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Satellite tracking reveals habitat use by juvenile green sea turtles *Chelonia mydas* in the Everglades, Florida, USA

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ABSTRACT: We tracked the movements of 6 juvenile green sea turtles captured in coastal areas of southwest Florida within Everglades National Park (ENP) using satellite transmitters for periods of 27 to 62 d in 2007 and 2008 (mean ± SD: 47.7 ± 12.9 d). Turtles ranged in size from 33.4 to 67.5 cm straight carapace length (45.7 ± 12.9 cm) and 4.4 to 40.8 kg in mass (16.0 ± 13.8 kg). These data represent the first satellite tracking data gathered on juveniles of this endangered species at this remote study site, which may represent an important developmental habitat and foraging ground. Satellite tracking results suggested that these immature turtles were resident for several months very close to capture and release sites, in waters from 0 to 10 m in depth. Mean home range for this springtime tracking period as represented by minimum convex polygon (MCP) was 1004.9 ± 618.8 km^2 (range 374.1 to 2060.1 km^2), with 4 of 6 individuals spending a significant proportion of time within the ENP boundaries in 2008 in areas with dense patches of marine algae. Core use areas determined by 50% kernel density estimates (KDE) ranged from 5.0 to 54.4 km^2, with a mean of 22.5 ± 22.1 km^2. Overlap of 50% KDE plots for 6 turtles confirmed use of shallow-water nearshore habitats ≤0.6 m deep within the park boundary. Delineating specific habitats used by juvenile green turtles in this and other remote coastal areas with protected status will help conservation managers to prioritize their efforts and increase efficacy in protecting endangered species.

KEY WORDS: *Chelonia mydas* · Green turtle · Everglades · Satellite telemetry · Satellite tracking · Home range · Kernel density · Endangered species

INTRODUCTION

Green sea turtles *Chelonia mydas* are found in tropical and subtropical marine and coastal environments. Once hatchlings leave the beach, they begin an oceanic phase, perhaps passively floating in major currents or gyres for several years (Carr & Meylan 1980, Carr 1987). These young turtles then recruit from oceanic habitats to neritic developmental habitats rich in seagrass or marine algae where they forage and grow to maturity (Bjorndal 1980, Musick & Limpus 1997).

Whereas the ecology and movements of nesting adult *Chelonia mydas* are reasonably well studied (see Godley et al. 2008 for a review), relatively little is known about the habitat needs and movements of juveniles of this endangered species. In previous satellite tracking studies of juvenile green turtles, Godley et al. (2003) focused on describing movements of 8 fishery-caught turtles off the coast of Brazil, and Pelletier et al. (2003) compared oceanic movements of 2 displaced wild and 4 captive-reared turtles in the Indian Ocean. Both of these satellite tracking studies were conducted outside US waters and both involved animals that spent at least some time (i.e. hours to hundreds of days) in captivity. In contrast, McClellan & Read (2009) tracked movements and habitat use of 10 wild juvenile green turtles to determine how turtle behavior and site fidelity affected their vulnerability to

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incidental captures in an artisanal gill net fishery in North Carolina.

Despite the low number of satellite tracking studies on immature greens, several studies are available for comparison in which home ranges of immature turtles were quantified using radio and ultrasonic telemetry (Table 1). Overall, most studies have been relatively short in duration and have documented nearshore coastal habitat use and residence patterns. To date, McClellan & Read (2009) obtained the maximum tracking duration (154 d) for any juvenile green turtle tracking study using telemetry. However, home ranges were remarkably comparable across all studies of juvenile greens, regardless of method (Table 1).

Because satellite tags have become smaller and thus more suitable for use on juvenile sea turtles, we sought to use satellite tracking to characterize movement and residence patterns of juvenile greens observed in remote, difficult to access areas of Everglades National Park (ENP), Florida, USA. The Everglades is the largest subtropical wilderness in the USA, and it contains many species of both rare and endangered flora and fauna. Designated as a World Heritage Site, an International Biosphere Reserve, and a Wetland of International Importance, ENP harbors much neritic foraging habitat and shallow-water refuge sites that may be particularly suitable for juvenile green turtles.

Chelonia mydas can generally be found throughout the entire Atlantic Ocean. The species is listed as Endangered by the International Union for the Conservation of Nature (IUCN) (Groombridge 1982) and threatened under the US Endangered Species Act (ESA) in all areas, except for breeding populations in Florida and on the Pacific coast of Mexico, which are listed as endangered (NMFS & USFWS 1991). The major nesting sites for Atlantic green turtles can be found on continental beaches and islands throughout the Caribbean coast of Central America, the eastern coast of the South American continent, and on isolated islands in the North Atlantic. The east coast of Florida has the largest breeding assemblage of green turtles in the USA.

Chelonia mydas feeding grounds are widely distributed throughout the region. Such developmental habitats are important for the survival of juvenile marine turtles and the recovery of depleted stocks (Bjorndal et al. 2003, Kubis et al. 2009). Foraging areas for the species in the Atlantic and in Florida specifically include Indian River Lagoon, Palm Beach and St. Lucie Counties, the Florida Keys, Florida Bay, Homosassa, Crystal River, and Cedar Key (Mendonça 1983, Ehrhart & Redfoot 1992, Schmid 1998, Bresette et al. 1991, Bresette & Gorham 2001, Witzell & Schmid 2004, Makowski et al. 2006, Ehrhart et al. 2007). Previously, Schmid (1998) characterized Cedar Key turtles in a study spanning 1986 to 1995 at a site 463 km to the north of our sampling location, and Witzell & Schmid (2004) worked 71 km to the north and documented juvenile green turtles around the Ten Thousand Islands. Other studies including juvenile green turtles in Florida sampled at sites farther from our study site (e.g. St. Lucie County, Bresette et al. 1998; Brevard and Volusia Counties in East Central Florida, Mendonça 1983; Palm Beach County, Makowski et al. 2006).

