Evidence of an Island-Associated Population of False Killer Whales (*Pseudorca crassidens*) in the Northwestern Hawaiian Islands[1]

Robin W. Baird,[2,7] *Erin M. Oleson*,[3] *Jay Barlow*,[4] *Allan D. Ligon*,[5] *Antoinette M. Gorgone*,[6] *and Sabre D. Mahaffy*[2]

Abstract: Two populations of false killer whales, *Pseudorca crassidens*, are recognized from Hawaiian waters: the Hawaiian insular population, an island-associated population found around the main Hawaiian Islands; and the Hawai'i pelagic population, found in offshore waters. This species has not been previously documented near the Northwestern Hawaiian Islands. During a 2010 large-vessel survey throughout the Exclusive Economic Zone (EEZ) surrounding the Hawaiian Islands, false killer whales from 11 encounters were individually photo-identified, and photos were compared among encounters and with a catalog of false killer whales from the main Hawaiian Islands. Individuals from three of the encounters, all in the Northwestern Hawaiian Islands within the eastern part of the Papahānaumokuākea Marine National Monument, were the only ones documented that matched with false killer whales previously seen around the main Hawaiian Islands, and the matches were to individuals documented off Kaua'i in 2008 that were of unknown population membership. Two individuals from one of these three 2010 encounters were instrumented with satellite tags attached to dorsal fins, and their movements were documented over 4.6 and 52 days. Movements of the tagged individuals ranged from French Frigate Shoals to Middle Bank (between Nīhoa and Ni'ihau) and included shallow nearshore waters and deep waters to 147 km from land. Combined, the photo-identification and satellite-tagging results suggest that there is a second island-associated population of this species in Hawai'i that primarily uses the Northwestern Hawaiian Islands, with a range that overlaps with that of the main Hawaiian Islands insular population.

Two populations or stocks of false killer whales, *Pseudorca crassidens*, have recently been recognized in Hawaiian waters (Chivers et al. 2007, 2010, Baird et al. 2008, Carretta et al. 2012). An insular, or island-associated, population is found around the main Hawaiian Islands, and a pelagic, or open-ocean, population has been documented in offshore waters (Chivers et al. 2007, 2010, Baird et al. 2008, 2010). Based on movements of satellite-tagged individuals, the range of the Hawaiian insular population extends throughout the main Hawaiian Islands from Ni'ihau in the west to Hawai'i Island in the east, and movements out to 122 km from shore have been documented (Baird et al. 2010, 2012).

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[2] Cascadia Research Collective, 218 ½ West 4th Avenue, Olympia, Washington 98501.

[3] NOAA Pacific Islands Fisheries Science Center, National Marine Fisheries Service, 1601 Kapi'olani Boulevard, Honolulu, Hawai'i 96814.

[4] NOAA Southwest Fisheries Science Center, National Marine Fisheries Service, 8901 La Jolla Shores Drive, La Jolla, California 92037.

[5] 3-2259 Kūhiō Highway, Līhu'e, Hawai'i 96766.

[6] NOAA Southeast Fisheries Science Center, National Marine Fisheries Service, 101 Pivers Island Road, Beaufort, North Carolina 98250.

[7] Corresponding author (e-mail: rwbaird@cascadiaresearch.org).

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Individuals can be attributed to one or the other population based on genetics (i.e., mitochondrial haplotypes [Chivers et al. 2007, 2010]) or on photo-identification matches of distinctive individuals. Although the number of distinctive individuals from the pelagic population that have been photographically documented is small (29 noted in Baird 2009) and no resightings of pelagic individuals have been documented to date, the majority of individuals in the insular population have been photographically documented multiple times (Baird et al. 2008, Baird 2009). The insular population is relatively small (estimated at about 150 individuals [see Oleson et al. 2010]), and Baird et al. (2008) noted that, on average, within a group of insular individuals 75% of distinctive individuals photographed had been previously documented; thus assigning individuals to one or the other population based on photo-identification can be done with some certainty if more than a few distinctive individuals from any group are photo-identified.

