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Satellite tracking reveals use of Biscayne National Park by sea turtles tagged in multiple locations

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ABSTRACT

Although historical observations date back to the 1800's, there is little information on sea turtle occupancy within Biscayne National Park (BNP). The park is located along the Florida reef tract and is dominated by the Gulfstream, which acts as a corridor for many marine animals. Here we used satellite telemetry to determine areas of use in BNP for two species of imperiled sea turtles, loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) turtles. We included data for turtles tagged between 2009–2021 at sites both within park waters and in five locations outside the park boundary; individuals were captured both in the water and on land. We tagged 60 individuals (female, n = 48; male, n = 3; immature, n = 9); loggerheads (n = 33) ranged in size from 66.2 to 109.9 cm CCL (curved carapace length) and green turtles (n = 27) ranged in size from 39.1 to 111.9 cm CCL. We used behavioral switching state-space modeling (SSM) to obtain daily predicted positions for each turtle, classified turtle behavior within the park as either foraging, migration, or both foraging and migration, and summarized high-use areas for each species across all months of the year. Turtles used park waters year-round, with concentrated use of deeper waters during seasonal migrations. Across all 60 turtles, 21 spent their tracking time foraging within BNP boundaries and 30 used the park as part of their migratory pathway; five turtles used the park for both foraging and migration, and the remaining four had SSM points very close to the park. Loggerhead migration occurred from February through November, whereas green turtle migration was concentrated in August. Both turtle species exhibited high overlap (i.e., usage) with seagrass habitat. These findings are relevant as managers consider strategies to minimize anthropogenic impacts to resident and migratory sea turtles using park waters.

1. Introduction

Protected areas provide a solution to conserving biodiversity and improving population trajectories for declining species. Protected areas (e.g., national parks, wilderness and marine protected areas) often have a higher biodiversity and abundance compared to unprotected areas (Gray et al., 2016). However, this safeguard is dependent upon animals' use of protected areas (Grüss et al., 2011) and is most effective where human-dominated land use is minimized (Gray et al., 2016). Where marine parks and protected areas are adjacent to highly developed urban areas, fisheries and human activity may still occur within the park boundaries and impact marine resources (Ault et al., 2001). Therefore, to successfully manage and conserve endangered or threatened species, it is critical to understand the distribution, movement behavior, and habitat interactions species have with the environment (Jeffers and Godley, 2016).

Marine species conservation has evolved over the past few decades to include satellite tracking technology, which has increased our ability to understand movement behaviors and high-use areas of various species (Block, 2005; Zbinden et al., 2007; Graham et al., 2012). Tracking patterns of migratory species, like tuna, sharks, billfish, and sea turtles can reveal migratory pathways and hotspots used for foraging, breeding, spawning, nesting, or overwintering (Block et al., 2001; Godley et al., 2008; Doherty et al., 2017). For example, a tracking study on leatherback turtles (*Dermochelys coriacea*) nesting in Mayumba National Park found that turtles spent an average of 62% of the tracking duration in unprotected waters outside the park (Witt et al., 2008). Other

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studies looking at global green turtle (*Chelonia mydas*) movement found that marine protected areas (MPAs) were positively correlated with foraging grounds for this species (Scott et al., 2012), a finding underscored in the Dry Tortugas where 82% of green turtles foraged within the MPAs (Hart et al., 2013). Similarly, throughout the Florida Keys National Marine Sanctuary, sea turtles were more likely to use multi-use protected areas than unprotected areas (Roberts et al., 2021). Multi-use protected areas allow for a range of resource use, for example recreational or commercial fishing typical of urbanized regions. In heavily urbanized areas of southern California, some green turtles use both restored and highly developed habitat, possibly benefitting from some human-implemented structures within developed habitats (Crear et al., 2017). These studies on sea turtle movement and behavior demonstrate the benefits of satellite telemetry to quantify habitat use of protected areas within marine regions. Results that summarize telemetry data can thus inform conservation policy and management strategies (Hays et al., 2019).

Biscayne National Park is located in southeastern Florida, south of Miami (Fig. 1). The park is adjacent to the Florida Keys National Marine Sanctuary, and proximal to Everglades National Park. It also lies adjacent to the Florida Straits and the Gulf Stream; the Florida Current moves north following the Florida Keys and the Florida Straits (Gyory et al., 2006). These marine areas are used by migrating sea turtles (see Arendt et al., 2012; Foley et al., 2014; Evans et al., 2019; Iverson et al., 2020), but use of areas specifically within Biscayne National Park is not documented. Despite Biscayne National Park's protected area status, boating, diving, and fishing are allowed, and there is a high level of recreational vessel usage within the bay (Jurowski et al., 1995). An aerial survey of Biscayne National Park found mean daily vessel counts varied between 362 and 417 in the spring and summer of 2003, and between 243 and 366 in the fall and winter of 2004 (Ault et al., 2008). In nearby Everglades National Park, motorboating in the shallow waters of Florida Bay was related to a large degree of seagrass scarring, especially in areas of high boat usage (Hallac et al., 2012). Though such studies have not been conducted in Biscayne National Park, it is reasonable to suggest similar instances occur because of the similarities in water depth and high levels of boating in the bay. Concomitant with boating activity is risk of boat strikes to large marine animals. In a study on injuries of nesting female loggerheads (*Caretta caretta*) on southeastern Florida beaches, 24% of turtles had at least one injury, and of these, 75% were caused by boat strikes (Ataman et al., 2021).

