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RESEARCH ARTICLE

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# Home range and habitat use of juvenile Atlantic green turtles (*Chelonia mydas* L.) on shallow reef habitats in Palm Beach, Florida, USA

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**Abstract** Many animals, including sea turtles, alter their movements and home range in relation to the particular type and quality of the habitat occupied. When sufficient resources are available, individuals may develop affinities to specific areas for activities, such as foraging and (or) resting. In the case of green sea turtles (*Chelonia mydas* L.), after a number of years in the open ocean, juveniles recruit to shallow-water developmental habitats where they occupy distinct home ranges as they feed and grow to maturity. Our goal was to study the habitat use and home range movements of juvenile green turtles along a shallow, worm-rock reef tract in Palm Beach, Florida. Six turtles, measuring from 27.9 to 48.1 cm in straight carapace length and from 7.2 to 12.6 kg in mass, were tracked via ultrasonic telemetry from August to November 2003. Upon capture, each turtle's esophagus was flushed via lavage to determine recently ingested foods. In addition, four turtles were recaptured and fitted with a time-depth recorder to study dive patterns. Home range areas measured with 100% minimum convex polygon and 95% fixed kernel estimators varied from 0.69 to 5.05 $km^2$ (mean=2.38±1.78 $km^2$) and 0.73 to 4.89 $km^2$ (mean=2.09±1.80 $km^2$), respectively. Home ranges and core areas of turtles were largely restricted to the reef tract itself, and showed considerable overlap between food and shelter sites. The mean number of dives during daylight hours (0600–1800 hours) was 84±5.0 dives, while the mean during night hours (1800–0600 hours) was 39±3.0 dives. Dives during the day were shallower (mean=3.20±1.26 m) than dives at night (mean=5.59±0.09 m). All six turtles were found to have a mixed diet of similar macroalgae and sponge fragments. Our results reveal that juvenile green turtles occupy stable home ranges along the nearshore worm-rock reefs of Southeast Florida, during the summer and fall. Determining which habitats are used by green turtles will assist conservation managers in their global effort to protect this endangered species.

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## Introduction

Most marine vertebrates undergo ontogenetic shifts in habitat use over the course of their lives. Considerable research has centered on how these organisms select, move about within, and exploit resources in those habitats (e.g., Zeller 1997; Parsons et al. 2003). The green sea turtle (*Chelonia mydas* L.) is a typical example. After 3–5 years of pelagic existence in the open ocean, juvenile turtles recruit to coastal waters and occupy a series of developmental habitats over the many years required to reach sexual maturity (Musick and Limpus 1997). Upon attaining sexual maturity, green turtles commence breeding migrations between foraging grounds and nesting areas that are undertaken in multiple year intervals (Hirth 1997). Migrations are carried out by both males and females and may traverse oceanic zones, often spanning thousands of kilometers (Mortimer and Carr 1987; Luschi et al. 1998). During non-breeding periods adults reside at neritic feeding grounds that may coincide with juvenile developmental habitats (Limpus et al. 1994; Seminoff et al. 2003).

While previous research on sea turtle movements has dealt primarily with adult reproductive migrations (e.g., Balazs and Ellis 2000; Cheng 2000; Addison et al. 2002), juvenile movements in neritic developmental habitats are less understood. To date, home ranges have been studied for the green turtle (Mendonca 1983; Brill et al. 1995; Seminoff et al. 2002), the hawksbill (*Eretmochelys imbricata*; van Dam and Diez 1998; Houghton et al. 2003), the loggerhead (*Caretta caretta*; Renaud and Carpenter 1994), and the Kemp's Ridley (*Lepidochelys kempii*; Schmid et al. 2003). In each study, normal daily activities were concentrated in areas where food resources were in the greatest abundance. Those findings are consistent with the hypothesis that by establishing a home range, juveniles enhance their access to resources that offer the most benefit for the turtles' growth to sexual maturity (Limpus and Walter 1980; Limpus et al. 1994).

The development of animal-borne telemetry systems has enabled studies of sea turtle behavior, habitat use, and migratory movements that would otherwise be impossible. One such tool is ultrasonic telemetry, which is ideal for tracking sea turtles within their home ranges because ultrasonic pulses are transmitted through the water, irrespective of the turtle's depth. By using several underwater hydrophones in conjunction with one another, ultrasonic telemetry can be used to locate telemetered turtles with a greater precision than either VHF or satellite telemetry (Epperly et al. 1996, Boarman et al. 1998). Moreover, when this technology is coupled with time-depth recorders (TDRs), both the vertical and horizontal movments of turtles can be characterized and periods of inactivity (i.e., resting behavior) can be distiguished from periods of activity (Eckert et al. 1989; van Dam and Diez 1996).

Sea turtle tracking efforts utilizing both ultrasonic telemetry and TDR technology have been undertaken in Kaneohe Bay, Hawaii (Brill et al. 1995), Gulf of California, México (Seminoff et al. 2002), and Mona Island, Puerto Rico (van Dam and Diez 1996; 1998). The con- current use of these telemetry techniques were effective in showing that sea turtles occupy distinct home ranges within nearshore habitats and that turtle diving behavior may differ depending on the time of day and the type of habitat occupied. These studies also revealed that green turtle foraging strategies may vary in response to site- specific differences in abundance and concentration of essential resources. In Kaneohe Bay, where resources (i.e., macroalgae and shelter sites) were concentrated in space, the estimated average green turtle home range measured less than 3.00 km$^2$ (Brill et al. 1995). However, in a large marine basin like the Gulf of California, where pastures of macroalgae were found to grow at widely spaced patch intervals, the estimated average green turtle home range measured greater than 16.00 km$^2$ (Seminoff et al. 2002). Comparisons among these studies suggest that this variation in home range size coincides with the respective ecological differences of each study site (e.g., food and shelter resource availability and distribution).

In this study, we used ultrasonic telemetry and TDRs to track juvenile green turtles along shallow (2–6 m deep) worm-rock reefs in Southeast Florida (Palm Beach County, eastern Atlantic coast, USA), a developmental habitat not previously investigated. Our goals were to (1) measure the home range and diving activity of juvenile turtles, (2) examine the relationship between foraging behavior and habitat structure of shallow worm-rock reefs, (3) determine if the turtles showed an affinity to any specific core areas, and (4) reveal patterns of overlap among the turtles' home ranges. With knowledge of these movement patterns and habitat use, conservation managers will be better equipped to protect the nearshore foraging habitat of juvenile green turtles.

