Studies of dolphins and whales on and around the Pacific Missile Range Facility using photo-identification and satellite tagging: evidence for resident and non-resident species

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Introduction

There are 18 species of odontocetes found around the main Hawaiian Islands, and 11 of these have resident, island-associated populations in the eastern main Hawaiian Islands (Baird 2016). Until recently, relatively little was known about the presence and residency status of most of these species in the western main Hawaiian Islands, in particular around Kaua‘i and Ni‘ihau. The U.S. Navy’s Pacific Missile Range Facility (PMRF) is located off the west and northwest side of Kaua‘i, and is the site of regular Navy training activities, and it is therefore of particular interest to understand species composition, use of the area, and potential short- and long-term impacts of Navy activities on these species.

As part of a long-term study of odontocete cetaceans in Hawaiian waters, Cascadia Research Collective (CRC) carried out small-boat based field projects off Kaua‘i and Ni‘ihau in 2003 (Baird et al. 2003), 2005 (Baird et al. 2006), and 2008 (Baird et al. 2008a). These efforts have involved assessing species composition based on distribution of sightings in relation to survey effort, and have utilized photo-identification of individuals to examine sighting histories, both around Kaua‘i and Ni‘ihau, as well as in comparison to photo-identification and survey effort undertaken elsewhere in the main Hawaiian Islands (Baird et al. 2008b, 2009, 2013a). In addition, biopsy samples have been collected from most species for studies of genetic differentiation (e.g., Courbis et al. 2014) and in 2008 CRC began deploying satellite tags to examine movements of individuals (Baird et al. 2008a). With support from the U.S. Navy more regular efforts off Kaua‘i began in 2011, and from 2011 through 2015 CRC had two field efforts each year off Kaua‘i, and had a single field effort in 2016, greatly increasing the information available to assess odontocete presence and residency around Kaua‘i and Ni‘ihau. Funding for this recent work came from the Naval Postgraduate School (2011-2012; see Baird et al. 2013b), Pacific Fleet (2011-2016), and by a contract through the Naval Undersea Warfare Center (NUWC: 2014-2015).

This is the final report for work at PMRF under the NUWC contract, focusing on combined results from the 2014-2015 period as well as including the 2013 effort, to increase the sample size. We also include information from the larger sample of survey effort, sightings, and tag deployments off Kaua‘i and Ni‘ihau to place what is known about odontocetes around those islands in the larger context of what is known about them elsewhere off the main Hawaiian Islands. Information obtained through field work supported by this contract has also been incorporated into a review of whale and dolphin populations in Hawaiian waters (Baird 2016).

Methods

Field operations were undertaken in conjunction with the Marine Mammal Monitoring on Navy Ranges (M3R) program (Jarvis et al. 2014), using a combination of small vessel field efforts and passive acoustic monitoring to increase encounter rates of high priority species. Species priorities for these efforts were generally in inverse proportion to their sighting rates, i.e., those species encountered the least often were given highest priority, and the least amount of attention was focused on species that were not found on PMRF during the day (i.e., spinner dolphins). Methods have been outlined in detail in Baird et al. (2016, 2017) so are only briefly summarized here. Field efforts were undertaken twice a year from 2013 through 2015, with one effort in February each year and one in late summer/early fall each year (late July/August, September or October). The February efforts and the late July/August effort were timed to occur prior to a Submarine Commanders Course held off Kauaʻi, while the September and October efforts were timed to try to take advantage of periods of relatively calm winds that often occur during those periods. The primary study area for field efforts was the PMRF, but other areas were surveyed when either weather conditions or range restrictions limited access to PMRF. Survey effort typically began at sunrise each day to take advantage of relatively calm winds early in the day. Efforts were made to remain in areas with sea states of Beaufort 3 or less to both increase sighting rates and to allow for good working conditions for tagging, biopsy and photo-identification. A GPS on board the research vessel (a 24' rigid-hulled zodiac with custom bow pulpit) was used to record locations at 5-minute intervals.

All groups of odontocetes observed were approached for species identification and recording of information on the group. This included location, group size, number of neonates and young-of-the-year in the group, the percentage of the group observed close enough to enumerate neonates and young-of-the-year, the spatial extent of the group, the number of sub-groups present (and distance apart), any associated birds or fish, and information needed for permitting requirements. Neonates were defined as individuals with fetal folds (which may also have had bent dorsal fins), while young-of-the-year were defined as individuals estimated to be ≤50% the length of the presumed mother (based on surfacing position) and surfacing in close proximity to an adult female-sized individual. For most groups we obtained photos for both species and individual identification, and for a sub-set of groups we also collected biopsy samples (using a crossbow) or deployed LIMPET satellite tags (using a pneumatic projector).

We determined the proportion of neonates and young-of-the-year (hereafter referred to as calves) by summing the number of observed neonates and young-of-the-year and dividing this number by the sum of the observed group sizes. The observed group size was determined by multiplying the percentage of the group observed by the estimated group size. Encounters with less than 50% of the group observed were excluded from these analyses. This comparison was done both for encounters off Kaua'i and Ni'ihau from 2013-2015 and encounters off Hawai'i Island during a similar period. These comparisons were undertaken for short-finned pilot whales, bottlenose dolphins and rough-toothed dolphins.

Sub-samples of biopsy samples obtained were sent to the marine mammal tissue archive at the Southwest Fisheries Science Center for genetic analyses as well as to Hawai'i Pacific University/University of Hawai'i at Manoa for hormone chemistry analyses. Photos obtained of any species for which CRC has photo-identification catalogs were compared to the catalogs to determine the individual sighting histories. Within each encounter, photos were sorted by individual and each individual was assigned both a distinctiveness rating and a photo quality rating from the pool of the best photos available for each animal, following Baird et al. (2008b, 2009). Age classes of individuals in the rough-toothed dolphin photo-identification catalog were determined based on photos available from the entire sighting history of each individual, and incorporated a number of factors, with multiple factors used to classify age when possible. Individuals that had first been identified eight or more years prior to recent sightings were classified as adults in recent sightings based on age of maturity of these species. Individuals that had not been in the catalog for eight or more years were classified based on the number of markings on the dorsal fin and body (as markings accumulate with age), the presence of small calves in close association (indicating an adult female), size relative to other individuals in the same photo (young-of-the-year were ≤ half the length of known adults, juveniles were ≥ half the length of known adults), and neonates were determined based on small size combined with the presence of fetal folds, lack of markings, short time in the catalog (<1 month), and close proximity to the presumed mother in photographs. For rough-toothed dolphins we compared the proportion of calves in the catalog based on photographic assessments, restricting analyses to individuals with good or excellent quality photos. For both methods we compared results from Kaua‘i and Ni‘ihau to sightings (or identifications) of the same species off Hawai‘i Island during the period of 2013-2015. If individuals were seen more than once during the three-year period they were counted only once in the analyses and we used only the initial age classification given (e.g., if an individual was first seen as a calf and two years later as a juvenile, it was only counted as a calf in the analyses).

When more than one sub-group was noted in the field, we used the re-sighting history of individuals within sub-groups to determine whether an encounter should be considered as one or two groups for analyses. Re-sighting information combined with social network analyses and information available from satellite tag deployments was used to determine population identity for false killer whales, short-finned pilot whales, rough-toothed dolphins and bottlenose dolphins. Associations among individuals and groups were assessed with SOCPROG 2.7 (Whitehead 2009), and associations were visualized using Netdraw 2.158 (Borgatti 2002). False killer whale groups were classified as either members of the northwestern Hawaiian Islands (NWHI) population or the main Hawaiian Islands (MHI) insular population (Baird et al. 2008c; Baird et al. 2013c). Groups of short-finned pilot whales, rough-toothed dolphins and bottlenose dolphins were assigned to specific populations (insular, pelagic, unknown). Insular pilot whales were also assigned to community, as there is evidence of three insular communities (western, central, eastern main Hawaiian Islands) that are partially overlapping (Baird 2016).

For Blainville's beaked whales we used all photos of this species available to us to assess the probability that individuals documented off Kauaʻi or Niʻihau were from a population similar in size to that which has been documented off the west side of Hawaiʻi Island (McSweeney et al. 2007; Baird 2016). Given the sample size of encounters and photos available from Kauaʻi and Niʻihau, we also included information on Blainville's beaked whale encounters from Oʻahu. Photos were restricted to include good or excellent quality photos of distinctive individuals only, both from those available from Kauaʻi, Niʻihau and Oʻahu, and from Hawaiʻi Island, the latter for creating a distribution of re-sightings from which to bootstrap sample (using R version 3.2.1) an equivalent number of sightings and identifications as those from Niʻihau to Oʻahu. The Hawaiʻi Island sample included 58 sightings, with a total of 153 identifications of 70 different individuals. Mean number of identifications per sighting was 2.7, with a range from 1 to 9. Most of the individuals from the Hawaiʻi Island sample were known to be from the resident population, but some were from an open-ocean population (Baird et al. 2011; Baird 2016), thus the comparison is to re-sighting rates for a combined resident population with occasional open-ocean individuals in the sample. Bootstrapping was performed on groups, with a sample without replacement taken from Hawaiʻi Island groups equivalent in size to the groups from Niʻihau to Oʻahu. If the Hawaiʻi Island group was not of sufficient size, another group was randomly selected. Bootstrapping was repeated 1,000,000 times, with the probability value taken as the number of samples with no re-sightings.