Two species of sea turtles are commonly found in Biscayne Bay, loggerhead turtles and green turtles. Occurrence records for these species date back to fisheries harvests in the 1800s (Smith, 1896). Green turtles are currently critically endangered globally (Mortimer and Donnelly, 2008), and loggerheads are listed as globally vulnerable (Casale and Tucker, 2017). All species are protected under the Unites States Endangered Species Act, with loggerhead and green turtles classified as threatened in the North Atlantic Distinct Population Segment (NMFS and USFWS, 1991, 2008, 2011; Conant et al., 2009; Seminoff et al., 2015).

To date, there have been no studies on sea turtle habitat use within Biscayne National Park. Here, we used satellite telemetry to determine high-use areas and movement behavior of two species of sea turtles captured both inside and outside the park. Our objectives were to determine spatio-temporal habitat use by turtles within park boundaries.

2. Materials and methods

Study Area

Biscayne National Park exists within Biscayne Bay. Biscayne Bay is a subtropical bay with shallow waters ranging from about 2 to 18 m, and a seafloor of carbonate sand and several species of seagrass (Zawada and Brock, 2009). There is a high density of urban and agricultural development adjacent to Biscayne Bay, with stormwater that carries chemicals, sediments, and nutrients into the bay (Browder et al., 2005). The Turkey Point Nuclear Power Plant site adjacent to Biscayne Bay is occupied by a closed-loop cooling canal system whereby artificially heated condenser cooling water is discharged into the system (Gaby et al., 1985). Most of the freshwater discharge into the bay occurs through controlled canals, which are used for flood water control and municipal water supply management (Wang et al., 2003). A comprehensive study on the water quality in the bay indicated high concentrations of ammonium were present in the southern portion. High ammonium concentration was correlated with decreased abundance of *Thalassia testudinum* (Caccia and Boyer, 2005), a seagrass which represents the primary food of green turtles (*Chelonia mydas*) in the Atlantic Ocean (Williams, 1988;