Baird (2009) noted that of all the distinctive individuals documented within 40 km of shore of the main Hawaiian Islands (524 identifications of >100 individuals), only 13 identifications did not link by association to the insular social network. Four of these 13 individuals were documented off the island of Hawai'i, in three encounters where only single individuals (two encounters) or a pair of individuals were identified. Thus the likelihood of finding matches with the Hawai'i insular population is small. Nine identifications were available from the island of Kaua'i, including seven from one encounter in July 2008, but none matched to the insular social network (Baird 2009). Baird (2009) noted that, given the small sample size, it was unclear whether these individuals photo-identified off Kaua'i were part of the insular population, part of the pelagic population, or members of a third, as yet undescribed, population. Additional data available since that analysis have brought the total number of distinctive identifications to over 900 from within 40 km of shore of the main Hawaiian Islands, and only one additional distinctive individual has been documented, also off the island of Kaua'i, that did not link to the insular social network (R.W.B., unpubl. data).

In 2010, the National Marine Fisheries Service undertook a large-scale survey throughout the Exclusive Economic Zone (EEZ) surrounding the Hawaiian Islands (HICEAS II) to assess population structure and abundance of false killer whales, among other goals. As part of this effort, individual false killer whales were photo-identified and satellite tags were deployed on two of the whales to examine their movements. The purpose of this note is to describe the results of the photo-identification and satellite tagging work in relation to what is known about false killer whales in Hawaiian waters.

MATERIALS AND METHODS

Between 4 August and 12 December 2010, two 68 m NOAA research vessels (the R/V *McArthur II* and the R/V *Oscar Elton Sette*) surveyed the entire Hawaiian EEZ using a survey design similar to that used in the first HICEAS cruise (Barlow 2006). The survey used a combination of visual and acoustic detection methods, and all detected groups of false killer whales were approached. If conditions were suitable each vessel launched a 6 or 7 m rigid-hulled inflatable to work with the group, and attempts were made to photograph all individuals and obtain biopsy samples for genetic studies. Photographs for individual identification were graded for photo quality, and individuals were categorized in terms of distinctiveness following the protocols of Baird et al. (2008). Photos of all qualities and individuals of all distinctiveness categories were compared among HICEAS II encounters and with the existing Hawai'i false killer whale photo-identification catalog by two experienced matchers. For comparison with results from Baird et al. (2008), the number of identifications of distinctive and very distinctive individuals (Distinctive categories 3 and 4) with good or excellent photo qualities (Photo Quality categories 3 and 4) were noted.

During one encounter, LIMPET satellite tags (see Andrews et al. 2008, Baird et al. 2010) were deployed on the dorsal fins of two

individuals. Details of the tags, programming, and data processing are presented in Baird et al. (2010) and are only briefly summarized here. The satellite tags used a location-only transmitter (Wildlife Computers SPOT5) in the LIMPET configuration with two 6.5 cm titanium attachment darts. The tag was secured to an arrow with a custom-made urethane holder and deployed with a pneumatic projector (Dan-Inject JM Special 25). Tags were programmed to transmit daily for 9 hr per day during hours with the best satellite coverage. After location data were downloaded from the Argos system, they were assessed for plausibility using the Douglas Argos-Filter ver. 7.08 (available at http://alaska.usgs.gov/science/biology/spatial/douglas.html) following the same criteria as for previous satellite tags deployed on this species (Baird et al. 2010, 2012), with location classes (LC) 3 and 2 retained, using a maximum sustainable rate of movement of 20 km hr^{-1} and the default rate coefficient for marine mammals of 25. Error associated with locations varied by location class (Argos User's Manual): LC3, <250 m; LC2, <500 m; LC1, between 500 and 1,500 m; no estimation of accuracy for other classes. Locations that passed the filter were processed with ArcGIS v. 9.2 (ESRI) to determine depth, distance from the closest shoreline, and distance from the 200-m isobaths.

