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Diet and habitat use of juvenile hawksbill turtles (*Eretmochelys imbricata*) in the Gulf of California, Mexico

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UNIVERSITY OF CALIFORNIA SAN DIEGO

Diet and habitat use of juvenile hawksbill turtles (*Eretmochelys imbricata*) in the Gulf of
California, Mexico

A thesis submitted in partial satisfaction of the requirements for the degree Master of Science

in

Biology

by

Kara Reynolds

Committee in charge:

Professor Carolyn Kurle, Chair

Professor Andrew Barton

Professor Sara Jackrel

2021

The thesis of Kara Reynolds is approved, and is acceptable in quality and form for publication on microfilm and electronically.

University of California San Diego

2021

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This thesis is coauthored with Kurle, Carolyn M.; Croll, Donald A.; and Martinez-Estevez, Lourdes and is currently being prepared for submission for publication of the material. The thesis author was the primary investigator and author of this paper.

ABSTRACT OF THE THESIS

Diet and habitat use of juvenile hawksbill turtles (*Eretmochelys imbricata*) in the Gulf of California, Mexico

by

Kara Reynolds

Master of Science in Biology

University of California San Diego, 2021

Professor Carolyn Kurle, Chair

The hawksbill sea turtle (*Eretmochelys imbricata*) is an endangered species thought to spend their juvenile years in protected, nearshore areas before returning to their natal beaches to breed. We caught, measured, and sampled tissues from hawksbill turtles (n=56) and their potential prey for stable isotope analysis in a foraging ground around Isla San Jose, Gulf of California, Mexico to determine the age and foraging habits of turtles using this location. The

morphometric data indicate that 96.4 % of individuals measured were juveniles. . A Bayesian mixing model analysis of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values indicated hawksbills are consuming a primarily invertebrate-based diet supplemented by plant matter composed largely of seagrass, algae, and some mangrove material. The $\delta^{13}\text{C}$ values from posterior scute samples increased with age, suggesting a potential location shift as younger turtles move from a more pelagic coastal habitat to the nearshore foraging area at Isla San Jose.

INTRODUCTION

Hawksbill sea turtles (*Eretmochelys imbricata*) are listed as critically endangered on the IUCN red list of threatened species, with the primary threats to their survival being the international shell trade, the destruction of nesting and foraging areas, and the illegal harvest of individuals and eggs for consumption (Meylan et al. 1999). Hawksbills have an estimated 35–45-year generation time and reach sexual maturity at ~10-40 years of age (Chacón 2009), leaving them vulnerable to multiple natural and anthropogenic risks for many years before reproduction. Hawksbills can be found in the Atlantic, Indian, and Pacific oceans (U.S. Dept. of Commerce, NOAA et al. 2013), but little is known of Eastern Pacific hawksbills, including their developmental biogeography, movement patterns, and foraging, especially during their early life and development (Van Houtan et al. 2016a).

Soon after hatching, Pacific hawksbills spend an unknown amount of time potentially occupying a number of habitats, from the coastal pelagic to shallow reefs, with little evidence for the oceanic phase observed in nearly all other sea turtle species (Van Houtan et al. 2016a). As hawksbills mature into their juvenile stage, they occupy benthic, nearshore habitats (Carrión-Cortez et al. 2013) and juvenile Eastern Pacific hawksbills are strongly associated with mangrove and estuarine habitats for foraging and nesting (Gaos et al. 2012, Martinez-Estevez et al. 2021). In addition, hawksbills in the Gulf of California appear to occupy relatively small home ranges throughout their juvenile years (Martinez-Estevez et al. 2021), with their nesting habitats likely located close to their foraging grounds (Gaos et al. 2017). Mangrove ecosystems are also important nearshore nursery habitats for coastal and pelagic fish species, providing relatively protected and productive areas for developing juveniles (Miththapala 2008), including fish species that are commercially important for small-scale fishing communities. This overlap in

association for turtles and fisheries raises potential challenges for hawksbills conservation (Aburto-Oropeza et al. 2008).

In the Atlantic Ocean, hawksbills are primarily spongivores (Lutz et al. 1996). However, multiple studies based upon stomach analysis indicate hawksbills in the Pacific Ocean are more omnivorous, consuming large quantities of vegetation and algae in addition to invertebrates (Lutz et al. 1996, Hornell 1927, Carr 1952). More recent research suggests their dietary makeup may be similar to that of their Atlantic relatives, with documentation of notable quantities of sponges in the digestive tracts of individual turtles from the Seychelles, Hawaii, Comores, and Oman (Lutz et al. 1996, Frazier et al. 1984, Meylan 1984). In addition, younger juvenile hawksbills may transition from an omnivorous diet to a more selective spongivorous diet (Carrión-Cortez et al. 2013) as they get older (Lutz et al. 1996).