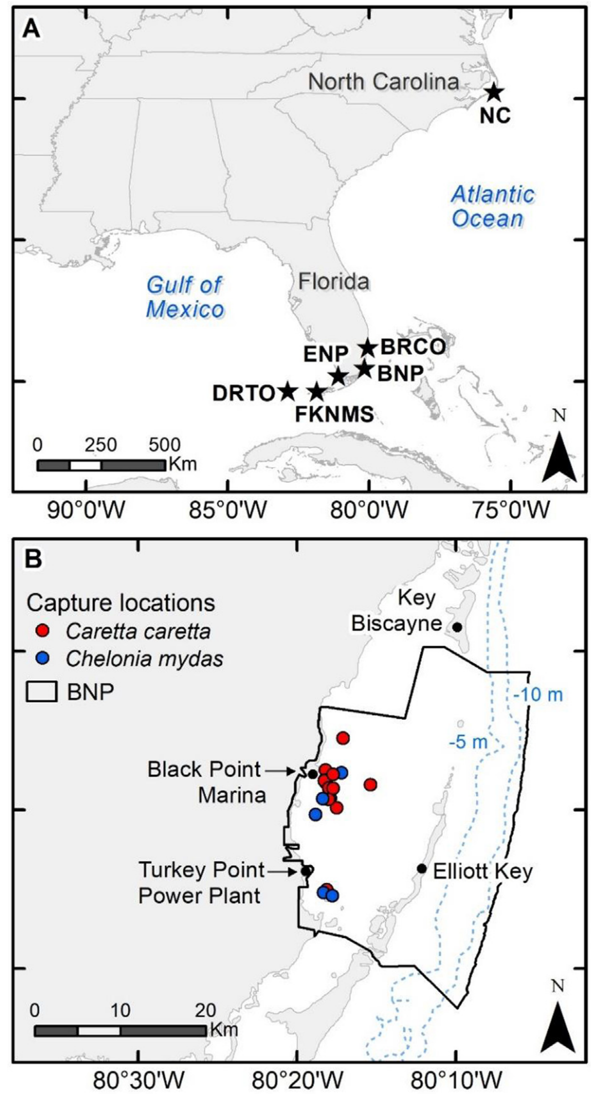

Fig. 1. Sea turtle tagging areas, and turtle capture locations from the Biscayne National Park (BNP) tagging area. A. Tagging areas are represented as stars and include: BNP, Florida (n = 20); Broward County, Florida (BRCO, n = 31); Dry Tortugas National Park, Florida (DRTO, n = 5); Everglades National Park, Florida (ENP, n = 2); Florida Keys National Marine Sanctuary, Florida (FKNMS, n = 1); Cape Hatteras National Seashore, North Carolina (NC, n = 1). B. Capture locations for loggerhead turtles (*Caretta caretta*) and green turtles (*Chelonia mydas*) within BNP. * All males were captured within FKNMS and BNP.

Table 1
Capture locations, species, and sex of loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) turtles satellite-tagged between 2009 to 2021within proximity to and within Biscayne National Park, FL, USA. See Hart et al. (2023) for more details.

Capture site	*Caretta caretta*			*Chelonia mydas*		
	Female	Male	Unknown	Female	Male	Unknown
Biscayne National Park, FL	9[a]	2[a]	4[a]	0	0	5[a]
Broward County beaches, FL	11	0	0	20	0	0
Dry Tortugas National Park, FL[b]	3[b]	0	0	2	0	0
Everglades National Park, FL	2	0	0	0	0	0
Florida Keys National Marine Sanctuary, FL	0	1[a]	0	0	0	0
Cape Hatteras National Seashore, NC	1	0	0	0	0	0

[a]Denotes in-water captures, the remaining turtles were intercepted on the nesting beach.
[b]Includes four loggerhead turtles that used waters close to park, but never entered the park.

Moran and Bjorndal, 2007; Gulick et al., 2021). The area west of Elliot Key is primarily between 0 and −3 m bathymetry, while the area east of Elliot Key reaches up to −18 m bathymetry in the farthest eastern corners of the park, although most of the eastern area is <−10 m (ETOPO1 Bedrock cell-registered bathymetry; Amante and Eakins, 2009).

Turtle Capture and Workup

We used methods to capture turtles including in-water methods (dip-netting, rodeo/turtle jumping; see Ehrhart and Ogren, 1999) and capture of adult females on beaches during nesting seasons (see Hart et al., 2013). For a detailed description of morphometric measurements taken as part of in-water captures see Fujisaki et al. (2016) and for land-based captures see Hart et al. (2013). Capture sites included Biscayne, Dry Tortugas, and Everglades National Parks, Broward County beaches, locations within the Florida Keys National Marine Sanctuary, and on land at Cape Hatteras National Seashore, North Carolina (Fig. 1).

Satellite Tracking

We outfitted turtles with Argos platform terminal transmitters (PTTs; SPOT and MK10 SPLASH tags; Wildlife Computers, Redmond, WA) following established protocols (NMFS SEFSC, 2008) and methods outlined in Hart et al. (2021). For all tags, daily transmissions were limited to 250 and optimized for times of satellite passes in the area. Fastloc MK10 SPLASH tags were programmed to obtain up to 4 Fastloc GPS locations, with a maximum of 10 attempts.

Switching State-Space Modeling

Following Hart et al. (2013) we analyzed data from Argos location classes (LC: 3, 2, 1, 0, A, B), but lowest quality LC Z points (for invalid locations) and points inland were removed. Argos assigns accuracy estimates of <100 m for GPS locations, <250 m for LC 3, 250 to <500 m for LC 2, 500 to <1500 m for LC 1, and >1500 m for LC 0 (CLS, 2016). We applied a Bayesian hierarchical switching state-space model (SSM) to the satellite-tracking data to estimate the location and behavioral mode for each turtle. We fit the model using the 'hDCRWS' model specification (hierarchical first difference correlated random walk switching model) in the R package bsam (Jonsen et al., 2005; Jonsen, 2016; Jonsen et al., 2017; R Core Team, 2021) and ran JAGS using the R package rjags (Plummer, 2022) to run the Markov chain Monte Carlo (MCMC) algorithm. We ran the SSM using a time step of 24 h (1 point per day). We ran two independent parallel MCMC chains, applied adaptive sampling for the first 3500 iterations, and discarded an additional 3,500 samples as burn-in. We drew 10,000 samples from the posterior distribution and thinned by 5 to reduce within-chain autocorrelation, which resulted in 2000 samples from the posterior distribution for inference. The hierarchical SSM accounted for location error, and estimated movement parameters jointly across individuals to enhance behavioral mode evaluation. Each SSM location was categorized into one of two behavioral modes: "area-restricted searching" (e.g., foraging) or "transiting" (e.g., migration; Jonsen et al., 2007, 2013), the former described locations with comparatively short step lengths and numerous turns (tortuous movement) and the latter described locations with comparatively long step lengths and very little turning (straighter movement).

