Final Report

Odontocete Studies on the Pacific Missile Range Facility in February 2016: Satellite-Tagging, Photo-Identification, and Passive Acoustic Monitoring

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Pantropical spotted dolphin (*Stenella attenuata*) off Kauaʻi. Photograph taken by Kimberly A. Wood under National Marine Fisheries Service permit no. 15330.

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Acronyms and Abbreviations

BARSTUR	Barking Sands Tactical Underwater Range
BSURE	Barking Sands Underwater Range Expansion
CRC	Cascadia Research Collective
FFT	Fast Fourier Transform
h	hour
Hz	Hertz
kHz	kilohertz
km	kilometer(s)
km^2	square kilometer(s)
m	meter(s)
M3R	Marine Mammal Monitoring on Navy Ranges
MFA	mid-frequency active
PAM	passive acoustic monitoring
PMRF	Pacific Missile Range Facility
RHIB	rigid-hulled inflatable boat
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 February 2016 a combining boat-based field effort and passive acoustic monitoring was carried out on and around the Pacific Missile Range Facility (PMRF). The U.S. Navy funded five days of small-boat effort and the National Marine Fisheries Service funded an additional two days of effort. There were 859 kilometers (49 hours) of small-vessel survey effort over the course of the seven-day project. There were 20 sightings of four species of odontocetes, six of which were directed by acoustic detections using the Marine Mammal Monitoring on Navy Ranges (M3R) system. Bottlenose dolphins (*Tursiops truncatus*) were encountered on five occasions, short-finned pilot whales (*Globicephala macrorhynchus*) on six, rough-toothed dolphins (*Steno bredanensis*) on eight, and pantropical spotted dolphins (*Stenella attenuata*) once. This was the first sighting of pantropical spotted dolphins on PMRF as part of Cascadia Research Collective (CRC) small-boat efforts, and only the 10th sighting off Kauaʻi or Niʻihau since effort began in 2003. During the encounters, we took 16,806 photographs for individual identification, with photographs added to long-term CRC regional photo-identification catalogs for bottlenose dolphins, short-finned pilot whales and rough-toothed dolphins. Individual identifications were used in social network analyses to help elucidate population structure of these species relative to results from satellite tagging. One biopsy sample was obtained from a pantropical spotted dolphin, with the sample contributed to the long-term tissue archive at the Southwest Fisheries Science Center as well as used for genetic analyses through Portland State University. Nine satellite tags were deployed on three species—six short-finned pilot whales (from four different social groups), two rough-toothed dolphins, and one pantropical spotted dolphin. In addition, information from tag deployments on two short-finned pilot whales, one rough-toothed dolphin, and one bottlenose dolphin, tagged in September 2015 as part of a CRC project funded through the Living Marine Resources program, were included in the analyses. The pantropical spotted dolphin was thought to be from the pelagic population, and the tagged individual ranged widely offshore to the south of Kauaʻi. All of the tagged rough-toothed dolphins and the bottlenose dolphin remained associated with the island of Kauaʻi and Niʻihau for the duration of the tag attachments. Based on photo-identification and social network analyses, all were part of groups known to be resident to the islands. Probability-density analyses of all tag-location data obtained for bottlenose dolphins and rough-toothed dolphins tagged off Kauaʻi since 2011 indicate that core ranges (i.e., the 50 percent kernel density polygons) are relatively small (1,173 and 1,535 square kilometers [km^2]). Tag data were available from five different social groups of short-finned pilot whales, one presumed to be from the pelagic population and four from the insular population, based on re-sighting histories and social network analyses. Probability-density analyses were undertaken separately for 17 resident short-finned pilot whales tagged off Kauaʻi since 2008, and for six pilot whales tagged off Kauaʻi and Oʻahu thought to be from the pelagic population. Core range for the pelagic population was more than 10 times larger (111,135 km^2) than for the resident population (9,062 km^2), and the overall range (using the 99 percent kernel density isopleth) was almost an order of magnitude larger for the pelagic population (695,419 km^2). This suggests that the likelihood of exposure to mid-frequency active sonar on the PMRF varies substantially between the two populations. Continued collection of photo-identification, movement and habitat-use data from all species should allow for a better understanding of the use of the range and surrounding areas, provide datasets that can be used to estimate received

sound levels at animal locations and examine potential responses to exposure, as well as estimate abundance and examine 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 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 relatively small size of the island and its orientation relative to prevailing trade winds result in a very 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 of the 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). CRC efforts using satellite tags to assess movements and behavior of individual toothed whales on and around PMRF were first begun 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 February 2016, CRC has had 10 additional vessel-based field projects off Kaua'i, nine in conjunction with passive acoustic monitoring (PAM) through the Marine Mammal Monitoring on Navy Ranges (M3R) program. M3R is a real-time PAM system implemented at three major Navy undersea training ranges: the Atlantic Undersea Test and Evaluation Center (2002–present, see Morrissey et al. 2006), the Southern California Offshore Range (2006–present, see Falcone et al. 2009), and most recently at PMRF (2011–present). During these 10 field efforts, 59 satellite tags were deployed on six different species of odontocete cetaceans (**Table 1**; Baird et al. 2011, 2012a, 2012b, 2013b, 2013c, 2014a, 2015, 2016). Results of field efforts through February 2015 have been previously summarized (Baird et al. 2016; Baird 2016).

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 Commanders Course in February 2016. Two additional days of effort were also undertaken, funded by a grant from the Pacific Islands Fisheries Science Center 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 February 2016 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, funding for analyses of received levels and potential responses was not received under this contract. 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 February 2016, we incorporate previous efforts, including results from a CRC vessel-based field effort off Kauaʻi in September 2015, supported by the Navy's Living Marine Resources program. As well as addressing specific Navy monitoring questions and increasing the general understanding of odontocete populations off Kauaʻi and Niʻihau, 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 Undersea Acoustic Range

The PMRF instrumented hydrophone range is configured with 219 bottom-mounted hydrophones, 199 of which are available for PAM. They 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 are partially overlapping, but SWTR is located in the shallow waters of the southeast part of the range spanning approximately 30 km north to south and varying from about 6 to about 12 km east to west. BARSTUR is located in the southwest 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 consists of specialized signal-processing hardware and detection, classification, localization, and display software that provide a user-friendly interface for real-time PAM, discussed in detail in Jarvis et al. (2014). Prior to 2016, the M3R system at PMRF was used on nine occasions (**Table 1**) in collaboration with vessel-based field efforts. This combination approach provides visual species verifications for groups detected acoustically, as well as visual sightings of animals on the range that have not 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 whales 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, so in some cases only the general area where individuals are vocalizing can be used for attempting at-sea species verifications. Sperm whales are more readily localized since the source level of their clicks has been measured at well over 200 dB (Mohl et al. 2000). Therefore, each click is typically detected on multiple range hydrophones. Detection reports with classification for selected species are produced and archived. These data are used in combination with time and 2-D and 3-D spectrogram displays to monitor multiple hydrophones and to help identify the species. For individual hydrophones, analysis software including Raven and Ishmael have been integrated into the M3R system and are available for real-time monitoring. Certain species such as Blainville's beaked whales produce distinct echolocation clicks at known repetition rates that allow reliable classification. Other small odontocete vocalizations are classified but with a high degree of uncertainty. SPAWAR low frequency (>3 kHz) detection algorithms have been integrated and assist the analyst to detect and localize several mysticete species. Classification may be to the species or guild level depending on the animal in question. Hydrophones are sampled at 96 kilohertz (kHz), providing an analysis bandwidth of 48 kHz. A Fast Fourier Transform (FFT) detection algorithm is run. A 2048-point FFT with a 50% overlap is run in real-time. 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 classified first by type (whistle or click). Clicks are further categorized, based on the hard-limited FFT 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. Additional Support Vector Machine-based classifiers are also being tested with a focus on Blainville's (*Mesoplodon densirostris*) and Cuvier's beaked whales (*Ziphius cavirostris*). The basic FFT-based detector adjusted for low-frequency baleen whale calls runs in parallel. It provides an analysis bandwidth of 3 kHz and a frequency bin resolution of 1.46 Hertz (Hz).

These broad automatic classifications are further refined using MMAMMAL real-time display software. MMAMMAL displays a color-coded map of the hydrophones indicating the level of detection activity for each hydrophone. The hydrophone color code indicates the number of standard deviations each hydrophone is above the mean detection rate of all the hydrophones. The PAM user can select hydrophones from the map based on detection activity and display a real-time, hard-limited FFT-based spectrogram. These spectrograms are used by trained PAM personnel to classify the whistles and clicks to species level when possible. Prior to the February 2016 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*), and Blainville's beaked whale. 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 visually identified and noted to aid in providing initial discrimination between species (**Table 3**). However, due to 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 frequency segmentationbased whale type similar to MMAMMAL. 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. Due to 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 clicks was also used. When the same click or whistle is visually observed on three or more hydrophones, the user can mark the time-of-arrival on each. These times are then used in a localization algorithm to estimate the animal's position. This tool was most often used on bottlenose dolphin (indicated *Tt*) whistles to give the at-sea team a posit (within approximately 100 meters [m]) of a vocalizing individual. 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.

The Raven signal-analysis package (Cornell Laboratory of Ornithology, Ithaca, New York) was also used for real-time analysis. An M3R interface module was added to the program, which allows selection of individual or small numbers of hydrophones for examination. The software analyzes selected hydrophone signals when questions arise as to signal type and origin. This is particularly useful for verifying the presence of beaked whale vocalizations, and for collecting time and frequency images and broadband cuts of selected signals.

Detection archives were collected from all hydrophones for the entire period, 24 hours per day. These archives capture all detection reports and automated localizations generated during the effort. Data post-processing is expedited by using the detection archives, which allow rapid evaluation of detections over long periods of time. Additionally, raw hydrophone data are recorded using the recently installed M3R 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 199 hydrophones.

Specific software tools have been developed for the automated isolation of Blainville's beaked whale click trains; a second tool then marks the position of individual foraging dives. These tools are being 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 will be possible (Moretti et al. 2010).

2.3 Coordination with Small-vessel Efforts

PAM was undertaken for five[1] of the seven days of small-vessel research effort. PAM began at 0630 every morning and continued until the research vessel left the range, either to return directly to port or 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 was closed. 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 range of 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 the group of interest was radioed back to the PAM team, this group was then followed closely using the M3R system by the PAM team, and an attempt was made to provide an updated position. 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 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 in the context of providing information for the next cycle.

[1]The PAM monitoring and coordination with the research vessel was undertaken for all five of the days funded by the Marine Species Monitoring Program.

3. Small Vessel Field Methods

3.1 Tag Types and Programming

Ten satellite tags were funded through the Marine Species Monitoring Program, including eight location-dive tags (Wildlife Computers Mk10-A) and two location-only tags (Wildlife Computers SPOT5), and three tags (two location-dive tags and one location-only 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 and pantropical spotted dolphins, long darts for short-finned pilot whales).

