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ASSESSMENT OF HABITAT USE PATTERNS OF GULF STURGEON *ACIPENSER OXYRINCHUS DESOTOI* OVERWINTERING IN CHOCTAWHATCHEE BAY, FLORIDA

By

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A THESIS

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Abstract

Gulf sturgeon *Acipenser oxyrinchus desotoi* have been listed as threatened under the U.S. Endangered Species Act since 1991 due to overfishing and habitat degradation. Although directed harvest has been banned, there are growing concerns about the declining quality of critical habitats including Choctawhatchee Bay, Florida. To address these concerns, I assessed habitat use of Gulf sturgeon in Choctawhatchee Bay to provide managers with a better understanding of important overwinter habitats.

In the fall 2009 and 2010, adult and juvenile Gulf sturgeon were captured and telemetered in the Choctawhatchee River prior to outmigration to Choctawhatchee Bay, and an array of passive acoustic receivers was deployed in nearshore areas throughout the bay to assess habitat use patterns. Gulf sturgeon that remained in Choctawhatchee Bay during the overwinter period were significantly smaller than individuals utilizing the Gulf of Mexico. These findings strongly suggest that juveniles are more dependent upon estuarine environments than adults, placing them most at risk for additional anthropogenic changes within the estuary.

The distribution of Gulf sturgeon varied significantly by residency status throughout the bay, as well as between years. Inter-annual differences in the distribution of Gulf sturgeon corresponded to markedly different flow regimes in the Choctawhatchee River. Large changes in the behavioral patterns of telemetered individuals during this study are suggestive of how Gulf sturgeon operate during "normal" or "low flow" conditions.

Given the role of overwinter habitats in mediating Gulf sturgeon growth, coupled with continuing habitat modification and loss, a better understanding of Gulf sturgeon habitat use in relation to potential prey resources are needed. To address this need, I collected benthic samples throughout Choctawhatchee Bay and assessed invertebrate composition. I examined the relationship between Gulf sturgeon residency and forage resources using generalized linear models. Gulf sturgeon occupancy generally increased in areas with greater abundances of amphipods, and decreased with high abundances of the polychaete order Scolecida. My findings suggest that amphipods may be important prey resources for Gulf sturgeon overwintering in Choctawhatchee Bay, or are indicative of other favorable conditions. Through the identification of factors that mediate habitat use, my work can help managers anticipate how changes to these habitats might impact Gulf sturgeon, and to better understand the relative importance of estuarine habitats required for the conservation and recovery of this imperiled species.

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Chapter 1

Assessing estuarine-dependency of Gulf sturgeon *Acipenser oxyrinchus desotoi* overwintering in Choctawhatchee Bay, Florida

Introduction

The Gulf sturgeon *Acipenser oxyrinchus desotoi* is a slow growing anadromous species that has been listed as threatened under the U.S. Endangered Species Act since 1991, largely due to overfishing and habitat degradation (USFWS 1991). Historically, Gulf sturgeon inhabited river systems and the Gulf of Mexico from the Mississippi River to Tampa Bay, Florida with sightings reported as far west as the Rio Grande River, Texas and as far south and east as Florida Bay, Florida (Wooley and Crateau 1985, Reynolds 1993). Gulf sturgeon are known to reproduce in seven river systems from the Pearl River, Louisiana and Mississippi east to the Suwannee River, Florida (USFWS and NMFS 2009), with the majority migrating annually into estuarine and marine environments during the overwinter period on an annual basis (Mason and Clugston 1993, Gu et al. 2001, Fox et al. 2002).

Anthropogenic habitat changes threaten recovery of Gulf sturgeon (USFWS and NMFS 2009). Potential threats to Gulf sturgeon are generally poorly understood in estuarine and marine environments compared to most freshwater environments, and a growing emphasis has been placed on improving knowledge of overwinter habitat use in the last couple decades (USFWS et al. 1995, Ross et al. 2009, Sulak et al. 2009, Duncan et al. 2011) likely due to recent advances in technology. These overwintering habitats are especially important as they are essential to Gulf sturgeon growth and reproductive potential; individuals > 2 years of age migrate into estuarine and marine environments during the cooler months presumably to feed (Huff 1975, Mason and Clugston 1993). They return primarily to natal rivers on an annual basis to spawn (Huff 1975, Mason and Clugston 1993) and fast and lose weight while in these environments (Wooley and

Crateau 1985). As such, Gulf sturgeon are reliant on high quality foraging habitat within estuarine and marine environments for growth and gonadal recrudescence (Gu et al. 2001, Fox et al. 2002). Given the importance of overwintering foraging areas for Gulf sturgeon, changes in estuarine and marine environments may impact Gulf sturgeon recovery (USFWS and NOAA 2003).