Turtle Use of Biscayne National Park

We overlaid SSM tracks for each individual with the Biscayne National Park boundary in ArcGIS 10.8.1 (ESRI, 2020) to determine marine turtle use of the park. For each species, we determined the number of tracking days per grid cell (2 *x* 2 km grid cell size) within Biscayne National Park using the R packages raster (Hijmans, 2021) and rgdal (Bivand et al., 2021). This grid cell selection of 2 *x* 2 km was used to incorporate the greatest error estimate for raw satellite tracking data points (CLS, 2016). We tallied the number of SSM points (each representing one tracking day) for each turtle in each grid cell and summed the total number of tracking days in each grid cell for all turtles, by species, for all months of the year, and also according to the female non-breeding (1 Oct–31 March) and breeding (1 April–30 Sept) seasonal time delineations. We also calculated the proportion of SSM tracking days spent in Biscayne National Park and compared it to the total SSM tracking days for each turtle. We determined the SSM behavioral mode(s) for each turtle during their tracking time in Biscayne National Park: area-restricted searching (ARS, or foraging); transiting (migration); both foraging/ARS and migration.

Additionally, we evaluated sea turtle use of seagrass habitat in Biscayne National Park. For turtles with foraging/ARS behavior in Biscayne National Park, we determined the core use area using 50% Kernel Density Estimation (KDE; Worton, 1995; Keating and Cherry, 2009) following methods in Hart et al. (2020) using the R package adehabitatHR (Calenge, 2006). After calculating the centroid (geometric center) of each core use area, we determined if the centroid overlapped with seagrass habitat (FWC, 2020) in ArcGIS 10.8.1 (ESRI, 2020). We also calculated the percentage of ARS (foraging) SSM points and transiting (migration) SSM points in Biscayne National Park that overlapped with seagrass habitat in ArGIS 10.8.1 (ESRI, 2020).

Finally, we evaluated sea turtle use of current zones of protection within Biscayne National Park, including the no trawl zone (where roller frame trawls are prohibited from operation), Coral Reef Protection Areas (CRPA; all traps are prohibited, and all lobster harvest is prohibited), the trap-free zone near Biscayne National Park headquarters, and the Biscayne Bay-Card Sound Spiny Lobster Sanctuary (where taking of lobster is prohibited; FWC, 2023).

3. Results

Turtles

Between 2009 to 2021, we satellite-tracked a total of 60 sea turtles (n = 33 loggerhead turtles, n = 27 green turtles) captured across six sampling locations. Forty-eight turtles were female, 3 were male, and 9 were immature (Table 1). Captures by sites were as follows: five locations in Florida including: Biscayne National

Park (n = 20); Broward County beaches (n = 31); Dry Tortugas National Park (n = 5); Everglades National Park (n = 2); Florida Keys National Marine Sanctuary (n = 1), and one location in North Carolina: Cape Hatteras National Seashore (n = 1, Fig. 1). Of the 60 turtles, 21 were in-water captures, whereas 39 were captured on nesting beaches outside of Biscayne National Park (Table 1). Across all turtles tagged, curved carapace length (CCL) measurements varied from 39.1 to 111.9 cm, with 20% (n = 12) classified as sub-adults and 80% classified as adults (n = 48; Prince et al., 2012). Nesting turtle sizes varied from 87.1 to 111.9 cm CCL, whereas size from in-water captures varied from 39.1 to 99.5 cm CCL. Loggerhead turtles varied from 66.2 to 109.9 cm CCL with 21% (n = 7) classified as sub-adults and 79% classified as adults (n = 26). Green turtles varied from 39.1 to 111.9 cm with 19% (n = 5) classified as sub-adults and 81% classified as adults (n = 22; Hart et al., 2023).

Satellite Tracking

Over the course of the study period, we tracked loggerhead and green turtles for a cumulative total of 11,523 and 4,160 days respectively. Individual tracking durations varied from 56 to 1,187 days (mean 349, SD ± 238 days) for loggerheads and from 22 to 333 days (mean 154, SD ± 89 days) for green turtles (Hart et al., 2023).