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. Location-dive tags programmed for short-finned pilot whales transmitted 17 hours/day with a maximum of 700 transmissions a day, giving an estimated battery life of approximately 25 days. Location-dive tags programmed for rough-toothed dolphins and pantropical spotted dolphins transmitted for 15 hours/day with a maximum of 700 transmissions per day, giving an estimated battery life of approximately 25 days. Location-dive tags were set to record a time series (recording depth once every 1.25 minutes for dolphins and once every 2.5 minutes for short-finned pilot whales), as well as dive statistics (start and end time, maximum depth, duration) for any dives greater than 30 m in depth, with depth readings of 3 m being used to determine the start and end of dives, thus dive durations are slightly negatively biased. Given typical odontocete descent and ascent rates of 1 to 2 m/second, dive durations recorded are likely only 3 to 6 seconds shorter than actual dive durations. Prior to the field effort, satellite passes were predicted using the Argos website to determine the best hours of the day for transmissions given satellite overpasses for the approximately 2-month period starting at the beginning of the deployment period.

A shore-based Argos receiver station was set up on Mākaha Ridge, Kauaʻi, 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. The antennas were at a 456-m elevation, one oriented to the north and one oriented to the southwest.

3.2 Vessel, Time and Area of Operations

The field project was timed to occur immediately prior to a Submarine Commanders Course scheduled for mid-February 2016. Five days of effort were funded as part of the Navy's Marine Species Monitoring program, and an additional two days of effort prior to the five days were funded by a grant from the National Oceanic and Atmospheric Administration Pacific Islands Fisheries Science Center 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 five of the seven 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). 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 due to 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 (short-finned pilot whales, pantropical spotted dolphins) were given higher priority than frequently encountered species (bottlenose dolphins, rough-toothed 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. For short-finned pilot whales, if individuals were clustered into subgroups with discrete gaps between subgroups of 400 m or more, the number of subgroups, the distance among subgroups, and associated camera frames were noted for each subgroup.

If conditions were suitable for tagging, for all infrequently encountered species (e.g., short-finned pilot 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.

3.4 Data Analyses

We processed 5-minute effort locations with ArcGIS to determine depth and whether locations were inside or outside the PMRF instrumented range boundaries. Photographs were sorted within encounters to identify individuals, and the best photographs of each individual within an encounter were categorized as to photo quality and distinctiveness following methods outlined in Baird et al. (2008a, 2009). For short-finned pilot whales, rough-toothed dolphins, and bottlenose dolphins, all individuals were compared to individual identification catalogs (Baird et al. 2008a, 2009; Mahaffy et al. 2015) to determine sighting histories. For these species, associations among individuals and groups were assessed with SOCPROG 2.7 (Whitehead 2009), and associations were visualized using Netdraw 2.158 (Borgatti 2002). With the exception of false killer whales in Hawaiʻi (Martien et al. 2014), 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 ArcGIS to determine depth, distance from shore, and location relative to PMRF boundaries. 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). Probability-density maps were generated excluding locations from the first 24 hours for three species satellite tagged off Kauaʻi. Kernel density polygons were generated using the R package adehabitatHR v. 0.4.11[2] 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.

[2] https://www.movebank.org/node/14620

4. Results

From 9 to 16 February 2016, there were 859 kilometers (km) (49.3 hours) of small-vessel field effort (**Figure 1**), with the boat on the water all seven days (**Table 4**). Forecasted winds over the seven days ranged from variable less than 10 knots (one day) to 20 knots from the northeast (one day). The research vessel was launched from Kīkīaola small boat harbor on all days, and we worked south of the range on the first day (when the forecast was variable <10 and no M3R support was available). We were able to work on the range for the remaining six days, although Navy operations were taking place on the range for three of the five days of effort funded through the Marine Species Monitoring Program, limiting some access to the range. In addition, on our last day (with a forecast of NE 20 knots and a NW swell of 7 feet) the range was generally unworkable, so effort was concentrated in shallow water to the east of the range. Just over 60 percent of the total search effort was in depths less than 1,000 m (**Figure 2**).

Sperm whales, beaked whales, and minke 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. Overall, there were 20 sightings of four species of odontocetes, 19 of which were on PMRF (**Figure 1**, **Table 5**). Rough-toothed dolphins were encountered on eight occasions, short-finned pilot whales on six, bottlenose dolphins on five, and pantropical spotted dolphins on one. Six of the 19 encounters on PMRF (five of six sightings of short-finned pilot whales and one group of rough-toothed dolphins) were directed by acoustic detections from the M3R system. The single encounter off the range was a group of bottlenose dolphins sighted near the edge of the range on our last day of field effort, when conditions on the range were unworkable due to weather. During the encounters, we took 16,806 photographs for individual identification, and deployed nine satellite tags on three species (**Table 6**).

4.1 Short-finned pilot whales

We encountered short-finned pilot whales on six occasions, with all sightings on PMRF (**Figure 1**). Encounter duration ranged from 36 minutes to 2 h 24 minutes (median = 45 minutes). During the six encounters, we obtained 109 identifications. Of those, there were 51 identifications of 46 distinctive individuals with good- or excellent-quality photos. Restricted to these 51 identifications, there were from 6 to 12 identifications obtained from each of the six encounters. The 46 individuals represented five different social groups, four seen once each during the field effort and one seen on two different days. All individuals were compared to our photo-identification catalog (Mahaffy et al. 2015), and 35 of the 46 distinctive individuals had been photo-identified in previous years, including individuals from each of the five social groups. The social network of short-finned pilot whales photo-identified off Kaua‘i and Ni‘ihau, including groups photo-identified elsewhere (i.e., O’ahu) but linked by association to those from Kaua‘i or Ni‘ihau, revealed a main component with 69.1 percent of the individuals and a large number of isolated clusters with multiple individuals (**Figure 3**).

Six satellite tags were deployed on individuals in four of the five social groups (**Table 6**). Two tags were also deployed in September 2015 on an additional social group. During that encounter, 17 distinctive individuals were photo-identified, none of which had been previously documented. Locations were obtained from all eight tags over spans from 8 to 40 days (median

= 20 days). In the three cases when two tags were deployed on individuals during the same encounter, the individuals remained close to each other (median distances apart of 1.45 km, 1.62 km, and 1.81 km) over the periods of tag overlap, indicating the individuals were acting in concert.

Of the six different social groups between the September 2015 and February 2016 field efforts, two were linked by association with the main component of the social network of short-finned pilot whales photo-identified off Kauaʻi and Niʻihau (**Figure 3**), indicating that they are part of the resident island-associated community. This included the one group for which no individuals were satellite tagged, and one group with two tagged individuals (the first group encountered on 14 February 2016, represented by individuals HIGm2681 and HIGm2682, aka GmTag154 and GmTag155). The other four social groups with tagged individuals were all isolated clusters in the social network (**Figure 3**), although one individual from one of the clusters (HIGm1404, aka GmTag151) had been previously tagged in February 2013 (Baird et al. 2013), and two other individuals from that social group had also been previously tagged (in February 2011 and February 2014; see Baird et al. 2011, 2015). Although this group had no links to the main component of the social network, based on previous tag data this group appears to be one generally resident to Kauaʻi and Niʻihau. Of the three remaining social groups with tagged individuals that did not link to the main component of the social network, we used a combination of re-sighting history and movements based on the tag data to assess whether the individuals were resident to the islands (i.e., part of an insular population) or part of a more broadly ranging (i.e., open-ocean) population.

While none of the individuals in the group encountered and tagged in September 2015 had been previously photo-identified (**Table 7**), movements of the two tagged individuals (HIGm2612, HIGm2615) were limited (**Table 8**), with the individuals remaining around Kauaʻi and Niʻihau, suggesting they are part of an insular population. The group encountered and tagged on 13 February 2016 had 7 of 11 individuals that were previously photo-identified. These individuals had only been seen on a single occasion (23 April 2009) off Hawaiʻi Island, associated with a large aggregation of individuals (estimated 185 individuals) dispersed over a wide area (an estimated 5 × 1.8 km). During the 40-day span of locations available from one of the two tagged individuals from this group (HIGm1798), they spent the majority of their time in deep water offshore of the islands (**Table 8**; **Figure 4**). Although there were individuals in the large aggregation from 23 April 2009 that are known to be part of the Hawaiʻi Island resident community (Mahaffy et al. 2015), the single prior sighting of this group, combined with the wide-ranging movements of the two tagged individuals suggest this group is not part of the resident, insular population. Members of the remaining group with no links to the main component of the social network were only previously seen off Lānaʻi in 2010, and this group was not associated with any other social groups. One individual in the group was satellite tagged on 14 February 2016 (HIGm1686), and spent the majority of its time over the next 27 days off the west and south side of O'ahu (**Figure 4**; **Table 8**).

All of the tagged individuals spent some time inside the boundaries of PMRF, ranging from a single visit to up to five visits inside the boundaries (**Table 8**). The percentage of time spent inside PMRF boundaries ranged from less than 1 percent to 16.7 percent (**Table 8**).

Over 1,700 hours of dive and surfacing data were obtained from seven different depth-transmitting tags (**Table 9**), representing 4,324 dives. Maximum dive depths ranged from 927 to 1,295 m, while maximum dive durations ranged from 19.2 to 24.6 minutes.

Given evidence suggesting that satellite tag deployments on pilot whales off Kauaʻi represent individuals both from the insular population and an open-ocean or pelagic population, probability density maps were plotted separately for individuals known or suspected to be from the open-ocean population and the individuals known or suspected to be from the island-associated population (**Figure 5**). The calculated area of the core range (inside the 50 percent isopleth) is more than 10 times larger for the individuals from the pelagic population (111,135 km^2) than for the island-associated population (9,062 km^2; **Table 10**), despite the much smaller sample size for pelagic individuals.

4.2 Rough-toothed dolphins

Rough-toothed dolphins were encountered on eight occasions, making them the most frequently encountered species (**Table 5**), with all of the sightings on PMRF (**Figure 1**). Only one of the eight encounters was cued by acoustic detection through the M3R system, and encounters were relatively short (median = 15 minutes, range = 2–39 minutes). Two individuals were satellite tagged, both on the second-to-last day of fieldwork, both with location-dive tags (**Table 6**). An additional individual was tagged with a location-dive tag in September 2015.

Identification photos were obtained from all eight encounters, representing 96 identifications. Restricting these to good- and excellent-quality photos of distinctive and very distinctive individuals, 47 identifications were obtained, representing 42 individuals, with one individual seen twice during the field effort, and two others seen each on three occasions. A comparison of the 42 individuals to the photo-identification catalog of this species (Baird et al. 2008b) revealed that 27 of the individuals had been previously photo-identified off Kauaʻi, including individuals in all of the encounters where more than one distinctive individual was photo-identified (**Table 5)**. Both the individual tagged in September 2015 and one of the two tagged in February 2016 had been previously documented off Kauaʻi, both in November 2005 (**Table 7**). A social network analysis indicates that almost 90 percent of individual rough-toothed dolphins documented off Kauaʻi and Niʻihau link by association in the main cluster of the social network (Figure 6), including all three of the tagged individuals (**Figure 6**).

