ODONTOCETE STUDIES OFF THE PACIFIC MISSILE RANGE FACILITY IN FEBRUARY 2013: SATELLITE-TAGGING, PHOTO-IDENTIFICATION, AND PASSIVE ACOUSTIC MONITORING FOR SPECIES VERIFICATION

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ABSTRACT

A joint project in February 2013 off the Pacific Missile Range Facility (PMRF) combined passive acoustic monitoring and boat-based field efforts. There were 1,010 kilometers (km) (55.9 hours [hr]) of small-vessel field effort over the course of the 8-day project. Of the 55.9 hr of survey effort, 64.2 percent of time was spent within the PMRF instrumented hydrophone range boundaries, and 14.8 percent of the effort was in depths greater than 1,000 meters (m). A total of 50.4 hr of acoustic monitoring coincided with the small-vessel field effort. There were 20 sightings of four species of odontocetes, 14 of which were directed by acoustic detections from the Marine Mammal Monitoring on Navy Ranges (M3R) system. Bottlenose dolphins were encountered on 12 occasions, spinner dolphins on four occasions, rough-toothed dolphins on three occasions, and short-finned pilot whales on one occasion. Recordings on the M3R system for species verification were made for three of the four species (all but spinner dolphins). During the encounters 3,875 photos were taken for individual identification, seven biopsy samples were obtained for genetic studies, and six satellite tags were deployed on three species (three on bottlenose dolphins, one on a rough-toothed dolphin, and two on short-finned pilot whales). Data from the tagged species show that all appear to have island-associated populations with restricted ranges, and the ranges of all three populations substantially overlap with the PMRF range. Based on preliminary sound propagation analyses[1] and the locations of animals tracked during this study, all of these populations are likely exposed to mid-frequency active (MFA) sonar on the PMRF range, but appear to use the overall area in different ways, thus the likelihood of exposure to different sound levels also probably varies by species. 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.

INTRODUCTION

The Marine Mammal Monitoring on Navy Ranges program (M3R) is a real-time passive acoustic monitoring system that has been 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 Pacific Missile Range Facility (PMRF) between Kaua‘i and Ni‘ihau (2011-present). The purpose of this report is to present results of a joint project in February 2013 off the PMRF instrumented hydrophone range involving a combination of M3R passive acoustic monitoring and boat-based field efforts. This work addresses a specific Navy monitoring question: what are the spatial movement patterns and habitat use (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? Additional goals include providing visual species verification for M3R acoustic detections and obtaining movement and habitat use information on cetaceans using the PMRF range before, during, and after a Submarine Commanders Course (SCC) scheduled to be undertaken after the field efforts.

The M3R system consists of specialized signal-processing hardware and detection, classification, localization, and display software that provides a user-friendly interface for real-

[1] Undertaken by S.W. Martin, SPAWAR Systems Center Pacific

time passive acoustic monitoring (PAM) of all 199 PMRF bottom-mounted hydrophones. Prior to 2013 the M3R system at PMRF had been used on three occasions (Table 1) in collaboration with vessel-based field efforts. This combination approach provides visual species verifications of groups detected acoustically as well as visual sightings of animals on the range that have not been acoustically detected, and increases the encounter rate for vessel-based efforts. Increased encounter rates results in greater opportunities for deploying satellite tags (see below) as well as photo-identifying individuals and collecting biopsy samples for genetic studies.

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). Studies 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 exercise (Baird et al. 2008a). During that effort three melon-headed whales (*Peponocephala electra*) and a short-finned pilot whale (*Globicephala macrorhynchus*) were tagged and tracked for periods ranging from 3.7 to 43.6 days (Baird et al. 2008a; Woodworth et al. 2011). Since 2008 and prior to 2013, there have been four additional vessel-based field projects off Kaua‘i (three in conjunction with M3R monitoring) during which satellite tags were deployed; during all of these efforts 22 satellite tags were deployed on five different species of odontocete cetaceans off the islands of Kaua‘i and Ni‘ihau (Table 1; Baird et al. 2011, 2012a, 2012b, 2013b).

To put the results from the February 2013 field effort into context, we also include results from previous photo-identification and satellite tagging efforts off the PMRF range. This includes matching of photos of tagged individuals and companions to long-term photo-identification catalogs (Baird et al. 2008b, 2009; Mahaffy 2012) to allow for the assessment of population identity and re-sighting history of tagged individuals, as well as presentation of location data from previously satellite-tagged individuals (Baird et al. 2013b).

METHODS

PMRF Undersea Acoustic Range

The PMRF instrumented hydrophone range is configured with 199 bottom-mounted hydrophones 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 (Figure 1). Each range consists of several offset bottom-mounted cables (“strings”), with multiple hydrophones spaced along each string to create hexagonal arrays. Six of the 42 BARSTUR hydrophones have low-frequency capability enabling passive detection of baleen whales such as humpback whales (*Megaptera novaeangliae*), calls of which were prevalent during February 2013.

M3R System

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 real-time embedded 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 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 click, 1.518 kHz clicks (representative of sperm whales, *Physeter macrocephalus*), 12-48 kHz click (representative of delphinid sp.), 24-48 kHz clicks (representative of beaked whales), and 45-48 kHz clicks. Additional Support Vector Machine based classifiers are also being tested with a focus on Blainville's beaked whales (*Mesoplodon densitrotris*).

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 this test, detection archives from previous PMRF species verification tests were reviewed to create a compilation of exemplar spectrograms for visually verified species including: rough-toothed dolphin (*Steno bredanensis*), spinner dolphin, 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 indicate potential species for prioritization of directing the small boat to groups when multiple groups were present in the area.

Supplementary to MMAMMAL, Worldview 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 derived from automated localization software and classification type (1-6) 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 same or neighboring 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. Automated click localizations provide the PAM user a real-time range-wide map 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 manually calculating 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 *Tt* whistles to give the at-sea team a precise location (~100m) 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 vise 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.

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 199 hydrophones of precisely time-aligned audio data. Specific software tools have been developed for the automated isolation of Blainville's beaked whale click trains which are then used by a second tool to mark 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)

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 unsuitable. At all times the PAM objective was to keep the scientists onboard 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 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 is left to the onboard scientists so that they can prioritize the combination of species preference, weather conditions, time of day, etc. Once the group of interest is radioed back to the PAM team, this group is then followed closely and an attempt made to provide an initial position. This often involves manually waiting for and selecting whistles to localize, termed a manual position. A best effort was made to also communicate the confidence level of the position provided, from best to worst: whistle localizations are the most accurate, either by the automated process or by manual localization, clusters of click localizations are less precise but definitively indicate the presence of a vocalizing animal, while a single-click localization is the least desirable. Human error can occur when calculating manual whistle localizations, but this is typically minimal with trained PAM personnel. As the vessel approached the group, additional position updates were communicated in real time until receiving confirmation that they had sighted the group. At this time, the PAM team would be on standby until receiving additional communication in order to not disrupt tagging and photo-identification activities onboard the RHIB. While standing by, the PAM team would again 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 hours per day. These archives capture all detection reports, and automated localizations generated during the test.

FIELD METHODS

Tag types and programming

Sixteen satellite tags were available for deployment, including 11 location-dive tags (Wildlife Computers Mk10-A) and five location-only (Wildlife Computers SPOT5) tags in the LIMPET configuration. While in most cases the location-dive tags were the first tag option for deployment with any particular group, they are slightly heavier and are less optimal in terms of ballistics, so were not always the first tag deployed in a group depending on the conditions for tagging (e.g., depending on weather and/or animal behavior). Each tag is attached with two titanium darts with backward facing petals, using either short (4 centimeters [cm]) or long (6.5 cm) darts, 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 ~30 days, which varies by species. Location-dive tags programmed for short-finned pilot whales transmitted 18 hours (hr)/day with a maximum of 750 transmissions a day, giving an estimated battery life of approximately 24 days. Location-dive tags programmed for rough-toothed and bottlenose dolphins transmitted for 17 hr/day with a maximum of 750 transmissions per day, also giving an estimate battery life of approximately 24 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 whales), as well as dive statistics (start and end time, maximum depth, duration) for any dives ≥ 30 meters (m) in depth, with depth readings of 3 m being used to determine the start and end of dives, thus dive durations are slightly negatively biased. Given typical odontocete descent and ascent rates of 1-2 m/second, dive durations recorded are likely only 3-6 seconds shorter than actual dive durations. Location-only tags programmed for bottlenose dolphins transmitted 17 hr/day with an estimated battery life of 41 days. 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 two-month period starting at the beginning of the deployment period.

A land-based Argos receiver station was set up on Makaha Ridge, Kaua‘i, to try to increase the amount of dive and surfacing data obtained from the location-dive tags. This system included a single Telonics TGA-100 7-element antenna and a Telonics TSUR-400 uplink receiver connected to a laptop with data recorded using Telonics Uplink Logger v. 1.00. The antenna was at 456 m elevation oriented to the west towards Lehua, which is located off the northern tip of Niʻihau (Figure 2).

Vessel, time and area of operations

The vessel used was a 24-foot rigid-hulled Zodiac Hurricane, powered by twin Suzuki 140-HP outboard engines, and with a custom-built bow pulpit for tagging and biopsy operations. Vessel operations involved launching each morning at sunrise, and operations continued in daylight hours as long as weather conditions were suitable. The launch site was the Kikiaola small boat harbor, but alternative sites were available if the prevailing weather conditions warranted, including Port Allen and Nawiliwili Harbor. For calculating effort by depth and time within the PMRF instrumented hydrophone range boundaries, effort locations were recorded on the GPS at 5-minute intervals. When weather conditions permitted the primary area of operations was the PMRF hydrophone range, with a focus on deep-water areas to increase the likelihood of encountering 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, the RHIB worked in areas off the range. The RHIB 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.

During encounters

Humpback whales were generally not approached, but sightings of all whales were assessed visually to determine the species. 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) was 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 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, splash), start and end behavior and direction of travel, the group envelope (i.e., the spatial spread of the group in two dimensions), the percentage of the group observed, the number of individuals bowriding, and information necessary for permit requirements.

If conditions were suitable for tagging, for all infrequently encountered species, we attempted to deploy at least one satellite tag per group. For frequently encountered species, we attempted to deploy one tag per group, unless the group was unusually large (e.g., >50 individuals) and thus likely comprised more than one social 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.

After tagging, or if individuals appeared un-approachable for tagging, we sometimes attempted to collect biopsy samples, either to confirm sex of tagged animals or, for species that are known or thought to exhibit population structure within Hawaiian waters (e.g., bottlenose dolphins, short-finned pilot whales), to help interpret results of tagging and photo-identification. Biopsy samples were sent to the Southwest Fisheries Science Center for genetic analyses.

Data analyses

Five-minute effort locations were processed with ArcGIS to determine depth and whether locations were inside or outside the PMRF instrumented hydrophone range boundaries. 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. 7.08 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 the PMRF range boundaries. From this, the proportion of time spent within the PMRF instrumented hydrophone range boundaries, as well as the number of visits to the range, were 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.

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 (~10 min). We use 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 that overlapped spatially and temporally with the SCC were provided to SPAWARSYSCEN-PACIFIC for calculation of estimated sound pressure levels (Baird et al. in prep.).