Stable isotope analysis (SIA) can be used to examine dietary composition and habitat use in animals (Fry 2006), and is especially useful for cryptic, highly migratory, or otherwise difficult to assess species (Hobson et al. 2019), including sea turtles (Heatherington 2018, Seminoff et al. 2012, Turner Tomaszewicz et al. 2015). The ratios of heavy to light stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopes (reported in parts per thousand or ‰) are measured in consumer tissues as well as their potential prey to estimate the proportional composition of prey types in a consumer's diet as well as the habitat within which the prey were consumed (Ben-David et al. 2012, Fry 2006). SIA is especially useful for elucidating diet and movement patterns of marine vertebrates utilizing multiple habitats over their lifetimes (Hobson et al. 1994, Turner Tomaszewicz et al. 2017). The $\delta^{13}\text{C}$ values are useful for determining diet and can indicate changes in habitat use related to regional differences in productivity, distance from shore, as well as other features (Ramos et al. 2012). Stable nitrogen isotope values can also be

used to assess animal habitat use (e.g., Turner Tomaszewicz et al. 2017) but are most commonly used to estimate animal trophic position and contribution of potential diet items to a consumer (Newsome et al. 2010, Hobson et al. 1994).

The time required for incorporation of stable isotopes from diet sources to consumer tissues varies with tissue type (Kurle 2009). Therefore, animal diets can be reconstructed for multiple time scales using stable isotope values measured across various tissues (Kurle 2009) as well as within tissues that are continuously growing (e.g., sea turtle scutes) (Reich et al. 2008). This can be especially useful for reconstructing dietary information for cryptic species that are only available for sampling during certain life-history stages, such as sea turtles that come ashore to breed, occupy nearshore ecosystems during their juvenile years, or wash ashore after death. SIA has been used as a means of tracking marine predators (Ramos et al. 2012) and as a method to examine dietary makeup for a number of sea turtle species including green (Lemons et al. 2011), loggerhead (Seminoff et al. 2012, Vander Zanden et al. 2014, Turner Tomaszewicz et al. 2017), and other populations of hawksbills (Méndez-Salgado et al. 2020).

In this study we examined the foraging habits of juvenile hawksbill sea turtles in a presumed foraging area off Isla San Jose in the southern Gulf of California (hereafter referred to as the San Jose foraging ground; Figure 1). Specifically, we used hawksbill morphometric data and the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from hawksbill shell and skin samples in combination with the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of their potential diet items to: (1) estimate the average life stage of hawksbill turtles utilizing the San Jose foraging ground, (2) examine potential differences in hawksbill diet for individuals captured in sandy embayment, rocky reef, and mangrove habitats within the foraging ground, and (3) determine if these turtles undergo temporal shifts in diet and/or habitat

use that could reflect an ontogenetic shift from the coastal pelagic to nearshore habitats with age or movement in and out of the San Jose foraging ground throughout their juvenile years.

MATERIALS AND METHODS

Study Site

The San Jose foraging ground is located at the southern end of Isla San Jose in the southern Gulf of California, 5.7 km offshore of the Baja California Sur Peninsula. The foraging ground contains three main habitats: 1. A sandy reef embayment, 2. A mangrove estuary with a main channel, several channels branching into mangrove forest, and a lagoon containing seagrass beds, and 3. A rocky reef outside the borders of the mangrove estuary (Figure 1). The lagoon is largely shallow with a slope down to a deeper section and is separated by a sandbar from open water. The mangrove estuary is protected from fishing by the establishment of a no-take marine protected area in 2012 under a collaboration between the National Commission of Fisheries (CONAPESCA), local fisheries, and a local non-profit organization (Sociedad de Historia Natural Niparaja A.C.).

Sample Collection

Between 2014 and 2019, hawksbill sea turtles (n=56) were captured using three methods: i) a live-entanglement net specifically designed for sea turtles (118-m long, 5-m deep, and 25-cm stretch monofilament mesh size) that was checked at regular intervals (ca. every 30 minutes), ii) strike netting where the entanglement net was deployed from a small skiff to surround and capture an individual, and iii) hand capture by free diving. Each captured turtle was measured for straight carapace length (SCL), curved carapace length (CCL), straight carapace width (SCW),

curved carapace width (CCW), body depth, plastron length, total tail length, and body weight (Eckert et al. 1999). We collected samples from the skin of the posterior flipper using surgical scissors (n = 55) and the anterior and posterior portions of the center anterior scute by scraping the scute with a surgical knife (n = 48, 51) (Figure 2). We stored samples in vials at room temperature until processed for stable isotope analysis.

We collected samples of potential dietary items in June 2017 and 2019. In 2017, we collected 1-3 samples each of 25 separate species (n = 83), whereas in 2019 we collected 9-10 samples each of 23 separate species (n = 236) (Supplemental Table 1). We washed samples in clean seawater and dried them at ~150°F in a foil-lined cooler until dry. Dried samples were stored in airtight zippered bags with desiccant until prepared for stable isotope analysis.

