Final Report

Odontocete Studies on the Pacific Missile Range Facility in February 2015: Satellite-Tagging, Photo-Identification, and Passive Acoustic Monitoring

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Prepared by:

Robin W. Baird[1], Daniel L. Webster[1], Stephanie Watwood[2], Ronald Morrissey[2], Brenda K. Rone[1], Sabre D. Mahaffy[1], Annie M. Gorgone[1], David B. Anderson[1], and David J. Moretti[2]

[1]Cascadia Research Collective,
218 ½ W. 4th Avenue, Olympia, WA, 98501

[2]Naval Undersea Warfare Center, 1176 Howell Street,
Newport, RI, 02841

Submitted by:

HDR
Honolulu, HI

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Rough-toothed dolphin (*Steno bredanensis*) off Kauaʻi. Photo taken by Robin W. Baird 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
hr	hour(s)
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

A joint project in February 2015 on and around the Pacific Missile Range Facility (PMRF) was carried out utilizing combined boat-based field efforts and passive acoustic monitoring from the Marine Mammal Monitoring on Navy Ranges (M3R) system. There were 1,132 kilometers (63.4 hours [hr]) of small-vessel survey effort over the course of the 13-day project. Weather conditions precluded field operations on 4 days, and strong westerly winds and/or range operations limited access to PMRF on seven additional days, with only 15.1 percent of search time (9.6 hr) spent within the range boundaries. Westerly winds resulted in effort off the east and southeast side of Kauaʻi on 5 days, the first Cascadia Research Collective (CRC) small-boat effort off the east side of the island since 2005. A total of 10.5 hr of M3R acoustic monitoring was undertaken during the field effort. There were 35 sightings of at least five species of odontocetes and one species of mysticete other than humpback whales (*Megaptera novaeangliae*), three of which were directed by M3R acoustic detections. Bottlenose dolphins (*Tursiops truncatus*) were encountered on seven occasions, spinner dolphins (*Stenella longirostris*) on two, short-finned pilot whales (*Globicephala macrorhynchus*) on three, rough-toothed dolphins (*Steno bredanensis*) on 20, dwarf sperm whales (*Kogia sima*) once, unidentified odontocetes once, and fin whales (*Balaenoptera physalus*) once. These were the first dwarf sperm whales documented in CRC small-boat efforts off Kauaʻi or Niʻihau since 2003, and the first CRC sightings of fin whales off Kauaʻi or Niʻihau. Two dead whales were found floating offshore in advanced states of decay, one sperm whale (*Physeter macrocephalus*) and one humpback whale. During the encounters 17,740 photos were taken for individual identification, and nine satellite tags were deployed on three species—four short-finned pilot whales (from two different social groups), two bottlenose dolphins, and three rough-toothed dolphins, although data were only obtained from seven of the tags (all but one short-finned pilot whale and one rough-toothed dolphin). Both of the other tagged rough-toothed dolphins and both of the bottlenose dolphins remained associated with the island of Kauaʻi, with bottlenose dolphins remaining in shallow depths (medians of 80 and 275 meters) and rough-toothed dolphins using slope waters (median depths of 1,450 and 1,680 meters). One of the tagged groups of short-finned pilot whales included re-sighted individuals known to be from the resident island-associated population. The other group had no re-sightings (of 21 distinctive individuals), and satellite-tag data suggest that they are part of the pelagic population. 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 (1,200 and 1,656 square kilometers [km^2]). Probability density analyses were undertaken separately for 13 resident short-finned pilot whales tagged off Kauaʻi since 2008, and for five pilot whales tagged off Kauaʻi and Oʻahu thought to be from the pelagic population. Core range for the pelagic population was more than 20 times larger (122,119 km^2) than for the resident population (6,157 km^2), and the overall range (using the 99 percent kernel density isopleth) was an order of magnitude larger for the pelagic population (755,166 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 movement and habitat-use data from all species should allow for a better understanding of the use of the range as well as provide datasets that can be used to estimate received sound levels at animal locations and examine potential responses to exposure.

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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) being undertaken by Cascadia Research Collective (CRC). In recent years most of the work 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, 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). Studies using satellite tags to assess movements and behavior of individual toothed whales on and around the 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 2015, there have been eight additional vessel-based field projects off Kaua‘i (seven in conjunction with passive acoustic monitoring [PAM] through the Marine Mammal Monitoring on Navy Ranges [M3R] program) during which satellite tags were deployed. During these eight efforts, 43 satellite tags were deployed on six different species of odontocete cetaceans (**Table 1**; Baird et al. 2011, 2012a, 2012b, 2013b, 2013c, 2014a, 2015). Results of field efforts through February 2014 have been previously summarized (Baird et al. 2015).

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, this work was conducted in the Hawai‘i Range Complex from 4 to 16 February 2015. This report presents findings from this monitoring effort, which was conducted in order to further our understanding of the following monitoring questions: what are the spatial-movement and habitat-use patterns (e.g., island-associated or open-ocean, restricted ranges vs. large ranges) of species that are exposed to mid-frequency active (MFA) sonar, and how do these patterns influence exposure and potential responses? The marine mammal monitoring reported here is part of a long-term monitoring effort under the U.S. Navy’s Marine Species Monitoring Program. In addition to the results of work in February 2015, we incorporate previous efforts, including results from a vessel-based field effort off Kaua‘i in October 2014, supported by the Navy’s Living Marine Resources program.

As well as addressing the specific Navy monitoring questions and increasing our general understanding of the odontocete populations off Kaua‘i and Ni‘ihau, there are several secondary goals, including providing visual species verification for acoustic detections through the M3R program. M3R is a real-time PAM system implemented at three major Navy undersea test and 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 the PMRF (2011–present). An additional goal is to obtain cetacean movement and habitat use information on and around the PMRF before, during, and after a Submarine Commanders Course scheduled to be undertaken after the field efforts, using data obtained from satellite tags (see Baird et al. 2014b).

2. Passive Acoustic Monitoring Methods

2.1 PMRF Undersea Acoustic Range

The PMRF instrumented hydrophone range is configured with 219 bottom-mounted hydrophones, 199 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. Each range consists of several offset bottom-mounted cables (strings), with multiple hydrophones spaced along each string to create hexagonal arrays.

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 via 199 PMRF bottom-mounted hydrophones (Jarvis et al. 2014). Prior to 2015, the M3R system at the PMRF was used on seven 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. 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 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. Signals from all of the hydrophones are processed in parallel, providing marine mammal detection, classification, and localization results for the entire range in real time. These real-time results allow a PAM analyst to isolate animal vocalizations on the range, confirm species classification, and choose optimal group localizations for attempting at-sea species verification. To date, classification is accomplished using software with manual review by an analyst. 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)-based detector is implemented using an adaptive threshold (exponential average) in each bin of the FFT. If the bin energy is over the adaptive threshold, the bin(s) is(are) set to a "one" and a detection report is generated. 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 2015 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 test. 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 segmentation-based 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 array, 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 is available. 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 determine 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) is also available for real-time analysis. An M3R interface module has been added to the program that allows selection of individual or small numbers of hydrophones for examination. The software is used to analyze selected hydrophone signals when questions arise as to signal type and origin. This is particularly useful for verifying the presence of beaked whale vocalizations. It has also proven useful for collecting time and frequency images and broadband cuts of selected signals.

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; then a second tool marks the position of individual foraging dives. These tools are being modified for the PMRF. As the mean group size and detection statistics for Blainville's beaked whales on the PMRF are determined, estimation of their density and distribution will be possible (Moretti et al. 2010).

2.3 Passive Acoustic Monitoring

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 typically minimal with trained PAM personnel. In addition, successive whistles were used to generate multiple solutions, which provide 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.

Detection archives were collected from all hydrophones for the entire period, 24 hr per day. These archives capture all detection reports, and automated localizations generated during the test.

3. Field Methods

3.1 Tag Types and Programming

Nineteen satellite tags were available for deployment, including 14 location-dive tags (Wildlife Computers Mk10-A) and five location-only tags (Wildlife Computers SPOT5) in the LIMPET configuration. Each tag is attached 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 bottlenose 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 are 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 hr/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 bottlenose dolphins transmitted for 15 hr/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 1–2 m/second, dive durations recorded are likely only 3–6 seconds shorter than actual dive durations. Prior to the field effort, satellite pass predictions were carried out using the Argos web site 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 land-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 is a similar system to that used in July 2013 and February 2014 (see Baird et al. 2014a, 2015); however, the system during this effort included three Telonics TGA-100 7-element antennas, each connected to a Telonics TSUR-400 uplink receiver, rather than a single antenna/receiver system. Each system was connected to a laptop with data recorded using Telonics Uplink Logger v. 1.00. The antennas were at a 456-m elevation, one oriented to the north, one oriented to the west, 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 2015. Ten days of effort was funded as part of the Navy’s Marine Species Monitoring program, and an additional three days of effort was funded by the Living Marine Resources program, with funds left over from a field project in October 2014 that ended early due to a hurricane.

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 in daylight hours as long as weather conditions were suitable. The primary launch site was the Kīkīaola small boat harbor, but alternative sites, including Port Allen and Nāwiliwili Harbor, were used when prevailing weather conditions warranted.

For calculating effort by depth and time within the PMRF instrumented hydrophone range boundaries, vessel locations were recorded on the 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. However, if there were no acoustic detections of high-priority species (e.g., species other than rough-toothed dolphins and bottlenose dolphins), survey effort was concentrated in deeper-water areas where working conditions were conducive to detecting and tagging high-priority species.

When positions from the M3R system were available, the RHIB would transit to specific locations in response to the positions and otherwise would survey areas for visual detection of groups. 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) were undertaken 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) were given higher priority than frequently encountered species (spinner, bottlenose, and rough-toothed dolphins). Extended work with frequently encountered species was typically only undertaken with groups that were suitable for tagging given behavior and sea conditions, and when no other higher-priority species were in areas suitable for working.

In general, species were photographed for species confirmation and individual identification. For each encounter we recorded information 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 and the distance among subgroups was also noted, and, when possible, camera frames were noted to allow for sorting by subgroup.

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

Five-minute effort locations were processed with ArcGIS to determine depth and whether locations were inside or outside the PMRF instrumented range boundaries. Photographs of most species were sorted within encounters to identify individuals, and the best photos of each individual within an encounter were categorized as to photo quality and distinctiveness following methods outlined in Baird et al. (2008a, 2009). All individuals of most species were compared to individual identification catalogs (Baird et al. 2008a, 2009; Mahaffy et al. 2015) to determine sighting histories. For each species, associations among individuals and groups were assessed with SOCPROG 2.64 (Whitehead 2008), and associations were visualized using Netdraw 2.155 (Borgatti 2002). Pilot whales encountered were assigned a population (insular, pelagic, or unknown) based on associations, sighting histories, and movement patterns taken from tagging data. When tagging data were available, population identity of sub-groups recorded in the field was assessed independently and 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 protocols previously used (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 proportion of time spent within PMRF boundaries, as well as the number of times an individual was found inside the range 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.