Information on the spatial biology of marine turtles can reveal variability in life history strategies among disparate subpopulations (Bolten 2003). Moreover, because green turtles spend a vast majority of their lives in coastal foraging and developmental habitats (Musick & Limpus 1997, Plotkin 2003), where susceptibility to human impacts is often very high (e.g. Groombridge & Luxmoore 1989, Campbell 2005), understanding their movement patterns in protected areas such as US National Parks may be considered a priority for ongoing conservation efforts and federal recovery plans. Thus, we used satellite telemetry to track juvenile green turtles in the southwest coastal Everglades, a developmental habitat not previously investigated.

Previous research has shown that by establishing a home range, juvenile green turtles enhance their access to resources that offer the most benefit for their growth to sexual maturity (Limpus & Walter 1980, Limpus et al. 1994, Makowski et al. 2006). Thus, our goals were to (1) measure the seasonal home range of juvenile green turtles in our study site using both minimum convex polygon (MCP; Burt 1943, Mohr 1947) and kernel density estimation (KDE) methods (White & Garrott 1990, Seaman & Powell 1996), (2) determine the proportion of area used in ENP, and whether the turtles displayed resident behavior during the tracking period, (3) determine whether turtles showed an affinity to any specific core areas, and (4) describe patterns of overlap among the turtles' home ranges or core areas of activity.

With an understanding of these movement patterns and habitat use, resource managers will be better able to prioritize their efforts to protect all life stages of endangered species using ENP. The Comprehensive Everglades Restoration Plan (CERP; US Army Corps of Engineers and South Florida Water Management District 2004), initiated in 2000, has a goal of restoring the hydrological characteristics of the Everglades while simultaneously meeting the water needs of south Florida's urban and natural areas. The CERP is vital to reducing ecosystem and species vulnerability to stressors associated with future climate change and sea level rise. Monitoring species protected under the US ESA is a major component of the adaptive management framework of the plan; our study will help to

Table 1. *Chelonia mydas.* Summary of green turtle home range data from published studies. Mean home range column: values are ±SD where available. USVI: US Virgin Islands; MCP: minimum convex polygon; KDE: kernel density estimate; UD: utilization distribution; NE: not estimated, NA: not available; SCL: straight carapace length

Telemetry method(s)	N	Mean SCL, cm (±SD)	Location	Tracking duration (d)	Mean home range	Analysis method	Mean (±SD) and/or net distance traveled	Source
Sonic	14	<65 (NA)	Mosquito Lagoon, FL, USA	15–115	2.9 km^2 (0.5–5.1 km^2); 0.16 km^2 'core' activity area; winter: 13.9 ± 2.3 km^2 (n = 6); summer: 3.5 ± 4.1 km^2 (n = 10)	MCP	Winter: 8.2 ± 1.8 km d^{-1}; summer: 2.6 ± 1.0 km d^{-1}	Mendonça (1983)
Sonic and visual	3	38.3 (NA)	St. Croix, USVI	Up to 10	0.2 to 0.5 km between resting and feeding areas	Distance between locations	0.2–0.5 km between resting and feeding areas	Ogden et al. (1983)
Sonic	12	51.3 (NA)	Kaneohe Bay, HI, USA	13	2.6 ± 1.0 km from release point	Visual examination, density	Maximum 3 km	Brill et al. (1995)
Radio and sonic	9	34.5 ± 6.9	Texas, USA	14–58	2.2–3.1 km^2; core areas 0.1–7.4 km^2	MCP	Mean movement: 8–568 m h^{-1}; daily movements <50 to >1000 m	Renaud et al. (1995)
Radio and sonic	12	70.1 ± 8.0	Gulf of California, Mexico	34–96	MCP: 16.6 ± 3.2 km^2 (5.8–39.1 km^2), KDE: 15.4 ± 2.8 km^2 (4.1–32.3 km^2) with 1–3 activity centers of 17.8 ± 0.6 km^2 (0.4–6.4 km^2)	MCP and KDE	NE	Seminoff et al. (2002)
Sonic and TDRs (N = 4)	6	36.7 ± 8.1	Palm Beach, FL, USA	55–62	MCP: 2.4 ± 1.8 km^2 (0.7–5.1 km^2), 95% KDE: 2.1 ± 1.8 km^2 (0.7–4.9 km^2)	MCP and KDE	NE	Makowski et al. (2006)
Radio and acoustic	6	69.8 ± 11.0	Baja California Peninsula, Mexico	24 h tracking periods	Short-term (24 h) activity ranges: 4.6 ± 202 km^2 (0.7–12.5 km^2)	MCP; distances (km) between successive resightings for one 24 h interval	8.2 ± 1.6 km 4.3–15.3 km	Seminoff & Jones (2006)
Sonic (N = 8) and satellite (N = 10)	10	32.1 ± 4.1	North Carolina, USA	0–74 (sonic); 17–154 (satellite)	Summertime UD: 84.6 ± 48.3 km^2 (satellite) and 39.7 ± 12.3 km^2 (sonic)	95% UD (fixed kernel UDs)	9–1558 km (satellite) and 2–11 km (sonic)	McClellan & Read (2009)
Satellite	6	45.7 ± 12.9	Everglades National Park, FL, USA	27–62	MCP: 1004.9 ± 618.8 km^2 (374.1–2060.1 km^2); 95% KDE: 154.4 ± 136.1 km^2 (24.6–371.0 km^2); 50% KDE: 22.5 ± 22.1 km^2 (5.0–54.4 km^2)	MCP and KDE	1053.8 ± 641.8 km; 387–2049 km	Present study

meet this objective by providing baseline information on juvenile green turtles in the southwest coastal zone of ENP.

