Analysis of the foraging ecology of hawksbill turtles (*Eretmochelys imbricata*) on Hawai`i Island: an investigation utilizing satellite tracking and stable isotopes

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ABSTRACT

Foraging studies on hawksbill sea turtles (Eretmochelys imbricata) in Hawai'i are limited. Previous tracking investigations have identified the Hāmākua Coast (northeastern shore of Hawai'i Island) as the main foraging habitat of hawksbill adult females; however, there is little information on the prey species from the area, though the species is thought to prefer sponges. Satellite transmitters were attached on post-nesting females (n=3) from Hawai'i Island to ascertain feeding periods and depth, and benthic surveys at one region within the Hāmākua Coast were conducted to determine sponge percent cover. Further, carbon and nitrogen stable isotope analyses were conducted to verify the dominant prey organisms of female turtles foraging around Hawai'i Island. One of the three hawksbill females migrated to the Hāmākua Coast foraging during the daytime at depths up to 30m. Results from a two-source mixing model suggest she fed primarily on sponges. Carbon isotopes of all adult females varied, which may indicate possible differences in prey preferences or habitat type. Differences of carbon isotopes were also indicated among the deceased hatchlings. Carbon and nitrogen isotopes of the few deceased hatchlings compared to known females were similar suggesting deceased hatchlings could be incorporated in future foraging studies, leading to a less invasive monitoring program.

INTRODUCTION

Hawksbill turtles (*Eretmochelys imbricata*) are distinguished from other marine turtles by their slender head, beak-like mouth and thick, overlapping scutes with unique and attractive shades of amber coloration. The carapace became a popular harvested item, which continues to be sold as artifacts or crafted into jewelry, diminishing the slowgrowing hawksbill turtle population (Groombridge & Luxmoore 1989, Meylan 1999). Distributed circumtropically in coastal waters of 100+ countries, the International Union for Conservation of Nature (IUCN) re-registered the global population to critically endangered in 2008 (Mortimer & Donnelly 2008).

Adult hawksbill turtles are migratory animals, traveling between 150 to 2,000 km between nesting and foraging habitats (Hillis-Starr et al. 1999, Parker et al. 2009). Juveniles, after having spent the first few years in pelagic realms, are recruited to neritic zones and prevail in shallow-water, hard bottom reefs, bays, estuaries (Carr et al. 1966) and reef wall habitats (van Dam & Diez 1996). For the remainder of their lives, hawksbill turtles dwell in the same foraging habitat aside only from breeding periods when they migrate to nesting grounds (Witzell 1983). Sponges are reported as the preferred choice of prey for adult hawksbill turtles (Carr & Stancyk 1975, Meylan 1984, 1988, Alvarez 1998) along with opportunistic feeding on other small invertebrates. Bjorndal (1997) suggests hawksbill turtles change favored prey items as they increase in carapace length. Hawksbill turtles from different regions prey on a wide array of marine organisms: bryozoans, cnidarians, chordates, mollusks, sponges and algae (Carr & Stancyk 1975, Valeris et al. 2002), as well as cephalopods, echinoderms, and arthropods (Den Hartog 1980, Stampar et al. 2007). These prey data were gathered essentially from stomach and intestinal contents and also from relatively rare underwater observations of feeding.

Documentation of feeding of Hawaiian hawksbill turtles (known locally as *honu*'ea or 'ea), however, is limited. On Oahu, one deceased hawksbill turtle had three sponge specimens in its stomach and intestines (Balazs 1978). Sightings on Maui were recently recorded of hawksbill turtles feeding on fireworms, urchins, octopus, meandering sponge (Chondrosia sp.), and a few algal species including the invasive Hypnea musciformis (Cheryl King, Hawai'i Wildlife Fund, personal communication). Documentation of this feeding took place primarily in shallower depths but there have been occasional sightings of foraging as deep as 55m. A stranded juvenile was washed up at Laupāhoehoe point, northeastern side of Hawai`i Island; its stomach contents comprised primarily red algae (Stacy Hargrove, NOAA Pacific Islands Fisheries Science Center, Marine Turtle Research Program, personal communication). In 1991, research and monitoring of the nesting activities of Hawaiian hawksbill turtles was initiated; satellite tracking began in 1995 and became a high priority in 1998, when they were undertaken by the National Marine Fisheries Service (NMFS 1998). To date, sea turtle biologists have satellite-tracked nine adult females in Hawai'i (Parker et al. 2009). These migration data suggest Hawaiian hawksbill females nest and forage exclusively within the main Hawaiian Islands. Five of the nine turtles tracked foraged in coastal habitats along the Hāmākua coast between Waimanu and Honomu, and the remaining four migrated to the east shores of Molokai, Oahu, and Maui. On Hawai'i Island, there have been no known documented sightings of feeding activity of Hāmākua Coast foragers.