## Materials and methods

### Study area

This study was conducted from August to November 2003 on a nearshore reef segment in Palm Beach County along Florida's East Coast (26°46.300'N, 80°03.500'W; Fig. 1). The reef tract consisted of a rv9.0-km long segment of hardbottom, was 300 m at its widest, and had an average water depth of 4.0 m (range: 2.0 – 6.0 m). The reef was characterized by slender hard-bottom substrates created by *Phragmatopoma lapidosa*, a colonial species of sabellariid polychete worm (Kirtley 1966). Dominant macroalgae species included various species of Rhodophytic algae (e.g., *Gracilaria mammillaris*, *Hypnea spinella*, and *Acanthophora spicifera*) (Wershoven and Wershoven 1988, 1992; Coastal Planning & Engineering, Inc. 2003).

### Marine turtle foraging habitat assessment

Atlantic and Gulf Rapid Reef Assessment (AGRAA) protocol was used to evaluate the macroalgal communities for green turtle foraging habitat (Ginsburg 2000). AGRAA protocol specifies sampling along 50-m tran- sects every 3 m using a 25·25 cm$^2$ quadrat. Six transects were monitored with an assessment station designated every 3 m, for a total of at least 16 stations per transect. At every 3-m interval, the overall macroalgal percent cover, the two dominant macroalgal species, and any additional benthic organisms (e.g., sponges, tunicates, hydroids) were recorded. The percent cover of turf and coralline algae and the presence of any stony and soft coral were also recorded.

### Turtle capture and initial measurements

Using SCUBA, six resting juvenile green turtles were captured by hand from under reef ledges. Turtles were seized at the nuchal and posterior marginal scutes, brought to the surface, and placed aboard the research vessel. This method of capture has been shown to be safe for juvenile turtles in a number of previous studies (e.g., Wershoven and Wershoven 1988; van Dam and Diez 1998; Balazs 1999; Ehrhart and Ogren 1999).

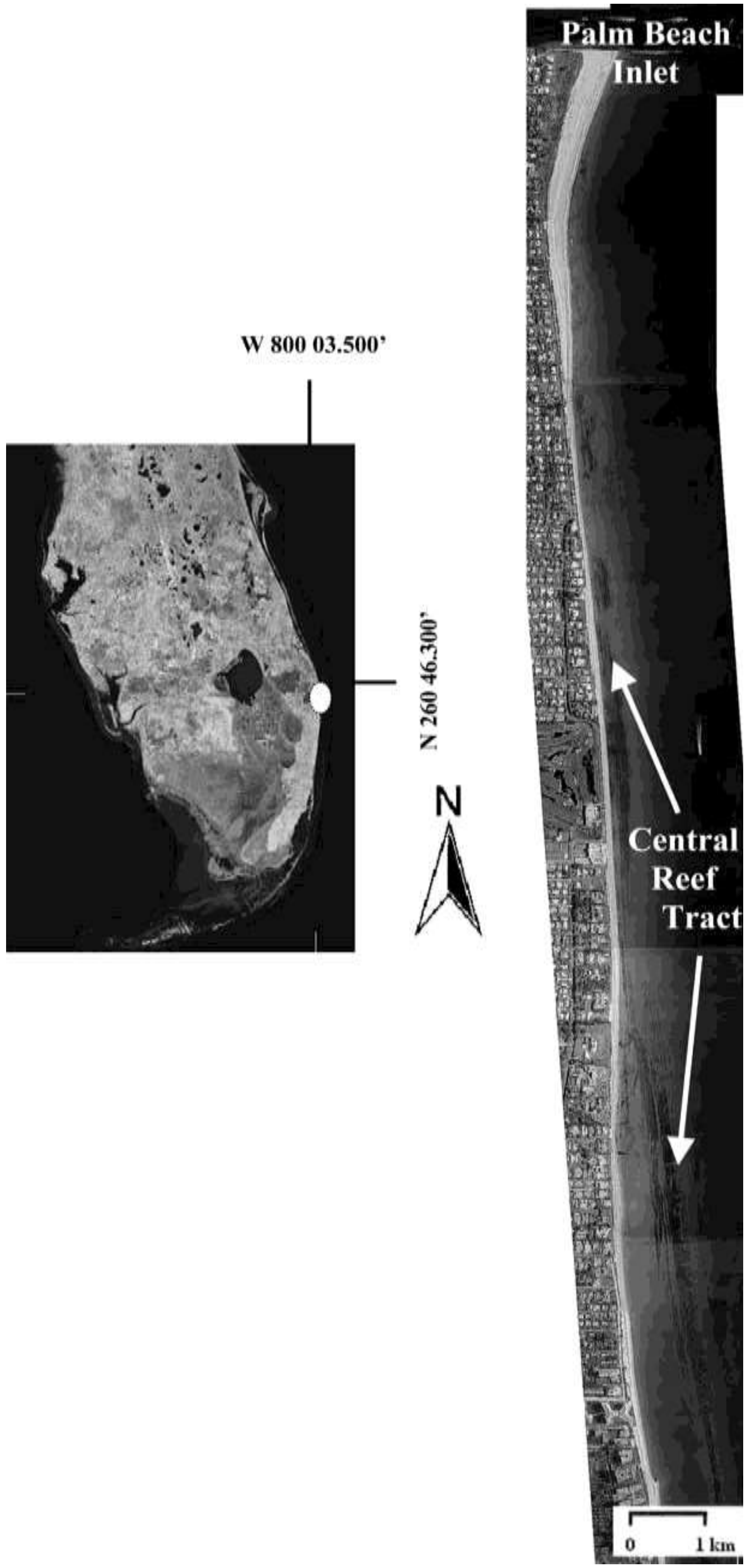


Fig. 1 Our study site along the coastal shoreline of Palm Beach, Florida, USA. *Dark areas* running parallel to shore are worm-rock reef tracts

Upon capture, turtles were transported within 1–2 h to the Florida Atlantic University Sea Turtle Laboratory, where they were housed in a plastic holding container and kept wet. The straight-line carapace length (SCL; ±0.1 cm) and curved carapace length (CCL; ±0.1 cm) from the nuchal notch to the posterior-most portion of the rear marginals were measured. Turtles were weighed (±1.0 kg) with a spring balance and cargo netting. Each turtle was photographed to record individual marks, such as papillomas, epiphytes, and injuries. All turtles were released at the site of initial capture within 24 h.

### Lavage

Diet was determined once for each turtle by esophageal lavage. This technique was used to flush the esophagus and stomach, providing a sample of food resources that the turtles had ingested (Forbes and Limpus 1993). Turtles were placed on their carapace, with their head positioned downward and the mouth was kept open with a plastic pry bar. A thin water-injection tube (3.5 mm inside diameter) was lubricated with vegetable oil and passed down the esophagus until resistance was met when the stomach was reached. Four liters of sea- water, collected in the field, were then pumped through the tube to begin the flushing. A bucket was placed underneath the mouth to retrieve the water sample in addition to any food left in the crop or lodged in the esophageal papillae. Once the sample was acquired, the tube was removed.

