

Short-Range Movements of Hawksbill Turtles (*Eretmochelys imbricata*) from Nesting to Foraging Areas within the Hawaiian Islands¹

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Abstract: Hawksbill sea turtles, *Eretmochelys imbricata*, reside around the main Hawaiian Islands but are not common. Flipper-tag recoveries and satellite tracking of hawksbills worldwide have shown variable distances in post-nesting travel, with migrations between nesting beaches and foraging areas ranging from 35 to 2,425 km. Nine hawksbill turtles were tracked within the Hawaiian Islands using satellite telemetry. Turtles traveled distances ranging from 90 to 345 km and took between 5 to 18 days to complete the transit from nesting to foraging areas. Results of this study suggest that movements of Hawaiian hawksbills are relatively short-ranged, and surveys of their foraging areas should be conducted to assess status of the habitat to enhance conservation and management of these areas.

HAWKSBILL SEA TURTLES, *Eretmochelys imbricata* (L.), are found in nearshore habitats in tropical regions of all oceans. Hawksbill turtles are listed as Critically Endangered in the International Union for Conservation of Nature (IUCN) Redbook (Hilton-Taylor 2000) and as Endangered under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Washington, D.C., 1973) and the Endangered Species Act (U.S.A., 1973). The species has historically not been commonly harvested for consumption in the Pacific because the edible parts can sometimes be toxic (Fussy et al. 2007). Hawksbills in the Caribbean were not generally harvested for food before the

1900s because of toxicity, but as hawksbill numbers declined due to harvesting for scutes (Carrillo et al. 1999, Campbell 2003) toxicity also seemed to decline. McClenachan et al. (2006) suggested that this reduction in toxicity may be connected to the declines in hawksbill numbers because of an increased availability of less-toxic sponges on which hawksbills prefer to forage. Large numbers of hawksbills were taken in the Pacific, mainly for their scutes, which are the thickest and most decorative of all sea turtle scutes. Items that were fashioned from bonding, shaping, and carving these scutes include combs, jewelry, decorative art, and tools (Kaeppler 1978, Canin 1991, Hainshwang and Leggio 2006). Despite international protection, hawksbills are still being harvested and exploited for curios and for tortoiseshell, known in Japan as *bekko* (Canin 1991, MSNBC News Service 2007). Knowledge of hawksbill movements, locations, and habitat usage of critical marine foraging habitats can aid state and local entities to develop effective protection and management schemes for the species.

Before 1995, few studies had been conducted using satellite telemetry to determine post-nesting movements of hawksbill turtles. Knowledge about population size and distribution of hawksbills was obtained mostly from flipper-tagging and recapture programs. Records of flipper-tag recoveries have indi-

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cated that many hawksbill populations within the Pacific and Atlantic oceans can have long-distance post-nesting movements. In the Pacific, hawksbill turtles on breeding migrations moved between Australia and neighboring countries including Vanuatu, Solomon Islands, Papua New Guinea, and Indonesia. Migratory distances between foraging areas and nesting beaches ranged from 368 to 2,425 km (Miller et al. 1998, Bell et al. 1999). A flipper-tagged hawksbill that nested in the Solomon Islands was recovered in Papua New Guinea after the turtle had traveled an estimated straight-line distance of 1,400 km (Vaughan and Spring 1980). Post-nesting flipper-tag recoveries from the Caribbean provided movement distances of 1,400–2,000 km between nesting and foraging areas (Groshens and Vaughan 1994, Hillis 1994, Meylan 1999).

Since 1995, there has been increased usage of satellite telemetry worldwide to monitor the movements of post-nesting hawksbills. To date, much of the published turtle-tracking research has been in the Caribbean (Byles and Swimmer 1994, Hillis-Starr et al. 2000, Horrocks et al. 2001, Troëng et al. 2005, van Dam et al. 2008). These telemetry studies showed long-distance movements from Buck Island, St. Croix, U.S. Virgin Islands, to both Nicaragua (1,400 km) and Venezuela (2,000 km), as well as short-distance movements—staying within 300 km of Costa Rica and Buck Island, Virgin Islands. Conversely, satellite tracking of five post-nesting hawksbills in the Seychelles, Indian Ocean, in 1998 showed movements limited to 35–175 km (Mortimer and Balazs 2000).

