Final Report

Odontocete Studies on the Pacific Missile Range Facility in August 2017: Satellite-Tagging, Photo-Identification, and Passive Acoustic Monitoring

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Melon-headed whale (*Peponocephala electra*) in the background and a hybrid between a melon-headed whale and rough-toothed dolphin (*Steno bredanensis*) in the foreground, off Kaua‘i. Photograph taken by Kimberly A. Wood under National Marine Fisheries Service permit no. 20605.

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14. ABSTRACT
As part of a long-term U.S. Navy-funded marine mammal monitoring program, in August 2017 a combination of boat-based field effort and passive acoustic monitoring was carried out on and around the Pacific Missile Range Facility (PMRF) off Kauaʻi prior to a Submarine Command Course scheduled for mid-August 2017. The U.S. Navy funded five days of small-boat effort and the National Marine Fisheries Service funded an additional six days of effort. There were 1,113 kilometers (77.4 hours) of small-vessel survey effort over the course of the 11 day project. There were 34 sightings of five species of odontocetes, with four of the five species being documented on PMRF. Of the 34 sightings, 24 were on PMRF, and of those, 15 were directed by acoustic detections using the Marine Mammal Monitoring on Navy Ranges (M3R) system. During the encounters, we took 37,727 photographs for individual identification, with photographs being added to long-term Cascadia Research Collective (CRC) regional photo-identification catalogs for bottlenose dolphins (Tursiops truncatus) and rough-toothed dolphins (Steno bredanensis). Spinner dolphins (Stenella longirostris) were seen on two occasions, both times in areas outside of PMRF. As expected based on previous CRC efforts off Kauaʻi and Niʻihau, rough-toothed dolphins were the most frequently encountered species, with 22 of 34 encounters (64.7 percent) being of this species. Nineteen of the 22 encounters were on PMRF, and 10 of those groups were found in response to acoustic detections from M3R (66.7 percent of all responses to acoustic detections). One sighting was of a mixed group

of rough-toothed and bottlenose dolphins, only the second sighting of a mixed-species group involving those two species in a combined 722 sightings of the two species in CRC's Hawaiʻi dataset. Two tags were deployed on rough-toothed dolphins, a depth-transmitting tag and a location-only tag, although locations were only received from the location-only tag. During the seven days of location data from the functioning tag, the tagged individual remained off the west and northwest coasts of Kauaʻi, moving off and on PMRF on 10 occasions. A social network analysis of photo-identification data of rough-toothed dolphins indicated that the tagged individuals were part of the resident, island-associated population. There were four encounters with melon-headed whales (Peponocephala electra) representing two groups that were each seen on two occasions, one a large group (estimated at 300 and 200 individuals on the two different days), and one a pair of individuals found associating with rough-toothed dolphins. The large group sightings were the first time that melon-headed whales have been visually confirmed on PMRF and matched to acoustic signals recorded through the M3R system. Two satellite tags were deployed on individuals in the large group of melon-headed whales when they were first encountered on PMRF. This is only the second time that melon-headed whales have been satellite-tagged off Kauaʻi or Niʻihau, and the first time during coordinated small-boat and acoustic monitoring efforts. The two individuals remained together during most of the period of tag overlap. They left and returned to PMRF in the first day after tagging, then moved to the south of the range and remained off the range for the rest of the period, eventually moving east of Kauaʻi. Over the eight days of tag data, the individuals moved 786 kilometers, with a median depth and distance from shore of 3,053 meters and 44.3 kilometers, respectively. One of the pair of melon-headed whales seen on two occasions had pigmentation and morphological characteristics suggesting it may be a hybrid between a melon-headed whale and a rough-toothed dolphin. Genetic analyses of a biopsy sample obtained from the putative hybrid in comparison to a melon-headed whale and a rough-toothed dolphin indicated that the individual has the genotype expected for an F1 hybrid at 11 of 14 nucleotide positions. This is the first-known hybrid between these two species. There was one sighting of pantropical spotted dolphins (Stenella attenuata), only the second sighting of this species on PMRF as part of CRC small-boat efforts since 2003, and the first time that acoustic recordings were made on M3R of a visually confirmed sighting of this species. Two individuals were satellite-tagged, and the two individuals remained associated over the period of tag overlap. In the first two days after tag deployment the tagged individuals moved off and on PMRF three times, before moving south of Kauaʻi, eventually meandering far to the north of Oʻahu. Over the 14 days of tag data the individuals moved 1,307 kilometers, with a median depth and distance from shore of 3,603 meters and 49.5 kilometers, respectively. Movements and habitat use information suggests this group was from the pelagic stock of pantropical spotted dolphins. This sighting provides further support for the suggestion that there is no island-associated population of pantropical spotted dolphins off Kauaʻi or Niʻihau, as there are off the other main Hawaiian Islands. Probability-density analyses were undertaken of all tag-location data obtained for the three species tagged during this effort and two species tagged in previous Navy-funded efforts off Kauaʻi. Small core areas (50 percent kernel densities) were identified for resident populations of bottlenose dolphins (1,173 square kilometers) and rough-toothed dolphins (1,450 square kilometers). In comparison, large core areas were identified for individuals from pelagic or Hawaiian-island wide populations (7,675; 40,744; and 111,135 square kilometers for pantropical spotted dolphins, melon-headed whales and the pelagic population of short-finned pilot whales, respectively). This suggests that the likelihood of exposure to mid-frequency active sonar on PMRF varies substantially between insular and pelagic populations. Although all tagged individuals left the area around PMRF prior to the start of the surface component of the Submarine Command Course, 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. Future efforts may provide datasets that can be used to estimate received sound levels at animal locations and examine potential responses to exposure to mid-frequency active sonar.

15. SUBJECT TERMS
Monitoring, marine mammals, toothed whales, satellite tagging, photo-identification, passive acoustic monitoring, biopsy, Hawaii Range Complex, Pacific Missile Range Facility

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Table of Contents

Acronyms and Abbreviations

BARSTUR	Barking Sands Tactical Underwater Range
BSURE	Barking Sands Underwater Range Expansion
CRC	Cascadia Research Collective
CS-SVM	class-specific support vector machine classifier
FFT	Fast Fourier Transform
kHz	kilohertz
km	kilometer(s)
m	meter(s)
M3R	Marine Mammal Monitoring on Navy Ranges
MFA	mid-frequency active
PAM	passive acoustic monitoring
PMRF	Pacific Missile Range Facility
RHIB	rigid-hulled inflatable boat
SCC	Submarine Command Course
SWTR	Shallow Water Training Range

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Abstract

As part of a long-term U.S. Navy-funded marine mammal monitoring program, in August 2017 a combination of boat-based field effort and passive acoustic monitoring was carried out on and around the Pacific Missile Range Facility (PMRF) off Kaua‘i prior to a Submarine Command Course scheduled for mid-August 2017. The U.S. Navy funded five days of small-boat effort and the National Marine Fisheries Service funded an additional six days of effort. There were 1,113 kilometers (77.4 hours) of small-vessel survey effort over the course of the 11-day project. There were 34 sightings of five species of odontocetes, with four of the five species being documented on PMRF. Of the 34 sightings, 24 were on PMRF, and of those, 15 were directed by acoustic detections using the Marine Mammal Monitoring on Navy Ranges (M3R) system. During the encounters, we took 37,727 photographs for individual identification, with photographs being added to long-term Cascadia Research Collective (CRC) regional photo-identification catalogs for bottlenose dolphins (*Tursiops truncatus*) and rough-toothed dolphins (*Steno bredanensis*). Spinner dolphins (*Stenella longirostris*) were seen on two occasions, both times in areas outside of PMRF. As expected based on previous CRC efforts off Kaua‘i and Ni‘ihau, rough-toothed dolphins were the most frequently encountered species, with 22 of 34 encounters (64.7 percent) being of this species. Nineteen of the 22 encounters were on PMRF, and 10 of those groups were found in response to acoustic detections from M3R (66.7 percent of all responses to acoustic detections). One sighting was of a mixed group of rough-toothed and bottlenose dolphins, only the second sighting of a mixed-species group involving those two species in a combined 722 sightings of the two species in CRC’s Hawai‘i dataset. Two tags were deployed on rough-toothed dolphins, a depth-transmitting tag and a location-only tag, although locations were only received from the location-only tag. During the seven days of location data from the functioning tag, the tagged individual remained off the west and northwest coasts of Kaua‘i, moving off and on PMRF on 10 occasions. A social network analysis of photo-identification data of rough-toothed dolphins indicated that the tagged individuals were part of the resident, island-associated population. There were four encounters with melon-headed whales (*Peponocephala electra*) representing two groups that were each seen on two occasions, one a large group (estimated at 300 and 200 individuals on the two different days), and one a pair of individuals found associating with rough-toothed dolphins. The large group sightings were the first time that melon-headed whales have been visually confirmed on PMRF and matched to acoustic signals recorded through the M3R system. Two satellite tags were deployed on individuals in the large group of melon-headed whales when they were first encountered on PMRF. This is only the second time that melon-headed whales have been satellite-tagged off Kaua‘i or Ni‘ihau, and the first time during coordinated small-boat and acoustic monitoring efforts. The two individuals remained together during most of the period of tag overlap. They left and returned to PMRF in the first day after tagging, then moved to the south of the range and remained off the range for the rest of the period, eventually moving east of Kaua‘i. Over the eight days of tag data, the individuals moved 786 kilometers, with a median depth and distance from shore of 3,053 meters and 44.3 kilometers, respectively. One of the pair of melon-headed whales seen on two occasions had pigmentation and morphological characteristics suggesting it may be a hybrid between a melon-headed whale and a rough-toothed dolphin. Genetic analyses of a biopsy sample obtained from the putative hybrid in comparison to a melon-headed whale and a rough-toothed dolphin indicated that the individual

has the genotype expected for an F1 hybrid at 11 of 14 nucleotide positions. This is the first-known hybrid between these two species. There was one sighting of pantropical spotted dolphins (*Stenella attenuata*), only the second sighting of this species on PMRF as part of CRC small-boat efforts since 2003, and the first time that acoustic recordings were made on M3R of a visually confirmed sighting of this species. Two individuals were satellite-tagged, and the two individuals remained associated over the period of tag overlap. In the first two days after tag deployment the tagged individuals moved off and on PMRF three times, before moving south of Kaua‘i, eventually meandering far to the north of O‘ahu. Over the 14 days of tag data the individuals moved 1,307 kilometers, with a median depth and distance from shore of 3,603 meters and 49.5 kilometers, respectively. Movements and habitat use information suggests this group was from the pelagic stock of pantropical spotted dolphins. This sighting provides further support for the suggestion that there is no island-associated population of pantropical spotted dolphins off Kaua‘i or Ni‘ihau, as there are off the other main Hawaiian Islands. Probability-density analyses were undertaken of all tag-location data obtained for the three species tagged during this effort and two species tagged in previous Navy-funded efforts off Kaua‘i. Small core areas (50 percent kernel densities) were identified for resident populations of bottlenose dolphins (1,173 square kilometers) and rough-toothed dolphins (1,450 square kilometers). In comparison, large core areas were identified for individuals from pelagic or Hawaiian-island wide populations (7,675; 40,744; and 111,135 square kilometers for pantropical spotted dolphins, melon-headed whales and the pelagic population of short-finned pilot whales, respectively). This suggests that the likelihood of exposure to mid-frequency active sonar on PMRF varies substantially between insular and pelagic populations. Although all tagged individuals left the area around PMRF prior to the start of the surface component of the Submarine Command Course, 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. Future efforts may provide datasets that can be used to estimate received sound levels at animal locations and examine potential responses to exposure to mid-frequency active sonar.