RESULTS

During the HICEAS II cruise the two vessels covered a combined 18,469 km of trackline and had 418 sightings of cetaceans, 14 of which were of false killer whales (Figure 1). On-effort track length was 16,145 km, during which there were 229 cetacean sightings, six of which were false killer whales. Individual identification photos were obtained from 11 of the 14 false killer whale encounters (Figure 1, Table 1). From these, there were 91 identifications, not accounting for resightings among encounters. When only good-

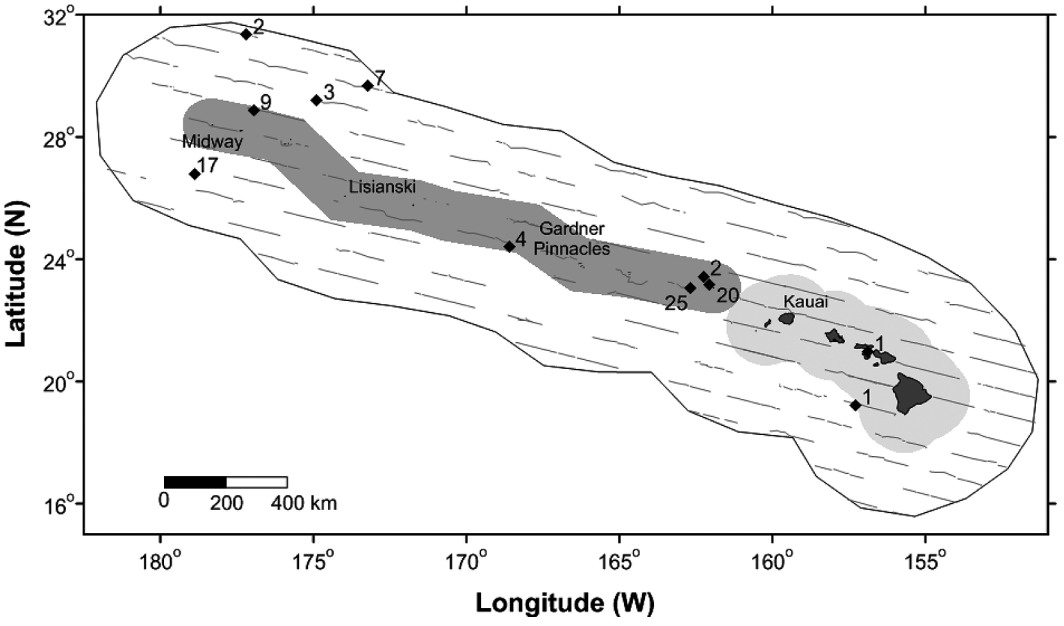

FIGURE 1. Survey tracklines from the HICEAS II cruise with sighting locations of false killer whales encountered when photos were available. The number of identifications (disregarding photo quality and distinctiveness) for each sighting are indicated next to the sighting location. The Papahānaumokuākea Marine National Monument is indicated by dark shading, while the stock range for the main Hawaiian Islands insular population is indicated by light shading.

TABLE 1

Details on Sightings during HICEAS II with Photographs Suitable for Individual Identification Including Information on Matches within the HICEAS II Data Set and between These Encounters and Encounters in the Main Hawaiian Islands