Genetic studies of hawksbill turtles have been published mainly on Caribbean populations (Bass 1999, Mortimer et al. 2007). Pacific populations are currently being analyzed (Limpus and Miller 2008; NOAA Southwest Fisheries Science Center, unpubl. data).

The Hawaiian Archipelago (U.S.A.) extends for 2,450 km across an isolated region of the North Pacific (19°N, 155°W to 28°N, 178°W). The hawksbill, known as 'ea or honu'ea in the Hawaiian language, is rare in the Hawaiian Islands (Balazs 1978b, Balazs

et al. 1994, National Marine Fisheries Service [NMFS] and U.S. Fish and Wildlife Service [USFWS] 1998). Hawksbill turtles do not currently nest or reside in the Northwestern Hawaiian Islands. Only one hawksbill has been recorded in that area: a juvenile found stranded alive at Pearl and Hermes Reef (2005, Pacific Islands Fisheries Science Center [PIFSC], unpubl. data).

Historically, hawksbills in Hawai'i were not eaten for food because of the toxicity and unpleasant taste of the meat, but the scutes were used for decorative inlay on important objects such as kähili and for medicine, bracelets, combs, and fishing hooks (Buck 1957, Pukui and Elbert 1992, Rose et al. 1993).

Compared with the green turtle (*Chelonia mydas*), hawksbill sightings and strandings around the main Hawaiian Islands are relatively uncommon, and the majority of the sightings have consisted of immature turtles (Balazs 1978a, Keuper-Bennett and Bennett 2002, Chaloupka et al. 2008). To date, only two flipper-tagged adult hawksbill turtles have been recorded away from the nesting beaches. Both turtles were tagged nesting at Pöhue Bay, island of Hawai'i. One was sighted in waters near Kahekili, Maui, a distance of 265 km, shortly after the 2005 nesting season (W. Seitz and C. S. K., unpubl. data), and the second was sighted shortly after the 2008 nesting season near Honokōwai, Maui, a distance of 260 km (W. Seitz, U. Keuper-Bennett and P. A. Bennett, unpubl. data).

The number of adult female hawksbills has been estimated at less than 100, nesting at 20 beaches (Katahira et al. 1994, Mangel et al. 2000, King et al. 2007; L. K. and W. Seitz, unpubl. data). Previously, Kamehame, a small, remote beach located on the southeastern coast of the island of Hawai'i, was the main nesting beach in the Hawaiian Islands (Katahira et al. 1994). In addition to Kamehame, 12 other nesting beaches can be found on the island of Hawai'i. When combined, these beaches currently host the majority of hawksbill nestings in the Hawaiian Islands (Katahira et al. 1994; L. K. and W. Seitz, unpubl. data). Nesting beaches can also be found on

other islands: two on the northeastern shore of O'ahu (Balazs 1978*b*), one on Moloka'i (Balazs 1978*b*, pers. obs.), and four on Maui (Mangel et al. 2000, King et al. 2007).

Hawksbills are known to be spongivores (Meylan 1988), but details about the diet and foraging areas of the hawksbill in Hawai'i are still being studied. However, preliminary results to date indicate that both sponges and algae are an important part of hawksbill diets in Hawai'i (NOAA PIFSC, unpubl. data). Preliminary results from genetic analyses suggest that the Hawai'i nesting population includes only a few haplotypes (P. H. Dutton, R. LeRoux, unpubl. data).

In this study, we characterize the movement patterns of nine adult female hawksbills within the Hawaiian Islands. Post-nesting movements to foraging areas are described to illustrate habitat use and offer recommendations for management and conservation of this endangered species.