Probability density maps were generated using all filtered satellite-tag data for all individuals of each of three species satellite tagged off Kauaʻi. Location data from the first 24 hours post-tagging were removed to address potential bias associated with the location where individuals were tagged. Kernel density polygons were generated using the R package adehabitatHR v.

0.4.11[1] and corresponded to the 50, 95 and 99 percent densities. Polygons were plotted in Google Earth Pro v. 7.1.2.2041.

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 individuals were acting independently, following protocols described by Schorr et al. (2009) and Baird et al. (2010).

Data obtained from the shore-based Argos uplink receivers and from the Argos System were processed through the Wildlife Computers DAP Processor v. 3.0 to obtain diving and surfacing data from the location-dive tags.

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

4. Results

From February 4 to 16, 2015, there were 1,132 km (63.4 hr) of small-vessel field effort, with the boat on the water 9 of the 13 days (**Table 4**). There was no survey effort on 4 days due to high winds, with winds forecasted from 20 to 25 knots from the west, northwest, or southwest. Westerly, southwesterly, or northwesterly winds were forecasted/present on 6 of the remaining 9 days, ranging from 15 to 20 knots, further limiting survey effort on the PMRF. On three of these days the research vessel was launched from Nāwiliwili Harbor and efforts were restricted to off the east side of Kauaʻi, and on 1 day the vessel was launched from Port Allen and efforts were primarily to the east of Kauaʻi due to unworkable conditions off the south shore. The research vessel was launched from Kīkīaola small boat harbor on 5 days, but the range was either unworkable due to winds (1 day) or range restrictions (2 days) for 3 of the 5 days. Acoustic monitoring with the M3R system was thus only undertaken on 2 days. On those days, acoustic monitoring was undertaken prior to the RHIB entering PMRF each day and concluded after the RHIB left the range, for a total of 21.5 hr of acoustic monitoring (**Table 5**).

Overall, there were 35 sightings of at least five species of odontocetes and one species of mysticete other than humpback whales (which were not approached), five of which were on PMRF (**Figure 1**, **Table 6**). Bottlenose dolphins were encountered on seven occasions, spinner dolphins on two, rough-toothed dolphins on 20, short-finned pilot whales on three, unidentified odontocetes once, dwarf sperm whales once, and fin whales once. Three of the five encounters on PMRF (two groups of pilot whales and one group of bottlenose dolphins) were directed by acoustic detections from the M3R system. The remaining two encounters (bottlenose dolphins) were visually sighted on the edge of the range on our last day of field effort, when the range had been closed until mid-afternoon and no M3R monitoring was being undertaken. Two dead whales were found floating offshore north of Kauaʻi in advanced states of decay, one humpback whale and one sperm whale (**Figure 1**). These are the first dead cetaceans documented during CRC's research efforts in Hawaiian waters.

During the encounters 17,740 photos were taken for individual identification and nine satellite tags were deployed on three species (**Table 7**). Identification photos were obtained from two encounters with spinner dolphins for contribution to a photo-identification catalog held at the Pacific Islands Fisheries Science Center, but no attempts were made to tag this species due to the small size of their dorsal fins.

4.1 Short-finned pilot whales

Short-finned pilot whales were encountered on three occasions, with two of the three sightings on the PMRF (**Figure 1**). During the three encounters 58 identifications were obtained, and of those 35 were of distinctive individuals with good- or excellent-quality photos. From 6 to 21 identifications were obtained from each of the three encounters. The 35 individuals represented three different social groups, each seen just once during the field effort. All individuals were compared to our photo-identification catalog (Mahaffy et al. 2015). Seven of the 35 distinctive individuals had been photo-identified in previous years, one of eight distinctive individuals from one encounter and all six distinctive individuals from another encounter. The previously re-sighted individuals were all 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 they are part of the resident island-associated community. Satellite tags were deployed on two individuals in one of these resident groups (**Table 6**); weather conditions and behavior of the whales prevented deployment of tags on the second resident group. Locations were obtained from the tags on the two individuals for 7.5 days (GmTag114, catalog ID HIGm1174) and 10 days (GmTag115, catalog ID HIGm2483). HIGm1174 was first documented off Oʻahu in 2008, while HIGm2483 had not been previously documented (**Table 8**). An analysis of the distances between satellite-derived locations for HIGm1174 and HIGm2483 during the period of overlap (not shown) indicates that they remained generally associated during this period, with a median distance between the two individuals of 1.7 km (maximum = 10.4 km). When location classes are restricted to LC1 and greater (n=4 pairs of locations), the median distance between the two individuals was only 0.7 km (maximum = 1.3 km), suggesting they were closely associated during the period of overlap. The two individuals spent between 25 and 29.7 percent of their time on PMRF (**Table 9**), with movements offshore to the east of Kauaʻi and Niʻihau (**Figure 4**).

One of the three groups of pilot whales had good-quality photos of 21 distinctive individuals, none of which had previously been photo-identified. Satellite tags were deployed on two individuals, although one tag only transmitted for approximately 1 hr. Location data for the second individual (GmTag117, catalog ID HIGm2523) were obtained over a 45-day period. During this time the whale was only briefly inside the PMRF boundaries, spending less than 1 percent of its time there (**Table 9**). Over the 45-day period the whale ranged broadly offshore around the main Hawaiian Islands, moving to the west, then back to the east south of Kauaʻi, to the north between Kauaʻi and Oʻahu, and offshore to the north of the islands as far east as Hawaiʻi Island (**Figure 4**). Based on the lack of re-sightings of the group and the wide-ranging movements, this group is likely from the pelagic/open-ocean population.

Very few individuals from the open-ocean population have been previously satellite tagged. These include three individuals tagged off Oʻahu in 2010 (Baird et al. 2013b) and one individual tagged off Kauaʻi in October 2014, both through field efforts funded by the Living Marine Resources program. Movements of the individuals tagged in 2010 were broadly ranging north and south of the main Hawaiian Islands (Figure 13 in Baird et al. 2013b), and the individual tagged in October 2014 (GmTag104, catalog ID HIGm0263, see **Table 7, Figure 4**) moved to the north of Oʻahu and then far to the west of the main Hawaiian Islands, near French Frigate Shoals within the Papahānaumokuākea Marine National Monument.

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 (i.e., the three individuals tagged off Oʻahu in 2010, as well as GmTag104 and GmTag117) and the 13 individuals known to be from the island-associated population (**Figure 5**). The calculated area of the core range (inside the 50 percent isopleth) is more than 20 times larger for the individuals from the pelagic population (122,119 km^2) than for the island-associated population (6,157 km^2; **Table 11**), despite the much smaller sample size for pelagic individuals.

4.2 Rough-toothed dolphins

Rough-toothed dolphins were encountered on 20 occasions, with all of sightings outside of PMRF boundaries and 18 of the 20 off the east side of Kaua‘i (**Figure 1**). Although three individuals were satellite tagged, data were only obtained from two of the three tags, one a location-dive tag and one a location-only tag (**Table 7**). Both individuals were tagged off the east side of Kaua‘i, whereas all previously tagged rough-toothed dolphins have been tagged off the west side of Kaua‘i.

Identification photos were obtained from 16 of the 20 encounters, representing 118 identifications. Restricting these to good- and excellent-quality photos of distinctive and very distinctive individuals, 89 identifications were obtained, representing 81 individuals, with eight individuals seen twice during the field effort. A comparison of the 81 individuals to our photo-identification catalog of this species (Baird et al. 2008b) revealed that 33 of the individuals had been previously photo-identified off Kaua‘i (including two of the tagged individuals, although tag data were only obtained from one), and one individual had been previously photo-identified off O‘ahu (**Table 8)**. A social network analysis indicates that both of the tagged individuals for which data were obtained are linked by association with the main social cluster of rough-toothed dolphins off Kaua‘i and Ni‘ihau (**Figure 6**).

Location data were obtained for 21.8 (SbTag014, catalog ID HISb1668) and 14.3 days (SbTag015, catalog ID HISb2045), and dive data were obtained for 104.1 hours from HISb2045.

An analysis of distances between locations of the two individuals obtained during the same satellite overpasses (not shown) revealed that those distances varied widely, with a mean distance between them of 16.5 km (maximum of 65.9 km). While there were five 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 both individuals circumnavigated Kaua‘i (**Figure 8**) and spent time in the channel between Kaua‘i and Ni‘ihau. There were four different periods for HISb1668 and eight periods for HISb2045 where the individuals were inside the PMRF boundary, respectively, with 17.5 percent and 26.7 percent of their time spent inside the range boundary (**Table 9**).

A probability density map using tag data from all 14 rough-toothed dolphins satellite tagged off Kaua‘i, excluding data from one of each pair of individuals acting in concert, and with the first 24 hours of data from each individual omitted, indicated that the channel between Kaua‘i and Ni‘ihau represents the core area for these individuals (**Figure 8**), with a large proportion of the core area overlapping with the PMRF.

Dive data indicated that HISb2045 exhibited relatively shallow dives (median and maximum depths of 57.5 and 351.5 m, respectively; **Table 10**). Given that the median depths of locations for HISb2045 was 1,680 m (**Table 9**), all dives were likely to mid-water.

4.3 Bottlenose dolphins

Bottlenose dolphins were sighted on seven occasions (**Figure 1**) and photos were obtained from six of the seven encounters, representing 80 identifications. Restricting analyses to good-quality photographs of distinctive individuals, there were 46 identifications representing 39 individuals. A comparison to the long-term photo-identification catalog (Baird et al. 2009) indicated that 33 of the 39 individuals were previously documented, all off Kaua‘i and/or Ni‘ihau. Of those 33 that were previously documented, 10 had been seen in one previous year, 17 had been seen in 2 previous years, 10 had been seen in 3 previous years, eight had been seen in 5 previous years, and one had been seen in 6 previous years. Eight of the individuals were first documented off Kaua‘i and Ni‘ihau over 11 years earlier (maximum span of years = 11.7), during CRC’s first field project off Kaua‘i in 2003 (Baird et al. 2003). Individuals from all encounters where more than a single individual were photo-identified (n=5, see **Table 5**) were linked by association in a single social network (**Figure 9**), indicating they were all from the island-associated population. Excluding 15 individuals photographed off Ka‘ula Island, 95.4 percent of the individuals photo-identified off Kaua‘i and Ni‘ihau since 2003 have been linked by association within this social network, suggesting that non-resident bottlenose dolphins rarely visit the area.