MATERIALS AND METHODS

Study area. We conducted this study from March 2007 to June 2008 along the coastline near the Big Sable Creek (BSC) Complex, southwest coastal ENP, Florida, USA (25° 16.780′ N, 81° 09.574′ W, Fig. 1). The BSC complex is a network of tidally-flooded creeks characterized primarily by mangrove forest and mudflat habitat. The mouth of the complex has areas of dense marine algae and sparse seagrass (K. Hart pers. obs.). The complex is located approximately 5 km north of the Cape Sable beaches (Fig. 1) and just south of the entrance to the Little Shark River. The coastal shoreline and the BSC complex are dominated by red mangroves *Rhizophora mangle,* although white *Laguncularia racemosa* and black mangroves *Avicennia germinans* are found in almost equal abundance in the interior mangrove stands (Smith et al. 2009) at BSC. The area searched for juvenile green turtles included creeks in the northern half of the BSC site which extend as far as 1.2 km upstream from the coast and coastal areas to the north and south of the complex, covering approximately 10 km of shoreline. The study area is completely within the protected wilderness area of the southwest coastal Everglades. Maximum tidal range in BSC on spring tides is approximately 2.5 m, and tides in this complex are semi- diurnal, with saline gulf waters penetrating into headwater streams (Morisawa 1968, H. R. Wanless & B. Vlaswinkle unpubl.) on high tides. The site is a mosaic of intertidal mudflats and mangrove forests dissected by subtidal creeks. Lack of detectable freshwater inflow results in near-marine salinities (27.7 to 34.2 ppt; Silverman 2006) year-round.

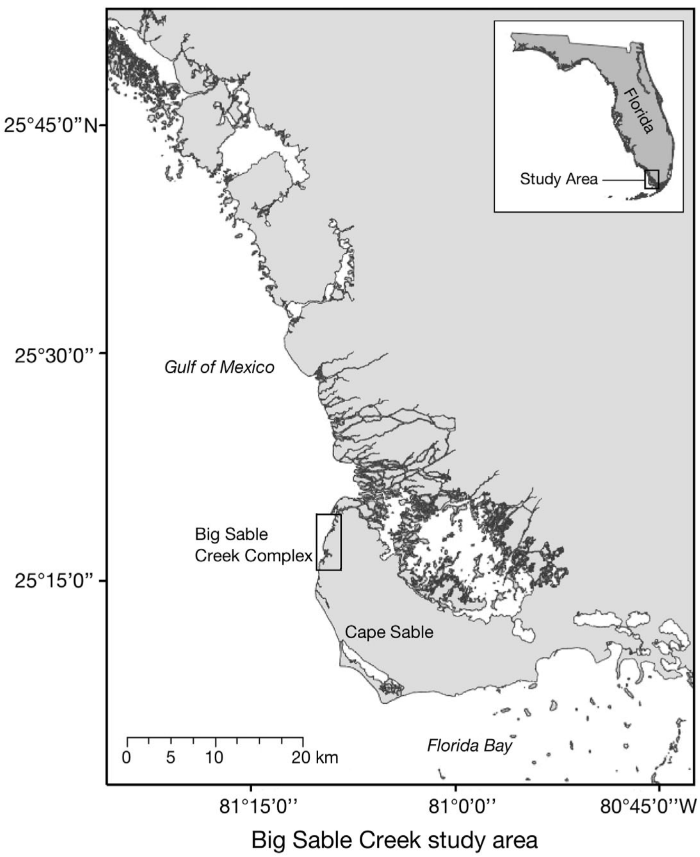

Fig. 1. Everglades National Park, southwest Florida, USA, with Big Sable Creek study site in inset

Captures. We conducted dip-netting activities at night primarily around new moons and during low tides, using high-powered (3 000 000 candle power) lightweight spotlights while searching for turtles on a 5.8 m Carolina skiff fitted with a 115 hp outboard motor. We also deployed a tangle net during the day from the skiff. The tangle net was ~180 m long and 3 m deep, constructed with a braided polypropylene top line and a 9.1 kg lead core bottom line, and secured to the bottom with a 3.2 kg anchor attached at either end. The mesh was constructed of 18-gauge nylon twine with a knot-to-knot diameter of 30.5 cm. We set the net and attached bullet-shaped buoys with longline clips along the top line of the net at 7 to 10 m intervals. The buoys moved vertically to indicate that something was captured in the net or that the net was snagged on some woody debris on the bottom. We checked the net at intervals of 30 min or less, or whenever something appeared to be entangled in it. If marine mammals were present in the area, we removed the net from the water until they left the area. We retrieved entangled turtles from the net with a dip net for backup, to avoid escape, and carefully worked out entangled bycatch (e.g. various species of sharks, endangered sawfish *Pristis pectinata*), checking all animals for tags, and when possible, photographing the animals. Our methods of setting and checking the tangle net were similar to those used by Ehrhart & Ogren (1999).

Upon capture, each turtle was placed in its own plastic rectangular cement-mixing tub and kept wet. This capture method has been shown to be safe for juvenile turtles in a number of previous studies (Schmid 1998, Ehrhart & Ogren 1999). We covered the eyes of each turtle with a wet towel, and returned them to the US Geological Survey research houseboat where we carefully transferred the turtles in their tubs to be processed for measurements and biological samples.

Standard turtle workup procedure. As part of the standard workup procedure for each turtle, we followed established protocols (NMFS SEFSC 2008). We individually marked each animal by inserting a passive integrated transponder (PIT) tag in the right shoulder region and affixing individually numbered flipper tags to each of the rear flippers. Immediately after marking each animal, we took standard carapace measurements including curved (CCL) and straight (SCL) carapace lengths. We weighed turtles with a spring scale and netting to the nearest 0.1 kg. Additionally, we photographed each turtle to document carapace and skin anomalies. We released all turtles at the site of capture within 2 h.