Gulf sturgeon are known to spawn in the Choctawhatchee River, Florida (Fox et al. 2000) and use Choctawhatchee Bay as overwinter habitat (Parauka et al. 2001, Fox et al. 2002). Unfortunately there are concerns that these foraging habitats are experiencing anthropogenic modifications (USFWS and NMFS 2009) given human population increases in the counties surrounding Choctawhatchee Bay since 1990 (Walton: 25%; Okaloosa: 95%) (USCB 2010). The majority of human growth within the Choctawhatchee Bay watershed has occurred in the regions nearby or adjacent to the bay, which has raised concerns over water quality deterioration (Long et al. 1997, Thorpe et al. 2002). Further, within Choctawhatchee Bay, human impacts may be compounded by eutrophication resultant from low flushing rates, high temperatures, and long algal growing seasons that characterize the system (Livingston 1986).

In addition to changes tied to alteration of the surrounding watershed, more insidious changes associated with climate change and sea level rise also threaten estuarine Gulf sturgeon habitats (USFWS et al. 1995, USFWS and NMFS 2009). Sea level rise is predicted to alter estuarine systems through fluctuating salinity and dissolved oxygen levels (Kennedy 1990, Rabalais et al. 2009), and associated impacts to existing habitat may be exacerbated by rising temperature (Scavia et al. 2002).

It is important to identify which segments of Gulf sturgeon populations may be most greatly affected by changes to overwintering estuarine habitats. Like other anadromous fishes, smaller juvenile Gulf sturgeon are thought to be dependent upon estuarine systems (Parauka et al. 2001, Sulak et al. 2009) while larger individuals utilize marine environments (Fox et al. 2002, Edwards et al. 2003). The underlying factors mediating such ontogenetic shifts in habitat use are poorly understood for Gulf sturgeon, but it is generally believed that shifts such as these occur when the growth-to-mortality ratio is improved by moving to an alternate habitat (Gross 1987). Similar to Atlantic sturgeon (Bain 1997, Niklitschek and Secor 2009), Gulf sturgeon undergo ontogenetic shifts in salinity tolerance, with smaller yearling Gulf sturgeon exhibiting less tolerance to higher salinities than larger yearlings (46–70 cm) (Altinok et al. 1998). Given these changes in salinity tolerance related to body size, it is likely that juvenile Gulf sturgeon remain in lower salinity overwinter habitats. Ultimately, developing a more complete understanding of the factors that mediate estuarine dependency will allow for a better understanding of how changes to these crucial foraging areas will impact Gulf sturgeon recovery.

In this chapter I examine the critical overwinter stage of Gulf sturgeon habitat use with the primary objective centered on understanding how habitat use is influenced by body length. By monitoring both adult and juvenile Gulf sturgeon, I hope to quantify the size classes that are most at risk to threats in estuarine environments. This will provide managers with an increased understanding of how future changes to estuarine habitats may impact Gulf sturgeon habitat use and recovery.

Methods

Study Locale:

The Choctawhatchee River largely flows unregulated from its headwaters in south central Alabama approximately 280 km before discharging into Choctawhatchee Bay (Livingston 1986). Mean discharge rates range between 156 m^3/s in late summer and 792 m^3/s in early spring (Blaylock 1983). The Choctawhatchee River empties into the eastern end of Choctawhatchee Bay, providing the system with ≈95% of its freshwater (Blaylock 1983). In addition to the river, a number of bayous throughout the basin contribute freshwater to the bay, particularly in the north (FDEP 2012).

Choctawhatchee Bay is approximately 45km long, averaging 6 km in width and 3 m in depth in the eastern one-third of the bay to 10 m in depth in the western section, with a maximum depth of 13 m (FDEP 2003). The only direct connection between Choctawhatchee Bay and the Gulf of Mexico is through the East Pass, which is located in the southwestern portion of the bay. Choctawhatchee Bay also connects to the Gulf Intracoastal Waterway to the east and to the west. Choctawhatchee Bay and its entrances are dredged to maintain navigation; however the Choctawhatchee River is no longer dredged.

Water movement within Choctawhatchee Bay has been described as a two layered system with slow moving higher saline waters flowing eastward up the deeper central and southern areas/portions (mean salinity: 14–26 ppt) while lower saline waters flow westward along the surface(mean salinity: 2–22 ppt) (Blaylock 1983, Jones and Huang 1994). Surface salinities are generally highest along the northern shore of the bay, and the water column is highly stratified during much of the year dependent on winds and discharge from Choctawhatchee River (Jones and Huang 1994).

Collection of Specimens:

Adult (fork length ≥ 130 cm; Huff 1975) and juvenile (fork length < 130 cm; Huff 1975) Gulf sturgeon were collected in the Choctawhatchee River, Florida near river kilometer (rkm) 40 in October 2009, June 2010, and October 2010 (Figure 1-1), using drift monofilament gillnets (2.7 m x 4.9 m x 30.5 m; 3.4 m x 6.1 m x 1.30 mm; 0.90 mm twine). Gulf sturgeon were held onboard in a transport tank with river water and brought to shore for surgery. A summary of captured fish is presented in Table 1-3 and Table 1-4.