Location data were obtained for 14.9 days (individual HISb0421 aka SbTag016), 9.5 days (HISb2359, aka SbTag017), and 16.9 days (HISb0413, aka SbTag018). Dive data were obtained from all three individuals: 263.2 hours (HISb0421), 166.2 hours (HISb2359), and 270.5 hours (HISb0413). Dives were shallow (maximum dive depths of 247 to 399 m) and short in duration (maximum durations of 5.63 to 6.17 minutes; **Table 9**). Median depths of locations for these individuals ranged from 746 to 1,078 m (**Table 8**), suggesting that most or all dives were near the surface or to mid-water, rather than to or near to the bottom.

An analysis of distances between locations of the two individuals tagged in February 2016 obtained during the same satellite overpasses (not shown) revealed that those distances varied widely, with a mean distance between them of 11.8 km (maximum of 52.4 km). While there were three occasions when the two individuals were within 1 km of each other, overall the movement data from the two individuals suggested they were acting independently. During the period of tag attachment all three individuals remained strongly associated with Kauaʻi and Niʻihau, primarily spending their time in the channel between the islands and associated with the east and west sides of Niʻihau and the northwest side of Kauaʻi (**Figure 7**). The tagged individuals were inside the PMRF boundary on five to 12 occasions, spending between 23.0 percent and 59.8 percent of their time inside the range boundary (**Table 8**).

A probability-density map using tag data from all 17 rough-toothed dolphins satellite tagged off Kauaʻi for which location data are available indicated that the channel between Kauaʻi and Niʻihau represents the core area for these individuals (**Figure 8**), with a large proportion of the core area overlapping with the 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.

4.3 Bottlenose dolphins

Bottlenose dolphins were sighted on five occasions (**Figure 1; Table 5**). Encounter durations were relatively short (median = 8 minutes, range = 1 minute to 1 h 30 minutes), with the exception of one extended encounter (1 h 30 minutes) on February 15th when conditions on the range were unworkable (winds from the NE at 20 knots and a 7' swell from the NW). Photographs were obtained from all five encounters, representing 70 identifications. Good or excellent quality photos were available from 61 of the 70 identifications, representing all five encounters. Restricting analyses to good-quality photographs of distinctive individuals, there were 36 identifications representing 35 individuals. A comparison to the long-term photo-identification catalog (Baird et al. 2009) indicated that 34 of the 35 individuals were previously documented, all off Kauaʻi and/or Niʻihau. Of those 34 that were previously documented, five had been seen in one previous year, five had been seen in 2 previous years, nine had been seen in 3 previous years, five had been seen in 5 previous years, and one had been seen in seven previous years. Nine of the individuals were first documented off Kauaʻi and Niʻihau over 12 years earlier (maximum span of years = 12.7), seven 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 9**), 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, 95.5 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.

No bottlenose dolphins were satellite tagged in February 2016. One was tagged in September 2015 with a location-dive tag (**Table 6**), although dive data were only obtained for just over seven hours and are not considered further. The individual tagged in September 2015 had been previously documented off Kauaʻi (in 2005), and remained associated with the northwest side of Kauaʻi over the six-day period over which locations were obtained (**Figure 10**). During this time the dolphin was inside PMRF boundaries on six occasions, spending an estimated 52.7 percent of its time inside PMRF (**Table 8**).

A probability-density map of tag data from all 13 bottlenose dolphins tagged off Kauaʻi indicates that much of the 50 percent core area overlaps with the PMRF (**Figure 11**). Assessment of the area within the 50 percent, 95 percent, and 99 percent isopleths from the kernel density analysis indicates that bottlenose dolphins off Kauaʻi have the smallest ranges of any of the three species examined (**Table 10**).

4.4 Pantropical spotted dolphins

A group of seven pantropical spotted dolphins was sighted on 14 February 2016 on PMRF. Good quality photographs of all seven individuals were obtained for eventual incorporation into a spotted dolphin photo-identification catalog. One location-dive satellite tag was deployed (SaTag003), and locations were obtained over an 18-day span (**Table 6**). During this period, the tagged individual moved a minimum of 1,557 km, moving away from Kauaʻi and spending its time in deep waters to the south and southeast (**Figure 12**). The median depth and distance from shore were 3,423 m and 43.9 km (**Table 8**). 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. The mtDNA haplotype was haplotype 3 from Courbis et al. (2014), the most common haplotype found in that study. Based on microsatellites, the individual clustered most closely with the Hawaiʻi Island population (S. Courbis, Portland State University, personal communication).

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5. Discussion and Conclusion

Over the seven-day field effort in February 2016 information was obtained on four species of odontocetes off Kauaʻi, three of which (short-finned pilot whales, rough-toothed dolphins and bottlenose dolphins) are regularly seen off the island, and one (pantropical spotted dolphins) which is rarely seen there (Baird et al. 2013; Baird 2016). In our prior work off Kauaʻi, pantropical spotted dolphins were only sighted off the island on nine occasions (Baird et al. 2013a), four times in 2003, once in 2005 (a lone 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. Overall they represent only about 2% of odontocete sightings off Kauaʻi and Niʻihau, compared to between ~23 and 26% 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 February 2016 sighting was the first one on PMRF; no prior sightings were on the range. Based on movements of the tagged individual (**Figure 12; Table 8**), this group appeared to be part of a pelagic population, rather than a resident population, as are found off the other islands (Courbis et al. 2014). This was only the third time a pantropical spotted dolphin has been satellite tagged in Hawaiian waters, and the first tag deployment on an individual from the pelagic population, thus providing the first detailed movement information on pelagic spotted dolphins in Hawaiian waters.

Satellite-tag data obtained from short-finned pilot whales, bottlenose dolphins, and rough-toothed dolphins all increased our understanding of how these three species use the area and potentially overlap with naval activities. Although data are available from these three species, they represent four different populations. We were able to obtain additional satellite-tag data both from the insular and pelagic short-finned pilot whale populations, and the tag data illustrate vastly different ranges (see **Figure 5** and **Table 10**). However, the social network of short-finned pilot whales (**Figure 3**) reveals a large number of isolated clusters and several clusters linked by only a single individual to the main component of the social network. Given the evidence from tag data that some of the isolated clusters are part of a resident insular population (represented by HIGm1686, HIGm1404, HIGm2612 and HIGm2615 in **Figure 3**), it is clear that additional photo-identification data are needed to fully understand associations and population structure. With better photographic coverage, in theory these resident groups should link by association with the main component of the pilot whale social network, as is seen in both bottlenose dolphins (**Figure 9**) and rough-toothed dolphins (**Figure 6**). There is evidence the insular population of short-finned pilot whales in Hawaiʻi is divided into three overlapping communities which are largely isolated, both socially and to some degree genetically (Baird 2016; Van Cise et al. 2015), and groups from other communities may occasionally move to Kauaʻi. Thus, some of the groups documented off Kauaʻi or Niʻihau may not link by association with the main component of the social network, even if they are part of an insular population.

In all three species, the core areas (represented by the 50 percent kernel polygons) overlap with PMRF to varying degrees (**Figures 5, 8,** and **11**), reflecting the importance of the channel between Kauaʻi and Niʻihau to these species and the potential for exposure to MFA sonar. Preliminary acoustic propagation analyses of sonar use on PMRF during Submarine

Commanders Courses suggest that MFA sonar on PMRF is generally audible to cetaceans throughout PMRF (S.W. Martin, unpublished data). These high-density areas overlapping with PMRF indicate that individuals from all three insular populations likely have repeated exposures to audible levels of MFA sonar at PMRF.

In order to understand the potential impacts of MFA sonar exposure to species encountered, it is necessary to evaluate exposure at the social group level. Several studies have suggested that reactions to MFA sonar are likely influenced by prior exposure history (Falcone et al. 2008; DeRuiter et al. 2013; Harris and Thomas 2015; Southall et al. 2016); thus, understanding potential consequences of exposure, both to the social group and to the population, will benefit from an increased understanding of the social organization of the population. The tag deployments to date on bottlenose and rough-toothed dolphins are from known resident populations (see also Baird et al. 2008b, 2009, Martien et al. 2011, and Albertson et al. 2016). Given the overlap in core areas with PMRF (**Figures 8 and 11**), individuals within these resident populations are likely repeatedly exposed to MFA sonar. However, the deployments of satellite tags on pilot whales occurred from five different social groups with varying re-sighting histories among the islands (**Table 7**). Groups from the resident population may receive more frequent exposure to MFA sonar when compared to the one group from the pelagic population (**Figure 4, 5**), illustrating that the amount of exposure to MFA sonar will likely vary by social cluster. For individuals in resident groups that have likely been repeatedly exposed to MFA sonar, it is possible that they may have become habituated to the noise and thus may not avoid the area when MFA sonar is used. If close enough to the sound source, there is the potential for repeated temporary threshold shifts, which might lead to permanent threshold shifts. This has been shown for terrestrial mammals (Kryter et al. 1966, Lonsbury-Martin et al. 1987, Kujawa and Kiberman 2009, Lin et al. 2011, Wang and Ren 2012) and suggested that it may also occur for marine mammals (Kastak et al. 2008, National Marine Fisheries Service 2016). Individuals in the pelagic population will be exposed less often, but may also be less likely to have developed behavioral responses that allow them to deal with high levels of exposure.

Over 2,400 hours of dive data were obtained from 11 individuals of three different species (**Table 9**), approximately doubling the amount of dive data available for both rough-toothed dolphins and short-finned pilot whales from Kauaʻi (see Baird et al. 2015, 2016). Dive patterns, in terms of dive durations and dive depths, were similar to those found in previous efforts, providing for a robust assessment of diel behavior patterns for both species.