SIA Processing

We prepared all samples for stable isotope analysis at UC San Diego by washing each in DI water, lyophilizing for ≥ 24 hr, homogenizing by hand, and packing subsamples of 0.001g (\pm 0.0005g) in 5 x 9mm tin capsules. All samples were analyzed for their $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values using a Carlo Erba CE1108 elemental analyzer interfaced via a CONFLO III device to a Thermo-Electron Delta Plus XP mass spectrometer at the Stable Isotope Laboratory, University of California, Santa Cruz. We determined average precision for these data using the standard deviations around the means for a subset of internal laboratory standards run at set intervals throughout analysis and these were 0.04‰ for $\delta^{13}\text{C}$ and 0.14‰ for $\delta^{15}\text{N}$.

Stable Isotope Model

We estimated the proportional contribution of potential prey items to the diets of the turtles using the Bayesian stable isotope mixing model MixSIAR (R v3.6.3). The posterior distributions from the model provide an estimate, with associated uncertainty, for the contributions of each source category to the diets of the hawksbill turtles (Phillips 2012). We condensed the stable isotope values from prey samples into four source categories: invertebrates (tunicates and sponges), algae (*Caulerpa* spp., *Dictyota* spp., *Halimeda* spp., *Padina* spp.), seagrass (*Halophila* spp.), and mangrove (*Rhizophora mangle*) leaf and root (Table 3). We then used MixSIAR to estimate the proportional contribution of each prey category to the diets of hawksbills using the mean (\pm SD) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from the four source categories and hawksbill skin tissue, and trophic discrimination factors specific to sea turtles (skin $\Delta^{13}\text{C} = 1.1\text{‰} \pm 0.2$ and $\Delta^{15}\text{N} = 1.6\text{‰} \pm 0.1$) (Reich et al. 2008).

SIA Analysis: Spatial and Temporal Changes in Diet

To determine if the stable isotope values varied among turtles captured from the three habitats (sandy reef, mangrove estuary, and rocky reef) within the San Jose foraging ground, we used single-factor analysis of variance (ANOVA) tests with the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of skin from turtles sampled within each microhabitat.

To determine whether juvenile hawksbills in the San Jose foraging ground exhibited temporal shifts in diet and/or habitat use with age, we compared the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from the posterior scute with the age/size of the turtles (SCL) using simple linear regression models. Scutes grow from front (anterior) to back (posterior), so we used the isotope values from the posterior portion of the scute because they reflect the oldest recorded dietary data, increasing the

likelihood we would observe isotopic signatures that reflect a potential transition from the turtles' earliest years in unknown habitat to their juvenile years in the nearshore San Jose foraging ground. Finally, to further understand potential diet and habitat changes over time, we used paired t-tests to compare the stable isotope values from posterior scutes collected from five turtles captured in 2016 (n = 3) and 2017 (n = 2) with those from their anterior scutes sampled when the same turtles were recaptured in 2019.

RESULTS

Population Morphometrics

We captured and processed 51 individuals, with 5 recaptured individuals (n = 56 total), from the sandy reef (n = 17), mangrove estuary (n = 35), and rocky reef (n = 4) habitats. Turtles were 33.8 to 82.6 cm SCL (mean = $48.2 \pm \text{SD } 9.6$ cm). Most of the turtles (54 of 56, 96.4%) fit within the size range estimates for juveniles, leaving only two within the average recorded size range for adult females (76.6 cm and 82.6 cm) (Palaniappan 2007). We removed these adults and recalculated the mean SCL for the juvenile population (n = 54) as 47.1 ± 7.6 cm (range 33.8 to 63.3 cm). The mean (\pm SD) weight of the overall population (n = 56) was 14.9 ± 7.6 kg (range 4.5 to 68.0 kg). The two adult outliers (52.5 and 68.0 kg) were removed, and the mean weight of the juvenile population (n = 54) was 13.2 ± 6.3 kg (range 4.5 to 30.3 kg) (Supplemental Table 2).

Stable Isotope Analyses

The $\delta^{13}\text{C}$ (-13.9‰, -13.9‰) and $\delta^{15}\text{N}$ (13.9‰, 13.8‰) values from skin from the two adults fell within the range of those from juveniles (-17.3‰ to -13.5‰ and 8.2‰ to 15.6‰, respectively) and the results from MixSIAR using only the stable isotope values from skin

collected from the juveniles (excluding the two adults) were not different from the results when the adults were included. Thus, we included the isotope values of skin from turtles of all sizes in our MixSIAR models to estimate overall diet for hawksbills in the San Jose foraging ground.

The mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the four prey types (algae, invertebrates, mangrove, seagrass) ranged from -27.3‰ to -9.5‰ and 6.7‰ to 10.8‰, respectively (Table 1) and these values (\pm SD) were used to estimate their potential contribution to the hawksbill diets. The posterior distributions of stable isotope values from hawksbill skin ($n = 55$) indicate the single highest diet item consumed by hawksbills was invertebrates (mean 64.4%), with the remaining diet composed of vegetation (seagrass mean 21.6%, algae mean 10.6%, and mangrove mean 3.4%; Table 2, Figure 3).

