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Internesting movements and behavior of hawksbill sea turtles (Eretmochelys imbricata) around Buck Island Reef National Monument, St. Croix, United States Virgin Islands

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ABSTRACT

INTERNESTING MOVEMENTS AND BEHAVIOR OF HAWKSBILL SEA TURTLES (*Eretmochelys imbricata*) AROUND BUCK ISLAND REEF NATIONAL MONUMENT ST. CROIX, U.S. VIRGIN ISLANDS

by Christopher H. Starbird

Radio and ultra-sonic telemetry were used to monitor movements of seven hawksbill sea turtles around Buck Island Reef National Monument (BUIS), St. Croix, U.S. Virgin Islands. Movements of three hawksbill sea turtles 48 hrs before nesting, indicated an ability to relocate 0.06 km sections of nesting beach on which they had previously nested. Offshore movements of all hawksbill sea turtles were confined to approximately 1.5 km^2, and indicated some level of residency. The resident areas were within 3 km of Buck Island and water depth ranged from nine to 20 m. Four hawksbill sea turtles left the Buck Island and St. Croix region immediately following their last seasonal nesting event, indicating hawksbills may undergo reproductive migrations after nesting. Dive behavior and movement patterns were analyzed for days 2-12 of the internesting periods. Mean duration of dive was 56.2 min (SD=17.3, n=147) and mean surface time was 1.6 min (SD=0.94, n=314) for the seven turtles. Mean duration of dive was 33.8 to 63.5 min during the day (0600-1759 hr) and 41.7 to 73.5 min at night (1800-0559 hr). Duration of dive and surface interval did not appear to be significantly different among individuals.

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INTRODUCTION

Sea turtles occupy different habitats throughout their lives. Immediately after hatching sea turtles are pelagic; thereafter they develop in coastal habitats. Adult females nest on beaches, and use offshore areas between nesting attempts within a season (internesting period, Carr et al. 1978, Carr 1980). Although the nesting behavior of sea turtles has been well studied (Ehrhart 1982), few studies have documented movements and behavior during other life cycle stages.

Sea turtles nest one to 11 times in a nesting season (Moll 1979). Within a nesting season, the period between successful nesting events is called the internesting period, and lasts 12 to 15 days for all species except leatherback sea turtles (Dermochelys coriacea) for which this period is 9 to 10 days (Ehrhart 1982). During the internesting period, sea turtles may be particularly vulnerable to commercial harvesting, incidental catch, collision with recreational boaters, and ecological disasters such as oil spills (Meylan 1984). Knowledge of the internesting habitat, behavior, and ecological requirements of sea turtles during this period is important to determine the environmental requirements before subsequent nesting attempts.

Telemetry has never been used to study movements of hawksbill sea turtles (Eretmochelys imbricata) but has been used to study internesting behavior of green (Chelonia mydas, Dizon and Balaz 1982) , loggerhead (Caretta caretta, Murphy 1979; Stoneburner 1982), Kemp's ridley (Lepidochelys kempii, Mendonca and Pritchard 1986), and leatherback (Chan et al. 1990) turtles. Methods varied from using towed drogues with sophisticated satellite transmitters (Stoneburner 1982) to radio transmitters attached directly to the carapace (Dizon and Balaz 1982).

Hawksbill sea turtles are distributed throughout tropical and subtropical waters with major nesting and foraging grounds between 25° N and 35° S latitude within the central Atlantic and Indo-Pacific regions (Witzell 1983). In the Caribbean, they range from southern Florida along the Central American mainland coast to Brazil and throughout the Bahamas and Lesser Antilles (Meylan 1984; Marquez 1990). Adult hawksbill sea turtles are typically found around coral reef formations although they have also been observed in coastal lagoons and bays (Marquez 1990).

Diagnostic features of hawksbill sea turtles include two pairs of prefrontal scales; thick, posteriorly overlapping scutes on the carapace, and a beak-like mouth (Marquez 1990). Mean straight carapace length in adult female hawksbill sea turtles is 53 to 114 cm (Marquez 1990). Color variation ranges widely from very bright colors to the largely melanistic forms found in the eastern Pacific. General color patterns are brown with splotches of yellow (Meylan 1984).

Hawksbill sea turtles feed primarily on sponges and secondarily on algae, sea grasses, tunicates, jellyfish, sea anemones, and other coral reef invertebrates. Meylan (1988) found sponges contributed 95.3% of the total dry mass of all food items in the digestive tract of 65 hawksbill sea turtles sampled.

Hawksbill sea turtles are diffuse, solitary nesters. Nesting aggregations occur in Isla de Pinos, Cuba (Ubeda 1973), San Blas Islands near Panama (Carr et al. 1982), Long Island, Antigua (Richardson et al. 1989), Yucatan Peninsula, Mexico (J. Frazier, Smithsonian Inst., pers. comm.) and Buck Island

Reef National Monument (hereafter BUIS), St. Croix, U.S. Virgin Islands (Hillis and Mackay 1989). In the Caribbean, nesting occurs between May and November with peak activity from June to October. Nesting occurs on a variety of beach habitats although most commonly on small beaches which are near vegetation. Hawksbill sea turtles average five nests per season, with an average internesting interval of 14 days and two to three years between each nesting migration (Richardson et al. 1989).

Movements of sea turtles within the internesting habitat may be associated with availability of food resources (Stoneburner 1982), propensity of an individual for movement (Limpus and Reed 1985), courtship or mating behavior (Carr et al. 1974; Dizon and Balaz 1982), or other unmeasured factors (e.g. water temperature, sea state, predator avoidance, photo-period, and physiological cues). Unlike other sea turtles, adult hawksbill sea turtles live primarily within coral reef systems, similar to those surrounding BUIS. Because hawksbill sea turtles occupy coral reef habitat, the reef habitat around BUIS could preclude the necessity for long distance migrations. This insular behavior may be more pronounced during internesting periods when movements away from the nesting beach would be energetically costly for females that must return to the same area within 14 days.

Conclusions from past studies on post-nesting movements of hawksbill sea turtles have been based on tagging studies and chance observations, and no study has specifically monitored internesting behavior. Hawksbill sea turtles have been documented to migrate 100 to 1,000 km after the nesting season (Limpus et al. 1983; Paramenter 1983; Marcovaldi and Filippini 1991), or to exhibit either short or no migration (Carr and Main 1973; Thurston 1976;

Bjorndal et al. 1985; Kamezaki 1987). Lack of conclusions regarding internesting and post-nesting movements of hawksbill sea turtles has contributed to controversy over whether Cuba should be allowed through the Convention for International Trade of Endangered Species (CITES) to trade hawksbill sea turtle parts internationally (Ross 1991). Cuban fishery representatives claim that hawksbill sea turtles constitute a defined stock restricted to the Cuban Shelf; thus they wish to manage hawksbill sea turtles as a sustainable fishery under this assumption. Knowledge of post-nesting and internesting movements of hawksbill sea turtles is especially important towards affecting international trade barriers and in understanding behavior of hawksbill sea turtles.

Dive behavior of sea turtles has been described for the Kemp's ridley (Mendonca and Pritchard 1986), loggerhead (Soma 1985), and the leatherback sea turtle (Eckert et al. 1986; Eckert et al. 1989). Sea turtles are able to remain submerged for extended periods of time due to: 1) a lung structure that allows rapid and almost complete exchange of lung gases (Lutz and Bentley 1985); 2) an increased tolerance for anoxic conditions (Felger et al. 1976; Lutz et al 1980); and 3) distinctive oxygen dissociation properties allowing complete depletion of oxygen from the lung (Lutz and Bentley 1985; Kooyman 1989). These adaptations combined with swim rate (i.e. metabolic demand) may determine dive duration for hawksbill sea turtles during their internesting period.

The objectives of this study were to determine patterns of female hawksbill sea turtle movements and behaviors during and after internesting periods. I sought to quantify daily patterns of activity, and determine the extent that hawksbill sea turtles use the near-shore reef area around BUIS. The hypothesis was that hawksbill sea turtles remain within the reef system of BUIS throughout the internesting period and would not leave the area around St. Croix after nesting. I expected that these areas would exhibit high sponge abundance. Physical and biological characteristics of areas most often used by hawksbills were quantified.