Data obtained from the land-based Argos uplink receiver 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. To visualize the depth time series in relation to bathymetry, a pseudotrack was developed. To generate this pseudotrack, both the time series and the Argos position data were imported into separate pages of an Excel spreadsheet. For each Argos position, the distance and bearing to the next Argos position were calculated using the GeoFunc Excel Geometry Add-in[2], and the average rate of travel to the next location was calculated by dividing the distance between the two points by the time lapse between them. We then used the time stamp for each point in the depth time series to look up the latitude and longitude of the nearest preceding Argos position in time. A new offset location for each time series point was generated using the time difference, the average rate of travel, and the bearing between the preceding and following Argos locations. The spatially-referenced depth time series

[2] www.afsc.noaa.gov/nmml/software/excelgeo.php

points were then converted to a three-dimensional track and overlaid on bathymetric imagery using GPSVisualizer[3] to create a Google Earth kml layer (e.g., Figure 3).

RESULTS

From 2-9 February 2013 there were 1,010 kilometers (km) (55.9 hr) of small-vessel field effort with effort on the water each of the 8 days (Table 4). Over the 55.9 hr of survey effort, 64.2 percent of the time was spent within the PMRF instrumented hydrophone range boundaries (Figure 1), and 14.8 percent of the effort was in depths greater than 1,000 m (Figure 4). Forecast winds during the 8-day period included 5 days of 15-knot winds, two days of 25-knot winds, and one day of 10-knot winds (8 February 2013), with winds either from the east or northeast, limiting field operations most days to relatively shallow waters west of Kaua'i and on some days primarily to areas south of PMRF (Figure 1). On the one day with a forecast of 10-knot winds, it was possible to work in deeper water in the northern part of the range (Figure 1). Acoustic monitoring with the M3R system was undertaken prior to the RHIB entering the PMRF range each day and concluded after the RHIB left the range, for a total of 50.4 hr of acoustic monitoring (Table 5). Overall there were 20 sightings of four species of odontocetes, 14 of which were directed by acoustic detections from the M3R system (Table 6). Confidence of acoustic detections on the range by species are given in Table 7. Sightings on 8 February included the only sighting of short-finned pilot whales and two of the three sightings of rough-toothed dolphins, the two deeper-water species encountered. Recordings on the M3R system for species verification were made for three of the four species of odontocetes encountered (all but spinner dolphins). During the encounters 3,875 photos were taken for individual identification, seven biopsy samples were obtained for genetic studies (sent to the Southwest Fisheries Science Center), and there were seven satellite tags deployed on three species (Table 8), although locations were only obtained from six of the seven deployments (one of the two deployments on a short-finned pilot whale).

Bottlenose dolphins

Bottlenose dolphins were sighted on 12 occasions and photographs were obtained from 11 of 12 encounters. Three tags were deployed on bottlenose dolphins, one location-only tag and two location-dive tags, with location data obtained for periods from 10.7 to 20.5 days. A social network including individual bottlenose dolphins photo-identified off Kaua'i and Ni'ihau from 2003 through February 2013 indicated that two of the three individuals were linked by association in the main cluster of bottlenose dolphins identified off the island (Figure 5). One satellite-tagged dolphin (HITt0810) was seen in a group of eight individuals, but the group was lost after tagging, prior to being able to photograph any of the other individuals in the group. As HITt0810 had not been previously documented there were no links to any other individuals in the social network (Figure 5). An analysis of distance between HITt0810 and HITt0806 (tagged on 4 February 2013) suggests that the two individuals did associate during the period of tag data overlap (Figure 6). One of the three individuals (HITt0359) had been previously documented in the area on seven occasions in three different years, first being seen in 2005 (Table 9). Two of the previous seven sightings of this individual were off Ni'ihau (during July 2011; see Baird et al. 2012a).

[3] www.GPSVisualizer.com

With location data from three individuals obtained in February 2013, there are now data available from six bottlenose dolphins from Kaua‘i, with previous deployments in August 2011 (Baird et al. 2012a) and June 2012 (Baird et al. 2013b). All six have remained associated with the island of Kaua‘i, and the three individuals tagged in February 2013 primarily used the west and north sides of the island (Figure 7). The percentage of locations inside the boundaries of PMRF ranged from 27.5 to 50.7 (Table 10). Although they traveled an average minimum straight-line distance of 1,018 km, the individuals remained a median distance of 12.5 km from the tag deployment location, and moved an average straight-line maximum distance from the tag deployment location of only 47 km (Table 10). All three individuals remained relatively close to shore (median distances from 3.0 to 5.4 km) in relatively shallow water (median depths ranging from 61 to 206 m), although occasional movements into deeper water were documented for all (Table 10).

For the two bottlenose dolphins tagged with location-dive tags, 183.6 hr of dive and surfacing data were obtained through the Argos system (30.5 hr for HITt0359 and 153.1 hr for HITt806). When combined with data from the Makaha Ridge land-based receiving station, a total of 264.2 hr of data was available, including more than doubling of the data obtained for HITt0359 (from 30.5 to 70.3 hr, Table 11). The straight-line distances between the land-based receiving station and the locations from both individuals were calculated for all locations starting 48 hr after tag deployment (as no dive data are typically transmitted in the first 2 days). The median distances of HITt0359 and HITt0806 from the land-based receiver were 13.1 km and 12.9 km (maxima of 16.6 and 45.6 km, respectively). An example of dive and location data for HITt0806 is shown in Figure 3 and summary dive data for both individuals are presented in Table 11.

Short-finned pilot whales

Short-finned pilot whales were only sighted on a single occasion. While two individuals were satellite-tagged (both with location-dive tags), data were obtained only from a single tag, deployed on individual HIGm1400 (Table 8), with data available over a period of 19.9 days. Both of the tagged individuals had been previously photo-identified off Kaua‘i (in February 2011), and HIGm1400 was satellite-tagged during that field effort (see Baird et al. 2011, 2013b). Although HIGm1400 and companion individuals have not been seen associated with the main social cluster off Kaua‘i (Figure 8), one of the companion individuals has been encountered with individuals from the main cluster off O‘ahu (CRC unpublished data). In addition, four locations over a 7-hour period obtained from HIGm1400 when tagged in February 2011 were less than 1 km from another tagged individual (HIGm0180) that has been previously documented off O‘ahu and Kaua‘i, providing further evidence of association in the same social network.

With the February 2013 tagging of HIGm1400, location data for short-finned pilot whales are available from seven tag deployments off Kaua‘i (Figure 9). During February 2013, HIGm1400 remained off the north and west side of Kaua‘i, moving through the channel between Kaua‘i and Ni‘ihau, and ranging to the west and north of Ka‘ula Island (Figure 9). In February 2013, HIGm1400 moved a minimum straight-line distance of 1,517 km but remained a median distance from the tagging location of 36.1 km (Table 10). From the Argos satellite system, a total of 419.8 hr of diving data was obtained, while only an additional 1.1 hr were obtained from the land-based receiving station (Table 11). The straight-line distances between the land-based receiving station and the locations from HIGm1400 were calculated for all locations starting 48 hr after tag deployment. The median distance of HIGm1400 from the land-based receiver was 41.8 km (maximum 131.5 km). An example of dive and location data combined is shown in Figure 10, with a summary of dive data presented in Table 11.

Rough-toothed dolphins

Rough-toothed dolphins were encountered on three occasions, and a single individual was satellite-tagged (Table 8). While matching of photographs obtained to the long-term photo-ID catalog for this species (Baird et al. 2008b) is still ongoing, photos of the tagged individual have been matched to the catalog (which currently contains 394 distinctive individuals), and the individual had been previously photo-identified off the island of Kauaʻi in February 2011 (Table 9). An analysis of association patterns indicates that this individual associated with the main social cluster documented off Kauaʻi and Niʻihau (Figure 11).

Data were received from this tag only over a 3.45-day period, with the individual moving from within the PMRF range first to the northwest and then southeast towards Kaʻula Island, before moving northeast off the north side of Niʻihau (Figure 12).

Location data are now available for eight rough-toothed dolphins satellite-tagged off Kauaʻi, with all individuals generally remaining associated with Kauaʻi and Niʻihau (Figure 12; see also Baird et al. 2013b), with a concentration of locations in the channel between the islands. Less than one hour of dive data were obtained (Table 11).

DISCUSSION AND CONCLUSION

Despite generally poor weather conditions during the February 2013 field effort, visual verifications of species detected on the M3R system were obtained for 20 sightings of four species (Table 6), and movement and diving data were obtained from three species of odontocetes on and around the PMRF instrumented hydrophone range (Table 8), thereby increasing the sample sizes for these species in the area. Prior to this effort diving data for odontocetes in the area of the PMRF range were available only for one bottlenose dolphin (tagged in June 2012), one short-finned pilot whale (tagged in February 2011) and two rough-toothed dolphins (tagged in July 2012), thus we have doubled the number of individuals for which dive data are available. The use of a land-based Argos receiving station on Kauaʻi also greatly increased the amount of diving data obtained from two of the four individuals with location-dive tags, more than doubling the hours of diving data for one bottlenose dolphin and adding 40 hr of dive data for the other bottlenose dolphin (Table 11). On average locations for these two individuals were approximately 13 km from the land-based receiving station. This demonstrates that such land-based receiving stations may have considerable utility for increasing the proportion of time that dive data are obtained from depth-transmitting tags, at least for individuals that spend time relatively close to the receiver station. Locations for the tagged short-finned pilot whale were an average of almost 42 km from the land-based receiving station. There was only a small increase in data obtained from the short-finned pilot whale tag (~1 hour), illustrating that tagged animals must be relatively close to the land-based receiving station in order to successfully receive transmissions.

The primary monitoring question to be addressed in this study is determining the spatial movement patterns and habitat use (e.g., island-associated or open-ocean, restricted ranges v. large ranges) of species that are exposed to MFA sonar, and how these patterns may influence exposure and potential responses. For bottlenose dolphins, previous photo-identification (Baird et al. 2009) and genetic (Martien et al. 2011) studies had documented that bottlenose dolphins off Kaua‘i and Ni‘ihau appeared to be demographically isolated from bottlenose dolphins off other islands and from offshore areas. Such research, however, was limited by spatial biases in survey effort and relatively small sample sizes. Location data from satellite-tag deployments are less biased, and the long time-series of locations has allowed us to estimate both how often individuals move onto and off the PMRF range and what proportion of their time they spend there. The three individual bottlenose dolphins satellite tagged in February 2013 were either known (Figure 5) or thought (Figure 6) to be part of the resident population of bottlenose dolphins around Kaua‘i and Ni‘ihau, and all three remained associated with primarily near-shore shallow waters of Kaua‘i (Figure 7, Table 10). Over the 10.7- to 20.5-day durations of signals from the satellite tags, these individuals spent between approximately 25% and 50% of their time on the PMRF range, and crossed onto the range once or twice a day, on average (Table 10). A comparison of location data from the three individuals tagged in February 2013 (with locations off the south, west and north shores of Kaua‘i) to the larger dataset including one individual tagged in 2011 and two in 2012 (with locations also off the east shore of Kaua‘i; Figure 7; see also Baird et al. 2013b) illustrates the value of deployments in multiple years to assess the range of this population. None of the satellite tag data show bottlenose dolphins moving to Ni‘ihau, yet photo-identification data (Baird et al. 2009), including for one of the individuals tagged in 2013 (Table 9), have documented movements between the islands, suggesting that additional satellite tag data are needed to more fully represent the range of this island-associated population.