MATERIALS AND METHODS

Argos satellite-linked transmitters, ST-3, ST-14 (1 watt), and ST-20 (model A-1010, 1/2 watt), manufactured by Telonics, Inc. (Mesa, Arizona), were safely and securely attached with polyester resin and fiberglass cloth to the carapaces of nine female hawksbill turtles following the procedures described by Balazs et al. (1996) and Schroeder et al. (2000). The two ST-3 and six ST-14 transmitters each weighed 750 g and measured 17 by 10 by 3.5 cm with the Tygon-protected antenna extending 13 cm from the top of the transmitter. Transmitters were programmed with either a 6 hr on, 6 hr off duty cycle or a 9 hr on, 3 hr off duty cycle. Units were turned on at a time computed to synchronize with optimum satellite overpass coverage. The single ST-20 transmitter, programmed with a duty cycle of 6 hr on and 48 hr off, weighed 276 g and measured 6.0 by 12.3 by 2.8 cm.

After completing nesting and before returning to the ocean, each turtle was carefully confined in a prone position inside a portable plywood pen while the satellite tag was attached to the carapace. Transmitters were

attached to four hawksbills nesting at Kamehame on the island of Hawai'i (two in August 1995 and two in August 1996) and five hawksbills nesting on the island of Maui at the following beaches: Keālia (1997, 2005), Kawililipoa (1998, 1999), and Oneloa (2004). Size of the turtles was measured in centimeters as straight carapace length (SCL) and/or curved carapace length (CCL).

All deployed transmitters sent data to polar-orbiting NOAA satellites carrying Argos receivers (CLS America, <http://www.clsamerica.com>). Argos locations were calculated by measuring the Doppler shift on the transmitter signals, which is explained at the CLS America, Inc. (2007) website <http://www.argos-system.org/>. Positional accuracy is defined by Argos as follows (LC = location code): LC 3, within 150–350 m to the given location; LC 2, within 350–500 m; LC 1, within 500–1,000 m; and LC 0, >1,000 m. LC A and LC B have no assigned value for accuracy, and LC Z positions were rejected due to their calculation with less than two signals received during the satellite pass. Positions were considered unacceptable if: (1) they were located on land, (2) the speed traveled between two locations was over 5 km/hr, or (3) the position made a turn greater than 90 degrees in less than a 24-hr period. Decisions for excluding a position were subjective based on these criteria.

The best daily location and the great circle equation with the WGS84 ellipsoid were used to compute distance traveled (Bowditch 1995, Wessel and Smith 1998). Speed (kilometers per hour) was calculated as the distance traveled between adjacent positions divided by the time spent traveling that distance. Speed over the total track was averaged, and the mean speed of transit was recorded. When available, LCs of 0, 1, 2, or 3 were used for distance and speed calculations; when unavailable, estimated distance and speed were calculated using the beginning and end points and the most likely route taken by the turtle, which was indicated by the data for each track. The end of a track was determined either by the last Argos position or when positional locations clustered in one general area