MATERIALS AND METHODS

Study Area

Buck Island Reef National Monument (BUIS) is located two km north of St. Croix, U.S. Virgin Islands and has been under the jurisdiction of the National Park Service (NPS) since 1961 (Fig. 1). It is composed of 72 ha of dry tropical forest surrounded by 171 ha of coral reef system (Hillis and Mackay 1989). Buck Island provides 1.3 km of nesting beach for hawksbill, green, and leatherback sea turtles (Small 1982). Topography of nesting beaches ranges from rock and coral cobbles bordered by dense supralittoral forest (southern and northern beaches), to open beach with extensive dune grass (west beach, Fig. 1; Hillis and Mackay 1989). Beach forest vegetation is comprised of manchineel (Hippomane mancinella), purple sage (Lantana involucrata), and sea grape (Coccolaba uvifera, Woodbury and Little 1976).

Flora and fauna of reef communities surrounding BUIS have been qualitatively described (Adey 1975; Gladfelter 1988). A barrier reef, dominated by elkhorn coral (Acropora palmata), runs adjacent to the southern shore, and forms an arc around the eastern end of the island. To the northwest, patch reefs extend two km away from BUIS. In the Buck Island Channel, between St. Croix and BUIS, are a series of deep patch reefs which offer a great diversity and biomass of sponge species (Gladfelter 1988). These reefs interface with sand and sea grass beds comprised mainly of the algae Dictyota spp, and Cladocelphalus sp., and the grass Syringodium spp.

Beach patrol

Data were collected between 1 July 1991 and 30 September 1991, during the peak of nesting activity. Beaches were patrolled by two NPS employees nightly (1830-0530 hr) on foot, at 20 min intervals. Nesting behavior was grouped into two major categories: dry run (turtles attempted but did not complete nesting) and successful nest (egg deposition observed). Nesting turtles were marked on both front flippers using numbered inconel tags issued by the National Marine Fisheries Service (NMFS, tag series PPW and QQD). Barnacle patterns and carapace deformities were recorded to aid in identification. Curved carapace length to the nearest 0.1 cm was measured along the median dorsal ridge from the nuchal scute to the posterior notch. Carapace width was measured at the widest point.

Telemetric procedure

Radio transmitters (Telonics Inc., Mesa, Arizona) were hermetically sealed in electrical potting resin (Scotchcast 3M, San Diego, CA). Each package weighed approximately 200 g, and measured 13 cm long by five cm wide by one cm thick. Lithium batteries (Eagle Keeper LTC 7PN) were used to maximize transmitting time and minimize weight of the package. Each transmitter had a unique frequency between 148.03 and 148.86 MHz, and turtles were identified accordingly (e.g. 148.86 MHz= animal #86). One transmitter (148.34 MHz) was placed on one turtle, recovered, and placed on another. These two turtles were identified by letters (i.e. 34A and 34B). Pulse width was between 12.0 and 13.9 msec, and life expectancy of transmitters was eight weeks.

An ultra-sonic telemetry system also was used to locate submerged turtles. Ultra-sonic transmitters (Sonitronics Inc., Phoenix, Arizona) weighed 12 g, and measured 10 cm by 1.8 cm. All transmitters operated at a frequency of 75 kHz, had self-identifying aural codes, and were expected to transmit for 12 months.

Radio and ultra-sonic transmitters were attached as one package to seven female hawksbill sea turtles. In 1987 and 1988, turtles nested an average of four times annually with a 15-day period between each subsequent nesting (Hillis and Mackay 1989). Turtles that were nesting for the first time or had not nested more than once previously during the 1991 season were selected for the telemetry study because these turtles were likely to return to BUIS to nest at least three more times. This yielded a maximum amount of data from each tagged individual and increased the likelihood of recovering transmitters.

The first two females were approached immediately after covering their nests and were secured to a padded plywood restraining-board with nylon straps (5 cm wide). This method was not used after the first two attempts because hawksbill sea turtles would try to escape until physically exhausted. All subsequent attachment was performed at the nest, as egg deposition began and before nest covering was complete. Transmitters were attached to the anterior most median ridge of the carapace in an area devoid of barnacles.

The area was rinsed with fresh water, sanded with medium grit sand paper, and wiped with isopropyl alcohol. Dental acrylic (Den-mat Corp, San Diego, CA) was applied to the transmitter package, set in place, and allowed to dry for five minutes. Marine epoxy (10-min Evercoat 660 , San Diego, CA) was mixed with a fiberglass coloring agent (brown) to reduce visibility of the package. The epoxy was then applied around the outside of the transmitter to improve adherence and protect the package from impact.

Radio telemetry receiving stations were located on a U.S. Coast Guard tower (BUIS, elev.= 109 m) and on a peak overlooking the Buck Island Channel near Pull Point, St. Croix (elev.= 69 m, Fig. 2). Five-element yagi antennas were attached to PVC pipe (5.0 cm dia.) and a mounted compass row was used to document the direction of the antenna. A radio transmitter placed on Pull Point (Fig. 2) was used to establish whether the receiving system was operational. Locations of sea turtles were determined from one station or both stations simultaneously. Reception from one station gave general locations, whereas reception from both stations allowed triangulation of the position of hawksbill sea turtles. Maximum range (30 km) and error at five km (±5°) was estimated by locating transmitters in a boat offshore. When radio signals were not received, telemetry stations were set up on the highest peaks on the east and west ends of St. Croix to determine if hawksbill sea turtles with transmitters remained in the area. At these stations, an omni-directional and three-element yagi antenna were used, and sessions consisted of three hours of continuous monitoring.

After leaving the nesting beach, turtles were tracked for 24 hrs or until movements ceased. Thereafter, tracking sessions were interspersed among eight three hour time periods during the day (i.e. 0800-1059 hr, 1100-1359 hr, etc.). Each individual with a transmitter was located at least once during a tracking session. Assistants at both telemetry stations monitored radio transmitter frequencies, and hand-held radios were used to communicate from station to station when hawksbill sea turtles surfaced. Positions of hawksbill sea turtles were determined by bi-angulating signals from two stations. All positions were recorded on National Oceanic and Atmospheric Administration (NOAA), National Ocean Survey Charts, or United States Geological Survey (USGS) topographical maps.

The islands of St. Thomas and St. John (north of St. Croix, Fig. 1) were monitored (Sept. 4-7) from their highest mountain peaks on the east and western ends of the islands to determine if three hawksbill sea turtles, which left St. Croix, had moved to these islands. Two 5-element yagi antennas were mounted in opposite directions on a piece of PVC pipe. Antenna leads were connected to a two-way relay switch so either antenna, but only one at a time, could be monitored. Tracking sessions lasted for three hours, during which time each antenna was monitored successively for 45 sec. This allowed for a maximum scan in all directions and ensured that hawksbill sea turtles were not missed during short surface intervals.

Ultra-sonic tracking sessions were conducted from a 5-m boat, three hrs every other day between 0800 to 1600 hr. A hand-held compass was used to locate the site of the turtle's last radio transmission. A hydrophone (Sonotronics Inc., Phoenix, Arizona), was lowered into the water as the boat followed an east-west heading at a constant speed (0.5 km/hr). Once a turtle was found, its ultra-sonic signal was monitored consistently. Transects were

50 m apart, one km in length, and were distributed equally around the last recorded position of the turtle. If ultra-sonic signals were not located within three hrs. then the session ended. Ultra-sonic signals were blocked or refracted by coral, heightened sea state, suspended material, biological organisms, and boat motors, hence maximum reception distance was reduced to an estimated 0.5 km. Location of a hawksbill sea turtle was estimated by positioning the boat directly over the turtle and taking compass bearings towards three known points of reference.

Habitat Description

Internesting habitat was described for two hawksbill sea turtles (#79 and #03) because their internesting location was known with the greatest accuracy and precision. Internesting areas were defined as the area of concentrated movements of each individual (900 m^2) and dive sites within these areas were chosen randomly.

Percent cover of three habitat types (sand, sea grass or algae, and coral reef) was estimated for each area. A diving mask was marked on the inside of the glass so the viewer, leaning over the side of a boat, saw an area of the bottom defined by these marks. A 30-m tape was extended on the bottom from the center of each study site and the viewer estimated the distance viewed along the length of tape and between marks on the mask. One viewer was used throughout the study. Depth was assumed uniform (16 m) throughout the study area and equal to the average depth measured randomly throughout the study area. The area of the bottom viewed from the surface was an estimated 64 m^2, the size of each quadrat.

Transects for estimating percent cover ran east to west and were 70 m apart. Buoys that had been placed over fish traps were used as points of reference for positioning the boat. At randomly timed intervals, the boat was stopped and the viewer estimated percent cover of the three habitat types to the nearest whole number within each quadrat. Five transects (41 quadrats) were completed in the internesting area of turtle #79 site and three transects (16 quadrats) for turtle #03.