Date	General Location	No. of IDs All	No. of Matches within HICEAS II	No. of Matches MHI[a]	No. of IDs Dist3+ PQ3+[b]	No. of Matches within HICEAS II Dist3+ PQ3+	No. of Matches MHI Dist3+ PQ3+	Biopsy	Notes
09/01/10	N of Midway	9	0	0	1	0	0	Y	
09/05/10	N edge of EEZ	3	0	0	0	0	0	N	
09/07/10	N of Pearl & Hermes	2	0	0	1	0	0	N	
09/10/10	NE of Pearl & Hermes	7	0	0	2	0	0	Y	
09/26/10	SW of Nīhoa	25	9	4	8	3	1	Y	2 tagged
09/27/10	W of Hawai‘i Island	1	0	0	0	0	0	N	
10/07/10	SW of Gardner Pinnacles	4	0	0	3	0	0	Y	
10/20/10	NW of Nīhoa	2	2	0	1	1	0	Y	From tag
10/21/10	W of Nīhoa	20	10	1	8	4	1	Y	From tag
10/29/10	Lāna‘i	1	0	0	0	0	0	N	
11/10/10	SW of Midway	17	0	0	4	0	0	Y	

[a] MHI, Main Hawaiian Islands. All matches with the MHI were with individuals documented off Kaua‘i that do not link by association to the insular social network.

[b] Dist3+ PQ3+, identifications restricted to distinctiveness categories of distinctive (3) and very distinctive (4) and photo qualities of good (3) and excellent (4).

or excellent-quality photos of distinctive or very distinctive individuals (hereafter "well-identified individuals") are considered, there were 28 identifications from eight encounters. Tissue samples for genetic analyses are available from seven of the 11 encounters, though those results are not yet available and will not be discussed further here.

Using either the complete photographic data set, or only considering the subset of well-identified individuals, resightings among encounters were only documented for three encounters, all in the Northwestern Hawaiian Islands within the eastern one-third of the Papahānaumokuākea Marine National Monument (Figure 2). During the first of these encounters (26 September 2010) satellite tags were deployed on two individuals (see following paragraph). Information from one of the satellite tags was used to direct one of the two research vessels in the survey to the general area of the tagged whale approximately a month after tagging, resulting in the two additional encounters where there were resightings from the 26 September encounter. For these three encounters, considering only well-identified individuals, there were eight individuals documented 26 September 2010, one individual documented 20 October 2010, and eight individuals documented 21 October 2010, and matches of distinctive individuals linked all three encounters (Table 1). There were no resightings of individuals from the remaining groups photographically documented during HICEAS II.

Satellite tags were deployed on two adult-sized individuals in a group encountered on 26 September 2010 near Nīhoa in the Northwestern Hawaiian Islands. One of the tags attached with only a single dart in the fin (PcTag24) and transmitted for 4.6 days. The other tag (PcTag25) attached with both darts