Surgical Procedures:

Individual Gulf sturgeon were transferred from the vessel to shore using a sling and placed in an 1100 L wooden tank filled with water taken directly from the river for processing. Water in the tub was mixed with tricaine methanesulfanate (MS-222®) administered at a dosage of 50–100 mg/L (Harms and Bakal 1994). Water and MS-222® were changed frequently to maintain anesthetic concentration levels, ambient water temperature, and dissolved oxygen levels.

Gulf sturgeon were measured for fork length (cm) and total length (cm) and weighed (kg). All Gulf sturgeon were scanned for the presence of passive integrated transponder (PIT) tags (AVID® Power Tracker VIII) and active acoustic transmitters (VEMCO Ltd. VR-100 and hydrophone). When absent, a 14mm 125 kHz PIT tag (2009) or a 12 mm 134.2 kHz PIT tag (2010) was inserted at the base of the left dorsal fin. Acoustic transmitters were surgically implanted into Gulf sturgeon according to previously developed protocols (Fox et al. 2000). Adults received VEMCO Ltd. V-16, 6-H transmitters (16X95 mm, 36 g in air, 69 kHz, 160 dB) while juveniles received smaller VEMCO Ltd. V-16, 4-H transmitters (16X68 mm, 25 g in air, 69 kHz, 158 dB) with battery life and delay times varying by transmitter model (Table 1-1). These transmitters complimented those implanted in 2008 by the U.S. Fish and Wildlife Service (USFWS) as summarized in Table 1-2. A small tissue sample from the caudal fin was preserved in 95% ethanol for genetic analysis as part of a range-wide population structure study.

Telemetry:

I deployed a passive acoustic array comprised of VEMCO Ltd. VR2-W receivers in nearshore habitats of Choctawhatchee Bay to monitor spatial and temporal residency patterns (Figure 1-1) of telemetered Gulf sturgeon. The passive acoustic array was deployed systematically in nearshore areas previously identified as important Gulf sturgeon habitats (Parauka et al. 2001, Fox et al. 2002) between October and May 2009–2010 and 2010–2011. Receivers were secured to 1.3 cm braided line approximately 1.5 m above a concrete block (27–36 kg) and suspended in the water column by a sub-surface float. A limited number of receivers were deployed during the summer months to quantify potential use of the estuary when Gulf sturgeon were predicted to be in riverine habitats (Fox et al. 2000, Hightower et al. 2002) (Figure 1-2).

Arrays of fully compatible passive receivers were deployed during the 2009–2010 and 2010–2011 overwinter periods in adjacent systems including the Gulf of Mexico, Santa Rosa Sound, and Choctawhatchee River as part of Gulf sturgeon studies conducted by Eglin Air Force Natural Resources Branch and the USFWS Panama City Field Office

(Figure 1-3). Collaboration between organizations allowed for incorporation of data collected by distant receivers into this study.

Environmental Data

Mean daily flow for Choctawhatchee River was derived from the USGS gaging station (02366500) deployed near Bruce, Florida (rkm 34) (waterdata.usgs.gov). Mean daily wind speed data for Destin, Florida was derived from Weather Underground www.wunderground.com (Weather Underground 2012).

Detection Efficiency

I conducted a range test to document signal attenuation and reception of the acoustic array and to identify a 50 % detection threshold between acoustic transmitters and receivers. The study was conducted at an area commonly utilized by Gulf sturgeon during overwinter periods (Figure 1-4), but during a time when Gulf sturgeon were absent from the system in order to reduce potential for transmitter code collisions. At the range test site, I deployed a test VEMCO Ltd. V-16, 6-H test transmitter (16X95 mm, 36 g in air, 69 kHz, 160 dB) with mean delay times of 360 seconds (min 350 seconds, max 370 seconds) (Table 1-1). Eight acoustic receivers were deployed in a linear fashion at increasing distances from the test transmitter (297, 451, 544, 648, 757, 833, 910, 1007 m) (Figure 1-4). The test transmitter was moored to 1.3 cm braided line 1 m above the bottom of a concrete block and suspended in the water column with subsurface and surface floats.

Analyses

Habitat Utilization:

To account for growth of Gulf sturgeon detected in years subsequent to telemetering, a Von Bertalanffy predictive growth model was applied to estimate fork lengths using parameters derived for the Apalachicola River, Florida (Flowers et al. 2010) (Table 1-2, 1-3, 1-4).