Lavage samples were preserved in 5% formalin mixed with filtered seawater. Cross-sections of macroalgae samples were prepared and identification was made through overall plant cell structure. The frequency of occurrence (% Freq.) of each alga in the diet was defined as follows:

$$\%\,\text{Freq.} = (\text{No. of turtles containing food item}/\text{total no of turtles}) \times 100$$

### Transmitter attachment and specifications

Ultrasonic transmitters (Model DT-97; Sonotronics, Tucson, Arizona) were attached to the posterior-most marginal scutes of the carapace using 5-min quick-set epoxy and electrician 'zip-ties', fit through two ~3 mm- diameter drilled holes treated with a Betadine antiseptic solution (Mendonca 1983; Seminoff et al. 2002). Each transmitter (1.8·8.6 $cm^2$) weighed 190 g (19 g in water), equivalent to 1.4–2.6% the body mass of telemetered turtles. The attachment site did not restrict swimming behavior, or otherwise affect the turtle's movements. Transmissions were at ultrasonic frequencies (32– 83 kHz), well above the hearing range of green turtles (30 Hz – 1 kHz; Ridgeway et al. 1969).

Four turtles were recaptured and fitted with a TDR (LTD-1110; Lotek, Wireless, Inc., Newfoundland, Canada). The TDR (1.1·3.2 $cm^2$; 2 g in water) was contained inside a 9.0·13.4 $cm^2$ plastic net pouch, attached with electrician 'zip-ties' and fixed with 5-min quick-set epoxy to the posterior-most marginal scutes on the side opposite of the sonic transmitter location. TDRs recorded depth (±0.5 m) and temperature (±0.5°C) every 5 s for 24 h. Upon a second recapture within 48–72 h after deployment, the TDR was removed and data were downloaded to a computer for analysis.

### Tracking

Tracking of turtles commenced after a 24-h post-release acclimation period and occurred daily from August to November 2003. Each individual was located several times each day, either during the daylight hours (0600–1800 hours) or at night (1800–0600 hours). All tracking was weather permitting and was conducted from an 18-ft (6.0 m) research vessel (Parker 1800) equipped with a 115 hp outboard motor. To locate the position of each turtle, a USR-5W sonic receiver (Sonotronics Inc., Tucson, Arizona) was used in conjunction with either a DH-3 omni-direction hydrophone (Sonotronics Inc., Tucson, Arizona) or a DH-4 directional hydrophone (Sonotronics Inc., Tucson, Arizona). The omni-directional hydrophone had the greatest sensitivity (reception range up to 3 km) and was thus used to determine the general presence or absence of telemetered turtles in the study area. When a signal was identified, the directional hydrophone to was used pinpoint the turtle's exact location. Once within ~20 m of the turtle, its location was confirmed visually as the turtle surfaced or with the use of snorkel equipment. Upon visual confirmation, the turtle's location was recorded with a hand-held Global Positioning System (GPS; Garmin Etrex Venture; Ramsey, UK) on board the boat. Accuracy of the GPS locations was ±3–5 m. To min- imize observer disturbance to the turtles, the tracking vessel maintained a distance of ≥10 m from all tracked turtles.

### Home range spatial analysis

Home range areas were estimated using the Animal Movement Analyst Home Range Extension (HRE; http://www.blueskytelemetry.com/hre.asp) for the ArcView version 3.3 geographic information system (ArcView GIS) software (Environmental Research Systems Institute; Redlands, CA, USA). The HRE used the minimum convex polygon (MCP; Burt 1943) and fixed kernel density estimator (FKD; Worton 1989) methods to estimate home range size of each turtle. MCP home range estimates were constructed by connecting the peripheral locations from a group of fixed sighting data with a solid line and provided the total estimated area traversed by an individual (Harris et al. 1990; White and Garrott 1990). Fixed kernel home ranges were calculated with least square cross validation as a smoothing parameter (Silverman 1986; Seaman and Powell 1996). A 95% utilization distribution (UD) was used to estimate the overall home range used by a turtle, whereas a 50% UD was used to establish the core area of activity (Worton 1989; White and Garrott 1990). To minimize serial correlation, home range analyses included resighting positions temporally separated by ‡ 4 h (Swihart and Slade 1985; Hansteen et al. 1997). All home ranges were plotted on a digital, geo-referenced aerial photograph of the study site (supplied by the Department of Environmental Resources Management, Palm Beach County, FL, USA).

### Statistical analysis

General linear modeling (GLM; Cohen and Cohen 1983) was used to determine the relationship between the home range estimates (log MCP; log 95% FKD) and the home range predictors (log SCL; log mass). The MCP and FKD home range area estimates for each individual turtle were compared with a Wilcoxon rank sum test (Zar 1999).

Diving frequencies during the day (0600–1800 hours) were compared to those at night (1800–0600 hours) with a paired two sample *t*-test. Two sample t-tests were used to compare the daytime dive depths to the nighttime dive depths for individual turtles. A variance ratio *F*-test was used to compare the variance of dive depths between daytime and at night for all four turtles. Dive profi le plots of time (h) versus depth (m) were created for each subject.

Analyses were conducted with SPSS software (SPSS Inc.; Chicago, IL, USA) with signifi cance based on *P* £ 0.05. Mean values are followed by standard errors (± SE), unless otherwise noted.

## Results

### Tracking eff ort and home range characteristics

A total of six turtles measuring between 27.9 – 48.1 cm in SCL (mean=36.7±8.1 cm) and 7.2 – 12.6 kg in mass (mean=9.9±2.1 kg) were tracked in this study. Tracking duration ranged from 55 to 62 days (mean=59.3±2.5 days), with an average of 94±5 sightings per turtle (Table 1).

Home range area plots for the six turtles tracked in this study are presented in Figs. 2, 3 and 4. MCP home range areas ranged from 0.69 to 5.05 $km^2$ (mean=2.38±1.78 $km^2$) and FKD home ranges spanned from 0.73 to 4.89 $km^2$ (mean=2.09±1.80 $km^2$) (Table 1). Mean 100% MCP was slightly larger than mean 95% FKD, but a Wilcoxon rank sum test indicated that the medians were not signifi cantly diff erent (*Z*=-1.99, *P*=0.05). There were no signifi cant relationships between home range estimates (log 100% MCP; log 95% FKD) and home range predictors (log SCL; log mass) ($R^2_{MCP\text{-}SCL}=0.09$, $P=0.51$; $R^2_{MCP\text{-}MASS}=0.16$, $P=0.36$; $R^2_{FKD\text{-}SCL}=0.17$, $P=0.39$; $R^2_{FKD\text{-}MASS}=0.20$, $P=0.32$).