Switching State-Space Modeling

Switching state-space modeling was performed on 60 turtles. Four turtles were excluded from analyses (all females) because although some satellite points were recoded within Biscayne National Park, SSM movements were not assigned within park boundaries. Of the 56 turtles that remained, 21 turtles used the park for foraging (behavior was ARS) while 30 used the park for migration (behavior was transiting), and five used the park for both foraging and migration; Fig. 2. For example, one turtle (T46, adult female loggerhead) displayed both foraging (ARS) and migration (transiting) behaviors within the park over the course of 11 months; T46 spent about 10 months in ARS mode inside of the park, then exited the park at the beginning of August, migrating about 300 km north, only to return 20 days later, migrate south through (and out of) the park over the course of two days (see Fig. 2). Of the three males tagged, all were loggerheads and one (T33) displayed migration behavior within the park, one displayed foraging behavior within the park (T49) the other one (T48) displayed both foraging and migration behavior within the park. All of the nine immature turtles displayed foraging behavior within the park. By species, 12 loggerheads used Biscayne habitats for foraging, 16 used the park for migration, and three used the park for both foraging and migration. Nine green turtles used Biscayne habitats for foraging, 14 used parts of the park for migration, and 2 used the park for both foraging and migration.

Turtle use of Biscayne National Park

Satellite-tracked loggerhead turtles were within Biscayne National Park a total of 2,843 days, with individual turtles spending from 1 to 381 days within the park (mean 92, SD ± 116 SSM days). Satellite-tracked green turtles were within the park a total of 1,010 days, with individual turtles spending from 1 to 246 days there (mean 72, SD ± SSM days; Fig. 3). The primary use area for loggerhead turtles in this study was along the western half of the park, with >90% of the tracking days between the mainland and Elliott Key (Fig. 3). However, loggerhead turtles also used areas east of Elliott Key and other sites throughout the park (Fig. 3). Green turtle tracking days were concentrated primarily in the southern half of the park (>80% of tracking days; Fig. 3), especially in areas east of Elliott Key, with fewer tracking days in the western half of the park. Within the park, core use area centroids (50% KDE) for turtles classified as ARS (foraging behavior), primarily overlapped with seagrass habitat (23 out of 24 centroids). In total, 3,627 out of 3,802 (95%) ARS (i.e., foraging) SSM points overlapped with seagrass beds (Fig. 4). For individuals classified as transiting (i.e., migrators), 38 out of 51 (75%) SSM points overlapped with seagrass (Fig. 4). Turtles with transiting points in the park had one to three "transiting" SSM points within park boundaries (Fig. 2).

Temporal Movement

ARS foraging behavior was exhibited by loggerhead turtles within the park boundaries during all months of the year, whereas ARS foraging behavior of green turtles was limited to February through August (Fig. 2). Turtles that migrated through Biscayne National Park did so between March through August and in November and January (Fig. 2). Twenty turtles in the study spent much of their tracking time (>50%) inside park boundaries. Many turtles remained within the park for a variable amount of their tracking time (i.e., 25%–50%, n = 2; <25%, n = 34). The remaining four turtles spent little time within park boundaries, and displayed only 1–4 satellite data points near park margins in August or September, resulting in no SSM points within the park (i.e., single satellite point within park boundaries, n = 2; traveled through park with a single satellite point in the park, n = 1; migrated along the outer eastern boundary, with four satellite points in the park, n = 1).

Location of high-use grid cells varied over time and by species. Loggerheads in both breeding and non-breeding seasons primarily used the western park boundary along the coastline (Fig. 3). Green turtles primarily used the area east of Elliott Key, especially during the non-breeding season (Fig. 3). For each species, their spatial use of grids cells shifted temporally, and the cumulative number of occupied grid cells (cells with at least one tracking day) was highest in Biscayne National Park during the breeding time period. All transiting (migration) SSM points were generally located on the eastern side of Biscayne National Park and most of the ARS (foraging) core use area centroids were located on the western side of the park (Fig. 4). Lastly, high-use grid cells for both species overlapped with various zones of protection within Biscayne National Park over all months (see Supplemental Fig. 1).

4. Discussion

Our results provide the first information on sea turtle movement within Biscayne National Park, a shallow subtropical bay off the coast of southeast Florida. Turtles in this study were tagged at multiple sites across southern Florida, and from one site in North Carolina, representing a variety of genetically distinct subpopulations of two imperiled species, all of which use Biscayne National Park. We describe temporal variation in high-use areas within the park and present data on the size range of turtle captures. This is the first study to document year-round occupancy by both green and loggerhead turtles, and our data show that Biscayne National Park represents a previously unrecognized foraging area, that may also be important for turtle development given habitat use by several immature turtles. Finally, we suggest that Biscayne National Park provides important migratory pathways for turtles during both breeding and non-breeding periods.