Percent cover of flora and fauna within coral reef and sea grass habitats were described using randomly placed one m^2 quadrats within each of the study areas. At the center of each study area, two divers descended on an anchor line. The end of a 100 m tape was attached to the anchor and extended on a random bearing. The first reef or sea grass habitat encountered along this tape was chosen as the study site. At these sites, divers swam random distances along the 100 m tape and then used the 30 m tape to swim a random distance perpendicular to the axis of the 100 m tape. A 1 m^2 quadrat made of PVC pipe (1.27 cm dia.) was laid on the bottom with the center positioned over the 30 m tape. Percent cover of flora and fauna was estimated by eye, and photographs (Nikonos 5) were taken of each quadrat.

Description of Dive Behavior

Monitoring for presence or absence of a radio signal yielded a good approximation of the time a turtle spent at the surface or underwater. Duration of surface intervals and dives (amount of time at surface and below the surface) were recorded for daytime (0600 hr and 1759 hr) and nighttime (1800-0559hr). During a tracking session, dive behavior for each tagged hawksbill sea turtle was monitored continuously for two hours to determine periodicity and variation in dive durations. If dive durations were consistent then radio frequencies were not monitored continuously but in relation to the pattern determined (i.e. turtle surfacing each hour, then receiver was tuned to that frequency at quarter to the hour). In this way researchers were able to monitor a number of frequencies while hawksbill sea turtles remained submerged.

RESULTS

Seven of the 26 hawksbill sea turtles that nested on BUIS in 1991 were radio tagged. Twenty nesting events and eight dry runs were recorded after tagging (Table 1). Thirteen nests were on the northshore, three were on the southshore, two were on the west beach, and two were in Turtle Bay.

Hawksbills #14, 03, and 54 nested three times on the northshore, whereas their preferred in-water areas were located southeast (14, 03) and southwest (54) of BUIS (Fig. 2, 4). Nests of #14, 03, 34B and 54 were within 0.06 km of the previous nests created by that individual. Hawksbills #34A, 79, and 86 nested on different beaches on BUIS (Fig. 2, 3). Carapace length (over-the-curve) of the six hawksbill sea turtles was 86.5 to 99.0 cm (Table 2).

Radio signals from tagged hawksbill sea turtles were monitored for 13 to 45 days. Signals were received from one station (n=307) or from both stations simultaneously (n=73, Table 2). Hawksbill sea turtles were monitored for one (34A), two (14, 79, 03, 54), and three internesting periods (86). Acoustic fixes (n=16) were received for three hawksbill sea turtles (03, 79, 14).

Internesting movements of all monitored individuals were confined to areas of approximately 1.5 km^2. These areas were within three km of BUIS, and depth ranged from nine to 20 m. Five individuals were tracked in areas south of BUIS (79, 03, 14, 54, 34B) and two in areas to the north (86, 34A). Six tagged hawksbill sea turtles returned to the same offshore area after nesting. Hawksbill #14 did not return to the same area after nesting for a second time and moved closer to the south side of BUIS (Fig. 2, boxes 4-11). Movements of three individuals (79, 86, 03) were concentrated in an area of 0.5 km^2 (Fig. 3, 4) throughout their internesting periods. Using sonic telemetry, one hawksbill (79) was found on the same area near BUIS on five consecutive occasions during a two-week period (Fig. 3). Hawksbill #14 had less resident time within a particular area and wandered more than any of the other hawksbill sea turtles (Fig. 2). Due to low battery power and damaged transmitter antennas only the approximate area of movements of two hawksbill sea turtles (34B, 54) was estimated (Fig. 2, 4). Estimated movements of 34A were based on fixes and signal strength from the BUIS station only (Fig. 2).

Four tagged hawksbill sea turtles (86, 79, 14, 03) were eventually lost when hawksbill sea turtles left the area following the final nesting event. These hawksbill sea turtles were not located during subsequent tracking sessions around St. Croix, St. John, or St. Thomas Islands.

In the internesting area used by hawksbill #03, 12 quadrats were within reef habitat and 24 were in sea grass habitat . This area was composed of approximately 53% sand, 22% patch reef, and 25% sea grass beds. Percent cover was greatest for the coral Montastraea annularis (5%) within the reef habitat and the grass Syringodium spp. (13%) within the sea grass habitat

(Table 4). In the internesting area of hawksbill #79, five quadrats were within reef habitat and 32 were in sea grass habitat. This area was composed of approximately 76% sand, 22% sea grass beds, and two patch reefs (90 m^2, 60 m^2). Percent cover was greatest for gorgonians (14%) within the reef habitat and for the algae Halimeda spp (11%) within the sea grass habitat (Table 4).

Mean dive duration for all individuals increased between 0000 to 0559 hr (Fig. 7), and surface interval increased between 1000 to 1759 hr (Fig. 8).

Dive behaviors of tagged hawksbill sea turtles approaching (72 hr preceding nesting) and departing the nesting beach (24 hr post-nesting) were analyzed separately. During these periods dive and surface times were relatively short compared with other periods of the internesting period. Mean duration of dive for all individuals 72 hrs preceding nesting was 3.4 min (SD=3.6, n=127) and 24 hrs post-nesting was 7.7 min (SD=14.1, n=97, Fig. 5). Mean dive duration for all other periods of the internesting period (day and night) was 56.2 min (SD=17.3, n=147) and cumulative mean surface duration was 1.6 min (SD=0.9, n=314, Table 3). Mean dive duration ranged from 33.8 to 63.5 min during the day and 41.7 to 73.5 min at night.

Statistical comparisons among hawksbill sea turtles were not conducted due to potential lack of independence within an individual. Mean duration of dives of hawksbill #34B was less than others, whereas hawksbill #14 had a greater mean duration of nighttime dives than other hawksbill sea turtles tagged (Fig. 6).

DISCUSSION

The ability of hawksbill sea turtles to locate specific sections of beach within a nesting season has been documented (Bjorndal et al. 1985, Hillis and Mackay 1989). These studies were based on observations of turtles on nesting beaches, and did not examine internesting movements in relation to nest site selection. Offshore movements of hawksbill sea turtles immediately before and after nesting confirmed that they are capable of returning to specific locations on nesting beaches and internesting habitats around BUIS. Forty-eight hrs before nesting, movements of hawksbills #14 and 03 were directed toward the northshore and past other "suitable" nesting beaches. Meylan (1982) has documented the directed movements of green sea turtles during their internesting period near Tortuguero, Costa Rica. One green sea turtle swam greater than 4 km against a 1 km/hr current on a direct course to a resting position on Tortuguero Bank. Hawksbills #14 and 03 subsequent nesting events were within 0.06 km of their previous nests. On an eight km beach near Tortuguero, Costa Rica, the mean distance between successful nests of individual hawksbill sea turtles was 1.67 km within a season (±1.48, range 0-6.23; Bjorndal et al 1985). The short distance between nesting sites may be related to the reduced size of nesting beaches on BUIS (northshore= 200 m) rather than the ability of a turtle to relocate a specific site. Although mechanisms for selection of nest and internest location are unknown, advantages may include retention of a favorable place to nest or spend the internesting periods (Carr and Carr 1972).

Internesting movements of hawksbill sea turtles were directed toward specific areas around BUIS. Fidelity (long resident time and site specificity) for offshore areas varies among individuals and among sea turtle species (green, Carr et al. 1974; loggerhead, Limpus and Reed 1985). One loggerhead sea turtle was associated with a specific refuge for the entire 1983 nesting season (15 Nov-30 Jan) near Heron Island, Australia, whereas other loggerheads moved throughout an area greater than one km^2 of the reef front (Limpus and Reed 1985). When divers repeatedly disturbed this individual she returned to the same area approximately one km from the nesting beach. Similar to loggerhead sea turtles, hawksbill sea turtles exhibited variation in the size of the internesting area. Hawksbills #03 and 14 used internesting areas encompassing approximately 2 km^2 while hawksbills #86 and 79 used areas of 1 km^2.

Hawksbill sea turtle movements may reflect the pattern of prey distribution within the internesting habitat as do the movements of loggerhead sea turtles (Stoneburner 1982). The Buck Island Channel (Fig. 2) is composed of a series of small patch reefs (16-20 m depth) with high sponge abundance (Gladfelter 1988, Table 4), the primary prey of hawksbill sea turtles (Meylan 1984). Stoneburner (1982) reported internesting loggerhead sea turtles in the Georgia Bight made similar direct movements towards small patches of natural and artificial stable substrate with abundant prey. However, such movements were in excess of 15 km, probably reflecting differences in distances between patches of prey (Stoneburner 1982). The loggerhead sea turtles did not remain on patches but moved between them on a regular basis. The localized distribution and abundance of food resources within the Buck Island Channel enable hawksbill sea turtles to successfully forage within a more confined area.