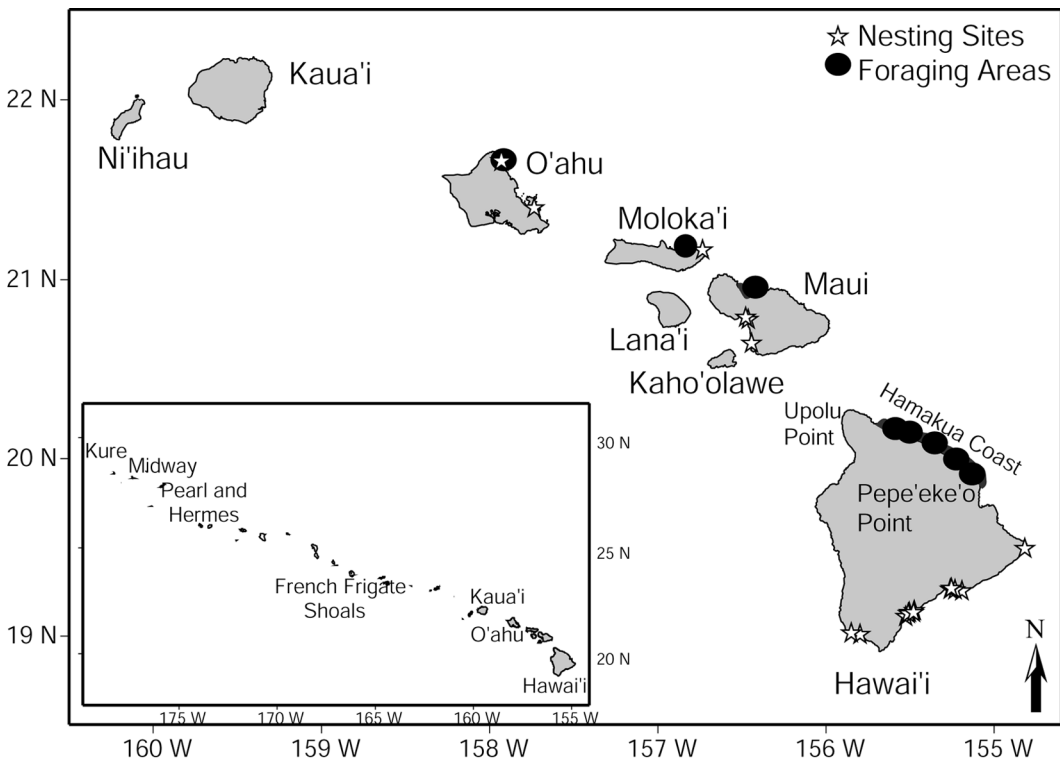


FIGURE 1. Distribution of foraging areas (indicated by black dots) as determined by satellite tracking of nine hawksbills from 1995 to 2005. Open stars indicate nesting sites. The entire Hawaiian Archipelago is in the inset for scale.

for more than 1 month. The earliest date at an end point was considered the end date for distance and speed calculations. Home-range area in square kilometers was determined for three of the nine tracks using a simplified minimum convex polygon analysis of the foraging area data scatter, using only LC 2 and LC 3 data. Only three tracks had data sufficiently accurate for analysis.

Average dive time in a 12 hr period and time of last dive were collected and transmitted by the ST-3 and ST-14 transmitters. Average dive time and time of last dive were converted into minutes using the formula given by Argos (data times 2 divided by 60). A mean was calculated for each of these variables to provide an index for each turtle during the inactive periods (when the turtle was foraging, resting, or during the interesting

period) and the transit period (defined by the date the turtle started moving away from the nesting beach until the date it arrived at the foraging/resting area, or the end data).

RESULTS

Hawksbill foraging areas in Hawai'i based on these satellite tracking results are shown in Figure 1 along with known hawksbill nesting beaches. Six of the nine hawksbills moved to the northeastern shore of the Hāmākua Coast on the island of Hawai'i. The other three individuals traveled to different island foraging areas. The turtles traveled distances ranging from 90 to 345 km, taking between 5 and 18 days to complete the transit (Table 1).

The mean duration of the last dive had a

TABLE 1

Distance and Duration of Post-nesting Hawksbill Movement from Nesting Beaches on the Islands of Hawai'i and Maui to their Respective Foraging Areas

Turtle ID	Nesting Site	SCL or CCL Carapace Length ^a (cm)	Days Transmitting	Distance Traveled (km)	Number of Days in Transit	Mean Speed of Transit (km/hr)	Foraging Site, Arrival Location
22126-95	Kamehame, Hawai'i	88.1 SCL	263	180	10	0.8	Honoka'a, Hāmākua Coast
22134-95	Kamehame, Hawai'i	83.0 SCL	277	135	8	0.7	Honomu, Hāmākua Coast
24191-96	Kamehame, Hawai'i	82.4 SCL	250	275	12	1.0	Pa'auilo, Hāmākua Coast
25695-96	Kamehame, Hawai'i	85.3 SCL	348	345	18	0.8	Kahului Bay, Maui
4802-97	Keālia, Maui	87.5 CCL	142	231	8	1.2	Kuku Pt., Hāmākua Coast
4801-98	Kawililipoa, Maui	89.0 CCL	300	172	7	1.0	Waipi'o, Hāmākua Coast
25692-99	Kawililipoa, Maui	89.0 CCL	322	90	5	0.8	Pelekunu, Moloka'i
19591-04	Oneloa, Maui	88.0 SCL	372	280	14	0.8	Mālaekahana, O'ahu
53751-05	Keālia, Maui	86.6 SCL	312	254	16	0.7	Welokā, Hāmākua Coast

^a SCL, straight carapace length; CCL, curved carapace length.

range of 34–77 min during nontransit periods and a range of 5–35 min during transit periods. The index range for average dive time during a 12 hr period was 14–79 min for nontransit periods and 5–19 min during transit periods. Home ranges for the three tracks with sufficient data to analyze were estimated to be 0.5 to 2.0 km² (± 1.0 km²).