Two individuals were satellite tagged, both with location-dive tags, on two different days (**Table 7**), although dive data were only obtained from one of the two tags (**Table 10**). An assessment of distances between locations of the two individuals during the same satellite overpasses (not shown) indicated that those distances varied widely, with a median distance between them of 43.2 km (maximum of 60.5 km). There was no occasions when the two individuals were within 2 km of each other, thus they appeared to be travelling independently. One individual (TtTag022, catalog ID HITt0904) was tagged off the east side of Kaua‘i, the first bottlenose dolphin satellite tagged off the east side of the island. HITt0904 remained associated with the east and southeast side of the island over the 7.2 days of signal contact (**Table 7; Figure 10**). HITt0904 had not previously been documented (**Table 8**), and was the only distinctive individual in a group of three, thus did not link by association to the resident social network (**Figure 9**). The other individual (TtTag023, catalog ID HITt0911) was tagged off the west side of the island and used the north, south, and west sides of the island (**Figure 10**). Median depths at tag locations were 80 m for HITt0904 and 275 m for HITt0911 (**Table 9**). Sixty-four hours of dive data were obtained from HITt0904, and median depth of dives was 79.5 m (maximum = 423.5), suggesting that most dives were to, or close to, the bottom (**Table 10**).

Tracks of two individual bottlenose dolphins satellite tagged in October 2014 are also shown in **Figure 10**. One of the two individuals (TtTag019, catalog ID HITt0898) spent nine days around Kaua‘i before moving to an area south of O‘ahu, remaining there for a further 6 days before the tag stopped transmitting (**Figure 10**). A probability density map of tag data from all 12 bottlenose dolphins tagged off Kaua‘i 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 Kaua‘i have the smallest ranges of any of the three species examined (**Table 11**).

4.4 Fin whales

Two adult fin whales were encountered in deep water (2,800 m) to the southwest of Kaua‘i on February 12, 2015. These were the first fin whales documented in CRC’s research off Kaua‘i or Ni‘ihau. Although we were unable to get close enough to attempt to tag, both individuals were distinctive and good-quality photographs were obtained for individual identification. Prior to this field effort no photo-identification catalog existed for fin whales in Hawaiian waters, so a catalog was established with all known identifications available, including six fin whales photographed during a National Marine Fisheries Service 2010 survey, one fin whale documented off Kauaʻi in 2010, one fin whale documented during CRC research off Lānaʻi in December 2012, and three fin whales photographed off Hawaiʻi Island in January 2015. No matches were found among the 13 identifications in the catalog.

5. Discussion and Conclusion

Over the 13-day field effort it was only possible to work on the PMRF on 2 days, primarily due to strong prevailing winds coming from the west (**Table 5**). Given the low densities of most species of odontocetes around the main Hawaiian Islands (Baird et al. 2013a), the amount of field effort, particularly in deep waters (**Figures 1 and 2**), was not enough to have a high likelihood of encountering many of the high-priority deep-water species, such as Cuvier's beaked whales, sperm whales, or melon-headed whales. There was one sighting of dwarf sperm whales off the south shore of Kaua‘i (**Figure 1**), CRC's first sighting of this species off Kaua‘i since a field project in 2003 (Baird et al. 2003).

While strong prevailing winds precluded extending much effort into the PMRF, it did provide an opportunity to survey off the east side of Kaua‘i, an area not surveyed in our small-boat work since 2003 (see Baird et al. 2003). The large number of sightings of rough-toothed dolphins off the east side of Kaua‘i (18 of 20; **Figure 1**) was particularly notable, with an overall sighting rate of rough-toothed dolphins approximately an order of magnitude higher than has been typical for projects off the west side of Kaua‘i during this time of year (see Baird et al. 2012b, 2013c, 2015). Based on the high proportion of photo-identified individuals that had been previously documented off the island (33 of 81; 40.7 percent), these individuals appear to be part of the resident island-associated population.

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 the addition of tags deployed on two rough-toothed dolphins and a bottlenose dolphin off the east side of the island help reduce potential spatial biases resulting from tag deployment locations. Although data are available from these three species, they represent four different populations. Satellite-tag data are available from both the insular and pelagic short-finned pilot whale populations, and the tag data illustrate vastly different ranges (see **Figure 8** and **Table 11**). In all three species, the core areas (represented by the 50 percent kernel polygons) overlap with the PMRF to varying degrees (**Figures 5, 8,** and **11**), reflecting the importance of the channel between Kaua‘i and Ni‘ihau to these species, and also having implications for exposure to MFA sonar. Preliminary acoustic propagation analyses of sonar use on the PMRF during Submarine Commanders Courses suggest that MFA sonar on the PMRF is generally audible to cetaceans throughout the PMRF (S.W. Martin, National Marine Mammal Foundation, personal communication). These high-density areas overlapping with the PMRF indicate that individuals from all three insular populations likely have repeated exposures to audible levels of MFA sonar at the 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. The tag deployments to date on bottlenose and rough-toothed dolphins appear to be from the known resident populations (see also Baird et al. 2008b, 2009, and Martien et al. 2011). Given the overlap in core areas with the PMRF (**Figures 8 and 11**), it is likely that individuals within these resident populations are repeatedly exposed to MFA sonar. However, the deployments of satellite tags on pilot whales occurred from three social groups with varying re-sighting histories among the islands (**Table 8**). Two of the groups from the resident population may receive more frequent exposure to MFA sonar when compared to the one group from the pelagic population (**Figure 5**), illustrating that the amount of exposure to MFA sonar will likely vary by social cluster. Reactions to MFA sonar are likely to be influenced by prior exposure history, 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. For example, repeated exposure might lead to permanent threshold shifts in individuals in the resident population, but they might also have become more habituated to the noise, and developed behavioral adaptations to reduce their exposure. Individuals in the pelagic population will be exposed less often, but they will also be less likely to have developed behavioral responses that allow them to deal with high levels of exposure.

As photo-identification sample sizes increase, the ability to estimate abundance of the respective populations with higher levels of precision improves, 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, 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.

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8. Figures

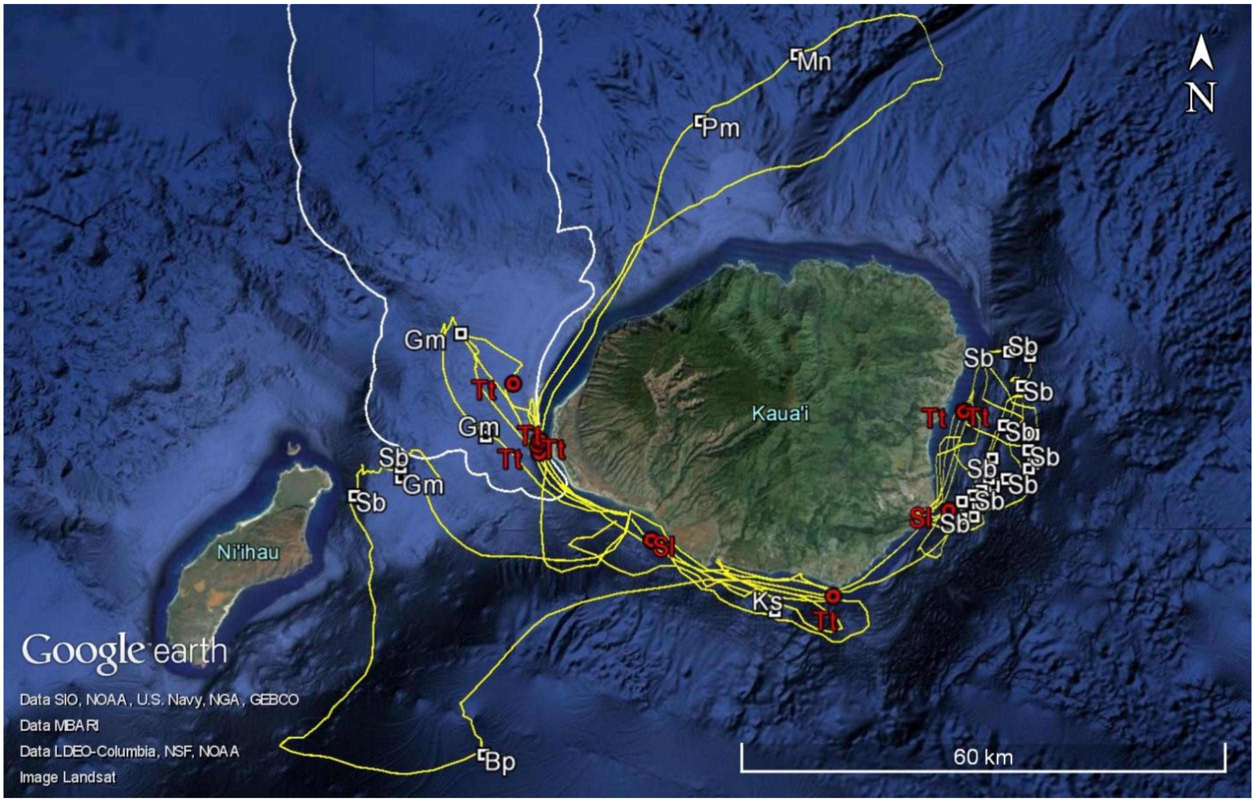


Figure 1. February 2015 tracklines of small-vessel field effort (yellow) and sighting locations (symbols with species abbreviations as labels). The single sperm whale (Pm) and humpback whale (Mn) shown were dead animals. Sightings of live humpback whales are not shown as most groups were not approached. Symbols and labels for bottlenose dolphins (Tt) and spinner dolphins (Sl) are shown in red for clarity. The overall PMRF boundary is indicated with a solid white line. Bp = *Balaenoptera physalus*; Gm = *Globicephala macrorhynchus*; Ks = *Kogia sima*; Mn = *Megaptera novaeangliae*; Pm = *Physeter macrocephalus*; Sb= *Steno bredanensis*; Sl = *Stenella longirostris*; Tt = *Tursiops truncatus*.