Location of foraging habitats alone, however, does not provide sufficient information for conservation management of a species. The IUCN Marine Sea Turtle Group suggests the gastric lavage (stomach flushing) technique to assess recent diet to identify prey species (Forbes 1999) but capture of turtles at foraging sites is difficult due to the low density of animals in most regions, especially Hawai'i. Utilization of stable isotopes is an alternative but powerful method that can examine the ecological dietary history of an organism given a small tissue sample. Elements with naturally occurring isotopes have similar properties, different atomic masses, and resistance to decay from radioactivity; therefore, they can be used in scientific studies on predator/prey relationships. After bouts of feeding, biochemical properties of prey are synthesized into the tissues of predators (Hobson 1999) and in feeding studies using stable isotope methodology, one can identify dominant prey of predators with limited feeding preferences. Through the course of metabolic processes, heavy and light isotopes $({}^{13}C/{}^{12}C$ and ${}^{15}N/{}^{14}N)$ of organisms will have specific ratios which show the organisms' carbon and nitrogen isotopic signatures (Peterson & Fry 1987). By comparing these isotopic signatures, expressed as δ (delta) ¹³C and δ ¹⁵N, between predator and prey, feeding relationships can be estimated.

This study (1) identified dominant prey species of one foraging Hāmākua Coast hawksbill female by means of stable isotopes, (2) investigated carbon and nitrogen isotopic proximity of deceased hatchlings and hawksbill turtles that nested on Hawai`i Island, (3) satellite-tracked and ascertained feeding depths and periods of post-nesting females from Hawai`i Island and Maui, and (4) quantified sponge percent cover at one site along the coast where hawksbill turtles are known to feed. Results from this investigation contributed to the baseline database for the foraging of Hawaiian hawksbill adult females, upon which future conservation efforts will be focused.

FIELD METHODS

Satellite tracking

Satellite tracking was conducted to determine hawksbill foraging sites and feeding depth patterns. To accomplish this task, Argos satellite-linked transmitters (model ST-20 A-1025), obtained from Telonics Inc, Mesa, AZ, were outfitted with pressure sensor capabilities. To conserve battery power, each unit was equipped with a salt water switch feature which inhibits transmission during submersion. Six depth layers, or bins, were programmed at 10m increments, with exception of the last depth bin (0-10m, 11-20m, 21-30m, 31-40m, 41-50m, and 51-1000m). Underwater recording periods for each unit were set at either two-12 hour or eight-3 hour periods, in which dive information was accrued (i.e. 0000 to 1200, 1200 to 0000 GMT). Depth data were converted into dive counts within the allotted time period and percentages of time spent within the programmed depth increments with a Telonics Data Converter. If the total percentages of time spent within the first four depth bins (0-40m) were less than 90%, the dataset was removed for a more accurate analysis. Dive information was combined into 8-day blocks to account for missing data between the programmed underwater periods as explained in Eckert (2006). The last 8-day block was analyzed for a biphasic trend between resting and feeding at the foraging habitat.

Three satellite transmitters were attached onto post-nesting females at the primary nesting sites on Hawai`i Island: Kamehame (19°8'41"N, 155°27'57"W) and Pōhue Bay (19°5'32"N, 155°32'24"W) in August 2007 and 2008 (Fig. 1). When gravid hawksbill

females completed their 2nd or 3rd nesting event, a four-sided, padded corral was secured around the turtles to restrain them during transmitter attachment. Attachment of satellite transmitters conformed to procedures explained by Balazs et al (1995). Straight carapace length, width, and tag information from each turtle were recorded.