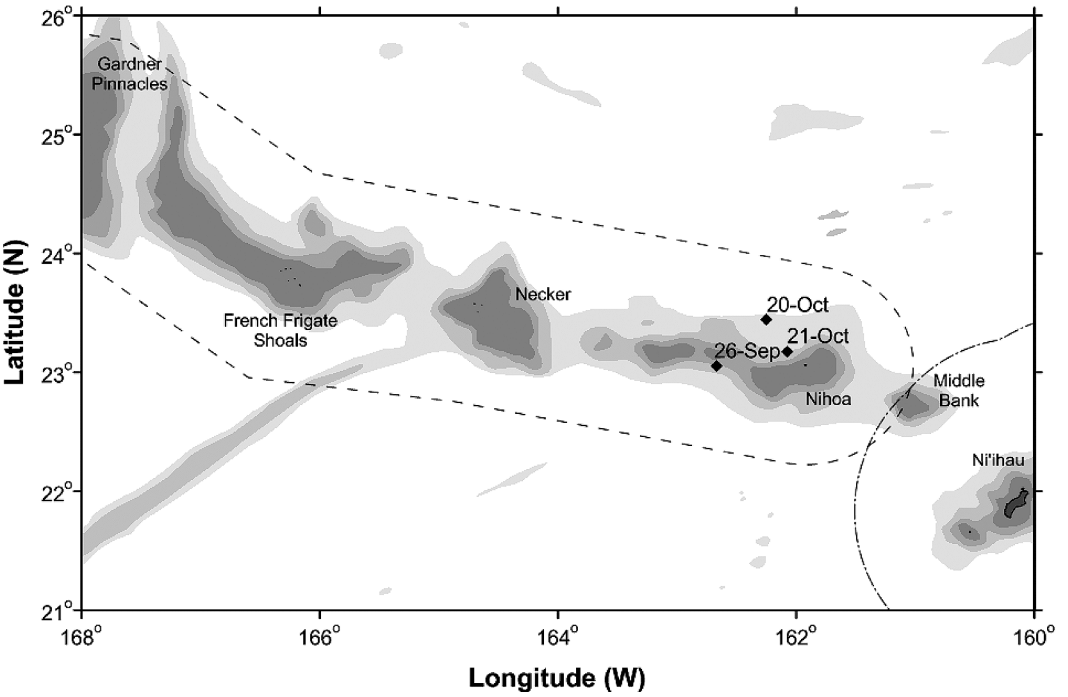

FIGURE 2. Sighting locations of false killer whales encountered during the HICEAS II cruise with photographic matches of individuals among encounters. The boundary of the Papahānaumokuākea Marine National Monument and the outer boundary of the main Hawaiian Islands false killer whale insular stock are shown. Bathymetry contours shown are the 1,000 m, 2,000 m, 3,000 m, and 4,000 m contours.

in, but the holder separated from the arrow and remained attached to the tag on deployment. No transmissions were received from this tag for the first 3 days after tagging, but locations were then received daily for a span of 52 days, presumably after the holder dislodged and uncovered the saltwater switch on the tag. After filtering, 34 locations were obtained from PcTag24 (61.8% of which were LC3, LC2, or LC1), and 337 locations were received from PcTag25 (55.8% of which were LC3, LC2, or LC1). Both individuals remained in the area around the eastern half of the Northwestern Hawaiian Islands (Figure 3), largely, but not entirely, within the boundaries of the Papahānaumokuākea Marine National Monument. Both individuals covered a wide range in depths (Table 2);