SIA Analysis: Spatial and Temporal Changes in Diet

The stable carbon and nitrogen isotope values from skin from the sea turtles captured across the three habitats were the same (skin ANOVA, $\delta^{13}\text{C}$ $F_{2,52} = 0.03$, $p = 0.97$, $\delta^{15}\text{N}$ $F_{2,52} = 1.02$, $p = 0.37$). Thus, we combined the isotope values from the turtles sampled across all habitats, which allowed for a broad characterization of hawksbill diet across the entire San Jose foraging ground.

There was no significant relationship between the $\delta^{15}\text{N}$ values from the posterior scute samples from the hawksbills and their SCL measurements ($F_{1,49} = 0.24$, $p = 0.63$, $R^2 = 0.005$) (Figure 4B). The $\delta^{13}\text{C}$ values increased significantly with increasing hawksbill SCL ($F_{1,49} = 11.48$, $p = 0.001$, $R^2 = 0.19$) (Figure 4A).

SIA Analysis: Recaptured Turtles

To maximize the length of time over which we could compare isotope values and thus detect potential temporal changes in habitat use, we compared isotope values from scute samples from turtles ($n = 5$) captured in 2016 and 2017, then recaptured in 2019. There was no significant change in the $\delta^{15}\text{N}$ values from the posterior scute sampled during the first capture ($14.3 \pm 0.1\text{‰}$) vs. those from the anterior scute sampled during the recapture ($13.3 \pm 1.8\text{‰}$; $t = 1.52$, $df = 8$, $p = 0.08$). However, the $\delta^{13}\text{C}$ values were higher for the anterior scute from the recapture ($-15.7 \pm 0.5\text{‰}$) than those from the initial capture's posterior scute (-16.9 ± 0.5 ; $t = -2.83$, $df = 8$, $p = 0.02$).

DISCUSSION

Population Morphometrics

Martinez-Estevez, et al. (2021) found that the San Jose foraging ground is one of the most important developmental hotspots for hawksbills in the Gulf of California, Mexico. The size range for the turtles we captured ranged from 33.8 to 63.8 cm, indicating that they had transitioned from their earliest, post-hatching habitat to their nearshore juvenile life history stage which is thought to occur at 35 cm SCL (Van Houtan et al. 2016b, Palaniappan 2007). In addition, most individuals (54 of 56, 96.4%) were less than the SCL size believed to indicate transition to adult stage (nesting adult females range from 69.4 to 109.0 cm SCL) (Palaniappan 2007). Thus, the turtles we sampled consisted largely of juvenile turtles across a range of development (Seitz et al. 2012, Van Houtan et al. 2016b). In addition, we recaptured five individuals over the three-year sampling period (2016-19), and their sizes increased on average

of 4.8 cm SCL, further supporting our hypothesis that this is a long-term habitat critical for juvenile hawksbills.

SIA and MixSIAR Model Analysis

This is the first stable isotope study of hawksbill sea turtles in the Gulf of California, Mexico. The MixSIAR results using the stable isotope values from the hawksbill skin and their presumed prey indicate they were eating primarily sponges, followed by seagrass, algae, and mangrove material (Table 2, Figure 3). Juvenile hawksbill turtles are generally believed to be omnivorous (Lutz et al. 1996, Nichols 2003), thus our estimates that the hawksbills in the San Jose foraging ground consume a mix of vegetation and invertebrates fits with estimated diets of other populations of Eastern Pacific hawksbills (Carrión-Cortez et al. 2013, Méndez-Salgado et al. 2020). As we observed no differences in the stable isotope values from turtles captured in each of three microhabitats within the San Jose foraging ground, it is likely they move freely among all three locations, fully utilizing all potential dietary sources across the sandy embayment, rocky reef, and mangrove habitats. Alternatively, as recent tracking data suggest hawksbills in the Gulf of California exhibit extremely small home ranges within their foraging grounds (Martinez-Estevez et al. 2021), the similarity in isotope values from turtles captured across the three habitats could also mean there is no isotopic differences in prey items among the habitats that would be reflected in the isotope values from the hawksbill skin samples. Whether these turtles will transition to focused spongivory in their adult stages, as do their Atlantic cousins (Lutz et al. 1996), and as recent research on Pacific hawksbills suggests (Carrión-Cortez et al. 2013), or remain omnivorous, which has historically been reported for the region (Lutz et al. 1996), is uncertain. We did not have samples from or access to adequate numbers of adults to

fully test this, but we recommend seeking and sampling from older turtles in the future to better understand the potential for ontogenetic diet shifts with the transition to adulthood.

