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Using acoustic telemetry to assess patterns in the seasonal residency of the Atlantic stingray *Dasyatis sabina*

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Abstract The Atlantic stingray *Dasyatis sabina* is found along the Atlantic and Gulf coasts of the United States. It consumes commercially important shrimp and crabs, and its diet overlaps with recreationally valuable red drum *Sciaenops ocellatus* and pompano *Trachinotus* spp. Despite the potential economic impact of this species, it is unclear whether the Atlantic stingray is present year-round or only seasonally in coastal habitats. The objective of this study was to assess the seasonal residency patterns of Atlantic stingrays in two creek systems in the Savannah River estuary. Forty stingrays were tracked using acoustic telemetry, and a seasonal residence index was calculated for each individual. Atlantic stingrays were present year-round in the Savannah River estuary, as 15 % ($n = 6$) of the tagged rays remained in the study areas throughout the year. This is the northernmost region where this species has been documented to be present all year. Of the 85 % ($n = 34$) of the rays that migrated during winter, 38 % ($n = 13$) of those were detected within the estuary less than 20 km away. Had trawls or mark-recapture been used instead, the few animals remaining in the creek systems and/or those that migrated may not have been collected. Acoustic telemetry is a more accurate means of studying the residency of fishes than periodic sampling that requires capture, and researchers should consider incorporating this technology in future studies about fish-environment interactions. Underestimating the presence of a species could result in miscalculation of its economic and ecological impact and, by extension, result in the implementation of ineffective or even detrimental management strategies.

Keywords Elasmobranch · Batoid · Dasyatid · Habitat utilization · Migration · Temporal use

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Introduction

The Atlantic stingray *Dasyatis sabina* is a demersal elasmobranch that inhabits salt, fresh, and brackish waters along the Atlantic and Gulf coasts of the United States from the Chesapeake Bay to the Gulf of Mexico (Dahlberg 1975; Johnson and Snelson 1996; Kells and Carpenter 2011). This species is tolerant of a wide range of environmental conditions, surviving in salinities as low as 0 ppt (Funicelli 1975; Schwartz 2000) and as high as 41 ppt (Snelson et al. 1988), and water temperatures ranging from 15 °C (Funicelli 1975; Snelson et al. 1988) to 35 °C (Schwartz and Dahlberg 1978; Snelson et al. 1988).

Dasyatis sabina is preyed upon by larger elasmobranchs, including the bull shark *Carcharhinus leucas* (Snelson et al. 1984), great hammerhead shark *Sphyrna mokarran* (C. Cotton, pers. comm.), sharpnose shark *Rhizoprionodon terraenovae,* and blacktip shark

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Carcharhinus limbatus (Hoffmayer and Parsons 2003). The Atlantic stingray is an opportunistic predator of commercially important crustaceans such as shrimp *Penaeus* spp. and blue crabs *Callinectes sapidus*, as well as grass shrimp *Palaemonetes* spp. (Funicelli 1975; Howard et al. 1977; Blonder and Alevizon 1988). Its diet overlaps with those of recreationally valuable red drum *Sciaenops ocellatus* and pompano *Trachinotus* spp. (Cook 1994). The Atlantic stingray is also an ecosystem engineer; when it feeds, it excavates pits (Howard et al. 1977) and significantly reduces the abundance of meiofauna in the benthos (Reidenauer and Thistle 1981; Cross and Curran 2000; Cross and Curran 2004; Ebanks 2005). Despite the trophic significance of this species and its potential to impact both commercial and recreational fisheries, it is unclear whether the Atlantic stingray is present year-round or only seasonally in its coastal habitats.

Atlantic stingrays have been reported to be present year-round in some regions (Schwartz and Dahlberg 1978; Snelson et al. 1988; Fangue and Bennett 2003), but only seasonally in others (Funicelli 1975; Lewis 1982; Schwartz 2000), although there may be confounding effects of sampling gear (Table 1). Atlantic stingrays are present year-round on the Atlantic coasts of Georgia (Schwartz and Dahlberg 1978) and mid-Florida (Snelson et al. 1988) as well as the northern Gulf coast of Florida (Fangue and Bennett 2003). In contrast, less than 100 km east along the Gulf coast of Florida, Atlantic stingrays are thought to be present only seasonally (Lewis 1982). Additionally, Atlantic stingrays are considered to be present only seasonally off the coasts of North Carolina (Schwartz and Dahlberg 1978), South Carolina (Ogburn et al. 1988), and Texas (Sage et al. 1972).

