Movements of satellite-tagged false killer whales around the main Hawaiian Islands

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Summary

To assess movements relative to stock boundaries and the long-line fishery exclusion boundary, satellite tags were remotely deployed on 11 false killer whales in Hawaiian waters in 2007 and 2008, 10 on individuals from the insular population and one on an individual from the offshore population. The offshore individual, tagged 123.8 km west of the island of Hawaiʻi, moved as close as 62 km from the island, inshore of the long-line fishery exclusion boundary. Individuals from the insular population moved as far as 83.1 and 95.9 km offshore, indicating the two populations overlap in terms of distance from shore, and that individuals from the insular population may overlap with the long-line fishery. Although tagged off the leeward (west) side of the island of Hawaiʻi, individuals from the insular population regularly moved to the windward (east) sides of the islands. One insular individual moved extensively, ranging among the main Hawaiian Islands as far as Kauaʻi over a 32-day period, while other individuals remained associated with the island of Hawaiʻi for periods greater than 45 days before moving extensively among the islands. Comparisons of distances between individuals tagged on the same day over subsequent days indicated that individuals within groups frequently disassociated and re-associated, occasionally moving greater than 100 km apart before re-associating. Individuals repeatedly used an area where large groups of false killer whales were documented from aerial surveys in 1989, lending support to the supposition that those individuals were part of the insular population.

Introduction

Two populations of false killer whales have been documented in Hawaiian waters, an insular population around the main Hawaiian Islands, and an offshore population (Chivers et al. 2007; Baird et al. 2008a). False killer whales are long-lived upper trophic level predators. Given the low productivity of the waters of the central tropical Pacific surrounding the Hawaiian Islands, it is not surprising that the population size of false killer whales in Hawaiʻi is small. The best estimate of population size for the insular population is 123 individuals (CV = 0.72), based on mark-recapture analyses of photographically-identified individuals from between 2000 and 2004 (Baird et al. 2005). There is considerable uncertainty regarding movements of individuals and the status of this population, however, due primarily to very low encounter rates. In 369 days of small-boat survey effort around the main Hawaiian Islands over a seven year period (covering 38,759 km of trackline), this species was only encountered on 18 occasions (Baird et al. 2008a). Based on photo-identification it is known that individuals move among islands, at least from Oʻahu to Hawaiʻi, but nothing is known about use of the windward sides of the islands or rates of movements (Baird et al. 2008a). Obtaining information on movement patterns is particularly important, as there is evidence of a large decline in the size of the insular population over the last 20 years (Reeves et al. 2009), and knowledge of movement patterns can be used both to assess stock boundaries and potential interactions with fisheries.

False killer whales in Hawaiian waters are known to interact with the Hawaiʻi-based long-line fishery (Forney and Kobayashi 2007), and estimated levels of mortality and serious injury in the fishery are greater than the Potential Biological Removal (PBR) level (Carretta et al. 2007). The fishery is managed with a geographic exclusion zone around the main Hawaiian Islands that varies in part seasonally. From February through September the closest that long-line fishing may occur to the main Hawaiian Islands is 79 km, while from October through the end of January more than half of the long-line fishery boundary contracts towards the islands, with some long-line fishing occurring as close as 45 km from the main Hawaiian Islands. Based on scarring patterns, there is evidence that individuals from the insular population may be interacting with the fishery (Baird and Gorgone 2005; Baird et al. unpublished). Although genetic analyses of samples from bycaught animals have been identified only as offshore false killer whales, only a subset of bycaught individuals have been sampled and samples that have been collected were far from the main Hawaiian Islands, although bycaught animals have been documented much closer to the main Hawaiian Islands. The degree of overlap of the insular and offshore populations is unknown, as is the distance from shore that individuals from the insular population may range.

The purpose of our study is to examine movements of false killer whales around the main Hawaiian Islands using remotely-deployed satellite tags. Given the low encounter rates with this species in Hawaiʻi and the difficulty in working in offshore and windward areas, such tag deployments are the most productive way to answer questions regarding potential overlap of the insular and offshore populations, assess whether insular animals may move far enough offshore to interact with the long-line fishery, and examine movements among islands and along the windward sides of the islands. Information on movements may also be important to assess whether efforts to photo-identify individuals for mark-recapture analyses of population size may result in biased estimates due to limited movements among the islands.

Methods

Field operations were undertaken as part of a multi-species study of odontocetes in Hawaiian waters. Medium-term satellite tags were remotely-deployed on false killer whales using a Dan-Inject JM Special 25 (Børkop, Denmark) pneumatic projector. The tags used were based on a design of Andrews et al. (2008). Details on the methods have been presented in Schorr et al. (2008) so are only briefly summarized here. The tag contained a Wildlife Computers (Redmond, Washington) SPOT-5 location-only Platform Transmitter Terminal, with the tag attached with two 6.5 cm titanium darts and held in place with backward facing petals. Tags were duty cycled, with transmissions either 12 (2007 and April 2008) or 13 hours per day (July 2008) during either three or four 3-5 hour blocks, with the blocks spread throughout the day corresponding to hours with the greatest density of satellite passes.