I developed a binomial logistic regression model to examine if body size (fork length) was a predictor for habitat use (estuarine-dependency or marine residency) with JMP 9.0 (SAS Institute Inc. 2010). Telemetered Gulf sturgeon that remained in Choctawhatchee Bay during the overwinter period were classified as estuarine-dependent, while telemetered individuals that inhabited both the Choctawhatchee Bay and Gulf of Mexico were classified as marine residents. Gulf sturgeon detected in Santa Rosa Sound and/or Gulf Intracoastal Waterway, but not detected in the Gulf of Mexico, were excluded from further analyses, as reduced coverage in these areas increased the likelihood that these individuals entered into the Gulf of Mexico without detection. Unless detected in subsequent years, I excluded Gulf sturgeon that were not detected during spring migration. I adopted this conservative approach in an effort to account for individuals that shed transmitters or died.

The arrival of Gulf sturgeon into Choctawhatchee Bay was defined as the day of first detection at any receiver deployed within the bay. I defined the day of arrival as the day of first detection on a receiver in Choctawhatchee Bay or Choctawhatchee River. Occupancy (days) in overwinter habitats was calculated by subtracting the river arrival date from the bay arrival date for each telemetered Gulf sturgeon.

I assessed the distribution of estuarine-dependent and marine residents throughout Choctawhatchee Bay each year to test my null hypothesis that Gulf sturgeon distribution was uniform between habitat use groups. To do so, I binned detections from individual Gulf sturgeon into hourly observations, so that any number of detections accrued within a given hour was reduced to one. Using receiver locations, I calculated the mean latitude and longitude of each telemetered Gulf sturgeon based on hourly observations between October and May each year. To provide spatial context, longitude was converted to distance from the river mouth (km) and latitude was converted to distance from the midline of the bay (km) (Figure 1-1). Negative distance from the midline values indicate a southerly distribution, while positive values suggest a northerly distribution. To allow for comparisons between years, only detections from receivers deployed for the same periods of time each year were utilized.

I then examined differences between habitat use groups in both timing of arrival and departure, overwinter occupancy, distance from river mouth, and distance from midline using student's t-tests with JMP (SAS Institute Inc. 2010). I also examined the proportion of hours that Gulf sturgeon were detected at each receiver by year, and habitat grouping. Data were entered into a GIS database and interpolated using an Inverse Distance Weighted Function with a power of 5 using ArcView ArcGIS 10 software ((ESRI Inc., Redlands CA) to visually compare distributions by resident group and year.

Array Performance

I assessed performance of each receiver in the range test for the duration of the of the study period (June 5, 2011–August 8, 2011). Total detections were tallied by receiver and compared with the expected detections, according to the random delay time of the test transmitter (Table 1-1). I used linear regression to examine the effect of distance on receiver performance (Simpfendorfer et al. 2008). The generated slope equation was used to estimate the 50% detection efficiency distance within Choctawhatchee Bay.

I estimated the performance of my passive acoustic array in documenting Gulf sturgeon while they resided within Choctawhatchee Bay. To do so, I calculated a residency index (RI) for telemetered Gulf sturgeon by dividing the number of days an individual was detected within the bay by the number of possible days it could have been detected within the bay (Simpfendorfer et al. 2011).

$$\frac{Total\ Observed\ Days}{Total\ Possible\ Days} = Residency\ Index$$

Total possible days was defined as the number of days between the first and last detection of each telemetered Gulf sturgeon in Choctawhatchee Bay prior to moving into Choctawhatchee River. The total days detected was simply a tally of the number of days an individual was detected within Choctawhatchee Bay between the first and last detection. RI values ranged between 1 and zero, with a value of 1 indicating that the Gulf sturgeon was detected every day and a 0 indicating no detections during the period of likely residency. Alpha level was set at $P \leq 0.05$ for all analyses.

Environmental Data

I used a student's t-test to compare inter-annual differences in mean daily flow documented on dates of outmigration each year, as well as to compare inter-annual differences in mean daily flow documented on dates of immigration each year as well. I also used a student's t-test to compare inter-annual differences in mean daily wind speed throughout each overwinter period.

Results

Telemetry

A total of 28 passive acoustic receivers were deployed and maintained along the shoreline of Choctawhatchee Bay (Figure 1-1) in October 2009 and 2010. Most receivers (n=22) were deployed by October 10, and six additional receivers were deployed by December 19, 2009. Receivers were pulled from June 1–6, 2010, with the exception of seven receivers that remained in the water through the summer. One receiver was lost following an April 17, 2010 download event. In the fall of 2010, 28 receivers were deployed from October 9–13, 2011 through May 31–June 1, 2011 (Figure 2-1). Three receivers remained deployed at the mouth of the Choctawhatchee River to record movements between June 1, 2011 and October 27, 2011, when Gulf sturgeon began migrating back to Choctawhatchee Bay (Figure 2-1).

Collections

2008

Sixteen adult Gulf sturgeon telemetered in Choctawhatchee River between July and October 2008 were documented utilizing Choctawhatchee Bay during this study (Table 1-2). At the time of capture, individuals ranged from 138–191 cm FL (mean = 164 cm, SE = 4.3) and weighed between 23–54 kg (mean = 37 kg, SE = 2.8).