For short-finned pilot whales around the main Hawaiian Islands, long-term re-sightings (Mahaffy 2012) and primary use of slope habitats (Baird et al. 2013a) both suggest the existence of an island-associated, resident population. Results from six previous satellite tag deployments off Kaua‘i showed that individuals tagged there move both around Kaua‘i and Ni‘ihau and over a broader area ranging from western O‘ahu to the southwest of Ka‘ula Island, and offshore north of the PMRF range boundaries (Figure 9; Baird et al. 2013b). Association patterns suggest that all of the pilot whales tagged off Kaua‘i to date are part of the same, apparently island-associated population (Figure 8). Whether there are some groups that restrict their movements to the Kaua‘i and Ni‘ihau area, and thus spend more time in the PMRF area, and others within this population that move more broadly to O‘ahu, is not yet known. The individual tagged in February 2013, HIGm1400, was one of the same individuals tagged off Kaua‘i in February 2011 (see GmTag51 in Figure 7, Baird et al. 2011); when tagged in 2011 this individual moved from Kaua‘i to off the southwest coast of O‘ahu and back. The broader range in movements of individuals in this population, as well as use of deeper waters (Table 10), suggest that they spend less time directly on the PMRF range than bottlenose dolphins, although on average HIGm1400 was on the range every second day while tagged. There is also evidence that pilot whales from an open-ocean population at least occasionally move through the PMRF instrumented hydrophone range (see Figure 6 in Baird et al. 2011), although we have not tagged any during our surveys off Kaua‘i. One or more of the isolated clusters in the social network (Figure 8) may be from an open-ocean population; assessing this possibility will require additional encounters from these groups along with associated photo-identifications, genetic samples, and satellite tagging data.

Multi-year re-sightings of photo-identified rough-toothed dolphins off of Kaua‘i and Ni‘ihau, and a very low level of movements of individuals to Hawai‘i Island, also suggest that individuals of this species exhibit some degree of site fidelity (Baird et al. 2008b). Preliminary genetic analyses of samples collected off Kaua‘i and Hawai‘i Island also suggest the two populations may be demographically isolated (Albertson et al. 2011). Although only just over 3 days of movement data were obtained from one satellite-tagged rough-toothed dolphin in February 2013 (Figure 12, Table 8), this individual remained associated with Kaua‘i and Ni‘ihau, albeit further from shore than other species tagged (Table 10). Data are now available from eight rough-toothed dolphins satellite tagged off Kaua‘i since July 2011, for periods ranging from 3.45 to 27.51 days (sum = 99.7 days). All the individuals were tagged in the channel between Kaua‘i and Ni‘ihau (as were most of the bottlenose dolphins and short-finned pilot whales discussed earlier), but movements around Kaua‘i and Ni‘ihau were widespread (Figure 12). However, the high density of locations in the channel between Kaua‘i and Ni‘ihau suggests the channel is a high density area for rough-toothed dolphins, more so than for the other species tagged in this study (Figure 12).

Data from all three species show that all appear to have island-associated populations with restricted ranges, and the ranges of all three populations substantially overlap with the PMRF range (Figures 6, 9, 12). Differences in habitat use, e.g., primary depths used and distances from shore, exist for all three species (Table 10). Preliminary acoustic propagation analyses of sonar use on PMRF during SCCs suggest that exposure to MFA sonar on PMRF is generally audible to cetaceans throughout the PMRF range (S.W. Martin, SPAWAR Systems Center Pacific, personal communication). Thus based on locations of animals tracked during this study, all three populations are likely exposed to MFA sonar on the PMRF range. As all appear to use the overall area in different ways, the likelihood of exposure to different sound levels also probably varies by species. Continued collection of movement and habitat use data from all three species should allow for a better understanding of the use of the range as well as provide data sets that can be used to estimate received sound levels at animal locations and examine potential responses to exposure.

Spinner dolphins are also regularly encountered off the west side of Kaua‘i (Baird et al. 2003, 2012a; Figure 2), in locations identified as day-time resting areas (Thorne et al. 2012). Based on genetic analyses (Andrews et al. 2010) spinner dolphins off Kaua‘i and Ni‘ihau have been recognized as a distinct stock (Carretta et al. 2013). We have not satellite tagged any spinner dolphins due to the small size of their dorsal fin, so their movements throughout the PMRF range and potential exposure to MFA sonar are not analyzed as part of this study. Only four species of odontocetes were encountered in the February 2013 effort, and in earlier combined M3R/small-vessel surveys in 2011 and 2012 only three other species have been documented (Baird et al. 2012a, 2012b). There are 18 species of odontocetes known in Hawaiian waters, 14 of which have been documented off Kaua‘i and Ni‘ihau in previous small-vessel surveys (Baird et al. 2013a). The relatively low species diversity documented in recent years reflects both a combination of limited survey effort in frequently poor sighting conditions, and, more importantly, the relatively shallow distribution of survey effort (Figure 4), which has primarily been limited by unworkable sea conditions in deeper areas. Most of the species that have not been encountered in recent years of survey effort are primarily deep-water and/or relatively uncommon species (Baird et al. 2013a). Given the typically poor working conditions off Kaua'i, assessment of how often these species use the PMRF range and whether they are from island-associated or open-ocean populations will require substantial additional effort.

As vocalizations are verified and species classifiers are developed, passive acoustics in concert with visual observations and satellite tags can be used to provide a long-term estimate of animals' reaction to on-going sonar exercises. Ultimately, tools to estimate the cumulative effect of sonar exposure will provide data that can then be used to develop a Population Consequences of Acoustic Disturbance (PCAD) model to estimate the effect on population health (New et al. 2013).

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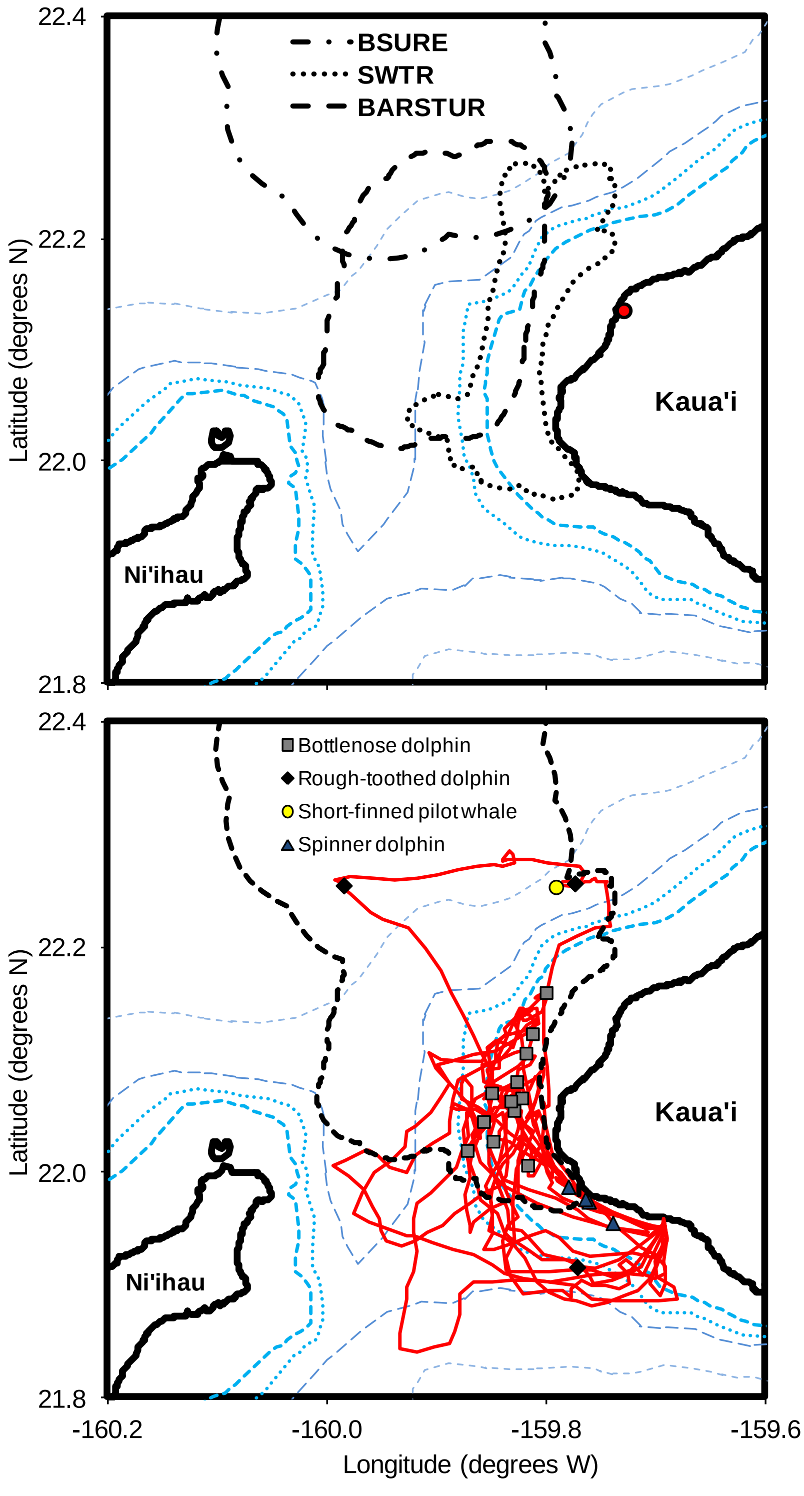


Figure 1. Map showing boundaries of instrumented hydrophone ranges (top, see Table 2) as well as tracklines of small-vessel field effort in February 2013 with sightings indicated with overall PMRF range boundary shown (bottom). The land-based receiver station on Makaha Ridge is indicated by a red circle (top map). The 100 m, 500 m, 1,000 m and 2,000 m depth contours are shown.