We processed 5-minute effort locations with ArcGIS to determine depth. Locations of tagged individuals were estimated by the Argos System using the least-squares methods and were assessed for plausibility using the Douglas Argos-filter v. 8.5 to remove unrealistic locations, following previously used protocols (Schorr et al. 2009; Baird et al. 2010, 2011). Resulting filtered location data were processed with ArcGIS to determine depth and distance from shore. When more than one tag was deployed on the same species, we assessed whether individuals were acting in concert during the period of overlap by measuring the straight-line distance (i.e., not taking into account potentially intervening land masses) between pairs of individuals when locations were obtained during a single satellite overpass (approximately 10 minutes). We used both the average distances between pairs of individuals and the maximum distance between pairs to assess whether or not individuals were acting independently, following protocols described by Schorr et al. (2009) and Baird et al. (2010).

For the purposes of generating probability-density maps, only a single individual from each group was used when pairs of individuals were acting in concert. Locations were only used prior to the tag going into duty cycling (i.e., when the tags were transmitting every day). Probability-density maps were generated excluding locations from the first 24 hours for three species satellite tagged off Kaua‘i. Kernel density polygons were generated using the R package adehabitatHR v. 0.4.11[1] and corresponded to the 50, 95 and 99 percent densities. Polygons were plotted in Google Earth Pro v. 7.1.2.2041.

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

Results

Over the six field efforts we spent a total of 54 days on the water (364.2 hours), and covered 6,878 km (Table 1, Figure 1). Due to weather conditions and as a result of transiting to and from PMRF almost 25% of survey effort was in depths of less than 200 m, however there was some survey effort out to almost 5,000 m depth. Most of the effort was off the west side of Kaua‘i, but there was some effort off the north, south and east sides of the island during periods when PMRF was closed to vessel traffic due to Navy activity or when wind conditions made the area unworkable.

During this effort there were 155 sightings of nine species of odontocetes, five sightings of odontocetes that could not be identified to species, and one sighting of a pair of fin whales. Sightings of humpback whales were not enumerated. Rough-toothed dolphins were the most frequently encountered species, representing 42.6% of all odontocete sightings identified to species, followed by bottlenose dolphins (26.5%), spinner dolphins (18.1%), and short-finned pilot whales (7.7%). Levels of effort and the total number of odontocete sightings were approximately equal during the winter (February) and early fall (August-October) periods (Table 2), but there were some differences in the species composition between periods. While spinner dolphins were seen at similar rates between the two periods, during the winter bottlenose dolphins and short-finned pilot whales were seen more frequently, false killer whales were not encountered at all during the winter, and rough-toothed dolphins were seen less often in the winter than they were during the early fall period (Table 2).

Forty-one satellite tags were deployed on six different species, although data were only obtained from 37 of the tags (Table 3). Photos were obtained of all nine species of odontocetes encountered, seven of which are of species with active CRC photo-identification catalogs. Photos of these seven species were compared to the catalogs; in total there were 1,290 identifications representing 634 individuals (Table 4). The proportion of identifications for which there were good quality photos available varied by species, with the highest proportion (92.5%) for bottlenose dolphins, and the lowest (0%) for the single encounter with pygmy killer whales (Table 4). In general, this reflects the difficulty in approaching individuals at appropriate distances for photo-identification. For the two species with the smallest number of identifications (dwarf sperm whales n =1; pygmy killer whales n = 4) there were no matches to the catalogs. Spinner dolphins were the third-most frequently encountered species of odontocete, encountered during all field efforts and exclusively in shallow near-shore areas (Table 1, Figure 1). Photos obtained of this species were given to the Pacific Islands Fisheries Science Center for use in studies of spinner dolphins in Hawai‘i. Species which were satellite tagged or which there were detailed analyses of photo-identification data are discussed by species below.

Blainville's beaked whales

Blainville's beaked whales were encountered on only a single occasion (a group of five in 2014), south of PMRF. The M3R system was used for directing the research vessel towards a number of groups on PMRF over the three years, but the groups were not sighted visually. In most cases the area where beaked whales were detected by the M3R system were in areas with large swells or sea conditions that were not otherwise conducive to detecting beaked whales. From the encounter we took 1,623 photos, collected one biopsy sample, and deployed two satellite tags. Based on the average amount of survey effort for every encounter with Blainville's beaked whales off Hawai‘i Island (Baird et al. 2013a), the expected number of encounters, assuming similar density to Hawai‘i Island, would be approximately three, suggesting that density of this species off Kaua‘i is similar to or less than that off Hawai‘i Island.

Five individuals were present and photo-identified in the single encounter, and none of these have been sighted before or since in comparisons to the photo-identification catalog, which includes 114 distinctive individuals with good or excellent quality photos from all the main Hawaiian Islands. Although two satellite tags were deployed on individuals in the group, location data were only obtained for one individual (an adult male), over an 8-day span. The group was tagged south of PMRF, but over the 8-day span the tagged individual moved onto and off the southwestern portion of PMRF, then moved south of Ni‘ihau and west to Ka‘ula Island (Figure 3). Over the 8-day span the tagged individual moved a minimum cumulative distance of 290.7 km, and moved a maximum of 83.3 km from where it was tagged. Median depth of locations was 960 m (maximum =1,912 m; n = 48), and median distance from shore was 8.4 km (maximum = 17.8 km).

For the bootstrap analysis a total of 29 identifications were available from Kaua‘i and O‘ahu of distinctive individuals with good or excellent quality photos, with a mean number of identifications per group of 1.6 and a range of one to four. None of these individuals have been seen more than once. The results of the analysis indicated that the probability of having 29 identifications with no re-sightings being from a population of similar size to that off Hawai‘i

Island (including both a resident population and some open-ocean individuals) was extremely low (p=0.00006).

False killer whales

False killer whales were encountered once in each of the three years of effort, with all three sightings during the early fall period. Group sizes were 12, 20 and 20 individuals. During the three encounters we took 4,349 photos, collected two biopsy samples (one in each of the 2013 and 2015 encounters), and deployed four satellite tags. From the photos, 40 identifications were obtained, 25 of which were with good or excellent quality photos. These represented 25 individuals from the three different encounters, with five to 13 identifications per encounter. Individuals within each of the three encounters had been previously documented: 4 of 7 (2013); 5 of 5 (2014); 4 of 13 (2015). The encounters in 2013 and 2015 were both with individuals from the NWHI insular population, while the encounter in 2014 were individuals from the main Hawaiian Islands insular population, from social cluster 1 (see Baird et al. 2012). A single satellite tag was deployed on individuals in encounters in 2013 and 2015 (with durations of 21.1 and 15.2 days) and two tags were deployed on individuals in the 2014 encounter (with durations of 60.8 and 108.5 days). One of the two NWHI individuals (PcTag044, tagged in 2013) repeatedly circumnavigated Kaua‘i and Ni‘ihau over the entire 21.1-day period, repeatedly passing through PMRF. The other individual (PcTag049, tagged in 2015) circumnavigated Kaua‘i twice and Ni‘ihau three times and passed through PMRF a minimum of eight times (Figure 4) in the first nine days of the tracking period. The individual then moved to Middle Bank, on the edge of Papahānaumokuākea Marine National Monument, where it spent over three days, and then moved to Nihoa within the NWHI. The two individuals from the MHI insular population were tagged on the southern portion of PMRF but were first found heading southeast away from the range, and did not return during the combined 108.5-day track (Figure 5). During this period they moved as far as the southern and eastern side of the island of Hawai‘i, covering almost all of the known-range of this population.

Sperm whales

Despite regular acoustic detections of sperm whales on PMRF through the M3R system, there were only two encounters with sperm whales in 2013-2015, both on the same day (October 8, 2014) and in response to direction from M3R to the locations of the encounter. Group sizes for these two encounters were six and nine individuals, and both groups were comprised of adult females and juveniles. Although 1,105 photos were taken during the two encounters, no fluking was observed, thus we were unable to obtain any fluke photos for individual photo-identification.

Other acoustic detections of sperm whales during 2013-2015 were either on the northern portion of PMRF (the BSURE range) or the far western part of the range, and the research vessel was not able to transit to those locations either due to closures of the range from Navy activity or due to unfavorable sea conditions. One satellite tag was deployed during one of the two encounters, and a 13.8-day track was obtained (Figure 6). During this period the tagged individual moved into deep waters (>4,000 m) to the northeast of the tagging location. It moved a cumulative minimum distance of 924 km, and a maximum distance from the tagging location of 328 km (median distance from tagging location of 234 km). During this time it ranged from 35 to 217 km from shore (median = 172 km), and was found in depths ranging from 2,442 to 4,842 m (median = 4,476 m).