2009

A total of 19 juvenile and 21 adult Gulf sturgeon were collected and telemetered from October 5–8, 2009 (Table 1-3). Sampling was initiated at ≈rkm 40 at corresponding mean water temperature of 23.8°C. Gulf sturgeon implanted with acoustic transmitters ranged from 89–194 cm FL (mean = 135 cm, SE = 4.1 cm) and weighed 4 – 61 kg (mean = 21 kg, SE = 2.1 kg) (Table 1-3).

2010

Two Gulf sturgeon collections occurred in 2010. On June 3, 2010, I captured and telemetered five Gulf sturgeon. Later in the fall, directed sampling occurred when water temperature was 21.9°C. A total of 25 juvenile and 45 adult Gulf sturgeon were collected between October 9-14, 2010; 22 juveniles and 33 adults were implanted with acoustic transmitters (Table 1-4). Telemetered Gulf sturgeon ranged from 89–188 cm (mean = 138 cm, SE = 3.2) and weighed 5–57 kg (mean = 25 kg, SE = 1.9).

Habitat use

A total of 54 telemetered Gulf sturgeon were detected occupying Choctawhatchee Bay during the 2009–2010 overwinter period: 16/40 individuals (40%) were telemetered in 2008 and 38/40 (95%) were telemetered in 2009. A total of 100 individual Gulf sturgeon telemetered in Choctawhatchee River were detected entering in Choctawhatchee Bay during the 2010–2011 overwinter period: 100% (n = 55) fish telemetered in 2010, 88% (n = 35) Gulf sturgeon telemetered in 2009, and 25% (n = 10) Gulf sturgeon telemetered in 2008.

In 2009 – 2010, the number of Gulf sturgeon that overwintered exclusively in Choctawhatchee Bay (n = 15) was less than those utilizing the Gulf of Mexico (n = 38). I was unable to classify habitat use of four individuals because they had prolonged periods of absence in the Choctawhatchee Bay array, were documented in the Santa Rosa Sound or Gulf Intracoastal Waterway, but were not documented on receivers in marine waters. During the 2010–2011 overwinter period, 38 Gulf sturgeon remained in the bay and 60 were recorded in the Gulf of Mexico. I was not able to classify the habitat use patterns of two Gulf sturgeon that exhibited prolonged absences in my array, or were detected in the Santa Rosa Sound, but were not detected in the Gulf of Mexico.

A total of four Gulf sturgeon that were classified as estuarine-dependent during the 2009–2010 overwinter period were documented transitioning to marine waters the following year. Of these individuals, three were captured in 2009 (mean = 126 cm FL, SE = 4.6), and one was captured in 2008 (142 cm FL at time of capture, estimated 151 cm FL in 2009). Only one individual (89 cm FL at time of capture, estimated 105 cm FL in 2010) that utilized the Gulf of Mexico the first year remained estuarine-dependent the following year, although there were two marine residents whose habitat use could not be classified the following year.

The size of individuals within each resident group did not vary significantly between years (marine and estuarine: P = 0.47, P = 0.69), so data from both years were pooled. These pooled data were used to examine the relationship between body size and habitat use. Estuarine residents (range 89–155 cm; mean = 125 cm FL, SE = 2.3) were significantly ($r^2 = 0.25$, $P < 0.001$) smaller than marine residents (range 89–197 cm, mean = 153 cm FL, SE = 2.5) (Figure 1-5, 1-6).

Seasonal Migrations, Occupancy, and Distribution

The fall migration of Gulf sturgeon from the Choctawhatchee River into the Choctawhatchee Bay spanned over 36 days in 2009 (October 6–November 11) and 86 days in 2010 (October 1–December 29) (Figure 1-7). One Gulf sturgeon had already entered the estuary when receivers were first deployed in 2009 as evidenced by immediate detections. The first day of immigration into the Choctawhatchee River occurred on the same day of year (March 3) in both 2010 and 2011; the immigration period lasted 76 days in spring 2010 (March 3–May 18) and 94 days in spring 2011 (March 3–June 5). While no Gulf sturgeon were documented in Choctawhatchee Bay after May 18, 2010, three Gulf sturgeon that had exhibited marine residency during the overwinter period were consistently detected in oligohaline habitats surrounding the river mouth between mid-June and mid-August 2011; however one individual was detected on receivers deployed in Choctawhatchee River between April 7–28, 2011.

Choctawhatchee River flow was significantly greater during outmigration in 2009–2010 (mean = 193 m^3/s, SE = 7.1) compared to 2010–2011 (mean: 66 m^3/s, SE = 1.6) ($P < 0.0001$). Significant differences ($P < 0.0001$) in flow also occurred between 2009 and 2010 (mean = 246 m^3/s, SE = 11.3 m^3/s) and 2010–2011 (mean = 92 m^3/s, SE = 5.5) spring immigration periods (Figure 6).

