headed whale (Pe) encounter also included false killer whales.

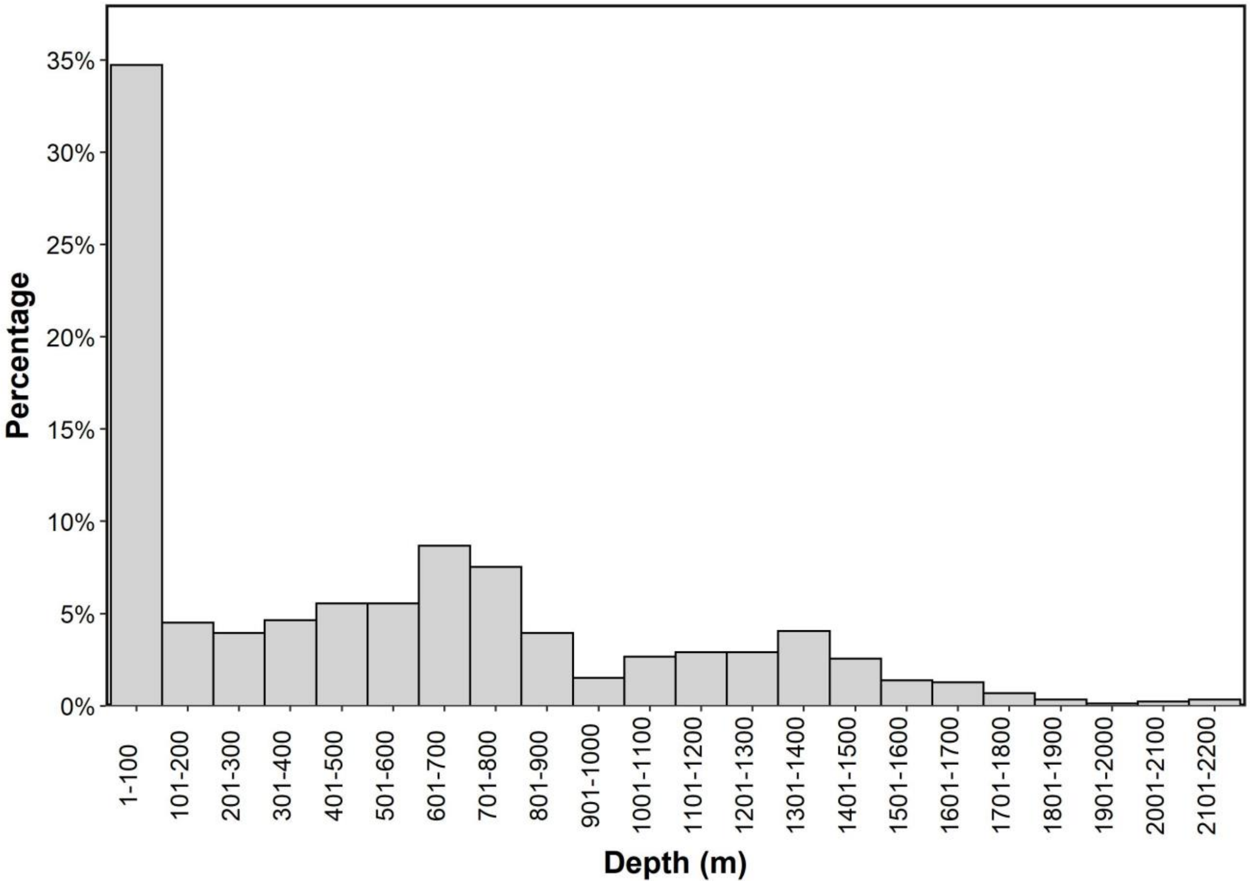

Figure 3. Depth distribution of search effort during 12 days of effort from 6 to 18 February 2020.

Overall, there were 71 cetacean sightings: 23 of humpback whales and 48 of odontocetes (one of which was unidentified). Twenty encounters with four of the seven species of odontocetes (rough-toothed dolphins, bottlenose dolphins, false killer whales, and a melon-headed whale) were documented on PMRF (**Figure 2**, **Table 5**). Rough-toothed dolphins were encountered on 18 occasions (38.3 percent of all encounters with known species), spinner dolphins on 12 (25.5 percent), bottlenose dolphins on nine (19.1 percent), false killer whales on three (6.4 percent), melon-headed whales on three (6.4 percent), short-finned pilot whales on one (2.1 percent), and pygmy killer whales on one (2.1 percent).

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Table 4. February 2020 small-vessel 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
06-Feb-20	64.6	5	3	7:06	12:04	0	11.8	44.2	8.6	0
07-Feb-20	67.5	5	2	6:59	11:56	0	13.2	35.8	13.4	5.1
08-Feb-20	76.5	6.5	7	6:57	13:24	0	22.4	51.5	2.6	0
09-Feb-20	71.2	5.7	2	6:55	12:34	0	0	37.4	11.6	22.2
11-Feb-20	70.7	5.2	3	6:51	12:02	0	0	61.7	9	0
12-Feb-20	110.3	6.8	3	6:55	13:44	0	4.7	98.6	0	7
13-Feb-20	130.3	6.7	2	6:53	13:36	11.4	0	93.3	8.6	17
14-Feb-20	113.3	7.1	7	6:56	14:03	0	0.8	59.5	24	29
15-Feb-20	116.3	7.6	9	6:47	14:21	0	2.4	59.2	54.7	0
16-Feb-20	89.3	5.2	3	6:52	12:05	0	15.4	52.6	11.4	9.9
17-Feb-20	87.2	6.1	5	6:57	13:04	0	0	57.4	25.5	4.3
18-Feb-20	66.8	4.4	2	6:50	11:15	0	4.8	41.7	9.2	11.1
Total	1064.0	71.3	48			11.4	75.5	692.9	178.6	105.6

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

Table 5. Odontocete sightings from small-vessel effort during February 2020.

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 Latitude (°N)	Visual ID Longitude (°W)
06-Feb-20	7:59	*Sb*	5	0	0	no	0	0	21.86360	159.61181
06-Feb-20	8:26	*Tt*	10	0	1	no	4	4	21.88813	159.62742
06-Feb-20	11:02	*Sl*	100	0	2	no	NA	NA	21.88848	159.60836
07-Feb-20	9:07	*Sl*	-[2]	0	0	no	NA	NA	21.93668	159.68387
07-Feb-20	9:55	*Fa*	12	0	0	no	6	0	21.84055	159.57172
08-Feb-20	8:47	*Sb*[3]	11	0	0	no	2	2	21.80285	159.50678
08-Feb-20	9:07	*Sb*	6	0	1	no	2	2	21.80421	159.51783
08-Feb-20	10:00	*Sb*	5	0	1	no	2	2	21.84726	159.55795
08-Feb-20	10:47	*Sb*	16	0	0	no	5	5	21.84409	159.49619
08-Feb-20	10:47	*Pe*[4]	1	0	0	no	1	1	21.84409	159.49619
08-Feb-20	12:56	*Sl*	150	0	0	no	NA	NA	21.88793	159.59658
09-Feb-20	7:00	*Sl*	-[2]	0	0	no	NA	NA	21.88232	159.60174
09-Feb-20	8:15	*Gm*	15	1	0	no	10	10	21.81042	159.44845
11-Feb-20	10:12	*Tt*	3	0	0	no	0	0	21.90681	159.66419
11-Feb-20	10:29	*Sl*	90	0	0	no	NA	NA	21.91718	159.65640
11-Feb-20	11:43	*Sl*	100	0	4	no	NA	NA	21.89488	159.59089
12-Feb-20	11:09	*Sb*	3	0	0	yes	1	0	22.07551	159.87599
12-Feb-20	12:55	*Sb*	6	0	0	no	2	1	21.93873	159.76461
13-Feb-20	12:09	*Sl*	175	0	0	no	NA	NA	22.14052	159.74609
13-Feb-20	12:21	*Sl*	35	0	0	no	NA	NA	22.13649	159.75496
14-Feb-20	7:33	*Tt*	8	0	0	yes	9	9	22.01674	159.80717
14-Feb-20	9:28	*Pc*	8	0	2	yes	4	1	22.22973	159.78831
14-Feb-20	10:29	*Sb*	3	0	0	yes	0	0	22.17465	159.88944
14-Feb-20	10:57	*Sb*	7	0	0	yes	1	0	22.17088	159.88969

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 Latitude (°N)	Visual ID Longitude (°W)
14-Feb-20	11:49	*Sb*	1	0	0	yes	0	0	22.12233	159.91684
14-Feb-20	12:14	*Sb*	6	0	0	yes	1	1	22.12127	159.90564
14-Feb-20	12:58	*Pc*	2	0	1	yes	0	0	22.08971	159.82418
15-Feb-20	7:02	*Sl*	20	0	0	no	NA	NA	21.96220	159.73959
15-Feb-20	8:42	*Sb*	4	0	1	yes	2	2	22.16717	159.93687
15-Feb-20	9:58	*Sb*	2	0	0	yes	0	0	22.18658	159.83170
15-Feb-20	10:08	*Sb*	13	0	0	yes	5	5	22.20730	159.82174
15-Feb-20	10:30	*Sb*[3]	22	0	0	yes	0	0	22.22059	159.80462
15-Feb-20	10:31	*Pc*	1	0	0	yes	0	0	22.22059	159.80462
15-Feb-20	11:23	*Tt*	21	1	0	yes	20	19	22.15986	159.81861
15-Feb-20	14:05	*Sl*	12	0	0	no	NA	NA	21.96518	159.73662
16-Feb-20	8:29	*Sb*	8	0	0	yes	3	3	22.06563	159.89104
16-Feb-20	9:41	*Tt*	3	0	0	yes	0	0	22.12930	159.79339
16-Feb-20	10:06	*Tt*	1	0	0	yes	0	0	22.12200	159.81170
17-Feb-20	7:40	*Sb*	10	0	0	no	4	4	21.91393	159.77553
17-Feb-20	9:07	*Sl*	75	0	0	no	NA	NA	21.97675	159.76873
17-Feb-20	9:16	*Tt*	12	1	0	no	11	11	21.96392	159.74603
17-Feb-20	10:45	*Tt*	10	0	1	yes	1	all within-day	21.98896	159.81989
17-Feb-20	12:24	*Sl*	60	0	0	no	NA	NA	21.97979	159.76558
18-Feb-20	7:47	*Sb*	5	0	0	no	0	0	21.95586	159.85183
18-Feb-20	8:53	*Tt*	3	0	0	yes	1	1	21.98935	159.80697

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

[2] Group not approached closely enough to determine group size.

[3] Although not noted during the encounter, based on photo analysis the lone melon-headed whale and the melon-headed whale x rough-toothed dolphin hybrid were both present in this encounter

[4] The melon-headed whale x rough-toothed dolphin hybrid is counted under rough-toothed dolphins for these encounters

4.1 Rough-toothed dolphins and melon-headed whales

Rough-toothed dolphins were the most frequently encountered species, seen on eight out of 12 total field days, and constituting 18 of our 47 encounters with known species (38.3 percent). Ten of the 18 encounters were on PMRF (**Figure 2, Table 5**), and three of those groups were found in response to acoustic detections from M3R. Encounter duration ranged from <1 minute to 58 minutes (median=8 minutes), although the 58-minute encounter was a mixed species group with a higher-priority species present (see below). The maximum encounter duration for single-species encounters with rough-toothed dolphins was 22 minutes. Group sizes ranged from 1 to 22 individuals (median=5). Three encounters were of mixed groups of rough-toothed dolphins (with group sizes estimated at 11, 16 and 22 individuals) and a single melon-headed whale. In each of these three encounters one photographed individual (always photographed next to the melon-headed whale) was matched to a rough-toothed dolphin x melon-headed whale hybrid that was documented off Kauaʻi in August 2017 (see Baird et al. 2018). One of these encounters also included a false killer whale that briefly passed through the group. Three additional encounters were mixed groups with false killer whales.