Short-finned pilot whales

Short-finned pilot whales were encountered on 12 occasions during five of the six field efforts, all but the shortest effort in July/August 2013 (Table 1). Group size ranged from eight to 57 (median = 23.5). Nine of the 12 sightings were on PMRF, and the remaining three sightings were in deep water to the south and southwest of the range (Figure 1). One of the 12 sightings (1 Feb 2014 in Table 5) had two distinct sub-groups present 700 m apart, and for the purposes of analysis we consider these to be two different groups. In the 12 encounters we collected six biopsy samples, took 17,562 photos, and were able to deploy 15 satellite tags, with tags deployed during 10 of the 12 encounters.

From photos, 298 identifications were obtained, and of these 195 had good or excellent quality photos. The 195 identifications represented 156 different individuals. The two sub-groups within one encounter were considered to be from different populations (one insular, one pelagic), based on divergent re-sighting histories and tag data. An individual in one of the sub-groups, considered a pelagic group, was tagged off O‘ahu in 2010 and was documented roaming widely offshore (GmTag046 in Baird et al. 2013a). Thus the 12 encounters represented eight different social groups, with one group re-sighted on the same day, two re-sighted within the same field project several days apart, and two groups sighted in two different years (Table 5).

Location data were obtained from 13 of the tags (two of the tags did not transmit) over periods from 7.6 to 89.1 days (median = 19.9 days). Of the eight social groups, tag data were obtained during this field effort from seven groups, and the eighth group had been previously tagged. Eleven of the tags, representing five different social groups (Table 5) were individuals from the insular population. Insular population individuals ranged primarily off Kauaʻi and Niʻihau, with movements to Oʻahu and with one group traveling as far as 180 km west of Niʻihau (Figure 7). These individuals regularly used waters of PMRF. Tag data were obtained from two individuals from the pelagic population for 28 (GmTag104) and 45 (GmTag117) days. These individuals ranged widely offshore both of the main Hawaiian Islands and the eastern-most of the northwestern Hawaiian Islands and did not return to PMRF after the first day after tagging (Figure 7). GmTag104 traveled a minimum cumulative distance of 2,761 km, remaining a median distance offshore of 171.8 km (maximum = 355.2 km), while GmTag117 traveled a minimum cumulative distance of 4,252 km, remained a median distance offshore of 132.1 km (maximum = 246.8 km).

Bottlenose dolphins

Bottlenose dolphins were the second-most frequently encountered odontocete species, with sightings in all field efforts and 41 sightings total, representing 25.6% of all odontocete groups sighted (Table 1). Group size ranged from one to 45 (median = 12). Most of the sightings of this species were off the western side of Kauaʻi on or immediately adjacent to PMRF (Figure 1). Sighting rates of this species were 1.85 times higher in winter than in early fall periods (Table 2). In the 41 encounters we collected six biopsies, took 7,878 photos, and deployed 10 satellite tags in 10 different encounters. Location data were obtained from the 10 satellite tags over periods from 5.9 to 20.5 days (median = 12.8 days). Tagged individuals primarily remained around Kauaʻi, although one individual (tagged in October 2014) moved to southern Oʻahu and off the west end of Penguin Bank (Figure 8). This individual has not yet been re-sighted, either off Kaua‘i or O‘ahu, so it is unknown whether this movement represented dispersal or if the individual returned back to Kaua‘i.

From the photos obtained there were 395 identifications with good quality photos, representing 142 individuals (Table 4). Of the 142, 76 (53.5%) had been previously documented, and 107 of the individuals were seen multiple times if including re-sightings within the 2013-2015 period. Nine of the 10 satellite tagged individuals were linked by association the main component of the social network (not shown), indicating they are from the resident, island-associated population. The one individual not linked by association was the only distinctive individual present in the encounter when it was tagged (in February 2015) and the individual had not been seen previously or since. However, based on locations from the satellite tag this individual appeared to be from the resident population (Figure 8).

Rough-toothed dolphins

Rough-toothed dolphins were the most frequently encountered odontocete species. They were seen during each field effort, with 66 sightings total, representing 41.2% of all odontocete groups documented (Table 1). Group size ranged from one to 140 (median = 4). During the 66 encounters we took a total of 24,250 photos, collected one biopsy sample, and deployed nine satellite tags. Rough-toothed dolphins were frequently documented on PMRF and in deep waters south of PMRF. During the one field project where efforts were concentrated off the east side of Kaua‘i (February 2015) they were frequently encountered (Figure 1). Sighting rates of this species were 1.7 times higher in the early fall than in winter efforts (Table 2).

From the photos there were 485 identifications obtained, of which 359 were represented by good or excellent quality photos. These 359 identifications represented 305 individuals, 102 of which had been documented prior to 2013. All of the tagged individuals were linked by association within the main component of the social network, indicating they are part of the resident, island-associated population. The nine satellite tags were deployed in eight different encounters, and location data were obtained from eight of the tags (from seven encounters) ranging over spans of 3.4 to 21.8 days. Individuals primarily ranged around Kaua‘i and Ni‘ihau with one individual moving to western O‘ahu and back (Figure 9).

Comparisons among populations

For three species we were able to compare the proportion of neonates and young-of-the-year (hereafter referred to as calves) as recorded in the field to the proportion of non-calves, between encounters off Kaua‘i and Ni‘ihau versus those off Hawai‘i Island. Results shown in Table 6 indicate that off Hawai‘i Island the highest proportion of calves were recorded for bottlenose dolphins (4.15%), followed by rough-toothed dolphins (3.72%) and short-finned pilot whales (2.13%). Off Kaua‘i and Ni‘ihau, slightly lower proportions were found for bottlenose dolphins (3.66%) while slightly higher proportions were found for short-finned pilot whales (2.44%). The proportion of rough-toothed dolphin calves off Kaua‘i and Ni‘ihau (1.57%) was 42.3% that of what it was off Hawai‘i Island (Table 6). For rough-toothed dolphins we also compared the proportion of individuals in our photo-identification catalog that were classified as calves to non-calves.

Discussion

Results from survey efforts as well as satellite tagging and photo-identification of odontocetes off Kaua‘i and Ni‘ihau during this study have greatly increased what is known about the species diversity and residency status of odontocetes off the islands. One of the most interesting findings of this effort relates to Blainville’s beaked whales, a species of particular interest to the U.S. Navy due to their susceptibility to impacts from mid-frequency active sonar (England and Evans 2001). This species has been studied extensively in the Canary Islands, the Bahamas and off Hawai‘i Island, and in all three areas the species shows considerable site fidelity, with evidence of relatively small resident populations (Baird 2016; Claridge 2013; McSweeney et al. 2007). Blainville’s beaked whales are regularly detected acoustically on PMRF (Henderson et al. 2016; Manzano-Roth et al. 2016), and have been sighted elsewhere around Kaua‘i (Baird 2016). Our relatively low sighting rates of this species suggest that density of Blainville’s beaked whales off Kaua‘i and Ni‘ihau is probably similar to or even potentially lower than density of this species off Hawai‘i Island. When combined with the bootstrapping results of photo-identification data, this suggests that Blainville’s beaked whales around Kaua‘i and Ni‘ihau (and O‘ahu) are not part of a relatively small resident population, similar in size to that found off Hawai‘i Island, but instead may be part of a larger broadly-ranging open-ocean population. This is of particular interest given that reactions to, and thus potential impacts of, exposure to mid-frequency active sonar is likely to depend in part on the prior exposure history of individuals involved (Falcone et al. 2008; Harris and Thomas 2015; Southall et al. 2016), with individuals that are regularly exposed to sonar likely showing less of a reaction than those that are naïve to it. Admittedly, our sample size of Blainville’s beaked whale photo-identifications from Kaua‘i and Ni‘ihau is small, and we had to combine photos obtained off O‘ahu to produce a robust analysis. Thus additional photo-identification effort from this area will be particularly of value.

Our photo-ID and satellite tagging results indicate that, in contrast to Blainville’s beaked whales, there are resident island-associated populations of both rough-toothed and bottlenose dolphins off Kaua‘i and Ni‘ihau, as suggested by Baird et al. (2008b, 2009). The presence of resident, island-associated populations of both bottlenose and rough-toothed dolphins is also supported by genetic evidence (Martien et al. 2011; Albertson et al. 2016). Sighting data show the two populations use somewhat different depths, but partially overlap in the southeastern part of PMRF (Figure 1). The satellite tagging results show that the ranges of both populations appear to be largely restricted to the area around Kaua‘i, and regularly overlap with PMRF (Figures 8 and 9). There is also an island-associated population of short-finned pilot whales that overlaps extensively with PMRF, although individuals from this population appear to range more widely among the western main Hawaiian Islands (Figure 7).