Seasonal migration into Choctawhatchee Bay was significantly different between 2009–2010 and 2010–2011 overwinter periods for both estuarine and marine residents: estuarine residents entered the bay significantly ($P < 0.0001$) earlier in 2009–2010 (mean = October 28) compared to 2010–2011 (mean = November 12); marine residents entered the bay significantly ($P < 0.0001$) earlier in 2009 (mean = October 26) compared to 2010 (mean = November 6) (Table 1-5). There were no significant differences ($P = 0.32$) in the timing of arrival between estuarine and marine residents in 2009 (mean = October 28 and October 26, respectively), however estuarine-dependent individuals entered the bay significantly later than marine residents during the 2010–2011 overwinter period (mean = November 12 and November 6, respectively) ($P < 0.04$). The date fish emigrated from the bay into the Choctawhatchee River was not significantly different (Estuarine: $P =$

0.96, Marine: $P = 0.61$) each year within classified habitat use groups. However, in 2009 estuarine residents returned to the bay significantly ($P < 0.04$) earlier than marine residents (mean = April 3, April 13 respectively) (Table 1-5).

During both overwinter periods, the estuarine-dependent residents (2009–2010 mean = 5.2 months, 2010–2011 mean = 4.7 months) spent significantly less (2009: $P < 0.005$; 2010: $P < 0.002$) time in overwinter habitats than marine residents (2009–2010 mean = 5.6 months, 2010–2011 mean = 5.2 months), and both groups spent significantly more (Estuarine: $P < 0.01$; Marine: $P < 0.004$) time in overwinter habitats in 2009 compared to 2010 (Table 1-5).

The distribution of the estuarine and marine residents within the bay varied greatly. In 2009–2010, estuarine-dependent residents were distributed further north ($P < 0.0001$) (mean distance from the midline 2.1 km, SE = 0.4 km) than marine residents (mean distance from the midline = 0.7 km, SE = 0.2 km). Estuarine residents were also distributed further east ($P < 0.0004$) in 2009 – 2010 (mean distance from river mouth: estuarine = 15.9 km, SE = 0.6 km) than marine residents (20.13 km, SE = 1.3 km) (Table 1-5; Figure 1-7). In 2010–2011, estuarine-dependent residents (mean distance from the midline = 1.0, SE = 0.3) were distributed more southerly ($P < 0.02$) than the previous year (mean distance from the midline = 2.1, SE = 0.4) but continued to occupy habitats on the north shore at significantly higher rates ($P < 0.001$) be distributed significantly further along the northern bank relative to the marine-residents (mean distance from the midline = 0.84, SE = 0.19). However, estuarine residents in 2010–2011 were distributed more to the west ($P < 0.2$) (mean distance from river mouth = 20.3, SE = 1.3 km) than the previous year (mean distance from river mouth = 15.92 km, SE = 0.6 km), exhibiting a pattern similar to that of the marine residents (Figure 1-8, 1-9).

Detection Efficiency

As predicted, transmitter detection probabilities decreased in a linear fashion with increased distance ($r^2 = 0.95$, $P < 0.0001$). Near 100% detection efficiency was achieved at the closest receiver (297 m). Using the predictive model generated from linear regression (y = 0.12x + 129.86) 50% detection efficiency occurred at 685 m (Figure 1-10).

The passive acoustic array proved very efficient in documenting Gulf sturgeon overwintering exclusively in Choctawhatchee Bay, though residency index values did vary significantly ($P < 0.0001$) between years (2009–2010: mean = 0.88, SE = 0.01; 2010–2011: mean = 0.77, SE = 0.02) (Table 1-6). With a mean of 15.2 m/s during the 2009–2010 overwinter period, and 14.1 m/s in 2010–2011, wind speeds were not significantly different between years ($P = 0.96$).

Discussion

Gulf sturgeon exhibited two general models of habitat use during the overwinter foraging period in Choctawhatchee Bay, Florida, with one group comprised of predominantly smaller individuals dependent on the estuary while larger individuals appeared to primarily utilize the Gulf of Mexico. While previous work has suggested that such habitat partitioning existed for Gulf sturgeon (Fox et al. 2002, Sulak et al. 2009), the relatively constrained nature of Choctawhatchee Bay, coupled with restricted points of entry and departure, allowed for an improved understanding of these ontogenetic shifts in habitat use.

