Marine Mammal Monitoring on Navy Ranges (M3R)
An Opportunistic Study of the Effect of Sonar on Marine Mammals
on the Pacific Missile Range Facility

PMRF

FY14 Summary

Contact:

David J. Moretti
Naval Undersea Warfare Center
Building 1351 Code 70T
Newport, RI 02879
Phone: 401-832-5749
Fax: 401-832-4441
Email: david.moretti@navy.mil

Robin W. Baird
Cascadia Research Collective
218 1/2 4th Ave W
Olympia, WA 98501
Phone: 360-943-7325
Fax: 360-943-7026.
E-mail: rwbaird@cascadiaresearch.org

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David J. Moretti
Robin W. Baird

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Naval Undersea Warfare Center, Building 1351 Code 70T, Newport, RI 02879
Cascadia Research Collective, 218 1/2 4th Ave W, Olympia, WA 98501

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14. ABSTRACT
With funding from the Living Marine Resources (LMR) Program, the Marine Mammal Monitoring on Navy Ranges (M3R) passive acoustic monitoring system has been installed at the Pacific Missile Range Facility (PMRF). The overall goal of the program is to provide tools and methodologies for long-term monitoring of marine mammal populations. The program is laying the groundwork needed to adapt combined passive acoustic, tagging, and visual monitoring methods for animals and conditions at PMRF. For sonar-sensitive Blainville's beaked whales (Mesoplodon densirostris; Md), the short- and long-term distribution, density, and habitat can be measured provided basic behavioral data such as group size and dive rates at PMRF are known. In addition, the empirical risk function developed for Md at AUTEC can be cross-validated. With on-water observers and satellite tags, the species present, group behavior and composition, and broad-scale animal movement and dive behavior can be documented. The methodologies developed through this program can then be applied to long term in-situ monitoring of population health.The results of such monitoring can be used to assess the population health of species that are repeatedly exposed to mid-frequency active (MFA) sonar on the Pacific Missile Range Facility (PMRF).

In FY14, collaborative tests with Cascadia Research Collective (CRC) were conducted which expanded our knowledge derived from past tests of species present and their distribution. The tests combined both expert on-water observers and M3R passive acoustics. During these tests, observers are directed to vocalizing animals to verify the species, record surface behavior and group composition, photo-identify individuals, attach satellite tags (a mix of location-only and depth-transmitting satellite tags, depending on the species encountered and conditions for tagging), and collect biopsy samples (for sex determination of tagged individuals and for stock determination for some species). While the use of the hydrophones is largely weather independent, the on-water team operates in a mix of sea-states and productivity is largely weather-dependent. In FY14, animals were satellite tagged, corresponding vocalizations recorded, and passive acoustic detection data archived.

15. SUBJECT TERMS
Monitoring, marine mammals, beaked whales, passive acoustic monitoring, Hawaii Range Complex, satellite-tagging, behavior, M3R, PMRF

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1. Program Overview

With funding from the Living Marine Resources (LMR) Program, the Marine Mammal Monitoring on Navy Ranges (M3R) passive acoustic monitoring system has been installed at the Pacific Missile Range Facility. The overall goal of the program is to provide tools and methodologies for long-term monitoring of marine mammal populations. The results of such monitoring can be used to assess the population health of species that are repeatedly exposed to Mid-Frequency Active (MFA) sonar on the Pacific Missile Range Facility (PMRF) undersea acoustic ranges.

To meet this goal, the program incorporates the following objectives:

1. Conduct passive acoustic monitoring at the PMRF and adapt real-time tools for detecting both baleen and odontocete species on the PMRF.

2. Provide visual verification of marine mammals isolated using passive acoustics to link vocalizations to species, and assess the likelihood of detecting species acoustically based on the proportion of sightings on the PMRF that are detected visually but not acoustically.

3. Produce an initial catalog of beaked whale species, develop and validate methodologies to measure their abundance and spatial and temporal distribution, and estimate their density by comparing visual sighting and satellite tag data to passive acoustic data.

4. Assess spatial movement patterns and habitat use (e.g., island-associated or open-ocean, restricted range or large ranges) of marine mammal species that are exposed to MFA sonar and determine how these patterns potentially influence exposure and responses.

5. Obtain baseline dive data on odontocetes that use the PMRF range to allow for future comparisons of potential changes in diving behavior in relation to MFA sonar exposure and for use in development of abundance and density estimation methods.

6. Obtain baseline age/sex class information of beaked whales and resident odontocete species at PMRF for comparison to age/sex class structure of the same species in areas with infrequent (e.g., Abaco, Hawaii Island) or frequent (e.g., AUTEC, SOCAL) MFA sonar exposures.

7. Establish procedures and methodologies at PMRF to determine the behavioral reaction of species to MFA sonar operations using combined passive acoustic, satellite tag, and range ship-track data.

With the current M3R tools in place at PMRF, marine mammal vocalization detection archives can be collected on every range hydrophone over extended time periods (days to months). For six BARSTUR and all BSURE replacement hydrophones, low frequency baleen call data can also be archived. The program is laying the groundwork needed to adapt combined passive acoustic, tagging, and visual monitoring methods for animals and conditions at PMRF. For sonar-sensitive Blainville's beaked whales (*Mesoplodon densirostris*, *Md*) [1], [2], [3], the short and long term distribution, density, and habitat can be measured provided basic behavioral data such as group size and dive rates at PMRF are known. In addition, the empirical risk function developed for *Md* at AUTEC can be cross-validated. With on-water observers and satellite tags, the species present, group behavior and composition, and broad-scale animal movement and dive behavior can be documented. The methodologies developed through this program can then be applied to long term in-situ monitoring of population health.

2. Background

PMRF provides a unique opportunity to develop passive acoustic tools for marine mammal monitoring as the range extends from shallow (100 m) to very deep (4,000 m) waters with an instrumented area that covers well over 1,000 km^2. This allows the monitoring of species against broad and varied environments with and without the presence of MFA sonar. Species diversity in Hawaiian waters is high, with 18 species of odontocetes documented [7] as well as several species of baleen whales.

PMRF encompasses 3 adjacent range areas. First, the shallow water range consists of a set of multiplexed arrays with 78 working hydrophones. The sensors cover the mid to high frequency bandwidth. Second, the BARking Sands Tactical Underwater Range (BARSTUR) consists of 42 individually cabled hydrophones. Six hydrophones have a bandwidth that can be used to monitor low frequency baleen whale species as well as higher frequency odontocetes. The remaining 36 hydrophones cover mid to high frequency consistent with odontocetes species. The new 41 deep water (> 2.5 km) wideband Barking Sands Undersea Range Expansion (BSURE) hydrophones allow monitoring of both baleen and odontocetes vocalizations.

3. FY14 Summary

In FY14 collaborative tests with Cascadia Research Collective (CRC) were conducted which expanded our knowledge derived from past tests (Table 1) of species present and their distribution.

