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Short Note

Open-Ocean Movements of a Satellite-Tagged Blainville's Beaked Whale (*Mesoplodon densirostris*): Evidence for an Offshore Population in Hawai'i?

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In Hawaiian waters, a single stock of Blainville's beaked whale (*Mesoplodon densirostris*) is recognized, extending throughout the U.S. Exclusive Economic Zone (EEZ) surrounding the archipelago and into adjacent international waters (Carretta et al., 2011). Abundance within the entire EEZ around Hawai'i was estimated at 2,872 individuals based on a large vessel sighting survey (Barlow, 2006), with a single on-effort sighting near the western boundary of the EEZ (Hamilton et al., 2009). There is, however, considerable uncertainty associated with this estimate (CV = 1.17; Barlow, 2006), and there is recent evidence that individuals documented around the main Hawaiian Islands may not be part of an open-ocean population (McSweeney et al., 2007; Schorr et al., 2009). Individual Blainville's beaked whales instrumented with satellite tags off the island of Hawai'i have remained strongly associated with the island, primarily using slope habitats for the entire duration of satellite tag transmissions (up to 71 d; Schorr et al., 2009). Schorr et al. (2009) noted a mean distance from shore of 16.9 km (range 4.4 to 27.7 km) and a mean depth of 1,156 m (range 880 to 1,455 m) for six satellite tagged individuals, over periods ranging from 15 to 71 d (median = 43 d), with from 26 to 405 locations per individual (median = 195 locations/individual). Although these individuals moved a cumulative distance of at least 8,000 km over the duration of their tag attachments, median distances of locations from the tagging location for the different individuals ranged from 19.9 to 91.8 km, and the maximum distance any individual moved from where it was tagged was only 139 km (Schorr et al., 2009). Combined with long-term resightings of distinctive individuals off the island (McSweeney et al., 2007), such results suggest the existence of an island-resident population. Mark-recapture population estimates based on photo-identification data suggest this island-resident population is quite small, with approximately 140 individual Blainville's beaked whales (CV = 0.30) using the area off the island of Hawai'i over a 4-y period (Baird et al., 2009b).

While Blainville's beaked whales are generally thought to be distributed throughout tropical oceanic waters (Jefferson et al., 2008), research efforts to examine movements and spatial use have focused on studies of animals around oceanic islands (Claridge, 2004; Schorr et al., 2009; Tyack et al., 2011). Nothing is known of the movements or habitat use of individual Blainville's beaked whales in the open ocean, away from island habitats. In Hawaiian waters, there have been few sightings of Blainville's beaked whales in the open ocean (Carretta et al., 2011), and thus limited opportunities to study this species in such habitats. Here, we report on the movements of a Blainville's beaked whale satellite tagged off the island of Hawai'i but thought to be from an open-ocean population, rather than the resident island-associated population. Using photo-identification data on this species in the area since 1986 (McSweeney et al., 2007) and sighting information from our study of odontocetes off the island since 2002 (Baird et al., 2008, 2009a), we compare sighting characteristics and photo-identification results from the tagged group with other sightings of Blainville's beaked

whales and discuss the management implications of our results.

The tag used was a location-only LIMPET satellite tag (see Andrews et al., 2008; Schorr et al., 2009). Details of the tag configuration and deployment system, as well as data processing, can be found in Andrews et al. (2008) and Schorr et al. (2009), so they are only briefly mentioned here. The tag was set up to transmit 10 h/d during periods that corresponded to the highest density of satellite overpasses, with a limit of 300 transmissions per day. These 10 h of on-time were in four blocks ranging from 2 to 3 h in duration, with intervals of 2 to 5 h in between transmission periods. Satellite locations were assessed for plausibility with the *Douglas Argos-filter*, Version 7.06 (available at Alaska.usgs.gov/science/biology/spatial/douglas.html). Horizontal rate of movement calculations were restricted to pairs of locations from 4 to 24 h apart for comparison with analyses of Schorr et al. (2009). Depths and distances from shore of sightings and filtered satellite locations were determined using *ArcGIS*, Version 9.2 (ESRI, Redlands, CA, USA). Filtered locations were plotted in conjunction with offshore eddy systems using output from the Archiving, Validation, and Interpretation of Satellite Oceanographic (AVISO) data (see www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/global/index.html). AVISO data were available as weekly means of sea surface height (SSH) at $0.25° \times 0.25°$ resolution and geostrophic currents at $0.5° \times 0.5°$ resolution.