It is possible that Atlantic stingrays are present all year in some regions and only seasonally in others. However, it is also possible that they are present throughout the year in all regions but not collected using certain sampling methods. For example, benthic irregularities can reduce the effectiveness of bottom trawls and long-lines historically used to study residency. Both of these sampling gears can become entangled in or damaged by rocks, driftwood, oyster rakes, abandoned crab pots, and other debris. Strong winds can also interfere with the deployment of trawls, as occurred when McQuinn and Nellis (2007) trawled for lake sturgeon *Acipenser fulvescens* in the middle St. Lawrence estuary. Acoustic telemetry is also more effective than mark-recapture for assessing residency because movement data can be obtained even if the tagged animal is never encountered again (Heupel et al. 2006). For example, Schmid (1988) marked 203 Atlantic stingrays in the Indian River Lagoon but only recaptured 75 (37 %). However, 100 % of the Atlantic stingrays tagged by Brinton (2015) were “recaptured” by acoustic receivers at least 1 day after release. In addition, data can be collected by acoustic receivers even when weather conditions make it unsafe for researchers to be on the water (Heupel et al. 2006) and allow for greater temporal and spatial coverage of a study area than periodic sampling that requires capture (e.g., trawls,

Table 1 List of locations in which the seasonal presence of the Atlantic stingray *Dasyatis sabina* has been described, including the gear type used and whether or not rays were found year-round or only seasonally

Study Site	State	Gear	Present	Citation
Cape Fear River estuary	NC	Mark-Recapture	Seasonally	(Schwartz and Dahlberg 1978)
Cape Fear River estuary	NC	Bottom Trawl	Seasonally	(Schwartz 2000)
North Inlet estuary	SC	Bottom Trawl	Seasonally	(Ogburn et al. 1988)
Savannah River estuary	GA	Acoustic Telemetry	Year-Round	present study
St. Catherines Sound	GA	Bottom Trawl	Year-Round	(Schwartz and Dahlberg 1978)
Sapelo Sound	GA	Bottom Trawl	Year-Round	(Schwartz and Dahlberg 1978)
Indian River Lagoon	FL (Atlantic)	Gill Nets	Year-Round	(Snelson et al. 1988)
Live Oak Island	FL (Gulf of Mexico)	Bottom Trawl	Seasonally	(Lewis 1982)
St. Joseph’s Bay	FL (Gulf of Mexico)	Observation	Year-Round	(Fangue and Bennett 2003)
Mississippi Sound	MS	Bottom Trawl	Seasonally	(Funicelli 1975)
Gulf Coast bays	TX	Bottom Trawl	Seasonally	(Sage et al. 1972)

hooking gear, entanglement gear). Furthermore, the longevity of acoustic tags allows for the observation of animal movements over multiple years, such that researchers can determine the repeatability of movement patterns (Hussey et al. 2015). Passive acoustic telemetry does not require constant close proximity to a study organism, which could influence its behavior (Heupel et al. 2006). Finally, animals can be detected using acoustic telemetry even in regions of complex bathymetry where the deployment of trawls or long-lines is difficult or inefficient (Ramsden 2015; Brinton 2015).

Despite the effectiveness of passive acoustic telemetry in assessing the home ranges, habitat use, distribution, and site fidelity of many aquatic species (Hussey et al. 2015), there are few studies in which this technology has been used to assess the long-term movement patterns of batoid elasmobranchs. In Australia, acoustic telemetry has been used to investigate the activity patterns and habitat use of freshwater whiprays *Himantura dalyensis* (Campbell et al. 2012), mangrove rays *Himantura granulata* (Davy et al. 2015), shovelnose rays *Glaucostegus typus*, and reticulate whiprays *Himantura uarnak* (Vaudo and Heithaus 2012). Acoustic telemetry has been used to study the foraging behaviors of southern stingrays *Dasyatis americana* (Corcoran et al. 2013) and pink whiprays *Himantura fai* (Gaspar et al. 2008), and the seasonal residency patterns of round stingrays *Urobatis halleri* have also been studied using this technology (Vaudo and Lowe 2006). To date, the long-term movement patterns of the Atlantic stingray have not been studied using acoustic telemetry. The objective of the present study was to assess seasonal patterns in residency of Atlantic stingrays in two creek systems in the Savannah River estuary on the coast of Georgia using acoustic telemetry.