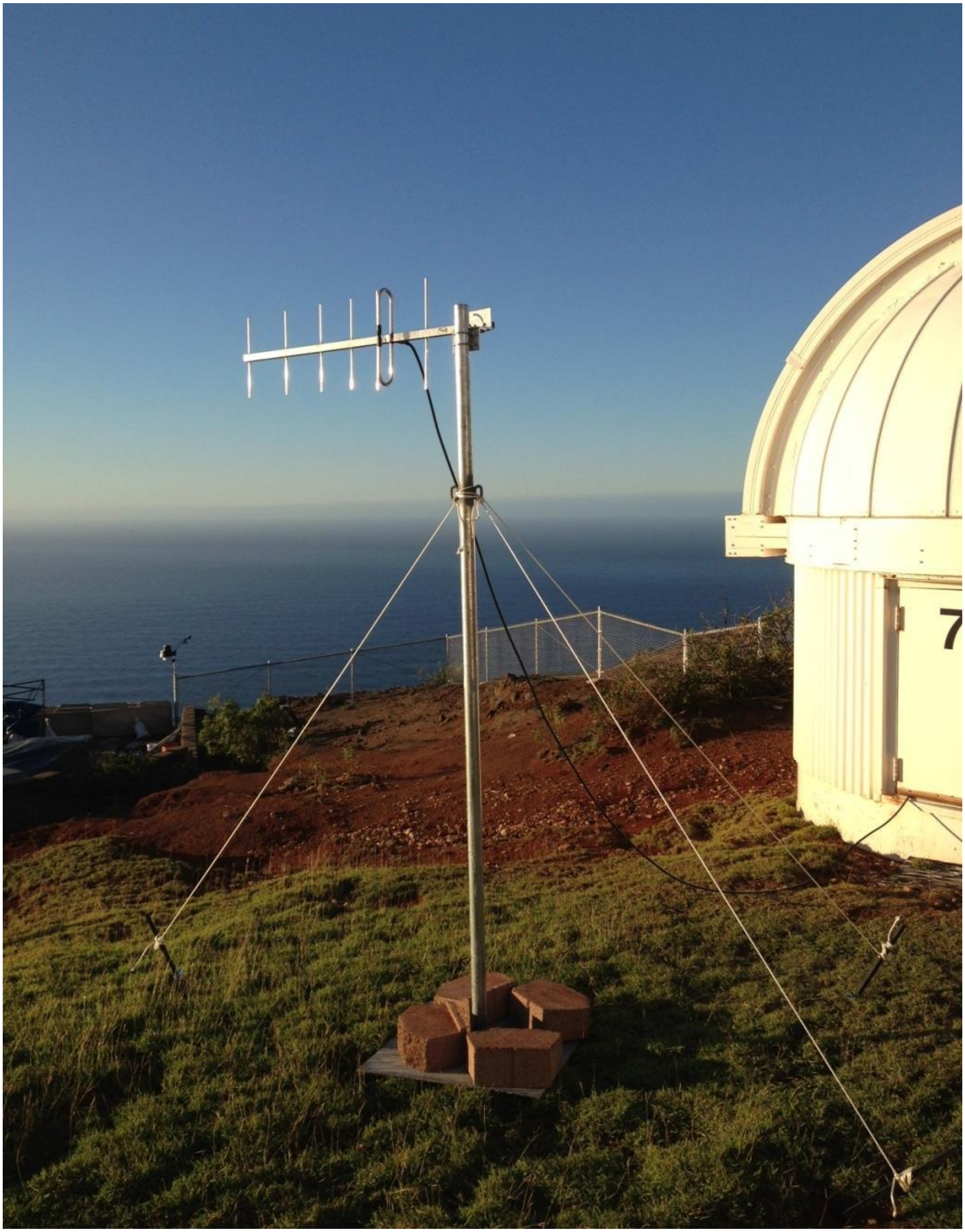


Figure 2. Land-based Argos antenna/receiver system on Makaha Ridge, Kauaʻi, established to increase the amount of dive and surfacing data obtained from depth-transmitting tags. Photo by Michael Richlen/HDR.

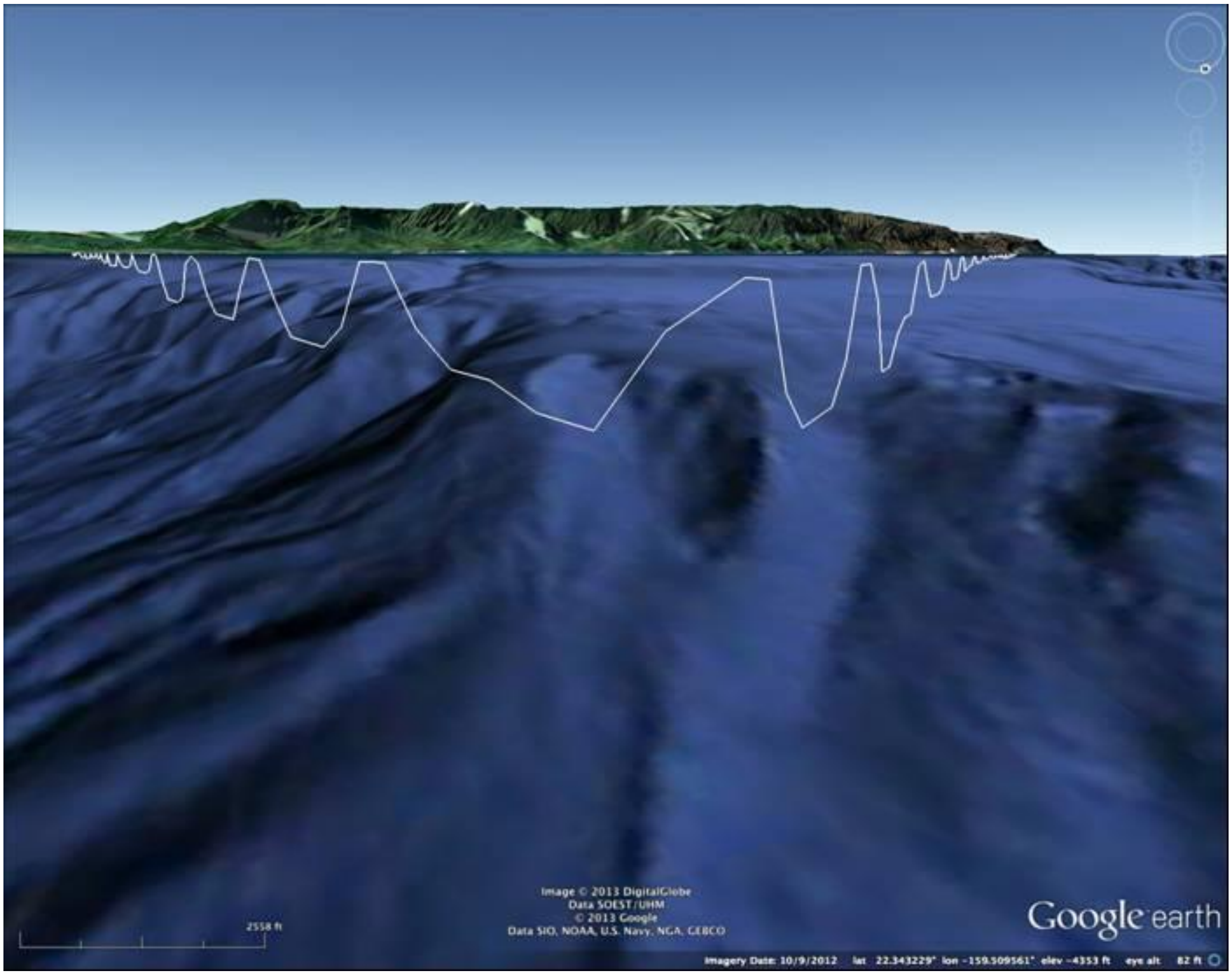


Figure 3. An example of dive and location data from bottlenose dolphin HITt0806 over a 2-hr and 17 minute period starting on 11 February 2013 at 19:00 hr (HST), as the animal travels from the southwest to the east (right to left) off the north side of Kaua‘i. This representation uses time-series data with depths recorded every 1.25 minutes. Maximum depths of the individual shown in this example are 218 m, with the individual appearing to dive to or close to the seafloor on deeper dives as it moved into deeper water.

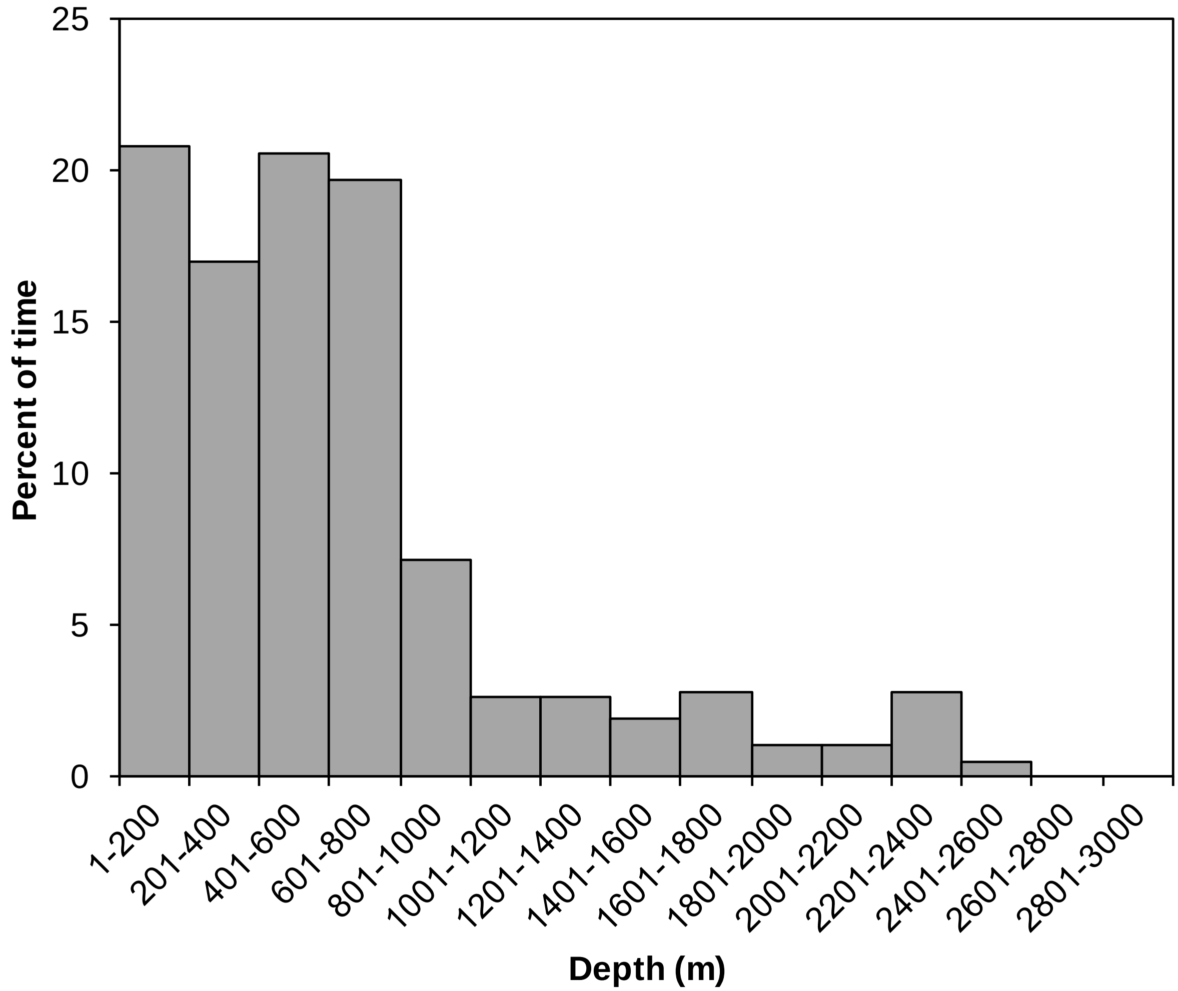


Figure 4. Distribution of small-vessel effort by depth during February 2013 field effort.