Photographs were taken for individual identification in 14 of 18 encounters. During the 14 encounters where photographs were taken, we obtained 67 identifications of rough-toothed dolphins (**Table 5**). Of those, there were 30 identifications of 28 distinctive individuals with good- or excellent-quality photographs. A comparison of the 28 individuals to the CRC photo-identification catalog of this species (Baird et al. 2008a) revealed that 23 of the individuals had been previously photo-identified off Kauaʻi, and one individual had been previously identified off both Kauaʻi and Oʻahu. Of those 24 that were previously documented (85.7 percent), six had been seen in one previous year, seven had been seen in two previous years, five had been seen in three previous years, and six had been seen in five previous years. Four individuals were first documented over 10 years ago, the earliest during a CRC field project in May 2003 (Baird et al. 2003). Among the 12 encounters where one or more distinctive individuals with good- or excellent-quality photographs were identified, 10 included individuals that had been previously documented (**Table 5)**. A social network analysis indicates that all but two of the identified individuals with fair-, good-, or excellent-quality photographs and slightly distinctive, distinctive, or very distinctive dorsal fins linked to the main cluster of rough-toothed dolphins documented off Kauaʻi, Niʻihau, and Oʻahu, which contains almost 92 percent of individuals identified off these islands. One of the individuals identified during this project, HISb0691 in the CRC catalog, is a cut point between the Oʻahu and Kauaʻi/Niʻihau segments of the main cluster (**Figure 4**).

Associations between the melon-headed whale/hybrid pair and rough-toothed dolphins were compared among the encounters in February 2020 as well as with the encounters with this pair and rough-toothed dolphins in August 2017, to determine whether there were stable associations between the pair and any rough-toothed dolphins. Two of the encounters that included the pair were on the same day and had rough-toothed dolphins in common between them. Excluding one of these same-day encounters, there were 58 different rough-toothed dolphins associated with the melon-headed whale/hybrid pair among the four encounters in the two different years. One individual rough-toothed dolphin was associated with the pair on two occasions, once in 2017 and once in 2020.

Three biopsy samples were collected from rough-toothed dolphins over the course of the field project, two on 8 February 2020 and one on 15 February 2020 (on PMRF), all from previously identified individuals (**Table 5**).

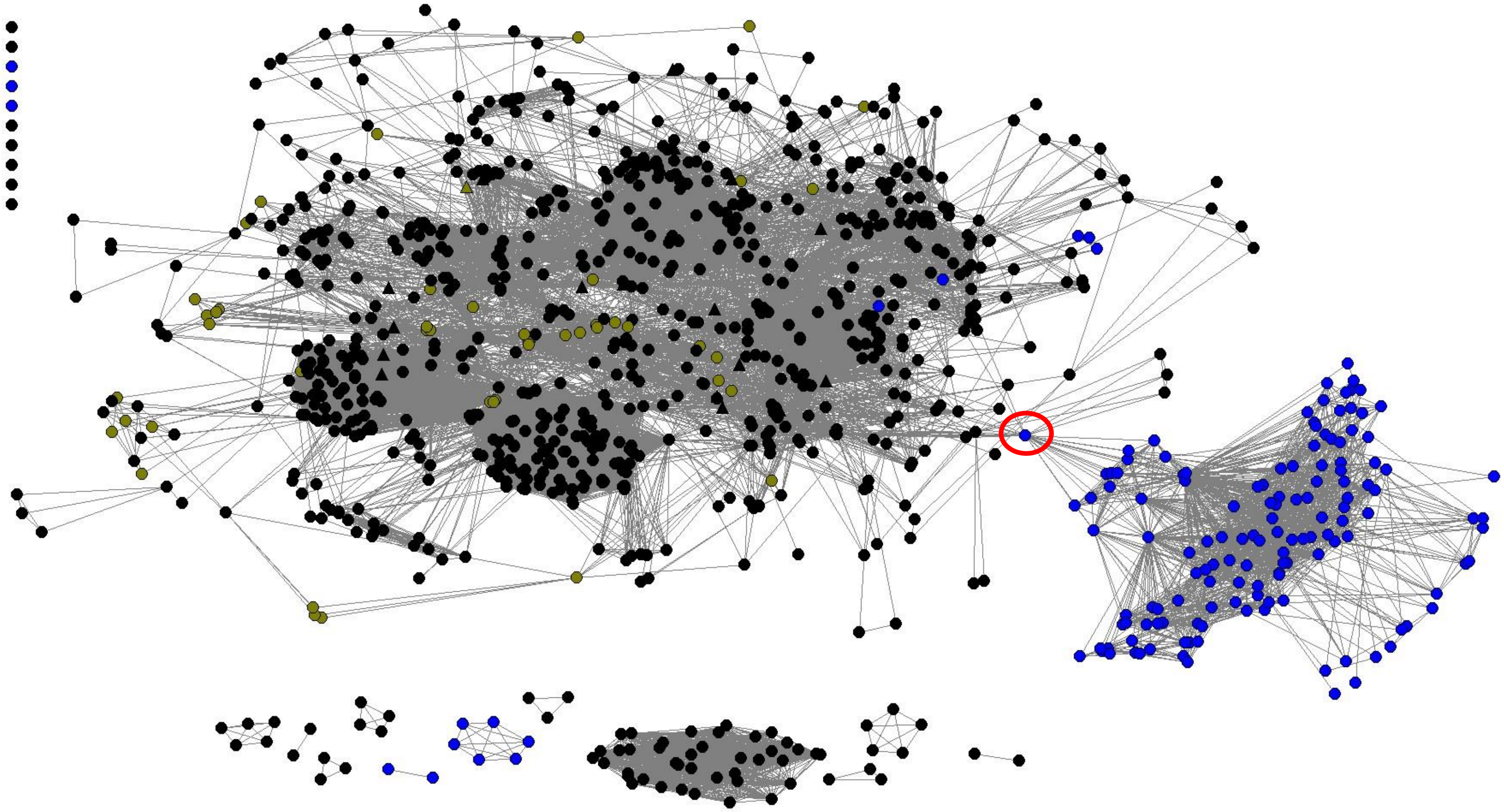

Figure 4. Social network of photo-identified rough-toothed dolphins off Kaua‘i, Ni‘ihau, and O‘ahu. Points represent individuals and lines join individuals encountered within the same group. Individuals are color-coded by location first seen: Kaua‘i – black; Ni‘ihau – green; O‘ahu – blue. All individuals tagged off Kaua‘i and Ni‘ihau in previous efforts are noted by black triangles. HISb0691 is indicated with a red circle, as it is a cut point between two segments of the main cluster. 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 1,025 individuals shown (the main cluster contains 939 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.

4.2 Short-finned pilot whales

Short-finned pilot whales were encountered only once (on 9 February 2020), off the range (**Figure 2, Table 5**). This was a high-priority species, so the encounter duration was extended (1 hour 42 minutes), and 1,639 photographs were taken. From these there were 14 individuals photographed, 10 of which were distinctive with good or excellent photographs (**Table 5**). All individuals identified had been previously seen off the island of Kauaʻi, and 12 had been previously seen off both Kauaʻi and Oʻahu. Eleven of the individuals were first identified during a CRC project in February 2011 (Baird et al. 2011). One individual was identified in one previous year, one in two previous years, three in three previous years, seven in four previous years, and two in five previous years. Although this group has not been linked by association with any other group of pilot whales (**Figure 5**), they have been considered to be part of the resident western community of short-finned pilot whales, given their sighting history and movement data from previous tag deployments.

One SPLASH-10F satellite tag was deployed, but the group was not approachable enough to deploy a second tag. The tagged individual (HIGm1393) had been previously seen seven times, with sightings off both Kauaʻi and Oʻahu (**Table 7**). Signal contact with the tag lasted for a period of 15.51 days (**Table 6**), and GPS locations were obtained over a 9.5-day span. After smoothing and Douglas filtering there were 314 Argos locations (median interval between locations=0.53 hours; maximum=8.96 hours), 177 (56.4 percent) of which were on PMRF. None of the tag locations (Argos or GPS) were on land. When substituting GPS locations for the period where both GPS and Argos locations were obtained, there were 277 locations (156 of these were GPS locations, with median interval between locations=1.05 hours; maximum=7.60 hours), 153 (55.2 percent) of which were on the range. The Argos data showed a median distance from shore of 26.3 km, and a median bathymetric depth of 3,248 m, compared to a median distance from shore of 28.1 km and a median bathymetric depth of 3,504 m for the combined Argos and GPS data (**Table 8**). In comparison, the crawl model produced 372 hourly locations, 197 (52.9 percent) of which were on the range, with a median distance from shore of 27.8 km, and a median bathymetric depth of 3,475 m (**Table 9**). HIGm1393 generally remained to the northwest of Kauaʻi, although it did venture far offshore to the north and west (**Figure 6**). The Argos data were also compared against Argos data for four previously tagged short-finned pilot whales of the same social group, revealing that the movements of GmTag231 represent the farthest documented northward movement of a member of this social group (**Figure 7**).

Data from this individual were combined with data from 18 other individuals from the western community of short-pilot whales tagged off Kauaʻi to produce a probability-density map (**Figure 8**), showing that the core area for this community (8,736 square kilometers [km^2]) is centered around Kauaʻi and Niʻihau and broadly overlaps the southern half of PMRF. The overlap of the core area with PMRF was 1,547 km^2, constituting 17.7 percent of the core area (**Table 10**).

Behavior data (dives and surfacing periods) from GmTag231 were obtained for 9.79 days, representing 86.8 percent coverage for the period that behavior data were collected. Over the 9.79 days, 452 total dives deeper than 50 m were recorded (median depth= 241.5 m, maximum=1,135.5 m), with a dive rate of 2.22 dives per hour and a median dive duration of 9.75 minutes (**Figure 9, Table 11**).