The presence of multiple resident populations with restricted ranges both around the western and eastern main Hawaiian Islands provides an opportunity to assess potential differences between populations of the same species that may be due to either environmental or anthropogenic factors. For Blainville’s beaked whales in the Bahamas, Claridge (2013) had noted differences in the age structure of two populations which had varying levels of exposure to mid-frequency active sonar. Blainville’s beaked whales off the AUTEC range, where there are higher levels of exposure to mid-frequency active sonar, had a lower proportion of calves and juveniles than a population of the same species located about 150 km away off Abaco. Our comparison of the proportion of calves to non-calves for bottlenose dolphins, rough-toothed dolphins and short-finned pilot whales off Kaua‘i/Ni‘ihau versus Hawai‘i Island revealed similar proportions for both bottlenose dolphins and short-finned pilot whales, but a much smaller proportion of calves for rough-toothed dolphins off Kaua‘i and Ni‘ihau in comparison to Hawai‘i Island (Table 6). For rough-toothed dolphins we compared both the proportion of calves observed during encounters to the total number of individuals observed, as well as using individually identified animals. Off the island of Hawai‘i the proportion of calves was almost identical with the two methods (3.72%, 3.85%; Table 6). Off Kaua‘i and Ni‘ihau both methods resulted in lower proportions of calves, but the proportions differed (1.57%, 0.66%). It is possible the difference between the two methods comes from the difficulty in obtaining good quality photos of neonates and small calves, given they surface for a much shorter period of time than adults and sub-adults. Regardless, the difference in the proportion of calves for rough-toothed dolphins between the two areas is of interest, and warrants further investigation. With Blainville’s beaked whales, responses to sonar exposure are thought to result in a reduction in foraging activity, and/or individuals moving into areas where foraging may be less productive. This reduction in foraging could result in reduced reproductive rates, if female reproduction was energy limited (New et al. 2013).

There were a number of other species that are known to have resident populations off the eastern main Hawaiian Islands where sighting rates in the present survey effort were low or where there were no sightings were documented over the three years. These include pygmy killer whales and dwarf sperm whales, with just a single sighting each, as well as pantropical spotted dolphins, melon-headed whales, and Cuvier's beaked whales. We had limited survey effort in depths greater than 1,000 m (Figure 1, 2), thus the lack of Cuvier's beaked whales is not surprising, but we had reasonable levels of effort in depths that the other species are typically found in (Baird et al. 2013a). Off the other main Hawaiian Islands pantropical spotted dolphins are frequently encountered, representing about a quarter of all odontocete sightings off the other islands (Baird et al. 2013a). Including all CRC efforts off Kaua'i and Ni'ihau from 2003 through 2016 there have only been 10 sightings of pantropical spotted dolphins off these islands, representing approximately 2% of all odontocete sightings (Baird et al. 2017). Of these 10 sightings, four were of the same lone individual, associating with spinner dolphins, thus they are less common off Kaua'i and Ni'ihau than even indicated by the proportion of sightings. Combined with genetic (Courbis et al. 2014) and satellite tagging data (Baird et al. 2017), this species does not appear to have an island-associated resident population off Kaua'i and Ni'ihau, as it does off the other main Hawaiian Islands.

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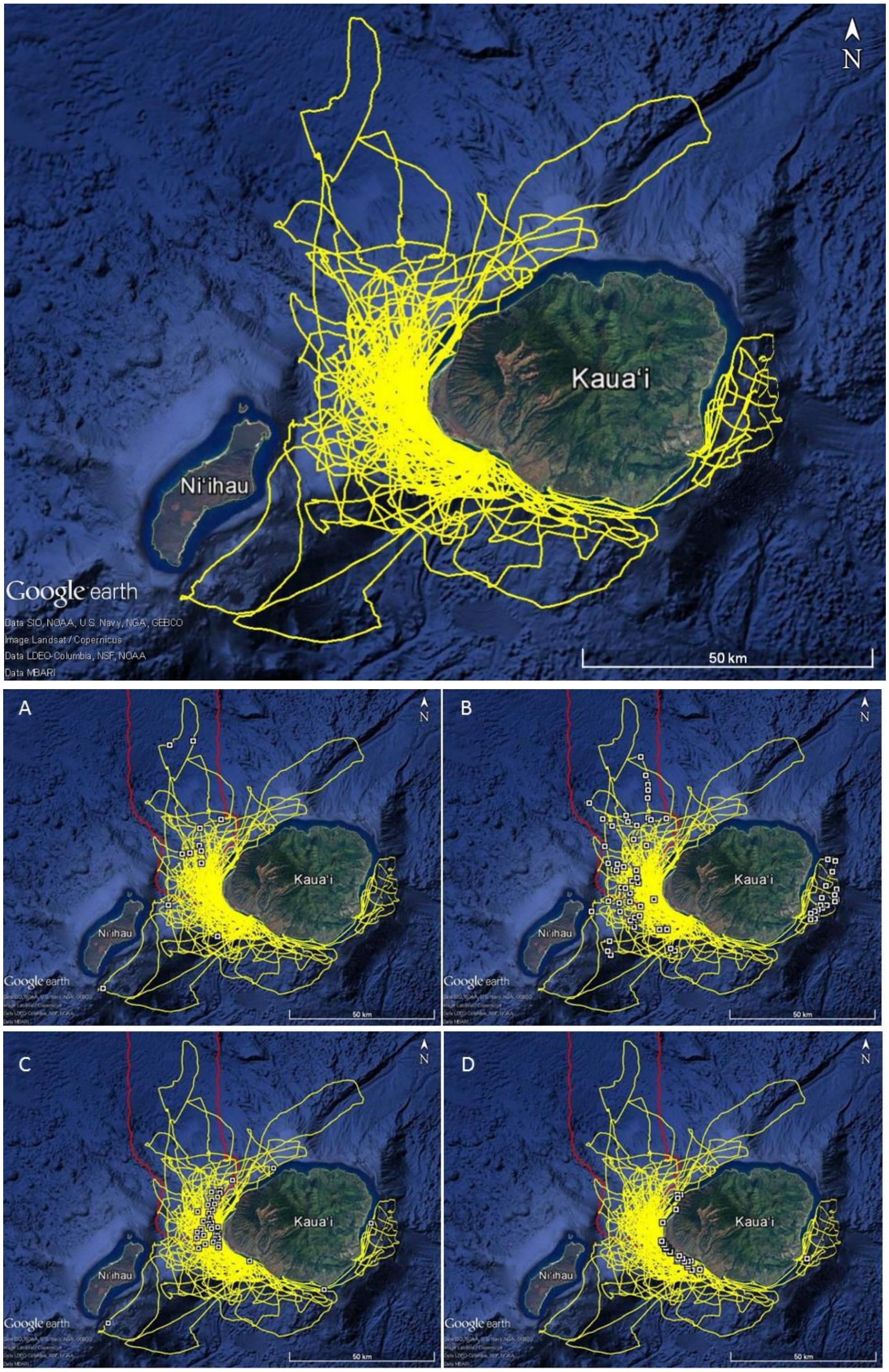


Figure 1. Top. Survey effort around Kaua‘i and Ni‘ihau in field efforts from 2013 through 2015. See Table 1 for details. Center and bottom. Sighting locations in relation to survey effort: A – short-finned pilot whales; B – rough-toothed dolphins; C – bottlenose dolphins; D – spinner dolphins. The PMRF boundary is shown in red.

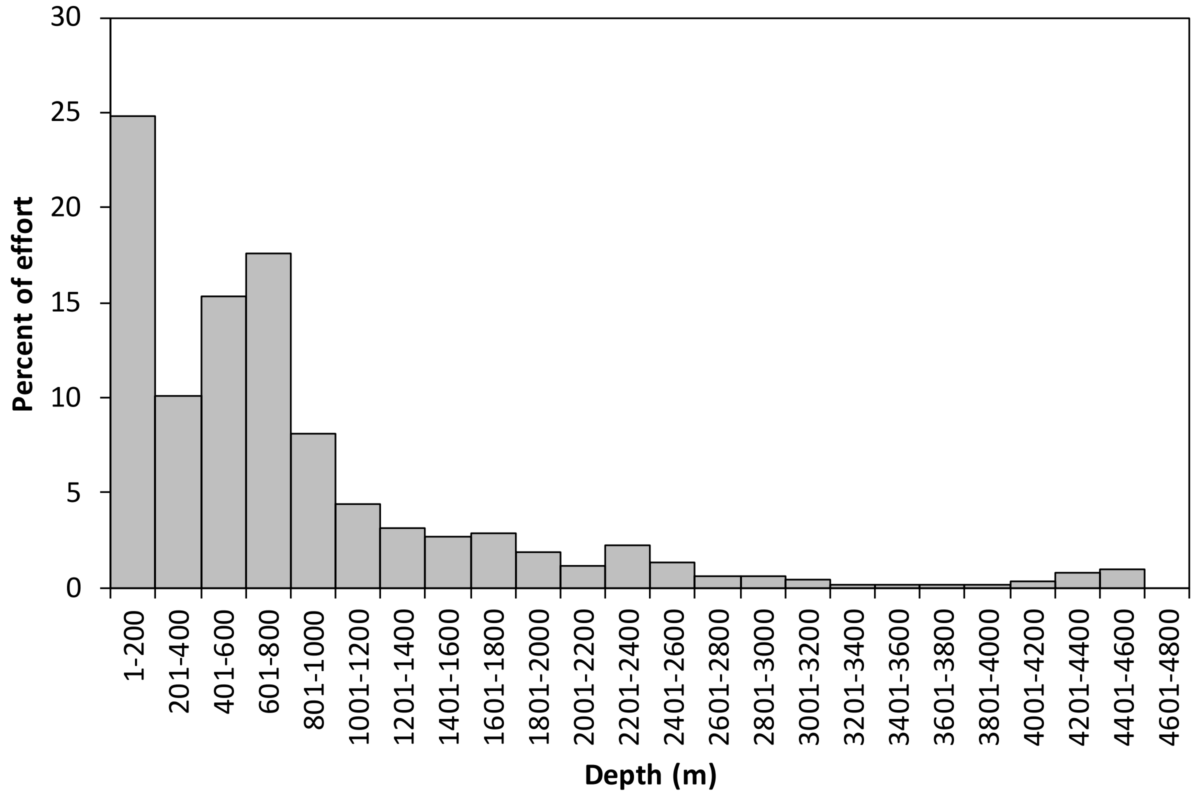


Figure 2. Distribution of search effort by depth from 2013 through 2015.