Photographs of tagged and companion individuals were compared to an existing photo-identification catalog following the protocols described by Baird et al. (2008a). The existing catalog contained 152 distinctive/very distinctive individuals (individuals with multiple dorsal fin notches that could be identified among encounters even with fair or poor quality photos; see Baird et al. (2008a)) documented from around the main Hawaiian Islands from 1986 through 2007. Information on sighting history and population identity was assessed through the sighting database compiled by Baird et al. (2008a). Age class (adult, sub-adult) of tagged individuals was estimated in the field based on body size. Sex of tagged whales was assessed based on the presence or absence of small calves or neonates for each individual over the entire sighting history for that individual, based on identifications in the catalog of Baird et al. (2008a).

Satellite-derived locations were assessed for plausibility using the Douglas Argos-Filter[1], version 7.06, using two independent methods (distance between consecutive locations, and rate and bearings among consecutive movement vectors). User-defined variables were set as: maximum-redundant-distance 3km; maximum sustainable rate of movement 20 km/h; location qualities 2 and 3 automatically retained; ratecoef = 25. To assess whether movements of individuals tagged on the same day were independent, the straight-line distance among locations of pairs of individuals overlapping for extended periods (>25 days) were calculated using the Posdist[2] function in Excel, using only locations that were obtained within five minutes of each other. Minimum rates of horizontal movement (km/h) were calculated using pairs of locations obtained at intervals between two and six hours. These intervals were chosen to reduce the likelihood of spurious rates of movements associated either with poor location quality locations and short-time intervals, or with long time intervals and the influence of direction changes. Because of differences in duty cycling rates of movements were only calculated for tags deployed in 2008.

Depth, slope, and distance to shore were extracted for all filtered locations by overlaying point location data on a bathymetric raster surface in ArcGIS Version 9.2 (ESRI, Redlands, California). Depths (in meters) were transferred to point locations using the 'intersect point tool' in Hawth's analysis tools (Beyer 2004). A 50 m x 50 m multibeam synthesis bathymetry model from the Hawaiʻi Mapping Research Group[3] was used. The model had areas of no data, so the grid was overlaid on a 3-arc second (90 m x 90 m) U.S. Coastal Relief Model bathymetry from the National Geophysical Data Center[4] to provide 90 m resolution data where 50 m resolution data were absent.

Results

Satellite tags were deployed on 11 individual false killer whales on four different days (Table 1). Ten individuals were tagged near-shore (< 3 km) off the west side of the island of Hawaiʻi. Identifications were obtained from all of these individuals; all 10 had been previously documented from around the main Hawaiian Islands and were linked by association with the insular population. These 10 tagged insular individuals had been previously documented

[1]Available from http://alaska.usgs.gov/science/biology/spatial/douglas.html
[2]Available from nmml.afsc.noaa.gov/Software/ExcelGeoFunctions/excelgeofunc.htm
[3]Available from http://www.soest.hawaii.edu/HMRG/Multibeam/index.php
[4]Available from http://www.ngdc.noaa.gov/mgg/coastal/coastal.htm

associating with each other (Table 2). One individual was tagged on Jaggar Seamount, 123.8 km west of the island of Hawaiʻi. This individual was not photo-identified, but none of the 10 individuals in that encounter that were photo-identified had been previously documented, and a biopsy sample from one individual in this group was genetically identified with an offshore haplotype (Baird et al. 2008b).

Excluding the one individual for which locations were only received over a two-day period (HIPc276), all tagged individuals from the insular population were documented moving from the leeward sides of the islands to the windward sides (Figure 1). One individual tagged in August 2007 (HIPc107) was documented moving from the island of Hawaiʻi among all the other main Hawaiian Islands including Kauaʻi. Two of the insular individuals moved as far as 95.9 and 83.1 km from shore (Table 3). Excluding HIPc276, all of the insular individuals were documented over a broad range of depths, including both near-shore (<50 m) and offshore (>1,000 m) areas. Four of the insular individuals were documented using very deep water areas (>4,000 m; Table 3). The furthest straight-line distance moved from the initial tagging location was 420.1 km (Table 3). Locations from the individual tagged offshore were obtained from five days over a 15-day period. During this time this individual moved from 62.1 to 210.0 km from shore (Table 2), crossing the long-line fishery exclusion boundary (Figure 1, Figure 2).

Determination of distances between two pairs of individuals tagged on the same day over the subsequent 35 (HIPc202 and HIPc205) and 29 (HIPc209 and HIPc213) days indicated that individuals remained in association (e.g., <10 km apart) for periods ranging from a few hours up to approximately 11 days, but also separated (by up to 104.2 and 105.6 km for the two pairs, respectively) for periods of up to three days (Figure 3). Median distance between individuals in each pair were 3.1 km (n = 383 pairs of locations) and 6.7 km (n = 247) for the two pairs, respectively. Average rates of horizontal movements (sustained over periods of two to five hours) ranged from 4.38 to 5.71 km/h, with maximum rates of up to 18.61 km/h (Table 5).