Sampling stable isotope values from different areas across a turtle scute allows for estimating temporal changes in their diet because turtles deposit scute material in growth layers, with the oldest portion in the posterior of the scute and the most recent in the anterior (Palaniappan 2007, Van Houton 2016). Hawksbill turtles deposit the keratin in these growth layers at rates of 5 to 14 per year (Van Houton et al. 2016b) and once scute growth layers are complete, they are inert, retaining the stable isotope values that reflect the diet ingested by the turtle during the time the layers were deposited (Van Houton 2016b). Thus, scutes have the potential to contain extensive chronologies, locking multiple years of diet data in their growth layers.

The time between posterior and anterior growth layer deposition varies from three to eight years for juvenile hawksbills (Van Houton 2016b), meaning stable isotope values from an anterior portion of scute would be incorporated several years after the material in the posterior portion. As the vertebral scutes are known to erode with wear (Van Houtan et al. 2016b), and we took imprecise scrapings of the scutes, we were likely unable to capture the isotope values reflecting hatchling diet from our older, posterior scute samples, but they may reflect foraging ecology of the hawksbills prior to their transition as juveniles into the nearshore San Jose foraging ground. Finally, the samples from the anterior portion could reflect turtle diet and foraging location anywhere from the month of collection to several months to a year before collection (Van Houtan et al. 2016b).

We observed increasing $\delta^{13}\text{C}$ values with increasing size (Figure 4) which may reflect a habitat transition from the coastal pelagic to the nearshore San Jose foraging ground, a transition

which has been hypothesized for other hawksbill populations in the Eastern Pacific (Van Houtan et al. 2016a). We also compared the stable isotope values in scutes from five turtles captured in 2016/17 and recaptured in 2019. To maximize the length of time between the oldest and most recent growth layers contained within these hawksbill scutes, and thus maximize our chance of observing notable shifts in isotope values across the longest temporal scale, we targeted the posterior scute from the first capture and the anterior scute from the second capture. We observed a significant increase in the hawksbill $\delta^{13}\text{C}$ values from the first to the second capture, again indicating a potential change in foraging location between the two time periods.

If the earlier posterior scute samples from the first capture contain isotope data collected by the turtle during their earlier, post-hatchling “lost years”, then the change in $\delta^{13}\text{C}$ values could indicate their arrival in this important nearshore environment as $\delta^{13}\text{C}$ values are higher in nearshore waters than offshore (France 1995, Rubenstein et al. 2004). The change in $\delta^{13}\text{C}$ values could also indicate a dietary shift, but this is not likely as we did not observe any change in the $\delta^{15}\text{N}$ values from turtles between the early and later scute samples, nor did we observe any relationship between their $\delta^{15}\text{N}$ values and SCL. Thus, regardless of foraging location, these turtles are likely foraging at the same trophic level across these time periods. With continued sampling and further recaptures, these timelines could be extended and replicated for more turtles, allowing for further insights into these trends.

Conclusions

The SCL measurements from the turtles within this population indicate that 96.4% of the hawksbills in the San Jose foraging ground were juveniles. Much like their Atlantic counterparts, the population of hawksbills in the San Jose foraging ground does appear to feed on sponges. However, while Atlantic post-pelagic hawksbills have a diet composed of 90+% sponges (Lutz et al. 1996), the hawksbills in this study are more omnivorous, incorporating significant amounts of vegetation into their diets. The $\delta^{13}\text{C}$ values from posterior scute samples from all individuals increased with increasing hawksbill SCL. In addition, the $\delta^{13}\text{C}$ values compared between the anterior and posterior scute samples from five turtles captured in 2016/17 and again in 2019 also increased. These two observations may demonstrate evidence of a transition from a coastal pelagic post-hatchling phase to one of juvenile development in the nearshore estuarine habitat. Further analyses of tissues collected from very small individuals (<40 cm CCL) may allow us to better understand the potential for ontogenetic habitat shifts. Our data, along with the recent spatial ecology data revealing the extreme site-fidelity, small home ranges, and strong preference for mangrove estuaries exhibited by juvenile hawksbill turtles in the Gulf of California (Martinez-Estevez et al. 2021), strongly indicate that the San Jose foraging ground is an important, long-term developmental ground for a relatively large number of juvenile hawksbills. The estimated number of mature females breeding per season in the eastern Pacific is less than 300 (U.S. Dept. of Commerce, NOAA et al. 2013), further underscoring the need for strong management and conservation efforts to protect this and other important foraging grounds in the Gulf of California, Mexico.

This thesis is coauthored with Kurle, Carolyn M.; Croll, Donald A.; and Martinez-Estevez, Lourdes and is currently being prepared for submission for publication of the material. The thesis author was the primary investigator and author of this paper.

FIGURES AND TABLES



Figure 1. Hawksbill sea turtles were captured and sampled for stable isotope values within the San Jose foraging ground located off Isla San Jose in the Gulf of California, Mexico. The foraging ground consists of three closely located microhabitats – rocky reef, sandy embayment, and mangrove estuary.