Benthic surveys

Benthic surveys were conducted to quantify sponge percent cover at one of the feeding sites. Preliminary surveys by Scuba at feeding depths were conducted at Laupāhoehoe (19°59'5"N, 155°14'7"W), Hawai`i Island to delineate methods of benthic surveys (Fig. 1). Geological substrate type, reef structures at different isobaths, and presence/absence of marine invertebrates were documented. Sponge percent cover was subsequently assessed with rapid ecological surveys utilizing a revised survey design as specified in the Hawai`i Coral Reef Assessment and Monitoring Program (CRAMP) (Brown et al. 2004). Within each of three randomly selected sites, two-100m linear transects were positioned parallel to the shoreline at 10m apart (Fig. 2.). On each 100m transect, six-10m sections were assigned. Within each of the latter sections, ten random meter markers were selected from either side for replicate purposes. Utilizing the benthic grid method, a 0.50m² quadrat (constructed with a 1-inch PVC pipe and nylon filaments strung into 4 equal parts) was placed on each of the selected meter markers, then sponge percent cover and substrate types (coral, sandy, rubble) were recorded.

Stable isotopes

Benthic organisms were gathered from the bay at Laupāhoehoe. Targeted invertebrate and marine plant groups included sponges, algae, gastropods, zoanthids, mollusks, bryozoans, ascidians, marine worms, and echinoderms. Less than 2 grams of tissue were removed from each species; if the species was too small to be sampled, the whole organism was used. Additionally, sponge species were opportunistically sampled from three sites along the Hāmākua Coast: offshore of Laupāhoehoe, Kuka`iau, and south of Honoka`a (Fig. 1.)

Epidermal tissue was collected for stable isotope analysis from post-nesting female turtles from Maui and Hawai'i Island, including the turtles with attached satellite transmitters. The skin sampling region, posterior edge of the hind flipper, was deadened with 2% lidocaine hydrochloride and cleaned with betadine. A small piece of tissue was removed with a 6mm biopsy punch and stored in a freezer (-20°C) in the lab for subsequent analysis. In addition to adult tissues, epidermal tissue from hatchling carcasses from nesting seasons 2004 to 2007 on Hawai'i Island were included in the sampling pool. Hatchlings were sorted based on decomposition levels and developmental stages.

LAB METHODS

At the lab, samples were thawed, rinsed in distilled water, and desiccated at 60° C for 48 hours in individual evaporating dishes. Tissues were then dried to mass and granulated to fine powder with a mortar and pestle or cut into fine particles with a thin lab scissor. Dependent on the tissue type, a range of 1.0 to 5.0 mg of homogenous tissues were transferred into individual 5 x 9 mm pressed tin capsules. At the UH Hilo Analytical Laboratory, samples were run initially through the Costech Elemental Analyzer, which separated the carbon dioxide (CO₂) and Nitrogen (N₂) by combustion. Ratios of heavy and light isotopes (¹³C /¹²C and ¹⁵N /¹⁴N), respectively, were tested against the ratios of referenced samples (Vienna Pee Dee Belemnite carbonate for C and

atmospheric air for N) in the Thermo-Finnegan Delta V Advantage Mass Spectrometer with a Conflo III interface with this formula: parts per thousand (‰)=[(R_{sample} - $R_{reference}$)/ $R_{reference}$] x 1000. Precision of measurement against referenced samples was ±0.1‰ and 95% for accuracy based on standards from the National Institute of Standards and Technology.

Analyses

All data were analyzed with statistical software, Minitab 15. Subsequent to meeting assumptions of normality, t-tests were used to determine differences of dive count and percentages spent within the programmed depth bins in the allotted time periods for each post-nesting female. Additionally, t-tests were used to test variations of sponge percent cover by substrate type. Delta (δ)¹³C and δ ¹⁵N values of hawksbill turtle tissues were investigated relative to isotope values of potential prey species. Identification of turtle prey items were deduced based on the isotope values being more depleted (negative) than the predator tissues; typically, predators are more enriched (positive) than their prev species by 1‰ for δ^{13} C and 3 to 5‰ for δ^{15} N (DeNiro & Epstein 1978, 1981, Peterson & Fry 1987). One-way ANOVAs were utilized to differentiate δ^{13} C & δ^{15} N among and between potential prev species. Furthermore, source partitioning of hawksbill turtle tissues to specify carbon source contribution were assessed with a two-source mixing model revised from Fredriksen (2003). Lastly, hatchling decomposition levels and developmental stages were differentiated with a oneway ANOVA to specify groups of hatchlings before further analysis on similarity of δ^{13} C & δ^{15} N to post-nesting females.