Three turtles nesting at Kamehame, island of Hawai'i, two turtles nesting at Keālia, Maui, and one from Kawililipoa, Maui, traveled to the Hāmākua Coast of the island of Hawai'i (Figure 2A–F). All turtles followed the coastlines closely whenever possible. Two of the Kamehame hawksbills traveled in a counterclockwise direction around Cape Kumukahi, taking the shortest route around the island of Hawai'i to foraging areas on the Hāmākua Coast (Figure 2A,B). One Kamehame post-nesting hawksbill traveled in a clockwise direction around the island of Hawai'i, around the southern tip of the island, north along the west coast and then around the northern tip of the island before arriving

at the foraging area near Pa'auilo on the Hāmākua Coast (Figure 2C).

All three hawksbills that traveled to the Hāmākua Coast from their nesting beaches on Maui took similar paths. They followed the southwest coast of Maui to Kanaloa Point, at which time they traversed across the 'Alenuihāhā Channel (Figure 2D–F). The hawksbills deflected southward during their channel transit. After reaching the coast of the island of Hawai'i near Kohala or 'Upolu Point, the turtles continued in a clockwise fashion around the island to a foraging site along the Hāmākua Coast.

Three of the turtles tracked did not travel to the Hāmākua Coast of the island of Hawai'i. One hawksbill traversed from Kamehame, island of Hawai'i, in a clockwise fashion crossing the 'Alenuihāhā Channel to continue along the north coast of Maui to a foraging area on the western side of Kahului Bay, Maui (Figure 3A). Another traveled from Kawililipoa, Maui, to a final foraging area of Pelekunu, Moloka'i (Figure 3B). The