The tests combined both expert on-water observers and M3R passive acoustics. During these tests, observers are directed to vocalizing animals to verify the species, record surface behavior and group composition, photo-identify individuals, attach satellite tags (a mix of location-only and depth-transmitting satellite tags, depending on the species encountered and conditions for tagging), and collect biopsy samples (for sex determination of tagged individuals and for stock determination for some species). While the use of the hydrophones is largely weather independent, the on-water team operates in a mix of sea-states and productivity is largely weather-dependent.

3.1 Satellite Tags

In FY14 animals were satellite tagged, corresponding vocalizations recorded, and passive acoustic detection data archived. One of the limiting factors for tagging is the timing of field operations: with the exception of the October 2014 field effort, timing of recent field operations to date off Kaua‘i have been driven by the schedule of Submarine Commanders Courses (SCC) or RIMPAC, rather than by targeting efforts when sea conditions and range availability are most conducive to tagging operations.

Field operations were undertaken in conjunction with M3R passive acoustic monitoring, to maximize the number of encounters with target species while simultaneously providing vital visual verification of species. The hydrophones were continuously monitored in real-time and the observer vessel was vectored to the animals based on M3R passive acoustic detections and localizations. M3R detection reports were archived on a 24 hour basis. In addition, recordings from selected time periods and/or hydrophones were made to document verified species vocalizations.

When weather conditions allowed, field operations were concentrated in the deepest portions of the PMRF range to maximize encounters with high priority target species (*i.e.*, beaked whales). Otherwise tagging operations were generally limited to areas with relatively calm seas (e.g., <Beaufort 3) to maximize the likelihood of both species detection and tag deployments, since tags cannot usually be deployed in rough seas except under unusual circumstances (e.g., extremely cooperative animals moving slowly down swell).

On-water operations were conducted from a 24' rigid-hulled Zodiac with a custom-made bow-pulpit to facilitate tagging operations [10]. Field crew included four key individuals provided by CRC, a vessel driver, a tagging specialist, a photo-ID specialist, and a data recorder, although some individuals performed multiple tasks (e.g., data recorders acted as secondary photographers, tagging specialists biopsied tagged animals). Field operations were undertaken under NMFS Scientific Research Permit No. 15330 (issued to CRC).

The primary satellite tag used was a depth-transmitting tag (Wildlife Computers MK10A), although location-only (SPOT5) tags were deployed when conditions for deploying depth-transmitting tags were sub-optimal. Both tags were in the LIMPET configuration [9], [10], [11], [6].

Odontocete species for which there is no/limited information on movements/behavior around Kaua'i were considered primary target species (Blainville's beaked whales, Cuvier's beaked whales, pygmy killer whales, sperm whales, killer whales), as well as for other species thought to be sensitive to MFA sonar (melon-headed whales, dwarf sperm whales), or ESA listed species (false killer whales) along with a number of species of baleen whales including blue whales, fin whales, minke whales, sei whales and Bryde's whales. Resident populations of odontocetes (i.e., short-finned pilot whales, rough-toothed dolphins, bottlenose dolphins) were secondary target species.

Tags were programmed for each species taking into account existing knowledge of diving behavior from prior tag deployments. Tags were also programmed to transmit during periods with the best satellite overpasses and for a varying number of hours during a 24 hour period (from 9-22 hours) depending on species (longer-diving species like beaked whales require transmission for a greater number of hours per day), and tag type (location-only tags were set to transmit for shorter periods of time than location/dive tags).

Tag data were processed using the Douglas Argos-filter to remove unrealistic locations [11], [6], [10]. Resulting filtered location data are being processed with ArcGIS to determine depth, distance from shore, and location relative to the PMRF range to assess whether locations are inside or outside of the range boundaries. From this, the frequency and duration of each animal's residency on PMRF is being estimated. Dive data obtained from the location/dive tags are being processed to assess the proportion of time spent at depth, and day and night-time dive rates and dive characteristics (e.g., depth, duration).

Photo-identification was undertaken simultaneously with tagging operations, with attempts made to obtain good quality photos of each individual present. We collected biopsy samples of tagged and companion individuals to allow for sex determinations from genetic analyses or from observation of external morphology.

With sufficient photo-ID data for a given species, estimates of abundance will be possible. These in turn can be used to cross-validate passive acoustic methods for the species of interest. A summary of all tags deployed to date including those in FY14 is provided in Table 1.

Table 1. Summary of small-boat/M3R field efforts off Kaua'i involving satellite tagging through 2014.

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*
Feb 1-10 2014	66.3	*Tt, Sb, Sl, Gm, Md*	*Md* (2), *Tt* (2), *Sb* (2), *Gm(6)*	*Tt, Gm*
Oct 7-17, 2014	77.7	*Tt, Sb, Sl, Gm, Pc, Pm*	*Pm (1), Gm (1), Pc (2), Tt (2)*	*Md, Gm, Tt, Pm, Gm*
Total		*Tt, Sb, Gm, Pe, Sl, Sa, Pc, Md, Oo*	*Gm* (15)[2], *Pe* (3), *Tt* (10), *Sb* (12), *Pc* (6), *Md*(2), *Pm* (1)	*Tt, Gm, Sb, Sl, Pc, Md, Zc, Pm*

[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, Mn = Megaptera novaeangliae.* [2]One tag did not transmit, thus data available from 14 pilot whale tags deployed off Kaua'i.

By tagging animals, baseline spatial and temporal habitat use along with diel dive behavior patterns are measured for multiple species. These data are then being compared to passive acoustic data as a means of validating the use of passive acoustics for these species at PMRF. Photo-identifications of tagged and companion individuals are compared to long-term catalogs held by Cascadia Research Collective in order to assess the sighting history and population identity (resident versus pelagic) of tagged individuals, to help interpret movement and dive behavior patterns. An understanding of each species' baseline behavior is critically important for the analysis of any measured changes during sonar operations. In addition, information on the age/sex structure of populations can be determined, to allow for comparisons in age structure for populations off PMRF in comparison to populations elsewhere. For Blainville's beaked whales, this could include populations off Kona and in the Bahamas, while for resident odontocetes off Kaua'i (e.g., bottlenose dolphins, rough-toothed dolphins, short-finned pilot whales), this could include comparisons with populations off Kona.