Satellite tracking

Foraging sites of three satellite-tracked post-nesting hawksbill turtles in August 2007 and 2008 are listed in Table 1. Hawksbill turtle #07a nested at Pohue Bay on August 8th, 2007 and migrated to Peleuli Point (19°54'39"N, 155°7'44"W) in less than 33 days (Fig. 3a.). Battery life ended after 55 days with 31 days of successful transmissions; however, there were not enough accurate location points to determine approximate travel length. At the foraging site during the time period of 0200 to 1400 (HST), she spent the following percentages of time within the associated depth bins: 74.4% (±18.4), 0-10m; 11.2% (±11.4), 11-20m; 5.5% (±6.8), 21-30m; and 4.7% (±8.4), 31-40m. During the second half of the 24 hour period (1400-0200), she spent more time in shallower waters: 0-10m (93.9% \pm 3.5), and <2% in 11-30m; however, the difference of time spent in shallower waters (0-10m) between the two 12-hour periods was not significant (T = 1.73: p = 0.122). Dive counts during 0200-1400 at foraging totaled to 29.1 (±8.8) dives, giving her an average of 2.4 dives per hour. Between 1400-0200, she dove 18.1 (±8.3) times, which averaged to 1.5 dives per hour. This is 62% less in the dive counts than the early period; and there is significant difference (T = -2.57: p = 0.023).

Hawksbill turtle #07b nested at Kamehame on August 2nd, 2007, then traveled in a clock-wise direction around Hawai`i Island and swam along the windward sides of all the main Hawaiian Islands in 20 days (Fig. 3b.). By mid-October, she turned and was heading southwest towards Johnston Atoll. South of Johnston Atoll, in early December, she turned west. Based on her last location (14°43'55"N, 175°6'18"W) on January 24th, 2008, she was still heading west. Dive data continued to be transmitted until April 21st totaling to 102 days of transmission. She traveled over 3,350 km at an average of 1.17 km/hr; however, her final destination was uncertain. During the last 8-day block, she spent 96.6% (\pm 2.7) of the time in shallower depths (0-10m), <1.0% in 11-20m, and <0.20% in depths between 21 to 40m. There was no biphasic trend during this time between 0-10m in all eight 3-hour periods. Dive counts recorded within the 3-hour periods were not significant (ANOVA: p = 0.881).

Hawksbill turtle #08a nested at Kamehame on August 25th, 2008 and traveled 335 km at a rate of 0.94 km/hr to Kihei, west Maui (20°44'6"N, 156°27'43"W) in 15 days (Fig. 3c.). She had a total of 52 days of transmission. The pressure gauge corrupted, so dive percentages and counts were not available.

Benthic surveys

One of the three survey sites at Laupāhoehoe was excluded from the dataset due to data collection inconsistency from rough wave conditions and low visibility. In depths between 7.5m to 11m, sponges accounted for 0.47% of the benthic cover within the 24 survey sections. Vermilion clathria (*Clathria* sp.) and vagabond boring (*Spirastrella cf. vegabunda*) sponges were intermittently observed in sandy and rubble substrate areas with a percent cover of 0.28%, whereas sponge percent cover of 0.93%, with higher diversity was found in coral reef communities. Sponge percent cover was statistically different between reef and rubble substrate types (T = 2.4, p = 0.042).

Stable isotopes

Delta ¹³C and δ^{15} N isotope values of hawksbill turtles are included in Table 1. The fourth hawksbill turtle (#08b) nested on Maui but a satellite transmitter was not attached due to prior knowledge of her foraging area. This turtle had higher enrichment in δ^{13} C (-14.3‰); whereas hawksbill turtle #08a had depleted values (-16.8‰); with a difference of 2.5‰ (Fig. 4.). Conversely, δ^{13} C of hawksbill turtle #07a and #07b were similar (a slight difference of 0.2‰) as well as δ^{15} N of all four hawksbill turtles with a difference of 0.6‰.