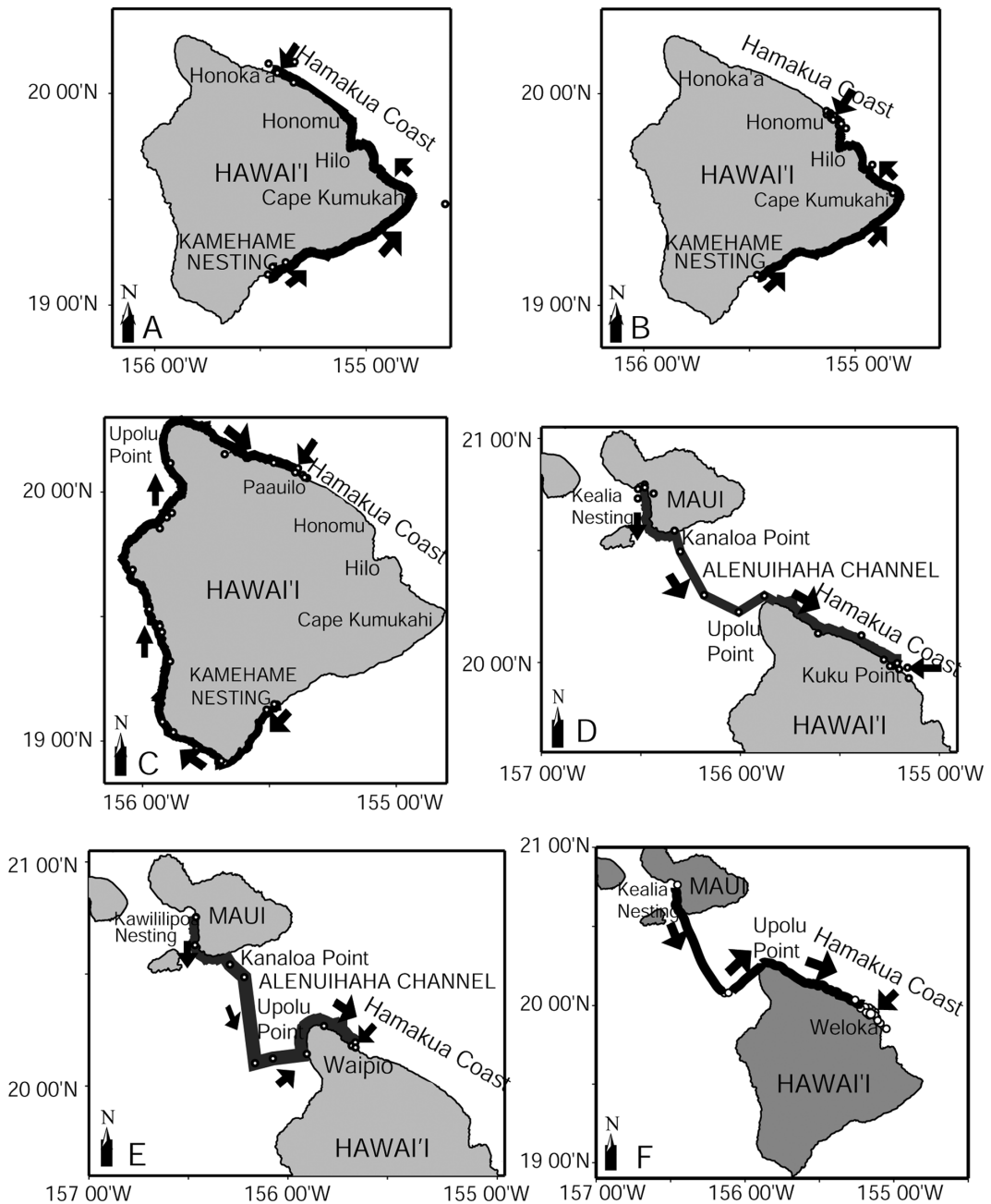


FIGURE 2A–F. Post-nesting movement of six hawksbill turtles from nesting beaches to foraging areas on the Hāmākua Coast of the island of Hawai‘i. (A) ID 22126: traveled 180 km in a total of 10 days between Kamehame nesting beach to Honoka‘a; (B) ID 22134: traveled 135 km in 8 days between Kamehame nesting beach to Honomu; (C) ID 24191: traveled 275 km in 12 days between the Kamehame nesting beach and Pa‘auilo; (D) ID 4802: traveled 241 km in 8 days between the Keālia, Maui, nesting beach and Kuku Point; (E) ID 4801: traveled 172 km in 7 days between Kawililipoa Beach, Maui, and Waipi‘o; (F) ID 53751: traveled 254 km in 16 days between the Keālia, Maui, nesting beach and Welokā.