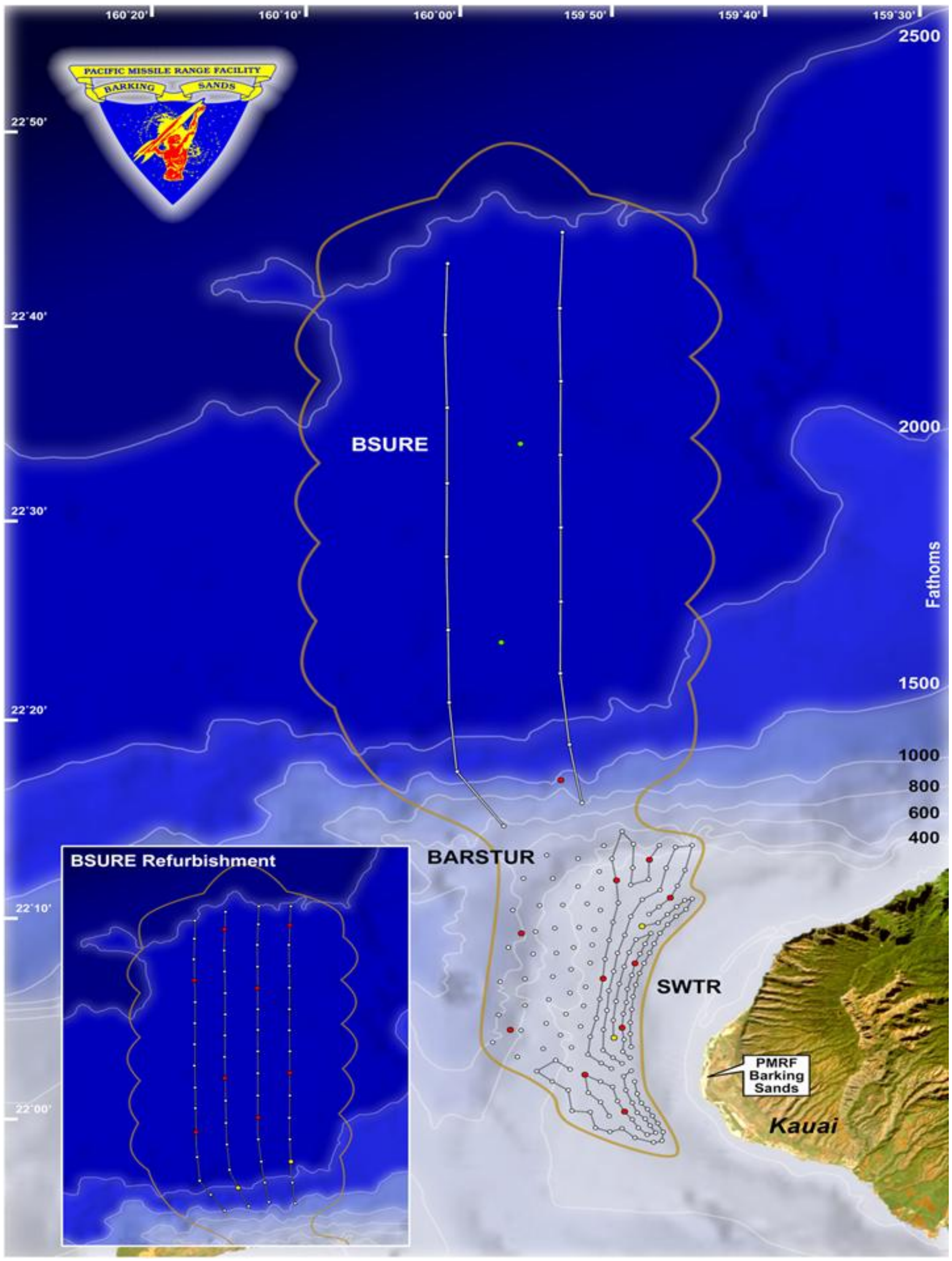


Figure 1. Pacific Missile Range Facility undersea range hydrophones off Kaua'i with BSURE refurbishment hydrophones in bottom-left inset.

The combined small boat tracks from October 2014 are shown in Figure 2 . The timing of the October 2014 project was driven by sea condition considerations, not operations, and during that effort the small-boat was able to operate in much deeper water than normal. As a result, we obtained our first encounters with two deep-water species seldom seen around Kauaʻi or Niʻihau (sperm whales and pygmy killer whales), and were able to deploy the first satellite tag on a sperm whale off PMRF, as well as tag pelagic short-finned pilot whales. Since 2011, 45 tags (21 depth-transmitting) have been deployed on six species of odontocetes off Kauaʻi, representing individuals from eight different populations (Table 2).