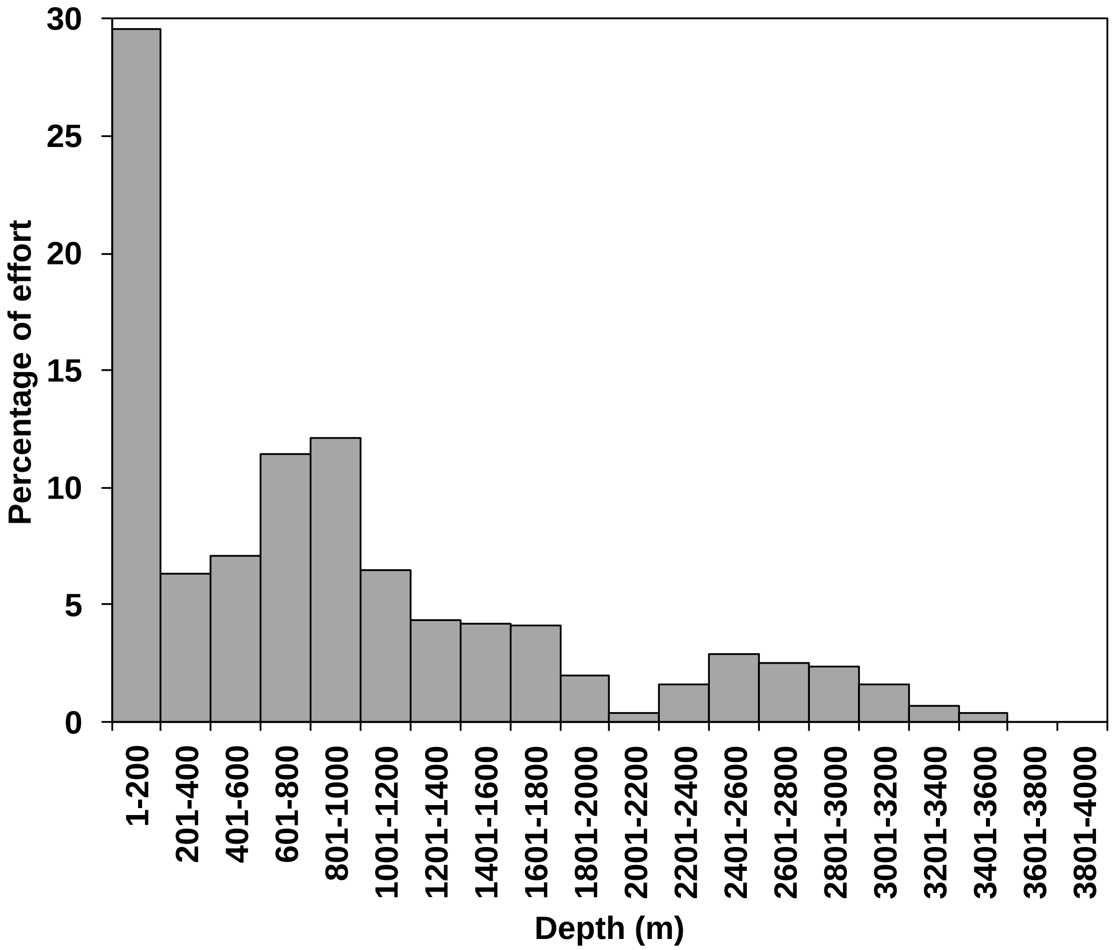


Figure 2. Depth distribution of small-vessel effort during February 2015 field effort.

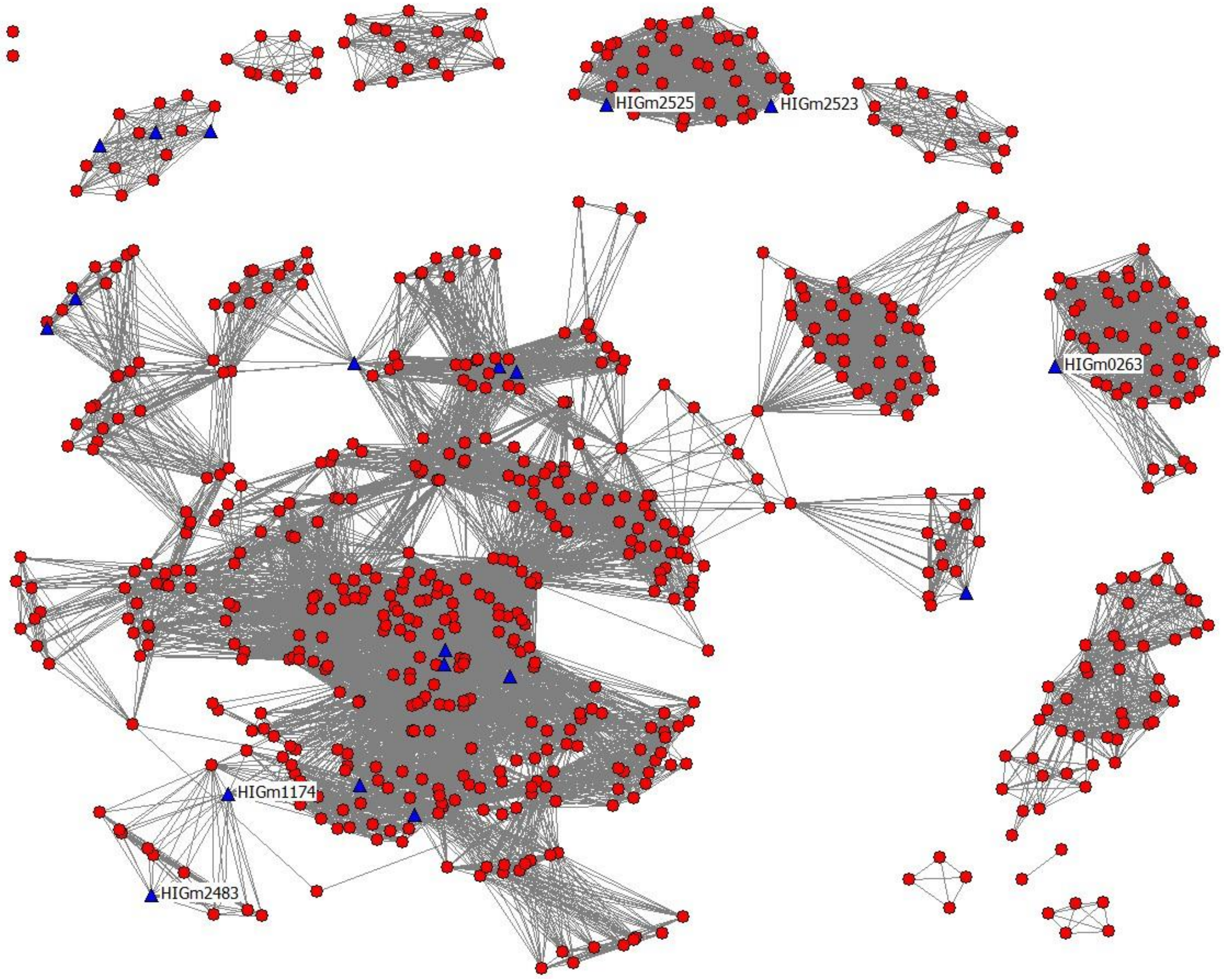
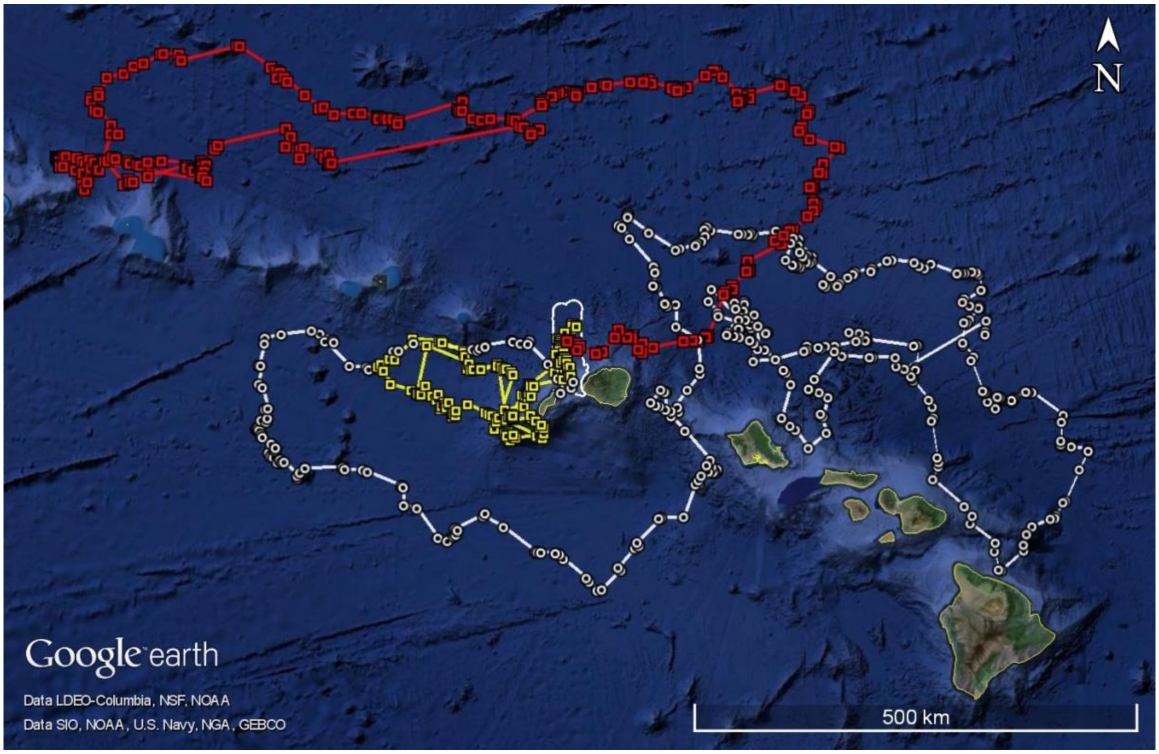


Figure 3. Social network of photo-identified short-finned pilot whales off Kaua'i and Ni'ihau, with all tagged individuals (including those tagged in previous efforts) noted by blue triangles. Those individuals tagged in February 2015 and October 2014 are indicated with ID labels. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Mahaffy et al. 2015), with a total of 685 individuals shown (the main cluster contains 487 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.