Materials and methods

Study sites

Two creek systems were studied on the northern coast of Georgia (Fig. 1). The Romerly Marsh Creek system is approximately 4.5 km in length from its mouth (31°55′ 46.45″ N, 80°59′4.66″ W) to its farthest tributary (31°55′32.81″ N, 81°1′45.13″ W), and, at mean low tide, the depth in the main channel ranges from 0.0 m in some places to 17.8 m at its deepest point. Salinity in Romerly Marsh Creek ranges from 20 to 30 ppt. The Herb River Creek system is approximately 10.0 km in length from its mouth (32° 0′ 31.57″ N, 81° 3′ 18.11″ W) to its farthest tributary (32° 1′ 22.16″ N, 81° 3′ 10.84″ W), and, at mean low tide, the depth of the main channel ranges from 0.0 in some places to 10.0 m at its deepest point. This creek system is farther from the open ocean than Romerly Marsh Creek, so its salinity is typically lower, ranging from 10 to 20 ppt. Both creeks experience semi-diurnal tides, ranging from −0.97 m to +2.91 m above mean lower low water. The banks are primarily vegetated with the smooth cordgrass *Spartina alterniflora*. The benthos of these systems is dominated by mud and sand flats with beds of the eastern oyster *Crassostrea virginica*. For the remainder of this manuscript, the terms 'Romerly Marsh Creek' and 'the Herb River' refer to both the main channels and smaller tributaries making up these systems.

Passive acoustic receiver arrays

Arrays of passive acoustic receivers (Vemco VR2W-69 kHz) were deployed in both Romerly Marsh Creek and the Herb River using the methods described by Smith (2012) and modified by Ramsden (2015). Smith (2012) attached his receivers to steel rebar mounted in a concrete block. In the present study, the receivers were instead attached to PVC pipes that would not rust. The mounted receivers were then moored to concrete blocks lodged on the marsh shore to minimize movement by strong currents. Fifteen receivers were deployed in Romerly Marsh Creek in September 2012 at low tide depths ranging from 0 to 15 m (Fig. 1). Eleven receivers were deployed in the Herb River in April 2013 at low tide depths ranging from 0 to 10 m (Fig. 1). Receivers placed in locations that would be dry during low tide were deployed upside down, so that the hydrophone remained in the water for as long as possible. The detection radii of receivers ranged from 200 to 300 m. However, there was a significant effect of tidal stage and tributary width on detection range, with receivers in the widest tributaries having the greatest detection radii during high tide and receivers in the narrowest channels having the shortest detection radii during low tide (Brinton 2015). Stingrays were probably not in the vicinity of receiver stations when there was no water and receivers were not collecting data. Therefore, it is unlikely that a ray present in the creek system would be