Satellite telemetry. We selected 6 juvenile green turtles in good condition (i.e. not emaciated, with fewer than 3 external fibropapillomas [FPs], each less than 2 cm in diameter) for tracking after capture in the southwest coastal Everglades. We included 2 FP turtles because Brill et al. (1995) found no obvious effects of movement patterns or habitat use on juvenile Hawaiian greens. Observations of these individuals 24 h post-tagging also indicated that they were feeding and behaving normally (i.e. swimming regularly).

We fitted a Wildlife Computers SPOT5 platform terminal transmitter (PTT) to each turtle. Each tag (2× AA model) had a saltwater switch, output of 0.5 W, and measured 79.7 × 49.5 × 18.1 mm (length × width × height), with a mass of 95 g in air. We ensured that each PTT plus epoxy did not exceed 5% of the turtle's body weight; the cut-off value for tagged turtles was >4 kg mass. Prior to transmitter application with Power-Fast™ 2-part marine epoxy, we removed epibionts (e.g. barnacles, algae) from the carapace of each turtle and sanded and cleaned the carapace with isopropanol. We streamlined attachment materials so that neither buoyancy nor drag would affect the turtle's swimming ability, and we minimized the epoxy footprint due to the small size of the turtles in the study. The anticipated battery life of each tag was 1 yr, and we set each tag to be active for 24 h d^{-1}. All tagged turtles were released at or near the point of capture.

Data filtering and analysis. We used the Satellite-Tracking and Analysis Tool (STAT; Coyne & Godley 2005) to archive and filter location data. Points were grouped into location classes (LCs) according to decreasing accuracy (i.e. highest to lowest accuracy: LCs 3, 2, 1, 0, A, B, and Z). Hays et al. (2001) and Vincent et al. (2002) found that accuracy of LC A was comparable to that of LC 1 locations from Argos, so we included LC 3, 2, 1, 0, A, and B locations, but filtered out locations that fell into any of the following categories: (1) LC Z, (2) locations that required straight-line travel speeds over 5 km h^{-1}, and (3) locations that occurred at elevations over 0.5 m. Using ArcGIS 9.3 (ESRI 2007), we manually removed obviously erroneous points (e.g. those that 'zig-zagged' land or large areas of open water) and implausible locations that remained after the STAT filtering process.

To facilitate comparisons to other previously published studies that used radio- and sonic-tracking methods to determine home ranges, we calculated MCP estimates (Burt 1943, Mohr 1947). Home range metrics by definition describe the area traversed by an animal during normal daily activities, excluding migrations or erratic movements (Bailey 1984). Calculating a home range requires re-sightings of individuals over extended time periods (White & Garrott 1990). Estimates of MCP identify home ranges as the area within the polygon formed by joining the outermost re-sighting positions of an animal (Burt 1943); this method has been commonly applied, especially in radio and sonic tracking studies on juvenile sea turtles (Table 1). However, MCP is sensitive to outlying observations and is constrained by its ability to identify fine-scale spatial use patterns within the home range boundary (White & Garrott 1990).

To minimize autocorrelation in spatial analyses, we generated mean daily locations for each turtle from the accepted locations. The resulting coordinates provided raw data for KDE analysis across all individuals. Kernel density is a non-parametric method used to identify 1 or more areas of disproportionately heavy use (i.e. core areas) within a home range boundary (for review see Worton 1987, 1989, White & Garrott 1990), with appropriate weighting of outlying observations. Seaman & Powell (1996) suggested this approach as the most accurate home range assessment technique, and since then it has been used to delineate foraging grounds for several species of sea turtle (Makowski et al. 2006, Seney & Landry 2008; our Table 1). We used the Home Range Tools for ArcGIS extension (Rodgers et al. 2005) and fixed kernel least squares cross-validation smoothing factor (h_{cv}) for each KDE (Worton 1995, Seaman & Powell 1996). When the variance of x and y coordinates of the points were highly unequal, the data were rescaled before applying the kernel method. We used ArcGIS 9.3 to calculate the in-water area (km^2) within each contour and to plot the data. We used a 95% KDE to estimate overall home range of a turtle during the springtime tracking period and a 50% KDE to represent the core area of activity during this same time period (Hooge et al. 2001). We overlaid the ENP boundary on all resulting maps and summed locations with respect to the boundary. We used NOAA chart 11433 to estimate depth, since there is no available bathymetric coverage for this area.

To test for and quantify site fidelity, we used the Spatial Analyst and Animal Movement (AMAE) extension for ArcView 3.2. We used Monte Carlo Random Walk (MCRW) simulations to test for site fidelity (100 replicates), testing tracks for spatial randomness against randomly generated walks (Hooge et al. 2001, Mansfield et al. 2009). Tracks exhibiting site fidelity indicate that the turtles' movements were more spatially constrained compared to randomly distributed or dispersed movement data (Hooge et al. 2001). Further, to assess residency within the protected area of the park, we tested the null hypothesis that satellite-tagged juvenile greens spent an equal proportion of time (e.g. number of days) within and outside of ENP boundaries by comparing distances from shore (distance measured as negative values towards shore, positive values towards the sea) for all filtered locations in a chi-squared test. We also used *t*-tests with a Satterthwaite approximation due to unequal variances to test the null hypothesis that each turtle's daytime and nighttime locations did not differ in their distance to the coastal line. We measured distance from the shoreline in ArcView. We calculated travel speed for each turtle using a linear distance between points in km h^{-1}, which was the average linear distance moved over time of 2 consecutive filtered locations. We conducted all statistical tests in SAS (SAS Institute 1996) and used an α level of 0.05 for all analyses.

RESULTS

Turtles

The 6 satellite-tagged juvenile greens ranged in size from 33.4 to 67.5 cm SCL (mean ± SD: 45.7 ± 12.9 cm). Mass of the 7 tracked individuals ranged from 4.4 to 40.8 kg (16.0 ± 13.8 kg; Table 2). We captured 2 of the 6 satellite-tagged turtles using dipnets at night and the remaining 4 using the tangle net during the day.