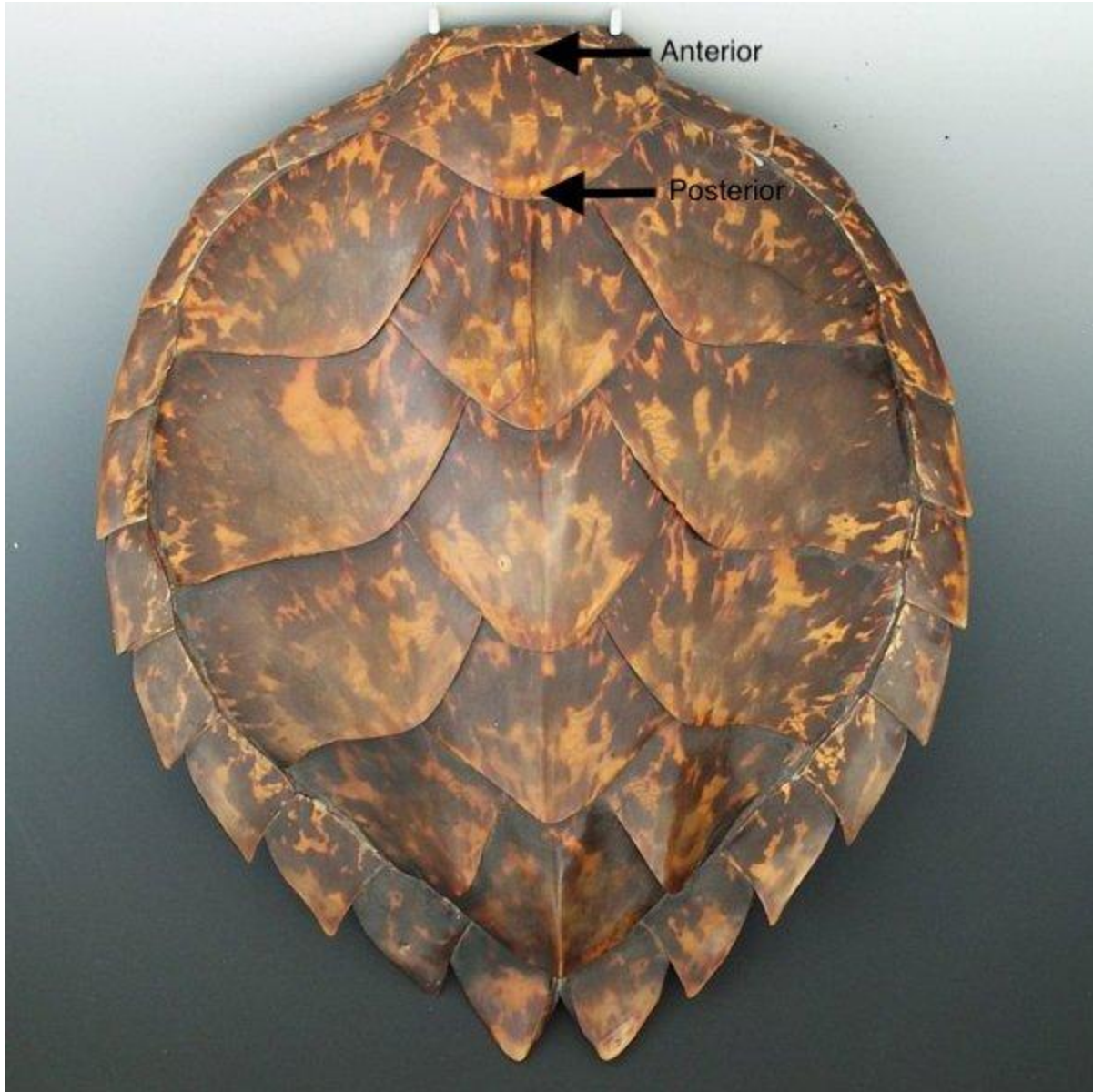


Figure 2. Locations for the posterior and anterior scute samples collected from hawksbill turtles for stable analyses in this study. Photo used with permission from liveauctioneers