Habitat niche shifts are believed to occur when the growth to mortality ratio improves by moving to an alternate habitat (Gross 1987), and is often linked to body size (Jones et al. 2003). Similar to Atlantic sturgeon (Bain 1997, Niklitschek and Secor 2009), Gulf sturgeon undergo ontogenetic shifts in salinity tolerance, with smaller yearling Gulf sturgeon exhibiting less tolerance to higher salinities than larger yearlings (46–70 cm) (Altinok et al. 1998). While the juveniles in this field study were larger than those used in the laboratory for salinity tolerance studies, differences in habitat use may still be attributable to size and required metabolic rates in estuarine environments. It has been suggested that larger juvenile green sturgeon *A. medirostris* utilize brackish waters due to the energetic advantage provided by near-isosmotic conditions despite being capable of osmoregulating in polyhaline environments (Allen and Cech 2007). Smaller Gulf sturgeon in this study may be adopting a similar strategy.

In addition to reduced salinity tolerance, smaller individuals may be utilizing the estuary as refuge from predators that may exist in marine environments. Not much is known about Gulf sturgeon predators, but sea lampreys *Petromyzon marinus,* long nose gar *Lepisosteus osseus,* birds, seals, and sharks have been documented or reported attacking Atlantic sturgeon in marine environments (see Greene et al. 2009 for a review). It is likely that Gulf sturgeon have a number of natural predators as well.

Other factors hypothesized to mediate habitat use include sex, maturity, and reproductive status. Previous work on Gulf sturgeon in the Choctawhatchee River suggested that adult females were more likely to move out into the Gulf of Mexico while males tended to remain in the estuary (Fox et al. 2002). In all sturgeons, females attain larger sizes and typically live longer than males, traits that are accompanied by delays in maturity, increased reproductive energy requirements, and often skipped spawning events (Billard and Lecointre 2000). Females preparing to spawn may select marine waters to access higher quality foraging grounds despite the energetic costs and risks associated with using such environments. Males, on the other hand, have significantly lower gonadosomatic indices than female Atlantic sturgeon (Van Eenanaam et al. 1996) and may not need to achieve a larger body size to efficiently produce gonads (Van Eenanaam 1998). As such they may not require the presumably higher quality forage habitat in the Gulf of Mexico, and may be less likely to risk exposure to threats in marine environments.

Within Choctawhatchee Bay Gulf sturgeon are known to select nearshore sandy habitats, typical of the embayments found in the northeast portion of the bay, in areas characterized by lower invertebrate abundance and diversity (Fox et al. 2002). My findings suggest that these areas are of greatest importance for estuarine-resident Gulf sturgeon, as marine residents are more evenly distributed across the bay as they transit to and from the Gulf of Mexico. Notably, estuarine-dependent Gulf sturgeon were distributed more widely during the 2010–2011 overwintering period, possibly due to altered environmental characteristics resulting from reduced riverine influence which increased salinities throughout the bay. During this low-flow year, Gulf sturgeon may have been distributed more widely as a result of altered salinity regimes and/or altered prey distribution and composition.

Flow regimes may also have influenced the timing and duration of Gulf sturgeon outmigration, as the duration of emigration from Choctawhatchee River was greatly prolonged during the second year of my study when flow was markedly reduced. In addition to water temperature and photoperiod, flow has been suggested as a factor which may influence migratory behavior; Higher flows have been linked to increased rates of outmigration in the Choctawhatchee (Parauka et al. 2001) and Pascagoula Rivers (Heise et al. 2005), and below normal flow has been linked to restricted migratory activity (Heise et al. 2005). The southeast United States is predicted to experience warmer and drier climate in the upcoming decade and have the potential to reduce minimum flows, the duration of lower flows, and alter the timing of peak flows (Gibson 2005). Such changes may in turn impact the cues that Gulf sturgeon rely upon for migration.

While receiver performance was high each year, I did note the reduced mean residency index during the 2010–2011 overwinter period. Receiver detection efficiency is found to be influenced by environmental factors including wind speed, biological noise, and current speed (Heupel et al. 2006, Simpfendorfer et al. 2008). Choctawhatchee Bay is a relatively shallow narrow estuary that is oriented predominantly east to west, leaving it well protected from wind coming from polar directions. Wind speeds were not significantly different between years, and strong currents are not common throughout the system, and are typically restricted to the mouth of the bay during ebbing and flood tides. With many more telemetered Gulf sturgeon utilizing the system during the 2010–2011 overwinter period, code collisions between telemetered individuals may have reduced overall efficiency (Heupel et al. 2006).