Movements of green sea turtles during their internesting period are related to courtship and mating (Carr et al. 1974, Dizon and Balaz 1982), but are probably not a factor in directing the movements of hawksbill sea turtles. Hawksbill sea turtles are considered diffuse, solitary nesters, and congregations of breeding individuals have never been observed. Unlike green sea turtles, hawksbill sea turtles do not congregate into mating groups.

All hawksbill sea turtles, which retained transmitters (n=4), exited the area around St. Croix immediately after their final nesting, indicating some hawksbill sea turtles that nest on BUIS may migrate from elsewhere in the Caribbean. Hawksbill sea turtles may leave the area around St. Croix and return within weeks or months of departure. Satellite telemetry studies on one individual that nested on BUIS indicated this individual had not returned to the area around St. Croix after 6 months (E. Molz, 1992, per. comm.). Post-nesting movements of this individual were northeast initially, but within two weeks it was off St. John (USVI), St. Thomas (USVI), and Tortola (British Virgin Islands). Such evidence is contrary to other studies which suggest that they undergo little or no migration (Carr and Stancyk 1975; Bustard 1979). Carr and Main (1973) reported indigenous turtle farmers of the Torres Strait area of northern Australia could identify the rookery where juvenile hawksbill sea turtles orginated by coloration alone. They suggested that populations of hawksbill sea turtles in the Torres Strait were isolated and underwent no migration, resulting in selective inbreeding that produced the observed distinctive color morphologies. Thurston (1976) suggested that repeated sightings of individual turtles in Puerto Rico indicated their residency. In Costa Rica, Bjorndal et al. (1985) found hawksbill sea turtles remained in coastal areas for over a year where the reef system was "good". A juvenile hawksbill sea turtle caught on Yaeyama Island, near Japan, was released and caught again 18 months later only nine km away (Kamezaki 1987). Contrary to such evidence, tagged hawksbill sea turtles have been reported to undergo migrations of 100 to 16,000 km (Pritchard 1976; Meylan 1984; Marcovaldi and Filippini 1991). An adult female hawksbill sea turtle, captured and tagged in northern Australia, near Cambell Island (9°33'S, 143°31'E), was recorded nesting 1,650 km away 322 days later within the Solomon Islands (7°25"S, 158°E; Paramenter 1983). De Silva (1986) reported one individual, captured in the Philippines, traveled 713 km in 40 days.

Long surface intervals of hawksbill sea turtles during the day (1000 hr-1759 hr, Fig. 8) were probably a result of basking-like behavior. Green sea turtles have been reported to bask on land in French Frigate Shoal, Hawaii (Dizon and Balaz 1982), and long mid-day surfacing by leatherback sea turtles probably represented basking (Eckert et al. 1986).

Except for the olive ridley sea turtles, duration of dives by hawksbill sea turtles were relatively long compared to other sea turtle species studied during their internesting period (Table 5). For all air breathing animals, submergence duration may be enhanced by increasing oxygen stores in the body, rationing oxygen stores so that vital organs are well supplied, using energy stores more completely, and reducing energy requirements by inactivity (less swimming; Kooyman 1982). Total metabolic requirements of animals are less when resting; although not well understood, the reason for this decline must be at least partially related to a reduced activity of the heart, kidney, and respiratory muscles (Kooyman 1982). Reduced underwater movements of hawksbill sea turtles during the internesting period would allow longer dive intervals due to reduced metabolic demand. On 13 occasions, one hawksbill sea turtle was located using acoustic telemetry and was found to be motionless amongst sea grass on a sandy bottom. Reduced metabolic demand during submergence and basking-like behavior may allow hawksbill sea turtles to conserve energy between nesting attempts.

Hawksbill sea turtles may remain motionless on the bottom during their internesting period to camouflage themselves from predators. Both tiger sharks (*Galeocerdo cuvieri*) and bull sharks (*Carcharhinus leucas*) occur in the Caribbean (Gladfelter 1988) and prey on sea turtles (Bustard 1982). By remaining on the bottom during long submergences, hawksbill sea turtles may effectively reduce the probability of encounter with coral reef predators.

Avoidance of male hawksbill sea turtles may also be an added benefit of remaining inconspicuous on the bottom during submergence (R. Byles, pers. comm., U.S. Fish and Wildlife Service). Carr et al. (1974) mentioned the existence of a "female reserve" area for green sea turtles where they rest on the bottom sand, apparently immune to the harassment of males. Male hawksbill sea turtles may mount females for long periods of time in which the female must swim with the burden of the male. Avoiding such contact with males would be a means of conserving energy. Female hawksbill sea turtles which remain motionless on the bottom are less likely to be encountered by males.

Short surface and dive intervals characterizing approach and departure of the nesting beach (Fig. 5) may have been related to movements and metabolic demand imposed on hawksbill sea turtles as they approached and departed the nesting beaches. Longer dives characterized days two through 12 of the internesting period and probably reflected a reduction of activity during this period.

Sea turtles seeking patchy prey under water must move often, thereby increasing metabolic requirements which should reduce dive durations. Dive duration of leatherback and Kemp's ridley sea turtles during the internesting period may be related to prey availability (Eckert et al 1989; Mendonca and Pritchard 1986). At Sandy Point Wildlife Refuge, St. Croix, diel movements of leatherback sea turtles were correlated with movements of their prey (e.g. pelagic medusae, siphonophores, and salps), and seasonal weight loss of turtles was negligible (Eckert et al. 1989). This suggests leatherback sea turtles feed during their internesting period. To forage on prey, leatherback sea turtles must swim persistently, dive deeply, and tolerate a variety of ambient temperatures (Eckert et al. 1989). Kemp's ridley sea turtles move up to 10 km a day and search for areas of high prey abundance or other turtles (Mendonca and Pritchard 1986). Due to long vertical and/or horizontal movements, metabolic demands on leatherbacks and Kemp's ridley sea turtles were likely high and dive times were relatively short when compared with hawksbill sea turtles (Table 5).

In order for hawksbill sea turtles to consistently dive for relatively long periods of time, they must be able to increase their aerobic dive limit (ADL). The ADL is the maximum breath-hold that is possible without any increase in blood lactic acid concentration during or after a dive (Kooyman 1989). This limit is dependent upon available oxygen stores, oxygen consumption rate, degree of peripheral vasoconstriction, and rate of lactic acid production and consumption. Animals cannot exceed the ADL without some tolerance to anoxia in some organs (Kooyman 1989). Such tolerance is not known to exist in any vertebrate except fresh water turtles (Gatten 1981). The ADL of 20 kg loggerhead sea turtles was reported to be 33 min (Lutz and Bentley 1985) and 44 min for a 450 kg leatherback sea turtle (Kooyman 1989). Assuming that ADL for hawksbill sea turtles is between that of a 20 kg loggerhead and a 450 kg leatherback, their ability to consistently exceed this maximum (mean dive duration= 56.1 min) must be related to a cessation of body function or unknown physiological conditions.

Hawksbill sea turtles relocated 0.06 km sections of the nesting beach that they had nested on previously. Six hawksbill sea turtles returned to the same offshore site after each subsequent nesting event. Studies of how hawksbill orient themselves in the marine environment are needed. The departure of four hawksbill sea turtles immediately following their last nesting event indicated that some may undergo a reproductive migration. Studies should focus on the extent of these migrations and variation within a population. Dive durations of hawksbill sea turtles were greater than reported for other species of sea turtles, except the olive ridley sea turtle. Long dive duration and motionless behavior of female hawksbill sea turtles may be related to avoidance of predators or of male hawksbill sea turtles. The physiological mechanism for such long dives is not known but may involve a reduced metabolism; therefore, studies are needed on blood chemistry and physiology of hawksbill sea turtle diving.

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Table 1. Location and time observed of nests and dry runs of seven hawksbill sea turtles tracked. Marker numbers refer to stakes placed on nesting beaches of Buck Island Reef National Monument, St. Croix, USVI: turtle bay (TB), southshore (SS), west beach (WB) and northshore (NS, Fig. 1).