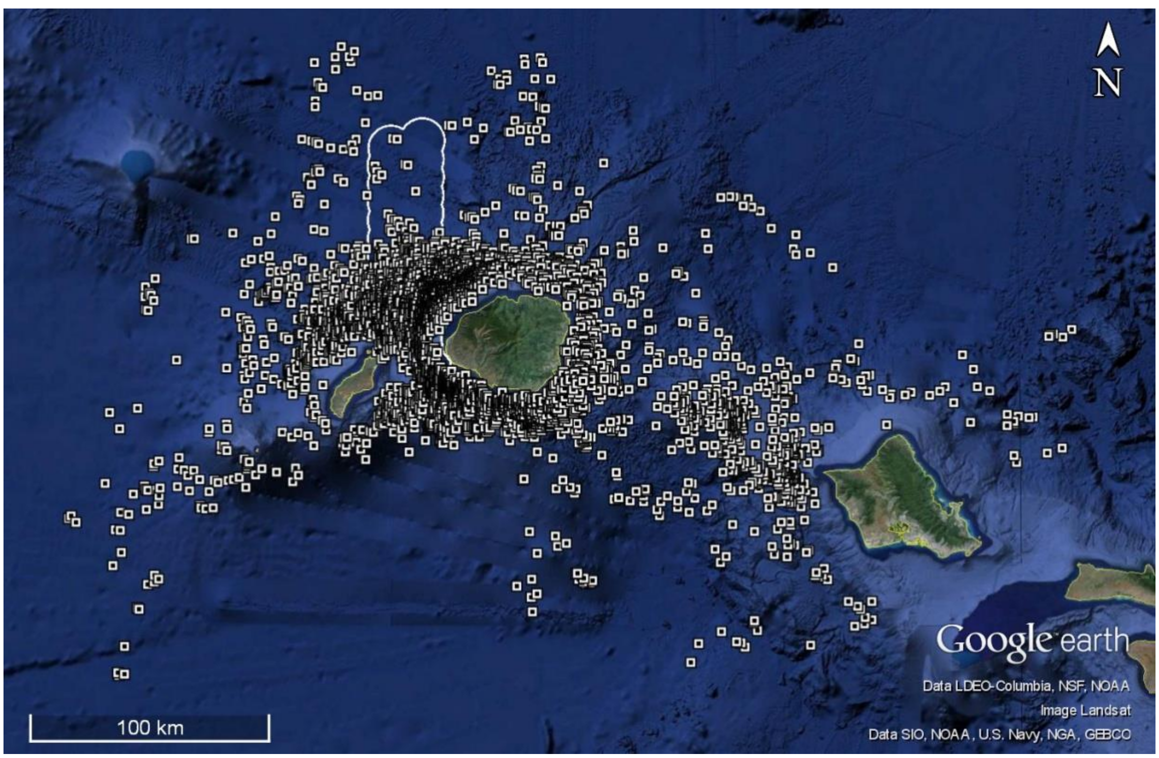
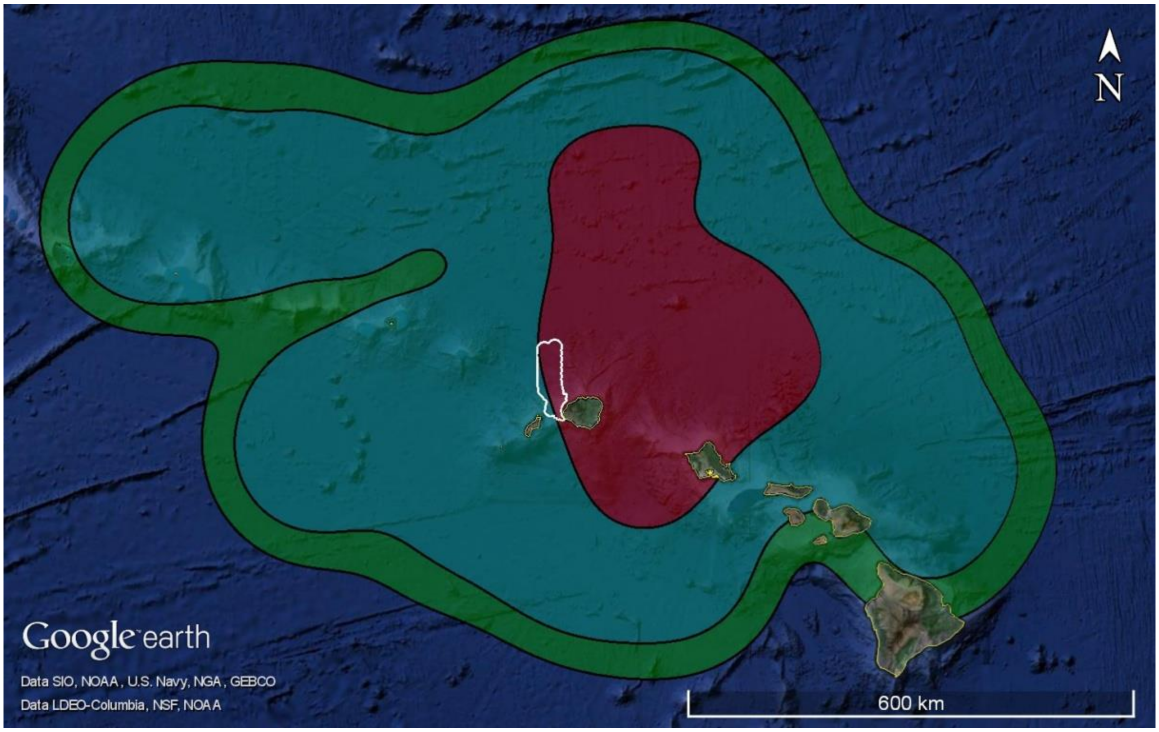


Figure 4. Top. Locations from short-finned pilot whales tagged off Kaua'i and Ni'ihau in October 2014 and February 2015. Lines connect consecutive locations. GmTag104 (red) was tagged in October 2014 and tracked over 28 days. GmTag114 and GmTag115 (yellow) were tagged in the same group in February 2015 and tracked over a total of 10 days. GmTag117 (white) was tagged in February 2015 and tracked over 45 days. Bottom. Locations from all 13 previous short-finned pilot whale tag deployments off Kaua'i. The PMRF boundary is shown in white.



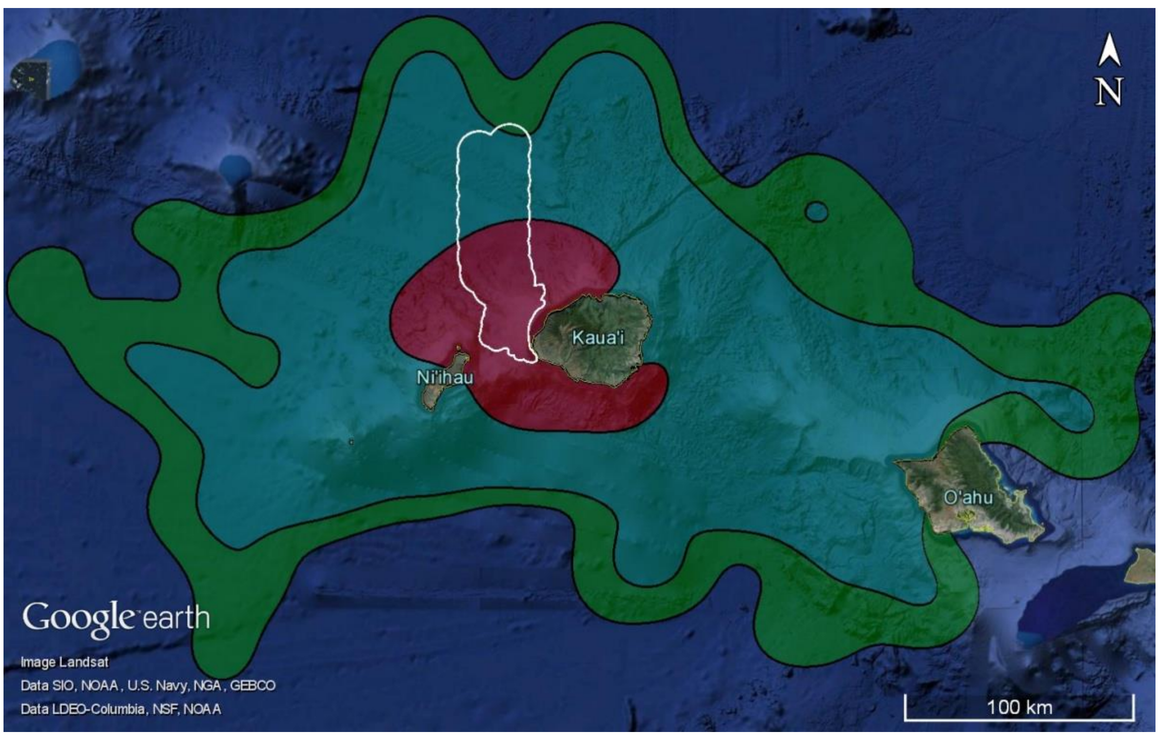


Figure 5. Probability density representation of short-finned pilot whale location data from satellite tag deployments off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals with overlapping tag data that were acting in concert were used. Top. Individuals known to be part of the open-ocean population (n=5), including three individuals tagged off O'ahu in 2010. Bottom. Individuals known to be part of the resident island-associated population (n=13). The red area indicates the 50% density polygon (the "core range"), the light blue represents the 95% polygon, and the green represents the 99% polygon. The PMRF boundary is shown as a solid white line.

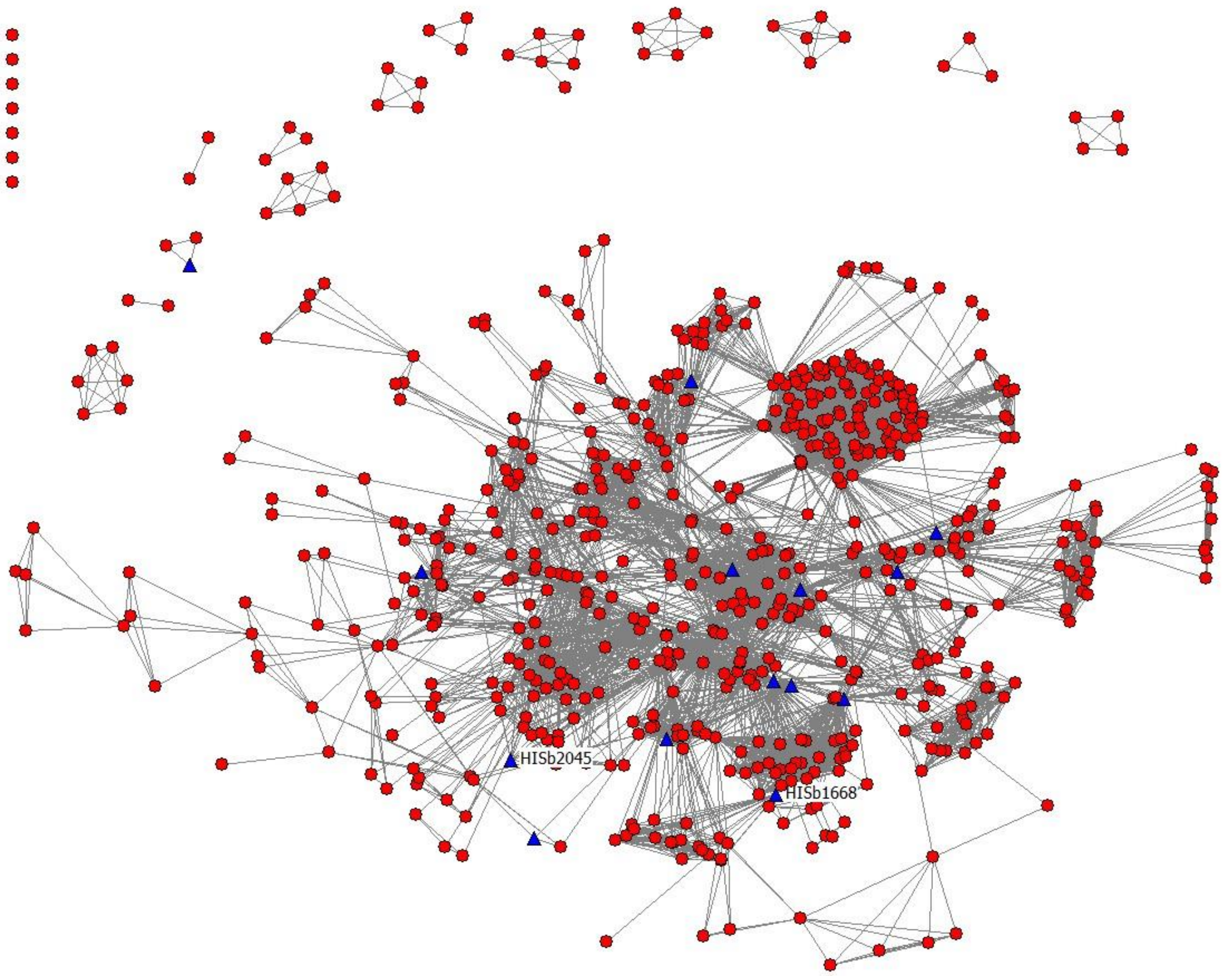
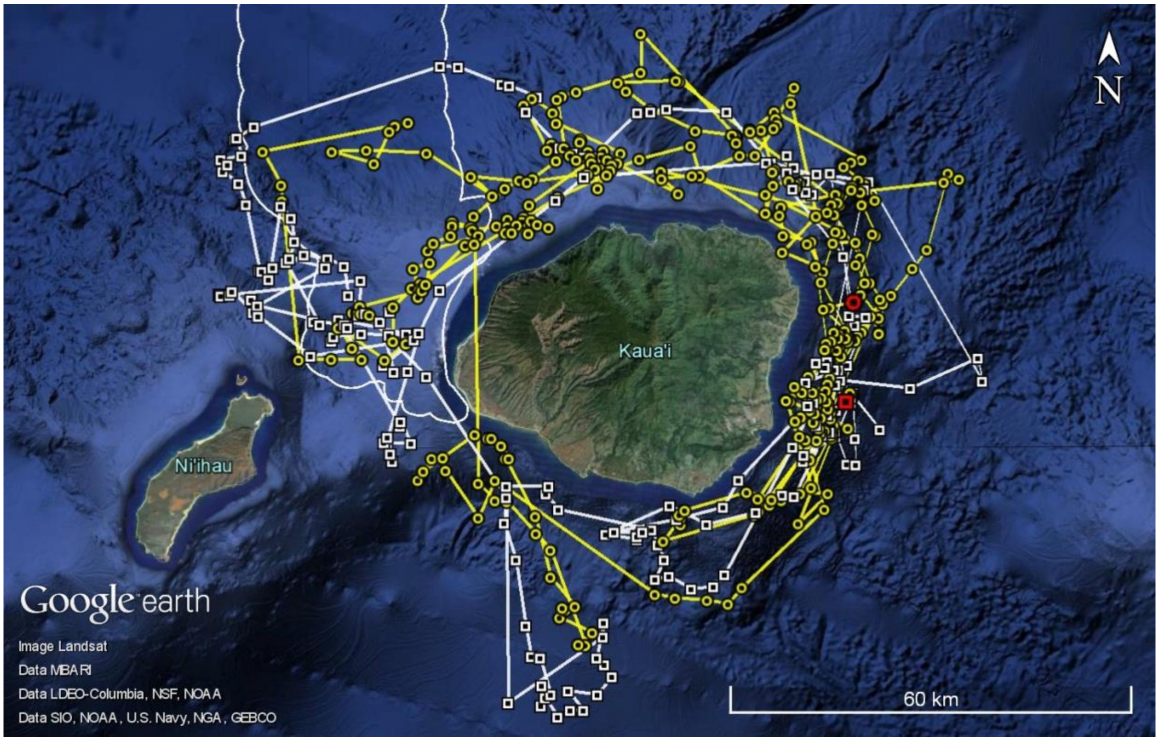