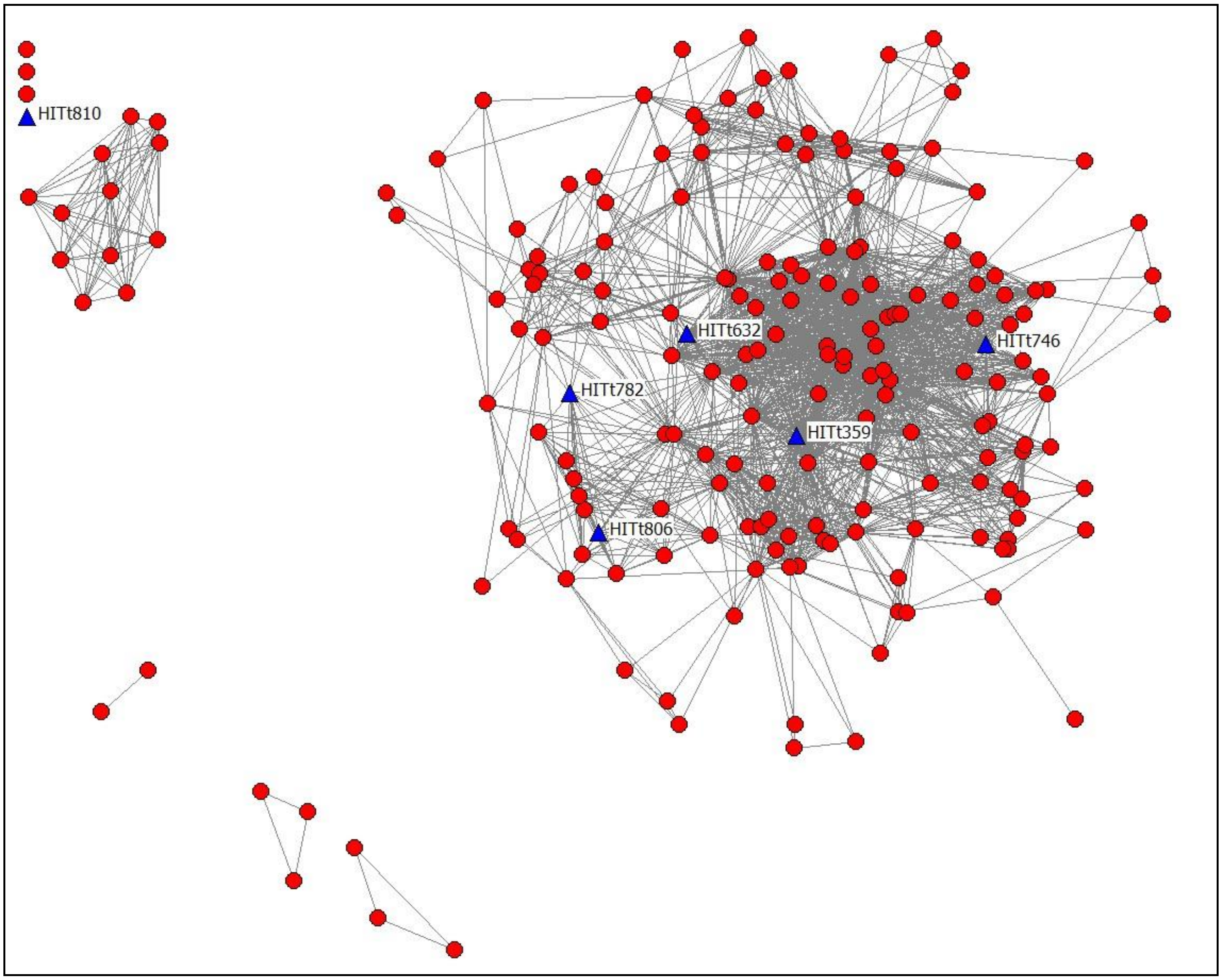


Figure 5. Social network of bottlenose dolphins photo-identified off Kaua‘i, Ni‘ihau and Ka‘ula Island from 2003-2013 including individuals considered slightly distinctive, distinctive or very distinctive, with fair or better photo qualities (see Baird et al. 2009). This social network contains 201 individuals, 177 of which are linked by association in the main cluster. Tagged individuals are noted with ID labels and by symbol type (triangles). Individuals tagged in February 2013 were HITt0359, HITt0806 and HITt0810. The large isolated cluster in the upper left, and one of the isolated clusters of three individuals (bottom left) were both documented off Ka‘ula Island, to the southwest of Ni‘ihau.

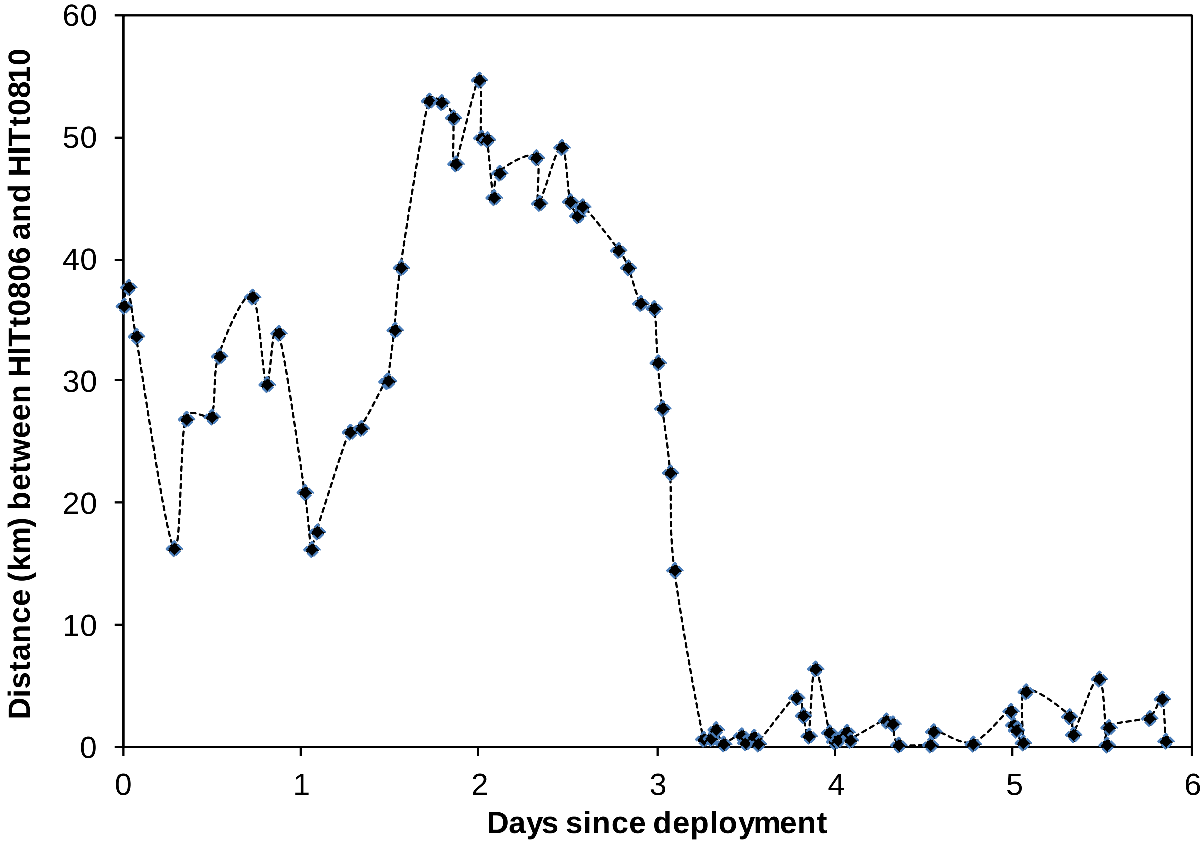


Figure 6. Distance between two satellite-tagged bottlenose dolphins, HITt0806 (tagged on 4 February 2013) and HITt0810 (tagged on 9 February 2013), for the approximately 6 days of overlap of data for the two individuals. Although the two individuals were approximately 35 km apart when HITt0810 was tagged, 3.2 days later locations from the two individuals were less than 1 km apart (with the closest distance 151 m apart), suggesting the individuals were associating and HITt0810 is likely part of the same resident social network.

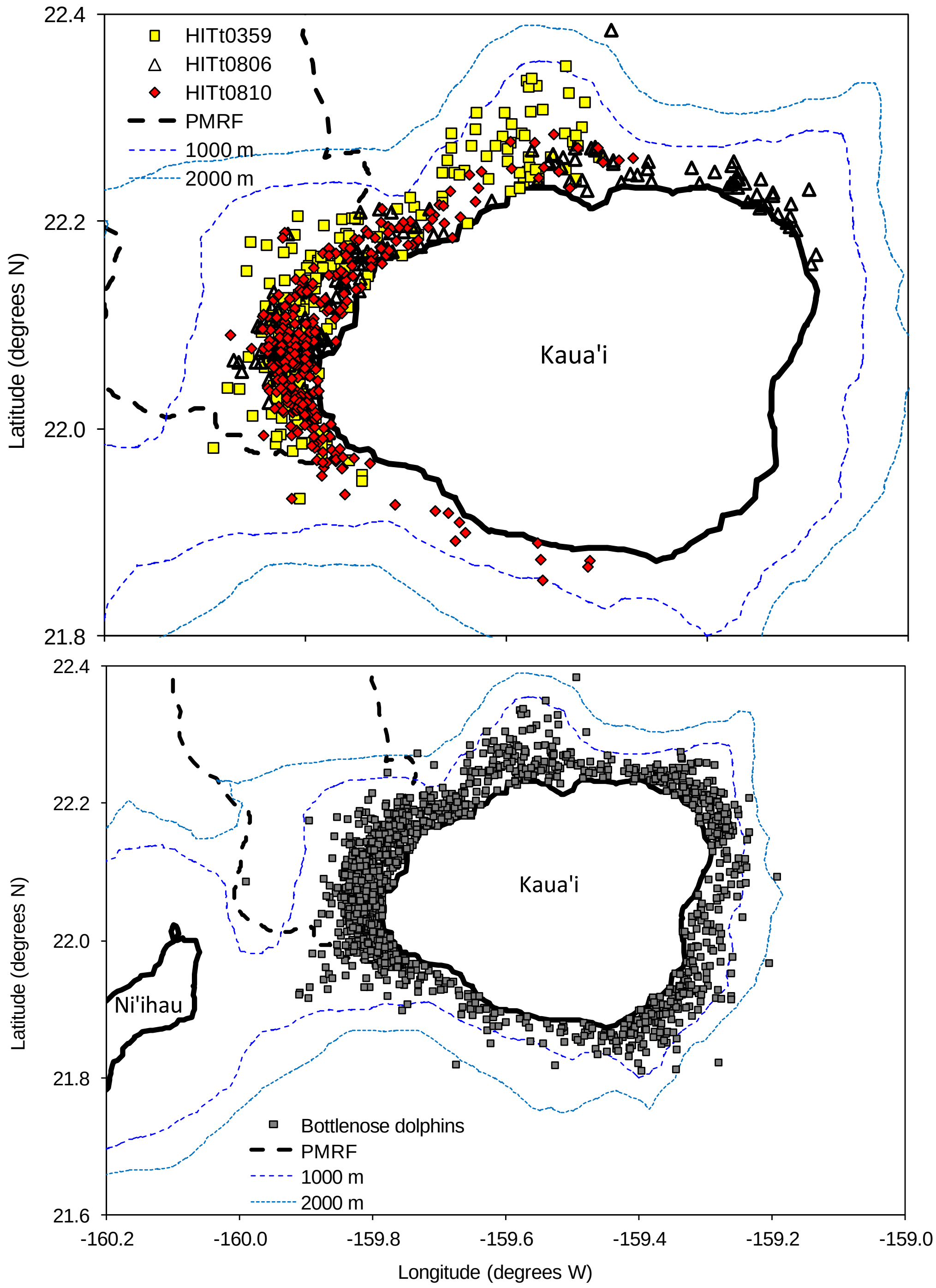


Figure 7. Top. Locations of three individual bottlenose dolphins satellite-tagged in February 2013, with individuals identified. Individuals HITt0806 and HITt0810 had not been previously photo-identified, but HITt0359 had been previously documented (first seen in 2005), including two sightings off the north tip of Niʻihau. Bottom. Locations of six satellite-tagged bottlenose dolphins, including individuals tagged in August 2011 (1 individual), June 2012 (2 individuals), and February 2013 (3 individuals).