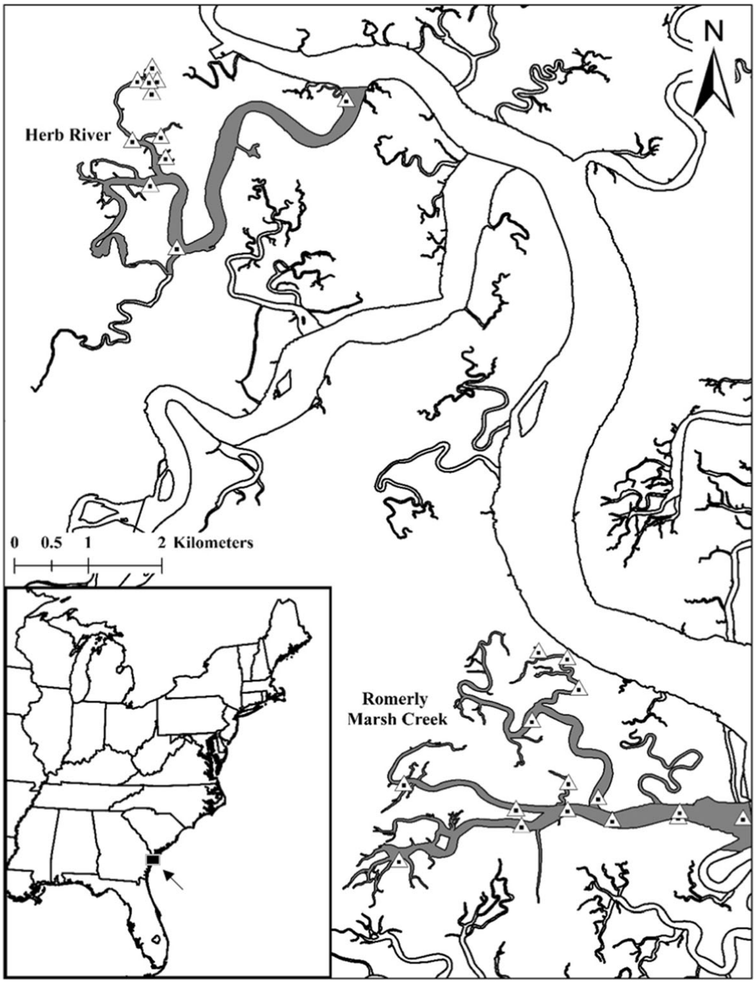

Fig. 1 Locations of the receiver arrays deployed in the Herb River and Romerly Marsh Creek systems in the Savannah River estuary on the coast of Savannah, Georgia. Receivers are denoted by *white triangles*. The *square and arrow* on the inset map represent the location of these creek systems on the East Coast of the United States

counted as absent, even though some receivers were not collecting data during certain hours of the tidal cycle.

In May 2013, a Vemco MINILOG-II-T temperature logger was attached to one acoustic receiver near the center of the widest tributary of each creek system. In Romerly Marsh Creek, the temperature logger was deployed at a low tide depth of 3 m. In the Herb River, the temperature logger was deployed at a low tide depth of 2 m. Strong tidal currents result in rapid mixing and prevent stratification in coastal Georgia estuaries (Ragotzkie and Bryson 1955). Both Romerly Marsh Creek and the Herb River experience extreme tidal ranges and currents, resulting in the waters of both systems being well mixed. Accordingly, temperatures collected from each logger location were considered to be representative of their entire respective system. Loggers recorded bottom-water temperature every 90 s to the nearest 0.1 °C. Temperature data from the loggers and detection data from the receivers were downloaded every 1–2 months.

Stingray capture and tagging

Stingrays were captured via long-lining using barbed, size 4 circle hooks baited with commercially collected frozen squid (*Loligo* spp.). Mass and disk width (DW) were measured on deck, and then stingrays were returned to the water for 1–2 min prior to the tagging surgery. Surgical instruments were in sterile packaging or were washed with 70 % ethanol solution. Rays were placed on their dorsal side, which was intended to induce tonic immobility, as described by Henningsen (1994). However, stingrays often remained mobile during the beginning of the surgery, so the tail was immobilized by sheathing it in a PVC pipe. The incision site was swabbed with a povidone-iodine swabstick and a 2–3 cm incision was made in the ventral surface of the stingray on the anterior lateral edge of the peritoneal cavity. Incisions were always made in the left edge to avoid the spiral valve, located on the right side. A Vemco V16-4H (24 g) or Vemco V13-1H (11 g) acoustic transmitter tag was inserted through the incision so that it lay lateral to the internal organs. Tag sizes were selected so that the weight of the tag was <2 % of the body mass of the stingray (Smith 2012). Incisions were closed with braided absorbable sutures coated with polyglycolic acid (MedRep-Express, 24 mm, 75 cm) using 1–2 interrupted sutures secured with surgeon's knots. The total handling time, including initial weight and length measurements, ranged from 10 to 15 min, with surgery times usually <5 min. After surgery, rays were moved through the water until they resumed independent swimming. Recovery times ranged from 0 to 15 min. All surgeons practiced the tagging procedure on dead organisms before being allowed to perform the procedure on a live stingray. This increased the speed of the surgical procedure and reduced mortality risk.

The movements of 40 Atlantic stingrays were analyzed from December 2012–July 2014, with 16 rays tagged in Romerly Marsh Creek and 24 in the Herb River. Twenty-one animals were implanted with V16 tags that had a battery life of 863 days; 19 smaller animals were implanted with V13 tags that had a battery life of 372 days. Individuals were excluded from analysis after the date on which their tag battery was expected to expire. The tags do transmit signals after the predicted expiration date; however, the reliability of the rate and tonal frequency of the transmitter pings is unknown after the battery begins to expire. Analyzing data collected after the expected tag expiration date could result in incorrectly assuming that a ray is absent because of inconsistent pinging.