The potential prey species available at Laupāhoehoe with their corresponding δ^{13} C and δ^{15} N values are listed in Table 2. Brittle stars (*Ophiocoma* sp.), blue-gray zoanthids (Palythoa caesia), collector urchins (Tripneustes gratilla), and one green algae species (*Halimedia opuntia*) were more depleted in δ^{15} N but constituted higher enrichment in δ^{13} C than the hawksbill turtle adult tissues. The δ^{13} C and δ^{15} N values of the remaining potential prey organisms (lined fireworms (*Pherecardia* sp.), mussels (Isognomon sp.), sea cucumbers (Holothuria sp.), red algae (Amansia glomerata), one green algae (*Caulerpa taxifolia*), meandering sponge (*Chondrosia* sp.), vagabond boring sponge (Spirastrella cf. vegabunda), and one unknown sponge species) were more depleted than the predator tissues (Fig. 4.). Differences between the above potential prey species in both δ^{13} C and δ^{15} N compositions were statistically significant (ANOVA: both p < 0.001). All three sponge species, predominant in deeper waters (6 – 10m), were slightly more depleted in δ^{13} C compared to fireworms, mussels, sea cucumbers, and C. *taxifolia*. The one unknown sponge species collected from different sites along the Hāmākua Coast by NOAA divers; hence, the unknown identification, did not significantly vary in both δ^{13} C and δ^{15} N values (ANOVA: p = 0.960, p = 0.970, respectively) and constituted a depletion of δ^{13} C compared to the other two sponges found inshore Laupāhoehoe.

A combination of the following prey sources for the two-source mixing model, fireworms (8.9% ±2.0), mussels (8.8% ±2.0), sea cucumbers (13.4% ±2.8), *C. taxifolia* (7.6% ±1.7), and *A. glomerata* (16.7% ±3.4) had lower levels of carbon contribution to hawksbill turtle #07a than the sponges. The three sponge species constituted a high percentage of carbon contribution (meandering sponge: 85.7% (±12.5); unknown sponge: 81.5% (±14.7); and vagabond boring sponge: 43.2% (±6.0)). Brittle stars, zoanthids, collector urchins, and *H. opuntia* were not included in the two-source mixing model based on the enrichment of δ^{13} C and δ^{15} N compared to the predator tissues.

Deceased hatchling samples did not show significant variation due to decomposition levels or developmental stages for both δ^{13} C (ANOVA: p = 0.110) and δ^{15} N (ANOVA: p = 0.970). Delta ¹⁵ N values of hatchlings were slightly more enriched than the adult hawksbill females (Fig. 5a.). Three hatchlings (including one partially developed hatchling) from one adult turtle that nested at Halapē in 2007 and two hatchling from a Kamehame nester in 2007 constituted a 5.5‰ enrichment in δ^{15} N (\overline{X} =14.8‰) than all four adult females. Three hatchlings from Kamehame in 2004 and 2005, from two different hawksbill turtles with unknown foraging habitats, were more depleted in δ^{13} C (\overline{X} =-17.5‰). Two hatchlings from hawksbill turtle #07a constituted average values of -15.8‰ (δ^{13} C) and 10.1‰ (δ^{15} N), a difference of 0.2‰ and enrichment of 0.9‰, respectively (Fig. 5b.). One hatchling from hawksbill turtle #07b had isotopic values of -16.1‰ for δ^{13} C and 9.8‰ for δ^{15} N, a difference of 0.3‰ and 0.8‰, respectively.

DISCUSSION

Dive patterns of hawksbill turtle #07a at the foraging site (Peleuli Point) indicate a biphasic trend, suggesting differences in feeding and resting activities. The patterns of activity can be demonstrated by a combination of data on percentages spent in different depth bins, dive count, and location of the foraging grounds. The increased number of dives in conjunction with percentages of time spent as deep as 30m differentiates foraging from resting. In this case, foraging activity appears to occur up to 30m from early morning to early afternoon periods. During the later period, dive count is low and percentage spent within 0-10m depth is relatively higher than the earlier period suggesting resting activity in shallower depths.