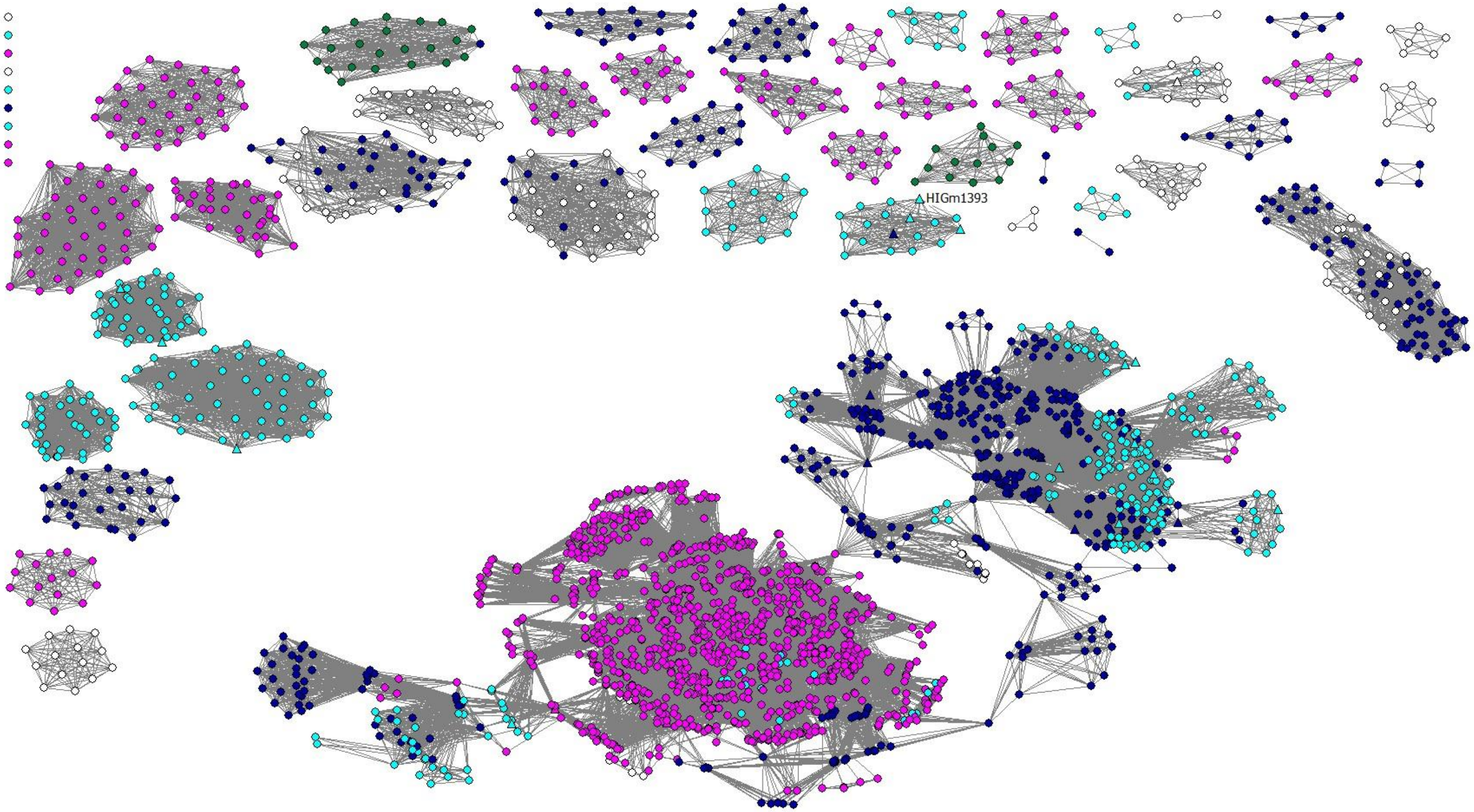

Figure 5. Social network of photo-identified short-finned pilot whales from the main Hawaiian Islands. Points represent individuals and lines join individuals encountered within the same group. Individuals are color-coded by island first documented: Kaua'i and Ni'ihau – light blue; O'ahu – dark blue; Moloka'i – dark green; Lāna'i – white; Hawai'i Island – pink. All individuals tagged off Kaua'i and Ni'ihau (including those tagged in previous efforts) are noted by triangles. The individual tagged in February 2020 is indicated with an ID label. The tagged individual (HIGm1393) linked by association to a peripheral cluster from Kaua'i and Ni'ihau. 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 2,445 individuals shown (the main cluster contains 1,671 individuals, 68.3 percent of all individuals).

Table 6. Details on satellite tags deployed during February 2020 field effort.

Species[1]	Tag ID	Individual ID	Date Tagged	Sighting #	Duration of Signal Contact (days)	Latitude (°N)	Longitude (°W)	Tag Type	Sex
Gm	GmTag231	HIGm1393	9-Feb-20	2	15.51	21.82035	159.49791	SPLASH10-F	Male
Tt	TtTag034	HITt1084	15-Feb-20	7	13.90	22.15288	159.80403	SPLASH10	Unknown
Tt	TtTag035	HITt0810	17-Feb-20	3	20.02	21.97837	159.78835	SPLASH10	Unknown

[1] See footnote to **Table 1**. ID=identification; °N=degrees North; °W=degrees West; #=number.

Table 7. Details on previous sighting histories of individuals satellite tagged in February 2020.

Individual ID	Date First Seen	# Times Seen Previously	# Years Seen Previously	Islands Seen Previously
HIGm1393	19-Feb-11	7	4	Kauaʻi, Oʻahu
HITt1084	11-Aug-17	3	2	Kauaʻi
HITt0810	3-Feb-13	9	5	Kauaʻi

Gm=*Globicephala macrorhynchus*; Tt=*Tursiops truncatus*; ID=identification; #=number.

Table 8. Details on Kalman-smoothed and Douglas-filtered tag analysis results of individuals satellite tagged in February 2020.

Tag ID	Location Data Type	# Locations	Median Distance From Shore (km)	Maximum Distance From Shore (km)	Median Bathymetric Depth (m)	Maximum Bathymetric Depth (m)	# of Douglas Filtered Locations Inside PMRF	Percentage of Locations Inside PMRF
GmTag231	Argos Only	314	26.3	67.2	3,248	4,573	177	56.4
GmTag231	Argos + GPS	277	28.1	63.9	3,504	4,573	153	55.2
TtTag034	Argos Only	223	3.1	16.2	119	2,316	75	33.6
TtTag035	Argos Only	383	3.7	16.0	180	2,662	133	34.7

Gm=*Globicephala macrorhynchus*; Tt=*Tursiops truncatus*; ID=identification; #=number; km=kilometers; m=meters

Table 9. Details on crawl model tag analysis results of individuals satellite tagged in February 2020, using Argos locations.

Tag ID	# Crawl Locations (1-hour steps)	Median Distance From Shore (km)	Maximum Distance From Shore (km)	Median Bathymetric Depth (m)	Maximum Bathymetric Depth (m)	# of Crawl Locations Inside PMRF	Percentage of Locations Inside PMRF
GmTag231	372	27.8	65.1	3,474	4,587	197	53.0
TtTag034	334	2.9	15.2	72	1,474	136	40.7
TtTag035	481	3.4	12.3	94	2,135	177	36.8

Gm=*Globicephala macrorhynchus*; Tt=*Tursiops truncatus*; ID=identification; #=number; km=kilometers; m=meters

Table 10. Areas within 50 percent ("core range"), 95 percent, and 99 percent isopleths based on kernel-density analyses of 12-hour crawl 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			Overlap between core range (50%) and PMRF boundary	
	50%	95%	99%	Area (km^2)	%
Short-finned pilot whale – western community	8,736	47,589	79,634	1,547	17.7
Bottlenose dolphin – Kaua‘i/Ni‘ihau stock	1,852	8,166	13,996	535	28.9

km=kilometers; %=percent

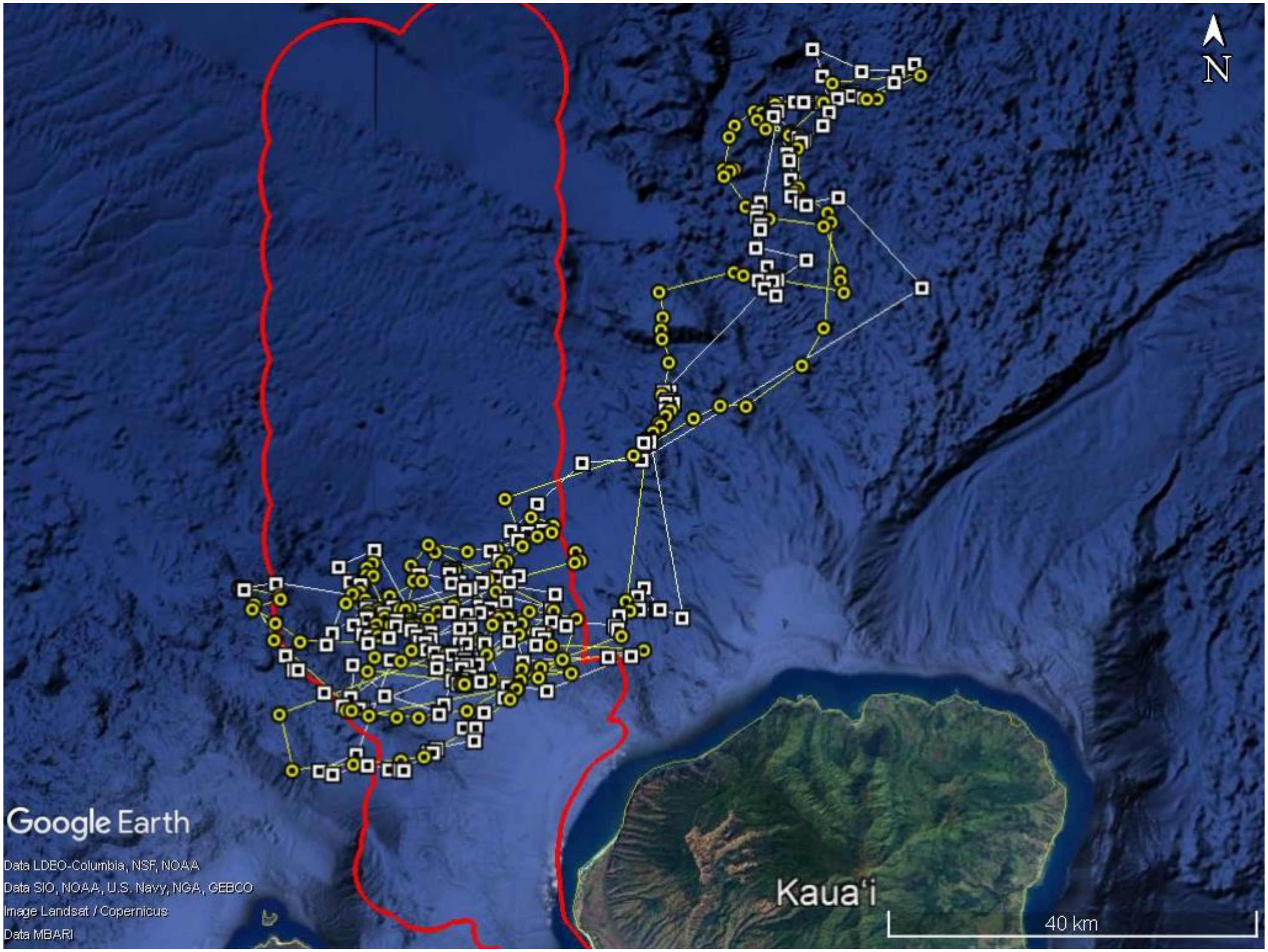

Figure 6. Kalman-smoothed and Douglas-filtered Argos locations (white squares) and Fastloc®-GPS locations (yellow circles) from satellite tagged short-finned pilot whale HIGm1393 (GmTag231) for the period where both location types were received. Consecutive locations of each type are joined by lines. The PMRF boundary is outlined in red.