The Navy's monitoring goals relate broadly to questions of marine mammal occurrence, their exposure to MFA sonar (and other Navy activities), their responses to MFA 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 (see Baird et al. 2014b). 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 Hawaiʻi (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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8. Figures

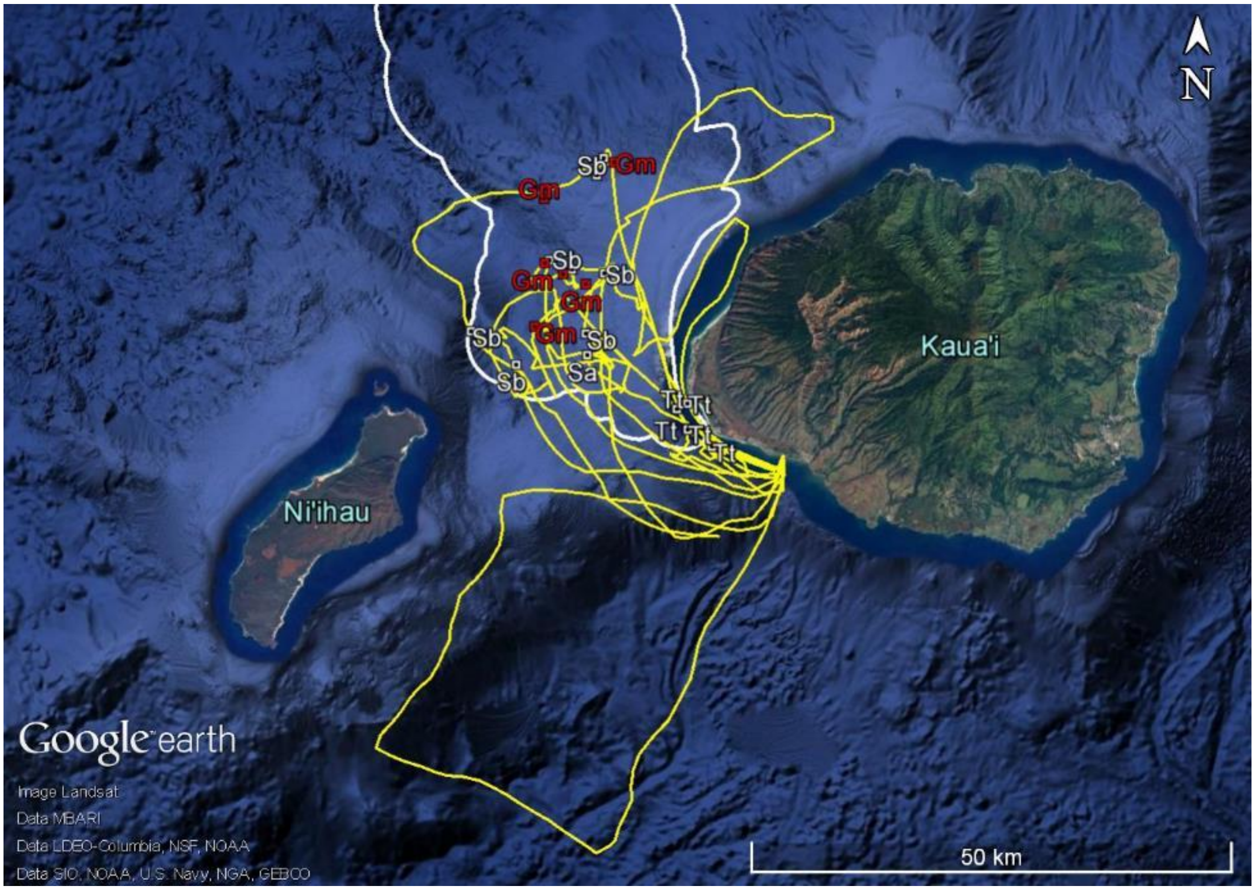

Figure 1. February 2016 tracklines of small-vessel field effort (yellow) and sighting locations (symbols with species abbreviations as labels). Sightings of humpback whales are not shown as most groups were not approached. Symbols and labels for short-finned pilot whales (Gm) are shown in red for clarity. The overall PMRF boundary is indicated with a solid white line. Gm = *Globicephala macrorhynchus*; Sb= *Steno bredanensis*; Sa = *Stenella attenuata*; Tt = *Tursiops truncatus*.

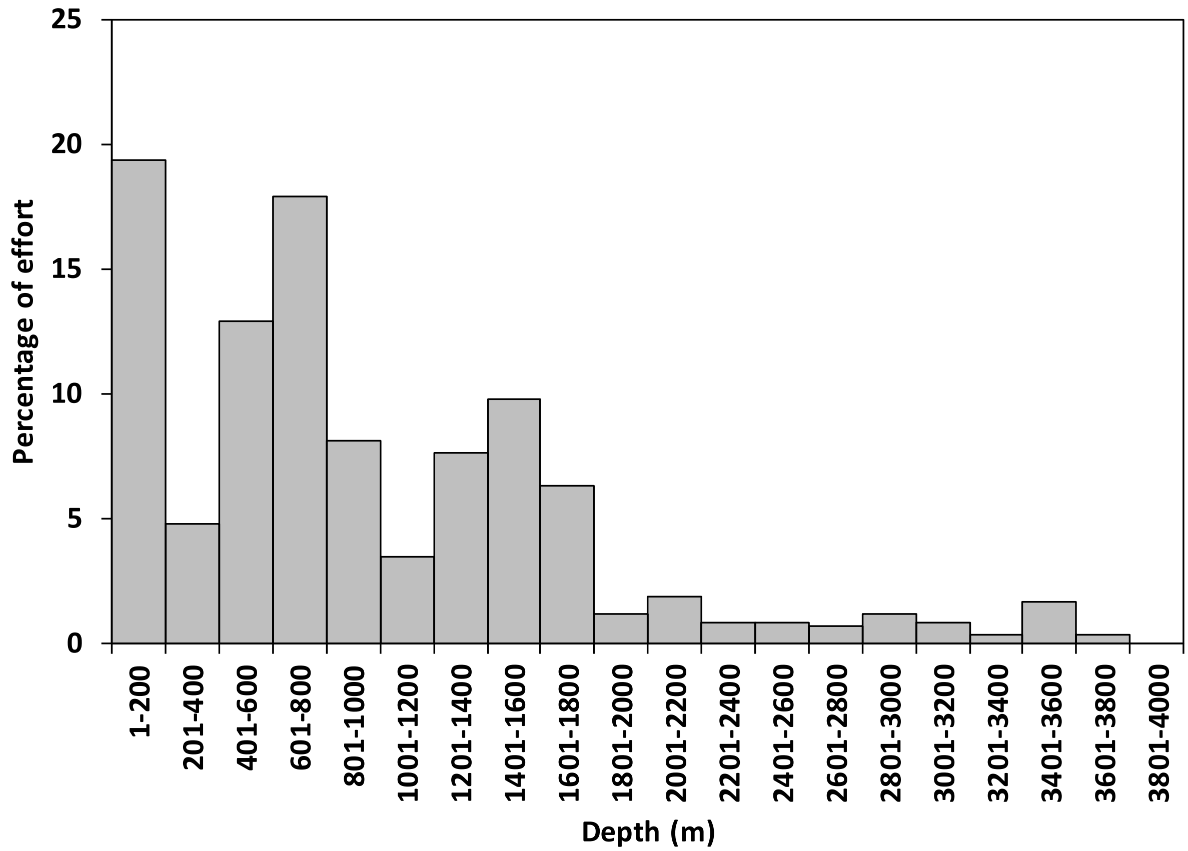

Figure 2. Depth distribution of small-vessel effort during February 2016 field effort.

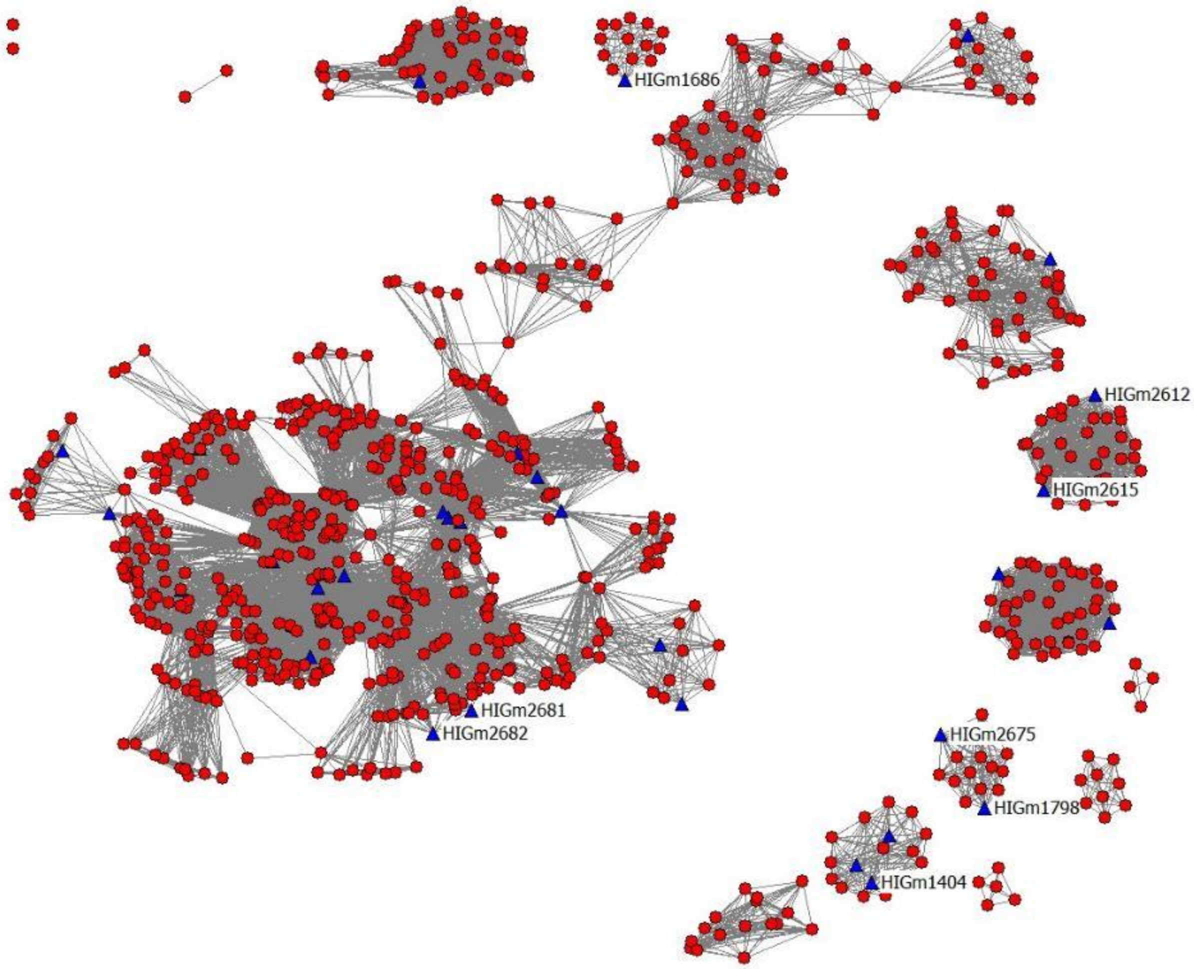

Figure 3. Social network of photo-identified short-finned pilot whales off Kaua'i and Ni'ihau and including those identified off O'ahu that link by association to the main component from Kaua'i and Ni'ihau. All individuals tagged off Kaua'i and Ni'ihau (including those tagged in previous efforts) are noted by blue triangles. Those individuals tagged in February 2016 and September 2015 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 Mahaffy et al. 2015), with a total of 799 individuals shown (the main cluster contains 552 individuals, 69.1% 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.