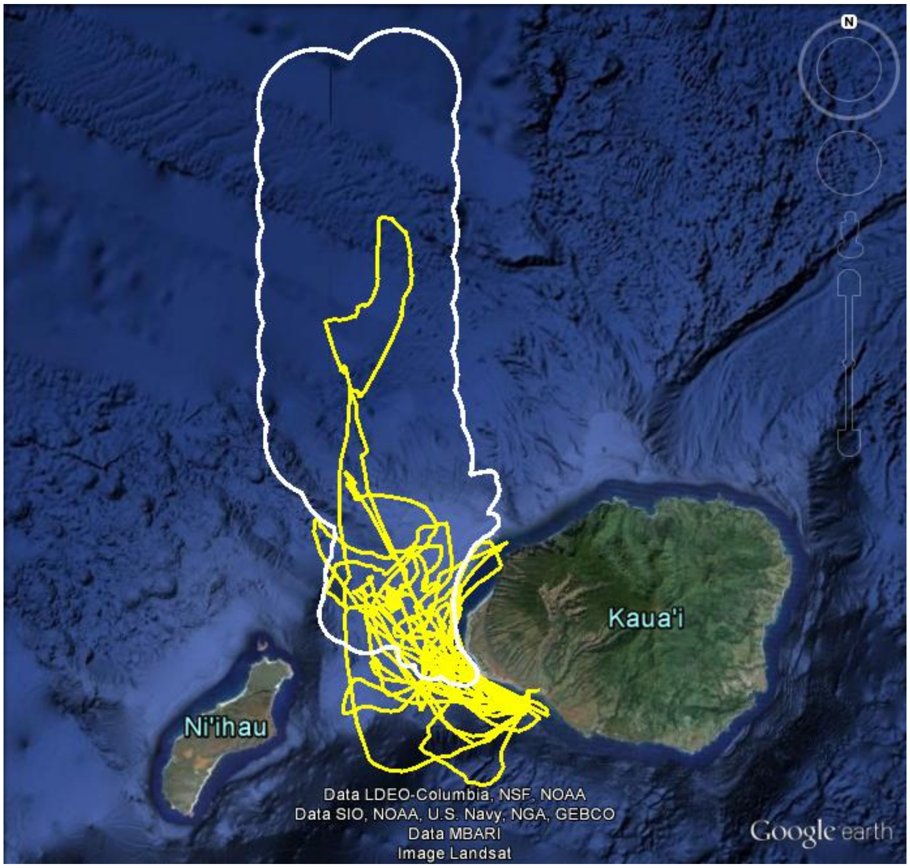


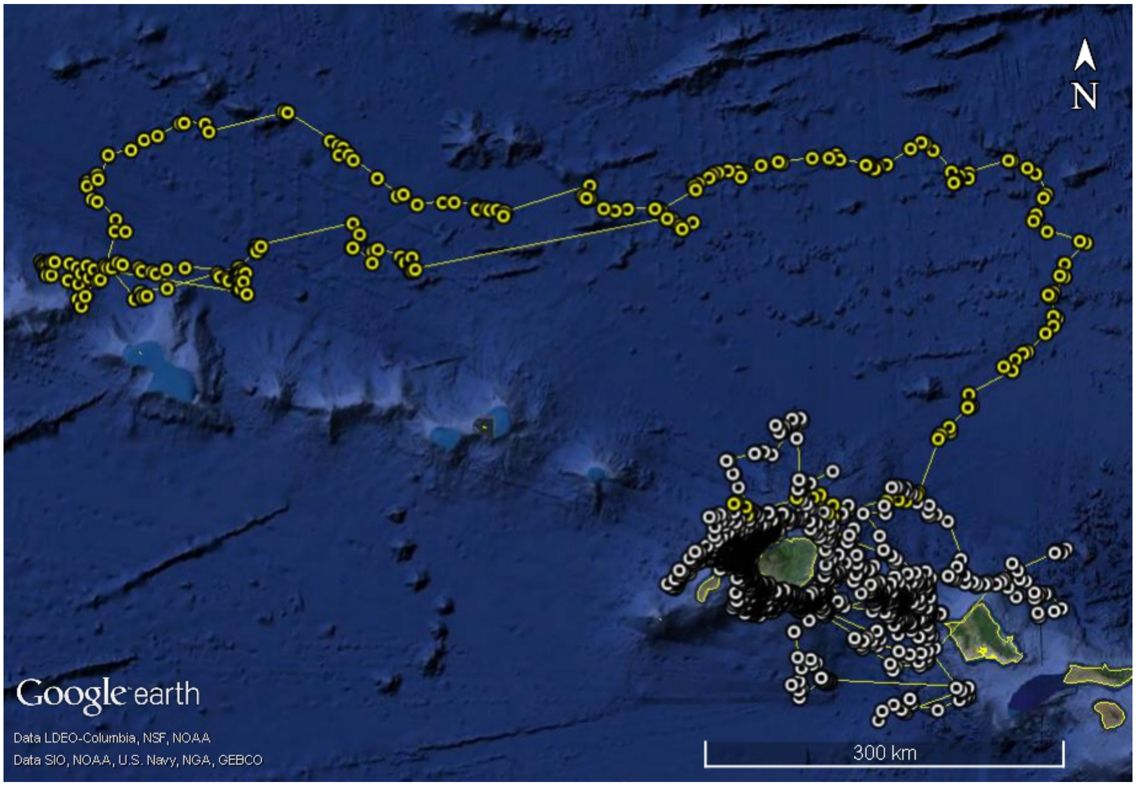
Figure 2. Map showing tracklines of small-boat field effort (yellow lines) in October 2014, with the PMRF boundary shown (white line).

Table 2. Tag deployments on odontocetes off Kauaʻi, 2011-2014.

Species	# tagged	# populations	Duration days Median (range)	# depth-transmitting tags	# days dive data
Short-finned Pilot Whale	15*	2	28 (1-89)	7	80.6
Rough-toothed Dolphin	12	1	11 (3-27)	6	38.2
Bottlenose Dolphin	10	1	19 (11-34)	4	23.2
False Killer Whale	6	2	21 (16-103)	4	22.9
Blainville's beaked whale	2*	1	8 (8)	1*	0
Sperm whale	1	1	14 (14)	1	11.3
Total	46	8		23*	176.2

*One tag deployed did not function.

The combined satellite tag localizations provide an emerging picture of habitat use with substantial variation among species for three species that all appear to be resident to the islands: short finned pilot whales (Figure 3); rough-toothed dolphins (Figure 4); common bottlenose dolphins (Figure 5). Data are also being obtained from less common species: Blainville's beaked whales (Figure 6) and sperm whales (Figure 7). As sample sizes grow, animal ranges are continuing to be expanded (e.g., Figure 3, Figure 5), and it is now possible to start to assess high use areas using kernel density estimation (Figure 8).