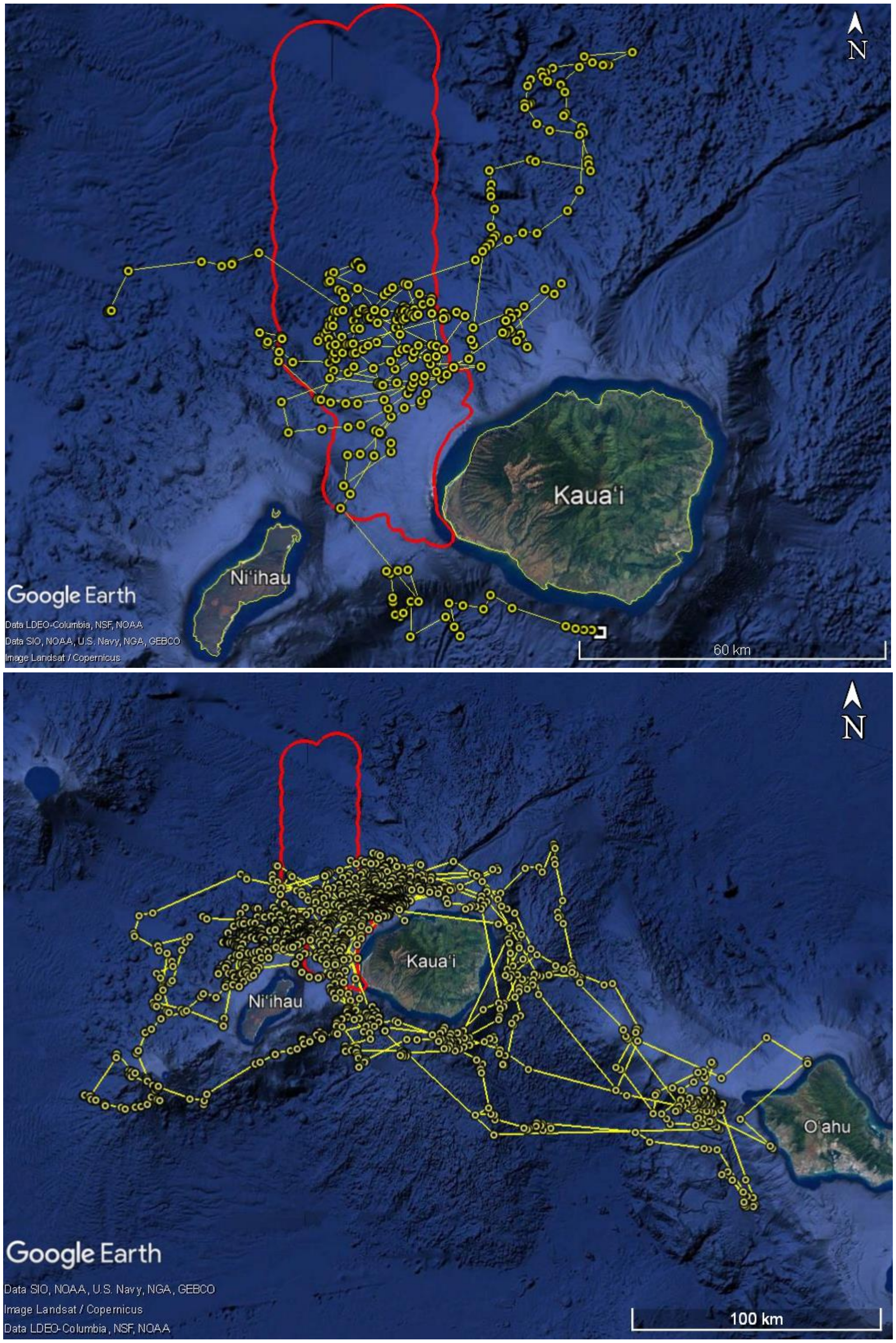

Figure 7. Top. A combined track with Fastloc®-GPS locations and filtered Kalman-smoothed Argos locations from short-finned pilot whale HIGm1393 (GmTag231) tagged off Kaua‘i in February 2020, with the tagging location shown by a white square. Bottom. Locations from four previous short-finned pilot whale tag deployments from the same social group off Kaua‘i (GmTag051, GmTag070, GmTag079, GmTag080, 2011–2014). Lines connect consecutive locations. The PMRF boundary is shown in red.

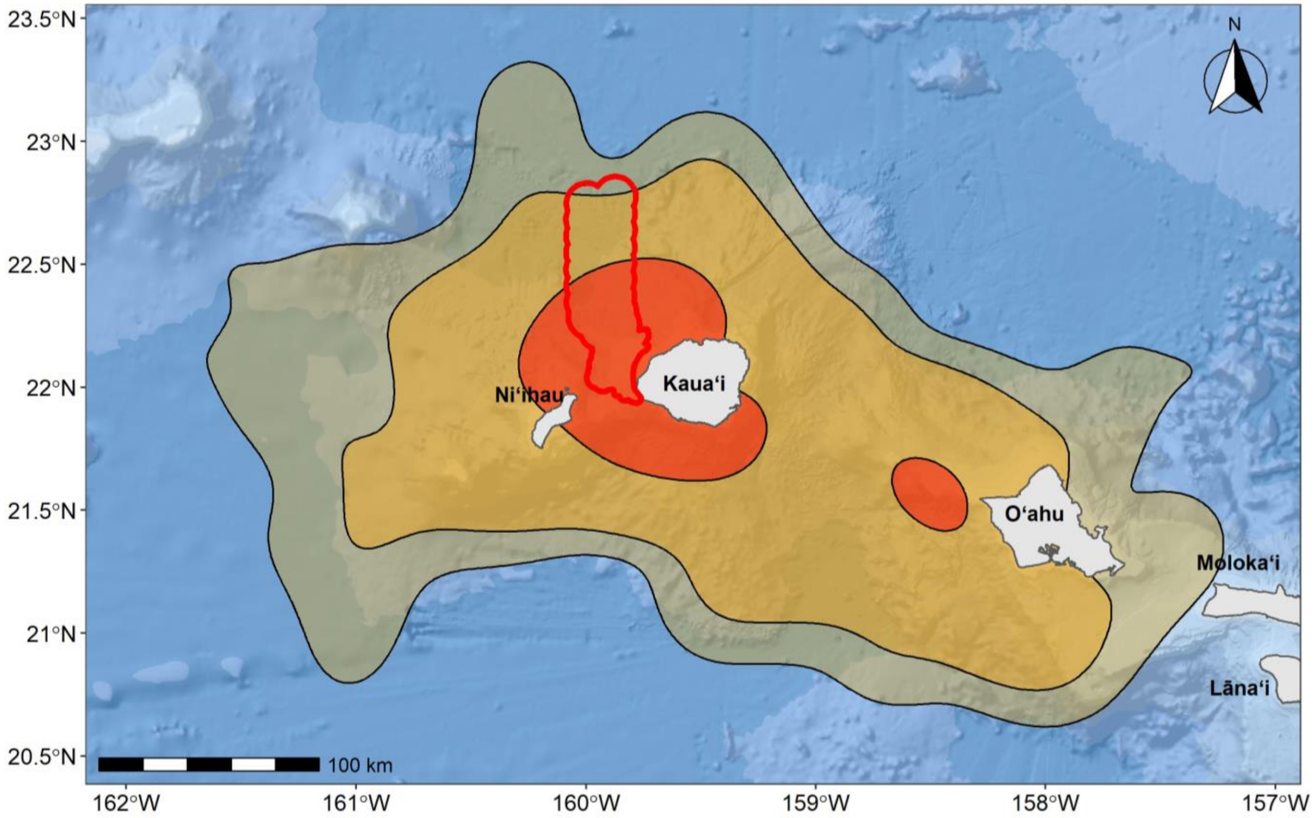

Figure 8. Probability-density representation of short-finned pilot whale 12-hour crawl state-space model locations from satellite tag deployments on 19 individuals from the western main Hawaiian Islands insular community. Location data from the first 24 hours of each deployment were omitted to reduce 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 11. Dive information from satellite tags deployed during February 2020 field efforts.

Tag ID	# Days Data	% of Total Record	# Dives (≥ 50 m)	Dives per hour[1]	Median Dive Depth (m) for Dives ≥ 50 m	Maximum Dive Depth (m)	Median Dive Duration[2] (min)	Maximum Dive Duration[2] (min)
GmTag231	9.79	86.8	452	2.22	241.5	1,135.5	9.75	20.17
TtTag034	9.86	100	400	1.69	311.5	591.5	7.62	11.47
TtTag035	8.30	100	265	1.32	311.5	623.5	8.17	13.53

[1] Dives per hour calculated as the total number of dives divided by the total amount of time (in hours) of behavior data recorded (surface and dives combined)

[2] 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.

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

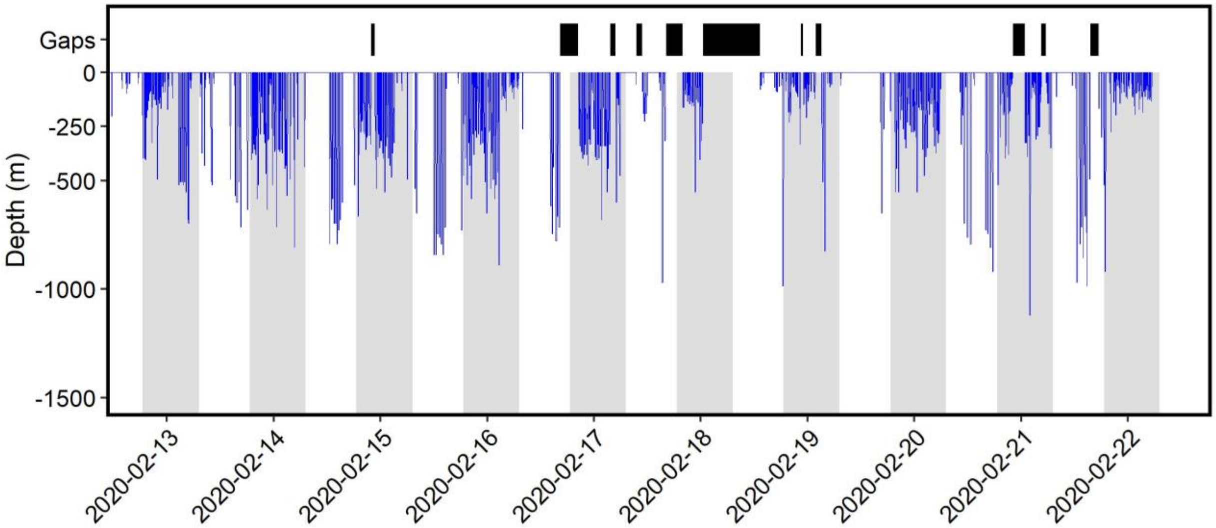

Figure 9. Behavior data from satellite-tagged short-finned pilot whale HIGm1393 (GmTag231). Dives were any incursion deeper than 50 m; when the whale was <50 m the tag records "surface" periods, indicated by a line at 0 m. The alternating vertical bars represent night (gray) and day (white). Black lines at the top represent gaps in dive and surface data.

4.3 Pygmy killer whales

Pygmy killer whales were sighted in association with a single humpback whale on 7 February 2020 off the PMRF (**Figure 2, Table 5**). The group was not approachable for tagging. The encounter lasted 1 hour 8 minutes, and analysis of the 3,109 photographs obtained from the encounter resulted in 15 identifications total, all with good- or excellent-quality photos. Of the 15, five were considered not distinctive, and four were slightly distinctive. Photographs were compared to CRC’s long-term photo ID catalog of pygmy killer whales, which contained 293 distinctive or very distinctive individuals with good- or excellent-quality photos, but none of the individuals documented had been previously identified.