Figure 6. Social network of rough-toothed dolphins photo-identified off Kaua'i and Ni'ihau from 2003 through February 2015, with tagged individuals noted by blue triangles. Those individuals tagged in February 2015 for which data were obtained are indicated with ID labels. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2008b), with a total of 654 individuals shown (the main cluster contains 596 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.



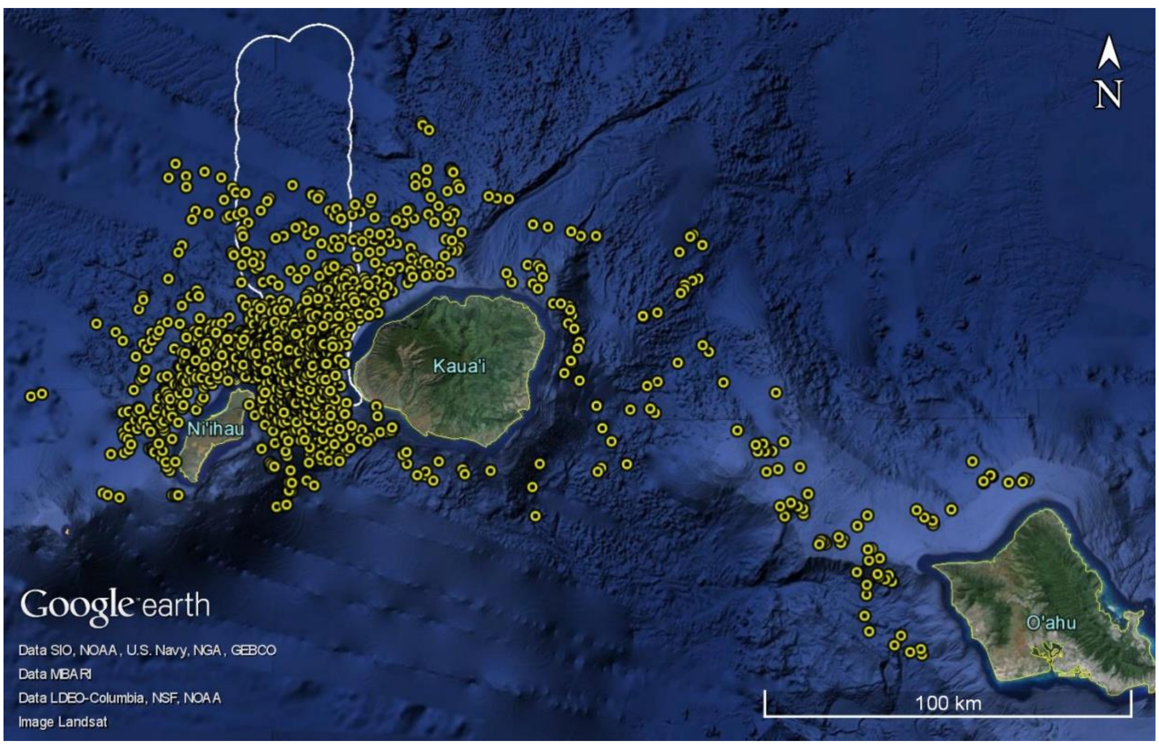


Figure 7. Top. Locations of rough-toothed dolphins satellite tagged in February 2015 (yellow circles SbTag014; white circles SbTag015), with lines connecting consecutive locations. Tagging locations are shown in red. Bottom. Locations of 12 previous satellite-tagged rough-toothed dolphins, including individuals tagged in July/August 2011 (three individuals), January 2012 (one individual), June/July 2012 (three individuals), February 2013 (one individual), July 2013 (two individuals) and February 2014 (two individuals). The PMRF boundary is shown as a solid white line.

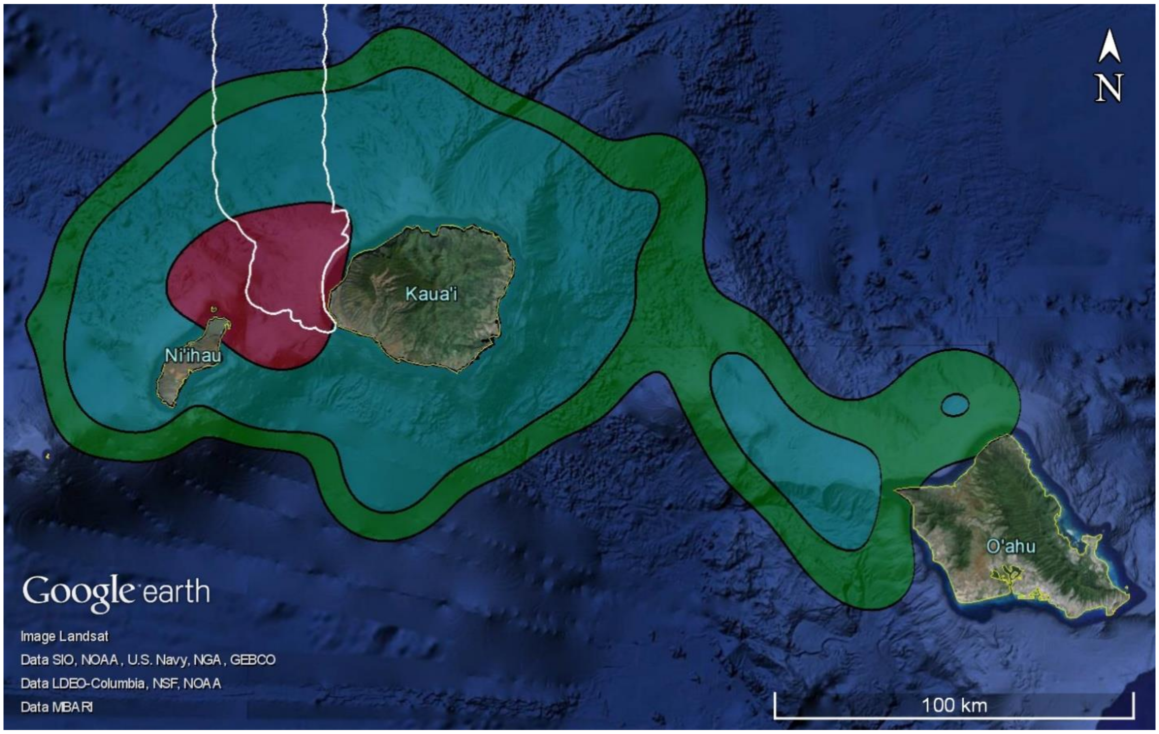


Figure 8. A probability density representation of rough-toothed dolphin location data from all 14 satellite tag deployments off Kaua'i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias, and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50% density polygon (the "core range"), the light blue represents the 95% polygon, and the green represents the 99% polygon. The PMRF boundary is shown as a solid white line.