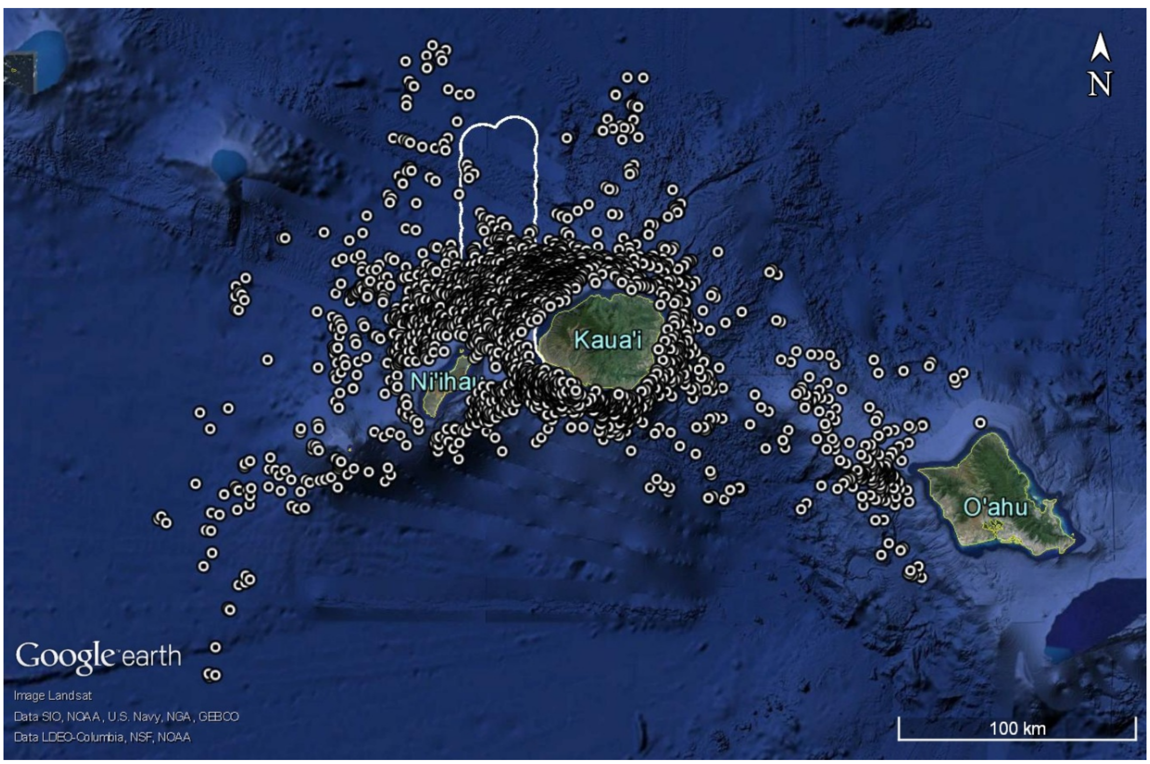


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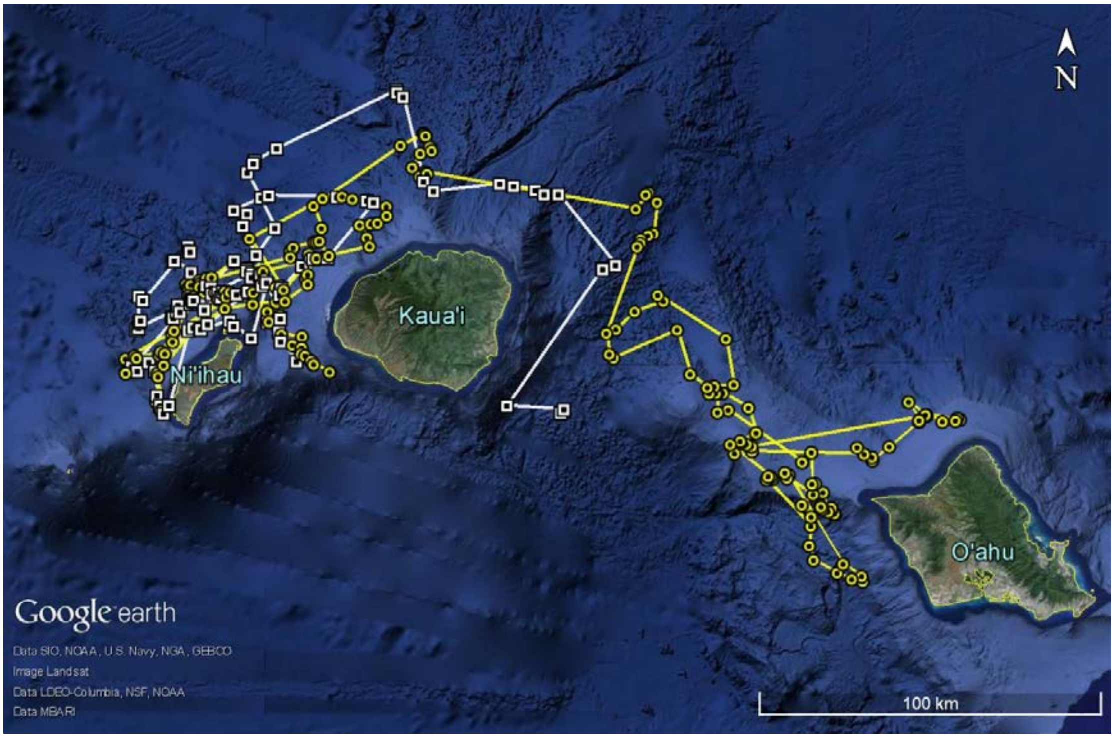
Figure 3. Top. Locations from short-finned pilot whales tagged in 2014. The points of GmTag104, a 28 day track of an animal tagged in October 2014, are shown in yellow. Bottom. Locations from all eight previous short-finned pilot whales tag deployments off Kaua'i. The PMRF boundary is shown in white.



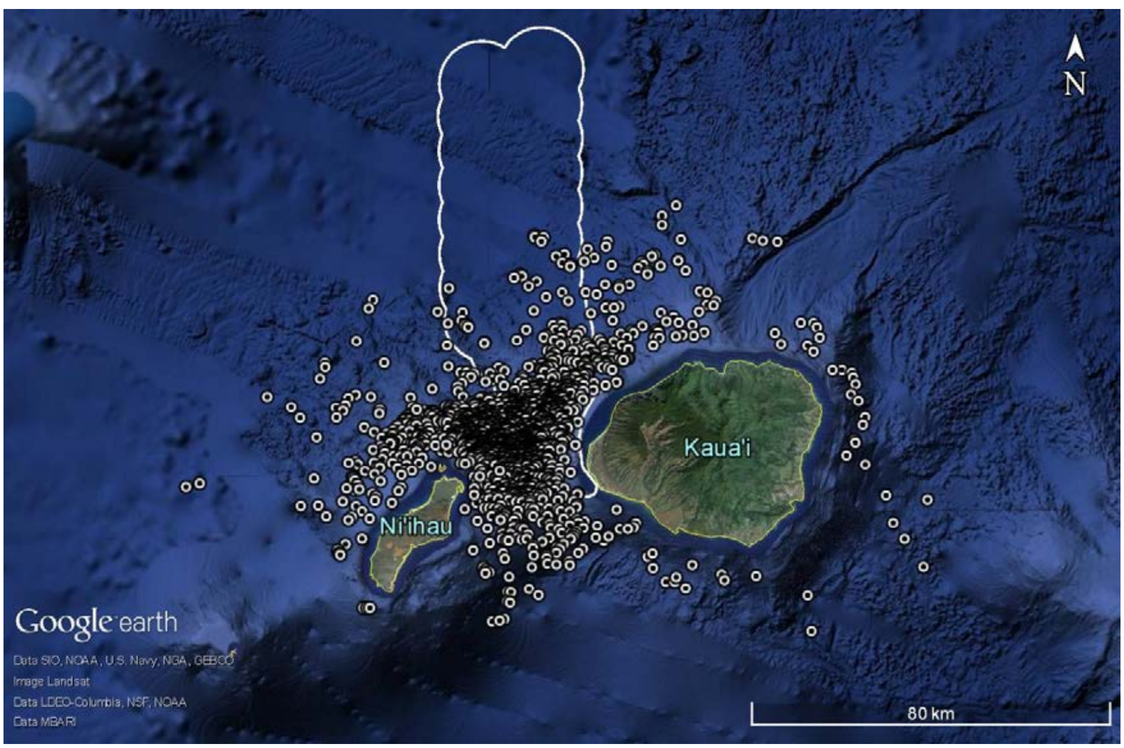


Figure 4 Top. Locations of rough-toothed dolphins satellite tagged in Feb 2014 (yellow circles SbTag011; white circles SbTag012). Bottom. Locations of 10 satellite-tagged rough-toothed dolphins, including individuals tagged in July/August 2011 (3 individuals), January 2012 (1 individual), June/July 2012 (3 individuals) February 2013 (1 individual), and July 2013 (2 individuals). The PMRF boundary is shown in a solid white line.