1. Introduction

The U.S. Navy regularly undertakes training and testing activities on or around the Pacific Missile Range Facility (PMRF) between Kaua'i and Ni'ihau. Vessel-based field studies of odontocetes first began off Kaua'i and Ni'ihau 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 Kaua'i. 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 Kaua'i and Ni'ihau has been sponsored by the U.S. Navy. Initially using photo-identification of distinctive individuals and biopsy sampling for genetic analyses, CRC surveys in 2003 and 2005 showed evidence of site fidelity for rough-toothed dolphins (*Steno bredanensis*), bottlenose dolphins (*Tursiops truncatus*), and short-finned pilot whales (*Globicephala macrorhynchus*), as well as provided information on relative sighting rates around the islands (Baird et al. 2006, 2008a, 2009). Sighting rates of a fourth species, pantropical spotted dolphins (*Stenella attenuata*), were low off Kaua'i and Ni'ihau in comparison to other areas (Baird et al. 2013a), and genetic samples obtained from sightings off Kaua'i and Ni'ihau suggest that spotted dolphins in that area are part of a pelagic, open-ocean, population (Courbis et al. 2014). CRC efforts using satellite tags to assess movements and behavior of individual toothed whales on and around PMRF began in June 2008 in association with the Rim-of-the-Pacific naval training event (Baird et al. 2008b). During that effort, three melon-headed whales (*Peponocephala electra*) and a short-finned pilot whale were tagged and tracked for periods ranging from 3.7 to 43.6 days (Baird et al. 2008b; Woodworth et al. 2011). While the melon-headed whales moved far offshore to the west, the short-finned pilot whale remained around Kaua'i and moved offshore of western O'ahu (Baird et al. 2008b). Since 2008 and prior to August 2017, CRC has had 11 additional vessel-based field projects off Kaua'i, 10 in conjunction with passive acoustic monitoring (PAM) through the Marine Mammal Monitoring on Navy Ranges (M3R) program. M3R, a real-time PAM system capable of fully automated detection and localization of marine mammals, has been implemented at three major Navy undersea training ranges: the Atlantic Undersea Test and Evaluation Center (2002–present; Jarvis et al. 2014), the Southern California Offshore Range (2006–present; Falcone et al. 2009), and most recently at PMRF (2011–present). In these cases, PAM is used by on-site operators to direct the research vessel to vocalizing groups of cetaceans, increasing encounter rates and providing visual verification of vocalizing species. During these 11 field efforts, 70 satellite tags were deployed on seven different species of odontocete cetaceans (**Table 1**; Baird et al. 2011, 2012a, 2012b, 2013b, 2013c, 2014a, 2015, 2016, 2017a). Results of field efforts through August 2016 have been previously summarized (Baird et al. 2017a; Baird 2016). Combined, these efforts through August 2016 account for 1,119 hours of boat-based search effort (19,194 kilometers [km]) over nine 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 five days of field work off Kaua‘i to be undertaken prior to a Submarine Command Course (SCC) in August 2017. Six additional days of effort were also undertaken, funded by a grant from the National Marine Fisheries Service to the State of Hawai‘i and a contract to CRC. This report presents findings from this combined effort. The marine mammal monitoring reported here is part of a long-term monitoring effort under the U.S. Navy's Marine Species Monitoring Program. The specific monitoring questions to be addressed during the August 2017 effort, as noted in the contract, were related to the occurrence and estimated received levels of mid-frequency active (MFA) sonar for a number of species, as well as short-term behavioral responses of these species when exposed to MFA sonar (see Baird et al. 2014b). However, individuals tagged in August 2017 had left the PMRF area prior to the start of the SCC. Thus, this report focuses on understanding the spatial movement and habitat use patterns of species that are exposed to MFA sonar, and how these patterns might influence exposure and potential responses. In addition to the results of work from August 2017, we incorporate previous efforts, including results where relevant from CRC work elsewhere in the main Hawaiian Islands. As well as addressing specific Navy monitoring questions and increasing the general understanding of odontocete populations off Kaua‘i and Ni‘ihau, one of the secondary goals to this work is to provide visual species verification for acoustic detections through the M3R program.

2. Passive Acoustic Monitoring Methods

2.1 PMRF Instrumented Hydrophone Range

The PMRF instrumented hydrophone range is configured with 219 bottom-mounted hydrophones, 132 of which are currently active and available for PAM. The hydrophones were installed in four phases, such that each system has different acoustic monitoring capabilities (**Table 2**). The four range systems are: the Shallow Water Training Range (SWTR), the Barking Sands Tactical Underwater Range (BARSTUR), the legacy Barking Sands Underwater Range Expansion (BSURE), and the refurbished BSURE. The ranges partially overlap, but SWTR is located in the shallow waters of the southeastern part of the range spanning approximately 30 km north to south and varying from approximately 6 to 12 km east to west. BARSTUR is located in the southwestern part of the range and spans approximately 28 km north to south and approximately 18 km east to west. BSURE is located in the northern part of the range and spans approximately 73 km north to south and approximately 30 km east to west. Each range consists of several offset bottom-mounted cables (strings), with multiple hydrophones spaced along each string to create hexagonal arrays. Passive acoustic data pass through the range's operational signal-processing system and the M3R system in parallel. In this way, marine mammal monitoring does not interfere with range use.

2.2 M3R System

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

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

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

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

Supplementary to MMAMMAL, Worldview software also displays the hydrophone layout, color-coded for detection rate, with the addition of satellite imagery and digital bathymetry as a background. The Worldview display includes the positions of vocalizing animals (each hereafter termed a posit) derived from automated localization software and the species classification from the CS-SVM. However, additional information is provided with each position to help the PAM user determine the accuracy of the automated localization, including the number of neighboring localizations and number of “same” localizations, where “same” is defined as the same position localized by multiple detections. Typically, a higher quantity of “near-neighbor” localizations indicates a more accurate localization. Because of the localization methodology, a single-click position is more likely to be a false positive than a cluster of click positions, each indicating several neighbors. The sub-array on which the detection occurred, referenced by center hydrophone, is also indicated. Overlapping posits from multiple arrays also provides assurance that the posit is accurate. Automated click localizations provide the PAM user a real-time range-wide map for odontocete distribution of click classification type (e.g., beaked whale, sperm whale, small odontocete). In the absence of automatically generated positions, a MMAMMAL tool for semi-manual calculation of positions using hand-selected whistles or low frequency calls was also used. When the same low frequency (baleen) 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.

Detection archives were collected from all hydrophones, 24-hours per day, for the entire period. These archives capture all detection reports and automated localizations generated during the effort. Data post-processing is significantly expedited by using the detection archives, which allow rapid evaluation of acoustic detections over long periods of time. Additionally, raw hydrophone data are recorded using the M3R hard disk recorder, allowing for detailed analysis of marine mammal and environmental signals. The disk recorder is capable of recording precisely time-aligned audio data from all range hydrophones.

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

2.3 Coordination with Small-vessel Efforts

PAM was undertaken for all 11 days of small-vessel research effort. PAM began at 0600 every morning and continued until the research vessel left the range, either to return directly to port, to survey in areas south of the range if weather conditions on the range were not suitable for small-boat operations, or if the range access was restricted. At all times, the PAM objective was to keep the scientists aboard the rigid-hulled inflatable boat (RHIB) informed of the species and distribution of vocalizing marine mammals that had been localized on the range, focusing in areas that were known to have suitable sea conditions for small-boat operations. 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 RHIB. As an example, a communication would detail groups on the SWTR and BARSTUR ranges, but not the BSURE range if the RHIB 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 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 RHIB. 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. In addition, successive whistles were used to generate multiple solutions, which provided an increased level of confidence. 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 RHIB. 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 and Programming

Ten location-dive satellite tags (Wildlife Computers Mk10-A) were funded through the Marine Species Monitoring Program, and two tags (one location-dive tag and one location-only [Wildlife Computers SPOT5] tag) were available for deployment through funding from the Living Marine Resources Program. Tags were in the LIMPET configuration, with attachment to the animals with two titanium darts with backward facing petals, using either short (4.4-centimeter) or long (6.8-centimeter) darts (Andrews et al. 2008), depending on species (e.g., short darts for rough-toothed, melon-headed whales, or pantropical spotted dolphins).

For each tag type (location-only or location-dive), there were different programming combinations depending on species. The combinations were based on the average number of respirations per hour from previous tagging studies, while taking into account the speed of surfacing and the likelihood of the tag remaining attached for longer than approximately 30 days, which varies by species. For small odontocetes (the only species tagged during this effort), location-dive tags transmitted for 15 hours/day with a maximum of 1,050 transmissions per day, giving an estimated battery life of approximately 17 days. These tags were set to record a time series (recording depth once every 1.25 minutes), as well as dive statistics (start and end time, maximum depth, duration) for any dives greater than 30 meters (m) in depth, with depth readings of 3 m being used to determine the start and end of dives, thus dive durations are slightly negatively biased. Given typical odontocete descent and ascent rates of 1 to 2 m/second, dive durations recorded are likely only 3 to 6 seconds shorter than actual dive durations. Location-only tags transmitted for 14 hours/day with a maximum of 1,050 transmissions per day, giving an estimated battery life of >30 days. Prior to the field effort, satellite passes were predicted using the Argos website to determine the best hours of the day for transmissions given satellite overpasses for the approximately 2-month period starting at the beginning of the deployment period.

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

3.2 Vessel, Time and Area of Operations

The field project was timed to occur immediately prior to a Submarine Command Course scheduled for mid-August 2017. Five days of effort were funded as part of the Navy’s Marine Species Monitoring program, and an additional six days of effort were funded by a grant from the National Marine Fisheries Service to the State of Hawai‘i, with a contract from the State of Hawai‘i to CRC.

The vessel used was a 24-foot rigid-hulled Zodiac Hurricane, powered by twin Suzuki 140-horsepower outboard engines, and with a custom-built bow pulpit for tagging and biopsy operations. The vessel was launched each morning at sunrise, and operations continued during daylight hours as long as weather conditions were suitable with a team of five to seven observers scanning 360 degrees around the vessel. The primary launch site was the Kīkīaola small boat harbor. Vessel locations were recorded on a global positioning system 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 11 days. When positions from the M3R system were available, the RHIB would transit to specific locations in response to the positions and would survey areas for visual detection of groups. Per Navy direction in the scope of work, high priority species (for working with groups and for responding to M3R-derived positions) were Endangered Species Act-listed species (e.g., sperm whales, fin whales, false killer whales), other baleen whales (e.g., minke whales), and other "blackfish" (e.g., short-finned pilot whales, melon-headed whales). In general, humpback whales were not approached other than to determine species or if there were other species potentially associating with them. 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 the range was closed because of Navy activity, the RHIB team worked in areas off the range. The RHIB team communicated each morning with the PMRF Range Control prior to entering the range and remained in regular contact with Range Control throughout the day as needed to determine range access limitations.

3.3 During Encounters

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

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), 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.

If conditions were suitable for tagging, for all infrequently encountered species (e.g., melon-headed whales and pantropical spotted dolphins), 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., bottlenose dolphins and 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. Decisions to deploy additional tags on frequently encountered species were based on the number of tags remaining to be deployed during the field effort, taking into account the number of remaining field days and the need to have tags available for high-priority species if encountered.

Skin/blubber biopsy samples were collected with a crossbow, using an 8-millimeter diameter dart tip with a stop that prevented penetration greater than approximately 15 millimeters. Species targeted for biopsy samples were those where additional samples were needed to help address stock structure questions (e.g., pantropical spotted dolphin, see Courbis et al. 2010), in the case of potential hybrids, or when behavior of the group and conditions facilitated sample collection. In encounters where tagging was going to be undertaken, biopsy sampling was only undertaken after the cessation of tagging operations.

3.4 Data Analyses

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

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

Locations of tagged individuals were estimated by the Argos System using the least-squares methods and were assessed for plausibility using the Douglas Argos-filter v. 8.5 to remove unrealistic locations, following previously used protocols (Schorr et al. 2009; Baird et al. 2010, 2011). Resulting filtered location data were processed with R (R Core Team 2017) to determine depth using package raster (Hijmans 2017), and distance from shore and location relative to PMRF boundaries using package rgeos (Bivand and Rundel 2017).

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

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

For the purposes of generating probability-density maps, only a single individual from each group was used when pairs of individuals were acting in concert. Locations were only used prior to the tag going into duty cycling (i.e., when the tags were transmitting every day). For the three species satellite tagged off Kaua‘i, probability-density maps were generated excluding locations from the first 24 hours, to reduce any bias associated with the tagging location. For melon-headed whales, tag data from 15 individuals from the Hawaiian Islands population tagged in previous years (Aschettino et al. 2011; Baird 2016; Martien et al. 2017) were included. Kernel density polygons were generated using the R package adehabitatHR v. 0.4.15 (Calenge 2006) and corresponded to the 50, 95 and 99 percent densities. Polygons were plotted in Google Earth Pro v. 7.1.2.2041.

Data obtained from the shore-based Argos MOTE receiver and from the Argos System were processed through the Wildlife Computers DAP Processor versions 3.0.392-3.0.411 to obtain diving and surfacing data from the location-dive tags.

4. Results

From 4 to 14 August 2017, there were 1,113 km (77.4 hours) of small-vessel field effort (**Figure 1**), with the boat on the water all 11 days (**Table 4**). Forecasted winds over the 11 days were either east 15 knots (six days) or east 20 knots (five days). The research vessel was launched from Kīkīaola small boat harbor on all days. We were able to work on the range all days, although Navy activities taking place on the northern part of the range for two days limited access to the southern part of the range. In addition, the range generally was unworkable because of strong winds on two days, so effort was concentrated in shallow water to the east and south of the range. Just over 84 percent of the total search effort was in depths less than 1,000 m (**Figure 2**).

Overall, there were 34 sightings of five species of odontocetes, four of which (all except spinner dolphins) were documented on PMRF (**Figure 1**, **Table 5**). Rough-toothed dolphins were encountered on 22 occasions, bottlenose dolphins on five, melon-headed whales on four, spinner dolphins on two, and pantropical spotted dolphins on one. Fifteen of the 26 encounters on PMRF (10 of 19 sightings of rough-toothed dolphins, two of three sightings of bottlenose dolphins, three melon-headed whale encounters—two of which were mixed encounters with rough-toothed dolphins—and the pantropical spotted dolphin sighting) were directed by acoustic detections from the M3R system. During the encounters, we took 37,727 photographs for individual and species identification, deployed six satellite tags on three species, and collected three biopsy samples (**Table 6**). The two encounters with spinner dolphins were short (7 and 14 minutes), and photographs were obtained from both, but no additional analyses of data from the spinner dolphin encounters was undertaken.