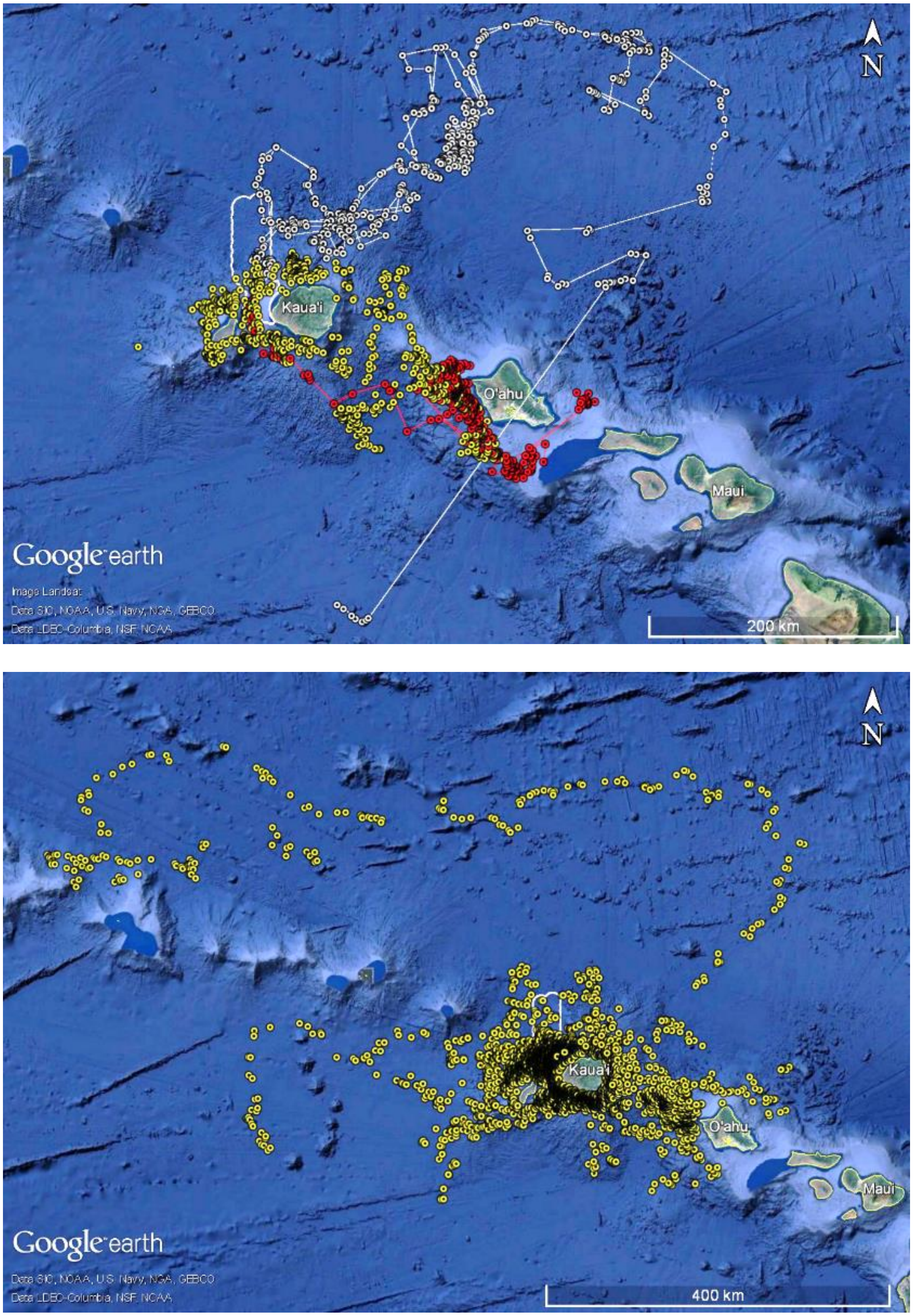

Figure 4. Top. Locations from short-finned pilot whales tagged off Kaua'i and Ni'ihau in September 2015 and February 2016. Lines connect consecutive locations for GmTag152 and GmTag153 (white points and lines) and GmTag156 (red points and line). GmTag152 and GmTag153 were tagged in the same group on 13-Feb-16 and tracked over 40 days. GmTag156 was tagged 14-Feb-16 and tracked over 27 days. Bottom. Locations from all 19 previous short-finned pilot whale tag deployments off Kaua'i. The PMRF boundary is shown in white.

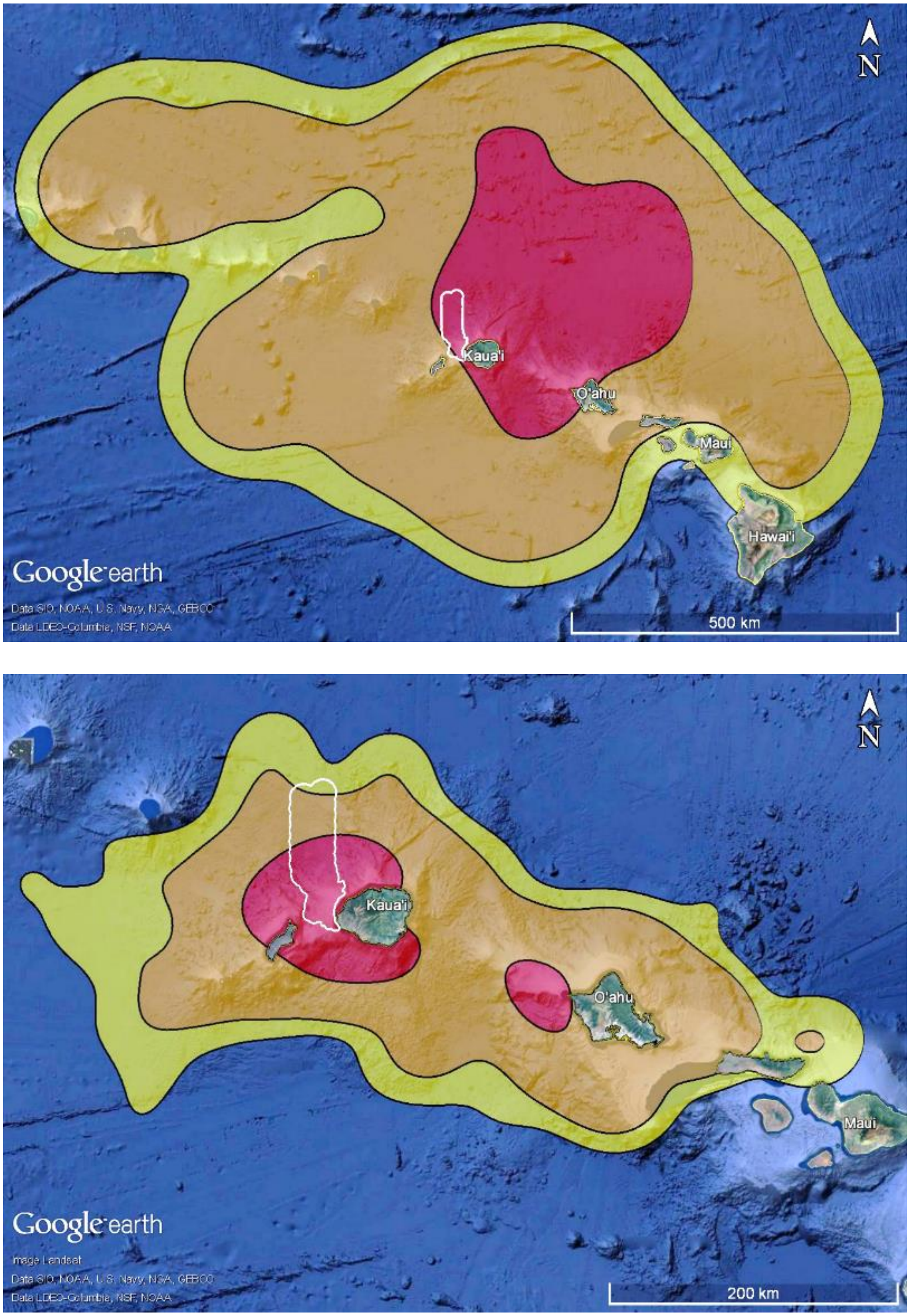

Figure 5. Probability density representation of short-finned pilot whale location data from satellite tag deployments off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals with overlapping tag data that were acting in concert were used. Top. Individuals known to be part of the open-ocean population (n=6), including two individuals tagged off O'ahu in 2010. Bottom. Individuals known to be part of the resident island-associated population (n=17). 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 white line.

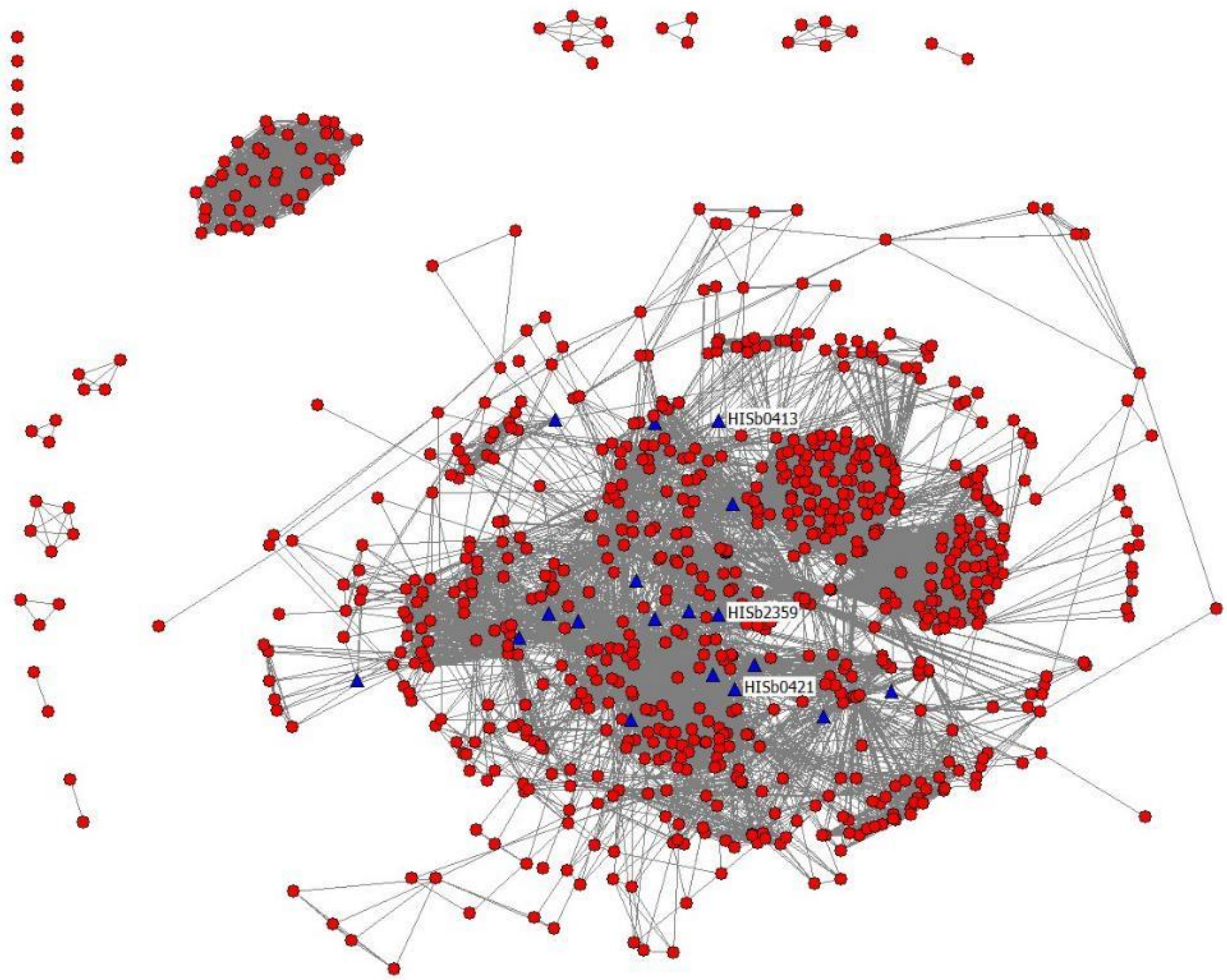

Figure 6. Social network of rough-toothed dolphins photo-identified off Kaua'i and Ni'ihau from 2003 through February 2016, with tagged individuals noted by blue triangles. Those individuals tagged in September 2015 and February 2016 are indicated with ID labels. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2008b), with a total of 799 individuals shown (the main cluster contains 718 individuals, 89.8% 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.