Discussion

Deployment of satellite tags on false killer whales around the main Hawaiian Islands have greatly added to our understanding of movements of individuals in both the insular and offshore populations. Re-sightings in 2008 of all three false killer whales tagged in 2007 indicated complete healing of the tag attachment site (Hanson et al. 2008).

One of the most important findings of this study is that the one offshore individual tagged (123.8 km from shore) did move inside of the long-line fishery exclusion boundary, to within 62 km of shore (Figure 2). Baird et al. (2008a) had previously suggested that offshore individuals may approach relatively close to the main Hawaiian Islands based on photo-identification of a group spread from 42-70 km offshore that had no matches to their catalog, although no genetic samples were obtained from that group to confirm their population identity. Although individuals from the insular population did not move outside of the long-line fishery exclusion boundary, two of the individuals did travel 83.1 and 95.9 km from shore, albeit not in the direction that the boundary approaches closest to the islands (Figure 1). Using simply the distance offshore of the islands, this indicates that these two populations may broadly overlap in their ranges, rather than being separated by a distinct geographical boundary. This situation is similar to populations of killer whales along the west coast of North America, with two discrete populations feeding on similar prey (i.e., “northern residents” and “southern residents”) broadly overlapping in range along the coast of Washington and British Columbia.

Movement patterns of insular individuals were extremely variable. Individuals tagged off the island of Hawaiʻi in July 2008 remained associated with the island for an extended period (>46 days), moving from the site of tagging off the west side of the island to the east side and back again on multiple occasions (Figure 4). Plots of distances among individuals tagged on the same day during this period indicate that the group did not consistently travel as a cohesive unit, but instead individuals were often separated by distances much greater than 20 km (as much as 105 km; Figure 3). Such a finding is particularly interesting in light of the observations of Reeves et al. (2009), who observed large groups of individuals spread over a wide area off the north-west side of the island of Hawaiʻi on multiple days in July 1989. This is an area where tagged whales in our study repeatedly visited over an approximately 57 day period. These results on movements of satellite tagged individuals lend support to the argument of Reeves et al. (2009) that the large groups they observed in July 1989 were part of the insular population. One individual tagged in August 2007 only remained associated with the island for approximately two days before making extensive movements among the main Hawaiian Islands, spending time both on the leeward and windward sides of the islands, both near-shore and in deep waters (Table 4), eventually moving to Kauaʻi before beginning to return east. In the photo-identification study of Baird et al. (2008a) only a small number of identifications were available from Kauaʻi and no matches to the rest of the catalog were found. Thus this is the first conclusive evidence that individuals that utilize waters from Oʻahu to Hawaiʻi also visit Kauaʻi. The extensive movements throughout the main Hawaiian Islands also suggests that efforts to photo-identify individuals for mark-recapture estimates of population size likely are not greatly biased by geographic biases in sampling effort, particularly since sampling effort off different islands has typically occurred with months or even years between sampling efforts (Baird et al. 2005, 2008a).

Whether movements of individuals from either the offshore or insular populations of false killer whales in Hawaiʻi vary seasonally is unknown. All but the one offshore individual were tagged in July or August, and none of those tags remained transmitting into the four month period when more than half of the long-line fishery boundary contracts towards the islands (October through the end of January). In addition, although we have tracks from eight different individuals from the insular population lasting longer than 10 days, tags were deployed on only three different days. While individuals tagged within the same group did not always travel together (Figure 3), their frequent re-associations suggest that the overlapping tag data from different individuals are not completely independent. As well, the variability in short-term movement patterns apparent even with our limited sample (Figure 4) indicates that tagging more individuals would be extremely informative in understanding movement patterns of this population. Tagging additional individuals from the offshore population is clearly needed, although logistics for tagging offshore, in particular having conducive sea states for tagging, are considerable more difficult. Assessing movements during the period when long-line fishing may occur as close as 45 km from the main Hawaiian Islands (October through January) would be particularly important in determining whether and how often individuals from the insular population may interact with the long-line fishery.

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Literature Cited

Andrews, R.D., R.L. Pitman and L.T. Ballance. 2008. Satellite tracking reveals distinct movement patterns for Type B and Type C killer whales in the southern Ross Sea, Antarctica. Polar Biology 31:1461-1468.

Baird, R.W., and A.M. Gorgone. 2005. False killer whale dorsal fin disfigurements as a possible indicator of long-line fishery interactions in Hawaiian waters. Pacific Science 59:593-601

Baird, R.W., A.M. Gorgone, D.L. Webster, D.J. McSweeney, J.W. Durban, A.D. Ligon, D.R. Salden, and M.H. Deakos. 2005. False killer whales around the main Hawaiian Islands: an assessment of inter-island movements and population size using individual photo-identification. Report prepared under Order No. JJ133F04SE0120 from the Pacific Islands Fisheries Science Center, National Marine Fisheries Service.