### Core areas

Turtle core areas were determined to be associated with either foraging activity centers or nocturnal resting sites. Foraging activity centers (50% FKD) measured between 0.18 and 1.17 $km^2$ (mean=0.49±0.39 $km^2$) and ranged from 10 to 67% of the 95% FKD area (Table 1). All core areas were confi ned to the narrow, nearshore reef track and showed considerable overlap with neighboring turtles; none were located over sand (Figs. 2, 3, 4).

At night, each turtle continously revisited their own exclusive resting site along the nearshore reef tract. Four of the six turtles (turtle no. 3, 4, 5, and 6; those with the smallest home range means) selected and returned to only one resting site (diff erent for each turtle), and two turtles (turtle no. 1 and 2; those with the largest home range means) each used two resting sites on opposite ends of their respective home ranges. No two turtles were observed at any one resting site.

### Marine turtle foraging habitat

AGRRA protocol assessed macroalgae characterization within the project area. The most dominant algal species

Table 1 Summary of the physical traits, tracking duration, and home range area estimates for six juvenile green turtles tracked at Palm Beach, Florida

| Turtle ID no. | SCL (cm) | Mass (kg) | Total no. of sightings (D/N) | 100% MCP ($km^2$) | 95% FKD ($km^2$) | 50% FKD ($km^2$) |
|---|---|---|---|---|---|---|
| 1 | 33.7 | 9.2 | 96 (58/38) | 5.05 | 4.89 | 1.17 |
| 2 | 31.7 | 8.3 | 84 (55/29) | 4.10 | 3.85 | 0.78 |
| 3 | 45.2 | 12.1 | 97 (62/35) | 0.95 | 0.73 | 0.21 |
| 4 | 33.4 | 9.8 | 92 (61/31) | 0.69 | 0.76 | 0.18 |
| 5 | 27.9 | 7.2 | 97 (60/37) | 1.77 | 1.25 | 0.34 |
| 6 | 48.1 | 12.6 | 98 (60/38) | 1.74 | 1.08 | 0.27 |
| mean±SE | 36.7±8.1 | 9.9±2.1 | 94±5.3 | 2.38±1.78 | 2.09±1.80 | 0.49±0.39 |

*SCL* Straight-line carapace length; *Mass* weight at initial capture; *MCP* minimum convex polygon estimates; *FKD* fi xed kernel density estimates

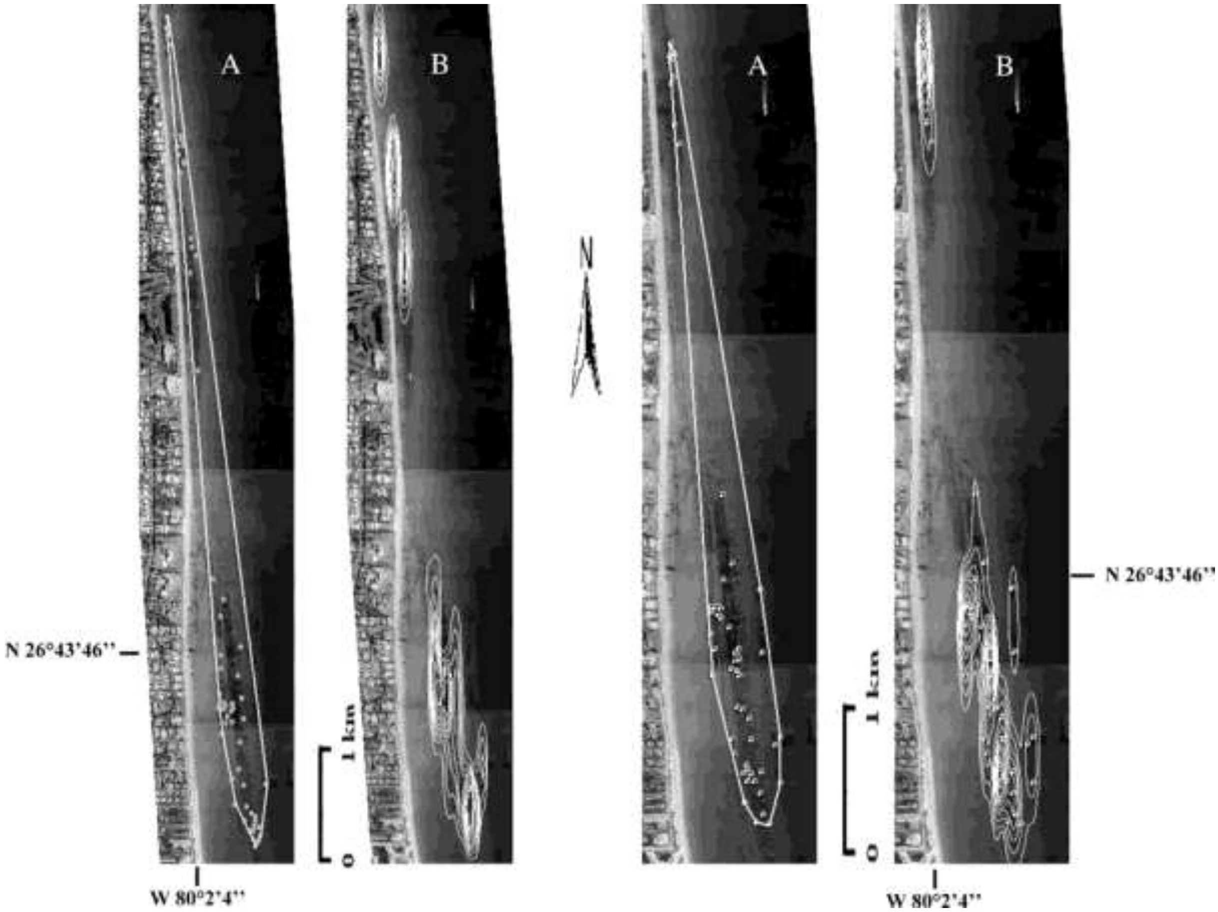


Fig. 2 Home range area estimates. *Left*, home range areas for turtle 1. *A* 100% MCP area; *B* FKD areas. *Right*, home range areas for turtle 2. *A* 100% MCP area; *B* FKD areas

(>80% cover of substrate) was *G. mammillaris*. Other species of macroalgae that displayed dominance (20–60% cover) included: *Dictyota* spp., *Jania adherens*, *H. spinella*, *A. spicifera*, and *Dictyopteris* spp. Along each monitoring transect, benthic sponges were present, as well as hydroids, bryozoans, zooanthids, tunicates, encrusting algae, and hard and soft corals.