Data analysis

Presence or absence of a ray was tabulated by day instead of using number of detections because several environmental factors such as seasonal temperature changes, daily tides, episodic weather events (Mathies et al. 2014), and biotic noises such as snapping shrimp (Cotton 2010) can interfere with the detection range of acoustic receivers; thus, the absolute number of detections is not particularly informative. A ray was considered present on a given day if it was detected more than once on that day by any receiver in the array in which it was tagged. This was to avoid counting false positive detections that can be caused by biotic noise. Monthly residence indices were calculated for each stingray as follows, per Vianna et al. (2013):

$$\text{Monthly Residence Index} = \frac{\text{days detected in the month}}{\text{days at liberty during the month}} \times 100$$

Average bottom-water temperature was calculated each month. A linear regression analysis ($\alpha = 0.05$) was used to determine if average bottom-water temperature was correlated with average monthly residence in either Romerly Marsh Creek or the Herb River.

Seasons from 2012 to 2014 were defined using equinox and solstice dates. A seasonal residence index was calculated for each stingray as follows, per Vianna et al. (2013):

$$\text{Seasonal Residence Index} = \frac{\text{days detected in the season}}{\text{days at liberty during the season}} \times 100$$

An ANOVA with Tukey's *post hoc* test ($\alpha = 0.05$) was completed using the general linear model (GLM) procedure in the SAS statistical software program (Version 9.3; SAS Institute Inc., Cary, NC, USA, 2012) to determine if there was an effect of season on Atlantic stingray residence.

Results

The disk widths (DW) of rays from Romerly Marsh Creek ranged from 23.2–36.4 cm, with an average DW of 28.3 ± 1.00 cm (Table 2). The DW of rays from the Herb River ranged from 23.0–43.3 cm, with an average DW of 30.9 ± 1.25 cm (Table 3). There was no significant difference between the DW of rays from Romerly Marsh Creek (28.3 ± 1.00 cm) and those from the Herb River (30.9 ± 1.25 cm) ($p = 0.11$). Female rays ($n = 29$) were significantly larger (31.1 ± 0.99 cm) than males ($n = 11$) (26.8 ± 1.45 cm) ($p = 0.02$). However, there was no significant effect ($p = 0.66$) of the sex of stingrays on their monthly or seasonal residence.

Although number of detections can be affected by a variety of environmental factors, rays were detected between 2 and 125,979 times in Romerly Marsh Creek (Table 2) and between 1073 and 188,687 times in the Herb River (Table 3). The maximum number of consecutive days that rays were detected in Romerly Marsh Creek ranged from 1 to 321 days, with an average of 198.9 ± 25.8 days (Table 2). The maximum

Table 2 Summary of Atlantic stingrays *Dasyatis sabina* tagged in the Romerly Marsh Creek system on the coast of Savannah, Georgia, including the number of times each ray was detected, the maximum number of consecutive days a ray was present in the creek system, and the total number of days each ray was present in the creek system. All averages are listed ±1 SE

Tag ID	Disk Width (cm)	Sex	Date Released	Last Date Monitored	Detections	Max Days Present	Total Days Present
29713	30.0	F	12/19/2012	03/19/2015	12,511	222	294
9005	26.0	M	06/06/2013	06/13/2014	52,083	141	290
9006	25.0	F	06/25/2013	07/02/2014	107	2	4
28358	26.7	F	06/25/2013	03/19/2015	1528	13	38
28094	28.4	F	07/26/2013	03/19/2015	125,979	232	462
10868	24.8	M	09/27/2013	09/22/2014	17,032	206	303
10869	25.0	F	09/27/2013	09/22/2014	25,333	216	295
9892	26.4	M	12/17/2013	03/19/2015	6491	317	375
9891	27.8	F	12/17/2013	03/19/2015	6026	321	345
11817	35.4	M	05/30/2014	03/19/2015	2	1	1
11816	36.4	M	05/30/2014	03/19/2015	7102	294	294
11815	23.2	M	05/30/2014	03/19/2015	8070	191	194
27589	31.0	F	05/30/2014	03/19/2015	45,577	207	246
11814	24.7	F	05/30/2014	03/19/2015	24,158	205	234
11821	28.6	M	06/12/2014	03/19/2015	3136	195	206
28357	33.8	F	06/13/2014	03/19/2015	1113	100	100
Average DW	28.3 ± 1.00			Average	21,015 ± 8029	198.9 ± 25.8	230 ± 33.5
Female Average DW	28.0 ± 1.04						
Male Average DW	28.7 ± 1.97						