Satellite tracks

We obtained 1598 locations from the 6 satellite-tagged turtles and a total of 286 PTT days. The range of days at large was 27 to 62 d (47.7 ± 13.0 d). Filtering by LC, travel speed, and topography resulted in 44.8 to 60.9% of locations across all turtles being retained for analysis. Across all 6 turtles, the average proportions of spatial data in each LC were 1.9 (LC3), 3.4 (LC2), 6.8 (LC1), 6.8 (LC0), 16.8 (LCA), and 65.2% (LCB).

Home range and movement

We observed consistent use of coastal habitats by juvenile green turtles near their capture and release sites in both 2007 and 2008 (Fig. 2). Estimates of MCP area for each turtle ranged from 374.1 to 2060.1 km^2 (101.3 to 184.8 km perimeter; Table 3). Fixed KDEs for 95% contour areas ranged from 24.6 to 371.0 km^2 (mean 154.4 ± 136.1 km^2). The 50% contour areas ranged from 5.0 to 54.5 km^2 (Table 3). The area representing the intersection of all turtles' 50% core areas (Fig. 3) was 3.1 km^2 and was spatially similar for both 2007 and 2008. Further, water depth of each turtle's 50% KDE and the intersection of all 50% KDEs was ≤0.6 m mean low water.

The site fidelity test confirmed that the observed turtle tracks and movements were more constrained than random movement paths (Table 3). In all cases, p or the proportion of the movement paths with higher mean squared distance (MSD) values was >98.0198 (Table 3). Thus, we observed site fidelity in the satellite tracking data. Turtles traveled a net distance of 387 to 2049 km (mean 1053.8 ± 641.8 km). Mean travel speeds for tracked turtles ranged from 0.78 to 1.49 km h^{-1} (SD range 1.01–1.30). Whereas the smallest turtle (ID no. 60591, mass 4.4 kg) had the lowest mean travel speed, larger turtles did not appear to swim significantly faster. However, these travel speeds should be considered approximate swim speeds, as we cannot confirm linear travel. Travel speeds (i.e. measured linear distance over time) may not equate to actual swim speeds, as swim speeds take into account directional movements, which may in fact not be linear.

Table 2. *Chelonia mydas.* Body size and tracking details for 6 juvenile green turtles from the southwest coastal Everglades, Florida, USA, in 2007 and 2008. SCL: straight carapace length from notch to tip; No. locations accepted: locations remaining after filtering raw Argos data as described in 'Materials and methods'

Turtle ID	SCL (cm)	Mass (kg)	Capture method	Date of deployment	No. days tracked	No. locations received	No. (%) locations accepted
60591	33.4	4.4	Dip net	14 March 2007	50	84	44 (52.4)
60589	40.4	8.6	Dip net	14 March 2007	41	23	14 (60.9)
55026	43.5	14.1	Tangle net	4 March 2008	60	516	231 (44.8)
60590	35.4	5.8	Tangle net	4 March 2008	62	148	76 (51.4)
55024	67.5	40.8	Tangle net	1 May 2008	46	578	298 (51.6)
55025	54.1	22.2	Tangle net	3 May 2008	27	249	131 (52.6)