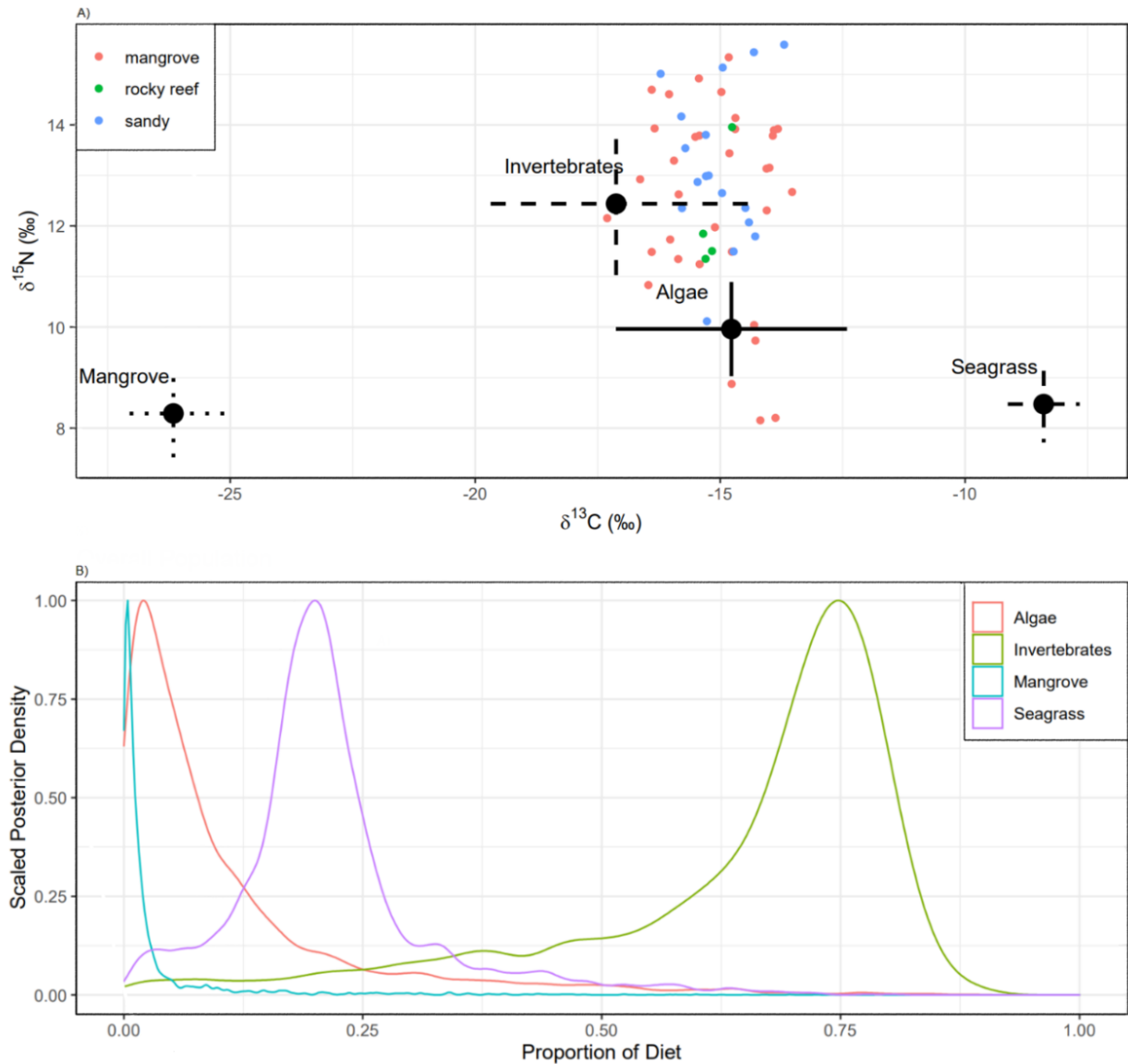


Figure 3: A) The isospace plot of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from the skin collected from hawksbill turtles within the San Jose foraging ground and the mean (\pm SD) stable isotope values from the four potential prey categories (invertebrates, algae, seagrass, and mangrove) collected from the study site. Each colored point represents a single turtle's pair of stable isotope values, and they are grouped by the microhabitat sites (mangrove, rocky reef, sandy reef) located within the San Jose foraging ground in which the turtles were captured. B) Estimated prey contributions to the diet of hawksbill turtles sampled within the San Jose foraging ground. The estimates were obtained using MixSIAR, a Bayesian stable isotope mixing model incorporating the mean (\pm SD) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from four aggregated prey sources and the skin samples collected from the turtles.