4.4 False killer whales

False killer whales were encountered on three occasions, all on the PMRF (**Figure 2, Table 5**). The first encounter was in response to an acoustic detection on 14 February 2020 and was a mixed encounter with rough-toothed dolphins. It had an extended duration, lasting 2 hours 36 minutes. The second encounter, which took place within an hour of the first encounter ending, was significantly shorter, lasting only eight minutes before the group was lost. In neither case were individuals approachable for tagging. Group sizes were eight individuals for the first encounter, and two individuals for the second encounter (**Table 5**). Between these two encounters 1,101 photographs were taken, representing nine identifications (eight from the first encounter and one from the second), and good- or excellent-quality photographs were obtained from seven individuals. The third encounter (on 15 February 2020) was also in response to an acoustic detection, but only a single individual was sighted and was lost shortly after and could not be re-located. No photographs were taken. Four of the individuals from the first encounter on 14 February had been previously documented, all either off O‘ahu or Kaua‘i. A social network analysis indicates that this group links by association with previously identified members of the Northwestern Hawaiian Islands population (**Figure 10**). Three biopsy samples were collected on 14 February 2020 (two from the first encounter and one from the second), all from previously unidentified individuals (**Table 5**).

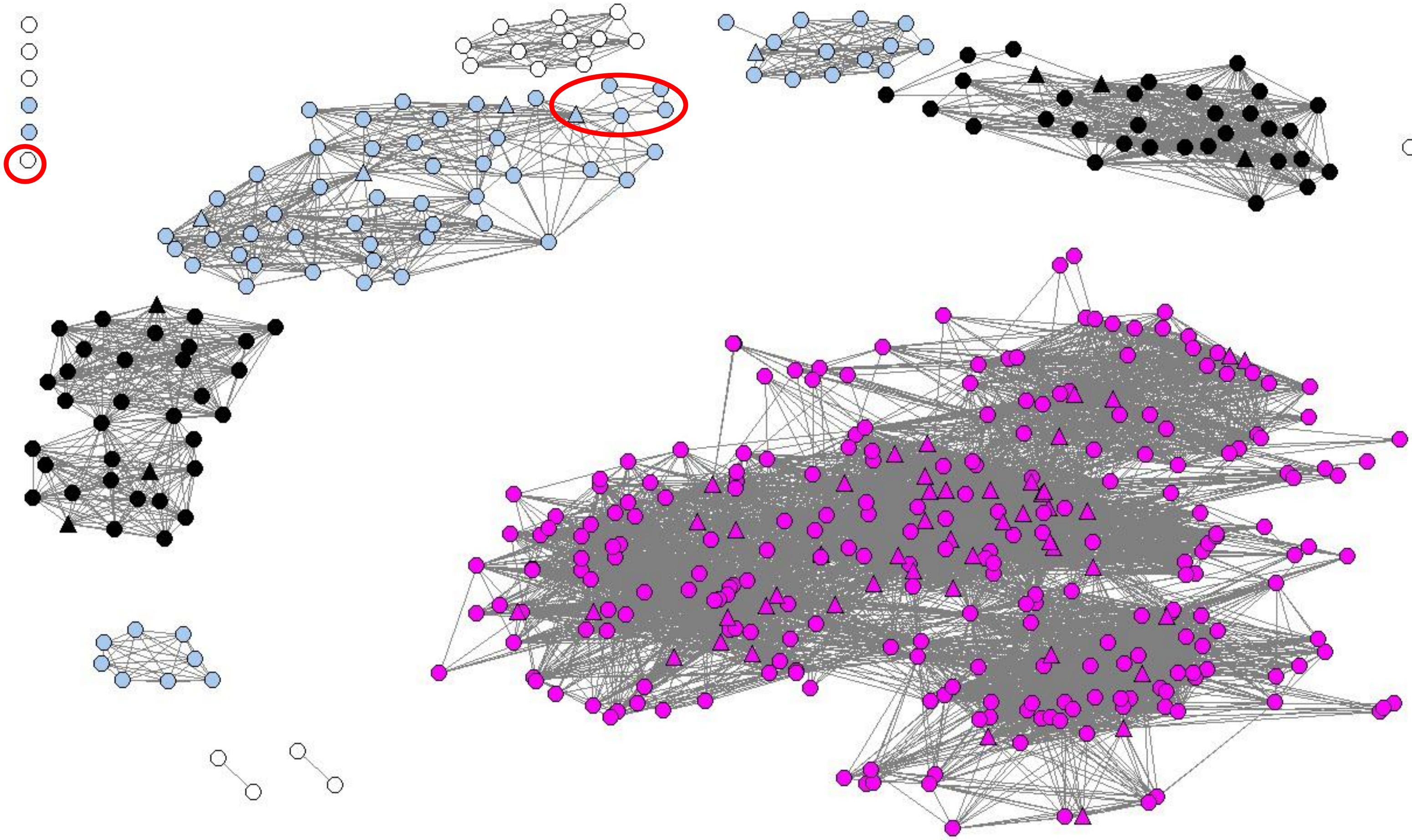

Figure 10. Social network of false killer whales photo-identified around the main Hawaiian Islands. Points represent individuals and lines join individuals encountered within the same group. Individuals are color-coded by population: Northwest Hawaiian Islands – light blue (n=74); Pelagic – black (n=75); Main Hawaiian Islands – pink (n=289); Unknown – white (n=29). All individuals tagged in previous efforts are noted by triangles. The groups seen on 14 February 2020 are indicated with red circles. 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 466 individuals shown. Individuals photo-identified only in the Northwestern Hawaiian Islands or offshore are not included.

4.5 Bottlenose dolphins

Bottlenose dolphins were sighted on nine occasions, with six encounters on the PMRF, twice in response to acoustic detections (**Figure 2, Table 5**). Encounter durations ranged from <1 minute to 1 hour 30 minutes (median=8 minutes), and group sizes ranged from 1 to 21 individuals (median=8) (**Table 5**). Photographs were obtained from seven encounters, representing 67 identifications. Good- or excellent-quality photographs were available from 59 of the 67 identifications, from six encounters. Restricting analyses to good- or excellent-quality photographs of distinctive individuals, there were 46 identifications representing 24 individuals (**Table 5**). A comparison to CRC's long-term photo-identification catalog (Baird et al. 2009) indicated that 23 of the 24 individuals had been previously documented, all off Kauaʻi. Of those 23 who were previously documented, 20 had been seen in two or more years (maximum=8). Five of the individuals were first documented off Kauaʻi over 10 years earlier (maximum span of years=16.06), and an additional 12 individuals had been documented over five years earlier. Individuals from all encounters were linked by association to the main cluster of the Kauaʻi/Niʻihau social network (**Figure 10**), which includes over 90 percent of all bottlenose dolphins photo-identified off the islands, indicating they were all from the island-associated population. Excluding 17 individuals photographed off Kaʻula Island, 96.1 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.

Two SPLASH10 tags were deployed on bottlenose dolphins during the field project, both on previously known individuals (**Table 6**). One of the individuals was also biopsied, allowing for sex determination at a later time.[1] TtTag034 was deployed on 15 February 2020 on PMRF onto an individual (HITt1084 in CRC's photo-identification catalog) that had been previously identified in two prior years (**Table 7**). Signal contact with the tag lasted 13.9 days (**Table 6**). After Douglas filtering, there were 223 locations obtained from this individual (median time interval between locations=0.47 hours, maximum=10.36 hours), 27 of which were on land. After excluding locations on land, the median distance from shore was 3.1 km and the median depth of locations was 119 m (**Table 8**). The tagged individual generally remained to the west and southwest of Kauaʻi, repeatedly entering into the PMRF (Figure 12**).** Locations were consistent with previous satellite-tag data from bottlenose dolphins tagged off Kauaʻi, with individuals primarily remaining associated with Kauaʻi except one individual who moved to the south shore of Oʻahu (**Figure 13**). Out of the 196 locations (after excluding locations on land), 75 (33.6 percent) were within the boundaries of the range (**Table 8**). In comparison, the crawl model produced 334 hourly locations, 136 (40.7 percent) of which were on PMRF, with a median distance from shore of 2.9 km, and a median bathymetric depth of 72 m (**Figure 12; Table 9**).

TtTag035 was deployed on 17 February 2020 off PMRF. The tagged individual (HITt0810) had been previously identified 9 times (**Table 7**), first in February 2013 and most recently two days prior to tagging. Signal contact with TtTag035 lasted 20.0 days (**Table 6**). Out of the 383 total filtered Argos locations obtained (median time interval between locations=0.46 hours,

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[1] During the coronavirus pandemic the genetic lab at the Southwest Fisheries Science Center has largely been shut down, thus it has not been possible to have this sample processed.

maximum=9.9 hours), 22 were on land. Excluding these locations, this individual was found at a median distance from shore of 3.7 km and at a median depth of 180 m (**Table 8**). This individual generally remained to the west and northwest of Kauaʻi, repeatedly entering into range (**Figure 14**). Out of the 361 locations, 133 (36.8 percent) of them were within the PMRF boundaries (**Table 8**). In comparison, the crawl model produced 481 hourly locations, 177 (36.8 percent) of which were on the range, with a median distance from shore of 3.4 km, and a median depth of 94 m (**Figure 14; Table 9**). This individual was previously tagged during a CRC project in February 2013 (TtTag010, Baird et al. 2013c), with 21 days of location data obtained. A comparison of movement data between the two years (**Figure 14**) showed similar patterns of spatial use, with some differences in each year.

An assessment of distance between the two individuals when locations were received during the same satellite overpass suggested they were likely associated during most of the period of tag overlap (median distance apart=2.01 km, maximum=23.4 km). Location data from the longer of these two tags (TtTag035) were combined with data from 13 other individuals tagged off Kauaʻi to produce a probability-density map (**Figure 15**), showing that the core area for this population (1852 km^2) is centered around Kauaʻi and Niʻihau and overlaps the southern half of PMRF. The overlap of the core area with the PMRF was 535 km^2, constituting 28.9 percent of the core area (**Table 10**).

Behavior data (dives and surfacing periods) were obtained from TtTag034 for 9.9 days, representing 100 percent coverage for the period that behavior data were collected. Over the 9.9 days, 400 dives were recorded (median depth=311.5 m, maximum=591.5 m), with a median dive duration of 7.62 minutes, and a dive rate of 1.69 dives per hour (**Figure 16; Table 11**). Behavior data (dives and surfacing periods) were obtained from TtTag035 for 8.3 days, representing 100 percent coverage for the period that behavior data were collected. Over the 8.3 days, 265 dives were recorded (median depth=311.5 m, maximum=623.5 m), with a median dive duration of 8.17 minutes, and a dive rate of 1.32 dives per hour (**Figure 16; Table 11**).