Blainville's beaked whales were encountered on 29 occasions during directed research surveys off the island of Hawai'i from 2002 through 2010 (see Baird et al., 2008, 2009a for methods). Sighting water depths ranged from 360 to 3,903 m (mean = 1,438 m, SD = 911 m), while distance from shore ranged from 2.1 to 48.9 km (mean = 11.3 km, SD = 11.9 km). Identification photos were available from 27 of the 29 encounters. From these there were 92 identifications of 52 distinctive individuals, 19 of which were seen on more than one occasion. Of these 27 encounters, individuals from 21 of these link by association in a single social network (not shown), including the previously satellite tagged individuals studied by Schorr et al. (2009). Some of these individuals have been resighted in the area over periods of up to 17 y (McSweeney et al., 2007), suggesting they are long-term residents and strongly associated with the island. All 21 of these encounters that were linked by association were in depths of < 2,100 m and within 32 km of shore.

On 29 April 2009, a group of three Blainville's beaked whales was encountered in 3,812 m water depth 32.3 km from shore, off the southwestern side of the island of Hawai'i (19.24° N, 156.18° W). This was the second deepest group and fourth farthest from shore of the 29 groups documented. A LIMPET tag was attached to the dorsal fin of one individual, identified as an adult male based on the presence of erupted teeth. Reaction to tagging consisted of a fast dive, while none of the other individuals in the group reacted. Both left and right sides of all three individuals in the group encountered 29 April 2009 were well-photographed, and all three were distinctive, with numerous scars to allow for long-term individual identification. Photos of all three were compared to a catalog of 115 distinctive individual Blainville's beaked whales that had been documented around the main Hawaiian Islands (see McSweeney et al., 2007). Neither the tagged individual, designated HIMd153 in our catalog, nor the other two individuals present (HIMd152 and HIMd154 in our catalog), had been previously documented photographically.

Five of the 27 sightings with photo-identified individuals (including the 29 April 2009 group) were either in depths > 2,100 m or at distances > 35 km from shore, and none of the photo-identified individuals from these groups were documented on more than one occasion (i.e., they had not been seen prior to or since these encounters). Only one of the 22 sightings in less than 2,100 m depth and within 35 km of shore was entirely composed of photo-identified individuals that had not been seen on more than one occasion (i.e., did not link by association to the known resident island-associated population). The high proportion of groups (21 of 22) documented in < 2,100 m and within 35 km of shore that match the resident social network, and the lack of such matches for the five groups documented in deeper water or farther from shore, suggests that individuals documented in very deep water or very far offshore are more likely to be from an open-ocean population.

Locations from HIMd153 were received over a 40-d span. After filtering, there were 109 locations on 37 different days. The distribution of location classes (LC, an indicator of the location accuracy and number of messages received by the satellite during the overpass) was similar (LC3 – 2.75%; LC2 – 9.17%; LC1 – 22.02%; LC0 – 44.04%; LCA – 11.01%; LCB – 10.09%; LCZ – 0.92%) to Schorr et al. (2009). The interval between consecutive locations ranged from 0.38 to 36.43 h (median = 6.55 h). Over the 40 d, HIMd153 moved a cumulative minimum distance of 1,801 km and traveled 1,008 km from the site of tagging (Figures 1 & 2). While covering similar or greater cumulative distances, satellite-tagged individuals from the island-associated population (Schorr et al., 2009) remained relatively close to