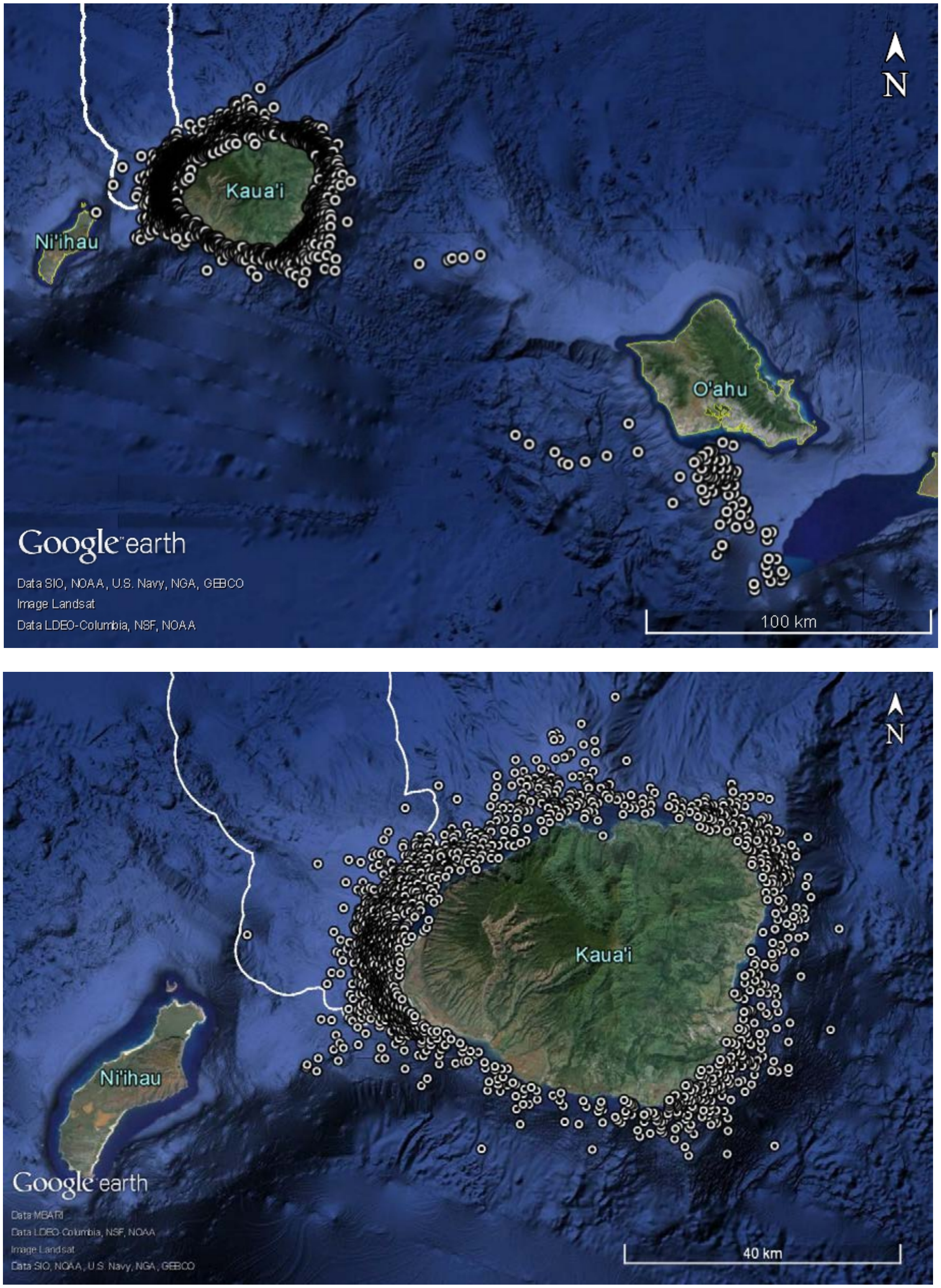


Figure 5 Top. Locations of all bottlenose dolphins satellite tagged through 2014, showing one individual that moved to off O'ahu. Bottom. Locations of six satellite-tagged bottle nose dolphins tagged prior to 2014. The boundary of PMRF is shown in a solid white line.

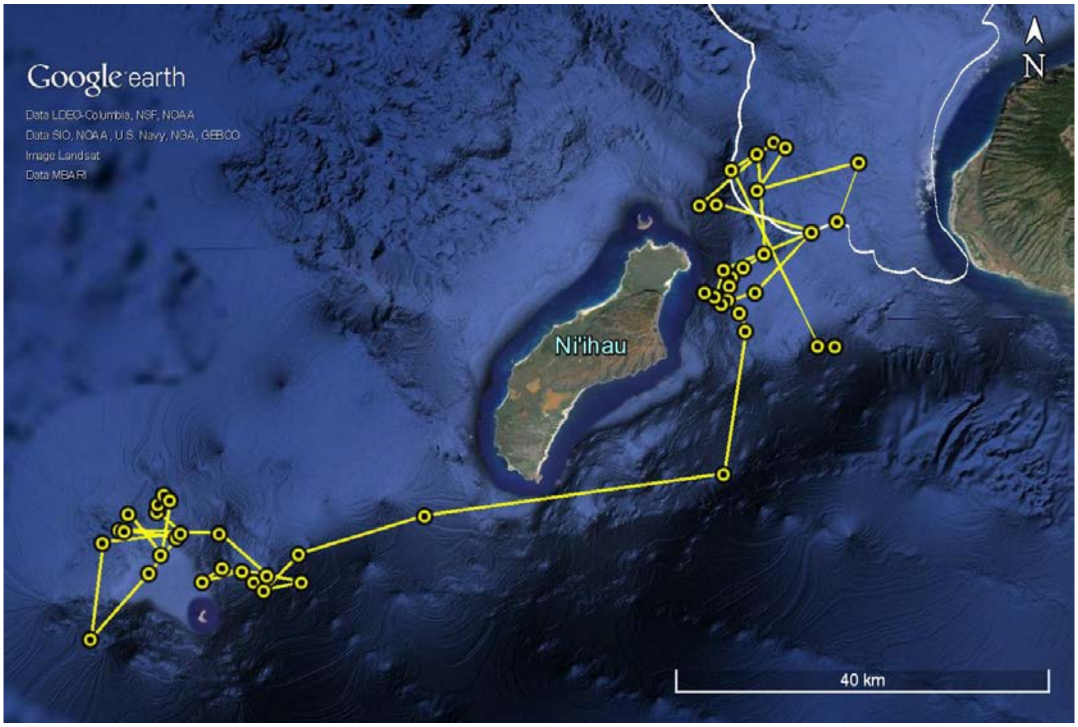


Figure 6. Locations of satellite tagged Blainville's beaked whale tagged in February 2014 over an eight-day period. The PMRF boundary is indicated by a solid white line.