## Lavage

Lavage samples were collected once from all six tracked turtles. Average ingesta sample volume was 369±15 ml. Lavage samples contained macroalgae in the following frequencies: *G. mammillaris* (*n*=6, or 100%), *A. spicifera* (*n*=3, or 50%), *Dictyopteris* spp. (*n*=2, or 33%), *Dictyota* spp. (*n*=2, or 33%), *Siphonocladus tropicus* (*n*=2, or 33%), *Jania adherens* (*n*=1, or 16%), *Dasycladus vermicularis* (*n*=1, or 16%), *Cladophora* spp. (*n*=1, or 16%), *Bryothamnion* spp. (*n*=1, or 16%), *Rhizoclonium* spp. (*n*=1, or 16%), and *Enteromorpha* spp. (*n*=1, or 16%) (Table 2). Sponge fragments were found in all turtles, but could not be identified to species.

## Dive profiles

The number of dives, mean depth of dives, and minimum and maximum dive depths for diurnal and nocturnal periods for each turtle are presented in Table 3. Turtles dove with significantly greater frequency during diurnal periods (mean=84±3 dives) versus nocturnal periods (mean=39±2 dives; *t*=20.11, *P*<0.001). A variance ratio F-test demonstrated that dive depths during the day were significantly more variable than those observed at night ($F_{1,3}$=69.00, *P*=0.002). The average dive depth for each turtle during the day (mean=3.20±1.26 m) was significantly shallower than at night (mean=5.59±0.09 m; *t*=-53.67, *P*<0.001).

## Discussion and conclusions

This study is the first to describe daily activity and home range size of juvenile green turtles on worm-rock reef habitats in Southeast Florida. Six juveniles (mean=36.7±8.1 cm SCL) were tracked along shallow, narrow developmental habitats within the nearshore of

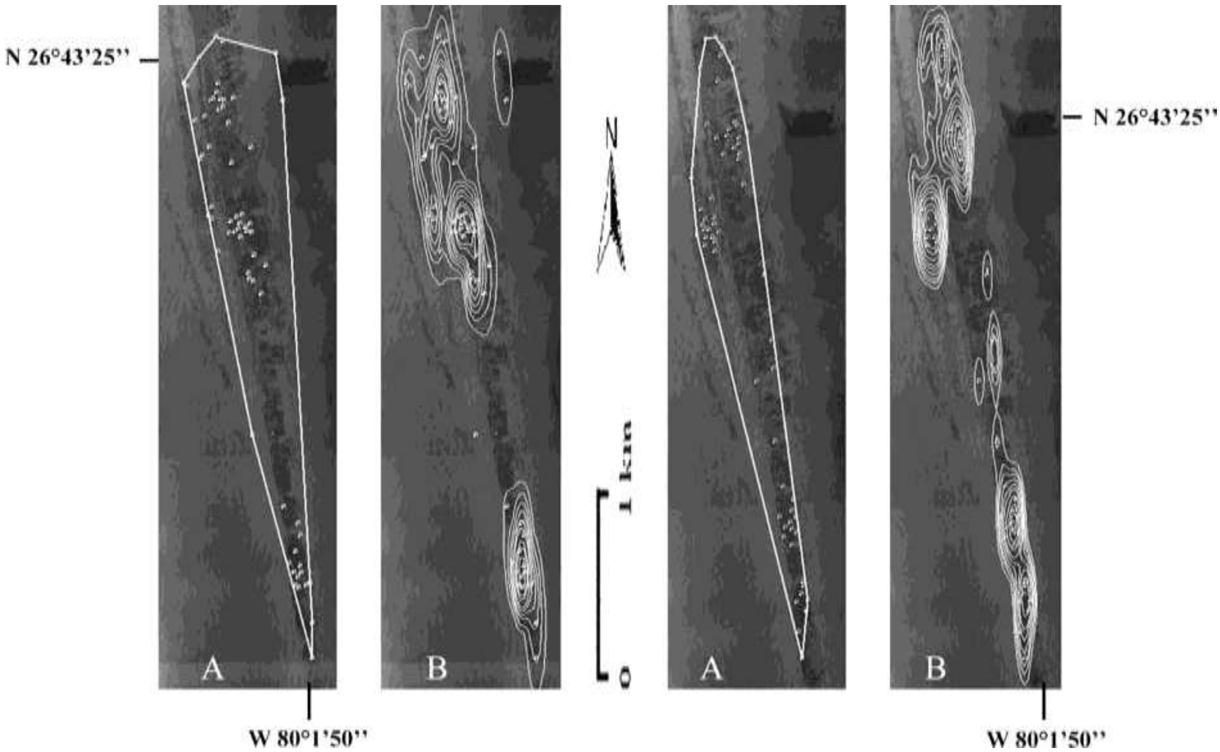


Fig. 3 Home range area estimates. *Left*, home range areas for turtle 3. *A* 100% MCP area; *B* FKD areas. *Right*, home range areas for turtle 4. *A* 100% MCP area; *B* FKD areas

Palm Beach. The importance of this foraging habitat is highlighted by the overlap of all six 100% MCP home range estimates measured in this study (Figs. 2, 3, 4). In addition, all six turtles exhibited an overlap of core areas with at least three other tracked turtles. These home range overlaps indicate that areas within this developmental habitat off er suffi cient resources to be commonly shared by neighboring turtles.

## Home range

The six turtles tracked at Palm Beach, Florida, inhabited an algae-rich localized patch reef system and established home ranges that measured between 0.69 and 5.05 km$^2$ (mean=2.38±1.78 km$^2$). These are among the smallest green turtle home ranges reported to date, and it is likely that the turtles adhered to specifi c reef patches as a means to undertake the most energetically economic spatial movement pattern exclusively tailored to benefi t from this site's resources (McNab 1963). Other studies (Bjorndal 1980; Mendonca 1983) have shown that juvenile green turtles venture to sandy areas rooted with seagrass to feed, however, by intentionally avoiding surrounding areas of sand cover void of marine algae and seagrasses, the turtles at Palm Beach avoided unnecessary energy expenditures. In addition to foraging effi ciency, knowledge of their physical environment may provide turtles a greater familiarity with escape routes, hiding places, and shelter from environmental extremes (Bailey 1984; Alcock 2001).

The MCP and Kernel home ranges of all six turtles tracked in this study were distributed exclusively over the slender nearshore reef habitat. Recorded movement patterns of each turtle consisted of foraging activity over marine algae pastures and resting occurring under reef ledges. Coupled with the fact that each turtle used specifi c foraging and resting sites, which never occurred over sandy substrates, these movement patterns suggest that each turtle had a through understanding of the spatial distribution of food and shelter resources within the area (Ford 1983; Bailey 1984). With movements confi ned to specifi c home ranges over the nearshore reefs of Palm Beach, Florida, it is apparent that these juve- niles were resident to this site. Such habitat affi nity among juvenile green turtles has been demonstrated at other foraging areas (e.g., Brill et al. 1995; Renaud et al. 1995; Seminoff et al. 2002), and is consistent with the general green turtle life history model, which suggests that Atlantic green turtles settle from pelagic to neritic habitats starting at a size of ca. 25.0 cm SCL (Musick and Limpus 1997).