Sperm whales, beaked whales, possible killer whales, and unidentified baleen whales were detected acoustically, but locations were either far to the north, or on the western edge of the range, and were not reachable given weather conditions at the time. One posit identified acoustically as likely killer whales was approached within five minutes of the posit, but only rough-toothed dolphins were found in the vicinity. Sea conditions during the approach to the posit and during the rough-toothed dolphin encounter were good (Beaufort sea state 2).

4.1 Rough-toothed dolphins

Rough-toothed dolphins were the most frequently encountered species, with 22 of 34 encounters (64.7 percent) being of this species. Nineteen of the 22 encounters were on PMRF (**Figure 1**), and 10 of those groups were found in response to acoustic detections from M3R (66.7 percent of all groups found in response to acoustic detections). Encounter duration ranged from <1 minute to 2 hours 47 minutes (median = 16 minutes), although it should be noted that the two longest encounters were mixed-species sightings including melon-headed whales. One sighting was of a mixed group of rough-toothed and bottlenose dolphins, only the second sighting of a mixed-species group involving those two species in a combined 722 sightings of the two species in CRC's Hawai‘i dataset. Photographs were taken for individual identification in 19 of 22 encounters. During the 19 encounters, we obtained 187 identifications (**Table 5**). Of those, there were 111 identifications of 95 distinctive individuals with good- or excellent-quality photographs. A comparison of the 95 individuals to the photo-identification catalog of this species (Baird et al. 2008b) revealed that 65 of the individuals had been previously photo-identified off Kauaʻi, and one additional individual had been previously photo-identified off Oʻahu. All encounters where more than one distinctive individual was photo-identified included individuals that had been previously documented (**Table 5)**. A social network analysis indicates that almost 91 percent of individual rough-toothed dolphins documented off Kauaʻi and Niʻihau link by association in the main cluster of the social network (**Figure 3**).

Two tags were deployed on rough-toothed dolphins, a depth-transmitting tag funded by Pacific Fleet and a location-only tag funded by another grant to CRC, although locations were only received from the location-only tag. Both of the individuals tagged in August 2017 had been previously documented off Kauaʻi, both in October 2014 (**Table 7**), and both were part of the main cluster of the social network (**Figure 3**). During the seven days of location data from the functioning tag, the tagged individual remained off the west and northwest coasts of Kauaʻi, moving off and on PMRF on 10 occasions (**Figure 4**), at a median distance from shore of 12.0 km and a median depth of 796 m (**Table 8**). Combined with previous tag deployments on rough-toothed dolphins (Baird et al. 2017a), this suggests the tagged group was from the resident, island-associated population. A probability-density map (**Figure 5**) using tag data from this individual and all those rough-toothed dolphins previously tagged off Kauaʻi and Niʻihau indicates their range encompasses both islands and extends to western Oahu, and the core area for the population broadly overlaps with the southern portion of PMRF. This analysis excluded data from one of each pair of individuals acting in concert, and omitted the first 24 hours of data from each individual.

4.2 Melon-headed whales

Melon-headed whales were encountered on four occasions, with three of the four sightings on PMRF (**Figure 1**). Two of the encounters were of a large group seen two days in a row (13 and 14 August 2017) on PMRF (group size estimates of 300 and 200), with a small group (estimated five individuals) of rough-toothed dolphins present during the first encounter (with an estimated 300 melon-headed whales). Both of the large groups were cued by acoustic detections from M3R. Encounter duration for these two encounters was 2 hours 40 minutes and 2 hours 15 minutes, respectively, and a total of 13,056 photographs were taken from these two encounters for future inclusion into CRC's melon-headed whale photo-identification catalog (Aschettino et al. 2011).

During the 13 August 2017 encounter, two individuals were satellite tagged, both with depth-transmitting tags, although dive data (30.4 hours) were only obtained from one (PeTag026) of the two tags (**Table 9**). Dive data obtained indicated relatively shallow dives (median = 207.5 m, maximum = 335.5 m) with a maximum dive duration of 9.67 m (**Table 9**). The individual spent most of its time during the day near the surface, with the majority of dives documented during nighttime periods (**Figure 6**).

An analysis of distances between locations of the two individuals obtained during the same satellite overpasses (not shown) revealed that the individuals remained associated over the first approximately five days of overlap (median distance apart = 1.7 km) and then separated for the remaining period of overlap (median distance apart = 57.9 km). Location data were obtained for 6.47 (PeTag025) and 7.44 days (PeTag026). In the first approximately15 hours after tagging, the tagged individuals moved off PMRF to the west, then returned to the range, where the group was re-encountered on 14 August 2017 approximately 24 hours after they had been encountered first. During the encounter on 14 August 2017, the group was traveling fast to the south, and by 31 hours post-tagging the tagged individuals were approximately 35 km south of PMRF, spending the remainder of their time in deep water to the south and east of Kauaʻi (**Figure 7**). Although photographs have not yet been compared to CRC's photo-identification catalog for this species, these groups are expected to be part of the Hawaiian Islands stock (Carretta et al. 2017). For context, location and trackline data for 15 additional individuals from the Hawaiian Islands population tagged by CRC from 2008 through 2014 (see Baird 2016) are shown (**Figure 8**). A probability-density map (**Figure 9**) using tag data from these individuals indicates a broad range covering all the main Hawaiian Islands and extending into offshore waters. This analysis excluded data from one of each pair of individuals acting in concert, and omitted the first 24 hours of data from each individual.

These were the first visually confirmed acoustic detections of melon-headed whales by the M3R system on PMRF. The melon-headed whales visually verified on 13 August 2017 produced a lot of whistle vocalizations above 8 kHz with few clicks. By comparison, rough-toothed dolphins appear to click incessantly with few whistles observed.

The other two encounters were composed only of the same pair of individuals seen four days apart (7 August and 11 August 2017), once mixed in with an estimated 20 rough-toothed dolphins, and the second time mixed in with an estimated 28 rough-toothed dolphins (**Table 5**). For these two encounters, 744 melon-headed whale photographs were taken and a biopsy sample was obtained from one individual. Encounter durations for these two encounters were 1 hour 3 minutes and 33 minutes, respectively. A comparison of photographs of the rough-toothed dolphins present between these two encounters (26 identifications on 7 August 2017 and 23 identifications on 11 August 2017, including individuals of all distinctiveness and photo quality ratings) revealed no matches between the two encounters.

During the encounters, one of the individual melon-headed whales was noted to have an unusual rostrum, and an examination of the photographs of the pair indicated that the individual in question shared features of both melon-headed whales and rough-toothed dolphins as well as having some intermediate features (**Figure 10**), suggesting it may be a hybrid between a melon-headed whale and a rough-toothed dolphin. In terms of pigmentation, the boundary between the darker dorsal cape and the lighter lateral field is diffuse, and below the leading edge of the dorsal fin the cape extends down sharply, consistent with melon-headed whale pigmentation patterns. At the base of and immediately below the dorsal fin, the individual has darker-colored blotchy pigmentation patches similar to those found on rough-toothed dolphins. The head shape appears intermediate between the two species, with a gently-sloping rostrum (rather than the rounded head of melon-headed whales) but which is truncated compared to rough-toothed dolphins. The biopsy sample collected from this individual was analyzed at the NMFS Southwest Fisheries Science Center. The individual was genetically sexed as a male, and with the melon-headed whale mitochondrial haplotype 4, a haplotype found only in the Hawaiian Islands population (Martien et al. 2017). One melon-headed whale, one rough-toothed dolphin, and the putative hybrid were sequenced at six nuclear loci that contained a combined total of 14 nucleotide positions at which the melon-headed whale and rough-toothed dolphin differed genetically. At 11 of those 14 positions, the putative hybrid has the genotype expected for an F1 hybrid between a female melon-headed whale and a male rough-toothed dolphin. At the remaining three positions, we hypothesize that deviation from the expected pattern is due to genetic variation within either melon-headed whales or rough-toothed dolphins that will be detected when additional samples are sequenced.

4.3 Pantropical spotted dolphins

A group of an estimated 50 pantropical spotted dolphins was sighted on 10 August 2017 on PMRF, cued by acoustic detections from M3R. A total of 3,999 photographs were obtained for eventual incorporation into a spotted dolphin photo-identification catalog. Two satellite tags were deployed, one location-only tag (SaTag006) and one location-dive tag (SaTag007), and locations were obtained for 13.99 and 3.33 days, respectively (**Table 6**). No dive data were obtained from SaTag007. During the period of tag overlap the two individuals remained associated (median distance apart of 1.29 km, minimum = 0.34, max = 7.42 km). During the 13.99 days, SaTag006 spent four separate periods inside the PMRF boundaries (11.9 percent of the 13.99-day period), before moving to the south. Over the 13.99 days, SaTag006 moved a minimum of 1,307 km, spending most of its time in deep waters to the south, southeast, and northeast of Kauaʻi (**Figure 11**). The median depth and distance from shore were 3,603 m and 52.8 km (**Table 8**). A probability-density map using tag data from the pelagic pantropical spotted dolphins satellite tagged off Kauaʻi in both 2016 and 2017 indicates that the core area for these individuals covers a broad area between Kauaʻi and Oʻahu (**Figure 12**), with among the largest range of any species tagged off Kauaʻi (**Table 10**). One biopsy sample was collected from an individual in the group for genetic analyses at Portland State University (following protocols outlined by Courbis et al. 2014), and a sub-sample was sent to the tissue archive at the Southwest Fisheries Science Center.

This was the first visually confirmed acoustic detection of pantropical spotted dolphins on the M3R system at PMRF. Pantropical spotted dolphin whistles observed on 10 August 2017 were characterized by distinct steep up-sweeps and/or up-sweep-down-sweep combinations similar to a '^' or a 'N', extending from approximately 8 to 20 kHz. The spotted dolphins also emitted rapid clicks between 12 and 45 kHz with most of the energy above 24 kHz.

4.4 Bottlenose dolphins

Bottlenose dolphins were sighted on five occasions (**Figure 1, Table 5**). Encounter durations were short (median = 24 minutes, range = 12–55 minutes), with the 55-minute encounter involving a mixed-species group including rough-toothed dolphins. Photographs were obtained from all five encounters, representing 27 identifications. Good or excellent quality photographs were available from 22 of the 27 identifications, representing all five encounters. Restricting analyses to good-quality photographs of distinctive individuals, there were 12 identifications representing 12 individuals. A comparison to the long-term photo-identification catalog (Baird et al. 2009) indicated that 11 of the 12 individuals were previously documented, all off Kauaʻi and/or Niʻihau. Of those 11 that were previously documented, three had been seen in one previous year, three had been seen in two previous years, one had been seen in three previous years, two had been seen in four previous years, and one each had been seen in five and six previous years. Four of the individuals were first documented off Kauaʻi and Niʻihau over 10 years earlier (maximum span of years = 14.2), three during CRC's first field project off Kauaʻi in

2003 (Baird et al. 2003). Individuals from all encounters were linked by association to the main component of the Kauaʻi/Niʻihau social network (**Figure 13**), which includes approximately 90 percent of all bottlenose dolphins photo-identified off the islands, indicating they were all from the island-associated population. Excluding 12 individuals photographed off Kaʻula Island during a NAVFAC PAC cruise in June 2011 (Uyeyama et al. 2011), 95.3 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.

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5. Discussion and Conclusion

Over the 11-day field effort in August 2017 information was obtained on five species of odontocetes off Kaua‘i, three of which (rough-toothed dolphins, spinner dolphins and bottlenose dolphins) are regularly seen off the island, and two (melon-headed whales, pantropical spotted dolphins) which are rarely seen there (Baird et al. 2013a; Baird 2016). For both of the rare species, we visually verified their species identity on PMRF simultaneous with recording of acoustic signals through the M3R program. This is particularly of value as neither species had been acoustically documented previously on PMRF with visual verification. Such visually verified recordings will be of value in using the M3R system for monitoring these two species use of the range in future years. These first exemplars will aid operators in discriminating between these high-interest species and other species that more frequently use the range. However, more verified (and recorded) encounters are likely needed to fully equip the M3R operators in identifying the vocal behavior of these species.

We also deployed satellite tags on three species prior to the SCC, although all tagged individuals either left the area prior to the start of the SCC (pantropical spotted dolphins, melon-headed whales) or the tags stopped transmitting prior to it (rough-toothed dolphins). A comparison of times when tagged individuals left the range to acoustic data recorded by SPAWAR during this period revealed there was potentially some exposure to MFAS for one or more tagged individuals prior to the start of the SCC (E.E. Henderson, personal communication), and exposure levels of those individuals will be calculated at a later time following similar methods to previous exposure analyses (Baird et al. 2017b). Regardless, the satellite-tag data obtained from these species all increased our understanding of how these three species use the area and potentially overlap with naval activities.