Our findings indicate that Biscayne National Park likely acts as an important segment of the migratory pathway for both Gulf and Atlantic turtles migrating to or from the Florida Keys (see Hart et al., 2023). Further, the park appears to provide an important area for adult males as well as nesting females post-breeding; both males and females showed migration and foraging behavior within the park. As with Arendt et al. (2012), we found that migratory male loggerhead turtles used a north-south corridor along the east side of the park, representing an area inshore of the continental shelf (Fig. 4). Corridors such as these may represent a mechanism for males to locate females (e.g., Arendt et al., 2012). Other studies in Florida have likewise identified important corridors. For example, Evans et al. (2019) conducted an on

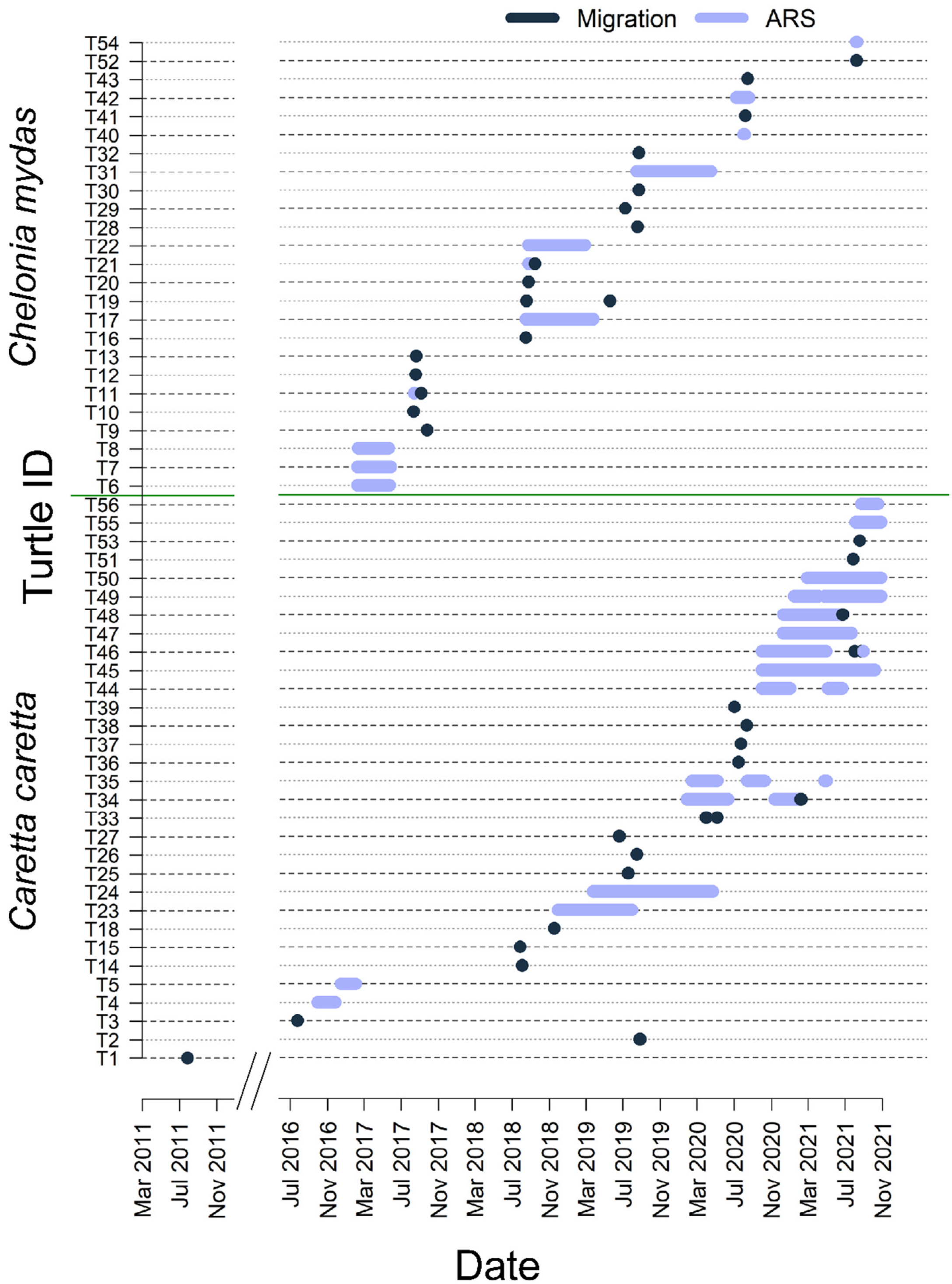

Fig. 2. Summary of behavioral mode classification within Biscayne National Park (BNP) for each turtle, by species over time, from switching state-space modeling tracking days. Migration behavior corresponds to transiting behavior and ARS (area-restricted searching) corresponds to foraging behavior. Five turtles showed both behaviors within BNP (*Chelonia mydas*: T11, T21; *Caretta caretta*: T34, T46, and T48). The horizontal green line is included to distinguish between species. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