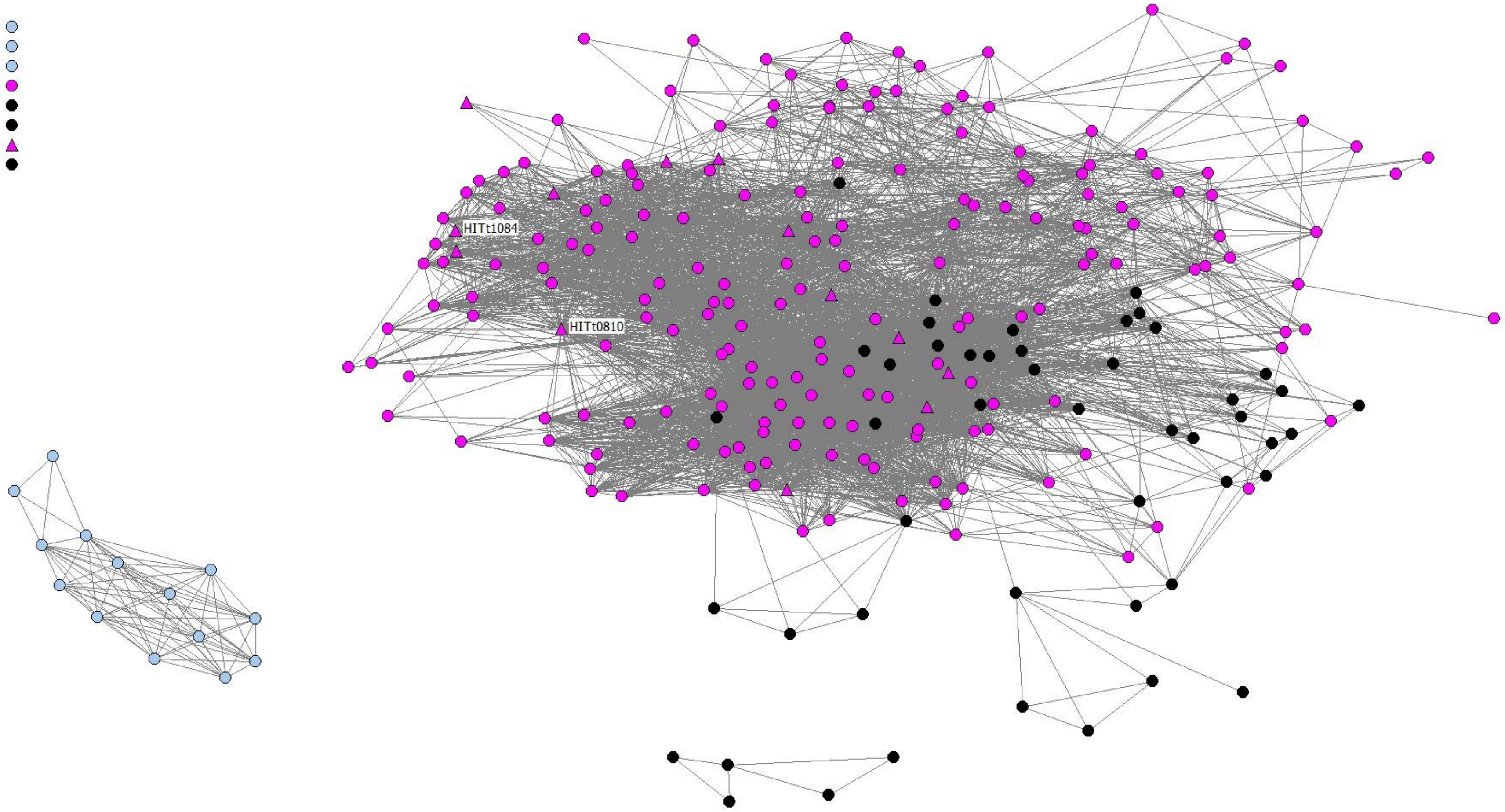

Figure 11. Social network of bottlenose dolphins photo-identified off Kaua‘i, Ni‘ihau, and Ka‘ula including all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2009). Points represent individuals and lines join individuals encountered within the same group. Individuals that have been tagged in previous efforts are noted by triangles. The individuals tagged in February 2020 are indicated with ID labels. A total of 273 individuals is shown, 246 (90.1 percent) of which are 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.

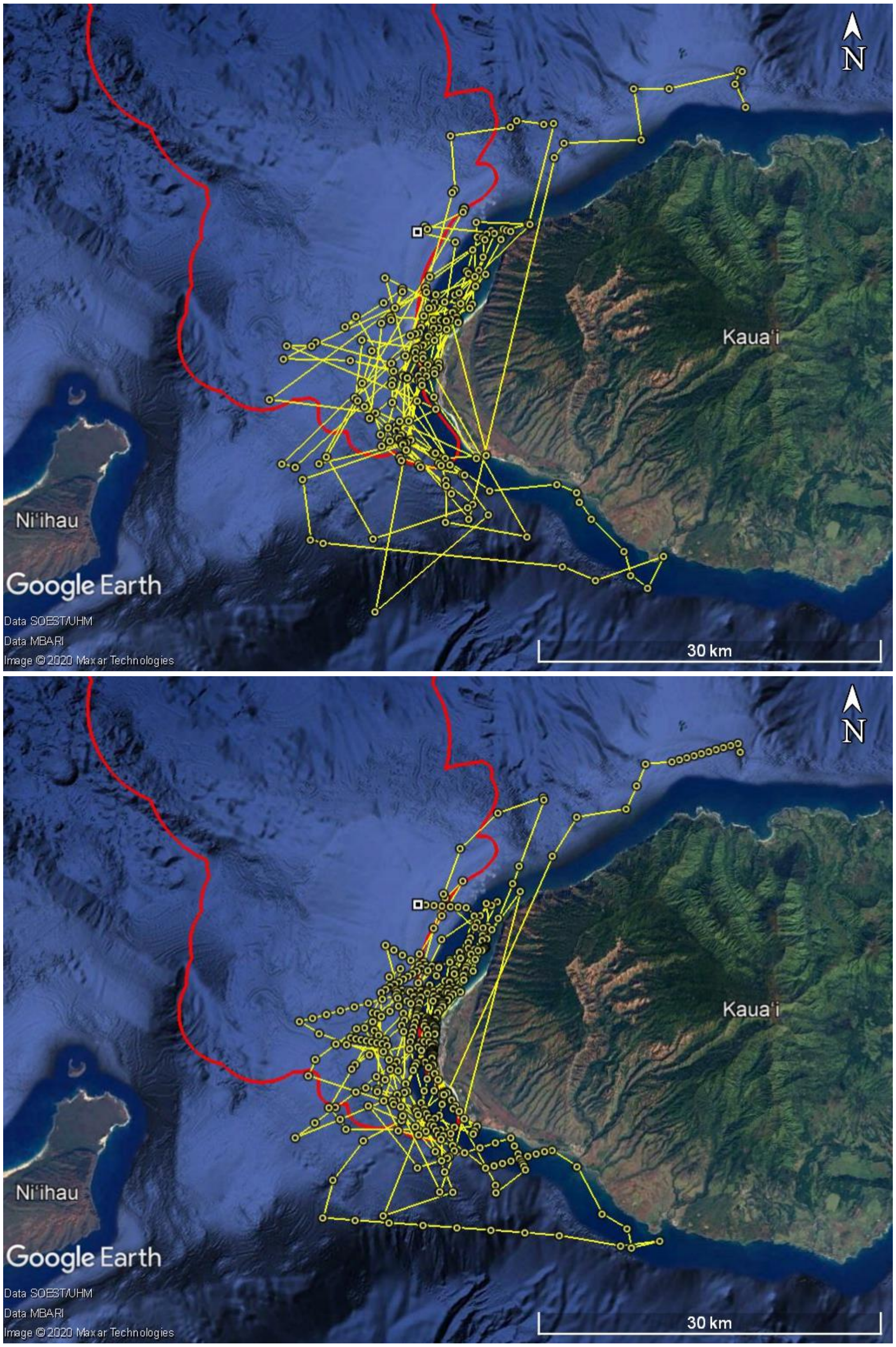

Figure 12. Top Douglas-filtered Argos locations (n=223) from bottlenose dolphin HITt1084 (TtTag034) tagged off Kauaʻi in February 2020, with the tagging location shown by a white square. Bottom. Crawl model locations (n=334) from the same individual. Lines connect consecutive locations. The PMRF boundary is shown in red.

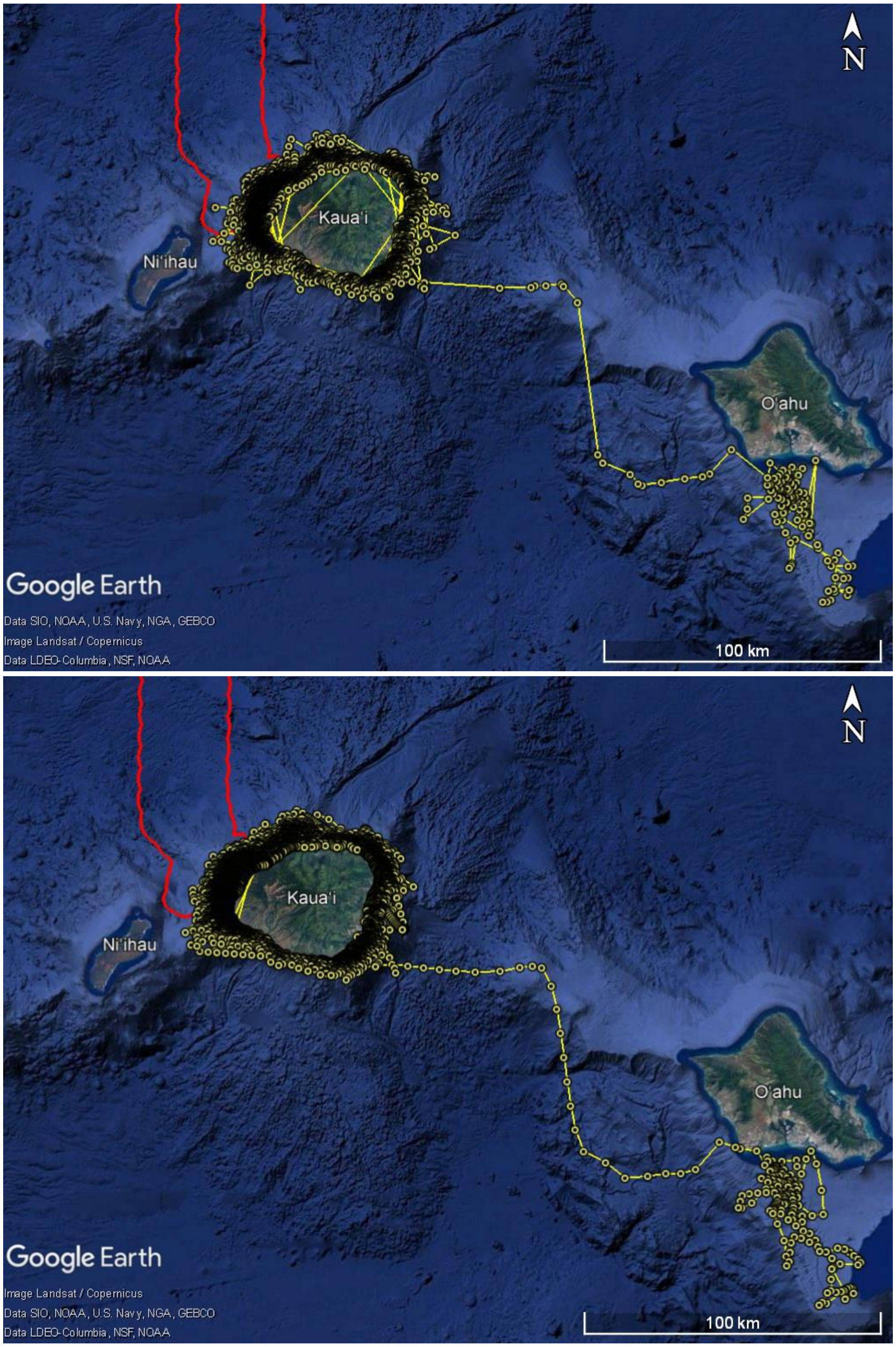

Figure 13. Top. Douglas-filtered Argos locations from 15 bottlenose dolphin tag deployments off Kauaʻi (2011–2020). Bottom. Crawl model locations for the same individuals. Lines connect consecutive locations. The PMRF boundary is shown in red.