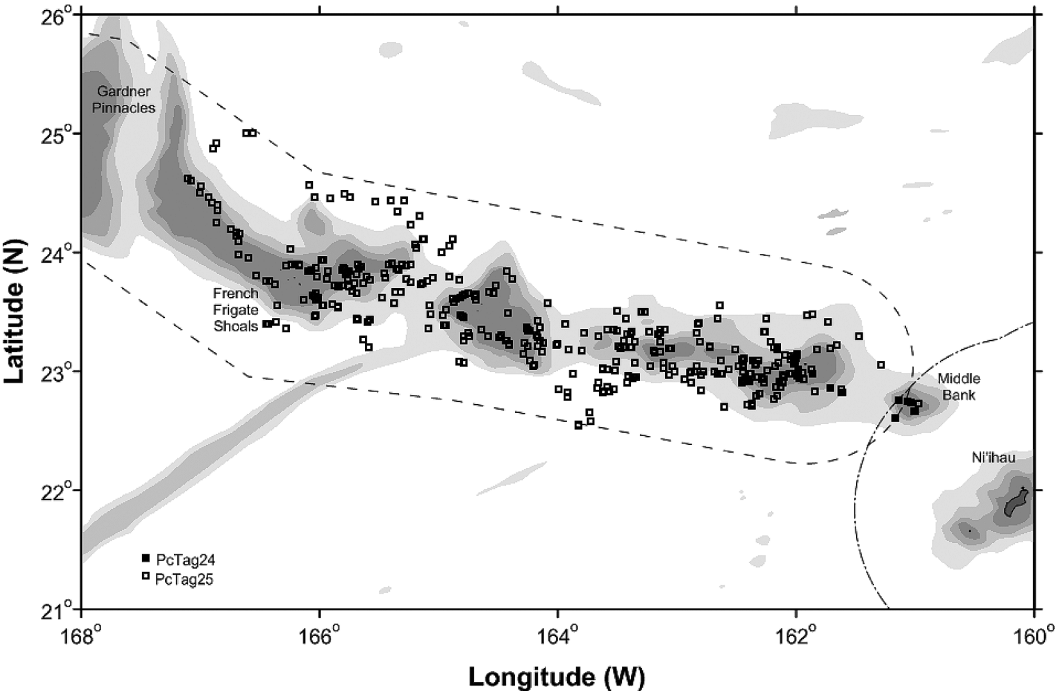

FIGURE 3. Locations of tagged false killer whales after filtering with the Douglas Argos-Filter. The boundary of the Papahānaumokuākea Marine National Monument and the outer boundary of the main Hawaiian Islands false killer whale insular stock are shown. Bathymetry contours shown are the 1,000 m, 2,000 m, 3,000 m, and 4,000 m contours.

TABLE 2

Characteristics of Satellite-Derived Locations from Two False Killer Whales Tagged during HICEAS II

Individual	No. of Locations	Water Depth (m)			Distance to Land (km)			Distance to 200 m Isobath (km)		
		Min.	Median	Max.	Min.	Median	Max.	Min.	Median	Max.
PcTag24	34	22	1,532	4,082	7.1	38.6	104.1	0.1	4.1	34.7
PcTag25	337	9	2,506	5,127	2.0	55.0	147.5	0.02	17.1	89.9

median distance from land for the two individuals was 38.6 km (PcTag24) and 55.0 km (PcTag25).

All HICEAS II photographs were also compared with the existing false killer whale photo-ID catalog that includes individuals from the insular population from the main Hawaiian Islands, the small number of individuals from the main Hawaiian Islands that did not link to the insular social network (13 individuals), and the 29 individuals from the pelagic population (Baird et al. 2008, Baird 2009). No matches were found between HICEAS II photos and any insular or pelagic false killer whales. The only matches were with individuals previously documented off Kaua'i whose population identity was not known (see Baird 2009). Regardless of restrictions by photo quality or distinctiveness, individuals from two HICEAS II encounters (26 September 2010, 21 October 2010) matched with individuals previously documented off Kaua'i (Table 1). One of the individuals that had previously been documented off Kaua'i was seen in May 2008 and June 2008, and the other three individuals previously seen off Kaua'i were seen in July 2008. All four of these were seen 26 September 2010 near Nīhoa, and one of the four was also seen 21 October 2010.

DISCUSSION

We documented photographic resightings among three encounters with false killer whales in the eastern portion of the Papahānaumokuākea Marine National Monument almost a month apart, and individuals from these groups matched with several individuals documented off Kaua'i in 2008. The lack of any resightings of individuals from the main Hawaiian Islands insular population suggests that the individuals documented off Kaua'i and off Nīhoa are not part of the main Hawaiian Islands insular population. Combined with movements of two satellite-tagged individuals from one of these encounters that remained generally associated with the eastern half of the Northwestern Hawaiian Islands, our results suggest that there is a second island-associated population of false killer whales in Hawaiian waters that primarily use the Northwestern Hawaiian Islands. The range of this population is known to overlap partially with the main Hawaiian Islands insular population, because satellite-tagged individuals from that population have been documented off the western side of Kaua'i and Ni'ihau (Baird et al. 2012). Despite the small sample size of satellite tag locations, the range of the population around the Northwestern Hawaiian Islands appears similar in scope to the range of the main Hawaiian Islands insular population (Figure 4). Additional satellite tag deployments would help establish the range of this population.