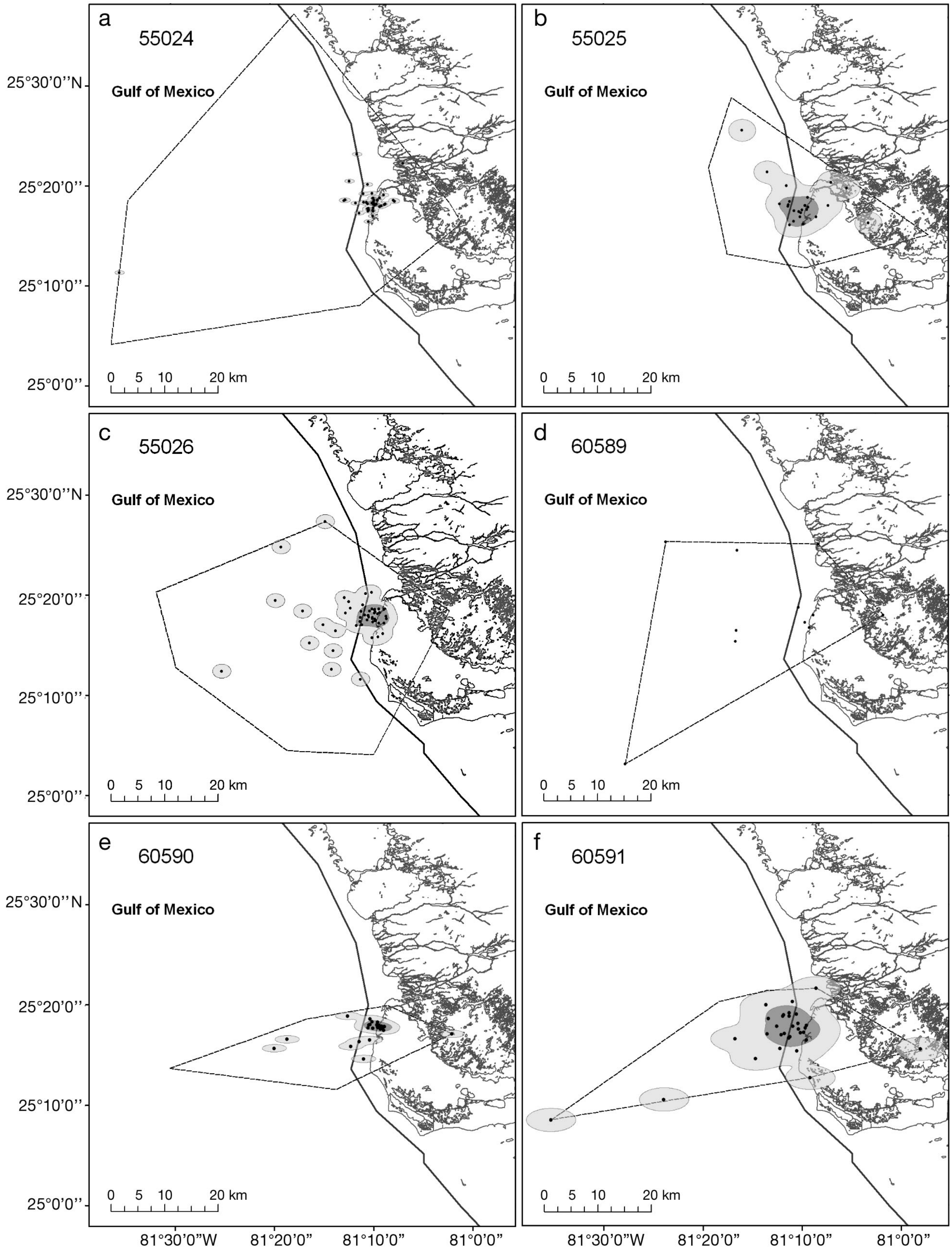

Fig. 2. Minimum convex polygon (MCP) and kernel density estimates for 6 juvenile green turtles (a–f) satellite-tracked in the Everglades National Park, southwest Florida, in 2007 and 2008. Core-use areas (50% kernel density) are shown in dark gray, and overall home ranges (95% kernel density) are in lighter gray. Dashed lines represent MCPs and bold lines the Everglades boundary line. Black dots represent mean daily locations (when available) for each turtle

Table 3. *Chelonia mydas.* Home range and core activity areas for 6 juvenile green turtles satellite-tracked in the southwest coastal Everglades, Florida, USA, in 2007 and 2008. Home range was determined using minimum convex polygon (MCP) and kernel density estimator (KDE) methods. The specific smoothing parameter (h_{cv}) used for KDE estimates for each turtle's data is presented. One turtle (ID 60589) did not have enough data for KDE estimates. Site-fidelity test results report p, the proportion of the movement paths with higher mean squared distance (MSD) values

Turtle ID	Tracking year	h_{cv}	Track duration (d)	Contour area 50% (km²)	Contour area 95% (km²)	MCP perimeter (km)	MCP area (km²)	Site fidelity test (p)	MSD (R^2) (km)	Avg. MSD (R^2) of random movement paths (km)
60591	2007	0.26	50	54.5	371.0	137.4	661.3	>99.0099	95 552.9	2 167 730.8
60589	2007	–	41	–	–	135.9	964.4	>98.0198	230 375.2	1 452 359.5
55026	2008	0.21	60	18.7	148.9	140.7	1360.8	>99.0099	52 744.4	2 717 534.9
60590	2008	0.20	62	6.9	54.7	101.3	374.1	>99.0099	37 071.6	1 178 531.3
55024	2008	0.53	46	5.0	24.6	184.8	2060.1	>99.0099	39 158.8	2 120 328.4
55025	2008	0.32	27	27.4	172.8	106.7	608.6	>99.0099	34 908.2	1 055 703.9

We detected no difference in diurnal patterns of time that turtles spent closer to the coast or farther out in deeper or open water. Daytime and nighttime locations and their respective distance from shore for each turtle showed no significant differences for any of the 6 turtles ($p > 0.1$ in all cases; ID no. 55024: $t_{296} = 0.28$, p = 0.778; ID no. 55025: $t_{129} = 0.65$, p = 0.517; ID no. 55026: $t_{229} = -1.23$, p = 0.219; ID no. 60589: $t_{12} = 0.34$, p = 0.742; ID no. 60690: $t_{57} = 1.65$, p = 0.104; ID no. 60591: $t_{18} = -0.32$, p = 0.752). However, chi-squared results indicated that 4 of 6 turtles (i.e. those that were tracked in 2008) spent a significant proportion of time within the boundaries of ENP (ID no. 55 024: $\chi^2_1 = 41.09$, $p < 0.0001$; ID no. 55025: $\chi^2_1 = 21.16$, $p < 0.0001$; ID no. 55026: $\chi^2_1 = 23.13$, $p < 0.0001$; ID no. 60589: $\chi^2_1 = 0.09$, p = 0.763; ID no. 60590: $\chi^2_1 = 22.15$, $p < 0.0001$; ID no. 60591: $\chi^2_1 = 0.807$, p = 0.369).

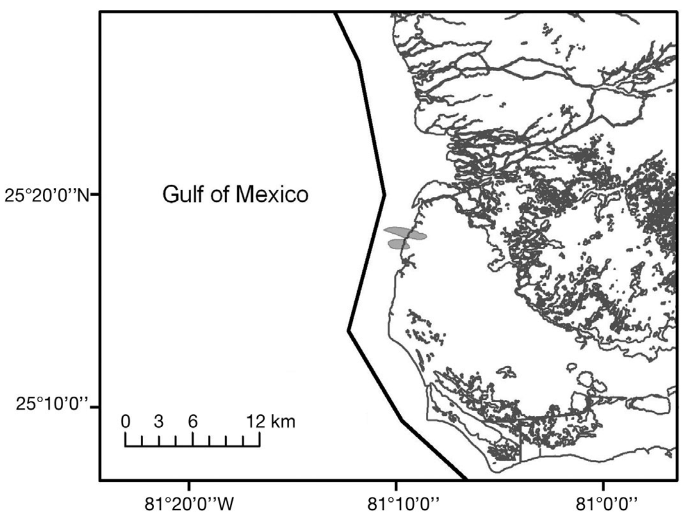

Fig. 3. Overlap of all 50% fixed kernel densities (grey patches) for satellite-tracked juvenile green turtles in the Everglades National Park (ENP), southwest Florida. Bold black line represents the ENP boundary