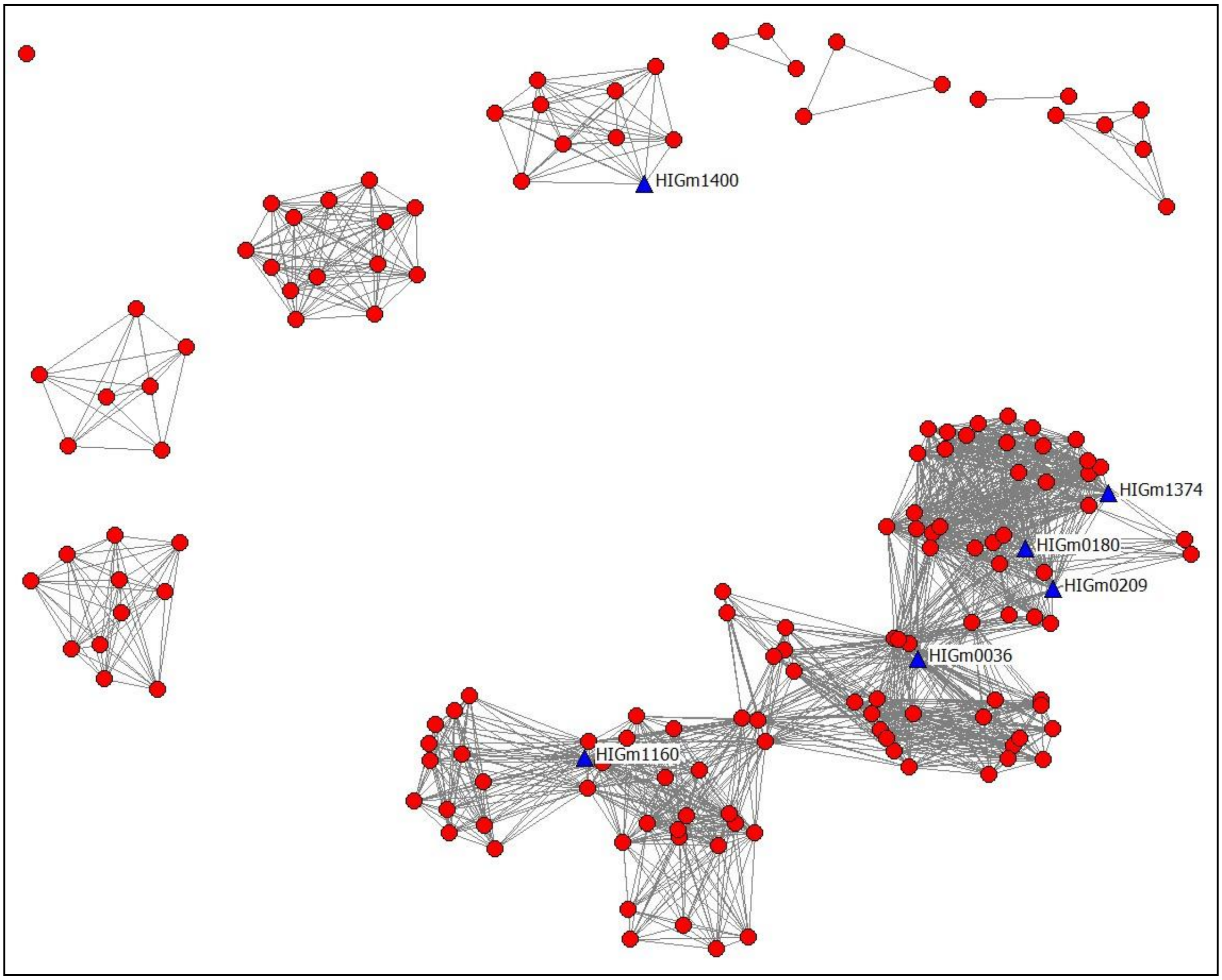
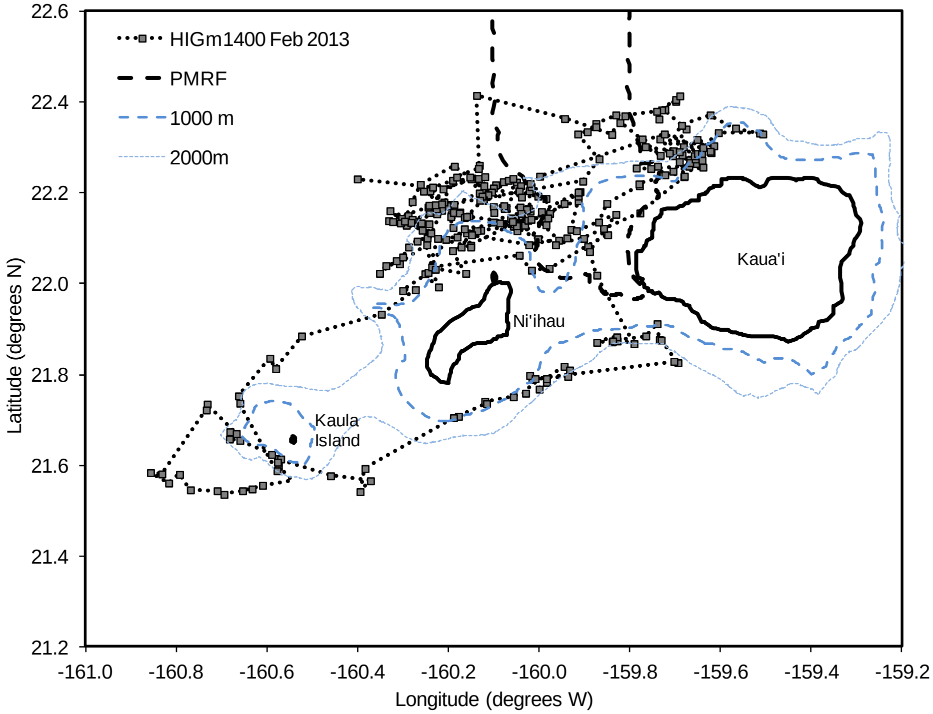


Figure 8. Social network of short-finned pilot whales photo-identified off Kaua‘i and Ni‘ihau from 2003-2013, with tagged individuals noted by symbol type (triangles) and with ID labels. This includes distinctive and very distinctive individuals with good or excellent quality photos (see Mahaffy 2012). A total of 159 individuals are represented, with 103 in the main cluster. Although HIGm1400 and companion individuals have not been seen associated with the main cluster off of Kaua‘i, one of the companion individuals has been encountered with individuals from the main cluster off O‘ahu (CRC unpublished data). In addition, four locations over a 7-hr period obtained from HIGm1400 when tagged in February 2011 were less than 1 km from HIGm0180, providing further evidence of association in the same social network.



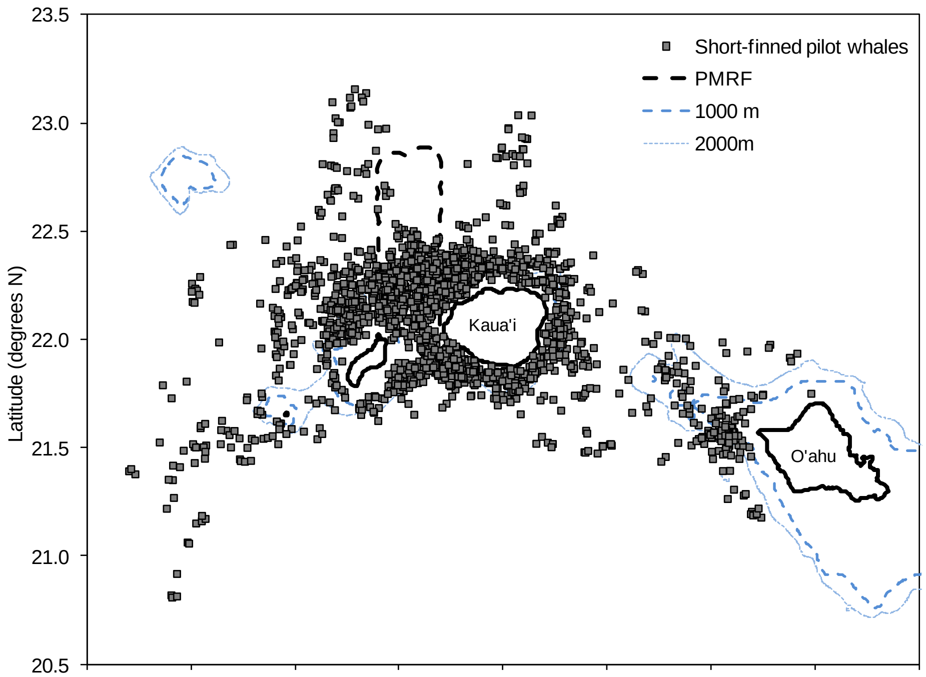


Figure 9. Top. Locations of pilot whale HIGm1400, satellite-tagged in February 2013. Although two individuals were tagged in February 2013, location data were only obtained from one tag. Bottom. Locations of seven short-finned pilot whales satellite tagged off Kaua‘i, including individuals tagged in July 2008 (1 individual), February 2011 (3 individuals), January 2012 (2 individuals), and February 2013 (1 individual).