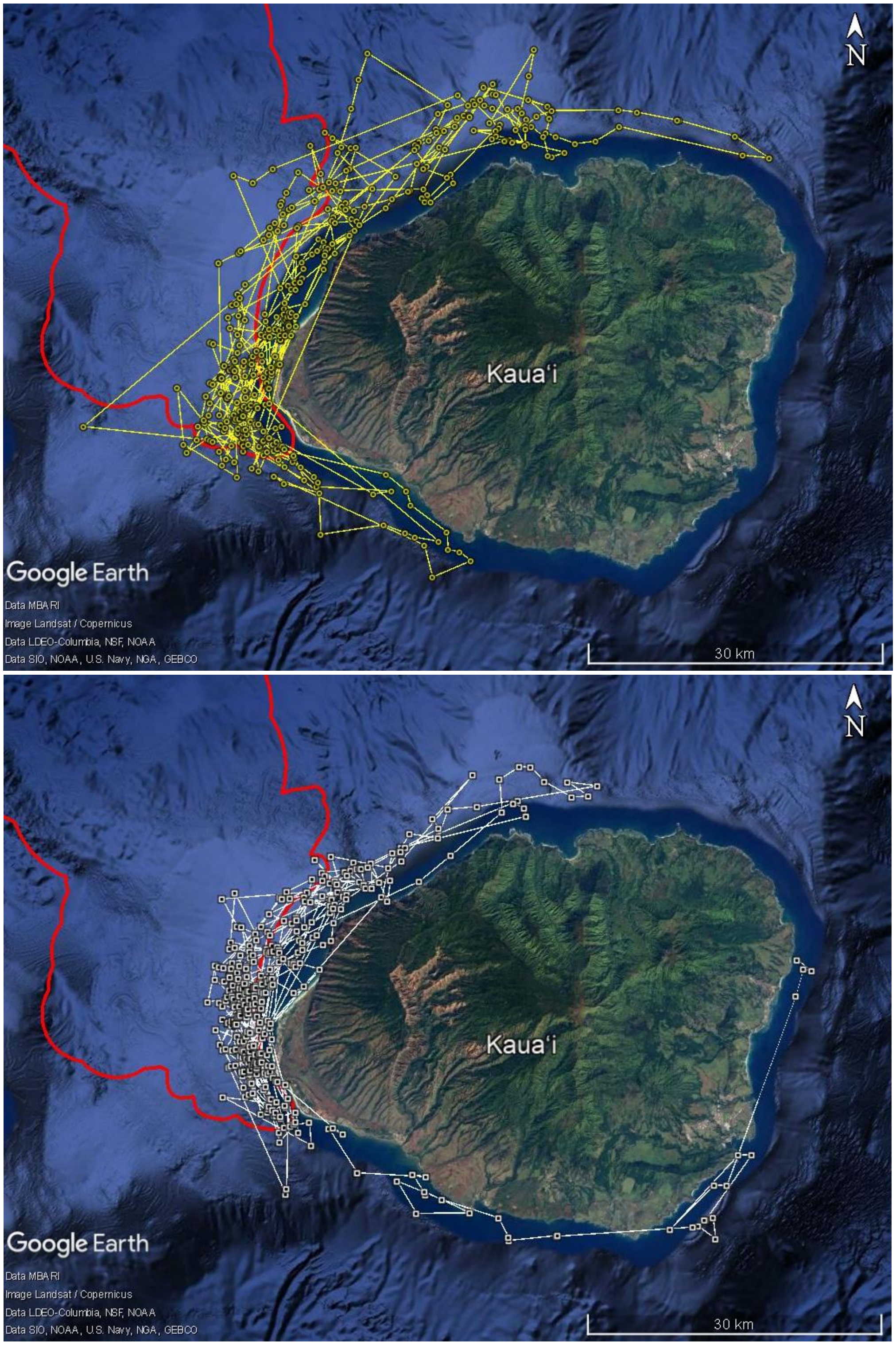

Figure 14. Top. Douglas-filtered Argos locations over a 19-day period from bottlenose dolphin HITt0810 (TtTag035) in February and March 2020. Bottom. Douglas-filtered Argos locations from the same individual bottlenose dolphin over a 21-day period in February and March 2013. Lines connect consecutive locations. Locations on land are excluded. The PMRF boundary is shown in red.

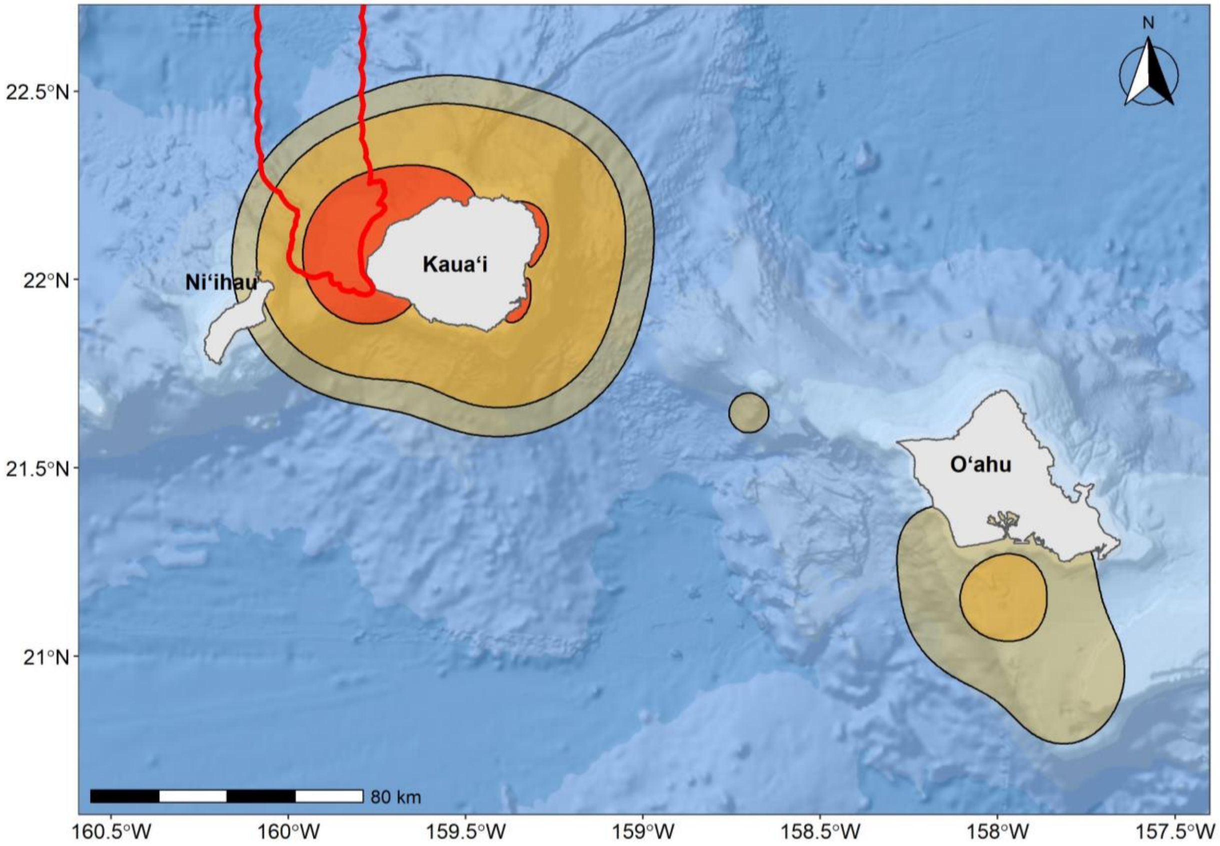

Figure 15. Probability-density representation of bottlenose dolphin 12-hour crawl state-space model locations from satellite tag deployments on 14 individuals off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals 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 percent polygon, and the green represents the 99 percent polygon. The PMRF boundary is outlined in red.

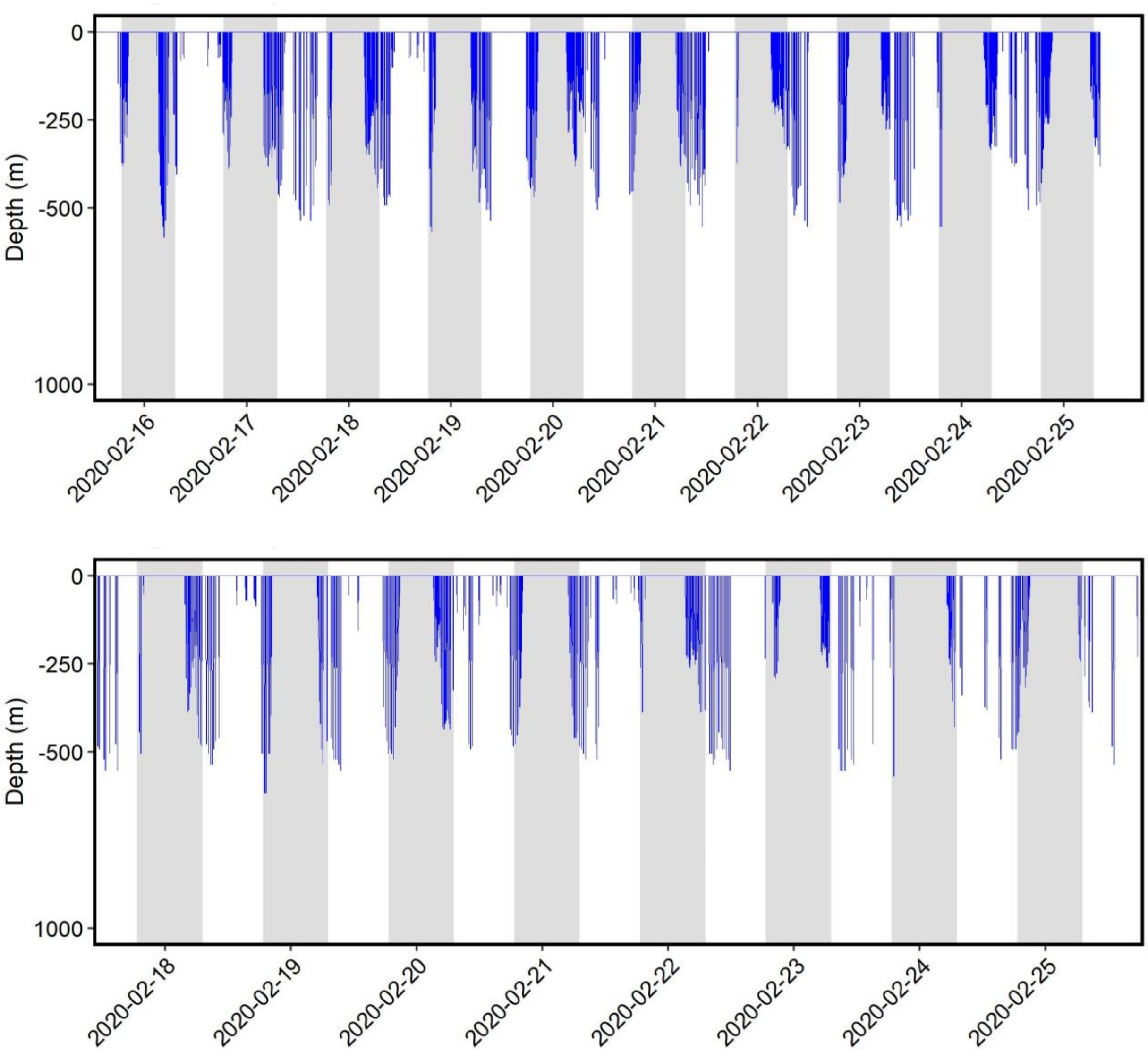

Figure 16. Behavior data from two satellite-tagged bottlenose dolphins: TtTag034 (top), and TtTag035 (bottom). Dives deeper than 50 m are shown; when the dolphins were <50 m the tag records "surface" periods, indicated by a line at 0 m. The alternating vertical bars represent night (gray) and day (white).