Turtle ID	Activity	Date	Time Observed	Location Marker
79	dry run	3 Jul	2103	TB
79	dry run	5 Jul	2120	SS 34
86	nest	11 Jul	2300	NS 3
14	dry run	14 Jul	2145	NS 3
14	nest	14 Jul	0145	NS 7
79	nest	22 Jul	0011	SS 26
86	dry run	25 Jul	0115	WB 13
86	nest	26 Jul	0429	NS 5
34A	nest	26 Jul	0145	SS 26
14	nest	30 Jul	0217	NS 7
79	nest	6 Aug	0245	NS 5
03	nest	8 Aug	2144	NS 5
86	nest	10 Aug	2100	WB 15
14	nest	15 Aug	2315	NS 5
54	nest	21 Aug	2015	NS 3
86	dry run	23 Aug	0203	SS 24
03	nest	23 Aug	2245	NS 5
34A	dry run	23 Aug	0140	TB 34
34A	nest	24 Aug	2148	TB 38
79	nest	24 Aug	2346	SS 30
86	nest	25 Aug	2334	WB 15
34B	nest	1 Sept	0422	TB 34
54	nest	5 Sept	2032	NS 5
03	dry run	6 Sept	2035	NS 3
03	nest	8 Sept	2356	NS 11
34B	dry run	13 Sept	2350	SS 28
54	nest	20 Sept	2215	NS 3
34B	nest	28 Sept	0140	NS 7
54	nest	4 Oct	2353	NS 3

Table 2. Size (cm, over the curve), date of transmitter deployment, days at large, number of fixes, and number of internesting intervals monitored for seven hawksbill sea turtles tracked. Locations are single, in which one telemetry station received a fix; or double, in which both stations received good radio signals or a acoustic fix was obtained. Each internesting interval represents a period of 14 days on average.

Turtle (ID)	Size (cm)	Date Deployed	Tracking Days	Location Single./Dbl.	Internesting Intervals
86	86.5	11 July	45	62/12	3
14	99	14 July	31	48/13	2
79	84	22 July	32	46/23	2
34A	88	26 July	29	26/1	unknown
03	90	9 Aug.	31	58/22	2
54	no data	21 Aug.	29	48/0	2
34B	91	1 Sept.	13	19/2	unknown

Table 3. Mean dive duration and surface intervals for day (0600-1759 hr), night (1800-0559 hr) and combined, for seven hawksbill sea turtles tracked.

Turtle ID	Period	Dive duration (min) Mean±SD	N	Surface interval (min) Mean±SD	N
86	Day	58.9±13.29	29	1.8±1.05	54
	Night	67.3±11.63	14	1.4±0.20	34
	Total	61.6±13.2	43	1.5±1.20	88
14	Day	55.4±21.25	13	2.0±0.96	32
	Night	73.5±8.76	15	1.6±0.56	26
	Total	65.06±18.03	28	1.8±0.82	58
78	Day	56.7±8.18	6	1.7±0.81	24
	Night	64.1±1.72	2	1.5±0.28	10
	Total	58.6±7.74	8	1.7±0.70	34
03	Day	63.5±13.07	11	1.7±1.19	29
	Night	45.8±23.15	5	1.3±0.58	18
	Total	58.0±21.90	16	1.6±1.02	47
34A	Day	no data		1.41±0.47	12
	Night	no data		1.04±0.12	8
	Total			1.27±0.41	20
54	Day	52.9±19.96	21	2.0±0.77	31
	Night	42.3±3.35	20	1.0±0.50	26
	Total	48.6±15.89	41	1.6±0.81	57
34B	Day	33.8±13.57	8	1.5±0.65	10
	Night	41.7±2.70	3		
	Total	36.0±12.00	11	1.5±0.65	10
	Cumulative	56.2±17.26	147	1.6±0.94	314

Table 4: Percent cover of flora and fauna found on reef and sea grass habitat within areas of concentrated movements for hawksbill #03 and 79.

Reef

Species	*#03 site*	*#79 site*
coral		
Montastraea cavernosa	4	2
Montastraea annularis	5	–
Manicina areolata	<1	–
Millepora spp.	<1	<1
Diploria labyrinthiformis	<1	–
Dichocoenia stokesii	<1	–
Diplora strigosa	<1	–
Agaricia agricites	<1	–
Cal. natans	<1	–
Siderastrea siderea	<1	<1
sponge	3	2
gorgonian	4	14
algae		
Dictyota spp.	6	–
sand/rubble	74	81

Sea Grass

Species	*#03 site*	*#79 site*
algae		
Dictyota spp.	4	<1
Halmeda spp.	2	11
Cladocelphalus spp.	2	–
Dasyi harveyi	1	–
unidentified	1	1
grass		
Syringodium spp	13	–
corals	–	<1
gorgonians	–	<1
sand/rubble	77	87

Table 5. Mean and maximum dive durations during the internesting period for five species of sea turtles: the Kemp's ridley, loggerhead, leatherback, olive ridley, and hawksbill sea turtles (Eckert et al. 1989).

Species	Dive Duration (min) Mean±SD		Maximum	*n*	Size	Source
Kemp's ridley 1986	16.7	22.74	167.0	536	mature	Mendonca and Pritchard
	32.2	34.50	480.0	71	mature	
Loggerhead	14.9	—	99.0	—	mature	Soma 1985
	20.3	—	99.0	—	mature	Soma 1985
Leatherback	11.2	4.20	21.3	339	139.8 cm	Eckert et al. 1986
	10.4	4.70	27.8	323	139.8 cm	Eckert et al. 1986
	14.5	5.20	37.4	306	145.5 cm	Eckert et al. 1986
	12.4	5.60	37.1	301	145.5 cm	Eckert et al. 1986
	10.4	4.82	37.4	952	144.1 cm	Eckert et al. 1989
	12.9	5.86	32.4	695	152.4 cm	Eckert et al. 1989
	6.9	2.37	17.6	1070	153.3 cm	Eckert et al. 1989
	13.5	8.3	21.5	503	157.2 cm	Eckert et al. 1989
	8.1	3.97	35.1	705	158.6 cm	Eckert et al. 1989
	9.6	3.90	19.9	1141	162.6 cm	Eckert et al. 1989
Olive ridley	82.1	58.1	165.8	10	72.0	P. Plotkin per. comm.
	54.8	54.2	182.0	22	69.0	P. Plotkin per. comm.
	6.8	47.6	178.3	17	72.0	P. Plotkin per. comm.
	48.5	46.7	126.4	20	72.0	P. Plotkin per. comm.
	34.8	34.6	136.8	25	68.0	P. Plotkin per. comm.
	45.4	38.5	127.2	22	69.0	P. Plotkin per. comm.
	90.7	55.8	170.2	14	75.0	P. Plotkin per. comm.
	57.0	13.7	95.6	4	66.5	P. Plotkin per. comm.
	35.7	35.8	104.7	9	68.0	P. Plotkin per. comm.
	27.2	28.9	74.1	8	66.5	P. Plotkin per. comm.
	40.3	26.8	60.3	4	70.0	P. Plotkin per. comm.
	73.2	39.1	130.8	9	69.5	P. Plotkin per. comm.
	43.6	27.0	74.5	7	67.0	P. Plotkin per. comm.
	32.0	23.5	66.2	14	65.5	P. Plotkin per. comm.
Hawksbill	61.6	13.2	88.2	43	86.5 cm	this study
	65.1	18.03	101.9	28	99.0 cm	this study
	58.6	7.74	65.3	8	84.0 cm	this study
	58.0	21.90	86.2	16	90.0 cm	this study
	48.6	15.89	101.5	41	no data	this study
	36.0	12.0	53.8	11	91.0 cm	this study

Note: Size refers to carapace length. All are from studies of wild (as opposed to captive) turtles.