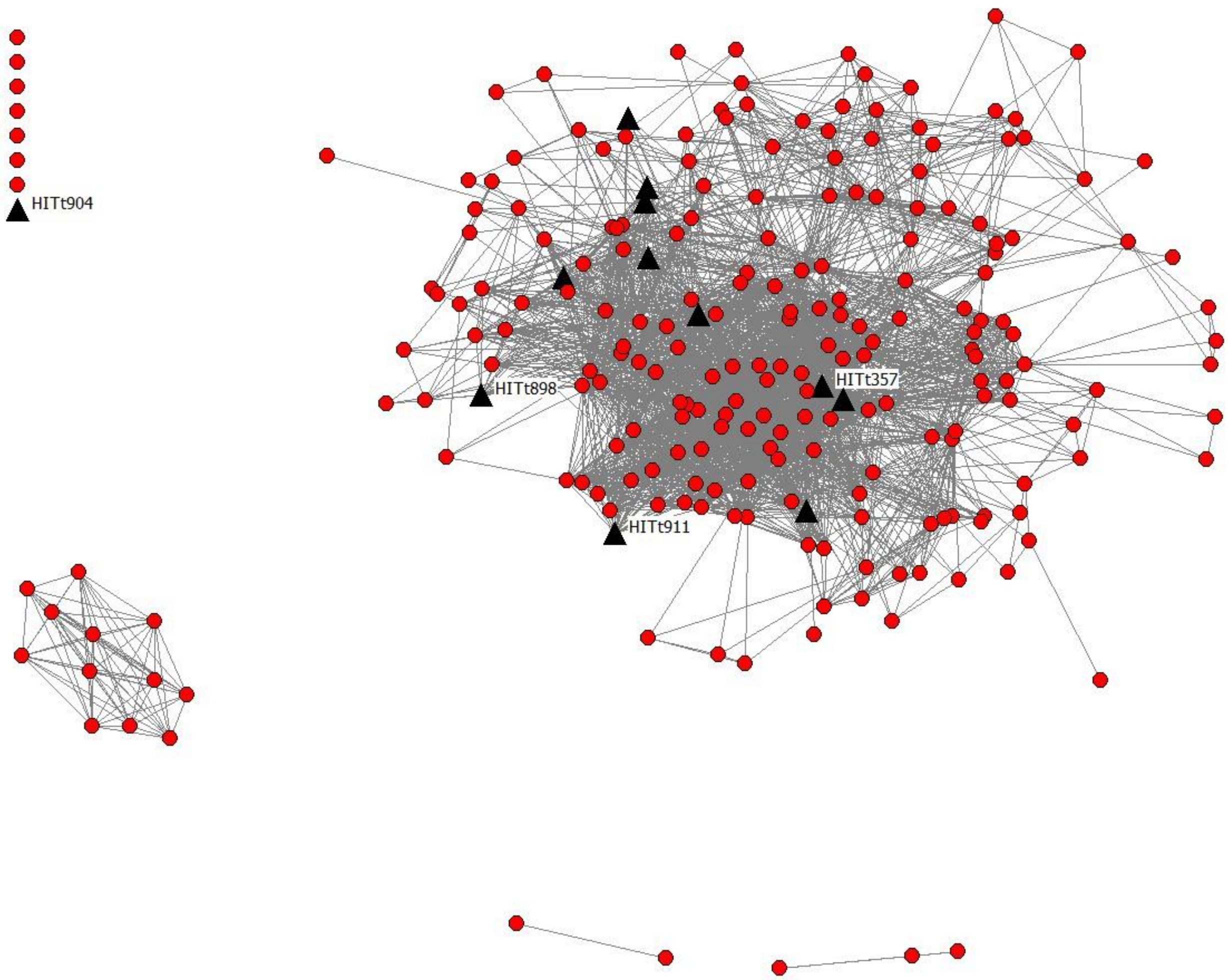


Figure 9. Social network of bottlenose dolphins photo-identified off Kaua'i and Ni'ihau from 2003 to February 2015, with tagged individuals noted by black triangles, with individuals tagged in October 2014 and February 2015 identified with ID labels. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair-, good-, or excellent-quality photographs (see Baird et al. 2009), with a total of 236 individuals shown (the main cluster contains 211 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.

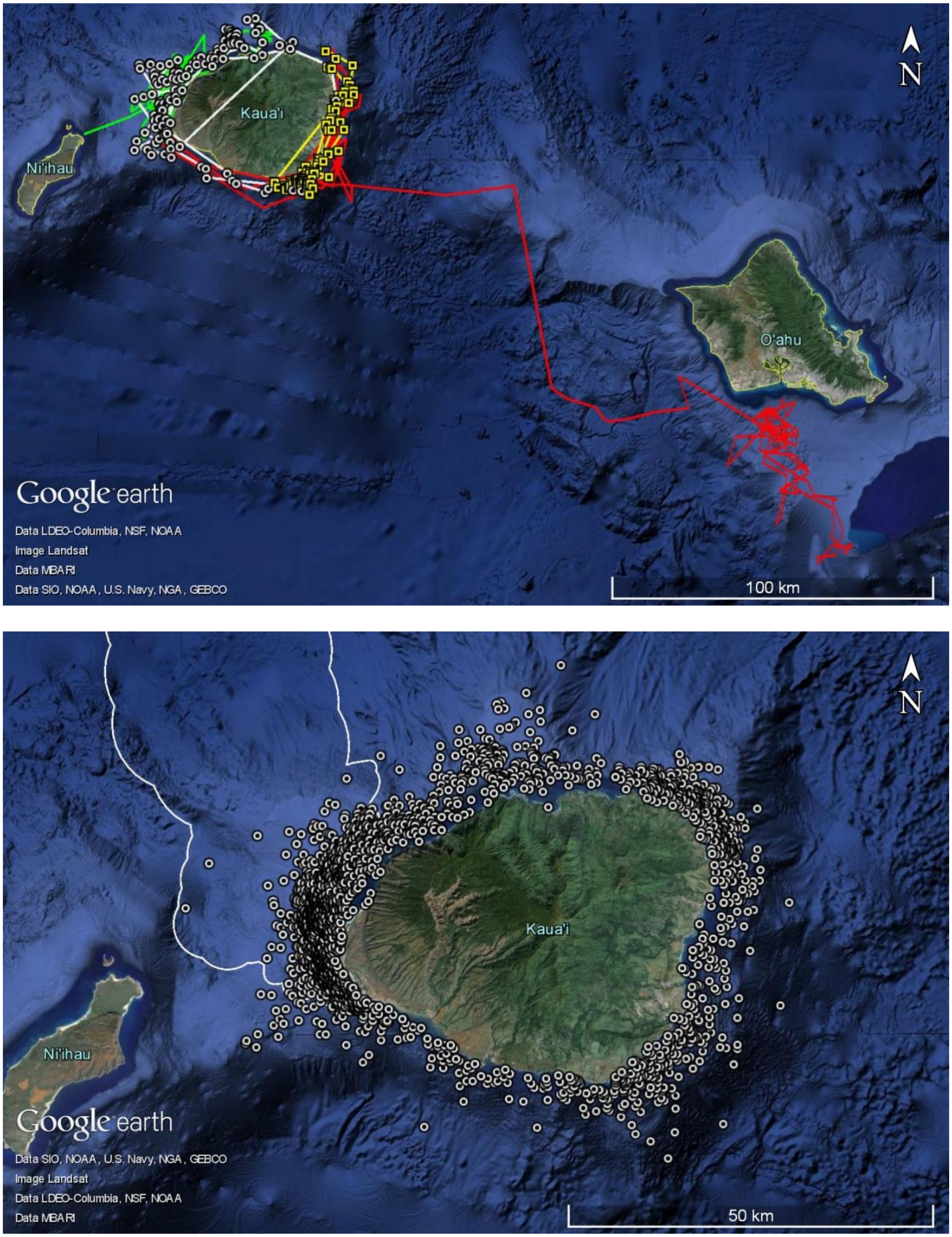


Figure 10. Top. Bottlenose dolphins satellite tagged in October 2014 and February 2015. Tracks only are shown for TtTag019 (red) and TtTag020 (green), while tracks and locations are shown for TtTag022 (yellow squares) and TtTag023 (white circles). Bottom. Locations of eight previous satellite-tagged bottlenose dolphins, including individuals tagged in August 2011 (one individual), June 2012 (two individuals), February 2013 (three individuals), February 2014 (two individuals). The boundary of PMRF is shown as a solid white line.

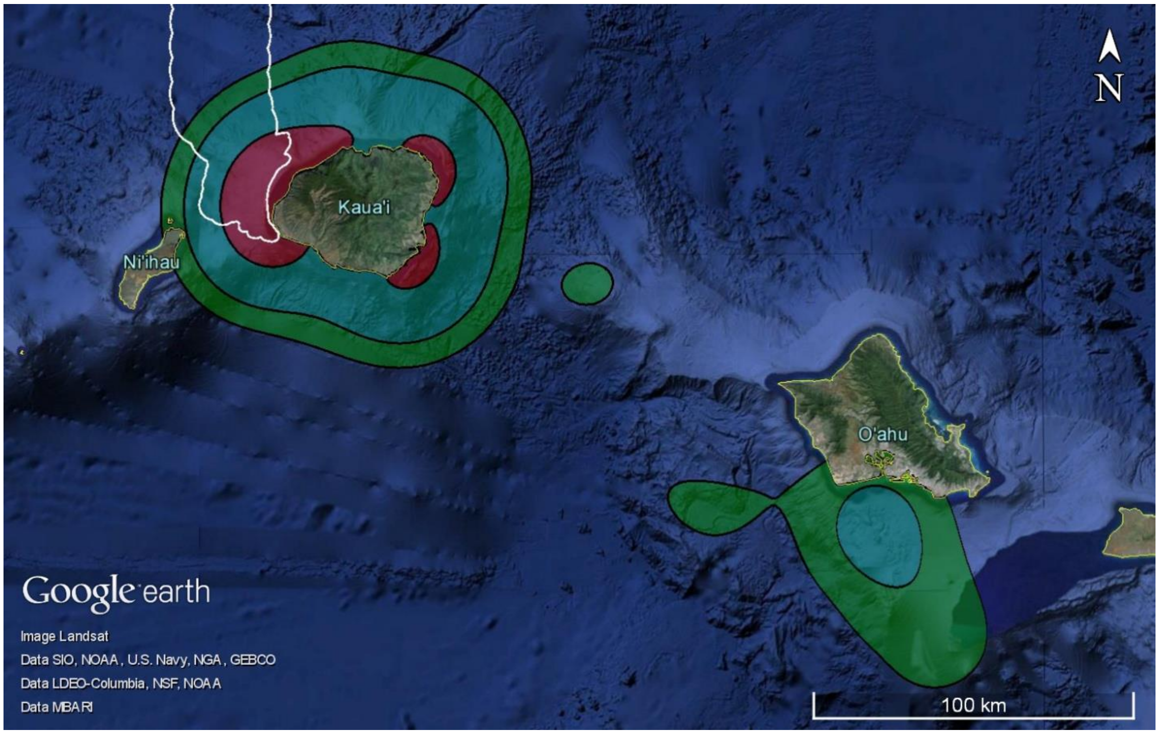


Figure 11. Kernel-density representation of bottlenose dolphin location data from all 12 satellite tag deployments off Kaua‘i. Location data from the first 24 hours of each deployment were omitted to reduce tagging area bias and only one of each pair of individuals with overlapping tag data that were acting in concert were used. The red area indicates the 50% density polygon (the “core range”), the light blue represents the 95% polygon, and the green represents the 99% polygon. 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, Gm, Sl*	*Gm* (1), *Pe* (3)	N/A
16-20 Feb 2011	33.9	*Tt, Sb, Gm, Sl*	*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, Gm, Sl, Md*	*Sb* (1), *Gm* (2)	*Tt, Sb, Gm, Sl, Md*
12 Jun-2 Jul 2012	115.7	*Tt, Sb, Gm, Sl, Sa, 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, Md, Gm*	*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*
Total	**600.9**		*Gm* (15)[2], *Pe* (3), *Tt* (10), *Sb* (12), *Pc* (6), *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	~1,000-2,000m	2-42 (1-5) 1,10,21,24,37,41	8-40 kHz 50 Hz-40 kHz
BSURE Legacy	~2,000-4,000m	43-60 (A,B)	50 Hz-18 kHz
SWTR	~100-1,000m	61-158 (C-H)	5-40 kHz
BSURE Refurbish	~2,000-4,000m	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 40-48 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	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 2015 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
04 Feb 2015	131.2	7.7	4	7:03	12:40	0	2.8	18.1	8.3	102.0
05 Feb 2015	63.4	4.1	8	7:05	15:44	0	2.5	51.4	9.5	0
06 Feb 2015	90.8	5.2	1	7:21	14:26	0	3.1	65.0	14.4	8.3
07 Feb 2015	85.6	4.6	1	7:32	8:17	0	8.3	35.4	30.2	11.7
08 Feb 2015	81.5	4.2	1	7:19	16:08	0	0	11.6	10.2	59.7
11 Feb 2015	81.1	5.7	8	7:24	10:45	0	0	25.8	38.9	16.4
12 Feb 2015	223.4	11.4	4	7:14	15:40	10.0	38.1	175.3	0	0
15 Feb 2015	153.2	9.2	3	7:16	15:32	0	8.4	48.5	72.2	24.1
16 Feb 2015	222.3	11.3	4	7:59	14:47	8.0	62.6	79.5	53.2	19.0
Total	1,132.5	63.4	34							