On Maui where feeding activities took place primarily in shallower waters, there has been documentation of hawksbill turtles foraging as deep as 55m (Cheryl King, Hawai'i Wildlife Fund, personal communication). Observations of resting depths and periods, however, were not reported. Some reports are available indicating hawksbill turtles foraging depths in other areas of the world. There were foraging dives between 25 to 40m noted from the hawksbill turtle population in the West Indies (Horrocks et al. 2001). In Puerto Rico, foraging grounds of adult hawksbill turtles occur between 25 to 31m (Vicente & Carballeria 1991) and juvenile hawksbill turtles from 5 to 15m (van Dam & Diez 1997). In other Caribbean sites, juvenile hawksbill turtles were observed to feed at less than 5m depth along a reef wall (van Dam & Diez 1996). Where a biphasic trend was indicated from this study, resting period also took place in shallower depths (<6.8m).

Sponges at Laupāhoehoe, a fringing reef with some steep wall communities, reside generally in coral reef communities. At depths up to 11m, meandering sponge, vermilion clathria, gray cacospongia (*Cacospongia* sp.) and vagabond boring sponges were frequently observed within the bay. From the end of the pier down alongside the coast, outside of the bay, coral reef communities housed a diversity of marine invertebrates including, but not limited to, sponges, zoanthids, fireworms, urchins, shrimp, and brittle stars. The dominant substrate type nearshore at Laupāhoehoe, however, is comprised mainly of rubble and coarse basalt sandy substrates. Four algal species (*Amansia glomerata, Halimedia opuntia, Lobophora variegata*, and *Caulerpa taxifolia*) were frequently observed on sandy bottoms with patches of basalt boulder. In addition, hermit crabs, juvenile and adult sea cucumbers, mussels, and bivalves were among the few invertebrates observed in shallower waters (<2m); whereas, encrusting sponges, a few species of algae, and organic and inorganic debris prevailed in deeper waters (2-10m).

Substrate types and marine invertebrate and algae species in Laupāhoehoe appear to be similar to sites offshore Laupāhoehoe, Kuka`iau, and south of Honoka`a. Survey results, in depths between 9 and 17m, were reported as basalt sand and boulders as principal substrate type with high variations of reef structure and coral diversity in patches of reef communities (NOAA CRED 2006 unpublished data). From each of the survey sites, algal communities, predominantly turf and crustose coralline, differed by no more than 6 species, including *Amansia glomerata* and *Caulerpa taxifolia*. Additionally, an unknown green sponge species was most prevalent of all the invertebrate species.

The differences of δ^{13} C among the four adult hawksbill turtles in Hawai'i may indicate habitat type or inter-island prey differences. In marine ecosystems, carbon isotopes of organisms typically vary dependent upon marine habitat type (Hobson et al. 1994). For example, δ^{13} C is more enriched in tidal habitats than in pelagic regions. Thus, nearshore foraging herbivores, such as green turtles, have higher enrichment in δ^{13} C than their pelagic counterparts (Burton & Koch 1999). Dominant prey species may vary dependent upon many factors (abundance, depth, proximity to nesting habitat, and foraging location). Of the available potential prey species at Laupāhoehoe during the survey period, meandering and one unknown sponge species had high levels of carbon contribution to hawksbill turtle #07a. Even though she forages south of Laupāhoehoe, the unknown sponge species collected from all three sites along the Hāmākua Coast were not different in both δ^{13} C and δ^{15} N values. This suggests her primary diet is sponges; however, this preferred prey species of one adult female may not apply to other females that forage at other sites. Hawksbill adults and juvenile turtles from Maui were seen feeding on a variety of marine invertebrates and algae, including the meandering sponge (Cheryl King, Hawai'i Wildlife Fund, personal communication). Where meandering sponges were present at Laupāhoehoe, Hypnea musciformis was not and fireworms were relatively infrequent in coral reef habitats.

Hawksbill turtles are typically spongivores; the preferred sponges within the Caribbean region are from Class Demospongiae (Carr & Stancyk 1975, Meylan 1988, Vicente & Carballeria 1991, Alvarez 1998). Other marine invertebrates and algae contribute to hawksbill turtle diet as well. Hawksbill turtles fed on sea cucumbers (*Holothuria cubana*) in Puerto Rico (Vicente & Carballeria 1991), sea anemone, squid, sea urchin, spider crab, and algae in the Canary Islands (Den Hartog 1980), and primarily zoanthids in Brazil and U.S. Virgin Islands (Mayor et al. 1997, Pemberton et al. 2000, Stampar et al. 2007). The prey preferences in Brazil and U.S. Virgin Islands are different perhaps because sponges are not abundant, hence, the increased feeding on zoanthids. Additionally, a larger diversity of sponges reside in the Caribbean, however, the sponges preyed upon by the hawksbill turtles are limited to a few species (i.e. *Chondrilla* sp., *Chondrosia* sp., *Thethya* sp., and *Geodia* sp.) (Leon & Bjorndal 2002).