number of consecutive days that rays were detected in the Herb River ranged from 7 to 255 days, with an average of 112.7 ± 16.3 days (Table 3). A few rays remained within detection range of a single receiver for months at a time, contributing to the large numbers of detections for some individuals; however, seemingly stationary rays did eventually move during the study period and were detected by other receivers. No tagged animal remained stationary for such a long time that it was assumed to have died. In contrast, other rays appeared to be in constant motion, swimming from one receiver station to the next. A detailed analysis and description of the movement frequencies of the Atlantic stingray is presented in Brinton (2015).

Atlantic stingrays were present throughout the entire year in the Savannah River estuary, as 15 % ($n = 6$) of the 40 individuals tagged remained in the study sites during all seasons. Of the 34 rays (85 %) that migrated during winter, 13 were detected within the estuary less than 20 km away by receiver arrays deployed by the Georgia Department of Natural Resources (C. Kalinowsky, pers. Comm.). There were 24 rays at liberty during winter 2013–14. Nineteen (79 %) of those rays departed from the creek system in which they were tagged, and 10 of those (53 %) returned to their creek system of origin during the subsequent spring after being absent for 1–4 months.

Although some individuals were present year-round, Atlantic stingrays were detected for a lower percentage of days during winter than during all other seasons. In Romerly Marsh Creek, stingrays were present during winter 2013–14 for a significantly smaller percentage ($p < 0.01$) of days (20.8 ± 6.5 %) than during spring, summer, and fall 2014 (65.4–72.7 %) (Fig. 2a). In the Herb River, rays were present for a significantly ($p < 0.01$) smaller percentage of days during winter 2013–14 (9.1 ± 6.6 % of days) and winter 2014–15 (11.6 ± 5.6 %) than during any other season (38.0–86.3 %) (Fig. 2b). Bottom-water temperature over the course of the entire study ranged from 9.8–30.0 °C. There was a significant

Table 3 Summary of Atlantic stingrays *Dasyatis sabina* tagged in the Herb River system on the coast of Savannah, Georgia, including the number of times each ray was detected, the maximum number of consecutive days a ray was present in the creek system, and the total number of days each ray was present in the creek system. All averages are listed ±1 SE

Tag ID	Disk Width (cm)	Sex	Date Released	Last Date Monitored	Total Detections	Max Days Present	Total Days Present
30469	40.0	F	04/07/2013	03/19/2015	69,627	107	188
8134	23.0	M	04/09/2013	04/15/2014	31,329	172	198
28936	35.5	F	05/01/2013	03/19/2015	33,411	85	124
8133	28.0	F	05/17/2013	05/23/2014	27,025	26	75
28089	35.0	F	05/21/2013	03/19/2015	188,407	198	488
8135	25.5	F	06/04/2013	06/10/2014	4305	9	11
10865	23.5	M	07/24/2013	07/19/2014	20,852	68	161
10866	25.0	F	08/09/2013	08/04/2014	19,875	62	126
28093	43.3	F	08/09/2013	03/19/2015	188,687	246	552
10867	25.0	F	09/13/2013	09/08/2014	8390	45	56
28092	38.7	F	09/26/2013	03/19/2015	177,976	255	359
28095	33.2	F	09/26/2013	03/19/2015	86,848	120	261
28360	37.2	F	09/26/2013	03/19/2015	32,070	25	44
28096	34.3	F	10/10/2013	03/19/2015	114,572	236	301
13135	35.0	F	10/31/2013	03/19/2015	133,779	229	243
11812	24.0	M	04/11/2014	03/19/2015	1299	7	7
13136	34.9	F	04/11/2014	03/19/2015	60,331	165	187
9890	28.6	F	04/11/2014	03/19/2015	40,214	72	195
27593	30.0	F	05/27/2014	03/19/2015	28,807	101	177
11813	27.2	F	05/27/2014	03/19/2015	1073	9	29
13134	30.0	F	05/27/2014	03/19/2015	36,605	159	176
11818	23.5	M	06/03/2014	03/19/2015	11,064	48	290
11819	24.1	F	06/03/2014	03/19/2015	17,955	114	144
27590	37.8	F	07/02/2014	03/19/2015	32,505	146	153
Average DW	30.9 ± 1.25			Average	56,959 ± 12,191	112.7 ± 16.3	189.4 ± 28.1
Female Average DW	32.4 ± 1.26						
Male Average DW	23.5 ± 0.20						