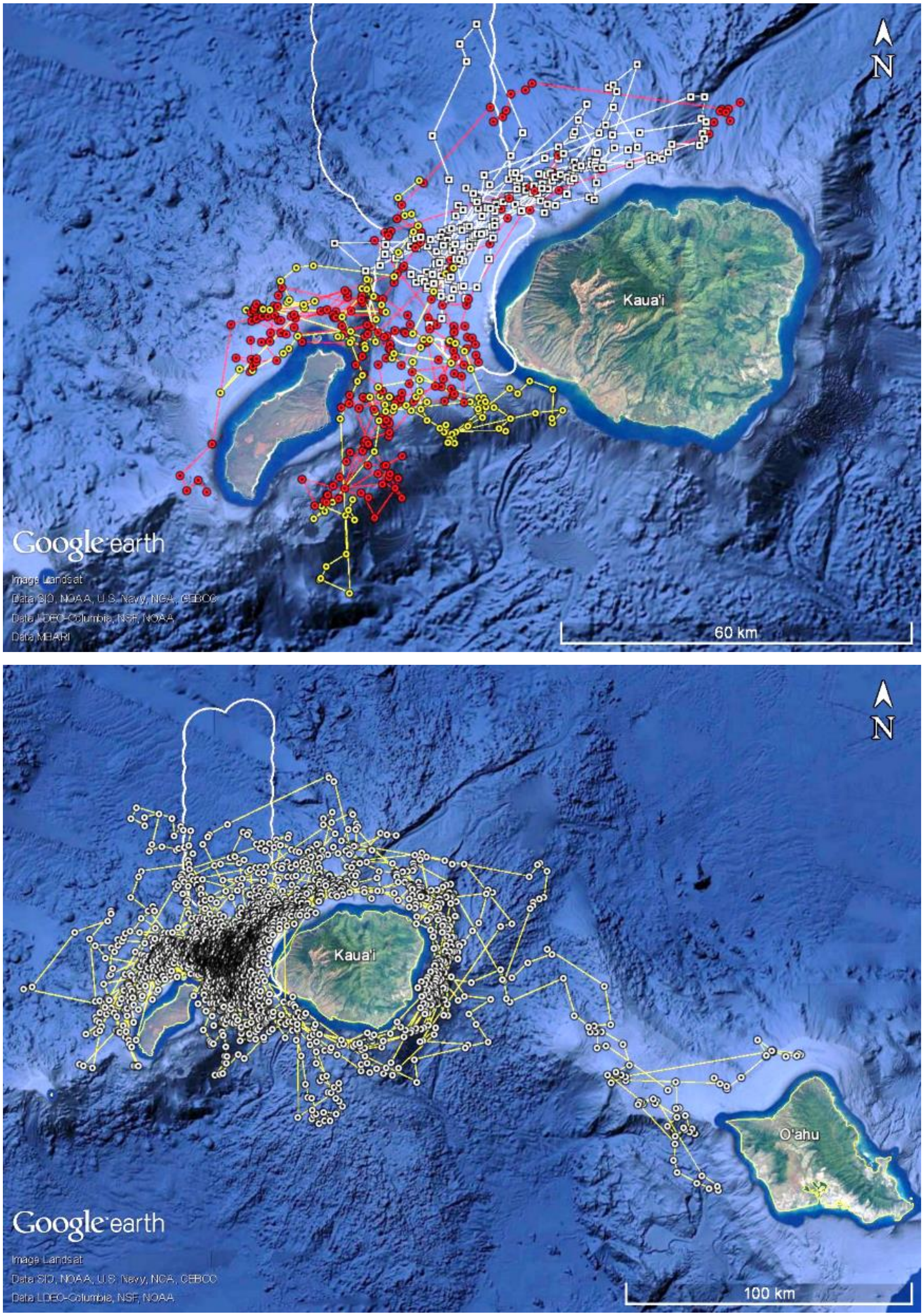

Figure 7. Top. Locations of rough-toothed dolphins satellite tagged in September 2015 and February 2016 (white squares and line SbTag016; yellow circles and line SbTag017; red circles and line SbTag018), with lines connecting consecutive locations. Bottom. Locations of 14 previous satellite-tagged rough-toothed dolphins. The PMRF boundary is shown as a solid white line.

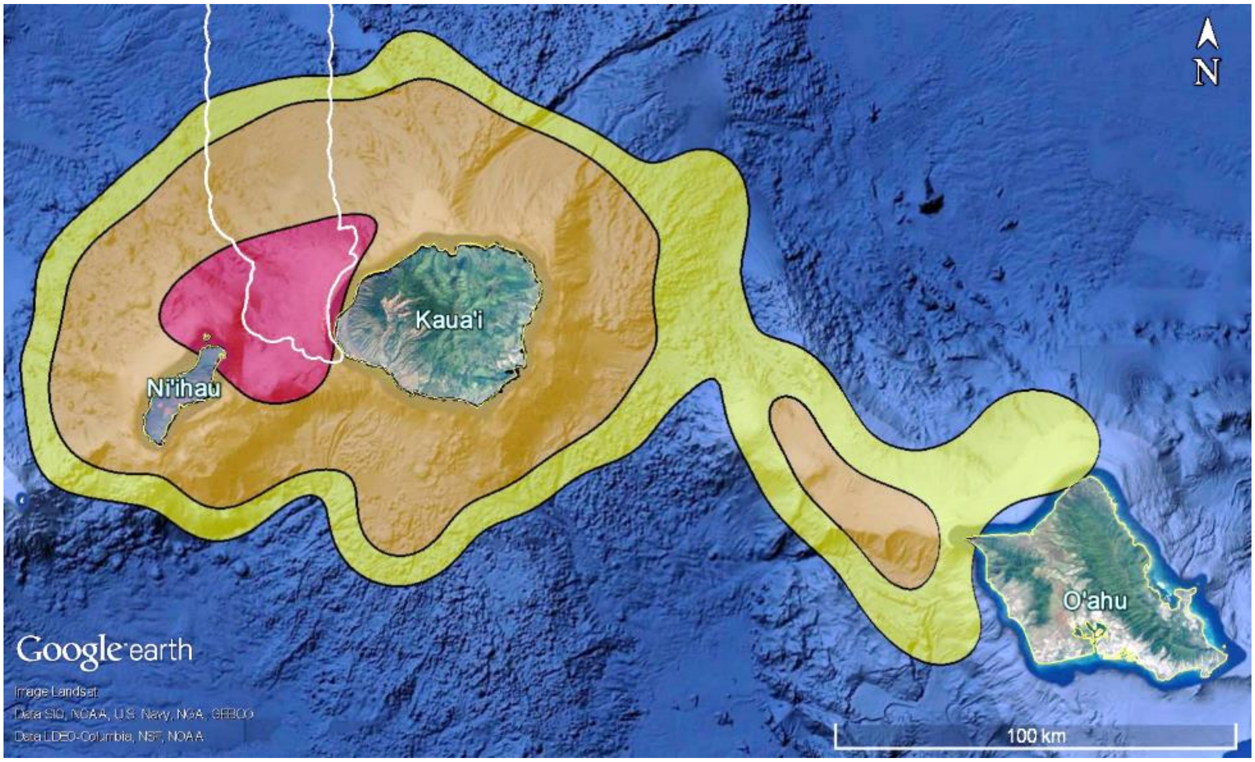

Figure 8. A probability density representation of rough-toothed dolphin location data from all 17 satellite tag deployments off Kaua'i for which location data were obtained. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of 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 white line.

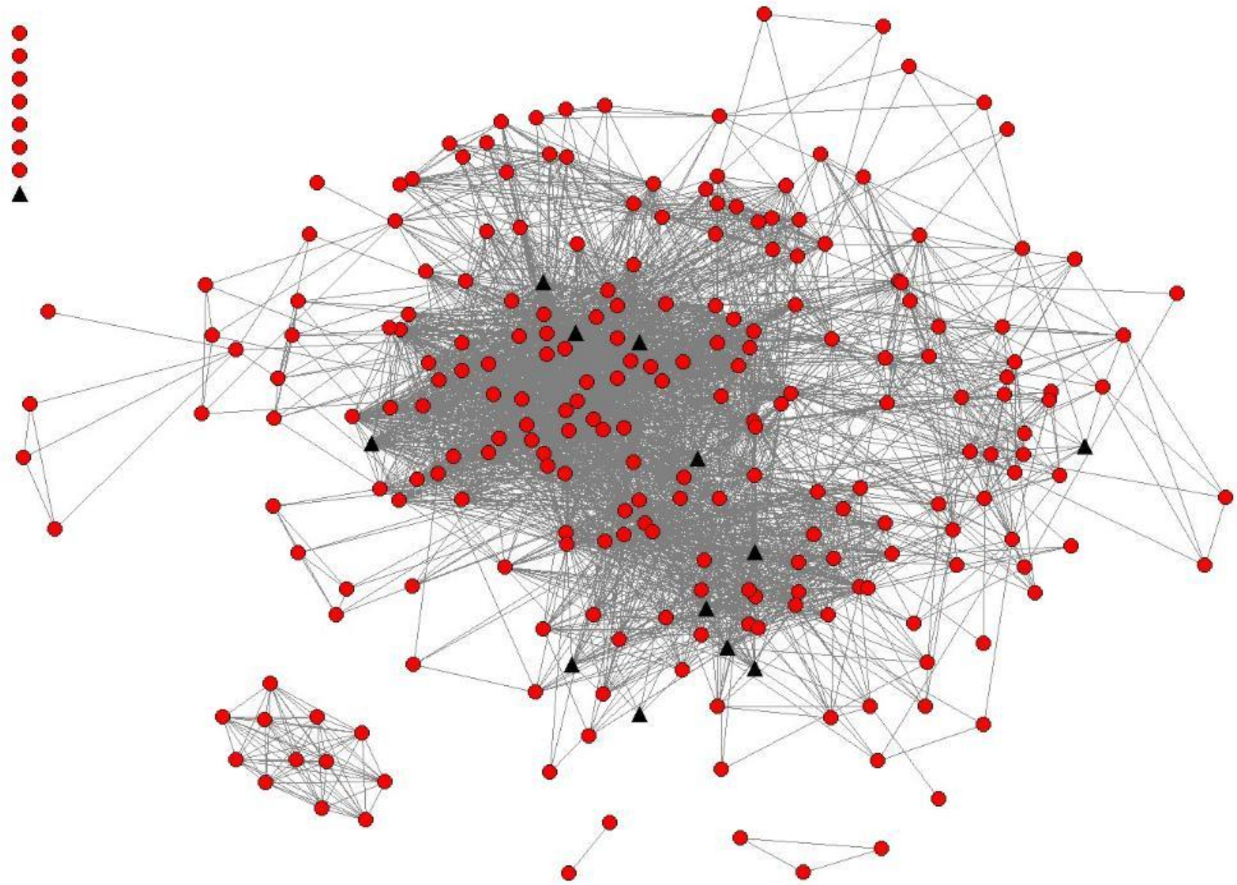

Figure 9. Social network of bottlenose dolphins photo-identified off Kaua'i and Ni'ihau from 2003 to February 2016, with tagged individuals noted by black triangles. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2009), with a total of 252 individuals shown (the main cluster contains 227 individuals, 90.1% of all individuals). The cluster of 12 individuals in the lower left 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.