In CRC’s previous work off Kaua‘i and Ni‘ihau, melon-headed whales had only been encountered on four previous occasions representing two or possibly three different groups, a sighting in June 2003 north of Kaua‘i (Baird et al. 2003), and sightings in June 2008 on three different days over a five-day span in the Kaulakahi Channel (CRC unpublished). Although there were numerous individuals in common among the sightings in June 2008, satellite tags deployed on two different days revealed some individuals were traveling independently, with one moving 460 km west of the channel over 18 days, and the other remaining within approximately 80 km of the channel over a 10-day period (Woodworth et al. 2011). While we had four encounters with melon-headed whales during the August 2017 effort, these represented two groups that were each sighted twice, representing only the third and fourth groups of melon-headed whales documented in CRC’s efforts off Kaua‘i and Ni‘ihau and the first groups documented since combined boat-based and PAM efforts began in 2011 (**Table 1**). One of these two groups was a typical group for this species, with estimated group sizes of 300 and 200 individuals the two days they were encountered. Mean group size of melon-headed whales in Hawaiian waters is approximately 250 individuals (Baird et al. 2013a). Two individuals were satellite tagged in that group, and their movements (**Figures 7 and 8**) and habitat use (**Table 8**) are consistent with this group being part of the Hawaiian Islands stock of melon-headed whales, which broadly uses offshore waters in Hawai‘i with movements among the islands (Aschettino et al. 2011; Baird 2016; Carretta et al. 2017; Martien et al. 2017). Movements of the individuals tagged in 2017, with the individuals traveling to the south and east of Kaua‘i, were quite different than those tagged in 2008. Dive data obtained from one of the melon-headed whales tagged showed a similar diel pattern of diving behavior (**Figure 6**) to that found in other melon-headed whales in Hawaiian waters (West et al. 2018).

The other group of melon-headed whales encountered was unusual for this species, in that only two individuals were present. During both encounters, these individuals were associated with rough-toothed dolphins, a common association for this species in Hawaiian waters (Baird 2016). However, both morphological (**Figure 10**) and genetic evidence indicates that one of the two individuals is an F1 hybrid between these two species. While inter-generic hybridization in the wild has been recorded for a number of species of odontocetes (e.g., Baird et al. 1998; Bérubé and Palsbøll 2018), this appears to be the first record of a hybrid involving either of these species in the wild, and only the third confirmed instance of a wild-born hybrid between species in the family Delphinidae (Dohl et al. 1974; Bérubé and Palsbøll 2018). Introgressive hybridization, in which genetic data from one species integrated into the genome of another species following a hybridization event, has long been suspected as a source of taxonomic uncertainty in the Delphinidae (Kingston et al. 2009; Martien et al. 2014b). The hybrid individual identified in this study lends support to this hypothesis.

In our prior work off Kauaʻi, pantropical spotted dolphins were only sighted off the island on 10 occasions (Baird et al. 2013a), four times in 2003, once in 2005 (a single individual associating with spinner dolphins), three times in 2011 (all of the same lone individual documented in 2005, and all three times associating with spinner dolphins), and once in 2012 and 2016. Overall they represent only approximately 2 percent of odontocete sightings off Kauaʻi and Niʻihau, compared to between approximately 23 and 26 percent of odontocete sightings off other islands (Baird et al. 2013a). Based on a combination of low sighting rates (particularly in comparison to the other main Hawaiian Islands) and genetic information (Courbis et al. 2014), pantropical spotted dolphins are not thought to be resident to Kauaʻi or Niʻihau (Baird 2016). The August 2017 sighting was only the second one on PMRF; the February 2016 sighting was the first on the range (Baird et al. 2017a). Based on movements of the tagged individuals (**Figure 11, Table 8**), this group appeared to be part of a pelagic population. This sighting and associated tag data provides further support for the suggestion that there is no island-associated population of pantropical spotted dolphins off Kauaʻi or Niʻihau, as there is off the other main Hawaiian Islands (Courbis et al. 2014). This was only the second time pantropical spotted dolphins have been satellite tagged off Kauaʻi, and the second (and third) tag deployments on individuals from the pelagic population, thus providing a considerable increase in what is known about movements of pelagic spotted dolphins in Hawaiian waters (**Figures 11 and 12**). In addition, acoustic recordings made during this encounter through the M3R system provide the first visually confirmed recordings of pantropical spotted dolphins on PMRF, providing a basis for assessing acoustic signals of this species that could be used for future acoustic monitoring of pantropical spotted dolphin presence and distribution on PMRF.

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

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6. Acknowledgements

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8. Figures

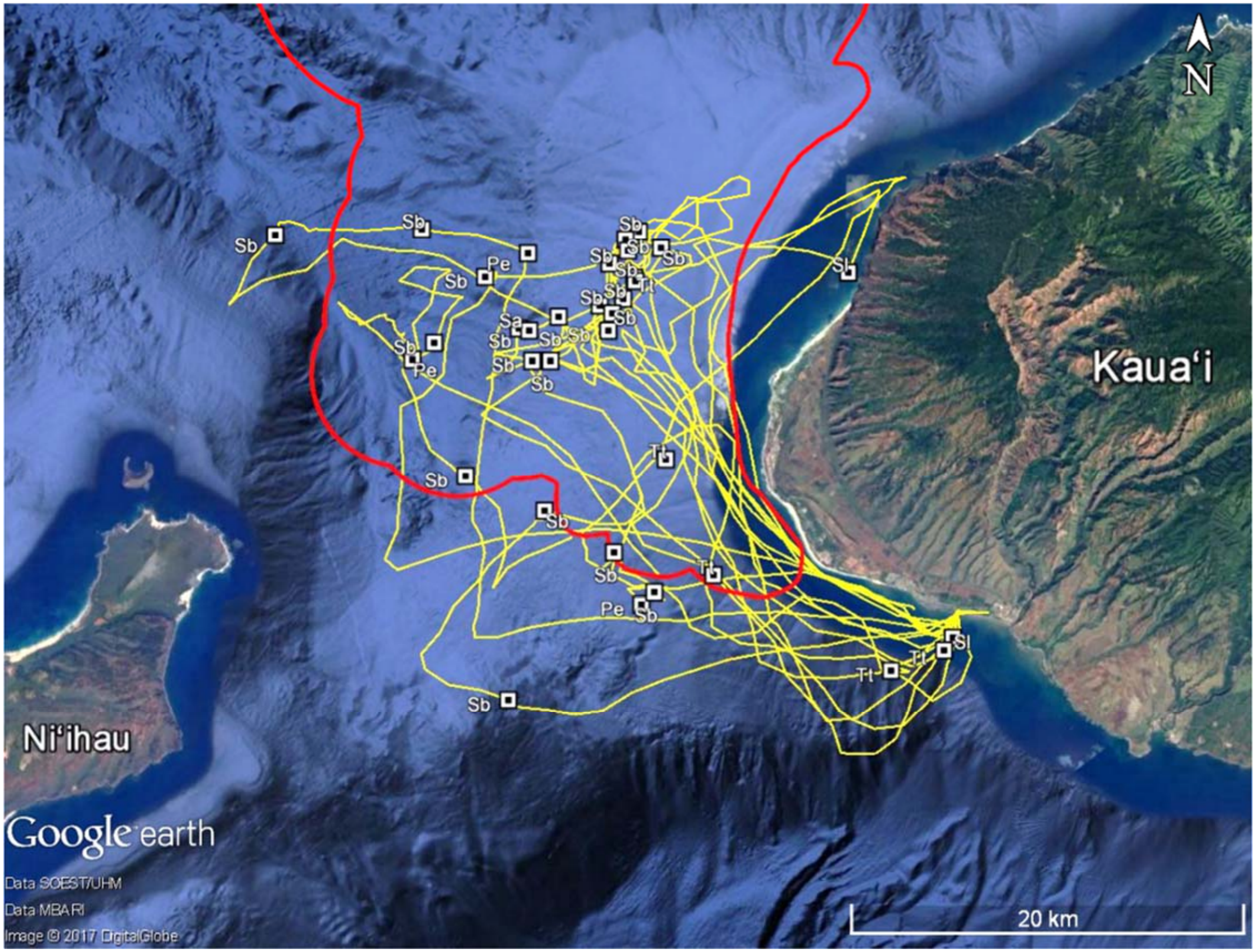


Figure 1. Search effort (yellow lines) and odontocete sightings (white squares) during 11 days of effort in August 2017. Species are indicated by two-letter codes (Sb = *Steno bredanensis*, Tt = *Tursiops truncatus*, Sl = *Stenella longirostris*, Pe = *Peponocephala electra*, Sa = *Stenella attenuata*). The PMRF outer boundary is indicated in red.

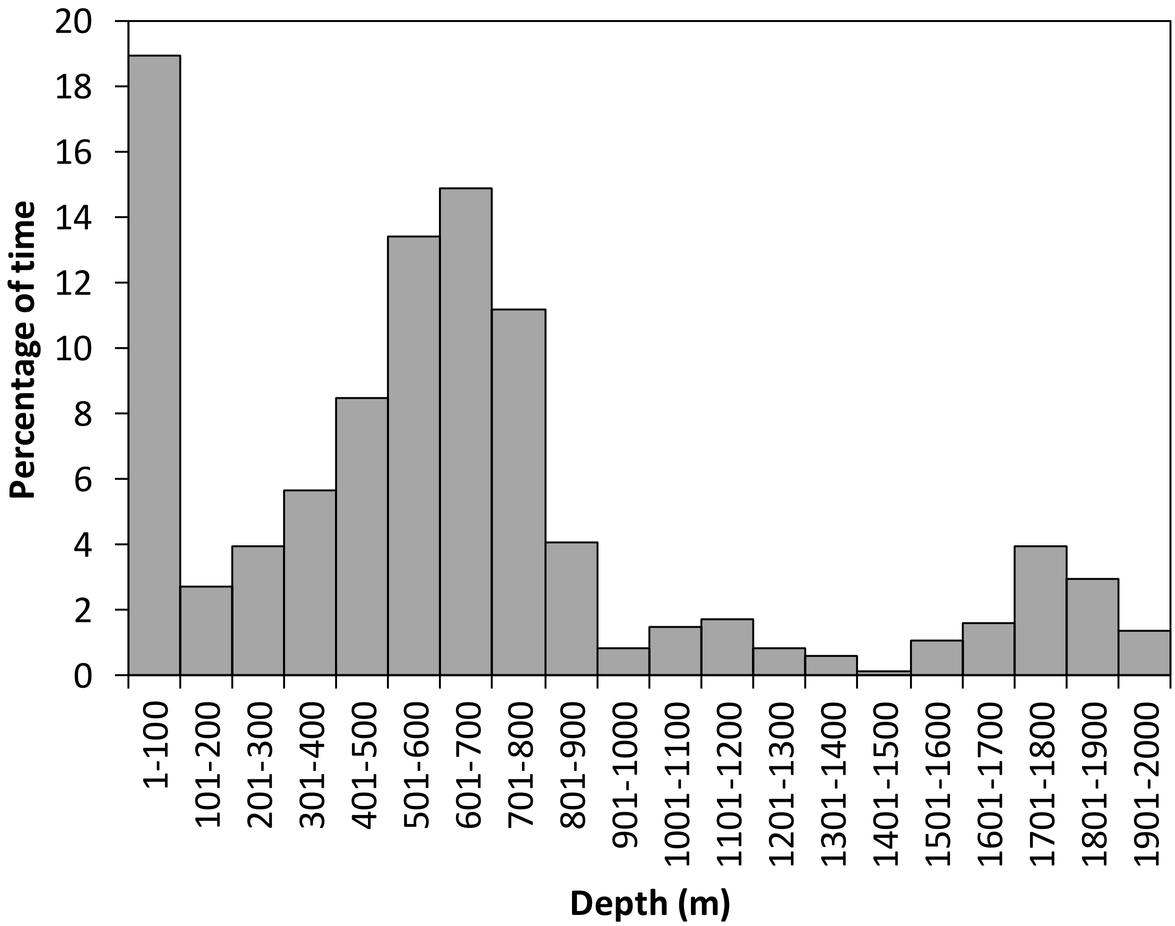


Figure 2. Depth distribution of small-vessel effort during August 2017 field effort.