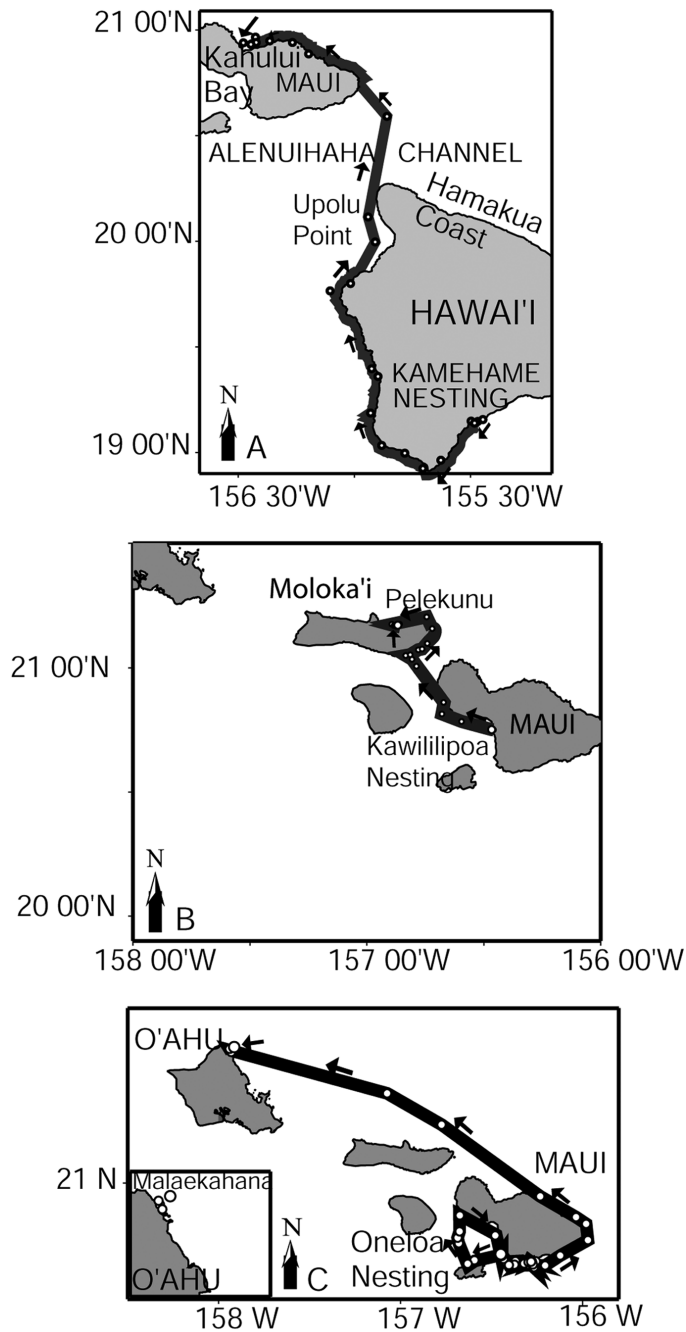


FIGURE 3A–C. Post-nesting movement of three hawksbill turtles from nesting beaches to different foraging areas. (A) ID 25695: traveled 345 km in 18 days from Kamehame, island of Hawai'i, to Kahului, Maui; (B) ID 25692: traveled 90 km in 5 days from Kawililipoa, Maui, to Pelekunu, Moloka'i; (C) ID 19591: traveled 280 km in 14 days from Oneloa, Maui, to Malaekahana, O'ahu.

third turtle used a more circuitous route, completing a 104-km loop returning to nest one last time before heading to her foraging area near Goat Island, Mālaekahana, on the island of O'ahu (Figure 3C).

DISCUSSION

Hawai'i, as an isolated archipelago in the middle of the North Pacific Ocean, is situated over 4,800 km from the nearest major landmass. Transpacific movements have been documented in other sea turtle species such as leatherbacks (*Dermochelys coriacea*) and loggerheads (*Caretta caretta*) via tag returns and satellite tracking (Resendiz et al. 1998, Polovina et al. 2004, Benson et al. 2007). Green turtles also migrate long distances, but solely within Hawai'i. Seasonally, green turtles travel from foraging areas in the main islands to mate and nest at French Frigate Shoals in the Northwestern Hawaiian Islands (Balazs and Ellis 2000). Hawksbills, however, are only rarely found in the Northwestern Hawaiian Islands and then only as stranded or injured, perhaps suggesting pelagic waifs. The Northwestern Hawaiian Islands are now part of a protected marine sanctuary known as the Papahānaumokuākea Marine National Monument, but very few of the hawksbill nesting sites are protected in a similar fashion. Organizations on Maui and the island of Hawai'i have volunteers monitor nesting beaches; this is not done on O'ahu or Moloka'i. However, in Hawai'i, all sea turtles are protected under the Endangered Species Act and under Hawai'i State law. Hawai'i also has a sea turtle public outreach and education system, in which both federal and state officials cooperate to educate the public on proper viewing of sea turtles.