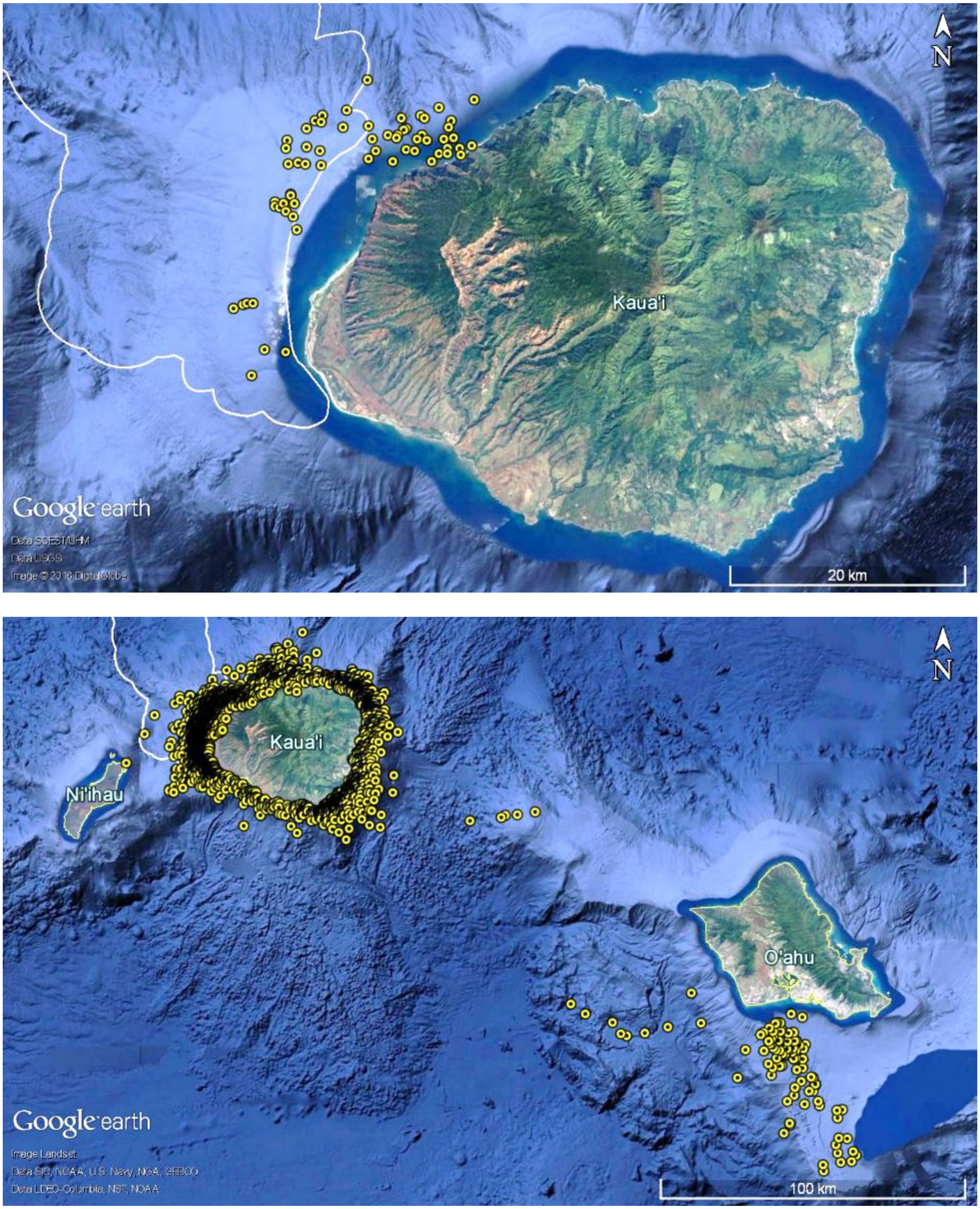

Figure 10. Top. Locations of bottlenose dolphin TtTag025 satellite tagged in September 2015. Bottom. Locations of 12 previous satellite-tagged bottlenose dolphins. The boundary of PMRF is shown as a solid white line.

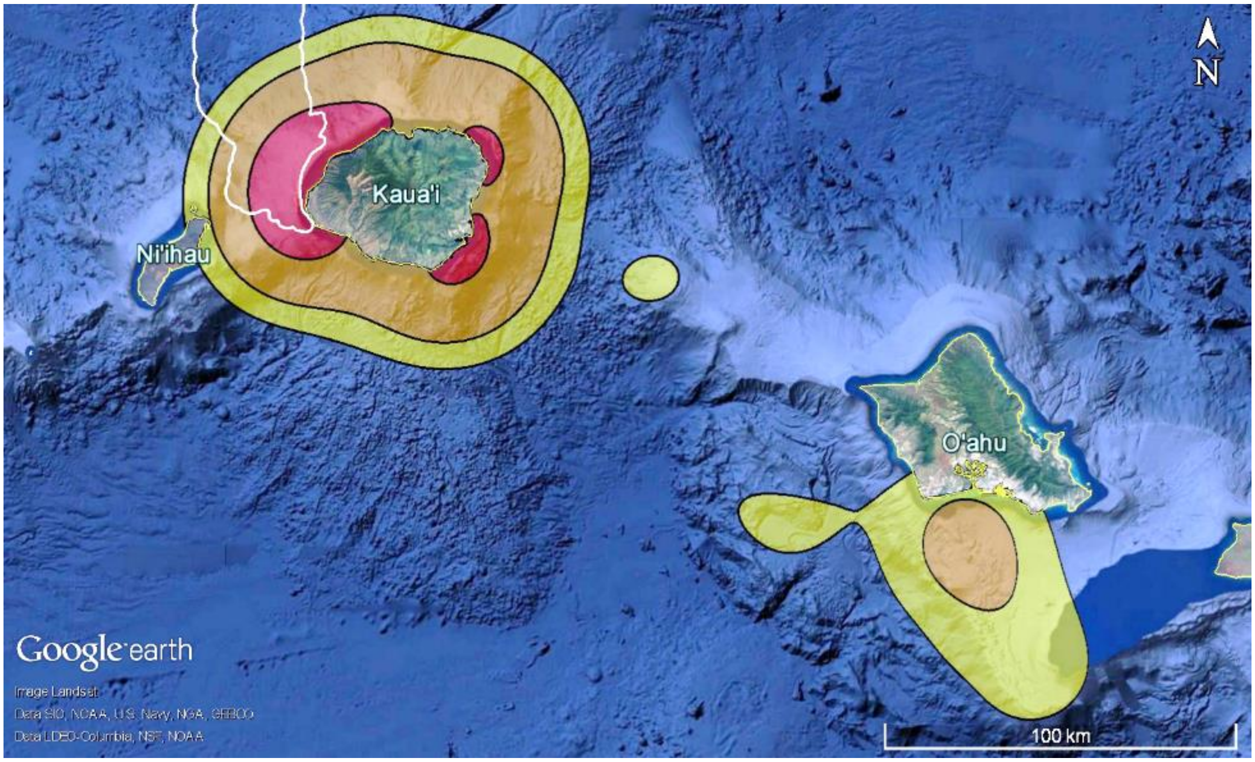

Figure 11. Kernel-density representation of bottlenose dolphin location data from all 13 satellite tag deployments off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50% density polygon (the "core range"), the orange area represents the 95% polygon, and the green represents the 99% polygon. The PMRF boundary is indicated by a solid white line.

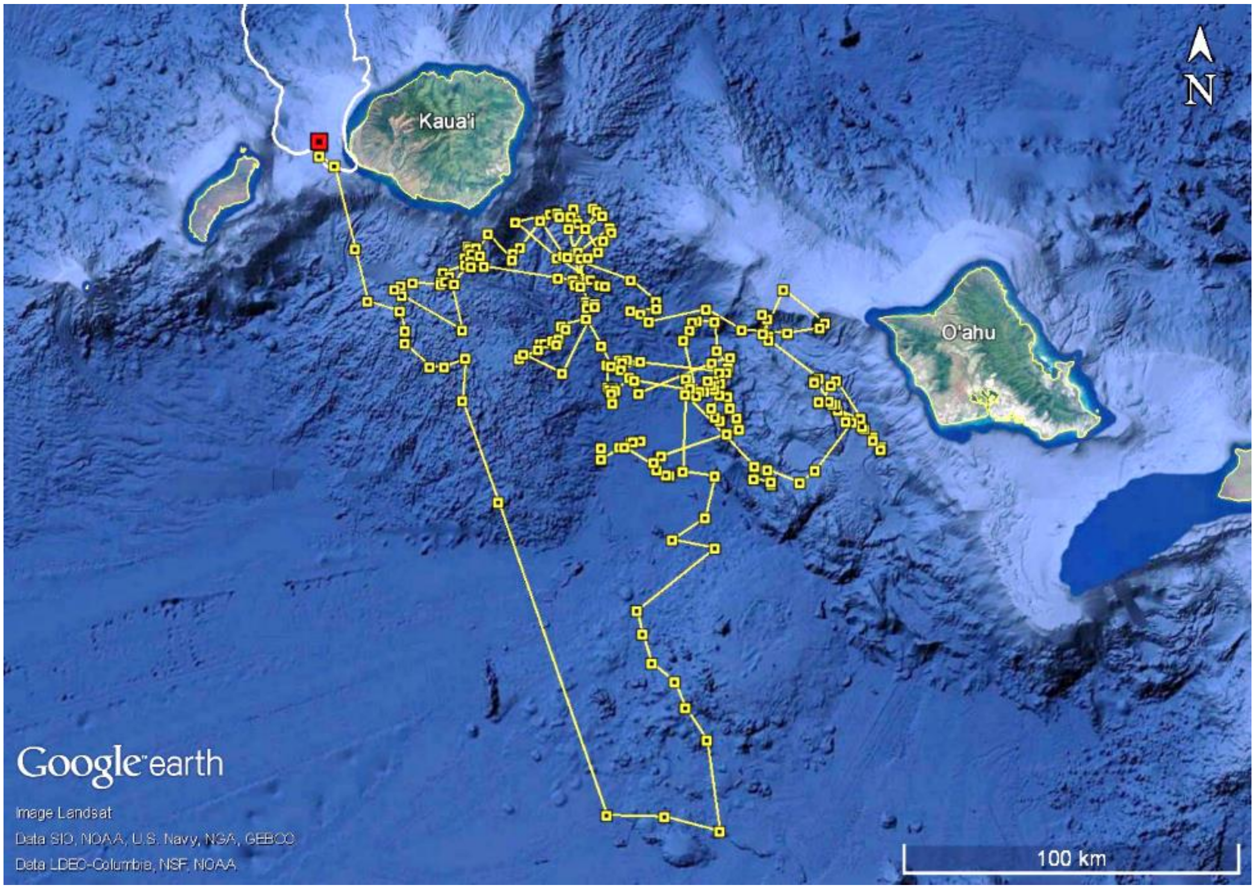

Figure 12. Locations of a pantropical spotted dolphin tagged in February 2016, with consecutive locations joined by a line. The location where the individual was tagged is indicated by a red symbol, and the PMRF boundary is indicated by a solid white line.