DISCUSSION

We provide the first estimates of juvenile green turtle core activity areas in the Everglades. We observed fidelity to the capture and release site for all 6 individuals in the spring over 2 different years; these observations are consistent with reports from other green turtle foraging grounds that documented juvenile green turtle affinity with areas characterized by marine algae patches (Ogden et al. 1983, Seminoff et al. 2002). Our data suggest that the marine algal pastures along the shallow-water margins of the study area are epicenters of juvenile green sea turtle activity. Our data also indicated that turtles visited mid-bay and insular habitats such as Whitewater Bay (Fig. 2), although they spent less time in such habitats than in the vicinity of the coastal capture and release sites. The microhabitat features of this core-use area (i.e. shallow cove with abundant sources of marine algae and dead mangrove logs that provide refuge sites from predators) may indicate important characteristics that are optimal for juvenile green turtles along the southwest Florida coast. Where these features are present along this coast and elsewhere in the Everglades, we may find additional groups of small juvenile green turtles.

Our tracking efforts delineated home ranges and quantified site fidelity for juvenile green turtles in the Everglades, indicating resident-type behavior for these 6 turtles. These results support the hypothesis that by establishing a core use area or home range, juveniles may enhance their access to resources that offer the most benefit for their growth to sexual maturity (Limpus & Walter 1980, Limpus et al. 1994, Makowski et al. 2006). The individual home ranges for juvenile green turtles in ENP in the spring are consistent with those derived from earlier radio and sonic-tracking studies of the behavior and ecology of juvenile green turtles in neritic, shallow-water, inshore feeding grounds in other locations in Florida and elsewhere (Table 1).

We obtained 286 total PTT days in this study, which is far fewer than the 728 tracking days reported by Seminoff et al. (2002) but comparable to both Mendonça's (1983) study that lasted 199 d and Makowski et al.'s (2006) 120 d tracking study. McClellan & Read (2009) also obtained similar tracking durations for juvenile greens of approximately the same size as the Everglades turtles (Table 1). Our tracking durations are most similar to those reported by Renaud et al. (1995), who radio- and sonic-tracked 9 green turtles (29.1 to 47.9 cm SCL, 2.6 to 14.8 kg) in Texas, USA, from 14 to 58 d, and the more recent study by McClellan & Read (2009), who sonic- and satellite-tracked 10 green turtles of 27.9 to 42.5 cm SCL for 17 to 154 d in North Carolina, USA (Table 1). Still, compared to longer-duration studies on adult sea turtles (see Godley et al. 2008 for a review), we obtained relatively short tracking times for our turtles. This short tracking may be indicative of battery failure or tag loss. Fast-growing juveniles may shed their scutes and the attached satellite tags much more quickly than adults, thus causing transmissions to cease prematurely. Tag shedding may also result from turtle interactions with habitat structures (i.e. vegetation, dead mangrove logs, other debris), particularly if young turtles are using habitats provided by such coarse woody debris for refuge or shelter. Future experimentation with captive greens and various tag attachment methods and materials similar to Seney et al. (2010) and Renaud et al. (1993) is warranted to determine optimal tag retention rates on juveniles over time.

Although we did not specifically test for instrument effects on each animal post-release, we did not see any difference in the timing or quality of locations obtained immediately post-release versus later during the tracking duration. We re-sighted 2 of our tagged turtles (60589, 60591) in the study site within 24 to 48 h of release, and both appeared to be feeding; thus, we assumed the tag effect was minimal. Watson & Granger (1998) previously tested for a hydrodynamic effect of a satellite transmitter on a model juvenile green turtle and found that a carapace-mounted transmitter increased drag by 27 to 30% and effectively reduced swimming speed by 11%. Because juvenile greens in our study appeared to be feeding and moving relatively slowly, the movements of these wild turtles may not have been affected as much as predicted by Watson & Granger (1998).

Juvenile green turtles in the Everglades displayed fidelity to capture and release sites with limited home ranges over the course of several months in 2 successive spring seasons. These findings are consistent with previously conducted satellite telemetry studies comparing movements of juvenile greens conducted outside of Florida. Godley et al. (2003) tracked 4 tagged juveniles in coastal waters off Brazil, 2 of which displayed behaviors similar to the Everglades turtles in that they all remained near the capture/release site for extended periods. Three of the turtles in that study (turtles A, B, and C) were similar in size to our study turtles, but 2 were tracked for longer durations (i.e. 96 and 197 d). Pelletier et al. (2003) tracked 2 wild-caught green turtles in the Indian Ocean that were similar in size and displayed similar fidelity to release sites to that observed for Everglades turtles. However, habitat differences between our study and theirs (i.e. near-shore versus open ocean), may preclude comparison of the results. Most recently, McClellan & Read (2009) tagged juvenile greens very close in size to those captured in the Everglades, and they obtained tracking durations and observed net distances traveled per individual that were similar to our observations (Table 1). Also, McClellan & Read (2009) determined summertime utilization distributions (UDs) for North Carolina greens as 84.6 ± 48.3 km^2 based on satellite tracking. This estimate falls between our observations of the mean 50% core use area (KDE; 22.5 ± 22.1 km^2) and the mean general use area (95% KDE; 154.4 ± 136.1 km^2). That these 2 independent measures of seasonal home ranges are so similar in mangrove (present study) versus salt marsh (McClellan & Read 2009) habitat is striking, perhaps reflecting limits to home range area for this size class of green turtles.