Baird, R.W., A.M. Gorgone, D.J. McSweeney, D.L. Webster, D.R. Salden, M.H. Deakos, A.D. Ligon, G.S. Schorr, J. Barlow and S.D. Mahaffy. 2008a. False killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands: long-term site fidelity, inter-island movements, and association patterns. Marine Mammal Science 24:591-612.

Baird, R.W., G.S. Schorr, D.L. Webster, D.J. McSweeney, A.M. Gorgone and S.J. Chivers. 2008b. A survey to assess overlap of insular and offshore false killer whales (*Pseudorca crassidens*) off the island of Hawai‘i. Report prepared under Order No. AB133F07SE4484 for the Pacific Islands Fisheries Science Center, National Marine Fisheries Service, Honolulu, HI. In review.

Carretta, J. V., K. A. Forney, M. M. Muto, J. Barlow, J. Baker, B. Hanson and M. S. Lowry. 2007. U.S. Pacific marine mammal stock assessments: 2006. NOAA-Tech. Mem. NMFS-SWFSC-398. 317p.

Chivers, S.J., R.W. Baird, D.J. McSweeney, D.L. Webster, N.M. Hedrick, and J.C. Salinas. 2007. Genetic variation and evidence for population structure in eastern North Pacific false killer whales (*Pseudorca crassidens*). Canadian Journal of Zoology 85:783-794.

Forney, K. A. and D. Kobayashi. 2007. Updated estimates of mortality and injury of cetaceans in the Hawaii-based longline fishery, 1994-2005. NOAA Tech. Mem. NMFS-SWFSC-412.

Hanson, M.B., R.D. Andrews, G.S. Schorr, R.W. Baird, D.L. Webster and D.J. McSweeney. 2008. Re-sightings, healing and attachment performance of dorsal fin-mounted tags on Hawaiian odontocetes. Document PSRG-2008-10 submitted to the Pacific Scientific Review Group, Kihei, HI, November 2008.

Reeves, R.R., S. Leatherwood, and R.W. Baird. 2009. Evidence of a possible decline since 1989 in false killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands. Pacific Science 63:in press.

Schorr, G.S., R.W. Baird, M.B. Hanson, D.L. Webster, D.J. McSweeney, and R.D. Andrews. 2008. Movements of the first satellite-tagged Cuvier's and Blainville's beaked whales in Hawai‘i. Report prepared under Contract No. AB133F-07-SE-3706 to Cascadia Research Collective, Olympia, WA from the Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, California.

Table 1. Information on tagged false killer whales.

Catalog ID	Population identity	Age/sex	# times previously documented	Previous islands documented
HIPc217	Insular	Adult	1	Maui
HIPc276	Insular	Adult	1	Maui
HIPc107	Insular	Adult	4	Maui
PcTag4[1]	Offshore	Adult	0	None
HIPc272	Insular	Sub-adult	2	O‘ahu, Hawai‘i
HIPc179	Insular	Adult	3	Maui, Hawai‘i
HIPc202	Insular	Adult	4	O‘ahu, Maui, Hawai‘i
HIPc145	Insular	Adult female	2	Maui
HIPc205	Insular	Adult	2	Maui
HIPc209	Insular	Adult	3	Maui, O‘ahu
HIPc213	Insular	Adult male	3	Maui, Hawai‘i

Notes to Table 1: [1]No identification photo obtained.

Table 2. Sighting history of tagged false killer whales when more than one individual to be tagged was documented. The first row showing the date of sightings and subsequent rows showing individuals identified. Highlighting for individuals tagged: 15 August 2007 – yellow; 16 July 2008 – pink; 26 July 2008 – green. On date of tagging individual identifications in italics.

28-Feb-01	**15-Apr-03**	**21-Jan-04**	**3-Mar-05**	**23-Feb-06**	**11-Apr-06**	**9-Sep-06**	**15-Aug-07**	**16-Jul-08**	**26-Jul-08**
HIPc107	HIPc107	HIPc145	HIPc202	HIPc202	HIPc107	HIPc213	*HIPc107*	*HIPc145*	*HIPc213*
HIPc145	HIPc179	HIPc209	HIPc205	HIPc205	HIPc179	HIPc272	*HIPc217*	*HIPc179*	*HIPc209*
		HIPc276	HIPc209	HIPc213	HIPc202		*HIPc276*	*HIPc202*	HIPc272
			HIPc213		HIPc213		HIPc202	*HIPc205*	HIPc145
			HIPc217					*HIPc272*	HIPc205[1]
								HIPc107	HIPc202[1]

Notes to Table 2: [1]Not seen but known to be present based on satellite data.