Deceased hatchlings, from 19 adult females with unknown and 2 with known foraging sites, had diverse δ^{13} C values which would support the possible differences of food preferences or habitat type of the female nesters. The δ^{15} N values of hatchlings were slightly higher than all four adult hawksbill turtles. Five of the hatchlings from two adult females had an unusually high nitrogen values. The latter turtles may have been larger in size. Nitrogen stable isotopes typically signify the position of the trophic level (McCutchan et al. 2003, Vanderklift & Ponsard 2003) and enrichment is explained by size differences of predators (Godley et al. 1998). Isotopic values of eggs reflect the female's biochemical properties (Hobson 1995). No difference in nitrogen values were found in sea turtle hatchlings from Moreton Bay, Australia (Arther et al. 2008). In Japan where hawksbill turtles are not extremely rare, hawksbill turtle eggs were retrieved within 24 hours of oviposition and scientists found similarities of isotopic values between adult hawksbill turtles and hatchlings (Hatase et al. 2002). Additionally, stable carbon and nitrogen isotopes of hatchlings did not vary compared to embryos (Godley et al. 1998). The similarities based on the previous tissues suggest that deceased hatchlings may be incorporated for ecological isotope studies.

Conclusion and Recommended Studies

Migration of Hawaiian hawksbill turtles is primarily within the main Hawaiian Islands, with exception of Hawksbill turtle #07b, where she was last located southwest of Johnston Atoll. Of the post-nesting females tracked in Hawai'i, half traveled to the Hāmākua Coast and the others migrated to the three other main Hawaiian Islands. Evidently, the Hāmākua Coast is an essential foraging site for the Hawaiian hawksbill turtle adult females. Feeding depth of one Hāmākua Coast forager occurs between 0 to 30m, predominantly <10m. A biphasic trend between foraging and resting was apparent; foraging occurred from early morning to early afternoon and resting in the evenings within 0-10m. Sponge percent cover was higher in coral reef habitats at Laupāhoehoe, although it appears that the primary substrate type is sandy, rubble bottoms. Meandering sponge from Laupāhoehoe and one unknown sponge species from three different sites along the coast were the predominant prey for hawksbill turtle #07a. The collective observations from Maui and stable isotope analysis of adult hawksbill turtles suggest possible inter-island prey variability. Stable carbon and nitrogen isotopes of deceased hatchlings from two adult hawksbill females were similar to the adult turtles suggesting a need for more of these comparative studies. Good correlation of isotope values of adults with deceased hatchlings could lead to a non-invasive prey preference monitoring program.

Hawaiian hawksbill turtles are extremely rare. Monitoring projects in Hawai'i have collected data on nesting females since 1991. Conservation efforts have included beach patrols to identify nesting sites, public outreach, and monitoring of nests to reduce human traffic and predators. There has been increased deployment of flipper and PIT (passive integrated transponder) tags to identify migration routes and foraging grounds. Knowledge and understanding of hawksbill sea turtle life history, behavior, and habitats is crucial to protecting the viability of this critically endangered species. Further investigation of the Hawaiian hawksbill turtle feeding activities and prey preferences at different foraging habitats and continuation to comparing deceased hatchlings to adults with known foraging sites will contribute to the long-term conservation management of the rare Hawaiian species.