However, questions remain as to the possibility of seasonal shifts in turtle habitat use within ENP because of the relatively short tracking duration in this study. Whether juvenile green turtle habitat-use patterns change in this area following the passage of summer tropical storms and hurricanes should be evaluated. Such storms generate tremendous wave and wind energy and have the potential to change shoreline topography and cover, dislodge marine algae, and change microhabitat features of the shoreline.

Our data show that the spatial location of the combined 2007 and 2008 50% core use areas (Fig. 3) is similar, perhaps suggesting that that there may be key microhabitat features of the site that make that area particularly suitable for juvenile greens either as a foraging area or a refuge site. An acoustic tracking study with deployment of a network of stationary receivers along the coastline may allow for longer tracking durations of individual turtles, which would help elucidate the extent of areas used by turtles at specific times of the year. An exploration of seasonal changes in habitat use, especially in areas where CERP activities are planned, would be valuable as a future study in this area.

Although we did not observe a difference in diurnal patterns of habitat use by juvenile green turtles in the coastal zone versus deeper water habitats (i.e. different distances from shore), it is possible that using satellite telemetry prevented us from capturing the fine-scale movements reported by Ogden et al. (1983) and Mendonça (1983) in their radio- and sonic-tracking studies of behavior and ecology of juvenile green turtles at other neritic, shallow-water, inshore feeding grounds. Ogden et al. (1983) conducted observations plus acoustic tracking to document diel foraging patterns of juvenile greens in St. Croix, US Virgin Islands. Similarly, Mendonça (1983) showed that green turtles in Florida fed on seagrass flats in mid-morning and mid-afternoon, then moved into deeper water during mid-day hours for resting. In the Everglades it is possible that turtle forage resources and ideal resting sites may be in the shallow coastal zone and that larger predators (i.e. various species of sharks) await the turtles in deeper habitat. However, to explore these finer-scale movement questions in this study site, focused, short-term radio and sonic tracking techniques should be employed.

Core activity areas generated from filtered data indicate relatively restricted, nearshore movement among juveniles during the springtime tracking period. This restricted movement implies a strong fidelity to the southwest coastal Everglades. The springtime home ranges of green turtles were extremely small, and individual turtles were located on successive days within the same coastal embayments or tidal creeks, a pattern that is consistent with other studies of green turtles on the east coast of the US (Mendonça 1983, McClellan & Read 2009). Mendonça (1983) reported that turtles tracked in an east coast Florida lagoon returned to resting sites within 3 m of their previous night's location. Although we did not observe differences in daytime versus nighttime distributions of satellite locations with respect to distance to shore, our results suggest that Everglades juvenile greens display similarly strong site fidelity especially to tidal creeks and embayments along the mangrove coastline.

Foraging optimality models suggest that animals will select resources of higher quality over those of lower quality (Krebs & Davies 1993, Bjorndal 1997, Gilbert 1998). In our study, we observed juvenile green turtles foraging in habitats with abundant patches of *Chlorophyta* and *Rhodophyta*; thus we hypothesize that these marine algae pastures may be more important than seagrass-dominated habitats as forage resources for juvenile green turtle populations in ENP or southwest Florida. When animals encounter areas of sufficiently abundant prey or sufficient resources for forage, they often engage in area-restricted searches by decreasing their travel rate and/or increasing their turning frequency and angle (Turchin 1991). Conversely, animals encountering unsuitable habitat often have fast travel rates and infrequent and small turning angles (Turchin 1991). We measured relatively small core activity areas, with site fidelity for all turtles and overlap of core areas used by individual turtles over a range of juvenile sizes in different years; all turtles also showed relatively slow travel speeds, similar to those reported by Seminoff & Jones (2006) (0.18 to 0.64 km h^{-1}). Thus, we surmise that juvenile greens tracked in this study displayed area-restricted search patterns, as well as behavior typical of resident turtles.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Our study has documented habitat use by juvenile green turtles in the mangroves of southwest Florida, a site not previously recognized as important for this endangered species. Because very little information is available globally for juvenile greens, this study represents an important contribution to data on sites in the USA that may serve as refuges and developmental habitat for these endangered sea turtles. Although it remains to be seen whether these juvenile green sea turtles are resident for longer than 62 d in this particular site, we observed considerable fidelity to capture and release sites among all individuals. We have also logged many sightings of juvenile greens in the study area since 2001 (K. Hart unpubl. data). Additional tracking of long-term (i.e. over the next several years) residence patterns of these turtles may help to elucidate the importance of this study site for other juvenile greens.

The results of our study also underscore the need to consider the impacts of Everglades restoration activities on juvenile green turtles and their habitat. Whether restoration of large coastal areas near the Everglades affects green turtles living downstream of construction activities and making use of coastal seagrass and marine algal resources remains to be seen. Characterization of marine turtle aggregations in the coastal zone likely to be impacted by restoration activities will allow for determination of how changes in hydrology affect the distribution and viability of juvenile green turtles and the seagrass and marine algal resources upon which they rely for food. Results of such a study could inform decision-makers about the effects of various freshwater release patterns to the coastal zone, as well as provide much-needed data for the Atlantic Green Turtle Recovery Plan (NMFS & USFWS 1991). If juvenile greens in other areas of the coastal zone of southwest Florida behave similarly to the juvenile greens tracked in this study, we may expect them to exhibit residence very close to the capture and release sites, in shallow depths, and in areas with dense patches of marine algae and sparse seagrass.

Determining the distribution and seasonal movements for all life stages of *Chelonia mydas* in the marine environment has been identified by the US Fish and Wildlife Service and the National Marine Fisheries Service as necessary to achieve recovery of the population of US Atlantic green turtles (NMFS & USFWS 1991). Decisions regarding restoration efforts in coastal areas of the Everglades that could serve as important developmental habitat for juvenile green turtles must take into account likely effects on forage resources found in those habitats. In order to conserve marine turtles, it is necessary to know more about their spatial patterns of habitat use at various life stages, as well as about the way these patterns vary among life stages.

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