During the decade of this study, nine post-nesting Hawaiian hawksbills were tracked moving to four different Hawaiian Islands. Movement distances for these turtles were relatively short, between 90 and 345 km. These data are comparable with the distances and time spent traveling by post-nesting hawksbills in the Seychelles (Mortimer and Balazs 2000). Hawksbills tracked from Barbados (Horrocks et al. 2001), Puerto Rico

(Hillis-Star et al. 2000, van Dam et al. 2008), Australia (Miller et al. 1998), and the Solomon Islands (Vaughan and Spring 1980) have shown that the species is capable of long-distance movements (>2,000 km), yet Hawaiian hawksbills were not found to make this type of movement. The dive duration data indicate that hawksbills spend more time underwater during nontransit periods (resting, foraging, and interesting) than when they are actively moving between nesting and foraging areas. This behavior is similar to that of green turtles in Hawai'i (Balazs 1994, Balazs and Ellis 2000).

On completion of post-nesting movements to a coastal area in the main Hawaiian Islands, most satellite transmissions continued for 2–6 months, confirming the residency of each turtle at its foraging area. The end of transmissions was believed to have usually been caused by drainage of the transmitter battery over time or from antenna damage or wear sustained while the turtle was resting in areas with coral and rocky overhangs. It is difficult to ascertain the exact cause of transmitter cessation. Manufacturers provide a theoretical estimated operational life for batteries used in the transmitters. However, when a transmitter stops giving data within a few weeks to a month of arriving in a foraging area, it is often thought that this is due to antenna wear. Evidence for this assumption comes from transmitters that have been recovered from green and hawksbill turtles, where antenna wear and missing antennae are apparent (Schroeder and Balazs 2000).

Argos positional data based on the Doppler shift do not have as precise accuracy as GPS transmitters (minimum of 150 m versus 5 m [Yasuda and Arai 2005]). However, the data are accurate enough for general tracking, and higher-accuracy positions (LC 1, 2, and 3) allow a relatively good estimate of the position of the turtle. High-accuracy data were very limited within foraging areas; hence only three of the tracks could be used for home range estimation. Based on the data collected for these three tracks (LC 2 and 3 data), estimates of hawksbill home ranges in Hawai'i were calculated to be 0.5 to 2.0 km² (±1.0 km²). These home ranges were slightly

larger than hawksbill home ranges found in the Caribbean area (<0.5 km² [van Dam and Diez 1998]). Argos data collected in the Hawaiian foraging areas also indicate that post-nesting females use depths of less than 30 m in the nearshore habitat. It is interesting to note that all of the Hawaiian hawksbills satellite tracked in this study established residency on the north-northeast side of the Islands. In contrast, immature hawksbills have been sighted by divers either on the south-southwest sides of the Islands, typically in waters less than 30 m or in very shallow protected areas on the north and northeast sides (Balazs 1978a, Keuper-Bennett and Bennett 2002; pers. obs. of authors). This difference in foraging location may be a mechanism to separate the food and space resources of the juvenile and adult stages of the hawksbill turtle in Hawai'i. These preliminary data may also reflect diver preference for calm ocean conditions and accessible coral reef ecosystems, hence additional research is needed on this topic.

Six of the nine Hawaiian hawksbills migrated to the Hāmākua Coast of the island of Hawai'i. These data indicate that the Hāmākua Coast is important habitat for the hawksbill in the Hawaiian Islands. The foraging area on the Hāmākua Coast spans from Pololū Valley to Pepe'ekeo Point, covering a distance of 112 km (Figure 1), and although each turtle may only use 1 km², appropriate management measures for the whole coast should be considered for the conservation of Hawai'i's hawksbill population.

In conclusion, hawksbills in Hawai'i are a small population and more information is needed to determine their conservation status to aid in recovery. The results of this study suggest that the post-nesting movements of the Hawaiian hawksbill are relatively short-ranged; therefore, management of resources within the State of Hawai'i will be key in the long-term survival of this species. Focused underwater hawksbill surveys and further study of their forage and habitat needs are necessary to address the distribution and abundance of Hawaiian hawksbills. Surveys along the Hāmākua Coast should be conducted to assess the status of the habitat for

conservation and management purposes. Surveys of all the foraging areas should also be conducted to identify similarities and differences to better understand the hawksbill's requirements in the Hawaiian Islands.

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