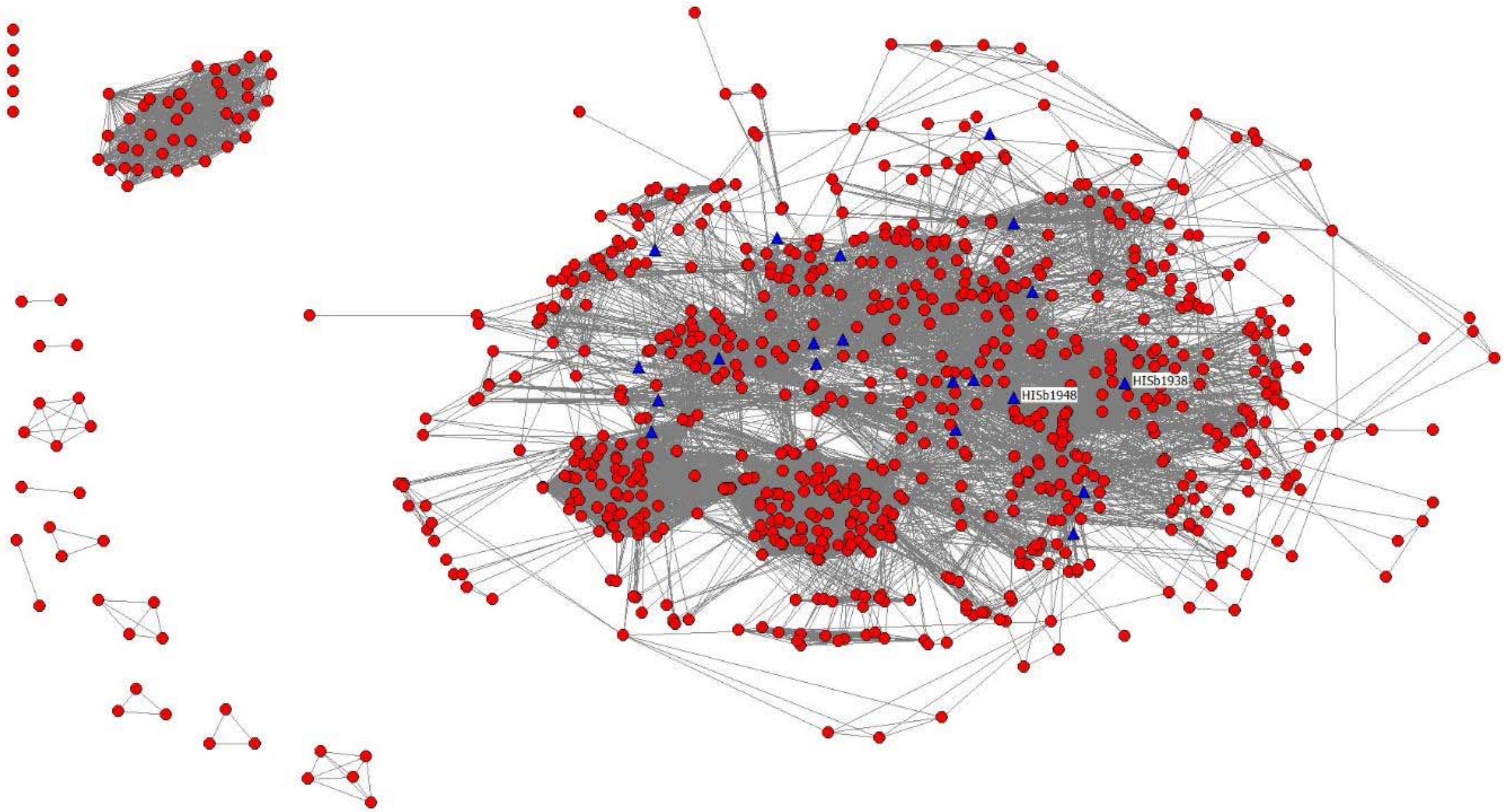


Figure 3. Social network of photo-identified rough-toothed dolphins off Kaua'i and Ni'ihau. All individuals tagged off Kaua'i and Ni'ihau (including those tagged in previous efforts) are noted by blue triangles. Those individuals tagged in August 2017 are indicated with ID labels. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2008), with a total of 852 individuals shown (the main cluster contains 775 individuals, 90.9% of all individuals). The lone points in the upper left corner of the figure are of individuals that have not been sighted with any others that meet the photo quality and distinctiveness criteria.

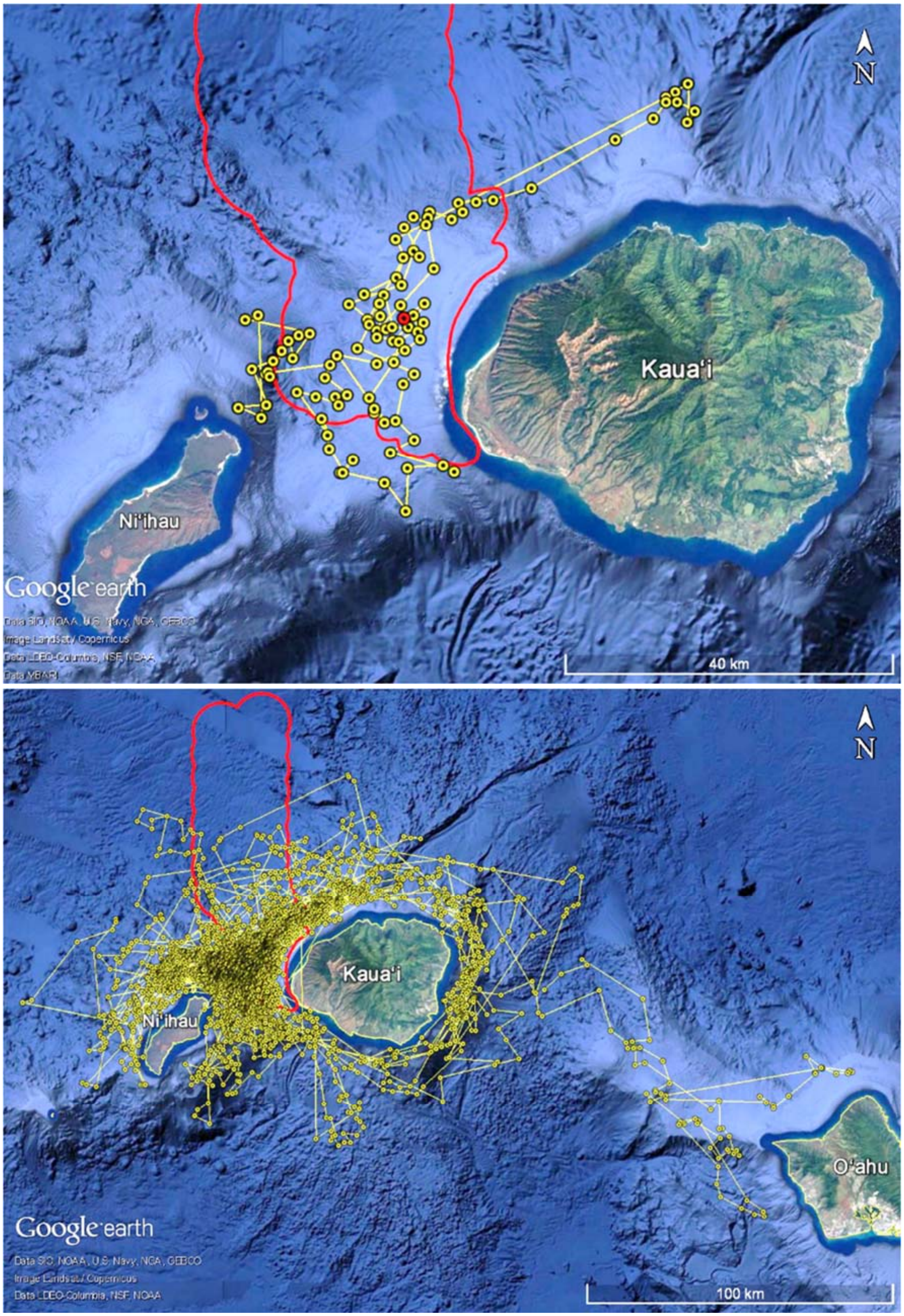


Figure 4. Top. Locations from rough-toothed dolphin SbTag019 tagged off Kaua'i in August 2017. Lines connect consecutive locations. Bottom. Locations from all 18 rough-toothed dolphin tag deployments off Kaua'i (2011–2017). The PMRF boundary is shown in red.

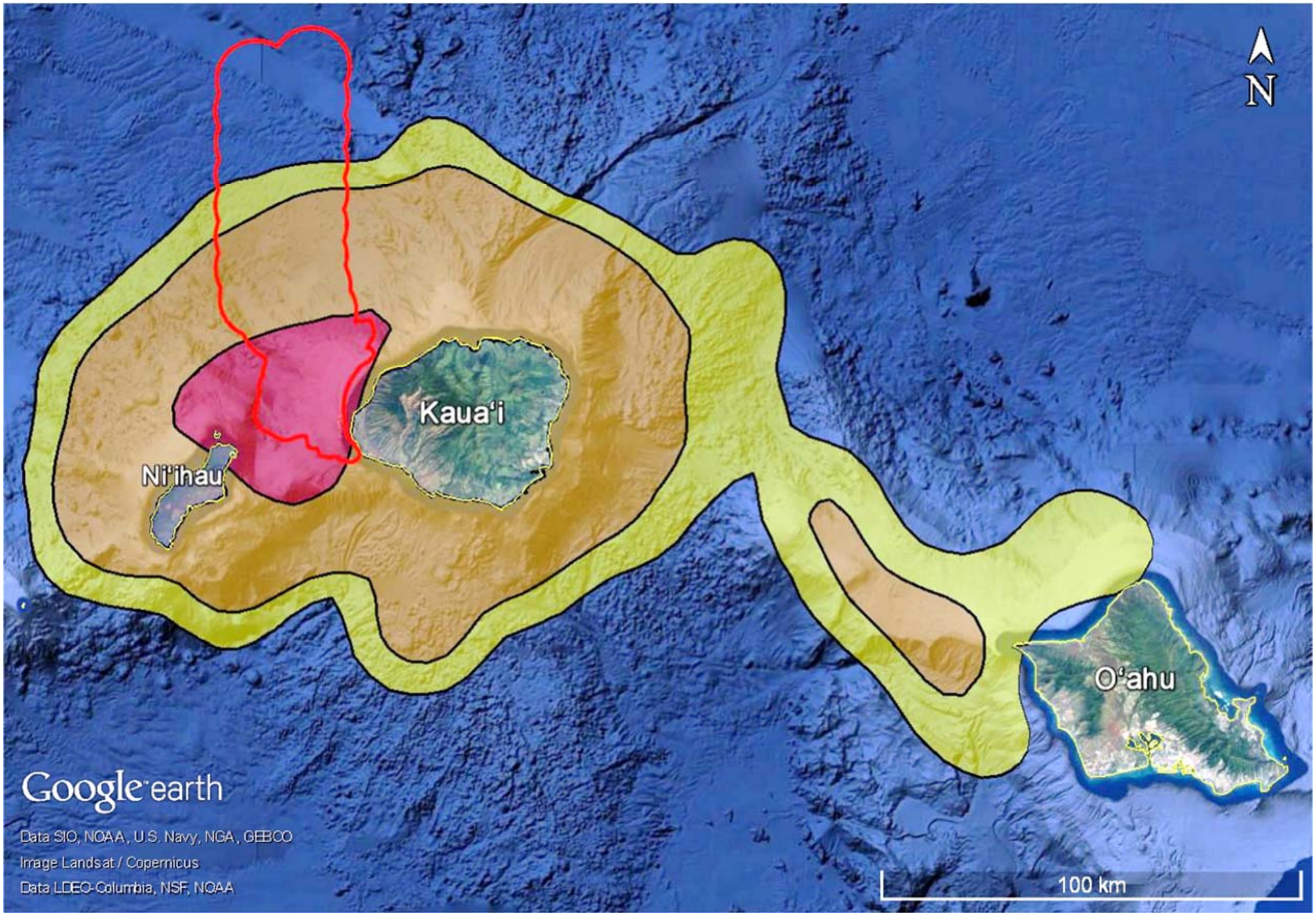


Figure 5. Probability density representation of rough-toothed dolphin location data from satellite tag deployments off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals with overlapping tag data that were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

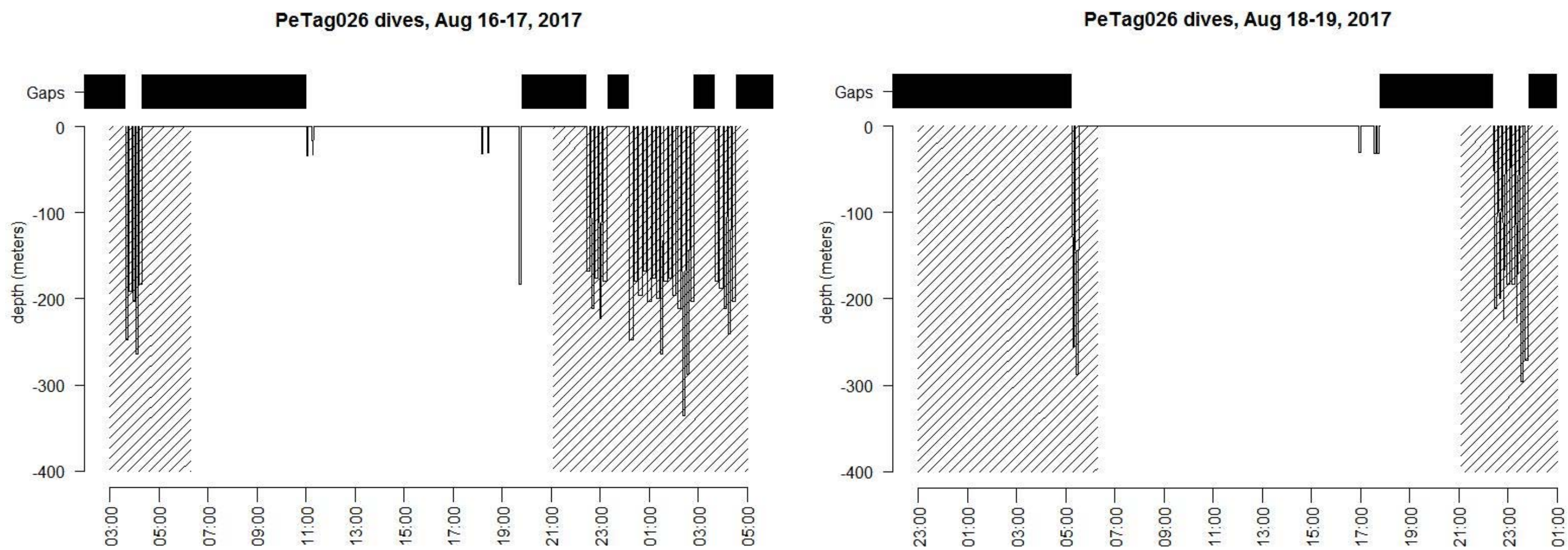


Figure 6. Dive data from melon-headed whale PeTag026 for the two periods with the least gaps in data. Times shown are in HST. Gaps in diving and surfacing data are shown in solid black bars at the top, and night-time periods are indicated by linear hatching. Note that when the animal is shallower than 30 m it is recorded as a "surface" period on the tag and is shown as a solid line at 0 m depth.