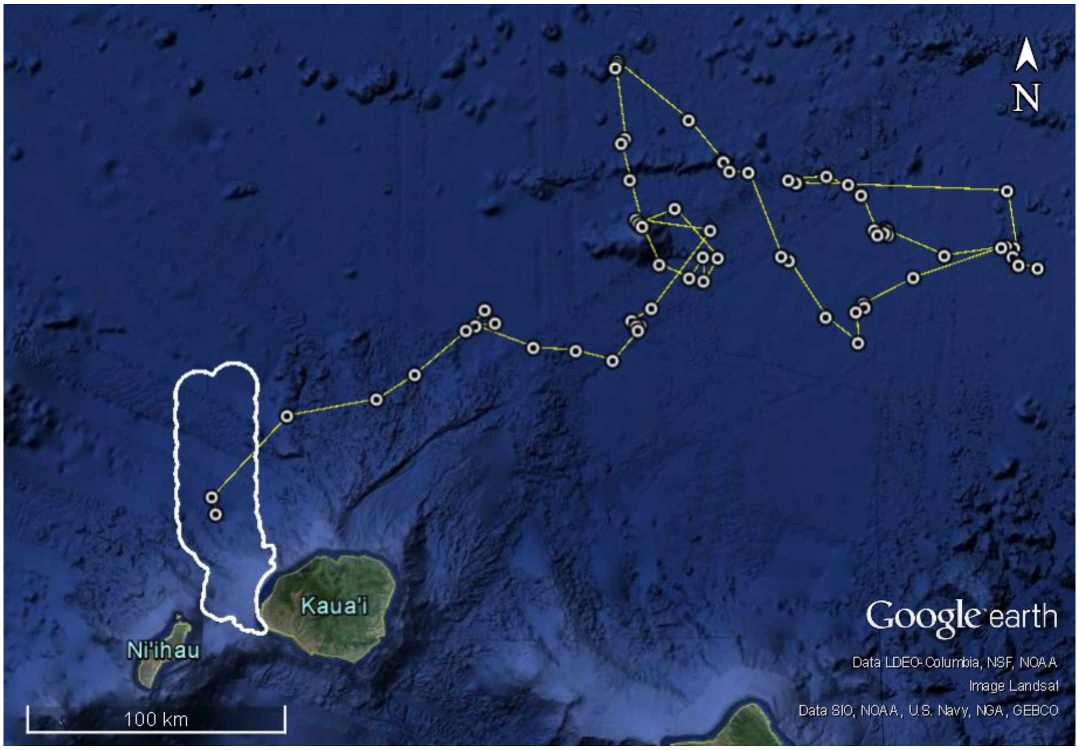


Figure 7. Locations of a satellite tagged sperm whale tagged in October 2014 over a 14-day period. The PMRF boundary is indicated by a solid white line.

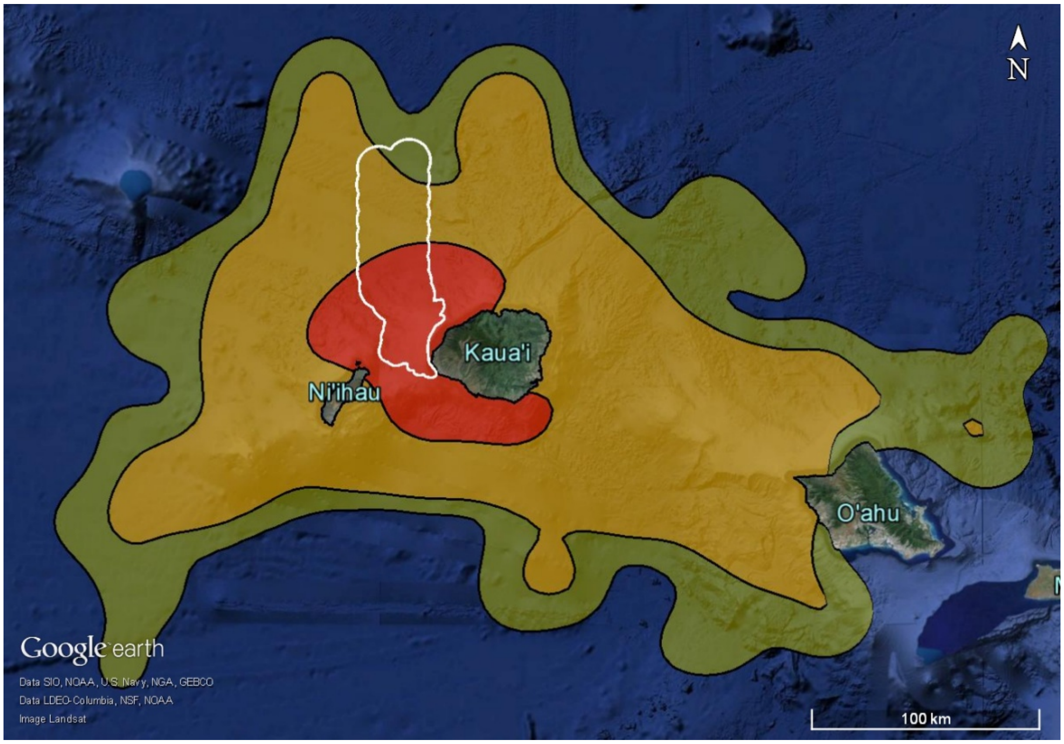


Figure 8. A probability density representation of short-finned pilot whale location data from 13 satellite tags deployed off Kauai. The red area indicates the 50% density polygon, the yellow represents the 95% polygon, and the green represents the 99% polygon. The PMRF boundary is shown in a solid white line.

Through these tests M3R observers have been able to acoustically differentiate among rough-toothed dolphins, bottlenose dolphins, pilot whales, and false killer whales by examining click and whistle structures that were documented during previous PMRF tests [4], [5].

3.2 Beaked Whales

After ten years of focused development, passive acoustic monitoring methodologies are best defined for Blainville's beaked whales (*Mesoplodon densirostris, Md*). The M3R software tools detect and classify echolocation clicks from deep foraging dives, and isolate groups of animals based on these detections. These Group Vocal Periods (GVPs) represent periods during deep foraging dives when a group of animals, diving in synchrony, emits echolocation clicks in search of prey. The rate of deep foraging dives is known from tags [6] and from recording tags it is know that the animals only echolocate during these deep foraging dives [7, 8]. Thus GVPs can be used as a proxy for both temporal and spatial distribution and foraging.

M3R real-time detection and classification software can be used to monitor all (~200) range hydrophones 24 hours a day, 7 days a week, over extended periods, and to create detection archives that can then be post processed. From these archives, the spatial and temporal distribution of *Md* can be measured. These methods, initially developed for *Md* at AUTEC, are being adapted for and validated at PMRF. As an initial test of the methods at PMRF *Md* foraging dives were extracted from the M3R detection archives (Table 3). These were then used along with visual sighting data as an initial estimate of *Md* abundance. Note, automated tools have been developed for AUTEC detection archives. These methods are currently being validated with PMRF data. Once the statistics for detection of dive starts at PMRF are completed, abundance can be estimated in a semi-automated mode making estimates over long time periods (years) possible as data become available. Preliminary analysis of the semi-automated tools compared to the manually extracted data show a true rate of GVP detection of ~95%.