HST = Hawai‘i Standard Time; km = kilometers

Table 5. February 2015 M3R effort summary.

Date	Range Availability for Small Boat Operations		PAM Effort (HST)	
	Area	Time	Start	Stop
08 Feb 2015	BARSTUR	0630-1700	0630	1700
15 Feb 2015	BARSTUR	0630-1700	0630	1630

HST = *Hawai‘i* Standard Time

Table 6. Odontocete and fin whale sightings from small-boat effort during February 2015. Details on two dead whales found during the survey are also included.

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	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-Feb-15	9:24	Sb	9	0	no	7	2	22.04867	159.24547
04-Feb-15	10:17	Sb	12	1[2]	no	6	3	22.09218	159.22363
04-Feb-15	11:07	Sb	18	1	no	14	3	22.12519	159.21374
04-Feb-15	11:39	Sb	5	0	no	0	0	22.13003	159.23868
05-Feb-15	7:44	Sl	60	0	no	N/A	N/A	21.95495	159.31132
05-Feb-15	7:52	Sb	18	0	no	7	5	21.96433	159.29576
05-Feb-15	8:14	Sb	1	0	no	0	0	21.97136	159.28236
05-Feb-15	8:23	Sb	1	0	no	0	0	21.97631	159.27218
05-Feb-15	8:33	Sb	11	0	no	7	5	21.98098	159.25753
05-Feb-15	8:57	Sb	3	0	no	3	0	21.95883	159.27662
05-Feb-15	9:06	Sb	4	0	no	2	1	21.94753	159.28171
05-Feb-15	9:19	Sb	4	0	no	1	0	21.94543	159.29637
06-Feb-15	10:54	Tt	3	0	no	3	3	22.06484	159.29273
07-Feb-15	10:01	Ks	2	0	no	1	0	21.84373	159.51952
08-Feb-15	8:34	Gm	13	1	yes*	8	1	22.03670	159.86461
11-Feb-15	8:01	Sb	8	0	no	4	0	22.01210	159.25912
11-Feb-15	9:09	Sb	2	0	no	1	1	22.03831	159.20996
11-Feb-15	9:26	Sb	1	0	no	1	0	22.02102	159.21606
11-Feb-15	9:28	Sb	6	0	no	0	0	22.00590	159.21007

Date	Time (HST) of Visual Sighting	Species[1]	Group Size	# Satellite Tags Deployed	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-Feb-15	9:59	Sb	13	1	no	13	7	22.00040	159.21552
11-Feb-15	10:49	Sb	8	0	no	6	4	21.98922	159.24223
11-Feb-15	11:06	Sb	19	0	no	14	4	21.98962	159.26344
11-Feb-15	11:46	Tt	3	1	no	1	0	22.06389	159.29317
12-Feb-15	9:02	Sb	2	0	no	1	0	22.00245	159.96610
12-Feb-15	9:06	Gm	40	2	no	21	0	21.99080	159.96573
12-Feb-15	11:35	Sb	4	0	no	2	1	21.97093	160.02147
12-Feb-15	14:48	Bp	2	0	no	2	0	21.68461	159.86689
12-Feb-15	17:48	Tt	45	0	no	0	0	21.86014	159.44959
15-Feb-15	8:21	Sl	130	0	no	N/A	N/A	21.92255	159.66659
15-Feb-15	13:43	Tt	20	0	yes*	13	13	22.09544	159.83162
15-Feb-15	14:55	Gm	17	0	yes*	6	6	22.15049	159.89429
16-Feb-15	13:12	UnID	2	0	no	0	0	22.48921	159.43122
16-Feb-15	16:49	Tt	26	1	no	22	19	22.03217	159.79973
16-Feb-15	18:03	Tt	4	0	yes	3	2	22.02668	159.80234
16-Feb-15	18:07	Tt	9	0	yes	4	3	22.01903	159.80018
16-Feb-15	13:57	Mn[3]	1	N/A	no	N/A	N/A	22.45936	159.49262
16-Feb-15	14:50	Pm[3]	1	N/A	no	N/A	N/A	22.38578	159.60754

[1]See footnote to **Table 1**, [2]No data obtained from tag. [3]Dead whale found floating in advance state of decay. Ks = *Kogia sima*, UnID = unidentified odontocete; 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.

Table 7. Details on satellite tags deployed during February 2015 field effort and October 2014 effort for species included in mapping (bottlenose dolphins and short-finned pilot whales, no rough-toothed dolphins were tagged in October 2014).

Species[1]	Tag ID	Individual ID	Date Tagged	Sighting #	Duration of Signal Contact (days)	Lat (°N)	Long (°W)	Tag Type	Sex
Tt	TtTag019	HITt0898	14-Oct-14	2	14.78	22.06	159.80	Mk10A	Unknown
Tt	TtTag020	HITt0357	15-Oct-14	1	12.32	22.10	159.85	Mk10A	Male
Tt	TtTag022	HITt0904	11-Feb-15	10	7.20	22.07	159.29	Mk10A	Unknown
Tt	TtTag023	HITt0911	16-Feb-15	3	15.65	22.07	159.81	Mk10A	Unknown
Sb	SbTag013	HISb1480	4-Feb-15	3	0	22.10	159.23	Mk10A	Unknown
Sb	SbTag014	HISb1668	4-Feb-15	5	21.82	22.13	159.22	SPOT5	Unknown
Sb	SbTag015	HISb2045	11-Feb-15	7	14.34	21.99	159.22	Mk10A	Unknown
Gm	GmTag104	HIGm0263	8-Oct-14	3	27.99	22.50	159.89	Mk10A	Male
Gm	GmTag114	HIGm1174	8-Feb-15	1	7.55	22.16	159.91	Mk10A	Male
Gm	GmTag115	HIGm2483	8-Feb-15	1	10.07	22.16	159.91	SPOT5	Male
Gm	GmTag116	HIGm2525	12-Feb-15	2	0.10	22.00	160.00	Mk10A	Unknown
Gm	GmTag117	HIGm2523	12-Feb-15	2	45.00	22.00	160.01	SPOT5	Male

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

Table 8. Details on previous sighting histories of individuals satellite tagged in February 2015 and those tagged in October 2014 included in mapping.

Individual ID	Date First Seen	# Times Seen Previously	# Years Seen Previously	Islands Seen Previously	Social cluster
HITt0898	14-Oct-14	0	0	N/A	N/A
HITt0357	16-Oct-05	7	3	Kauaʻi	N/A
HITt0904	11-Feb-15	0	0	N/A	N/A
HITt0911	16-Feb-15	0	0	N/A	N/A
HISb1480	21-Jul-11	4	2	Kauaʻi	N/A
HISb1668	30-Jun-12	2	1	Kauaʻi	N/A
HISb2045	11-Feb-15	0	0	N/A	N/A
HIGm0263	11-Nov-05	1	1	Kauaʻi	-
HIGm1174	24-Aug-08	1	1	Oʻahu	W11
HIGm2483	08-Feb-15	0	0	N/A	-
HIGm2525	12-Feb-15	0	0	N/A	-
HIGm2523	12-Feb-15	0	0	N/A	-

ID = identification; # = number; N/A = not applicable

Table 9. Information from GIS analysis of satellite-tag location data from February 2015 field effort.

Individual ID[1]	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)
HITt0904	N/A	92	0	0	433.3	22.0/29.1	80/1,372	2.1/7.4
HITt0911	N/A	123	9	23.3	731.4	15.2/54.0	275/1,321	4.5/16.8
HISb1668	N/A	286	4	17.5	1,482.2	33.1/90.4	1,450/4,099	10.0/33.2
HISb2045	N/A	179	8	26.7	1,044.4	52.6/99.5	1,680/4,276	12.2/36.8
HIGm1174	W11	92	2	29.7	783.0	74.1/209.09	4,294/4,603	45.4/114.2
HIGm2483	-	42	1	25.0	609.8	76.6/167.8	3,246/4,570	23.2/107.7
HIGm2523	-	346	1	0.7	4,251.9	285.0/585.4	4,549/5,704	132.1/246.8

ID = identification; km = kilometers; m = meters; # = number; % = percent; N/A = not applicable. [1]Only three locations obtained from HIGm2525 so information not included here.

Table 10. Dive information from satellite tags deployed during February 2015 field effort.

Individual ID	# Hours Data	# Dives ≥ 30 m	Median Dive Depth (m) for Dives ≥ 30 m	Maximum Dive Depth (m)	Median Dive Duration[1] (min)	Maximum Dive Duration[1] (min)
HITt0904	64.1	230	79.5	423.5	2.93	7.43
HISb2045	104.1	228	57.5	351.5	4.30	9.53
HIGm1174	99.6	344	83	1,184	8.23	23.13

[1]Duration of dives underestimated as time spent in top 3 m not included. Typical rates of ascent/descent are in the 1-2 m/second range, so durations likely only underestimated by 3-6 seconds.

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

Table 11. Areas within 50% ("core range"), 95% and 99% isopleths based on kernel density analyses of satellite tag data.

	Area (km^2) within selected isopleths based on kernel density		
Species/population	50%	95%	99%
Bottlenose dolphin	1,210	7,239	12,281
Rough-toothed dolphin	1,656	14,318	21,691
Short-finned pilot whale – insular population	6,157	47,849	75,653
Short-finned pilot whales – pelagic population	122,119	577,058	755,166

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