optimized hot spot analysis for loggerheads tagged north of our study site at Archie Carr National Wildlife Refuge (ACNWR), on the Atlantic coast of Florida. Loggerheads tagged within ACNWR used a corridor along the southeast coast of Florida, (Evans et al., 2019) and this area represents a significant migration zone that likely connects with the area adjacent to Biscayne National Park. This use of the southeast coast was also previously documented from loggerheads originally tagged in Melbourne, FL (Foley et al., 2013) and loggerheads using the straits as a migratory pathway to residence areas in the Bahamas from Dry Tortugas National Park (DRTO; Hart et al., 2015). Finally, a post-nesting female green turtle from DRTO was tracked, to locations within the Florida Keys National Marine Sanctuary, just south of Biscayne National Park (Hart et al., 2013). Taken together, these studies demonstrate important coastal migration routes in Florida, and we add Biscayne National Park to this network.

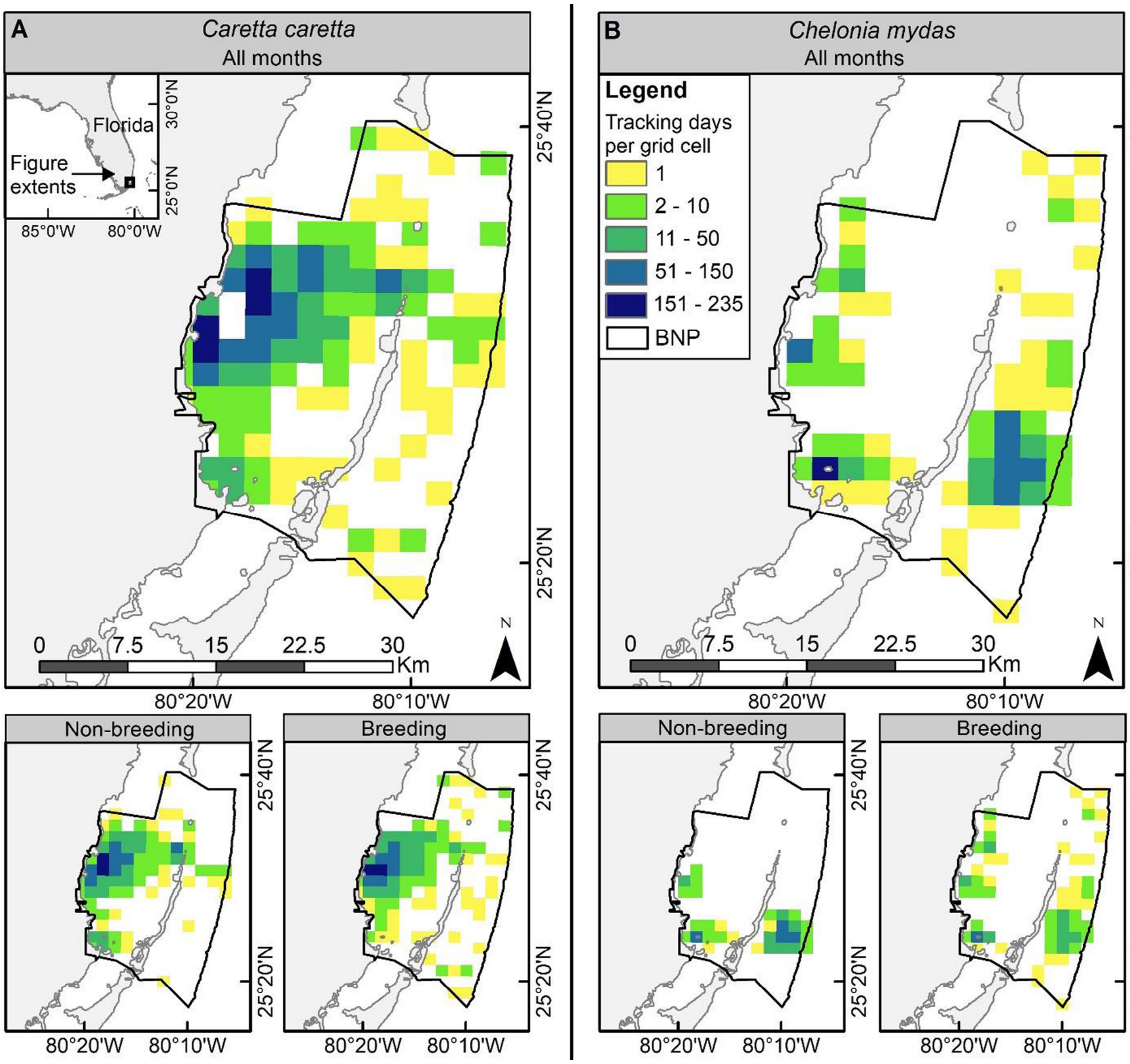

Fig. 3. The number of tracking days per 2 *x* 2 km grid cell in Biscayne National Park (BNP), Florida for A. *Caretta caretta*, and B. *Chelonia mydas*. The top panels show the tracking days for each species over all months of the year, and the bottom panels show the tracking days for each species for periods of non-breeding (1 Oct–31 March) and breeding (1 April–30 September) time, based on female nesting seasons.