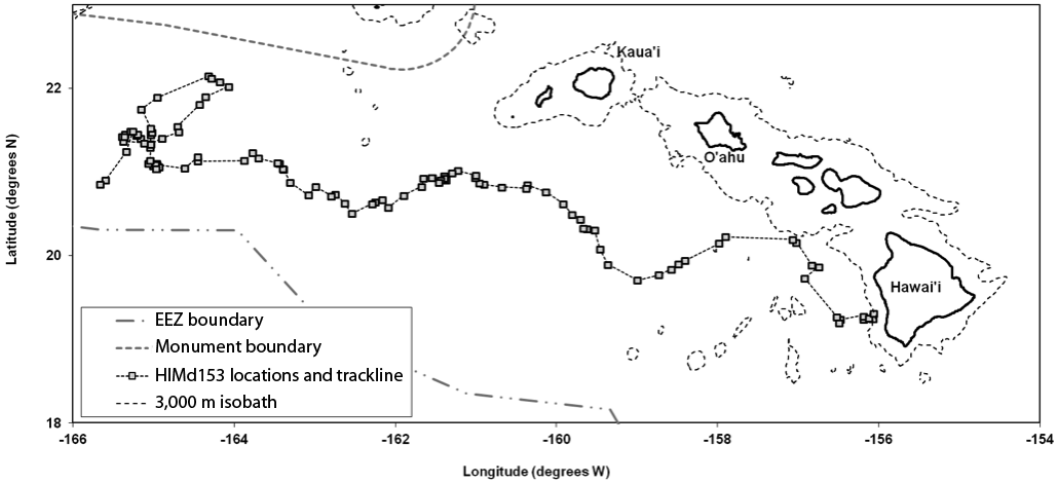

Figure 1. Map showing movements of HIMd153 over the 40 d of signals from the tag

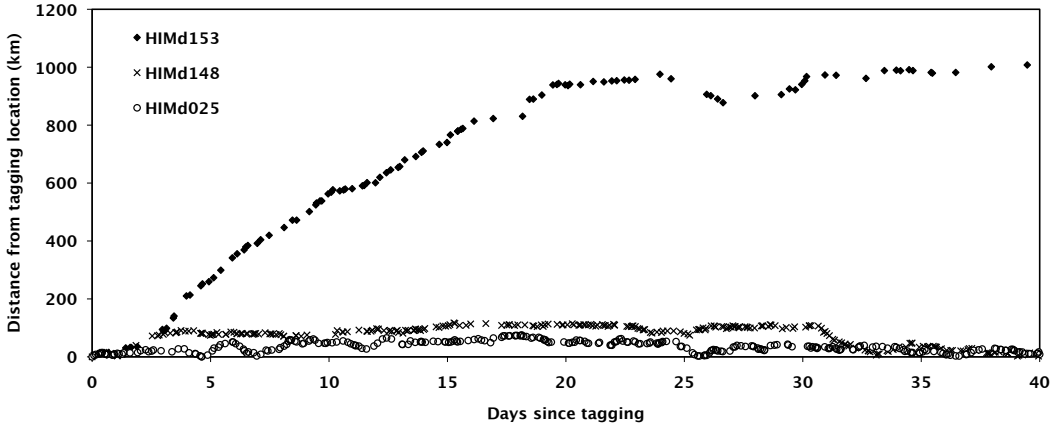

Figure 2. Distance from tagging location over time for HIMd153 and the two individuals from the island-associated population (HIMd148 and HIMd025) that had the greatest average distance from tagging locations (see Schorr et al., 2009)

the sites of tagging (Figure 2). The horizontal rate of movement calculated using all pairs of consecutive locations obtained from 4 to 24 h apart ranged from 0.17 to 8.51 km h^{-1} (median = 1.575 km h^{-1}); however, there was a significant negative relationship between the rate of movement and the time since tagging (regression, $r^2 = 0.118$, $p = 0.005$). During the first 20 d, while the whale generally travelled away from the island, the median horizontal rate of movement was 2.41 km h^{-1}; while during the last 20 d, when the whale used a broad area located 900 to 1,000 km from the tagging location, it was 0.99 km h^{-1}. By comparison, the grand mean of the median rates of horizontal movement from the six groups of Blainville's beaked whales previously satellite tagged was 1.16 km h^{-1} (Schorr et al., 2009). Many of the locations during the first 2 wks were associated with the northern edges of two cyclonic eddies, possibly moving with the currents, although movements in the latter half of the track were not associated with any strong oceanographic features visible in AVISO SSH and current data (Figure 3).

HIMd153 utilized depths ranging from 3,150 to 4,946 m (median depth = 4,702 m), on average using water four times deeper than individuals from the island resident population (Schorr et al., 2009). After the 4th d post-tagging, there were no depths associated with satellite-derived locations shallower than 3,500 m. The distance from the closest point of land in the main Hawaiian Islands ranged from 17.6 to 573.0 km (median = 282.6 km). When the tag stopped transmitting, HIMd153 was still inside the U.S. EEZ surrounding

the Hawaiian Islands, but only 60.9 km from the EEZ boundary (Figure 1).