## Resource distribution

The distribution and abundance of food resources most likely accounts for the recruitment of juvenile green turtles along these nearshore reefs. By exhibiting seasonal residencies, which involve small-scale localized movements within their home ranges, juveniles are able to utilize closely spaced food resource patches to help

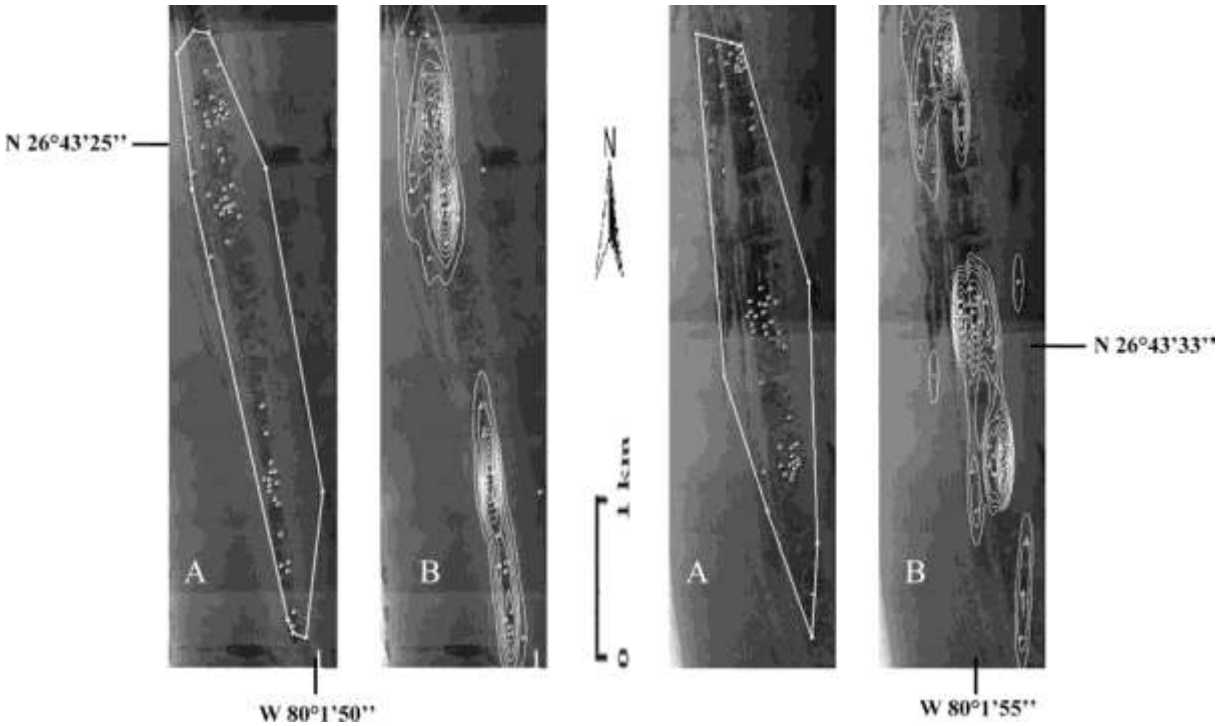


Fig. 4 Home range area estimates. *Left* home range areas for turtle 5. Figure *A* 100% MCP area; *B* FKD areas. *Right*, Home range areas for Turtle 6. *A* 100% MCP area; *B* FKD areas

achieve sexual maturity more rapidly. Dense algal communities, dominated (>80% cover) by the red alga, *G. mammillaris*, colonize the benthic, hardbottom substrate of Palm Beach in a clustered distribution (Coastal Planning & Engineering, Inc. 2003). This alga was reported as a primary dietary component of juvenile green turtles within nearshore worm-rock developmental habitats over a decade ago (Wershoven and Wershoven 1988, 1992), and has been found to be one of the primary dietary items in the lavage analyses (Table 2). Macroalgae regrowth, in response to this type of herbivore cropping, is high along these shallow reef tracts (Goldberg 1973), and the AGRRA transect surveys revealed that macroalgae cover dominated all benthic biota functional groups with an average of 60.4% (±5.5%) cover along the rv9.0 km of Palm Beach's nearshore reef tract (Coastal Planning & Engineering, Inc. 2003).

Previous studies of green turtle foraging movements have also shown that home range areas are concentrated around the specific distribution of food resources

Table 2 Lavage sample anaylsis of tracked juvenile green turtles

| | Turtle ID no. | | | | | | Overall Frequency |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| Macroalgae | | | | | | | |
| *Gracilaria mammillaris* | X | X | X | X | X | X | 1.00 |
| *Acanthophora spicifera* | | X | | X | | X | 0.50 |
| *Dictyopteris* spp. | | | X | X | | | 0.33 |
| *Dictyota* spp. | | | | | X | X | 0.33 |
| *Siphonocladus tropicus* | X | | | | | X | 0.33 |
| *Jania adherens* | X | | | | | | 0.16 |
| *Dasycladus vermicularis* | | X | | | | | 0.16 |
| *Cladophora* spp. | | | | | X | | 0.16 |
| *Bryothamnion* spp. | | | | | X | | 0.16 |
| *Rhizoclonium* spp. | | | | | X | | 0.16 |
| *Enteromorpha* spp. | | | | | X | | 0.16 |
| Benthic invertebrates | | | | | | | |
| Yellow sponge; unidentifiable | X | X | X | X | X | X | 1.00 |
| Green sponge; unidentifiable | | | | | X | | 0.16 |
| Bivalve fragments; unidentifiable | X | | | | | | 0.16 |
| Crustaceans/other Mollusks | | | | | | | 0.00 |