Green turtles in our study showed concentrated tracking days in the eastern and southeastern portion of the park whereas loggerheads primarily showed concentrated tracking days in the western portion of the park (Fig. 3). Adult turtles used deeper portions of the park on the eastern side when migrating both northward and southward, and as a stopover site during migration (Fig. 4). Green turtles with shorter track durations showed high-use grid cells biased towards capture locations. Green and loggerhead turtles are known to show site fidelity to foraging areas (Broderick et al., 2007), and the five tagged in Biscayne National Park exhibited high site fidelity with minimal post-release movement indicating residency and that they remain in areas with seagrass. Further, both species used areas that overlapped with management zones of protection within the park and some used grid cells proximal to the protection zones (e.g., no trawl zones or areas where lobster harvest is prohibited; see Supplemental Fig. 1). Future work to target, capture, and satellite-tag turtles within protection zones of Biscayne National Park could help to assess specifically if turtles are using them, and to what degree, throughout the year.

5. Conclusion

We demonstrate that distinct subpopulations of two imperiled marine turtle species use Biscayne National Park year-round, and these individuals are from multiple locations within and outside of Florida. Our study of tracked loggerhead and green turtles establishes the park as an important foraging ground and a component of a migratory corridor for both species, and is thus of conservation concern. We found that certain areas of the park represent high-use areas for both turtle species, and this may inform decision-making regarding critical habitat designations and park-specific protection zones (see Supplemental Fig. 1). Future work to incorporate standardized surveys to characterize variation in turtle density and abundance throughout Biscayne National Park, along with finer-scale resolution on habitat-use patterns in managed zones of the park is planned, and these studies may provide valuable information for resource managers.

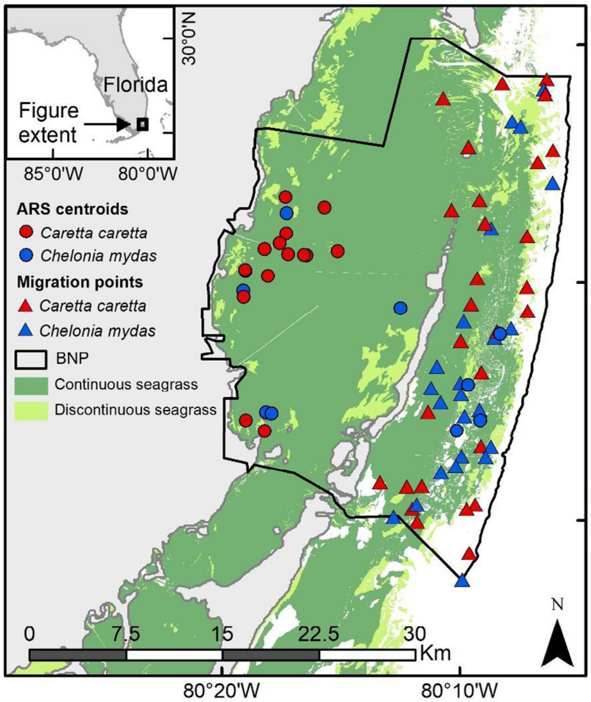

Fig. 4. Kernel density ARS (area-restricted searching) centroids (50% KDE's) representing the core areas used by loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) turtles while in Biscayne National Park (BNP), plotted with migration switching state-space modeling (SSM) points, and seagrass habitat. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

CRediT authorship contribution statement

Kristen M. Hart: Conceptualization, Formal analysis, Funding acquisition, Project administration, Data curation, Writing – original draft, Writing – review & editing. **Allison M. Benscoter:** Conceptualization, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Haley M. Turner:** Conceptualization, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Michael S. Cherkiss:** Data curation, Writing – original draft, Writing – review & editing. **Andrew G. Crowder:** Data curation, Writing – review & editing. **Jacquelyn C. Guzy:** Data curation, Writing – original draft, Writing – review & editing. **David C. Roche:** Data curation, Writing – original draft, Writing – review & editing. **Chris R. Sasso:** Funding acquisition, Project administration, Data curation, Writing – review & editing. **Glenn D. Goodwin:** Data curation, Writing – review & editing. **Derek A. Burkholder:** Funding acquisition, Project administration, Data curation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Public data release cited doi listed in literature cited section.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2023.103098.

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