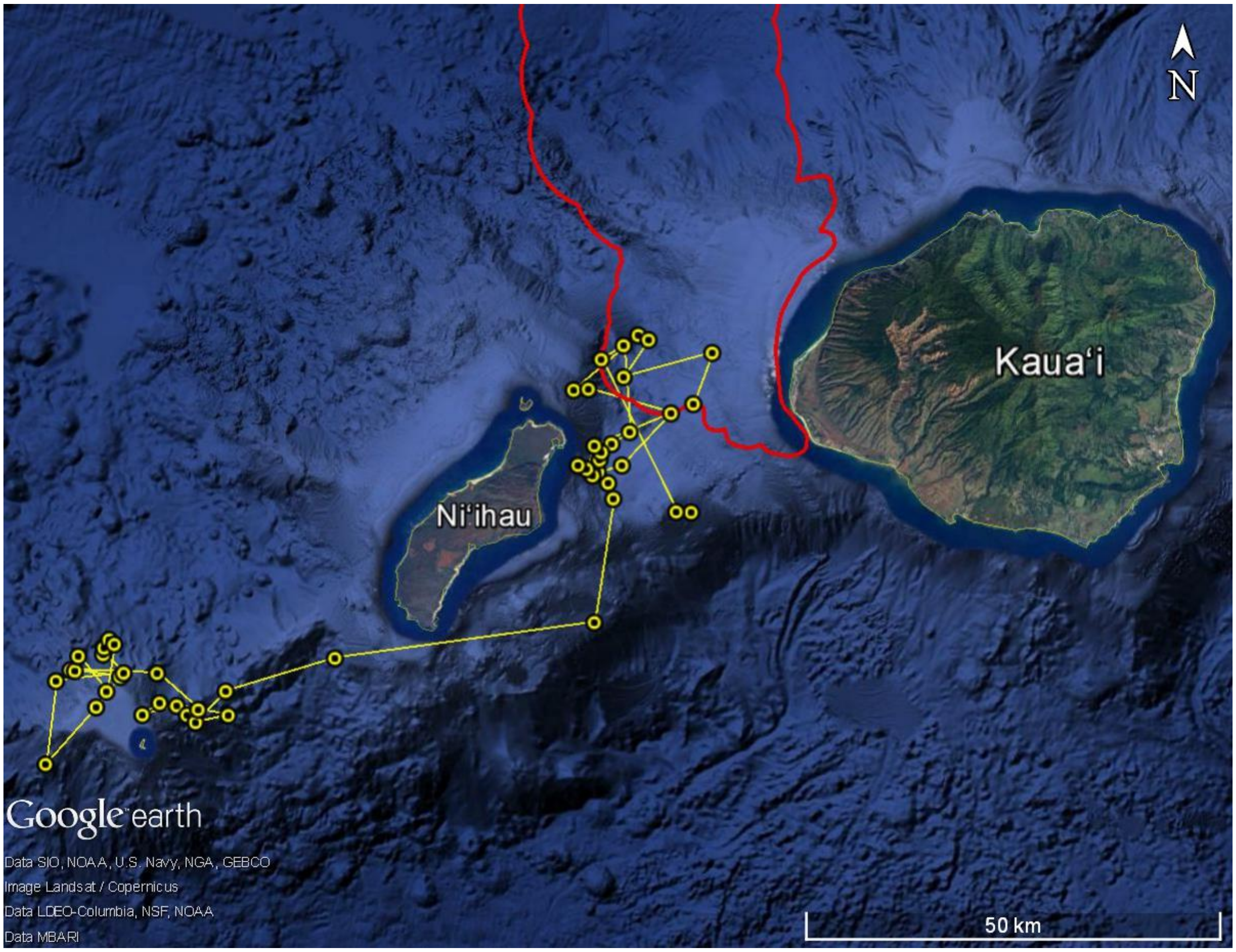


Figure 3. Locations (yellow circles) of a satellite tagged Blainville's beaked whale over an 8-day period in February 2014. Consecutive locations are joined by a yellow line. The individual was tagged south of PMRF, moved north to the southwestern portion of PMRF, before moving southwest to Ka'ula Island. The boundary of PMRF is indicated in red.

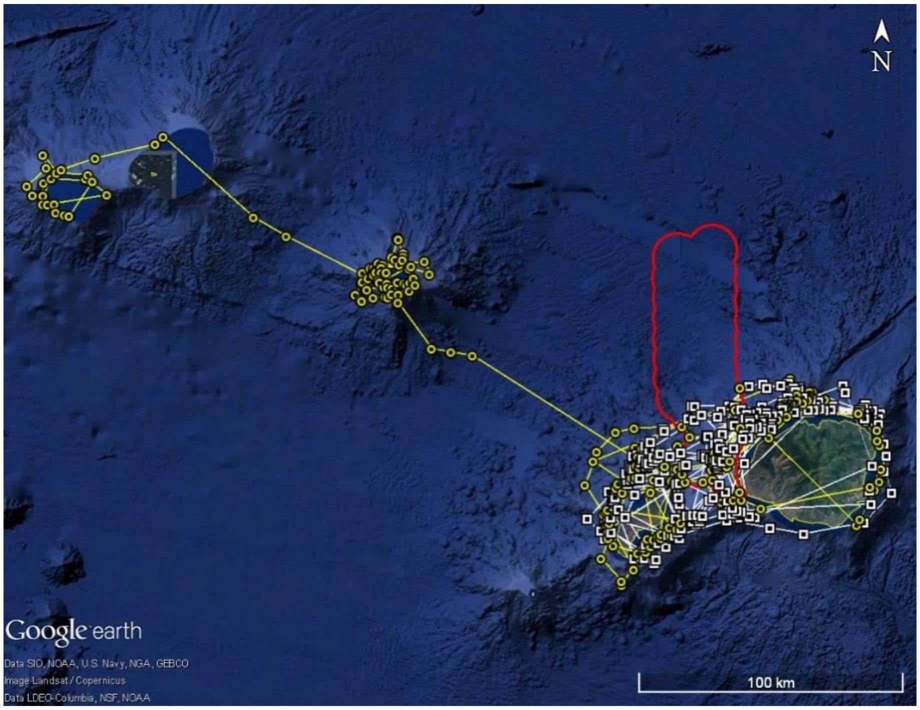


Figure 4. Locations of two satellite tagged false killer whales from the NWHI insular population. The individual tagged in 2013 (PcTag037) is shown in white, while the individual tagged in 2015 (PcTag049) is shown in yellow. The boundary of PMRF is indicated in red.

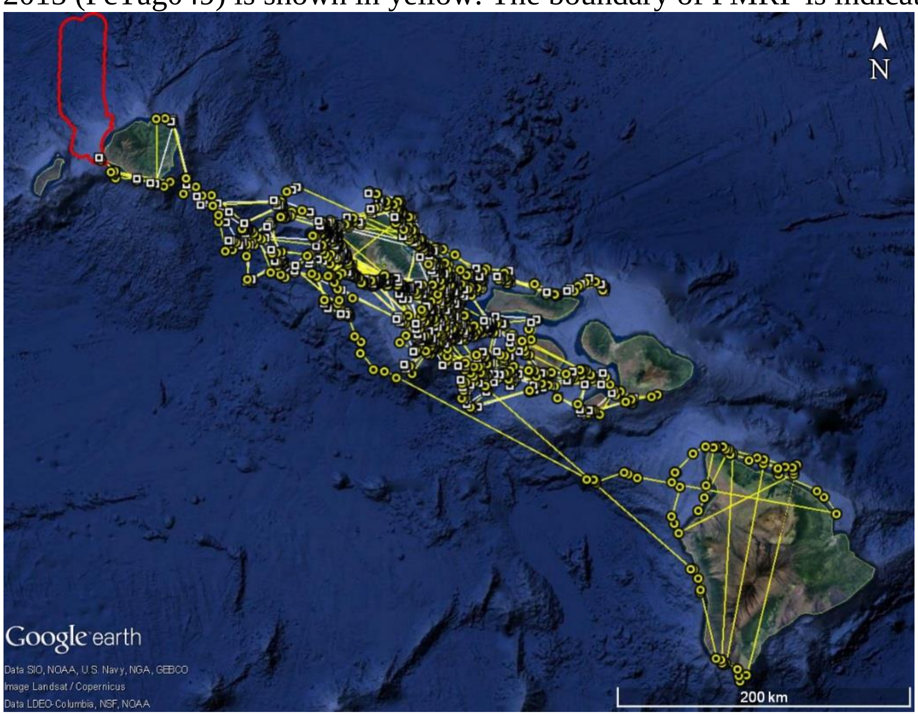


Figure 5. Locations of two satellite tagged false killer whales from the MHI insular population. PcTag044 is shown in white while PcTag045 is shown in yellow. Both remained closely associated during the period of overlap. The boundary of PMRF is indicated in red.