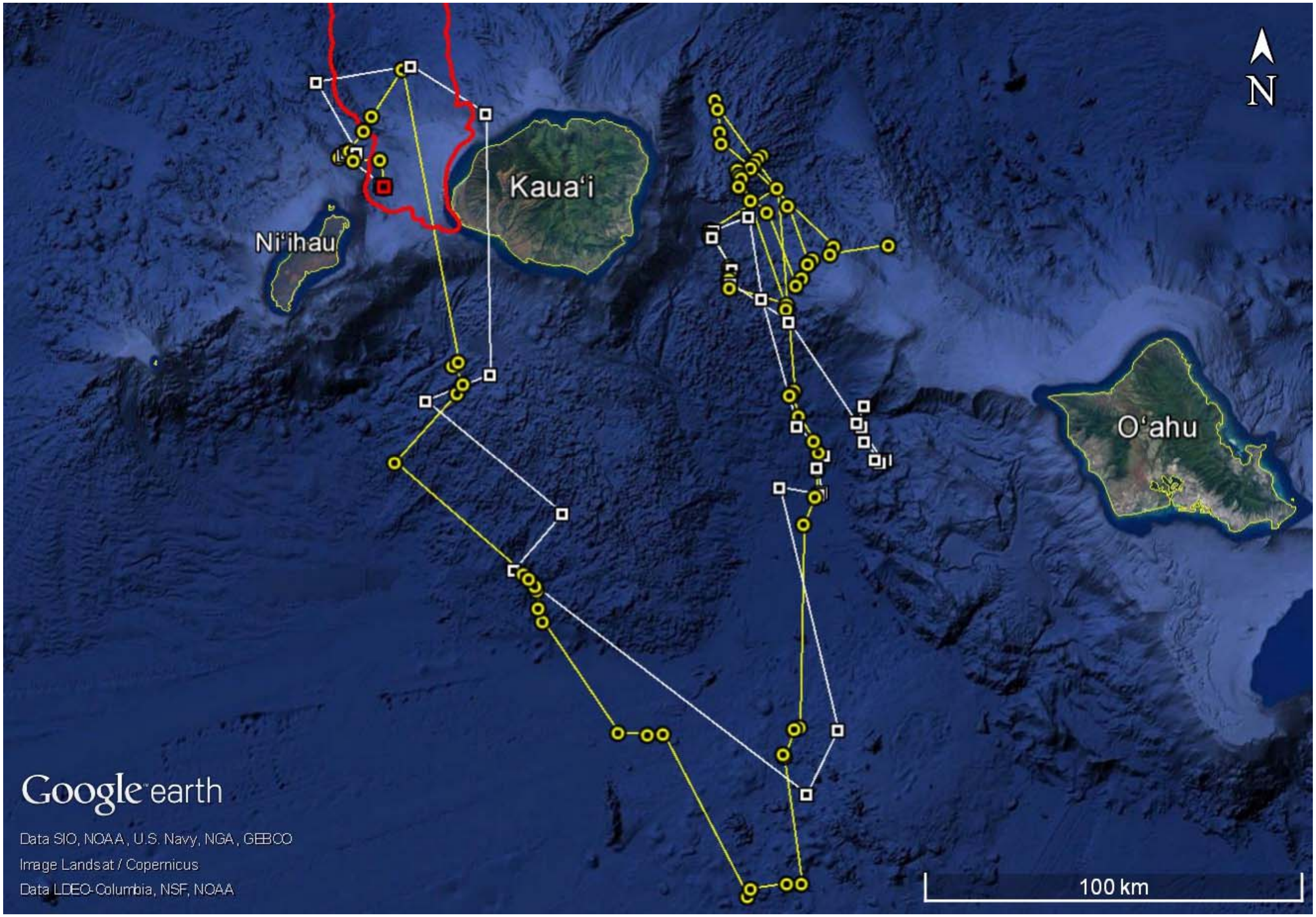


Figure 7. Movements of two satellite-tagged melon-headed whales (white squares – PeTag025; yellow circles - PeTag026) over an eight-day period from 13 to 21 August 2017. The tagging location is shown with a red circle, and consecutive locations are joined by lines. The PMRF boundary is outlined in red.

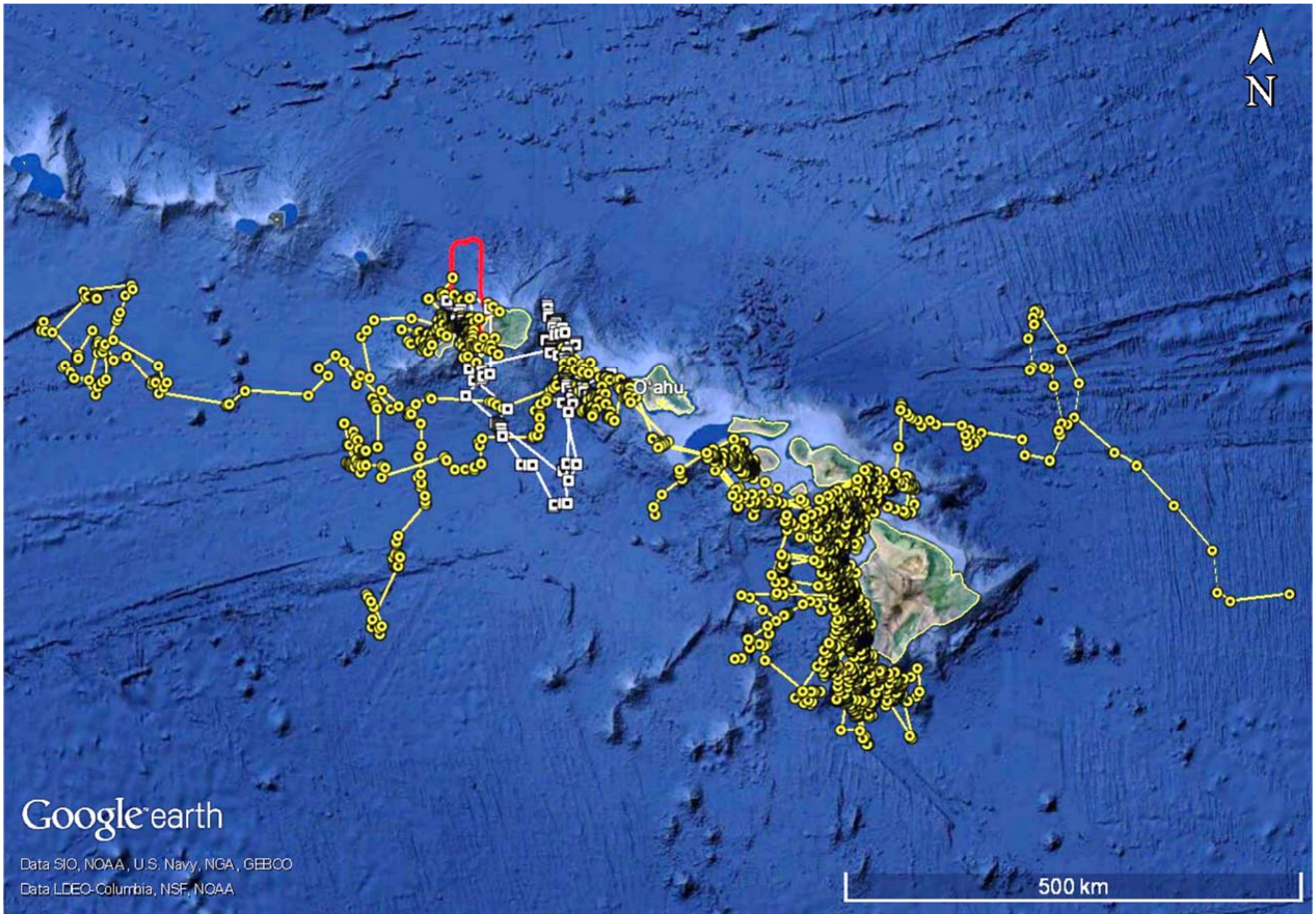


Figure 8. Locations of 17 melon-headed whales from the Hawaiian Islands population satellite tagged between April 2008 and August 2017, with lines connecting consecutive locations. Eleven individuals were tagged off Hawaiʻi Island (2008–2014), one was tagged off Lānaʻi (2012) and five were tagged off Kauaʻi (2008 and 2017). The two individuals tagged in August 2017 are shown in white. The PMRF boundary is shown as a solid red line.

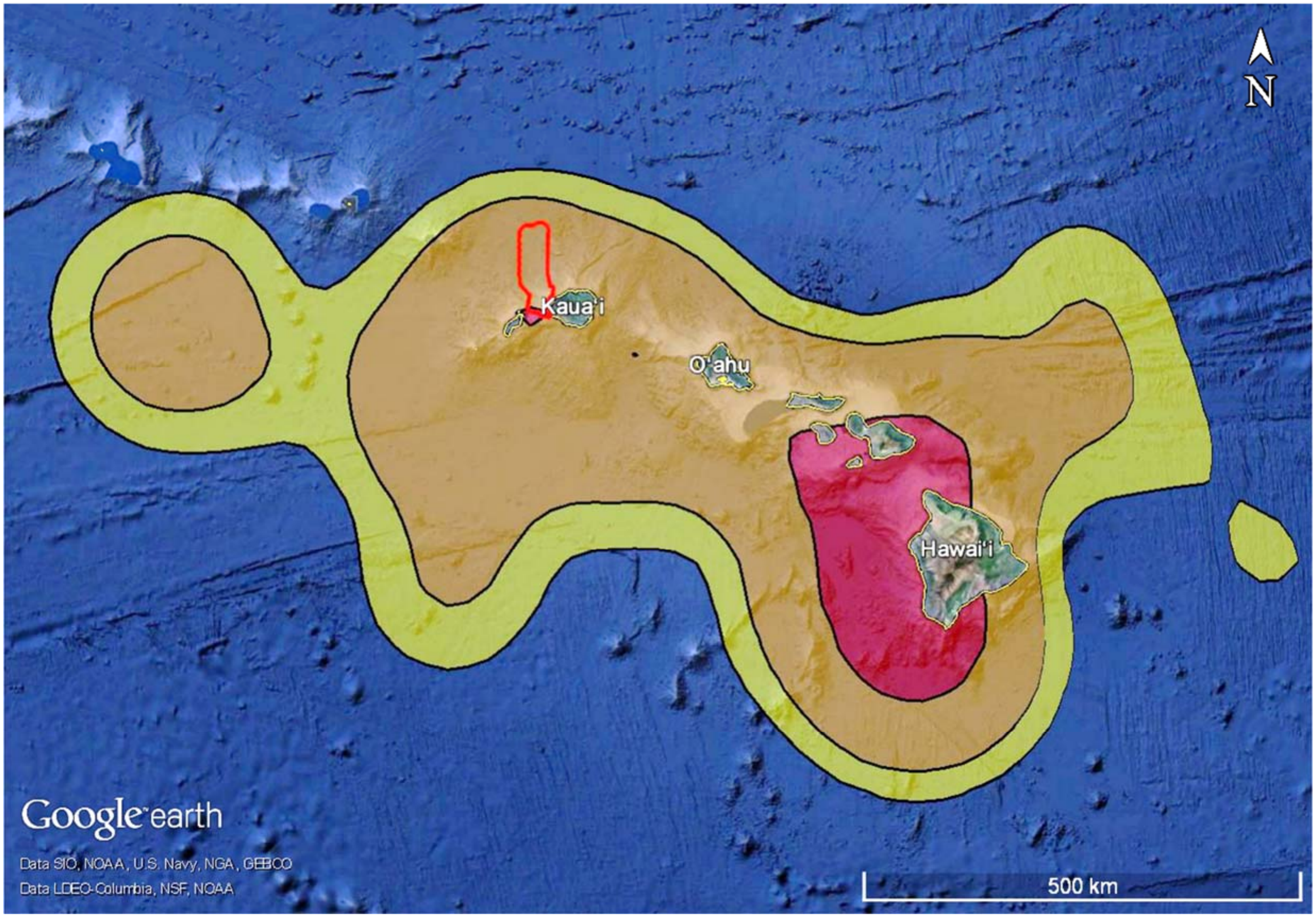
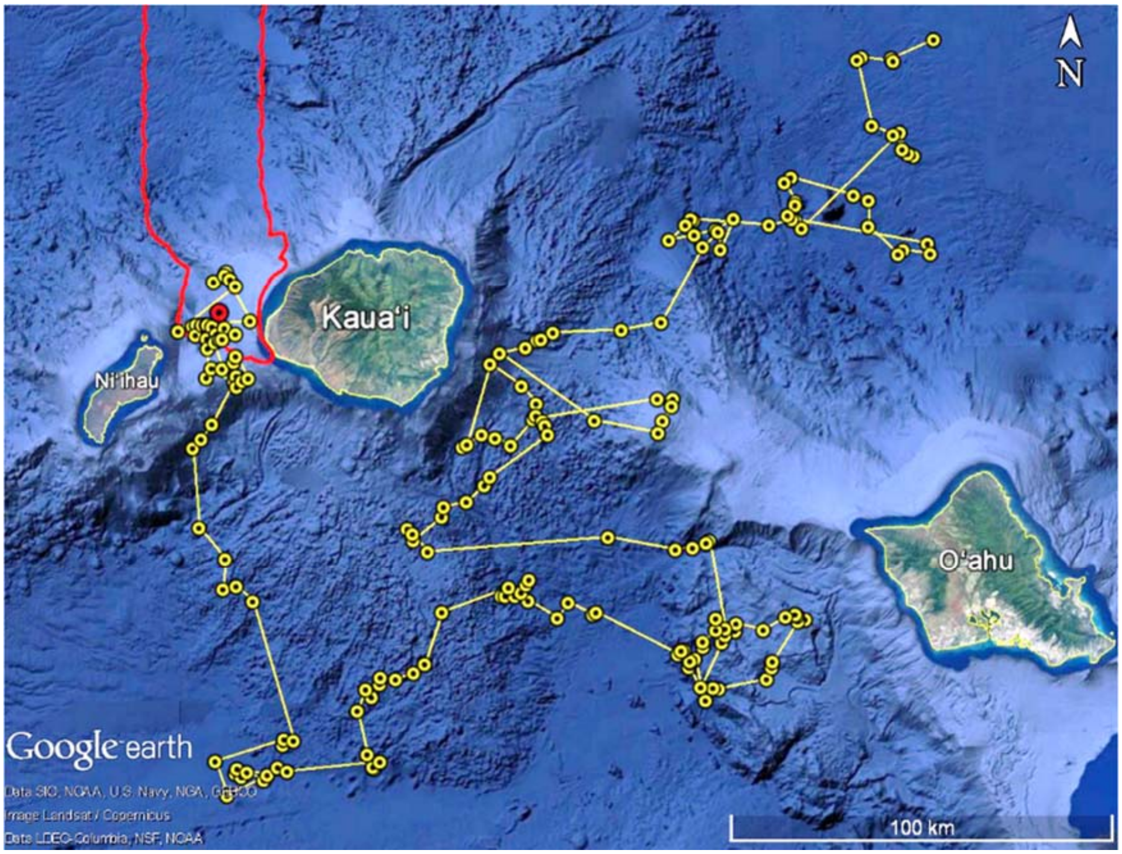