5. Discussion and Conclusion

Over the 13-day field effort in February 2020, information was obtained on seven species of odontocetes off Kauaʻi, four of which (short-finned pilot whales, rough-toothed dolphins, spinner dolphins, and bottlenose dolphins) are regularly seen off the island, and three of which (pygmy killer whales, false killer whales, and melon-headed whales) are observed infrequently (Baird et al. 2013a; Baird 2016).

While we had encounters with four high-priority species for tagging (i.e., short-finned pilot whales, false killer whales, pygmy killer whales, melon-headed whales), individuals of the latter three species were not approachable enough to tag, and for short-finned pilot whales we were only able to tag one individual in the group due to avoidance behavior. Only limited tagging effort was extended towards tagging lower priority species (i.e., bottlenose dolphins), but two tags were deployed on that species. All three satellite tags were deployed prior to the start of MFAS use during the SCC, which occurred from 19 February starting at 00:43 HST and ended on 22 February at 00:21 HST. All three individuals remained off the western or northwestern side of Kauaʻi during the period of MFAS use, so tag data will feed into ongoing assessments of potential behavioral responses to sonar (Henderson et al. in prep). In addition, the satellite-tag data obtained, when interpreted in the context of the association and re-sighting data, has increased our understanding of how these species use the area and potentially overlap with naval activities.

One of the tags, deployed onto a short-finned pilot whale, included GPS locations in addition to Argos locations and dive behavior. This was our second field project in which a GPS tag has been deployed onto an odontocete off Kauaʻi (we previously deployed six GPS tags during our August 2018 project, four on short-finned pilot whales, and two on melon-headed whales). We programmed the tag to maximize high-temporal-resolution data for a period of time around the SCC. While sacrificing longer-term data (both behavioral and GPS locations), overall this programming regime was extremely successful in terms of the high-resolution behavioral information and GPS locations received. The tag provided an almost complete (86.8 percent) record of diving behavior, and higher resolution data than was available from Argos alone (**Figures 6, 9; Table 8**). More Argos locations were obtained than locations from a combined dataset when GPS locations were used for the period where both GPS and Argos data were available. Previous odontocete satellite tagging efforts off Kauaʻi have used least-squared processing of Argos data, while during this effort we obtained Kalman processed data from Argos, which improves the error estimates associated with locations and increases the number of locations generated by Argos (Boyd and Brightsmith 2013; Lowther et al. 2015). Furthermore, data were post-processed with Kalman smoothing, resulting in better characterization of errors associated with locations (Lopez et al. 2015). That said, the accuracy of the GPS locations remains superior (Costa et al. 2010; Irvine et al. 2020), and the GPS locations filled in details of the animal’s track that were not available from Argos locations alone. During the period where data were received, the tagged individual moved onto and off the PMRF repeatedly with over half of locations within the PMRF boundaries (56.4 percent of Argos locations, and 55.2 percent of combined Argos and GPS locations; **Figure 6; Table 8**). We also constructed a crawl model producing locations at 1-hour steps, which minimizes any biases associated with tag programming regimes (**Tables 8, 9**).

All of the short-finned pilot whales encountered on 9 February 2020 had been previously identified, with many of them first identified almost a decade prior. Interestingly, this group has never been documented associating with any other group of short-finned pilot whales, so association patterns do not provide information on community affiliation. However, the repeated sighting history off Kauaʻi and Oʻahu, combined with movement patterns of this group from four previous tag deployments (**Figure 7**), suggest that they are likely part of the western community of resident pilot whales, which ranges primarily from Niʻihau to Oʻahu, with core areas around Kauaʻi and Niʻihau as well as off western Oʻahu (**Figure 8**). Based on comparisons of the satellite-tag data to previously tagged individuals within this social group, the group we encountered appeared to act similarly to how they have utilized the waters off Kauaʻi and Niʻihau in the past, although the tagged individual did move much farther northward than has been previously documented (**Figure 7**). This variation within the same social group reflects that even with intensive prior research and tagging on pilot whales in the islands (e.g., Abecassis et al. 2015; Baird 2016; Mahaffy et al. 2015; Van Cise et al. 2016, 2017a, 2017b, 2018), there is still much to be learned about their spatial use. Data from this tag, combined with 18 previously deployed tags from Kauaʻi and Niʻihau, show that the core range of the western community of short-finned pilot whales overlaps broadly with PMRF (17.7 percent; **Figure 8; Table 10**), making this an ideal species for assessing exposure and response to MFAS, as well as determining population-level consequences of exposure.

Analysis of photo-identification data from our nine encounters with bottlenose dolphins showed that all the encountered individuals linked to the main cluster of the Kauaʻi/Niʻihau social network, and a high proportion (almost 96 percent) of distinctive individuals with good-quality photographs had been previously identified (**Table 5**). This provides further evidence for a resident population that is rarely visited by non-resident bottlenose dolphins (**Figure 11**). Two SPLASH-10 tags were deployed onto bottlenose dolphins during the field project. The tagged dolphins were documented in association during both tagging encounters, and analysis of location data during the period of overlap suggests they remained largely associated (**Figures 12, 14**). The pair repeatedly crossed into the range, with 33.6 and 36.8 percent of Argos locations for TtTag034 and TtTag035 inside the PMRF boundaries, respectively, and 40.7 and 36.8 percent of crawl model locations inside the PMRF boundaries (**Tables 8, 9**). The higher proportion of time spent inside the range boundaries in the crawl model for TtTag034 likely reflect the use of a “fixed path” method, which shifted tracks that crossed land into the water, rather than just excluding those on land locations in the other analysis. That there were on-land locations for both bottlenose dolphins was not surprising, given the accuracy of Argos locations and the near-shore habits of individuals from this population (**Figure 13**). The use of GPS tags on bottlenose dolphins in the future could help address this issue.

One of the tagged individuals (TtTag035) represents the first repeat tagging of a bottlenose dolphin out of 24 tags deployed on this species in Hawaiʻi (CRC unpublished). A comparison of the movements during the two deployments showed similar patterns, although movements in 2020 spanned a broader range off the north side of Kauaʻi, while in 2013 the individual covered a larger area off the south and east sides of the island (**Figure 14**). A probability-density model constructed from tag data for 14 individual bottlenose dolphins, using data from 2013 through 2020, showed that approximately 36 percent of the core range of the Kauaʻi and Niʻihau stock of bottlenose dolphins overlaps with the PMRF range (**Table 10**). This demonstrates a significant likelihood of exposure to activities on PMRF for this species, making it another ideal candidate for exposure response studies.

As has been the case with previous CRC efforts off Kauaʻi, rough-toothed dolphins were the most frequently encountered species of cetacean on PMRF. Although encounters with this species were short (median=8 minutes) based on Navy priorities, we were able to obtain photo-identification data (**Table 5**) that provide additional evidence for a resident population around Kauaʻi and Niʻihau. This project had a particularly high resighting rate for previously identified rough-toothed dolphins, with 85.7 percent of distinctive individuals with good or excellent photographs having been previously identified, compared to 80.0 percent during the August 2018 project, 68.4 percent during the August 2017 project, and 64.3 percent during the February 2016 project (Baird et al. 2017a, 2018, 2019a). This indicates that coverage of the Kauaʻi/Niʻihau stock has been increasingly comprehensive, and may be reaching an asymptote.

Three rarely encountered species were documented during the February 2020 field effort: false killer whales, pygmy killer whales, and melon-headed whales. False killer whales were encountered on three occasions, and seven out of the eight identified individuals were linked to the Northwestern Hawaiian Islands population of false killer whales (**Figure 10**). False killer whales have only been encountered during CRC efforts off Kauaʻi and Niʻihau on five previous occasions, first in June 2012 and most recently in September 2015. Only one of these was a sighting of individuals from the Main Hawaiian Islands insular population (in October 2014), while members of the Northwestern Hawaiian Islands population have been documented four times (in June 2012, July 2013, and September 2015). Based on satellite tagging elsewhere in the main Hawaiian Islands, individuals from the main Hawaiian Islands insular population rarely use the area around Kauaʻi and Niʻihau (Baird et al. 2010, 2012c).

Pygmy killer whales were sighted on one occasion, and identifications were obtained for 15 individuals, none of whom had been previously identified (**Table 5**). Pygmy killer whales are among the rarest species to be encountered off of Kauaʻi or Niʻihau; we've only encountered them twice before—once in June 2003 and once in October 2014—and our February 2020 encounter appears to be only the fourth confirmed record off those islands (Baird 2016). Each encounter has consisted entirely of animals that have not been previously identified, and that have not been resighted since, providing further evidence that there is no resident population off Kauaʻi and Niʻihau, as is found off Oʻahu and Hawaiʻi Island (McSweeney et al. 2009; Baird 2016).

In CRC's previous work off Kauaʻi and Niʻihau, melon-headed whales had only been encountered on 10 previous occasions: 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), 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/rough-toothed dolphin hybrid (Baird et al. 2018), and two sightings in August 2018 that appeared to be the same group seen twice (Baird et al. 2019a). During this field project, a single melon-headed whale was seen on three different occasions, each time accompanied by the rough-toothed dolphin/melon-headed whale hybrid first seen in August 2017 (**Table 5**) and within larger groups of rough-toothed dolphins. It is important to note that in two of the three cases where this pair were documented, they were not recognized during the field encounters, and their presence within larger groups of rough-toothed dolphins (11 and 22 individuals) were only identified during the photo-matching process. These cases demonstrate the value of spending time with and obtaining photographs of low-priority species.

Melon-headed whales off Kauaʻi are part of a broadly ranging Hawaiian Islands stock (Aschettino et al. 2012; Baird 2016; Carretta et al. 2017; Martien et al. 2017; Woodworth et al. 2011), although they may remain in the area of the islands for short periods (e.g., a week or more). The lone melon-headed whale encountered is likely part of this stock, although this individual has not been compared with CRC's melon-headed whale photo-identification catalog.[2] This individual, along with the hybrid, have now been documented off Kauaʻi in two years, in each case associated with rough-toothed dolphins. Whether the melon-headed whale/hybrid pair is ranging more widely, or staying generally associated with Kauaʻi and Niʻihau, is unknown.

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 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 off the range, and bottlenose dolphins on the range. The value of the M3R detections cannot be overstated though; it was an M3R detection that led us to a large group of bottlenose dolphins on 15 February 2020 that was subsequently tagged, as well as directing us to two of our three encounters with false killer whales.

The Navy's monitoring goals relate broadly to questions of marine mammal occurrence, their exposure to MFAS (and other Navy activities), their responses to sonar, and the consequences of exposure and responses. This research broadly addresses occurrence questions and has provided data to address exposure and response questions (Baird et al. 2014b, 2017b, 2019b). 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 (e.g., Van Cise et al. in review). The presence of island-associated resident populations of these species off the island of Hawaiʻi (Baird 2016), an area with less frequent exposure to MFAS, will also provide a useful comparison of age and sex structure of populations with varying levels of exposure of MFAS, which may provide a strong basis for assessing consequences to exposure.

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[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.

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