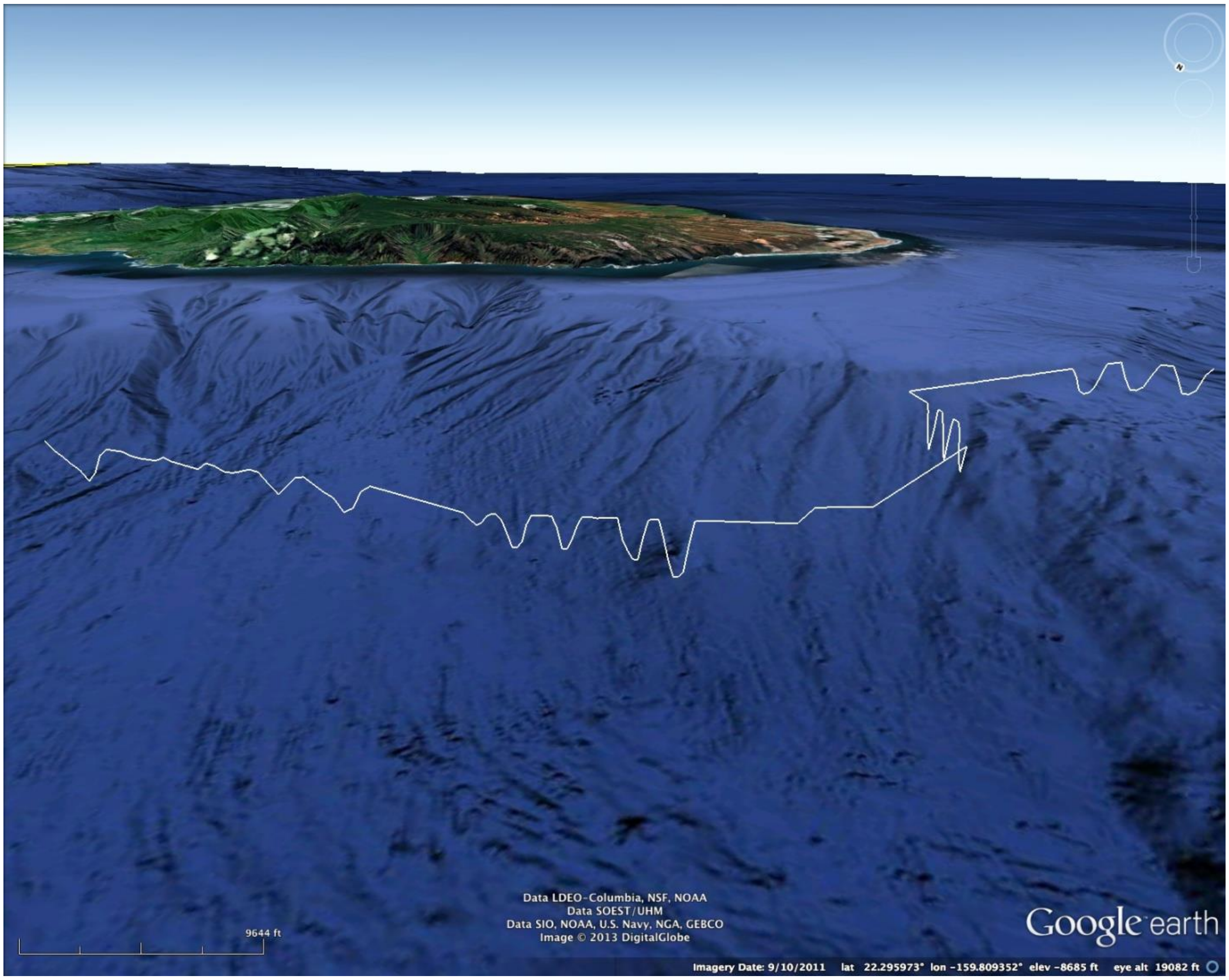


Figure 10. An example of dive and location data from short-finned pilot whale HIGm1400 over a 9-hr period starting on 11 February 2013 at 00:35 hrs (HST), as the animal travels from the east to the southwest (left to right) off the north side of Kaua‘i. This representation uses time-series data with depths recorded every 2.5 minutes. Maximum depths of dives shown in this example are 935 m. Deep dives appear to be to mid-water depths.

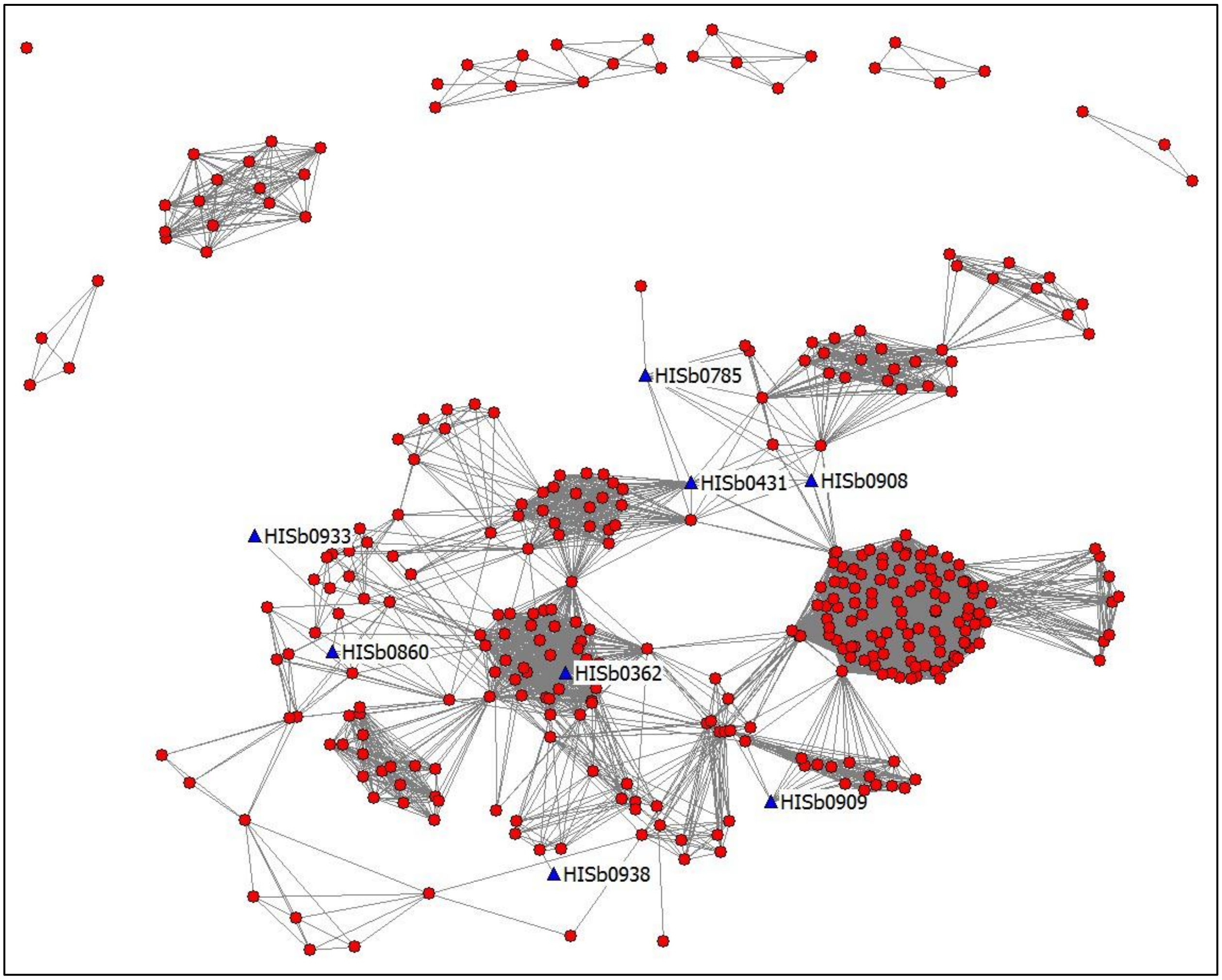
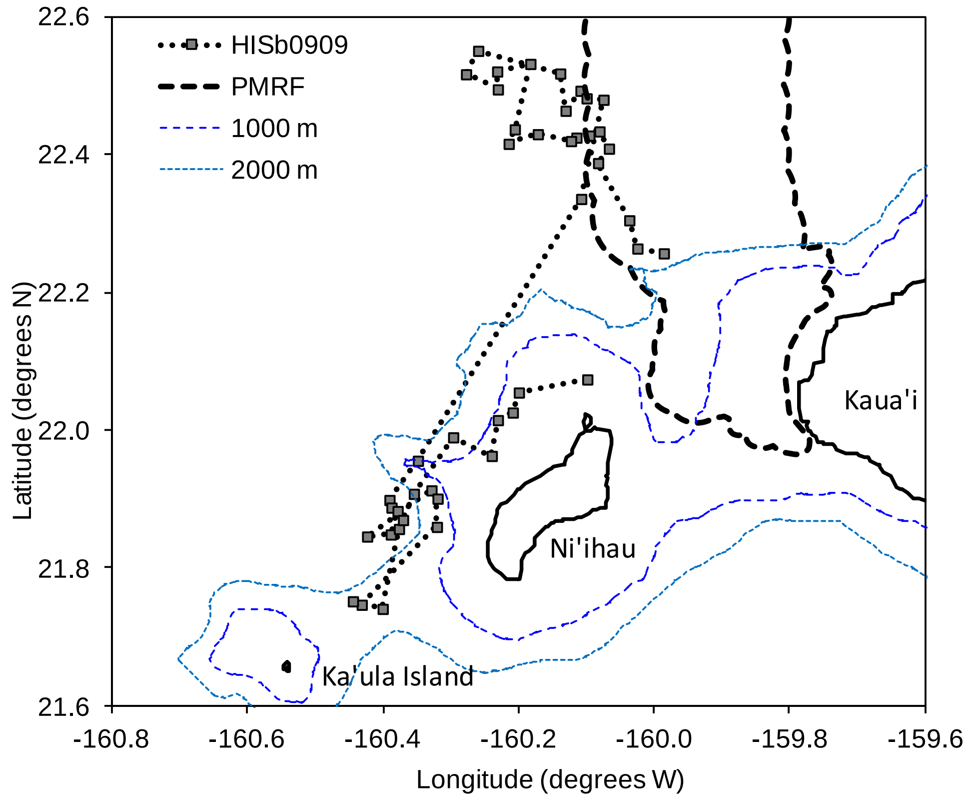


Figure 11. Social network of rough-toothed dolphins photo-identified off Kaua‘i and Ni‘ihau from 2003-2013, with tagged individuals noted by symbol type (triangles) and with ID labels. This includes all individuals categorized as slightly distinctive, distinctive, or very distinctive, with fair, good, or excellent quality photographs (see Baird et al. 2008b), with a total of 350 individuals shown (the main cluster contains 308 individuals). Individual HISb0909 was tagged in February 2013.



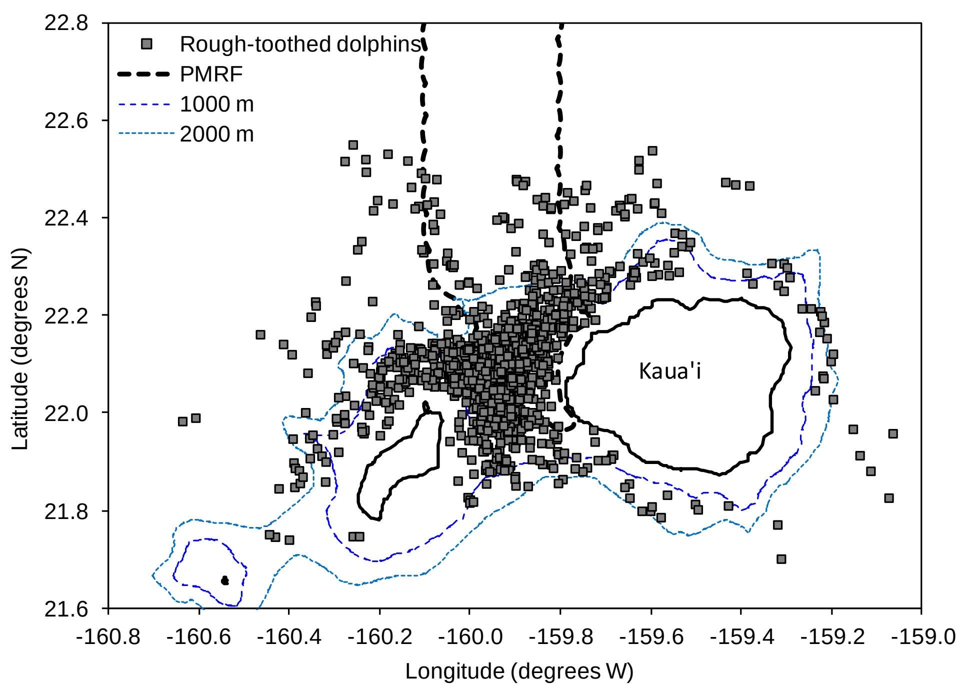


Figure 12. Top. Locations of rough-toothed dolphin HISb0909 satellite tagged in February 2013. Bottom. Locations of eight satellite-tagged rough-toothed dolphins, including individuals tagged in July/August 2011 (3 individuals), January 2012 (1 individual), June/July 2012 (3 individuals) and February 2013 (1 individual).