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TABLES

Table 1. Carapace measurements, for aging habitats, and $\delta^{13}C$ and $\delta^{15}N$ of individual adult females

| rtle SCL (cm) Foraging site | | $\bar{X}\delta^{13}C$ | $\bar{X}\delta^{15}N$ | |
|-----------------------------|--|--|--|--|
| 84.0 | Peleuli Pt, HI | -16.022 | 8.995 | |
| 86.8 | Unknown | -15.381 | 9.017 | |
| 84.5 | Kihei, Maui | -16.795 | 8.493 | |
| 88.0 | Malaekahana, Oahu | -14.323 | 9.136 | |
| | SCL (cm) 84.0 86.8 84.5 88.0 | SCL (cm)Foraging site84.0Peleuli Pt, HI86.8Unknown84.5Kihei, Maui88.0Malaekahana, Oahu | SCL (cm)Foraging site $\overline{X} \delta^{13}$ C84.0Peleuli Pt, HI-16.02286.8Unknown-15.38184.5Kihei, Maui-16.79588.0Malaekahana, Oahu-14.323 | |

Table 2. Delta $\delta^{13}C$ and $\delta^{15}N$ values of potential prey species

| Organism | $\overline{X} \; \delta^{13}C \; \pm SD$ | Range | ${\overline X} \delta^{15} N \pm SD$ | Range |
|---|--|----------------|--|------------|
| Amansia glomerata (n=3) | -17.3 ±1.0 | -18.5 to -16.7 | 2.2 ± 0.2 | 2.0 to 2.4 |
| Caulerpa taxifolia (n=2) | -16.2 ± 0.5 | -16.6 to -15.8 | 2.4 ± 0.3 | 3.2 to 2.7 |
| Halimedia opuntia (n=5) | -4.0 ± 1.4 | -5.7 to -2.5 | 2.3 ± 0.2 | 2.1 to 2.6 |
| <i>Ophiocoma</i> sp. (n=10) | -5.9 ± 1.3 | -8.4 to -4.4 | 5.3 ± 0.5 | 4.7 to 6.4 |
| Holothuria sp. (n=2) | -17.1 ±1.3 | -16.2 to -18.0 | 6.4 ± 0.6 | 5.9 to 6.8 |
| <i>Pherecardia</i> sp. (n=5) | -16.5 ± 1.0 | -17.7 to -15.2 | 4.8 ± 1.0 | 3.7 to 6.2 |
| Isognomon sp. (n=4) | -16.5 ± 0.7 | -17.2 to -15.7 | 3.9 ± 0.8 | 3.2 to 5.0 |
| Tripneustes gratilla (n=6) | -5.1 ± 1.4 | -7.0 to -3.9 | 4.2 ± 0.5 | 3.6 to 4.9 |
| Palythoa caesia (n=12) | -6.6 ± 1.4 | -9.0 to -4.7 | 4.2 ± 0.6 | 3.4 to 5.1 |
| <i>Spirastrella cf. vegabunda</i> (n=4) | -18.0 ± 0.2 | -18.1 to -17.6 | 4.8 ± 0.3 | 4.5 to 5.2 |
| <i>Tetrapocillon</i> sp. (n=5) | -18.2 ± 0.5 | -18.8 to -17.6 | 3.8 ± 0.4 | 3.0 to 4.1 |
| One unknown sponge (n=21) | -18.4 ± 0.6 | -19.2 to -17.2 | 3.2 ± 0.9 | 1.2 to 4.5 |



Fig. 1. Study sites (▲=surveys and prey collection at Laupāhoehoe, ★=sponge collection from offshore Laupāhoehoe, Kuka`iau, and south of Honoka`a, ⊙=nesting at Pōhue Bay and Kamehame)



Fig. 2. Survey design at Laupāhoehoe





Fig. 3a, b, c. Migration of hawksbill turtles #07a, #07b, and #08a (3a. hawksbill turtle #07a nested at Pōhue Bay and migrated to Peleuli Point, 3b. hawksbill turtle #07b migrated from Kamehame to 645 km southwest of Johnston Atoll, 3c. hawksbill turtle #08a traveled from Kamehame to Kihei, Maui)



Fig. 4. Delta ¹³C and δ^{15} N mean values of potential prey species and adult hawksbill turtles (\blacksquare =adult hawksbill turtle, \blacksquare =sea cucumbers, \blacktriangle =vagabond boring sponges, \triangle =meandering sponge, \blacktriangle =one unknown sponge species, $\bigcirc=C$. *taxifolia*, \bullet =mussels, \bullet =fireworms)



Fig. 5a, b. Delta ¹³C and δ^{15} N mean values of adults from different foraging sites and deceased hatchlings from Hawai'i Island (==adult hawksbill turtle, •=hatchlings from 21 adult females)

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