The presence of two nearshore false killer whale populations with partially overlapping ranges as well as a third offshore population is similar to what has been described for killer whales (*Orcinus orca*) in the temperate eastern North Pacific, where there are several populations of fish-eating killer whales whose ranges partially overlap (Baird 2000, Ford et al. 2000). There has been little research into ecological factors that may influence false killer whales or their prey in the main versus Northwestern Hawaiian Islands. The larger land masses and steeper slopes of the main Hawaiian Islands yield higher precipitation and nutrient input from land than the low-lying primarily submerged islands and atolls of the Northwestern Hawaiian Islands. Mountainous areas of the main Hawaiian Islands disrupt westward wind and current flows, generating persistent leeward eddies that may increase productivity and attract higher-trophic-level predators close to the main Hawaiian Islands than occurs in the Northwestern Hawaiian Islands (Seki et al. 2001, 2002), as well as increasing nearshore upwelling from the island mass effect (Doty and Oguri 1956). Combined, these factors lead to enhanced productivity around the main Hawaiian Islands, while the surrounding oceanographic waters are oligotrophic, resulting in a discontinuity between relatively productive insular and unproductive oceanic waters. The oceanic waters surrounding the Northwestern Hawaiian Islands, particularly north of 23° N, are influenced by the seasonal shifting of the productive waters of the

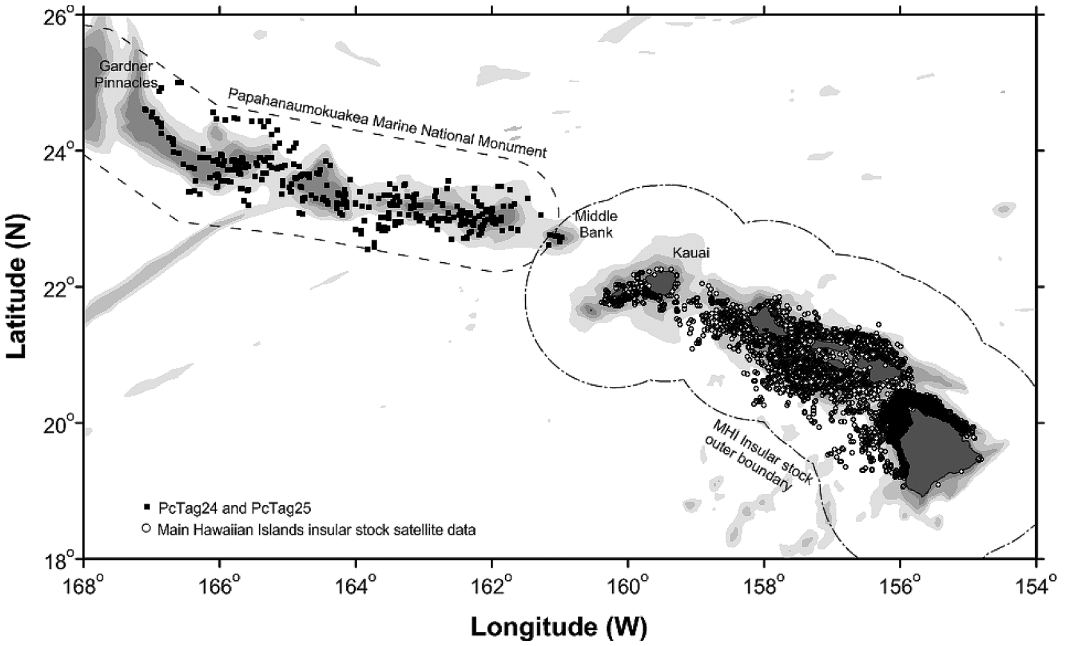

FIGURE 4. Locations of satellite-tagged false killer whales from HICEAS II (PcTag24 and PcTag25) and from the main Hawaiian Islands insular population (data from Baird et al. 2012).

Subtropical Convergence Zone, diminishing any difference in productivity between insular and oceanic waters surrounding the Northwestern Hawaiian Islands. Most known false killer whale prey species have not shown any specific differences in patterns of occurrence between the main and Northwestern Hawaiian Islands (Oleson et al. 2010), such that reliance on potential differences in prey distribution to explain the maintenance of two separate populations is difficult without further research.

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