Figure 9. A probability density representation of melon-headed whale location data from 16 individuals from the Hawaiian Islands population (see Baird 2016). Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50% density polygon (the "core range"), the orange area represents the 95% polygon, and the light green represents the 99% polygon. The PMRF boundary is shown as a solid red line.

Figure 10. A melon-headed whale (background) and a hybrid between a melon-headed whale and a rough-toothed dolphin (foreground), photographed 11 August 2017 off Kaua'i.



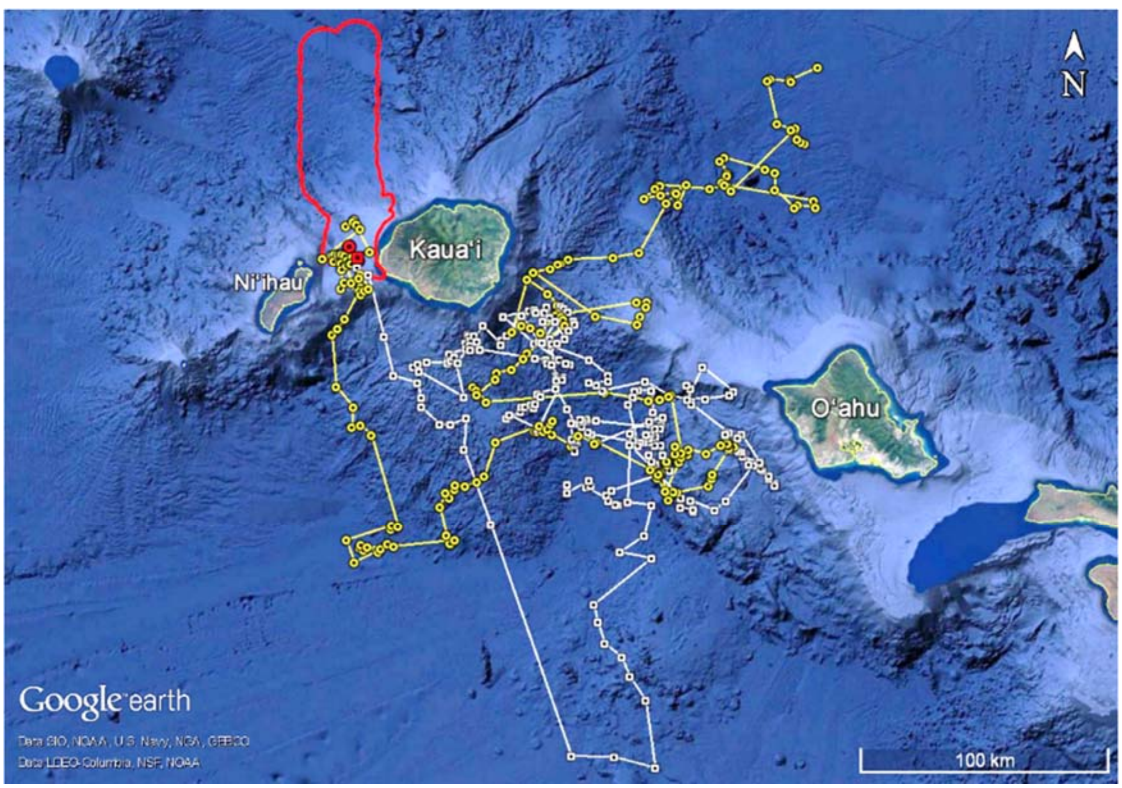


Figure 11. Top. Locations of pantropical spotted dolphin SaTag006 satellite tagged in August 2017, with consecutive locations joined by a line. Bottom. Locations of SaTag006 (yellow circles) and SaTag003 (white squares), tagged in February 2016. Tagging locations are indicated by red symbols. The boundary of PMRF is shown as a solid red line.

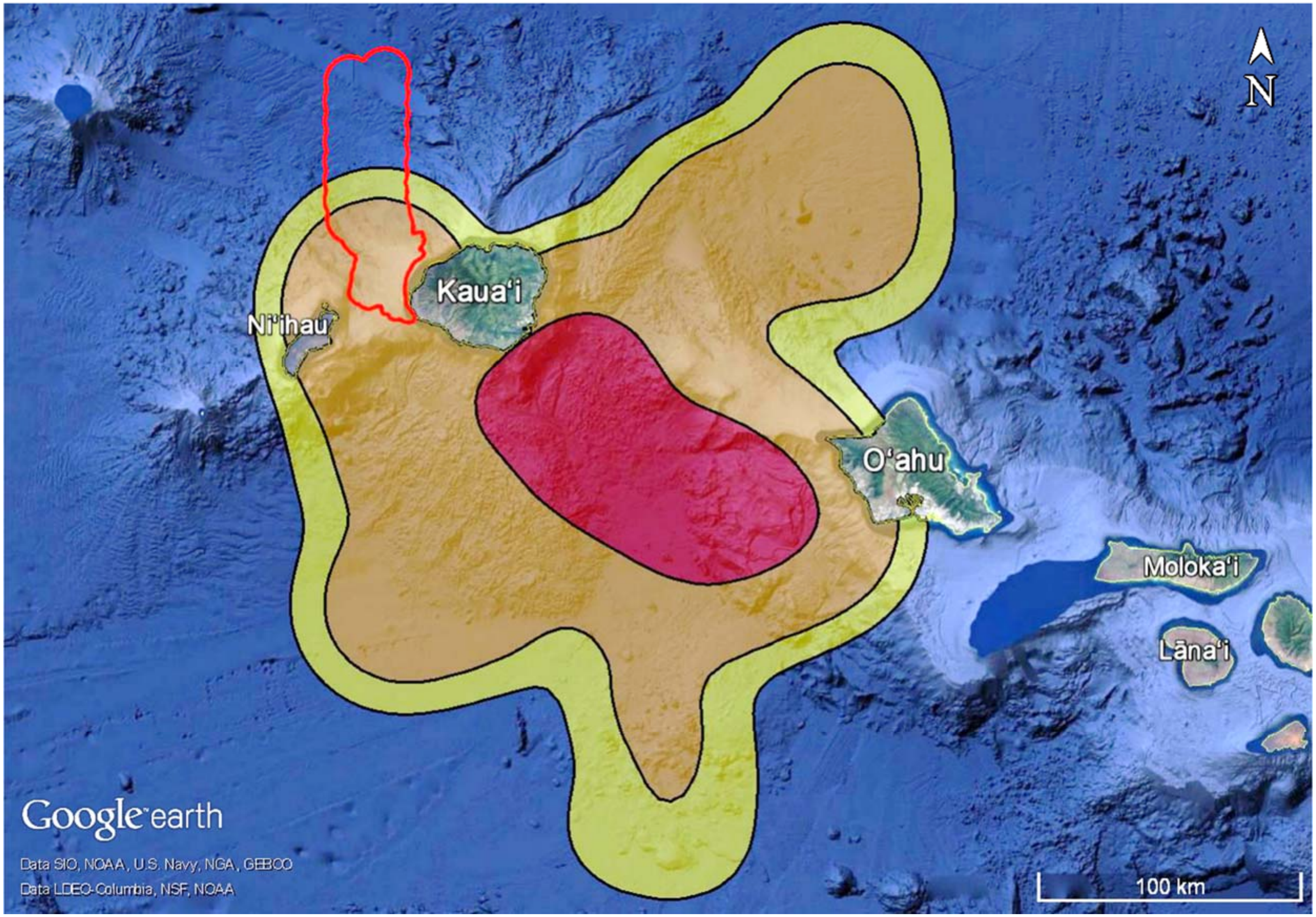


Figure 12. Kernel-density representation of pantropical spotted dolphin location data from two individuals satellite tagged off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50% density polygon (the "core range"), the orange area represents the 95% polygon, and the green represents the 99% polygon. The PMRF boundary is indicated by a solid red line.

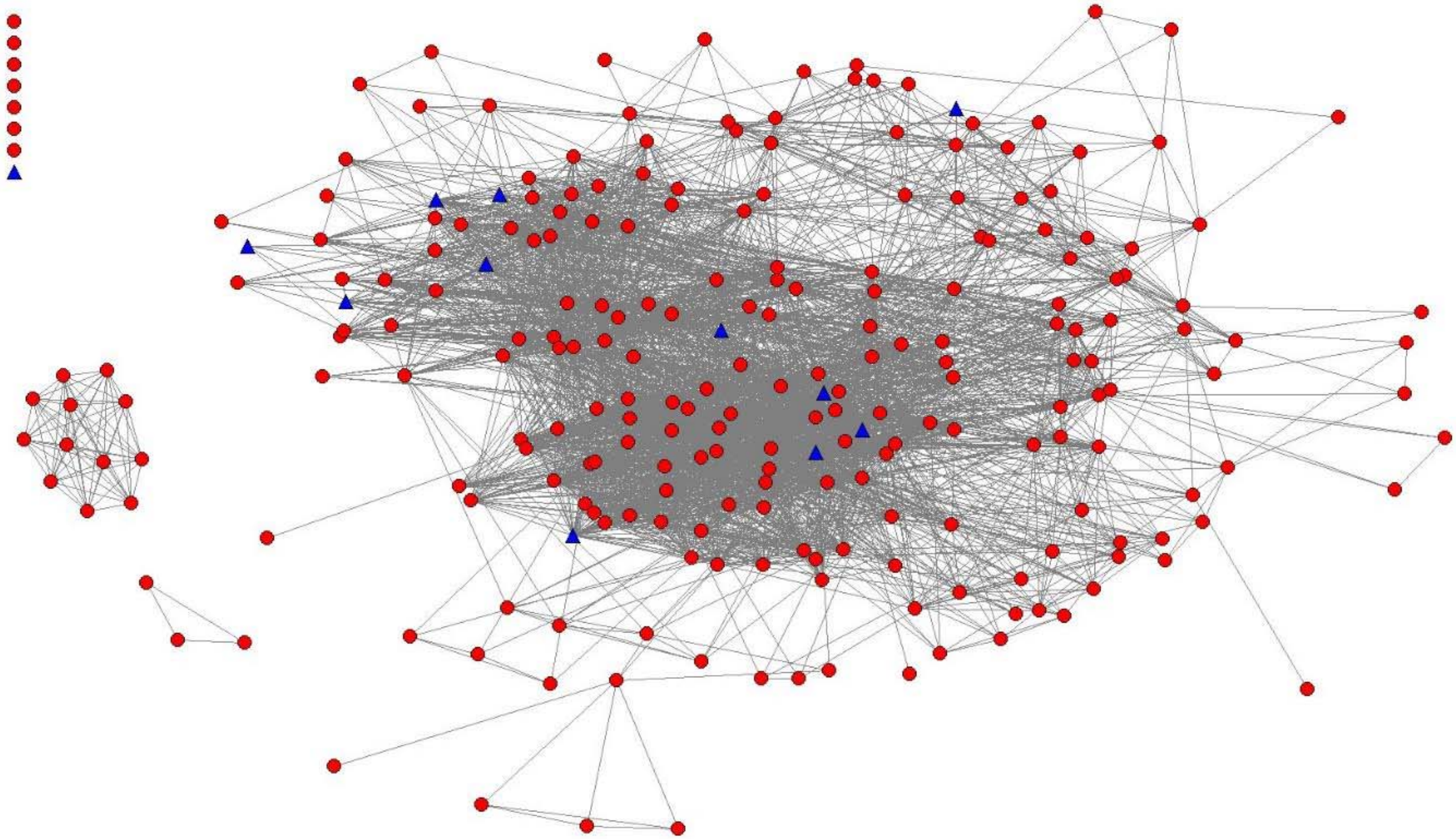


Figure 13. Social network of bottlenose dolphins photo-identified off Kaua'i and Ni'ihau including all individuals categorized as slightly distinctive, distinctive or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2009). Individuals that have been tagged in previous efforts are noted by blue triangles. A total of 247 individuals are shown, 224 (90.7%) in the main cluster. The cluster of 12 individuals on the left side and three of the singletons in the upper left were photographed off Ka'ula Island to the southwest of Ni'ihau. The lone points in the upper left corner of the figure are of individuals that have not been sighted with any others that meet the photo quality and distinctiveness criteria.