correlation between monthly Atlantic stingray residence and bottom-water temperature in Romerly Marsh Creek ($p < 0.01$) ($R^2 = 0.57$) and the Herb River ($p < 0.01$) ($R^2 = 0.92$), with stingrays using both creek systems more often when temperatures were warmer and less often when water temperatures were cooler (Fig. 3).

Discussion

The major finding of this study was that Atlantic stingrays were present year-round in the Savannah River estuary, as 15 % of the tagged rays were detected during all seasons. Additionally, many of the rays that did migrate out of the study areas during winter were detected within the estuary less than 20 km away. The rays that departed from, and then subsequently returned to, the creek systems in which they were tagged did so in as little as 1 month. The undulatory manner in which Atlantic stingrays swim is better suited for a slow-moving benthic lifestyle than fast, pelagic swimming (Rosenberger 2001). For an Atlantic stingray to return to the site at which it was tagged within 1 month of leaving, it could not have traveled far, further evidencing that this species probably remained in or near the estuary throughout the entire year.

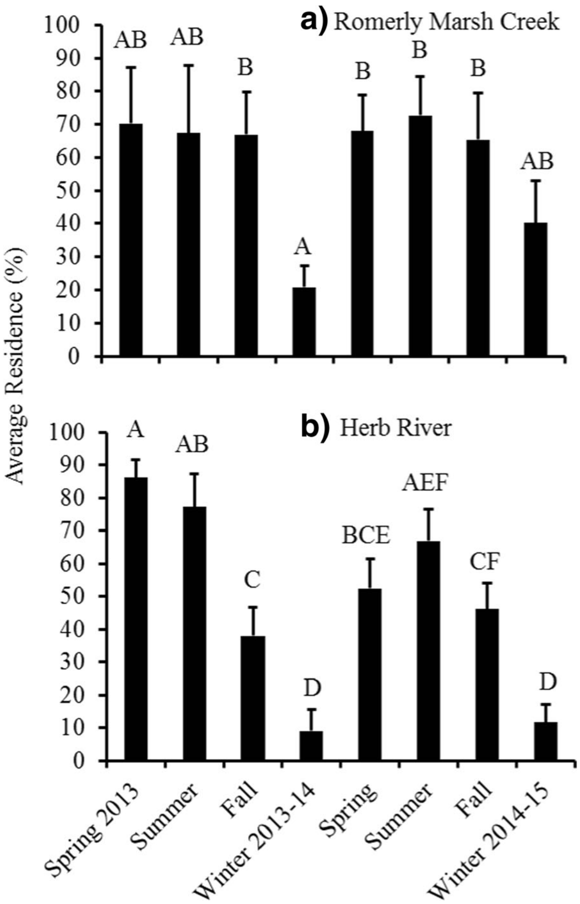

Fig. 2 Average seasonal residence indices of Atlantic stingrays *Dasyatis sabina* tracked in (**a**) Romerly Marsh Creek and (**b**) the Herb River, Savannah, Georgia. Error bars represent +1 standard error. Different *letters above bars* indicate difference at the α = 0.05 significance level. For example, in the Herb River, Atlantic stingray residence during winter in both years was significantly lower than residence during all other seasons

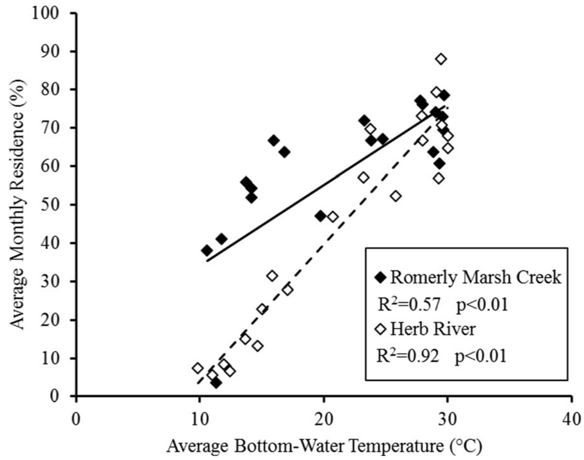

Fig. 3 Scatterplots of the relationship between the monthly residence indices of Atlantic Stingrays *Dasyatis sabina* and bottom-water temperature in Romerly Marsh Creek and the Herb River, Savannah, Georgia. The *solid line* represents the linear regression for Romerly Marsh Creek. The *dashed line* represents the linear regression for the Herb River