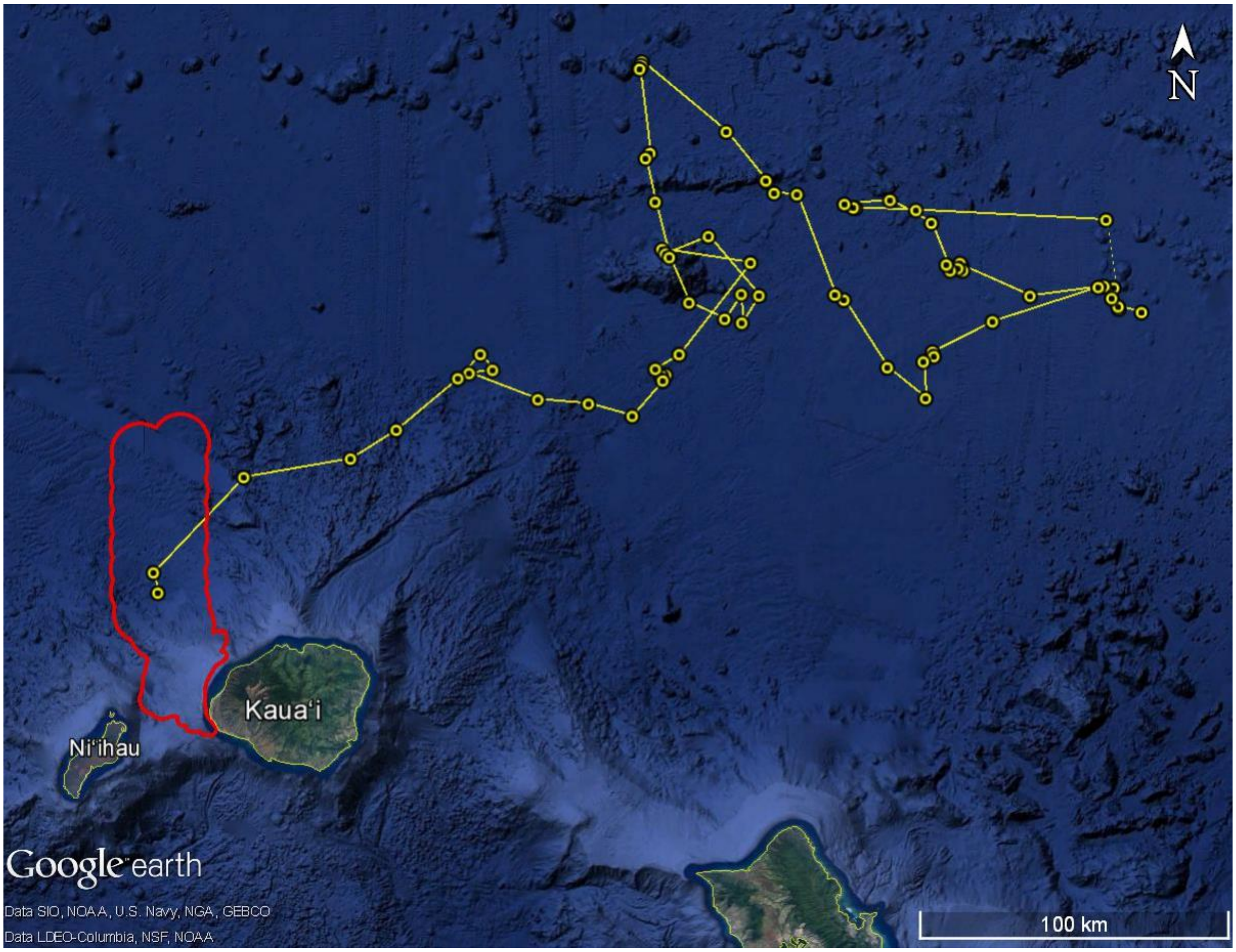
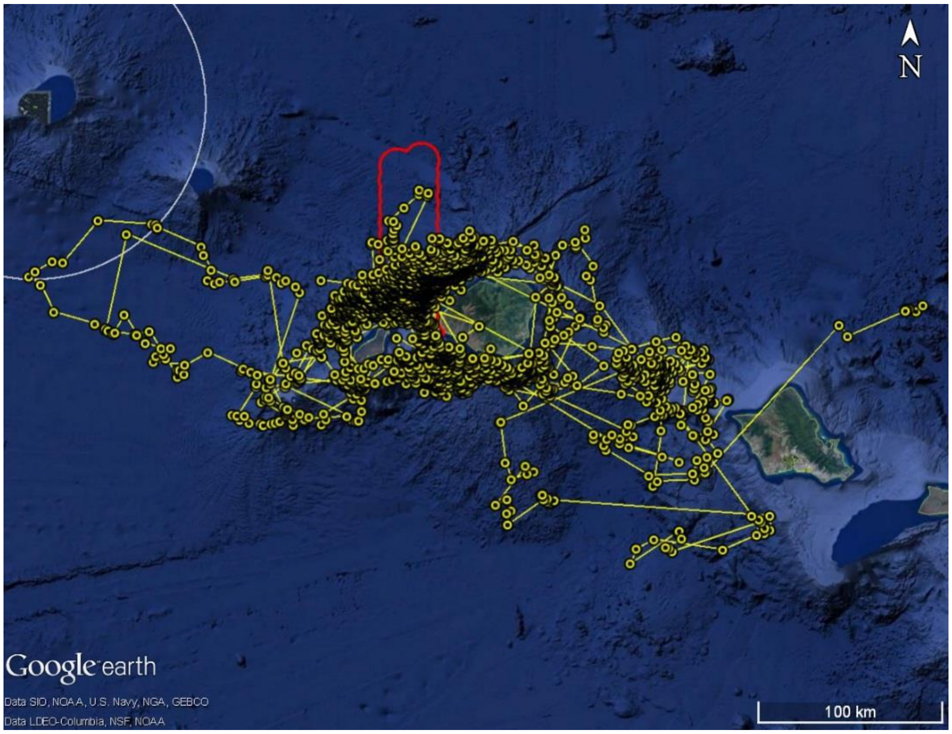


Figure 6. Locations (yellow circles) of satellite tagged sperm whale over a 13.8-day period in October 2014. Consecutive locations are joined by a line. The boundary of PMRF is indicated in red.



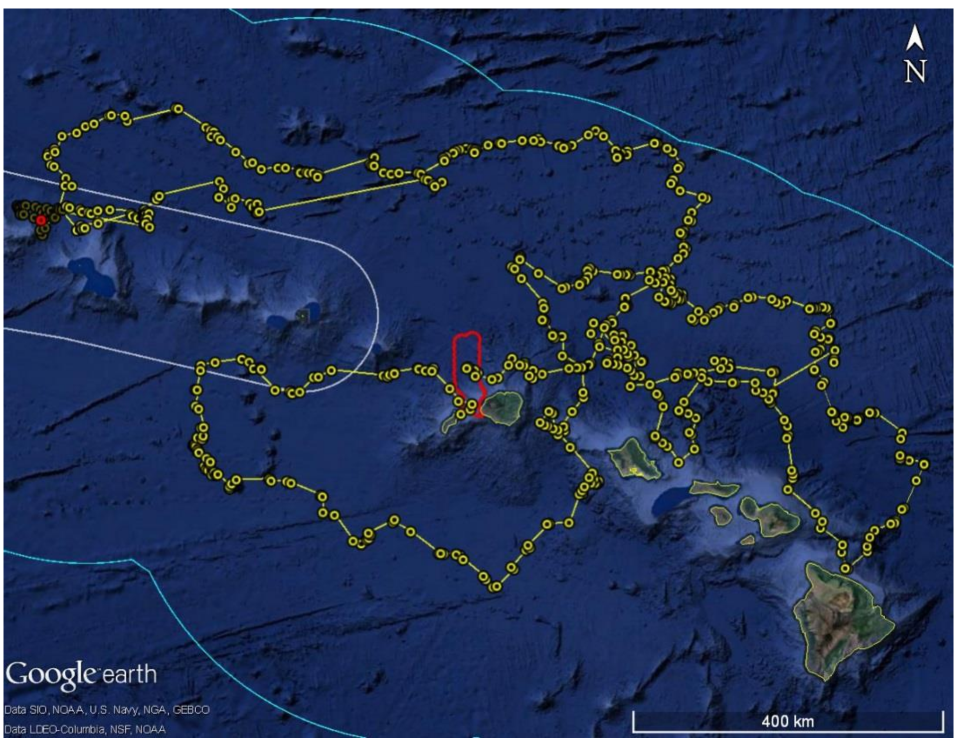


Figure 7. Top. Locations (yellow circles) of all tagged insular short-finned pilot whales (n=11) between 2013 and 2015. Bottom. Locations from two pelagic short-finned pilot whales tagged in 2014 and 2015. Consecutive locations are joined by a yellow line. The outer blue line is the 200 nm Exclusive Economic Zone boundary. The white line represents the boundary of the Papahānaumokuākea Marine National Monument, while the boundary of PMRF is indicated in red.