Table 3. Information on false killer whale tagging and tag attachments

Catalog ID	Date tagged	Distance from shore initially encountered (km)	Date last location obtained	Minimum attachment duration	# days locations obtained	# locations
HIPc217	15 Aug 07	2.6	29 Aug 07	14	14	57
HIPc276	15 Aug 07	2.6	17 Aug 07	2	2	13
HIPc107	15 Aug 07	2.6	16 Sep 07	32	29	131
PcTag4	21 Apr 08	123.8	5 May 08	14	5	12
HIPc272	16 Jul 08	1.6	30 Sep 08	76[1]	26	254
HIPc179	16 Jul 08	1.6	22 Jul 08	6	6	66
HIPc202	16 Jul 08	1.6	10 Sep 08	56	56	697
HIPc145	16 Jul 08	1.6	5 Aug 08	20	20	202
HIPc205	16 Jul 08	1.6	20 Aug 08	35	35	433
HIPc209	26 Jul 08	2.7	14 Sep 08	50	50	504
HIPc213	26 Jul 08	2.7	23 Aug 08	28	28	302
SUM					271	2,671

Notes to Table 2: [1]Tag began transmitting on day 50 after deployment

Table 4. Habitat use characteristics determined from satellite-derived locations after filtering.

Catalog ID	Distance from shore (km) Median (range)	Depth (m) Median (range)	Maximum distance moved from tag deployment location (km)
HIPc217	6.4 (0.1 – 35.3)	220 (10 – 1,742)	211.0
HIPc276	5.4 (0.1 – 10.1)	163 (6 – 564)	52.5
HIPc107	14.1 (1.6 – 95.9)	597 (46 – 4,833)	420.1
PcTag4	122.8 (62.1 – 210.0)	3,844 (1,474 – 4,747)	95.1
HIPc272	20.5 (0.9 – 83.1)	827 (46 – 4,767)	329.9
HIPc179	11.9 (0.4 – 33.7)	697 (11 – 1,673)	113.5
HIPc202	14.0 (0.1 – 37.9)	754 (12 – 4,652)	117.8
HIPc145	6.3 (0.1 – 27.4)	392 (6 – 2,105)	104.2
HIPc205	9.8 (0.1 – 31.7)	614 (1 – 2,619)	108.0
HIPc209	7.7 (0.1 – 39.3)	416 (8 – 3,401)	313.2
HIPc213	10.1 (1.2 – 28.7)	595 (46 – 1,940)	117.7

Table 5. Minimum rates of horizontal movements

Catalog ID	Rate of horizontal movements (km/h) Median (range)	n
HIPc272	5.71 (1.67 - 14.41)	50
HIPc179	5.53 (2.32 - 10.44)	9
HIPc202	4.38 (0.36 - 16.38)	112
HIPc145	4.64 (0.67 - 11.94)	24
HIPc205	5.41 (0.49 - 16.49)	63
HIPc209	4.99 (0.51 - 18.61)	76
HIPc213	4.53 (1.21 - 17.63)	40
Grand mean	5.03	