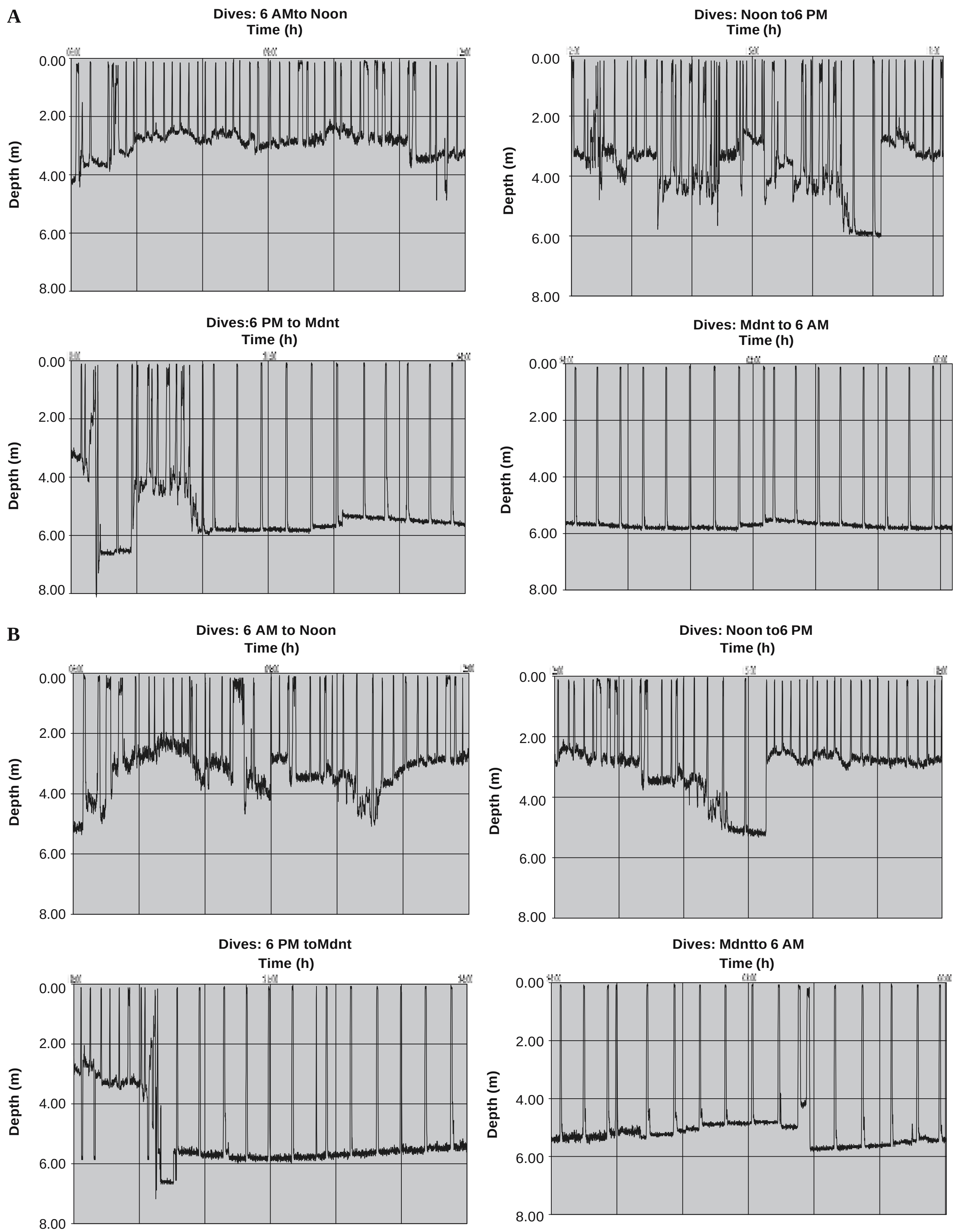


Fig. 5 24-h dive profi le plots. a turtle 1 b turtle 2

Table 3 A summary of dive data for green turtles monitored with TDRs at Palm Beach, Florida

| Turtle no. | Total no. of dives (24 h) | No. dives (day) | No. dives (night) | Min. Max. day diving depth (m) | Min. Max. night diving depth (m) |
|---|---|---|---|---|---|
| 1 | 125 | 85 | 40 | 1.05/5.97 | 4.84/7.88 |
| 2 | 116 | 80 | 36 | 1.07/5.18 | 3.88/7.14 |
| 3 | 122 | 80 | 42 | 1.01/6.09 | 3.92/5.96 |
| 4 | 128 | 91 | 37 | 0.93/5.08 | 3.90/5.91 |
| Mean±SE | 123±3 | 84±3 | 39±2 | 3.20±1.26 | 5.59±0.09 |

Daytime dive profiles were recorded between 0600 and 1800 h. Nighttime dive profiles were recorded between 1800 and 0600 h

(Mendonca 1983; Brill et al. 1995; Renaud et al. 1995; Whiting and Miller 1998; Seminoff et al. 2002) (Table 4). Mendonca (1983) studied the home ranges of nine juvenile green turtles in Mosquito Lagoon, Florida, and found that the turtles' daily movements were confined to areas between 0.48 and 5.06 km$^2$ (mean=2.88± 1.46 km$^2$) and centered around shallow estuarine flats that contained concentrated beds of manatee grass (*Syringodium filiforme*) and shoal grass (*Halodule wrightii*). Brill et al. (1995) found that the home ranges of 12 immature green turtles in Kaneohe Bay, Oahu (Hawaii, USA) was restricted to an average of 2.62 km$^2$ (±0.96 km$^2$) in area and were confined to tightly spaced coral-covered patches where macroalgae growth was most abundant. Whiting and Miller (1998) reported that the short-term foraging ranges of ten adult green turtles in Repulse Bay, Australia, were between 0.84 and 8.50 km$^2$ (mean=3.15±2.72 km$^2$). It was believed these turtles exhibited small-scale foraging behaviors in order to eat younger seagrass shoots of *Zostera capricorni*, *Halodule uninervis*, and *Halophila ovata*, which proliferate in localized areas and provide a higher nutritional quality of resources (Bjorndal 1979; Lanyon et al. 1989; Whiting and Miller 1998). Renaud et al. (1995) recorded some of the smallest daily movements for juvenile green turtles at a jettied pass in South Padre Island, Texas, with nine home ranges between 0.22 and 3.11 km$^2$ (mean=0.77±0.90 km$^2$). Their study area incorporated extremely narrow jetty channels, where marine algae were the most readily available food resource. Seminoff et al. (2002) reported home ranges of 12 green turtles in Bahı ´a de los Angeles, Gulf of California, Mé xico from 5.84 to 39.08 km$^2$ in area (mean=16.62±3.24 km$^2$). As the largest green turtle home ranges found to date, Seminoff et al. (2002) suggested that these home ranges resulted from the substantial distance between macro- algae food resources and benthic shelter sites within the 60 km$^2$ Bahı ´a de los Angeles.