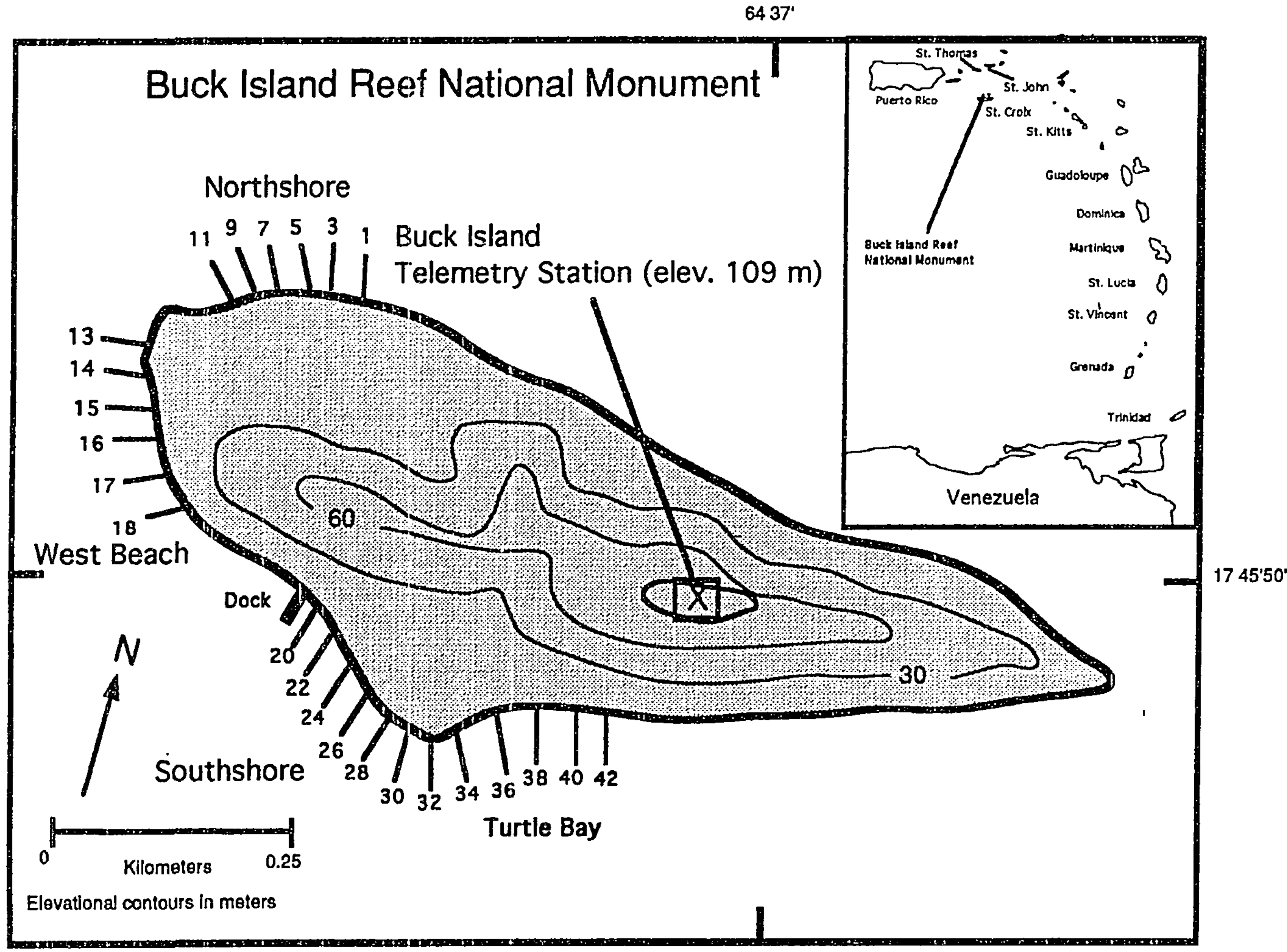

Figure 1. Map of Buck Island Reef National Monument study site. Numbers represent reference stakes on beaches patrolled for nesting hawksbill sea turtles.

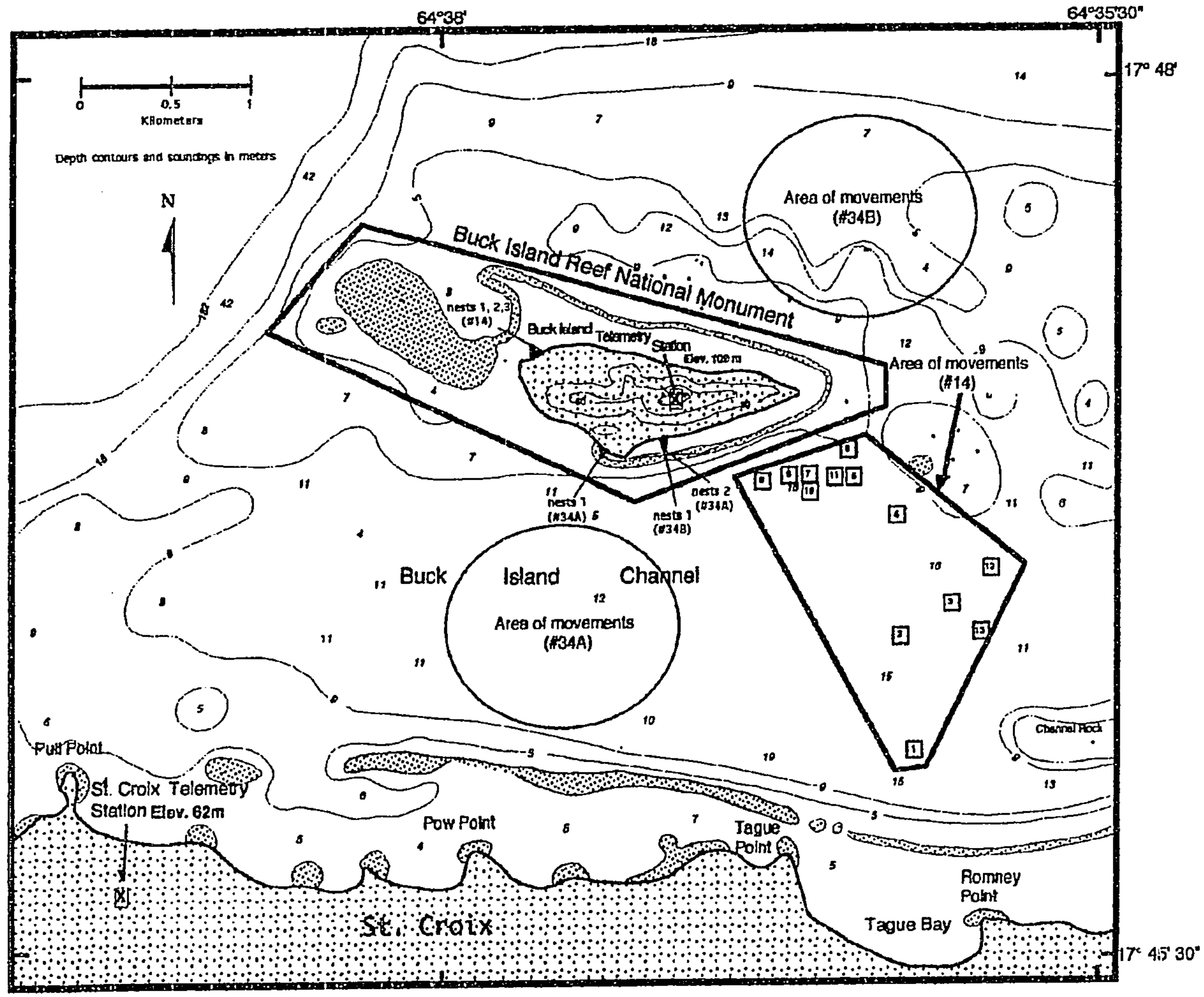

Figure 2. Areas of movements and nest sites of hawksbill sea turtles #14, 34A and 34B tracked near Buck Island Reef National Monument, St. Croix, U.S. Virgin Island. Movements of hawksbill sea turtles #34A and 34B were estimated from single fixes and are represented by circles. Radio and acoustic fixes for hawksbill #14 are numbered chronologically.