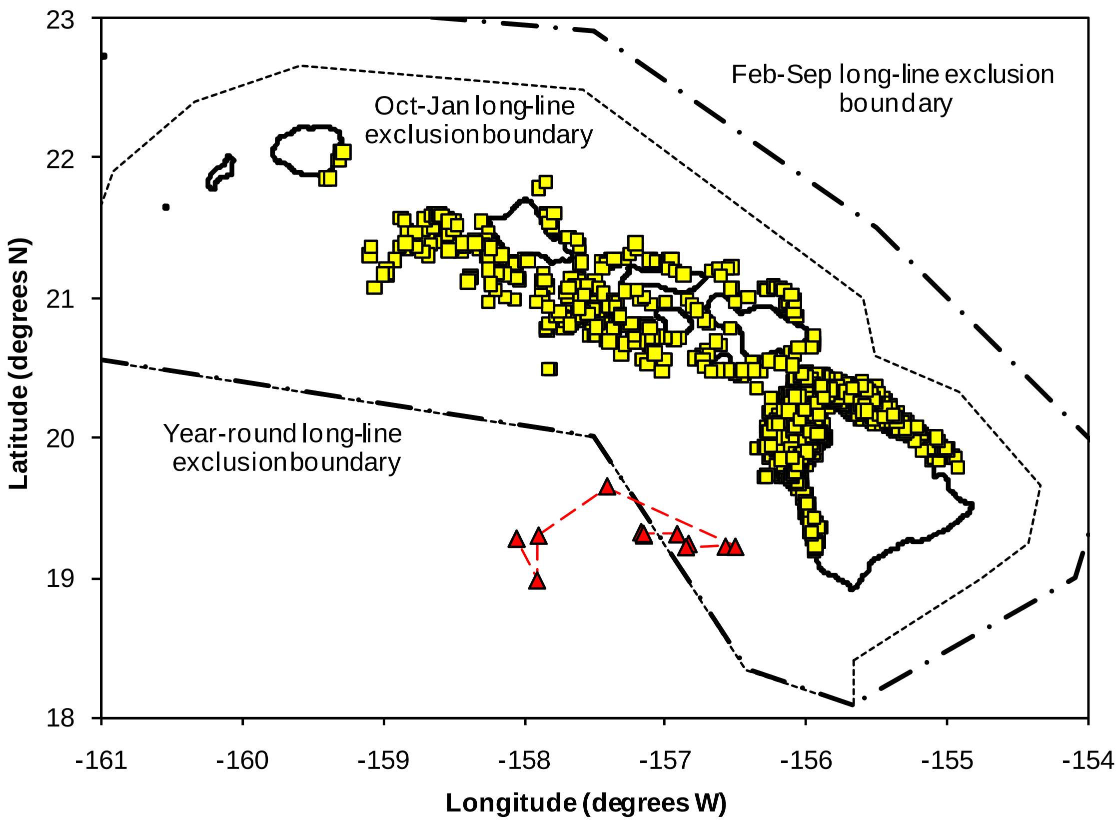


Figure 1. Locations of all satellite tagged false killer whales after filtering. The long-line exclusion boundary is shown for February through September (heavy dashed line), October through January (light dotted line), and year-round (combined dotted-dashed). Locations of individuals from the insular population are shown by yellow squares, while the individual from the offshore population is indicated by red triangles (with consecutive points joined with a red dashed line). See Figure 2 for detail of the offshore individual movements in relation to bathymetry.

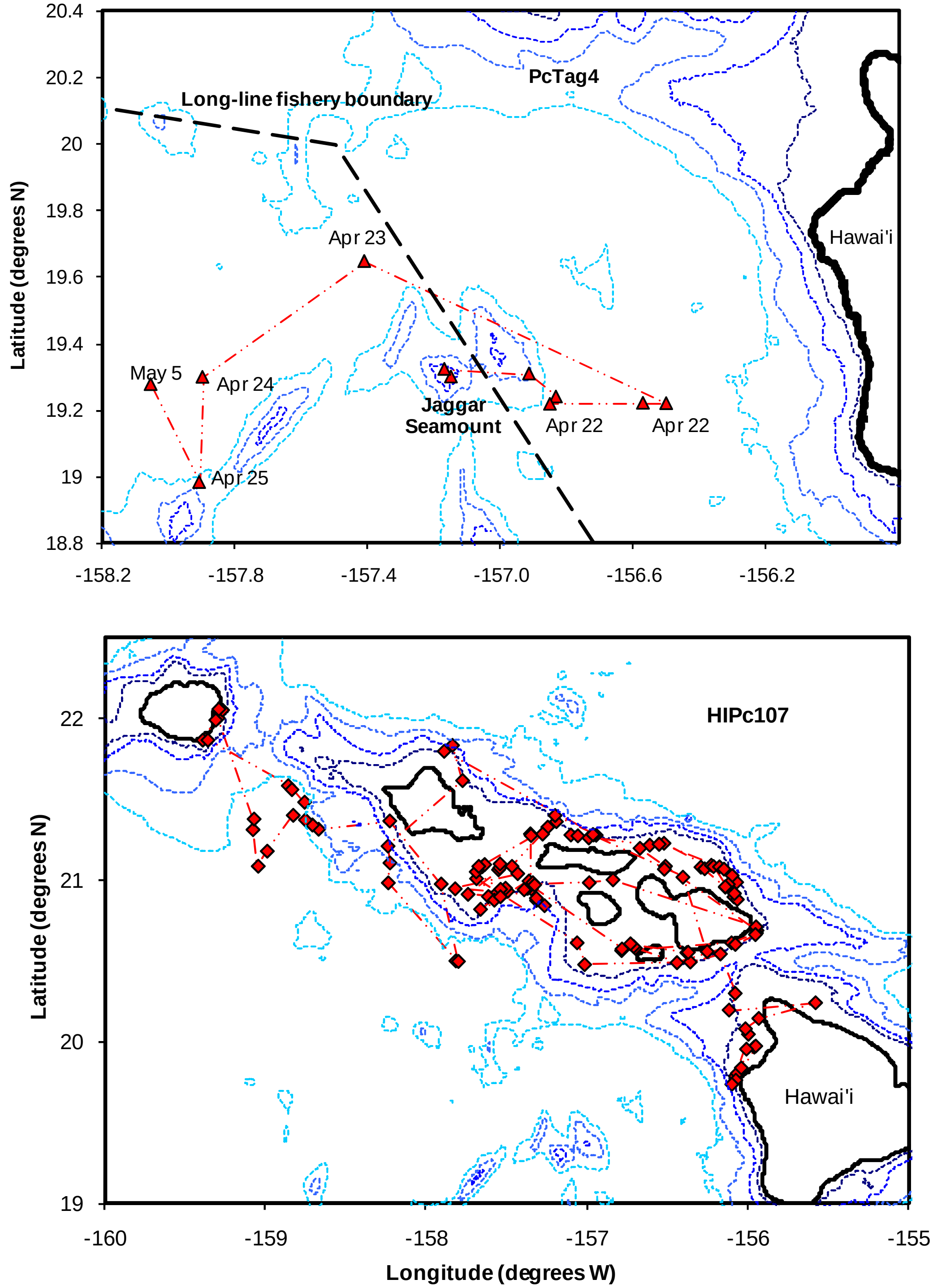
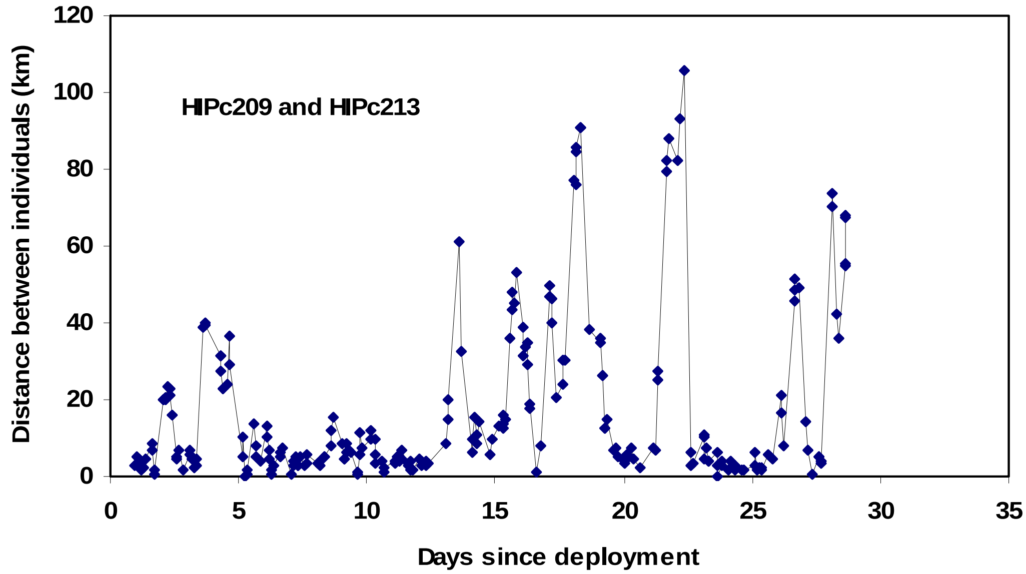