Table 3: Hand validated *Md* groups on the PMRF

Archive	Begin	End	Groups
1	21:07	0:11	4
2	0:16	3:24	6
3	5:01	8:40	5
4	11:15	16:05	3
5	16:03	21:25	3
6	22:07	22:57	3
7	22:54	1:54	3
8	1:48	2:01	2
9	3:56	4:43	3
10	4:37	5:11	1
11	5:15	7:42	5
12	8:17	9:22	4
13	9:46	12:25	4
14	11:48	15:43	5
15	16:09	17:25	5
16	18:02	19:53	5
17	19:48	20:39	4
18	20:51	22:02	3
19	21:43	22:36	4
20	23:06	0:30	2
21	23:53	0:54	4
22	1:06	2:37	4
23	3:06	6:57	3
24	6:24	6:54	1
25	7:53	8:20	1
26	9:22	10:20	3
27	11:46	16:14	5
28	16:19	17:15	1
29	18:24	19:43	5
30	19:46	22:25	5
31	21:27	22:58	4
32	22:43	0:47	6
33	0:49	2:47	3
34	3:07	6:58	4
35	7:56	10:44	4
36	10:16	11:06	4
		85.15 hrs	131 groups

To estimate abundance, the dive counting method as given below and presented in Moretti et al., 2010 was applied.

$$D = \frac{n_d s}{r_d T A}$$

n_d = total number of dive starts
s = average group size
r_d = dive rate (dives/unit time)
T = time period over which the measurement was made
A = measurement Area

Equation 1 : Dive counting density estimating equation (Moretti *et al.*, 2010)

To parameterize the equation, the dive rate and group size from Baird et al., 2008 were used (Table 3).

Mean Dive Rate (dive/hr)	Var	Dives/Day	Group Size mean	Var
0.46	0.01	11.04	3.69	5.71

Table 2: Mean dive rate and group size estimates from Baird *et al*., 2008

Initial abundance estimates for the limited period suggest on the order of a dozen *Md* in approximately three groups were present on the range (Table 4*)* during the time period analyzed. This is consistent with what has been reported by personnel monitoring the range hydrophones using passive acoustics during tests on range.

Animals	Groups
12.34 (6.63-18.05)	3.34 (1.8-4.89)

Table 3: Estimate of *Md* abundance and number of groups present on PMRF

Md dive start data can also be used to map the relative distribution of species on range (Figure 9). Typically, acoustic detections are concentrated in deeper water on west BARSTUR and south BSURE, although detections further north on BSURE and east on BARSTUR have been noted.

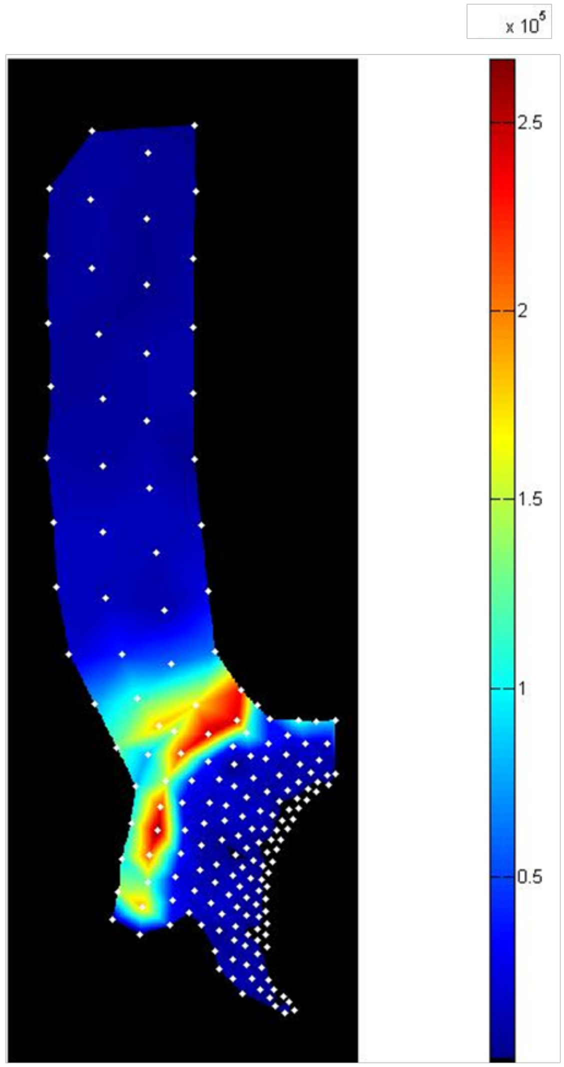


Figure 9. Distribution of *Md* Click Counts on the PMRF during the July, 2012 M3R test

Of course, passive acoustics is most applicable to the instrumented range. For species which frequent waters outside this area such as bottlenose dolphins, alternate methods such as visual observation and satellite tags are being used. As the mix of species and their reaction to operations become clearer, the methods developed here can be evaluated as part of an overall long-term monitoring plan.

3.3 Additional Species

Additional odontocete and mysticete species are also being monitored. The extent to which the above questions can be answered must be considered on a case by case basis, and there is a high species diversity of odontocetes off the PMRF range [9]. As the area surrounding the main Hawaiian Islands is oligotrophic, the density of most species is quite low, thus encounter rates are low. Despite low density, more than half the species of odontocetes are known to have resident island-associated populations. The development of the current *Md* methods provides a case study in the research steps required to provide the same information for additional cetacean species.

Detection and classification to a species level requires, at a minimum, basic knowledge of the species' call structure. The first step is directly associating vocalizations with the species of interest. For *Md* this was accomplished by placing recording tags directly on animals. With these data, passive acoustic tools could be programmed to detect the call. Using these passive acoustic tools on the Navy undersea acoustic ranges, vocalizing animals are being detected and classified. Expert observers are vectored to the animals to verify the species and validated recordings are obtained. By repeating this procedure multiple times, confidence in call classification and recorded data is gained. It is important to remember that detection of a sound on range hydrophones and the subsequent visual report from an expert observer does not guarantee the sound detected was emitted by the observed animal. It is entirely possible that the sound detected came from a different unseen species. Only through repeated acoustic and visual observation can a cause and effect relationship be validated.

This is possible with *Md* because the call characteristics have been well documented and multiple species verification tests have been conducted, and because of the stereotyped nature of their clicks. *Md* vocalizations have unique features that can be exploited to correctly classify to a species level. These features have been derived through a combination of recording tags, in-situ visual observation, and analysis of acoustic recordings collected on-site. To reach the same level of confidence in the performance of the tools with alternate species requires the same effort. Many small odontocetes produce similar clicks and whistles. Derivation of a strong feature set requires analysis of data from tags placed directly on the animal and recorded on surrounding hydrophones. When combined with data from surrounding hydrophones, it also becomes possible to measure the source level and beam pattern of tagged animals. These measurements along with the tag recordings can be used to estimate detection statistics.

4.0 M3R System Integration

These tests represent the first step in integrating long-term monitoring methods into range operations. Once operating, these data will be collected on a continuous basis by range personnel. The system should require little operator intervention. The operators must initialize the system and verify that processes are running and that archives are being collected. System tools for such operation are being developed under the AUTEC and SCORE components of the M3R system. Thus, initial transition to range operations should entail only the system verification and updating of disks for archiving. From these archives, final monitoring data products will be derived. The final phase in range integration will be the introduction of tools to automatically produce long-term monitoring reports from the archives. Finally, these tools will be integrated into real-time operations allowing long-term monitoring data products to be produced with minor analyst intervention.

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