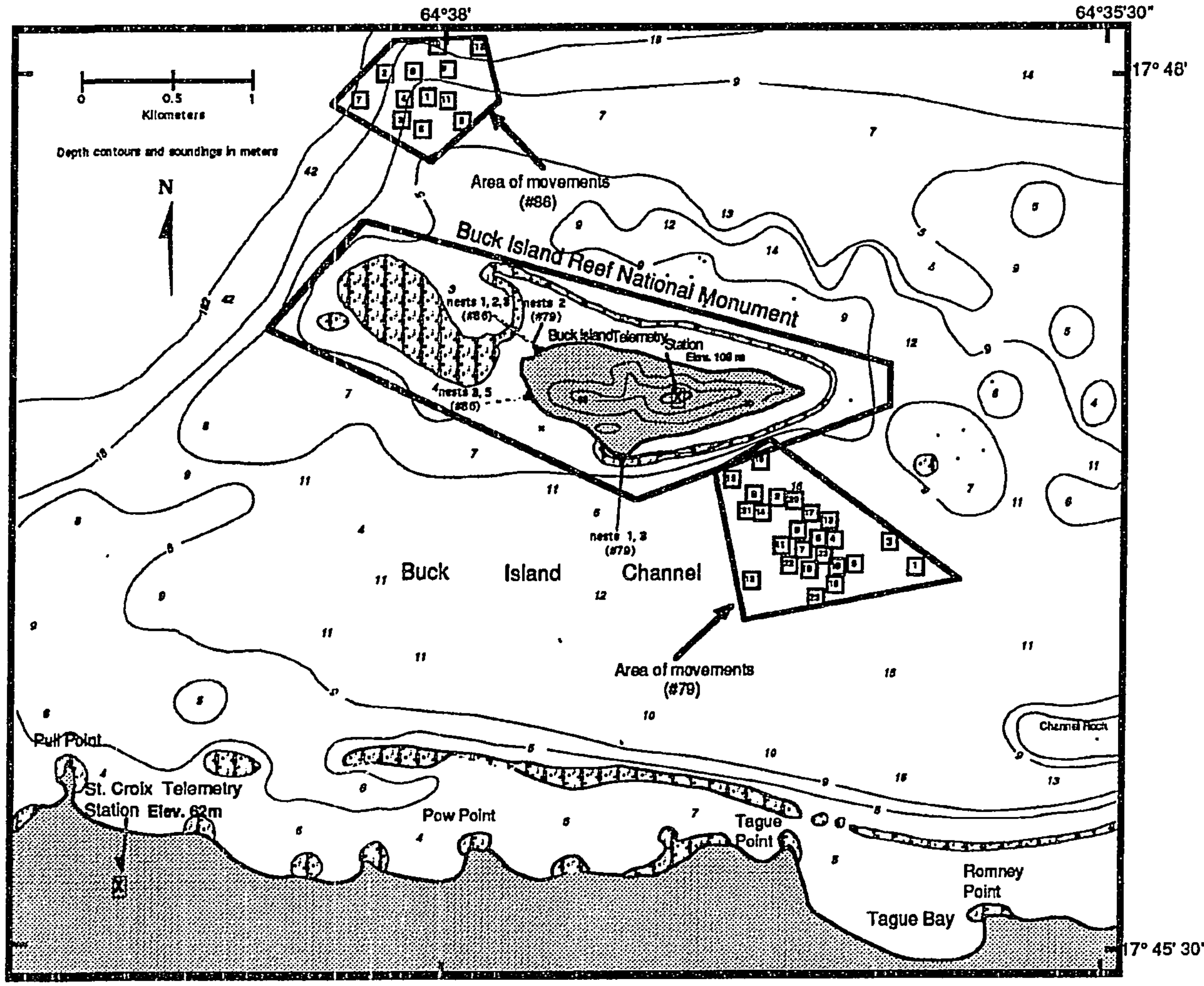

Figure 3. Areas of movements and nest sites of hawksbill sea turtles #86 and 79 tracked near Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands. Radio and acoustic fixes are numbered chronologically.

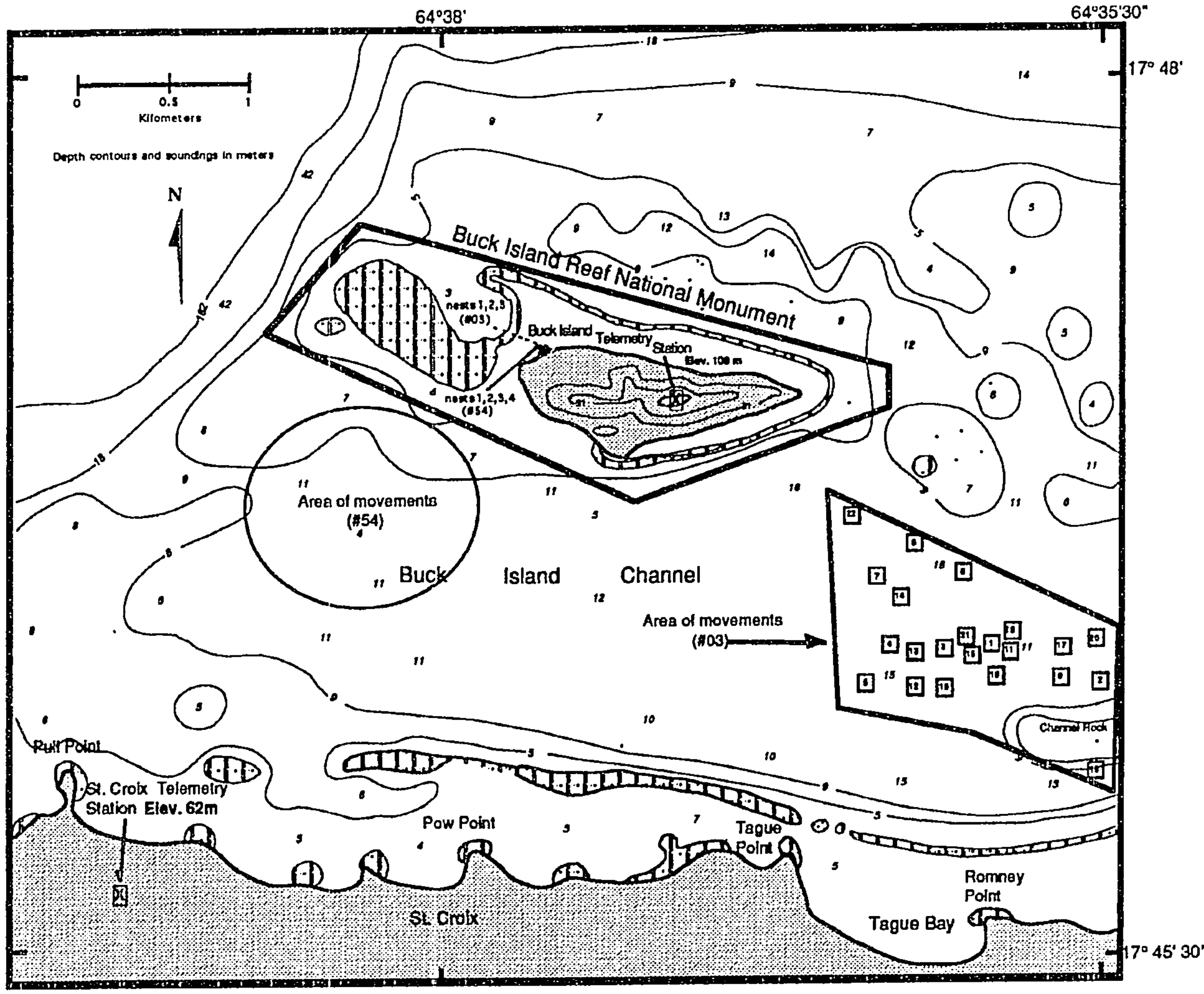

Figure 4. Areas of movements and nest sites of hawksbill sea turtles #03 and 54 tracked near Buck Island Reef National Monument, St. Croix, U.S. Virgin Island. Movement of hawksbill sea turtle #54 were estimated based on single fixes and are represented by a circle. Radio and acoustic fixes for hawksbill #03 are numbered chronologically.

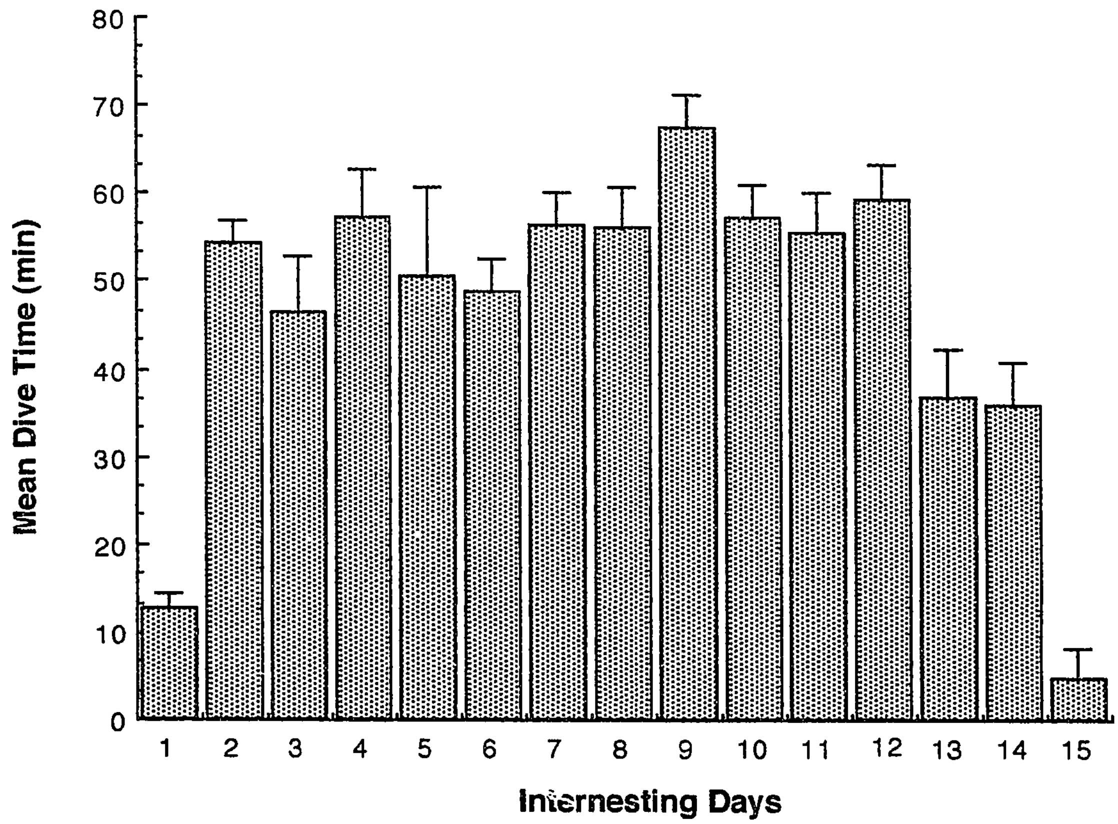

Figure 5. Cumulative mean dive time (min) compared with internesting days (1-15). Standard error bars are depicted for each day.