Differences among green turtle home range size in relation to the varying physical structure of each foraging site supplies further evidence that both home range size and shape, and thus the behavior of the turtles, are determined by the distribution of resources in a specific area. Other marine animals also promote their survival, growth, and reproductive success by altering their behavior in relation to the marine habitat they occupy (Krebs and Davies 1993; Lowe et al. 2003; Flores and Bazzalo 2004). Similar to the habitat affinities observed in Palm Beach, marine tucuxi dolphins (*Sotalia fluviatilis*) show beneficial spatial behaviors by estab- lishing home ranges (mean=13.38±1.92 km$^2$) around mangrove nurseries containing an abundance of nutri- ents and prey fishes, while avoiding less productive off - shore waters (Flores and Bazzalo 2004). Likewise, adult kelp bass (*Paralabrax clathratus*) form extremely small home ranges (mean=0.01±0.003 km$^2$) within select rock rubble and kelp habitats where high substrate relief attracts and facilitates prey capture; they do not venture

Table 4 Comparison of green turtle home range studies by site

| Study site (no. of turtles) | Avg. SCL (cm) and Wt (kg) | Avg. home range size (km$^2$) | Food spatial distribution | Method tracking duration |
|---|---|---|---|---|
| Kaneohe Bay, Oahu, Hawaii[a] (12) | 51.3 and 24.5 | 2.62 (±0.96) | Clustered macroalgae | Sonic Telemetry ≈13 days |
| Mosquito Lagoon, Florida[b] (9) | <65.0 and 31.2 | 2.88 (±1.46) | Clustered seagrass | Sonic Telemetry ≈40 days |
| Repulse Bay, Australia[c] (10) | 105.4 and NA | 3.15 (±2.72) | Localized seagrass | Radio Telemetry ≈11.5 days |
| South Padre Island, Texas[d] (9) | 34.5 and 5.5 | 0.77 (±0.90) | Thin algal channels | Sonic, Radio telemetry ≈50 days |
| Bahia de los Angeles, Gulf of California, Mexico[e] (12) | 66.7 and 43.6 | 16.62 (±3.24) | Scattered algae fields | Sonic, Radio telemetry ≈60 days |
| Palm Beach, Florida[f] (6) | 36.7 and 9.9 | 2.38 (±1.78) | Narrow clustered patches of macroalgae | Sonic telemetry, direct observations ≈60 days |

[a]Brill et al. 1995
[b]Mendonca 1983
[c]Whiting and Miller 1998
[d]Renaud et al. 1995
[e]Seminoff et al. 2002
[f]This study

into areas where vertical relief and countershading are low (Lowe et al. 2003). These studies demonstrate that fi delity to a home range is a universal behavior, allow- ing an individual to exploit the specifi c distribution of resources in one's niche.

## Dive profi les

In the present study, turtles foraged continously throughout the daylight hours (0600–2000 h). TDR data archives recorded a greater range in dive depth during diurnal versus nocturnal periods (day mean=3.20±1.26 m, night mean=5.59±0.09 m) and showed fewer mean number of dives per night (mean=39±2 dives) per turtle relative to diurnal peri- ods (mean=84±3 dives; Table 3). Dive profi ling graphs substantiated this diel pattern of diving activity among the juvenile turtles at Palm Beach, illustrating how active bounce dives (V-dives, Hays et al. 2000) occurred pri- marily during diurnal periods while fl at bottom resting dives (U-dives, Hays et al. 2000) were restricted to nocturnal periods (Fig. 5).

In addition to productive foraging grounds, juveniles need access to protective resting shelters. Along the nearshore worm-rock reefs of Palm Beach, Florida, dive profi ling revealed that juvenile green turtles do not re- treat to off shore waters during daylight hours to fi nd suitable sleeping sites. Instead, turtles rested only during noctural hours (2000–0600 h) and displayed an affi nity to sleeping sites underneath the same patch reefs upon which they actively forage, typically under the eastward- facing ledge. This emphasizes the importance of using the shallow, nearshore reef ledges exclusively as a noc- tural resting shelter resource (Wershoven and Wersho- ven 1988; Guseman and Ehrhart 1990; Ehrhart 1992).

These results contrast with fi ndings from other studies that suggest green turtle resting behaviors are often associated with diel movements away from for- aging pastures to deeper off shore waters (Bjorndal 1980; Mendonca 1983; Ogden et al. 1983; Brill et al. 1995). Mendonca (1983) reported that the diving behavior of immature green turtles within Mosquito Lagoon, Flor- ida, showed active feeding on shallow (0.5–1.0 m) sea- grass fl ats in mid-morning and mid-afternoon (0800– 1300 hours), with resting occurring in deeper (2.0– 2.5 m) waters during the mid-day hours (1400–1700 h). Similarly, Bjorndal (1980) demostrated that green turtles at Green Inagua fed at specifi c times during the morning (0800–1000 h) and afternoon (1400–1700 h), while shuttling to deeper water (7.0 m) to rest and thermo- regulate in the mid-day (1000–1400 h). Active move- ments away from foraging areas to deeper resting sites have also been shown in the dive profi les of Hawaiian green turtles (Brill et al. 1995) and Caribbean green turtles (Ogden et al. 1983).

The hypothesis that turtles remain inactive at night to avoid marine predator interactions may be the most appropriate explanation of this reduction in nocturnal diving/foraging activity at Palm Beach. Sharks are the primary marine predators for both adult and juvenile sea turtles (Marquez 1990; Stancyk 1995), and the nearshore waters of Southeast Florida inhabit two (the bull shark, *Carcharhinus leucas*, and the tiger shark, *Galeocerdo cuvier*) of the most common turtle predators (Compagno 1984; Witzell 1987; Heithaus et al. 2002). By reducing diving activity and seeking refuge during the crepuscular and nocturnal feeding periods of large marine predators, juveniles may avoid predation by rogue or schooling sharks.

## Conservation implications

The green turtle has been a species in need of global conservation for decades. It is currently listed as Endangered in the IUCN Red List (Baillie et al. 2004), due to an apparent decrease of over 50% in the world- wide female nesting population over the last 150 years (Seminoff 2004). Even though active harvesting of hatchling eggs outside the United States has been implicated as a major threat to the survival of this spe- cies, perhaps the greatest danger to existing green turtle stocks is the intentional capture and incidental fi sheries- related mortality of juveniles in coastal foraging areas (National Marine Fisheries Service and US Fish and Wildlife Service 1991). Currently, juvenile subpopula- tions are being decimated by high levels of take in the Caribbean Sea (Lagueux 1998), Indian Ocean (Hum- phrey and Salm 1996), Mediterranean Sea (Kasparek et al. 2001), eastern Pacifi c Ocean (Seminoff 2000), and Southeast Asia (Pilcher 1999).

With such a decline in this demographic segment, it is imperative for conservation eff orts to monitor and protect juvenile green turtle populations within their developmental ranges. This study provides answers to basic ecological questions that relate to the under- standing of habitat use and life history of juveniles in a previously unstudied developmental habitiat. Home range studies complement various other methods, such as the 'Shark Fishing' monitoring technique (Makowski et al. 2005), that are used to obtain an overall estimate of turtle abundance and distribution over neritic foraging grounds. With such knowledge, managers will be better positioned to protect specifi c localized resource patches, and the juvenile sea turtles that depend upon them at this stage of their development.

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