Figure 2. Consecutive locations of two individual satellite tagged false killer whales (top panel - PcTag4, offshore population; bottom panel - HIPc107, insular population). Lines connecting locations meant to show temporal patterns but do not necessarily reflect travel routes among locations. The offshore individual was tagged on Jaggar Seamount April 21, 2008, with the closest approach to land (62 km) documented on April 22. See Figure 4 for distance moved over time for HIPc107. The 1,000 m, 2,000 m, 3,000 m and 4,000 m depth contours, and the long-line fishery exclusion zone boundary are shown (top panel only).



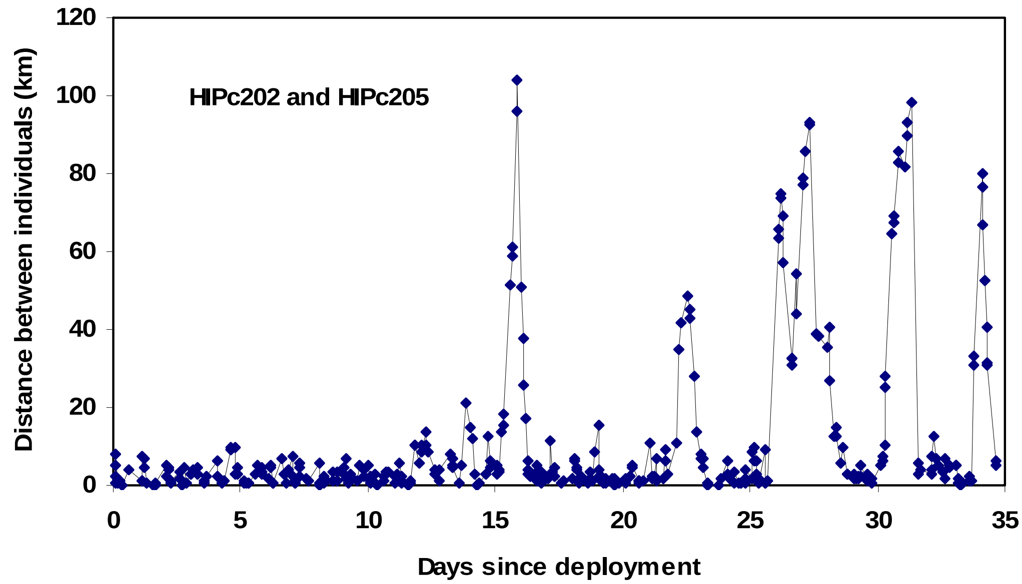


Figure 3. Distance between pairs of individuals tagged on the same day over the 29 (top) and 35 (bottom) days after deployment. Distances between pairs calculated only using filtered satellite-derived locations obtained within five minutes of each. These graphs illustrate that while individuals within a group may remain associated (within 10 km) for extended periods (up to 11 days for HIPc202 and HIPc205), they may disassociate and re-associate, with distances between individuals of over 100 km.