The seasonal residency patterns of Atlantic stingrays have previously been attributed to changes in water temperature (Sage et al. 1972; Funicelli 1975; Lewis 1982). Although there was a significant correlation between bottom-water temperature and stingray presence in the present study, temperature probably did not directly limit the ability of Atlantic stingrays to remain in the Savannah River estuary system during the winter. This species has an extremely wide thermal tolerance of 0.7–43.3 °C, though this was based on only brief (<1 min) exposure (Fangue and Bennett 2003). Temperatures in our study sites (9.8–30.0 °C) never approached the threshold values calculated by Fangue and Bennett (2003), which could potentially explain why some stingrays remained in these creek systems during all seasons.

To date, the Savannah River estuary is the northernmost region in which the Atlantic stingray has been documented to be present year-round. South of this region, Schwartz and Dahlberg (1978) caught Atlantic stingrays throughout the entire year in St. Catherines and Sapelo sounds in Georgia, and Snelson et al. (1988) and Fangue and Bennett (2003) found Atlantic stingrays to be present year-round off the Atlantic and Gulf coasts of Florida, respectively (Table 1). North of the Savannah River estuary, Atlantic stingrays have only been collected seasonally during spring, summer, and fall in the Cape Fear estuary off the coast of North Carolina (Schwartz and Dahlberg 1978; Schwartz 2000) and the North Inlet estuary off the coast of South Carolina (Ogburn et al. 1988) (Table 1).

It is possible that Atlantic stingrays are present year-round in some regions, but only seasonally in others. However, it is also possible that they are present throughout the year in all regions but not collected using certain gear types. Small-scale seasonal movement patterns could further interfere with accurate assessments of abundance. Several batoid elasmobranchs including the Atlantic stingray utilize deeper parts of their habitats during the winter. For example, the short-tailed stingray *Dasyatis brevicaudata* in New Zealand (Le Port et al. 2008) and the thornback skate *Raja clavata* in the Thames River estuary in England (Hunter et al. 2005) migrate away from shallow waters and utilize deeper waters during winter. Snelson et al. (1988) observed that Atlantic stingrays in the Indian River Lagoon in Florida were often found during winter in deep channels that were 2–5 °C warmer than the surrounding shallower waters. Thirteen Atlantic stingrays in the present study were detected in deeper waters less than 20 km from the two study sites, but still within the Savannah River estuary, during winter. Due to their wide thermal tolerance, Atlantic stingrays may not have needed to take refuge from the cold; however, the rays could have been seeking out places of higher food abundance. Two prey items of the Atlantic stingray, grass shrimp (Welsh 1975) and blue crabs (Livingston 1976), move into deeper waters during the winter. These deeper or more topographically complex areas may be more difficult to sample using bottom trawls. Rays that do remain in an area, but move into deeper waters during winter, will be detected using acoustic telemetry. These same animals may not be caught during periodic capture surveys.

Conclusion

We found that the Savannah River estuary is the northernmost region in which the Atlantic stingray has been documented to be present during the entire year. There has been uncertainty about the residency patterns of this species throughout its geographic range in part because the sampling methods used historically may not have captured rays even when they were present. The results of our study were clear: rays were present in the monitored areas throughout the entire year, and many (38 %) of the rays that left those areas during winter were detected elsewhere within the estuary.

Incorrect assumptions about the residency of Atlantic stingrays are problematic because this species is an ecosystem engineer and has the potential to affect trophic dynamics and impact commercial fisheries. Other larger elasmobranchs may have even greater economic and ecological impacts. Falsely assuming a species is absent because it is not captured is an inherent bias in many sampling designs; therefore, researchers should consider incorporating acoustic telemetry into future studies to clarify the residency patterns of fishes for which there is inconsistent reporting. Underestimating the presence of a species could result in subsequent miscalculation of its ecological and economic impacts and, by extension, result in the implementation of ineffective or even detrimental management strategies.

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