Table 1. Details of previous small-vessel/M3R field efforts off Kauaʻi involving satellite tagging.

Dates	Odontocete species seen[1]	Species tagged (# tagged)	Species detected on M3R
25-30 Jun 2008	*Pe*, *Sb*, *Gm*, *Sl*	*Gm* (1), *Pe* (3)	N/A
16-20 Feb 2011	*Tt*, *Sb*, *Gm*, *Sl*	*Gm* (3)	N/A
20 Jul-8 Aug 2011	*Tt*, *Sb*, *Sl*, *Sa*, *Oo*	*Tt* (1), *Sb* (3)	*Tt*, *Sb*, *Sl*, *Oo?*
10-19 Jan 2012	*Tt*, *Sb*, *Gm*, *Sl*, *Md*	*Sb* (1), *Gm* (2)	*Tt*, *Sb*, *Gm*, *Sl*, *Md*
12 Jun-2 Jul 2012	*Tt*, *Sb*, *Gm*, *Sl*, *Sa*, *Pc*	*Tt* (2), *Sb* (3), *Pc* (3)	*Tt*, *Sb*, *Gm*, *Pc*

[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*, *Md = Mesoplodon densirostris*, *Mn = Megaptera novaeangliae*.

[2]One tag did not transmit, thus data available from seven pilot whale tags deployed off Kauaʻi.

Table 2. PMRF undersea range characteristics

Range area	Depth range (m)	Hydrophone numbers (string names)	Low detection counts
BARSTUR	~1,000 – 2,000	2-42 (1-5) 1,10,21,24,37,41	3, 36, 42
BSURE Legacy	~2,000-4,000	43-60 (A,B)	
SWTR	~100-1000	61-158 (C-H)	63, 67, 101, 122, 126, 159-178
BSURE Refurbish	~2,000-4,000	179-219 (I-L)	

Table 3. Observations of acoustic features from passive acoustic monitoring during previous M3R field efforts.

Species1	# Visual Verifications	Whistle Features	Click Features	Distinctive Spectrogram Features	Acoustically Similar Species
Sb	22	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	9	primarily 8-24 kHz, highly variable, lots of loopy curves	16-48 kHz, rapid ICI	Density of clicks and whistles. Very wideband, long duration loopy whistles.	
Gm	2	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	1	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	1	n/a	24-48 kHz, 0.33 s ICI	Consistent ICI and click frequency content.	

[1]See footnote to Table 1.

Table 4. February 2013 small-vessel effort summary.

Date	Total km	Total hours on effort	# sightings total	# detected acoustically by M3R	Depart time HST	Return time HST	Total km Beaufort 1	Total km Beaufort 2	Total km Beaufort 3	Total km Beaufort 4	Total km Beaufort 5
2 Feb 2013	110.2	6.6	1	1	7:06	13:40	0	45.1	38.8	17.3	9
3 Feb 2013	139.8	8.0	5	3	6:56	14:56	16.8	75.9	34.6	12.5	0
4 Feb 2013	122.6	7.1	4	2	6:57	14:06	0	26.6	39.5	56.5	0
5 Feb 2013	78.6	4.6	2	3	6:54	11:32	0	7.1	58.2	7.8	5.5
6 Feb 2013	99.0	6.3	1	1	6:57	13:11	0	38.3	37.2	23.5	0
7 Feb 2013	182.0	8.9	1	1	7:00	15:53	0	91.5	56.9	33.6	0
8 Feb 2013	157.0	9.0	5	2	6:53	15:49	0	97.5	34.5	25	0
9 Feb 2013	121.0	5.4	1	1	6:57	12:18	6.8	92.1	22.1	0	0
Total	1,010.2	55.9	20	14			23.6	474.1	321.8	176.2	14.5

Table 5. February 2013 M3R effort summary

Date	Range Availability		PAM Effort (HST)		Recording (HST)	
	area	time	start	stop	start	stop
2 Feb 2013	unlimited	unlimited	0615	1255	N/A	N/A
3 Feb 2013	unlimited	unlimited	0615	1431	N/A	N/A
4 Feb 2013	unlimited	unlimited	0630	1224	N/A	N/A
5 Feb 2013	unlimited	unlimited	0640	1107	N/A	N/A
6 Feb 2013	unlimited	unlimited	0630	1310	N/A	N/A
7 Feb 2013	unlimited	unlimited	0645	1515	1300	1515
8 Feb 2013	unlimited	unlimited	0645	1200	0856	1200
9 Feb 2013	unlimited	unlimited	0645	1116	0715	1116

Table 6. Visually-verified odontocete sightings at PMRF 2-9 February 2013

Date	Time (HST)	Species[1]	Group size (#)	Satellite tag (Y/N)	Distance from PAM to visual ID position (km)	PAM position		Visual ID position	
						Latitude °N	Longitude °W	Latitude °N	Longitude °W
2 Feb 2013	1019	*Tt*	35	Y	0.46	22.0728	159.8461	22.0705	159.8498
3 Feb 2013	1128	*Tt*	20	N	2.51	22.0650	159.8454	22.0453	159.8573
3 Feb 2013	1238	*Tt*	35	N	1.01	22.0105	159.8729	22.0196	159.8722
3 Feb 2013	1334	*Tt*	1	N	0.22	22.0571	159.8302	22.0551	159.8302
3 Feb 2013	1405	*Sl*	60	N	NA	NA	NA	21.9874	159.7799
4 Feb 2013	0920	*Tt*	35	N	0.55	22.0016	159.8158	22.0064	159.8170
4 Feb 2013	1125	*Tt*	25	Y	0.37	22.0300	159.8512	22.0277	159.8486
5 Feb 2013	0916	*Tt*	2	N	NA	NA	NA	22.0661	159.8224
5 Feb 2013	1003	*Tt*	5	N	0.05	22.0807	159.8265	22.0807	159.8270
6 Feb 2013	0908	*Tt*	12	N	0.50	22.0676	159.8339	22.0633	159.8323
7 Feb 2013	1419	*Tt*	8	N	0.39	22.1024	159.8189	22.1059	159.8185
8 Feb 2013	0932	*Sb*	15	Y	0.28	22.2523	159.9847	22.2548	159.9849
8 Feb 2013	1154	*Gm*	22	Y	NA	No: clicks misclass *Tt*		22.2534	159.7912
8 Feb 2013	1423	*Tt*	10	N	0.29	22.1570	159.7994	22.1559	159.8020
9 Feb 2013	0839	*Tt*	8	Y	0.76	22.1168	159.8154	22.1231	159.8126

[1]See footnote to Table 1.

Table 7. PAM observations from the M3R system with species classification confidence indicated as High, Medium or Low. Table includes only real-time acoustic observations logged in notes, and cannot be interpreted for species presence/absence. Because we were often viewing only the BARSTUR/SWTR area where the RHIB was located, there could be days where, as an example, sperm whales were present on BSURE but were not noted.

Species[1]	2-Feb	3-Feb	4-Feb	5-Feb	6-Feb	7-Feb	8-Feb	9-Feb
Gm		Medium			Low	Low	Low	
Md	High	High	High	High	High	High	High	High
Mn	High	High	High	High	High	High	High	High
Pc						Low		
Pm				High		High	High	High
Sb		High	High	High		High	High	High
Sl	High	High	High	High	High	High	High	High
Tt	High	High	High	High	High	High	High	High
Zc				Medium				

[1]See footnote to Table 1. *Zc* = *Ziphius cavirostris*

Table 8. Details on satellite tags deployed during 2-9 February 2013 field effort.

Species[1]	Tag ID	Individual ID	Date tagged	Sighting #	Duration of signal contact (days)	Lat (°N)	Long (°W)	Tag type	Sex
Gm	GmTag070	HIGm1400	9 Feb 2013	2	19.87	22.26	159.79	Mk10-A	Male
Gm	GmTag071	HIGm1404	8 Feb 2013	2	0.00	22.26	159.75	Mk10-A	Male
Sb	SbTag008	HISb0909	8 Feb 2013	1	3.45	22.26	159.99	Mk10-A	Unknown
Tt	TtTag008	HITt0359	8 Feb 2013	1	18.17	22.12	159.84	Mk10-A	Unknown
Tt	TtTag009	HITt0806	4 Feb 2013	3	10.73	22.05	159.84	Mk10-A	Unknown
Tt	TtTag010	HITt0810	9 Feb 2013	1	20.53	22.13	159.81	Spot5	Unknown

[1]See footnote to Table 1.

Table 9. Details on previous sighting history of individuals satellite tagged in February 2013.

Individual ID	Date first seen	# times seen previously	# years seen	Islands seen previously
HIGm1400	19 Feb 2011	2	3	Kaua‘i, O‘ahu
HIGm1404	19 Feb 2011	2	3	Kaua‘i, O‘ahu
HISb0909	8 Aug 2013	1	2	Kaua‘i
HITt0359	6 Nov 2005	7	4	Kaua‘i, Ni‘ihau
HITt0806	4 Feb 2013	0	1	-
HITt0810	9 Feb 2013	0	1	-

Table 10. Information from GIS analysis of satellite tag location data from 2-9 February 2013 field effort.

Individual ID	# locations	# periods inside PMRF boundaries	% time inside PMRF boundaries	Total minimum distance moved (km)	Median/ maximum distance from deployment location (km)	Median/ maximum depth (m)	Median/ maximum distance from shore (km)
HIGm1400	284	10	14.8	1,517.5	36.1/133.3	1,956/4,466	16.3/42.9
HISb0909	44	2	8.5	281.0	36.4/73.3	2,794/4,701	27.5/60.2
HITt0359	205	21	51.9	1,106.0	10.9/40.1	206/1,570	5.4/13.9
HITt0806	171	12	23.2	690.1	17/59.1	61/2,214	3.0/17.2
HITt0810	314	43	43.5	1,259.2	9.6/41.7	80/1,071	3.3/10.7

Table 11. Dive data information from satellite tags deployed during 2-9 February 2013 field effort.

Individual ID	# hours data ARGOS only	# hours data combined ARGOS/ land receiver	# 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)
HIGm1400	419.8	420.9	1,072	171.5	1,103.5	10.82	22.0
HISb0909	0.77	0.77	10	49.5	81.5	2.82	4.50
HITt0359	30.5	70.3	219	73.5	751.5	3.07	12.0
HITt0806	153.1	193.9	455	79.5	686.0	5.37	11.4

[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.