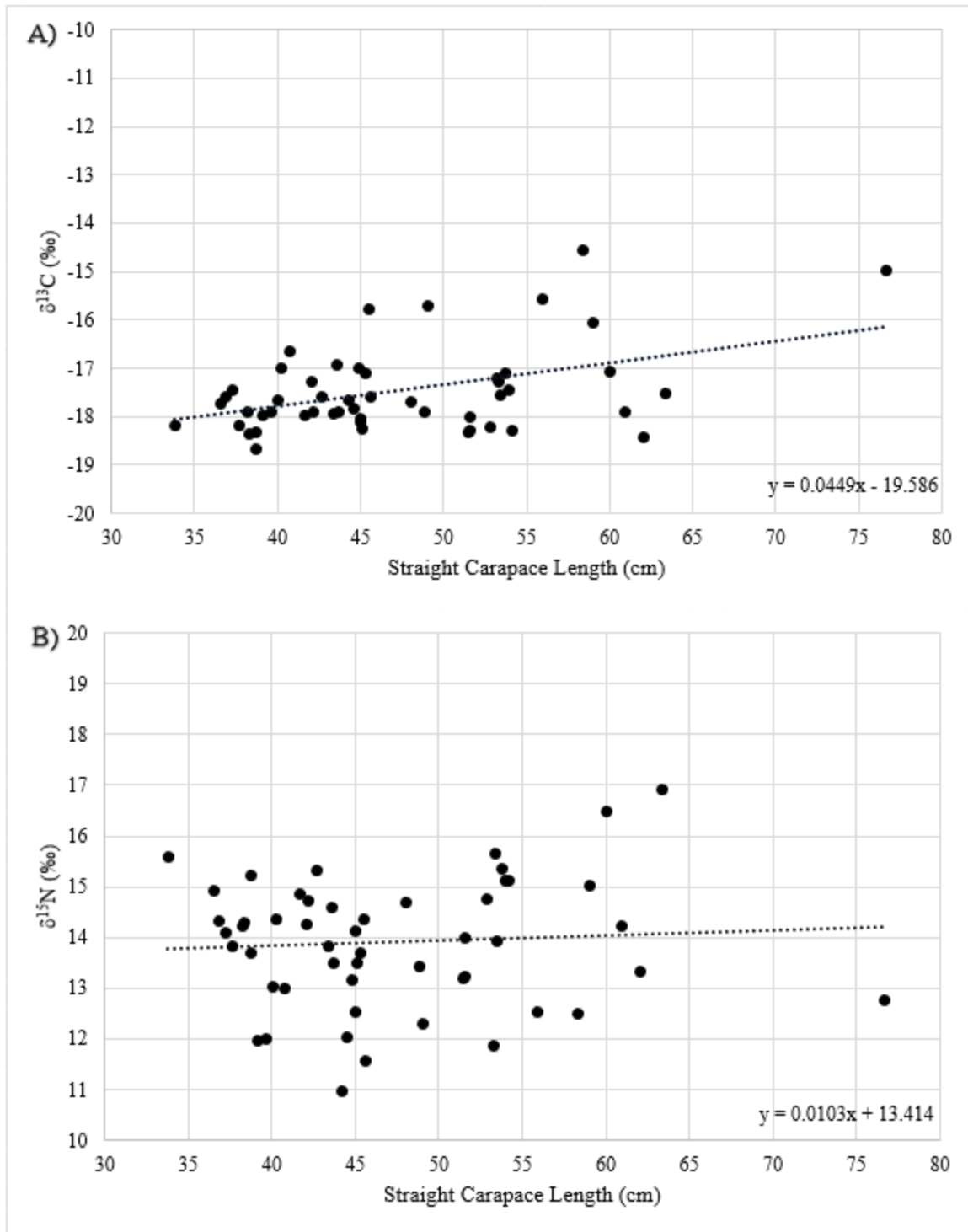


Figure 4: A) the $\delta^{13}\text{C}$ and B) $\delta^{15}\text{N}$ values from posterior scutes sampled from hawksbill turtles in the San Jose foraging ground and their corresponding SCL measurement. The $\delta^{13}\text{C}$ values increased significantly with increasing turtle size, whereas there was no change in the $\delta^{15}\text{N}$ values with turtle size.

Table 1. Mean stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope values (‰) for the four dietary categories used to estimate hawksbill turtle diets in the San Jose foraging ground, Gulf of California, Mexico. See supplemental material for full details of all collected diet items.

Source	n	Mean $\delta^{13}\text{C}$ (‰)	Mean $\delta^{15}\text{N}$ (‰)
Invertebrates	141	-18.2 ± 2.7	10.8 ± 1.4
Algae	41	-15.9 ± 2.3	8.4 ± 0.9
Seagrass	9	-9.5 ± 0.7	6.9 ± 0.8
Mangrove	14	-27.3 ± 1.0	6.7 ± 0.9

Table 2. Proportional dietary contributions for hawksbill turtles sampled in the San Jose foraging ground, Gulf of California, Mexico, 2014-2019. Parameters were estimated using the Bayesian stable isotope mixing model, MixSIAR.

Turtle tissue type	Food source	Population Mean (%)	1 SD	Credible Interval		
				2.5%	50%	97.5%
Skin	Algae	10.6	13.4	0.2	5.7	51.7
	Invertebrates	64.4	17.7	13.7	70.9	83.0
	Mangrove	3.4	7.9	0.0	0.9	29.0
	Seagrass	21.6	10.5	3.6	20.1	51.9
Anterior Scute	Algae	21.8	17.9	00.6	16.9	64.8
	Invertebrates	33.2	21.5	02.2	30.3	80.0
	Mangrove	22.3	18.6	00.5	17.7	68.6
	Seagrass	22.7	19.0	00.5	17.9	67.5
Posterior Scute	Algae	21.8	18.4	00.4	17.2	66.6
	Invertebrates	34.5	22.7	2.5	30.7	84.5
	Mangrove	22.8	18.3	0.6	18.4	66.7
	Seagrass	20.8	17.9	0.3	16.0	64.0

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