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9. Tables

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 (4), 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*
Total	**778.6**		*Gm* (27)[2], *Pe* (3), *Tt* (15), *Sb* (18), *Sa* (1), *Pc* (7), *Md (2)*[2], *Pm (1)*	

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

[2]One tag did not transmit for each species.

M3R = Marine Mammal Monitoring on Navy Ranges

Table 2. PMRF undersea range characteristics.

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

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

Table 3. Observations of acoustic features used for species identification and differentiation from passive acoustic monitoring during previous M3R field efforts.

Species[1]	# Visual Verifications	Whistle Features	Click Features	Distinctive Spectrogram Features	Acoustically Similar Species
Sb	30	8–12 kHz, short sweeps centered at ~10 kHz (typically very few whistles)	12–44 kHz with most energy 16-44 kHz	Short narrowband whistles centered at 10 kHz. Typically very few whistles but lots of dense 12–44 kHz clicks	*Pc* (whistles) *Sa* (clicks)
Sl	5	8–16 kHz, highly variable	8–48 kHz, distinct presence of 40-48 kHz click energy, single animal similar to *Zc*	HF click energy from 40 to 48 kHz. Loses LF click energy first. Long ICI for single species.	*Md, Zc* (clicks) *Tt* (whistles)
Sa	2	Steep 8-20 kHz up sweeps, sometimes ‘N’ or ‘^’ shaped	12–44 kHz with most energy above 24 kHz	Steepness of the up/down sweeps of whistles. Distinct sets of sweeps, up-down-up ‘N’ shape or up-down ^ shape	*Gm* (whistles) *Sb* (clicks)
Tt	25	primarily 8–24 kHz, highly variable, lots of loopy curves	16–48 kHz, short ICI	Density of clicks and whistles. Very wideband, long duration loopy whistles.	*Gm* *Sl* (whistles)
Gm	10	Combination of short 6–10 kHz upsweeps with long 10–24 kHz upsweeps	12–44 kHz, repetitive, slowly changing ICI	Very wide band but short duration whistles. Often single up or down sweeps.	*Tt* *Sa* (whistles)
Pc	4	5–8 kHz upsweeps, loopy whistles 8–12 kHz	8–48 kHz, most energy 8–32 kHz, continual presence of energy to 8 kHz	Click energy at 8 kHz, extending upwards to 32–40 kHz.	*Sb* (whistles), need to pay close attention to clicks to differentiate
Md	4	n/a	24–48 kHz, 0.33 s ICI	Consistent ICI and click frequency content.	*Sl* (clicks)

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

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

Table 4. August 2017 small-boat effort summary.

Date	Total km	Total Hours on Effort	Number of Odontocete Sightings Total	Depart Time HST	Return Time HST	Total km Beaufort 0	Total km Beaufort 1	Total km Beaufort 2	Total km Beaufort 3	Total km Beaufort 4–6
4 Aug 2017	102.0	6.3	1	6:31	12:54	0	18.2	55.1	18.2	10.5
5 Aug 2017	103.9	5.9	2	6:07	12:08	0	6.4	30.8	37.8	28.9
6 Aug 2017	87.9	6.5	1	6:09	12:38	0	0	47.3	36.8	3.8
7 Aug 2017	92.9	7.8	4	6:00	13:42	0	6.9	42.4	20.2	23.4
8 Aug 2017	112.0	7.5	5	6:02	13:35	0	0	86.8	12.7	12.5
9 Aug 2017	118.0	7.6	6	6:20	13:53	0	8.8	82.3	20.9	6.0
10 Aug 2017	104.0	8.1	5	6:10	14:17	0	1.6	63.7	15.0	23.7
11 Aug 2017	70.7	5.7	4	6:28	12:14	0	2.7	30.6	19.6	17.8
12 Aug 2017	94.1	5.5	1	6:08	11:34	0	0	24.7	39.3	30.1
13 Aug 2017	111.0	8.5	3	6:10	14:38	0	0	29.8	36.6	25.2
14 Aug 2017	120.0	8	3	6:01	13:59	0	0	31.3	15.9	53.8
Total	1113.10	77.4	35			0	44.6	524.8	273.0	274.1

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

Table 5. Odontocete sightings from small-boat effort during August 2017.

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	# Biopsy Samples Collected	On PMRF (yes/no)	# distinctive individuals photo-identified with good/excellent photos	# distinctive individuals previously photo-identified (excluding within-day)	Visual ID Position	
									Latitude (°N)	Longitude (°W)
04-Aug-17	10:22	Sb	8	0	0	yes	2	1	22.1179	159.8628
05-Aug-17	6:10	Sl	100	0	0	no	N/A	N/A	21.9474	159.6940
05-Aug-17	9:30	Sl	80	0	0	no	N/A	N/A	22.1137	159.7453
06-Aug-17	9:15	Sb	24	0	0	yes	5	3	22.1325	159.8484
07-Aug-17	6:10	Tt	2	0	0	no	0	0	21.9416	159.6984
07-Aug-17	8:25	Sb	20	1	0	yes	11	9	22.1289	159.8549
07-Aug-17	8:52	Pe	2	0	0	yes	2	0	22.1238	159.8537
07-Aug-17	11:37	Sb	5	0	0	yes	2	2	22.0736	159.8918
08-Aug-17	7:13	Tt	7	0	0	yes	3	3	21.9758	159.8117
08-Aug-17	8:42	Sb	22	0	0	yes	7	4	22.1018	159.8561
08-Aug-17	9:41	Sb	7	0	0	yes	0	0	22.0736	159.9008
08-Aug-17	10:48	Sb	9	0	0	yes	2	1	22.0052	159.8947
08-Aug-17	12:00	Sb	10	0	0	no	3	3	21.9190	159.9125
09-Aug-17	8:28	Sb	1	0	0	yes	1	1	22.0936	159.8878
09-Aug-17	8:41	Sb	5	0	0	yes	2	2	22.0987	159.8676
09-Aug-17	9:01	Sb	42	1	0	yes	36	23	22.1114	159.8506
09-Aug-17	9:12	Tt	3	0	0	yes	1	1	22.1098	159.8500
09-Aug-17	10:46	Sb	3	0	0	yes	2	1	22.1251	159.8374
09-Aug-17	11:30	Sb	15	0	0	yes	9	8	22.1117	159.9239
10-Aug-17	9:47	Sb	3	0	0	yes	2	1	22.0873	159.8633
10-Aug-17	9:59	Sb	18	0	0	yes	3	3	22.0951	159.8614
10-Aug-17	10:48	Sb	3	0	0	yes	1	0	22.0873	159.9023
10-Aug-17	10:55	Sa	50	2	1	yes	N/A	N/A	22.0883	159.9074
10-Aug-17	13:17	Tt	9	0	0	yes	6	5	22.0288	159.8351
11-Aug-17	6:54	Tt	12	0	0	no	2	2	21.9324	159.7244
11-Aug-17	9:22	Sb	2	0	0	yes	0	0	21.9862	159.8606

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	# Biopsy Samples Collected	On PMRF (yes/no)	# distinctive individuals photo-identified with good/excellent photos	# distinctive individuals previously photo-identified (excluding within-day)	Visual ID Position	
									Latitude (°N)	Longitude (°W)
11-Aug-17	9:45	Sb	28	0	1	no	13	9	21.9681	159.8408
11-Aug-17	10:27	Pe	2	0	1	no	2	2	21.9625	159.8471
13-Aug-17	8:22	Sb	3	0	0	yes	1	1	22.0211	159.9335
13-Aug-17	10:13	Sb	5	0	0	yes	9	9	22.0817	159.9490
13-Aug-17	10:24	Pe	300	2	0	yes	N/A	N/A	22.0742	159.9597
14-Aug-17	9:30	Sb	3	0	0	no	0	0	22.1309	160.0273
14-Aug-17	10:16	Sb	4	0	0	yes	0	0	22.1336	159.9552
14-Aug-17	10:31	Pe	200	0	0	yes	N/A	N/A	22.1226	159.9029

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

Table 6. Details on satellite tags deployed during August 2017 field effort.

Species[1]	Tag ID	Individual ID	Date Tagged	Sighting #	Duration of Signal Contact (days)	Latitude (°N)	Longitude (°W)	Tag Type	Sex
Sa	SaTag006	N/A	10-Aug-17	1	13.99	22.08	159.90	SPOT6	Unknown
Sa	SaTag007	N/A	10-Aug-17	5	3.33	22.06	159.93	Mk10A	Unknown
Sb	SbTag019	HISb1948	7-Aug-17	1	6.40	22.13	159.86	SPOT6	Unknown
Sb	SbTag020	HISb1938	9-Aug-17	3	0	22.11	159.85	Mk10A	Unknown
Pe	PeTag025	N/A	13-Aug-17	3	6.47	22.07	159.96	Mk10A	Unknown
Pe	PeTag026	N/A	13-Aug-17	3	7.44	22.08	159.96	Mk10A	Unknown

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

Table 7. Details on previous sighting histories of individual rough-toothed dolphins satellite tagged in August 2017.

Individual ID	Date First Seen	# Times Seen Previously	# Years Seen Previously	Islands Seen Previously
HISb1938	13-Oct-14	1	1	Kaua‘i
HISb1948	17-Oct-14	2	2	Kaua‘i

ID = identification; # = number.

Table 8. Information from GIS analysis of satellite-tag location data from August 2017 field efforts.

Tag ID	# Locations	# Periods Inside PMRF Boundaries	% Time Inside PMRF Boundaries	Total Minimum Distance Moved (km)	Median/Maximum Distance from Deployment Location (km)	Median/ Maximum Depth (m)	Median/ Maximum Distance from Shore (km)
SaTag006	185	4	11.9	1,307.1	116.2/199.1	3,603/4,970	52.8/112.5
SaTag007	30	5	43.9	279.2	10.5/130.4	814/4,668	13.3/97.8
SbTag019	97	6	68.9	373.4	12.5/44.7	796/2,125	12.0/17.4
PeTag025	38	2	7.5	619.5	100.1/193.1	3,182/4,756	44.1/108.8
PeTag026	73	2	7.6	786	105.8/212.1	3,053/4,765	44.3/138.4

ID = identification; km = kilometers; m = meters; # = number; % = percent.

Table 9. Dive information from satellite tags deployed during August 2017 field efforts.

Tag ID	# Hours Data	# Dives ≥ 30 m	Dives per hour	Median Dive Depth (m) for Dives ≥ 30 m	Maximum Dive Depth (m)	Median Dive Duration[1] (min)	Maximum Dive Duration[1] (min)
PeTag026	30.4	65	2.14	207.5	335.5	7.67	9.67

[1]Duration of dives underestimated because time spent in top 3 m not included. Typical rates of ascent/descent are in the 1–2 m/second range, so durations are likely only underestimated by 3-6 seconds. No dive data were available for SaTag007, SbTag020, or PeTag025.

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

Table 10. Areas within 50% ("core range"), 95% and 99% isopleths based on kernel density analyses of satellite tag data, excluding the first day of locations and using only a single individual from any pair when individuals were acting in concert. Results from species tagged off Kaua'i from previous field projects (bottlenose dolphins, short-finned pilot whales, from Baird et al. 2017a) included for comparison.

Species/population	Area (square kilometers) within selected isopleths based on kernel density		
	50%	95%	99%
Bottlenose dolphin	1,173	7,216	12,246
Rough-toothed dolphin	1,450	12,821	20,155
Pantropical spotted dolphin – pelagic population	7,675	36,073	52,558
Melon-headed whales – Hawaiian islands population	40,744	317,376	492,729
Short-finned pilot whale – insular population	9,062	56,006	87,778
Short-finned pilot whale – pelagic population	111,135	524,071	695,419

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