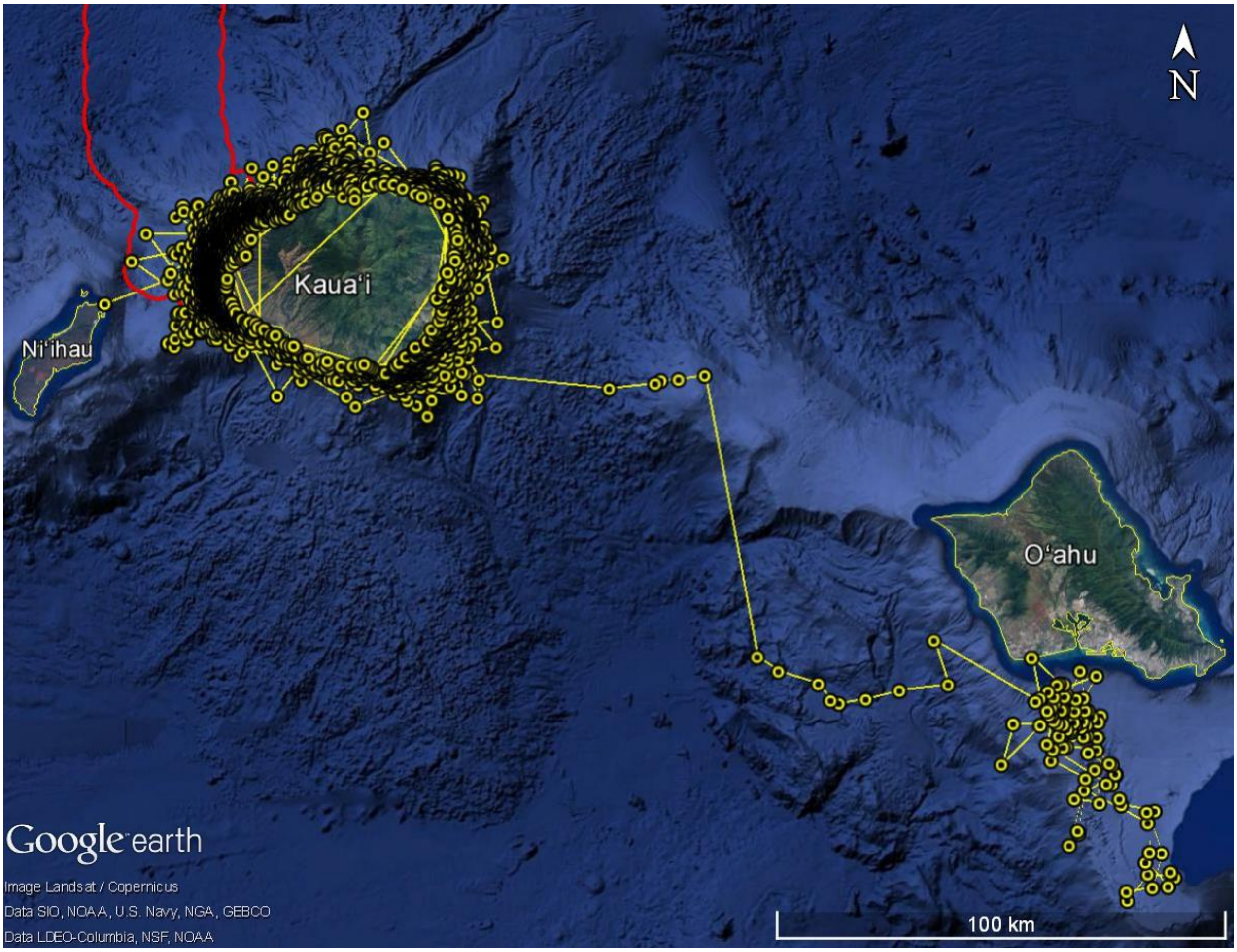


Figure 8. Locations (yellow circles) of satellite tagged bottlenose dolphins (n=10). Consecutive locations are joined by a yellow line. The boundary of PMRF is indicated in red.

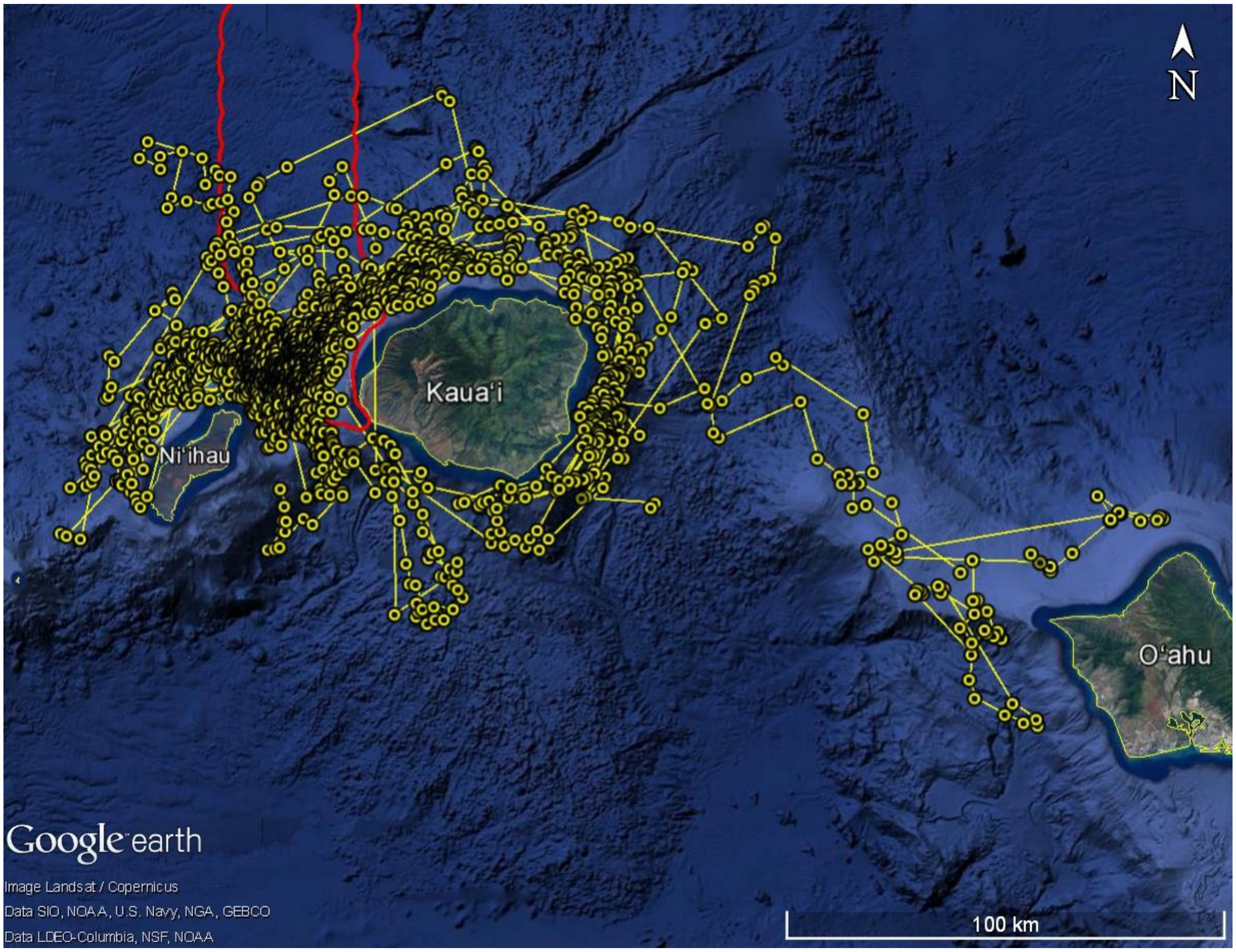


Figure 9. Locations (yellow circles) of satellite tagged rough-toothed dolphins (n=8). Consecutive locations are joined by a yellow line. The boundary of PMRF is indicated in red.

Table 1. Information on field efforts off Kaua'i from 2013-2015.