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*
Total	**729.3**		*Gm* (21)[2], *Pe* (3), *Tt* (15), *Sb* (16), *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	12–44 kHz with most energy 16-44 kHz	Short narrowband whistles centered at 10 kHz, lots of 12–44 kHz clicks	*Pc* (whistles)
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)
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*
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*
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.	

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

ICI = inter-click interval; kHz = kilohertz; n/a = not applicable; ~ = approximately

Table 4. February 2016 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 4–5
9 Feb 2016[1]	140.2	7.0	0	7:27	14:31	0	17.1	103.5	14.9	4.7
10 Feb 2016[1]	138.1	6.3	2	7:16	13:33	0	44.4	83.7	10	0
11 Feb 2016	156.3	8.3	2	7:10	15:30	0	30.7	91.1	26.5	8
12 Feb 2016	114.2	6.8	0	7:09	13:53	0	2.1	97.1	15.0	0
13 Feb 2016	137.2	8.6	6	7:13	15:49	0	24.7	63.4	49.1	0
14 Feb 2016	124.2	8.7	8	7:06	15:40	0	0	65	51.5	7.7
15 Feb 2016	49.2	3.6	2	7:08	10:45	0	13.7	35.5	0	0
Total	859.40	49.3								

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

[1]Two days of small boat effort funded by National Marine Fisheries Service were undertaken prior to the Navy-funded effort.

Table 5. Odontocete sightings from small-boat effort during February 2016.

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	On PMRF (yes/no)	# distinctive individuals photo-identified with good/excellent	# distinctive individuals previously photo-identified (excluding within-	Visual ID Position	
								Latitude (°N)	Longitude
10-Feb-16	7:53	Tt	2	0	yes	2	2	21.9854	159.7872
10-Feb-16	8:08	Tt	2	0	yes	0	0	22.0035	159.7980
11-Feb-16	8:54	Sb	15	0	yes	6	6	22.0447	159.9593
11-Feb-16	13:38	Gm	22	1	yes	13	12	22.0801	159.9406
13-Feb-16	9:24	Sb	7	0	yes	3	2	22.0758	160.0046
13-Feb-16	9:24	Gm	20	2	yes	11	7	22.1993	159.9314
13-Feb-16	12:13	Sb	8	0	yes	5	1	22.2209	159.8783
13-Feb-16	12:42	Gm[2]	15	0	yes	6	6	22.2330	159.8608
13-Feb-16	13:04	Sb	30	0	yes	11	8	22.2370	159.8714
13-Feb-16	14:51	Tt	28	0	yes	26	25	22.0086	159.7874
14-Feb-16	9:45	Sb	5	0	yes	3	2	22.0737	159.8893
14-Feb-16	10:17	Sb	21	2	yes	16	13	22.1297	159.8708
14-Feb-16	11:16	Sb	4	0	yes	4	0**	22.1333	159.9034
14-Feb-16	11:22	Gm	26	2	yes	12	8	22.1291	159.9121
14-Feb-16	12:06	Gm	17	0	yes	8	8	22.1196	159.8893
14-Feb-16	13:24	Gm	20	1	yes	7	4	22.1393	159.9307
14-Feb-16	13:53	Sb	20	0	yes	1	0	22.1419	159.9259
14-Feb-16	8:44	Sa	7	1	yes	N/A		22.0537	159.8880
15-Feb-16	7:37	Tt	19	0	yes	9	9	21.9844	159.7871
15-Feb-16	9:52	Tt	2	0	no	1	0	21.9685	159.7629

[1]See footnote to **Table 1**, [2]Five of six individuals were in the group encountered 11-Feb-16. HST = Hawaiʻi Standard Time; ID = identification; km = kilometer; N/A = not applicable; PAM = passive acoustic monitoring; °N = degrees North; °W = degrees West; *Sighting a result of being directed to the location of PAM detections but files of acoustic detection locations corrupted. **All four individuals have been seen in previous encounter.

Table 6. Details on satellite tags deployed during September 2015 and February 2016 for species included in mapping.

Species[1]	Tag ID	Individual ID	Date Tagged	Sighting #	Duration of Signal Contact (days)	Latitude (°N)	Longitude (°W)	Tag Type	Sex
Sa	SaTag003	N/A	14-Feb-16	1	17.91	22.04	159.87	Mk10A	Unknown
Tt	TtTag025	HITt0334	7-Sep-16	5	5.88	22.03	159.82	Mk10A	Unknown
Sb	SbTag016	HISb0421	5-Sep-15	1	14.92	22.04	159.91	Mk10A	Male
Sb	SbTag017	HISb2359	14-Feb-16	3	9.53	22.13	159.87	Mk10A	Unknown
Sb	SbTag018	HISb0413	14-Feb-16	3	16.92	22.14	159.86	Mk10A	Unknown
Gm	GmTag132	HIGm2612	10-Sep-15	3	18.35	21.73	160.19	Mk10A	Male
Gm	GmTag133	HIGm2615	10-Sep-15	3	18.93	21.73	160.20	Mk10A	Male
Gm	GmTag151	HIGm1404	11-Feb-16	4	8.56	22.08	159.94	Mk10A	Male
Gm	GmTag152	HIGm2675	13-Feb-16	2	16.92	22.20	159.93	Mk10A	Female
Gm	GmTag153	HIGm1798	13-Feb-16	2	39.69	22.20	159.93	Mk10A	Male
Gm	GmTag154	HIGm2681	14-Feb-16	6	21.23	22.13	159.91	Mk10A	Male
Gm	GmTag155	HIGm2682	14-Feb-16	6	25.01	22.13	159.91	Mk10A	Male
Gm	GmTag156	HIGm1686	14-Feb-16	10	27.21	22.14	159.93	Mk10A	Male

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

Table 7. Details on previous sighting histories of individuals satellite tagged in September 2015 and February 2016 included in mapping.

Individual ID	Date First Seen	# Times Seen Previously	# Years Seen Previously	Islands Seen Previously	Social cluster
HITt0334	26-Oct-05	2	2	Kauaʻi	N/A
HISb0421	4-Nov-05	1	1	Kauaʻi	N/A
HISb2359	11-Feb-16	2	0	Kauaʻi	N/A
HISb0413	4-Nov-05	4	2	Kauaʻi, Niʻihau	N/A
HIGm2612	10-Sep-15	0	0	N/A	N/A
HIGm2615	10-Sep-15	0	0	N/A	N/A
HIGm1404	19-Feb-11	4	4	Kauaʻi, Oʻahu	W25
HIGm2675	13-Feb-16	0	0	N/A	N/A
HIGm1798	23-Apr-09	1	1	Hawaiʻi	H28*
HIGm2681	14-Feb-16	0	0	N/A	W8
HIGm2682	14-Feb-16	0	0	N/A	W8
HIGm1686	13-Nov-10	1	1	Lānaʻi	W32

ID = identification; # = number; N/A = not applicable; *When first documented in April 2009, HIGm1798 was seen in a loose aggregation of pilot whales with an estimated 185 individuals spread over an area of approximately 5 km x 1.8 km. Of the 111 individuals photo-identified from the group, 61 have been previously documented.

Table 8. Information from GIS analysis of satellite-tag location data from September 2015 and February 2016 field efforts.

Individual ID	Social Cluster	# 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)
SaTag003	N/A	217	1	0.5	1,557	113.4/233.9	3,423/4,769	43.9/150.7
HITt0334	N/A	67	6	52.7	275	19.9/27.6	100/1,074	4.4/9.0
HISb0421	N/A	198	12	59.8	1,032	24.7/60.6	1,078/4,200	12.0/39.7
HISb2359	N/A	123	5	23.0	547	24.5/57.6	817/2,920	10.8/26.0
HISb0413	N/A	222	11	31.1	1,029	25.1/60.1	746/3,731	9.9/26.7
HIGm2612	N/A	203	5	16.7	1,384	53.0/122.4	1,673/4,289	13.6/33.6
HIGm2615	N/A	168	4	15.3	1,317	44.9/125.3	1,242/3,808	11.3/31.4
HIGm1404	W25	20	2	*	263	39.1/78.7	2,005/3,080	11.9/24.8
HIGm2675	N/A	184	4	7.5	1,562	161.9/365.7	4,442/4,892	118.2/271.8
HIGm1798	H28	289	3	4.1	2,672	211.8/403.4	4,347/4,900	147.1/276.6
HIGm2681	W8	218	1	1.2	1,504	144.4/224.5	2,571/4,732	31.5/92.7
HIGm2682	W8	196	1	1.0	1,442	147.4/227.4	2,451/4,727	28.4/90.4
HIGm1686	W32	279	1	0.7	1,788	185.4/279.3	1,169/4,721	18.1/63.2

ID = identification; km = kilometers; m = meters; # = number; % = percent; N/A = not applicable. *Unusually long gaps in locations invalidated the use of tag data for calculating percentage time inside PMRF boundaries for this individual.

Table 9. Dive information from satellite tags deployed during September 2015 and February 2016 field efforts.

Individual 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)
SaTag003	7.6	110	14.5	56.6	287.5	3.65	6.40
HISb0421	263.2	368	1.4	56.5	399.5	2.90	6.17
HISb2359	166.2	510	3.1	89.5	247.5	3.03	5.63
HISb0413	270.6	790	2.9	85.5	295.5	3.60	5.97
HIGm2612	427.7	803	1.9	335.5	1,071.5	12.43	24.60
HIGm2615	340.9	791	2.3	303.5	927.5	11.05	19.23
HIGm2675	212.0	467	2.2	319.5	1,199.5	12.33	21.07
HIGm1798	163.8	620	3.8	88.5	1,039.5	7.3	22.5
HIGm2681	194.9	497	2.6	375.5	1,295.5	11.6	21.3
HIGm2682	190.4	496	2.6	191.5	1,263.5	9.9	21.7
HIGm1686	184.5	650	3.5	87.5	1,103.5	9.2	21.9

[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 HIGm1401 (GmTag151).

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.

Species/population	Area (km^2) within selected isopleths based on kernel density		
	50%	95%	99%
Bottlenose dolphin	1,173	7,216	12,246
Rough-toothed dolphin	1,535	13,055	20,288
Short-finned pilot whale – insular population	9,062	56,006	87,778
Short-finned pilot whales – pelagic population	111,135	524,071	695,419

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