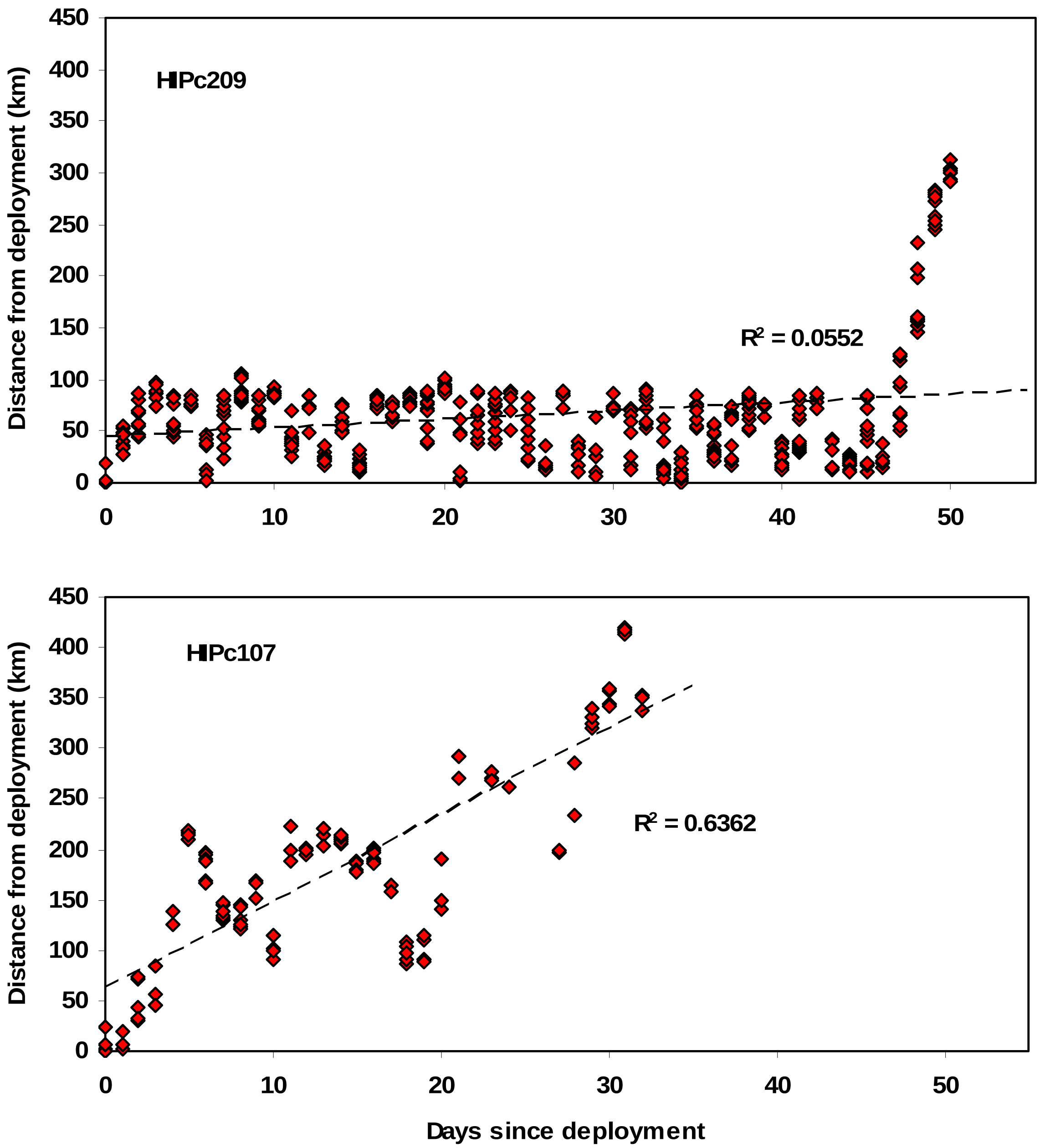


Figure 4. Distance from deployment location versus the days since deployment for two individuals, illustrating differences in movement patterns. HIPc209 (upper panel), tagged in July 2008, remained associated with the island and frequently returning close to the area it was tagged for 47 days, before traveling away from the island. HIPc107 (lower panel), tagged in August 2007, remained associated with the island for just three days before traveling among the islands, eventually reaching Kaua‘i on day 31 (see Figure 2, bottom panel). Regression lines and R^2 values are shown.