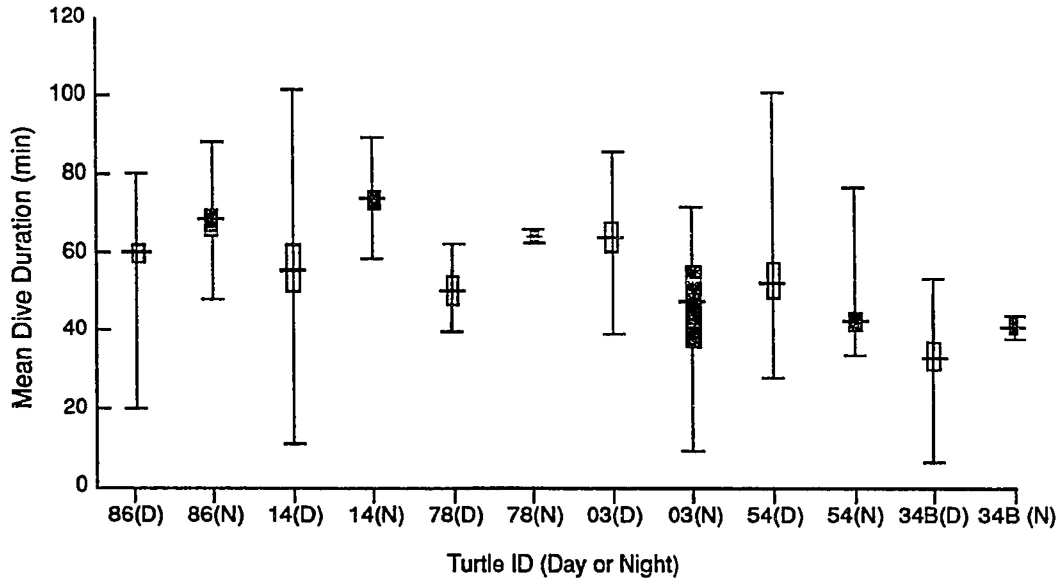

Figure 6. Mean dive durations (min) for individual hawksbill sea turtle monitored during day (0600-1759 hr) and night (1800-0559 hr). Light (day) and dark (night) boxes indicate standard errors and the range of dive times is indicated by the vertical lines.

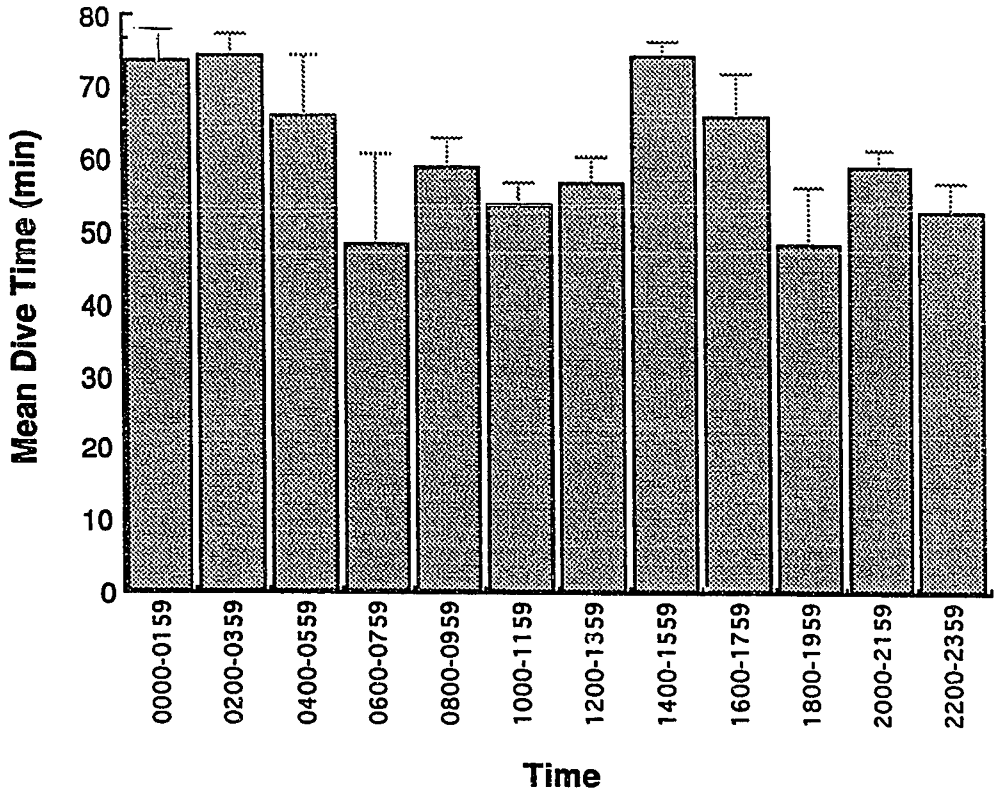

Figure 7. Cumulative mean dive time (min) compared with time of day in two hour blocks. Standard error bars (vertical lines) are depicted for each time period during the day.

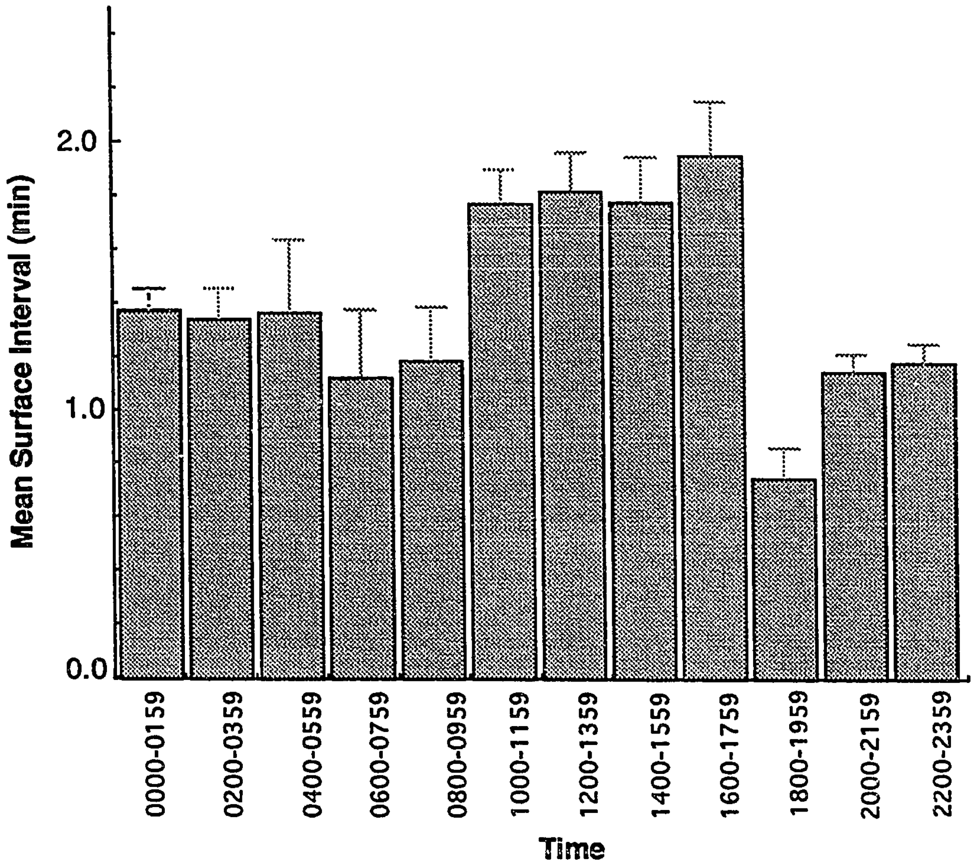

Figure 8. Cumulative mean surface interval (min) compared with time of day in two hour blocks. Standard error bars (vertical lines) are depicted for each time period during the day.