Based on the depth and distance that HIMd153 was encountered from shore and the lack of any link by association to the island-resident social network, we believe this individual was not part of the island-associated population of Blainville's beaked whales, but, rather, from an open-ocean population. The spatial use patterns and depths used by this individual differed dramatically from previous Blainville's beaked whales tagged in Hawai'i, moving over 900 km from where it was tagged in just 20 d and traveling over depths of up to almost 5,000 m. Although the tagged whale did not leave the EEZ in the 40 d we received locations from the tag, the broad ranging movements and proximity to the EEZ boundary suggest that Blainville's beaked whales in offshore waters surrounding the Hawaiian Islands are likely part of a larger oceanic population that uses both U.S. and international waters. Combined with the evidence of an island-resident population (McSweeney et al., 2007; Schorr et al., 2009), it appears that, like many other species of odontocetes in Hawaiian waters (Chivers et al., 2007, 2010; Baird et al., 2008, 2009a; Andrews et al., 2010; Aschettino et al., 2011), there is more than one population of Blainville's beaked whale in Hawaiian waters.

As well as their relevance for population structure, our results have implications for exposure and reactions of beaked whales to naval sonar exercises. Individuals of several species of beaked whales, including Blainville's beaked whales, have died in association with mid-frequency active sonar use (Balcomb & Claridge, 2001; Jepson et al., 2003; Fernandez et al., 2005). Such mortalities are thought to occur due to changes in diving behavior leading to decompression sickness (Jepson et al., 2003; Fernandez et al., 2005; Cox et al., 2006; Hooker et al., 2009). The history of prior exposure of individuals may be important in understanding their responses to mid-frequency sonar since naïve individuals would potentially show strong behavioral responses, while those exposed to mid-frequency sonar on a regular basis may habituate to some degree (Falcone et al., 2009). Movement patterns of HIMd153 suggest that individuals from an open-ocean population are much less likely to be regularly exposed to mid-frequency sonar use from naval exercises that typically occur in closer proximity to the islands (Anonymous, 2008). Since open-ocean animals may be naïve to sonar exposure, their reactions and potential impacts may differ from those that have been exposed on multiple occasions throughout their lives.

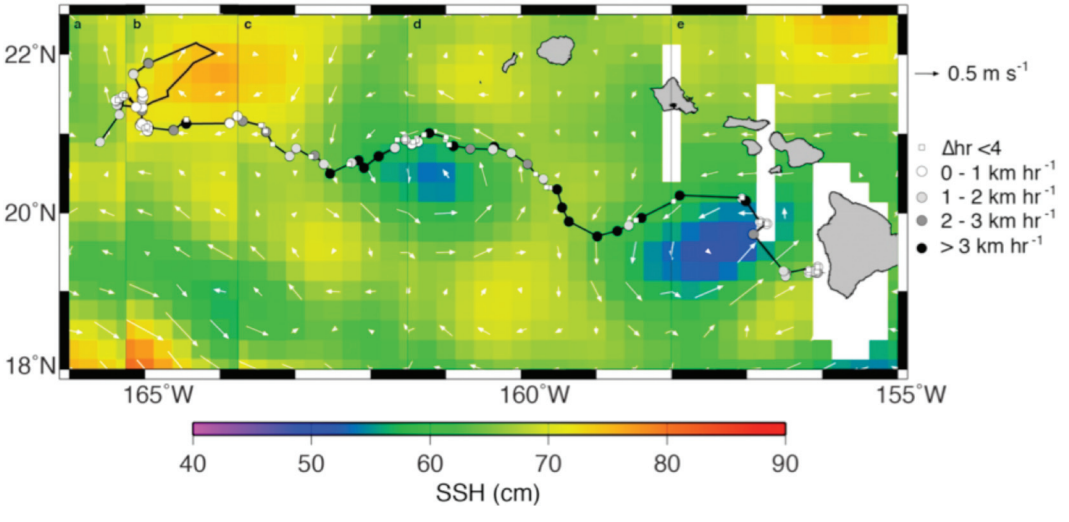

Figure 3. Track of the Blainville's beaked whale tagged 29 April 2009 with sea surface height (SSH) (color) and surface currents (vectors); locations during periods when SSH and current data are available are indicated by symbols: circles represent locations following intervals of > 4 h with shading indicating speed over the track from the previous location, and squares represent locations < 4 h from the prior location with no speed indicated (see text). SSH and current data are shown (in panels of varying widths depending on the distance moved, labeled in upper left of each panel) for the weeks of (a) 1 June 2009, (b) 18 May 2009, (c) 11 May 2009, (d) 4 May 2009, and (e) 27 April 2009 (from left to right). The trackline for the week of 25 May 2009 is shown, but no locations are indicated.

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