Period	Effort # days (km)	Odontocete sightings # species[1]	Satellite tag deployments # species[1]
2-10 Feb 13	8 (1,010)	12 Tt, 3 Sb, 1 Gm, 4 Sl	3 Tt, 2 Gm, 1 Sb
26 Jul–2 Aug 13	7 (671)	6 Tt, 1 Pc, 8 Sb, 3 Sl	2 Sb, 1 Pc
1-10 Feb 14	10 (1,287)	1 Md, 8 Tt, 2 Sb, 5 Gm, 7 Sl	2 Md, 2 Tt, 2 Sb, 6 Gm
7-17 Oct 14	11 (1,573)	3 Tt, 1 Pc, 1 Fa, 11 Sb, 2 Gm, 2 Pm, 8 Sl	2 Tt, 2 Pc, 1 Gm, 1 Pm
4-16 Feb 15	9 (1,289)	7 Tt, 1 Ks, 20 Sb, 3 Gm, 2 Sl	2 Tt, 3 Sb, 4 Gm
3-11 Sep 15	9 (1,204)	5 Tt, 1 Pc, 22 Sb, 1 Gm, 4 Sl	1 Tt, 1 Pc, 1 Sb, 2 Gm
Total	54 (6,878)	1 Md, 41 Tt, 66 Sb, 1 Fa, 3 Pc, 12 Gm, 1 Ks, 2 Pm, 28 Sl	2 Md, 10 Tt, 9 Sb, 15 Gm, 4 Pc, 1 Pm

[1]Species: Gm = *Globicephala macrorhynchus*, Pc = *Pseudorca crassidens*, Sb = *Steno bredanensis*, Sl = *Stenella longirostris*, Tt = *Tursiops truncatus*. Md = *Mesoplodon densirostris*, Fa = *Feresa attenuata*, Ks= *Kogia sima*, Pm = *Physeter microcephalus*

Table 2. Summary of effort and sightings by season

Period	Effort km	Number of sightings by species[1]						
		Tt	Sb	Gm	Pc	Sl	Others[2]	Total
Feb	3,586	27	25	9	0	13	2	76
Aug-Oct	3,449	14	41	3	3	15	3	79
Total	7,035	41	66	12	3	28	5	155

[1]Species: Gm = *Globicephala macrorhynchus*, Pc = *Pseudorca crassidens*, Sb = *Steno bredanensis*, Sl = *Stenella longirostris*, Tt = *Tursiops truncatus*. [2]Others include *Mesoplodon densirostris*, *Feresa attenuata*, *Kogia sima*, *Physeter microcephalus*

Table 3. Details of satellite tags deployed off Kaua‘i from 2013 through 2015.

Tag ID[1]	Population	Date tagged	Sighting #	Tag type	Tag duration days
GmTag070	Insular	2/8/2013	2	Mk10-A	19.9
GmTag071	Insular	2/8/2013	2	Mk10-A	0.0
GmTag078	Insular	2/1/2014	1	Mk10-A	12.8
GmTag079	Insular	2/2/2014	2	Mk10-A	30.5
GmTag080	Insular	2/2/2014	2	Spot5	16.0
GmTag081	Insular	2/3/2014	3	Mk10-A	25.8
GmTag082	Insular	2/9/2014	2	Mk10-A	30.4
GmTag083	Insular	2/9/2014	2	Spot5	89.1
GmTag104	Pelagic	10/8/2014	3	Mk10-A	28.0
GmTag114	Insular	2/8/2015	1	Mk10-A	7.6
GmTag115	Insular	2/8/2015	1	Spot5	10.1
GmTag116	Pelagic	2/12/2015	2	Mk10-A	0.0
GmTag117	Pelagic	2/12/2015	2	Spot5	45.0
GmTag132	Insular	9/10/2015	2	Mk10-A	18.3
GmTag133	Insular	9/10/2015	3	Mk10-A	18.9
MdTag016	Unknown	2/4/2014	7	Mk10-A	0.0
MdTag017	Unknown	2/4/2014	7	Spot5	8.0
PcTag037	NWHI Insular	7/26/2013	1	Mk10-A	21.1
PcTag044	MHI Insular	10/8/2014	7	Spot5	60.8
PcTag045	MHI Insular	10/8/2014	7	Spot5	108.5
PcTag049	NWHI Insular	9/6/2015	1	Mk10-A	15.2
PmTag023	Pelagic	10/8/2014	6	Mk10-A	13.8
SbTag008	Insular	2/8/2013	1	Mk10-A	3.4
SbTag009	Insular	7/29/2013	1	Mk10-A	9.9
SbTag010	Insular	7/31/2013	3	Mk10-A	13.4
SbTag011	Insular	2/4/2014	1	Mk10-A	12.5
SbTag012	Insular	2/4/2014	5	Spot5	7.3
SbTag013	Insular	2/4/2015	3	Mk10-A	0.0
SbTag014	Insular	2/4/2015	5	Spot5	21.8
SbTag015	Insular	2/11/2015	7	Mk10-A	14.3
SbTag016	Insular	9/5/2015	1	Mk10-A	14.9
TtTag008	Insular	2/2/2013	1	Mk10-A	18.2
TtTag009	Insular	2/4/2013	3	Mk10-A	10.7
TtTag010	Insular	2/9/2013	1	Spot5	20.5
TtTag012	Insular	2/4/2014	2	Spot5	6.1
TtTag013	Insular	2/6/2014	2	Spot5	13.3
TtTag019	Insular	10/14/2014	2	Mk10-A	14.8
TtTag020	Insular	10/15/2014	1	Mk10-A	12.3
TtTag022	Insular	2/11/2015	10	Mk10-A	7.2
TtTag023	Insular	2/16/2015	3	Mk10-A	15.7
TtTag025	Insular	9/7/2015	5	Mk10-A	5.9

[1]Species identification given in first two letters of tag ID; Gm = *Globicephala macrorhynchus*, Md = *Mesoplodon densirostris*, Pc = *Pseudorca crassidens*, Pm = *Physeter microcephalus*, Sb = *Steno bredanensis*, Tt = *Tursiops truncatus*

Table 4. Summary of photo-identification data by species obtained off Kaua'i from 2013-2015.

Species[1]	# photos available	# identifications	# identifications good photo quality	% identifications good photo quality	# individuals
Tt	7,878	427	395	92.5	142
Sb	24,250	485	359	74.0	305
Gm	17,562	298	195	59.5	156
Pc	4,349	40	25	62.5	25
Md	1,623	5	4	80.0	5
Ks	21	1	1	100.0	1
Fa	178	4	0	0	4

[1]Species: Tt = *Tursiops truncatus*; Sb = *Steno bredanensis;* Gm = *Globicephala macrorhynchus*; Pc = *Pseudorca crassidens*; Md = *Mesoplodon densirostris;* Ks = *Kogia sima;* Fa = *Feresa attenuata*.

Table 5. Information on short-finned pilot whale tagging and sighting history for groups encountered off Kaua‘i in 2013, 2014 and 2015.

Date	Sighting #	Sub-groups	# good quality IDs	# re-sighted individuals	# tags	Cluster[1]	Tags deployed, information on population identity for pelagic groups, and re-sightings
8-Feb-13	2		14	12	2	W25/OAKAMC	GmTag070, GmTag071 (ND[2])
1-Feb-14	1	A	11	12	1	H1/W45/HMC	GmTag078
1-Feb-14	1	B	5	3	0	W17/NL	Pelagic, previously tagged (GmTag046)
2-Feb-14	2		11	11	2	W25/OAKAMC	GmTag079, GmTag080
3-Feb-14	3		6	6	1	W2/OAKAMC	GmTag081
3-Feb-14	5		5	5	0	W25/OAKAMC	4 within-year (Feb 2 enc), 1 between year
9-Feb-14	2		14	12	2	W2/OAKAMC	GmTag082, GmTag083
8-Oct-14	3		30	4	1	W15	Pelagic, GmTag104
8-Oct-14	5		12	12	0	W15	Within-day encounter
8-Feb-15	1		13	2	2	W39/OAKAMC	GmTag114, GmTag115
12-Feb-15	2		35	0	2	W42/NL	Pelagic, GmTag116 (ND), GmTag117
15-Feb-15	4		7	7	0	W2/OAKAMC	group tagged 3 Feb 14 and 9 Feb 14
10-Sep-15	3		32	2	2	NL	GmTag132, GmTag133

[1]Cluster designations: OAKAMC = O‘ahu/Kaua‘i main cluster; HMC = Hawai‘i main cluster; NL = no links to main cluster; other designators (W25, H1, W17, W2, W15, W39, W42) are social cluster designations (see Mahaffy et al. 2015 for details). [2]ND=no data.

Table 6. A comparison of the proportion of neonates and young-of-the-year to juveniles and adults for three species documented both off Kaua'i and Ni'ihau and Hawai'i Island. Values are presented for all three species based on numbers recorded in the field, and for rough-toothed dolphins values are also presented based on photo-identification.

	Hawai'i Island	Kaua'i and Ni'ihau
Short-finned pilot whale		
Sum of observed group size	1,316	286
Sum of observed neonates and YOY	28	7
% neonates and YOY	2.13	2.44
# encounters	78	12
Bottlenose dolphin		
Sum of observed group size	120	410
Sum of observed neonates and YOY	5	15
% neonates and YOY	4.15	3.66
# encounters	20	36
Rough-toothed dolphin		
Sum of observed group size	108	508
Sum of observed neonates and YOY	4	8
% neonates and YOY	3.72	1.57
# encounters	18	57
# photo-IDd individuals	78	305
# photo-IDd neonates and YOY	3	2
% neonates and YOY from photo-ID	3.85	0.66