With a robust sample size of both small and large Gulf sturgeon, my findings build upon previous studies that suggest Choctawhatchee Bay provides important overwinter habitat to juvenile Gulf sturgeon (Parauka et al. 2001). Elasticity analyses conducted on several North American sturgeons indicate that survival of immature age classes have the greatest influence on population growth (Gross et al. 2002). Therefore, habitat loss and degradation in Choctawhatchee Bay may negatively impact overall recovery, as seen in Chesapeake Bay Atlantic sturgeon (Secor and Gunderson 1998). The Chesapeake Bay has experienced a rapid increase in hypoxic events in the last century, resulting in reduced habitat for Atlantic sturgeon, especially juveniles who are less tolerant to these conditions. The overall decline and lack of recovery of Atlantic sturgeon has been attributed in part to the reduced habitats created through increased hypoxia (Secor and Gunderson 1998). According to a study conducted by the National Oceanic and Atmospheric Administration, the Gulf of Mexico ranked highest in comparison to other regions like the mid-Atlantic in the number of point-sources of nutrients (NOAA 1997). The bay has also been recognized as experiencing increasing nitrogen and phosphorus concentrations attributed to non-point sources of pollution, and has exhibited a decreasing trend in dissolved oxygen levels from 1970–1997, typically occurring mostly between June and October (NOAA 1997). Given that Gulf sturgeon move through the bay in September and October, and occasionally during the summer months, these hypoxic conditions may be problematic.

In addition to increases in non-point pollution, the northern Gulf of Mexico has experienced a > 3°C change in both air and sea surface temperatures between the 1970's and 2007 (Fodrie et al. 2010). It has been suggested that "lower-latitude, warm tolerant" species may expand experience latitudinal expansion in response to rising temperatures (Kennedy 1990). In fact, range expansions for a few tropical and subtropical species into the northern Gulf of Mexico have been noted (Fodrie et al. 2010). However refuge from changing environmental conditions is limited for Gulf sturgeon given the geographic and thermal barrier created by the Gulf stream surrounding peninsular Florida (Rivas 1954). Therefore, the continued existence of Gulf sturgeon is dependent upon maintaining or improving quality of current habitats.

Through my efforts I quantified a relationship between residency status and size. My findings clearly show that juvenile Gulf sturgeon, which are more sensitive to habitat degradation (i.e. changes in temperature and dissolved oxygen), are more dependent on estuarine habitats than adults. In addition to improving the understanding of important habitats within the bay, I have also documented the complex relationship between Gulf sturgeon and the estuarine environment. I documented marked changes in the behavioral patterns of telemetered individuals during the two years of this study, which may be an indication of how Gulf sturgeon populations will operate during "normal" or "low flow" conditions. Moreover, my findings suggest that altered flow conditions may influence migration timing and duration, potentially leaving Gulf sturgeon exposed to sub-optimal environmental conditions. Ultimately it is my hope that my research will enable managers to more effectively anticipate how changes to critical estuarine foraging environments may impact Gulf sturgeon recovery.

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Table 1-1. Specifications of transmitters implanted in Choctawhatchee River, Florida Gulf sturgeon (4H, 6H, 6H A and 6H B) and deployed for range testing (6H C). Tags looped through cycles until maximum battery life is reached.

Transmitter Type	Dimensions (mm)	Weight in Air (g)	Power Output (dB)	Cycle One			Cycle Two			Tag Life (Days)
				Min. Delay (Sec.)	Max. Delay (Sec.)	Duration (Days)	Min. Delay (Sec.)	Max. Delay (Sec.)	Duration (Days)	
V-16, 4H	16x68	25	158	30	55	240	120	240	120	801
V-16, 6H	16x95	36	160	15	45	885	N/A	N/A	N/A	875
V-16, 6H A	16x95	36	160	50	130	2335	N/A	N/A	N/A	2335
V-16, 6 B	16x95	36	160	30	90	1630	N/A	N/A	N/A	N/A
V-16, 6H C	16x95	36	160	15	15	0.12	350	370	3650	3650

Table 1-2. Capture dates, transmitter type, PIT Tag ID, weight (kg), fork length (cm) and assigned habitat use during study period for individual Gulf sturgeon telemetered by the U.S. Fish and Wildlife Service in Choctawhatchee River in 2008. Only Gulf sturgeon documented during the current study are included. * denotes estimated fork lengths derived from Von Bertelannfy growth estimates (Flowers et al. 2010).

Capture Date	ID	Transmitter Type (V16)	Pit Tag ID	Weight (kg)	Fork Length (cm)		Habitat Use		River		Days of Overwinter Occupancy	
					2009–2010	2010–2011	2009–2010	2010–2011	2010	2011	2009	2010
7/31	08-01	6H B	48752D4338	41	174*	179	Marine	Marine	Choctawhatchee	Choctawhatchee	176	219
7/31	08-02	6H B	420B156056	29	162*	169	Marine	Missing	Choctawhatchee	Missing	161	N/A
7/31	08-03	6H B	4875434146	51	194*	197	Marine	Marine	Choctawhatchee	Choctawhatchee	154	166
8/5	08-04	6H B	116327220A	31	167*	173	Marine	Unknown	Choctawhatchee	Missing	174	N/A
8/12	08-05	6H B	42302D650F	24	151*	159	Estuarine	Marine	Choctawhatchee	Choctawhatchee	160	137
8/14	08-06	6H B	486A587F78	23	148*	156	Marine	Marine	Choctawhatchee	Yellow	184	N/A
8/14	08-07	6H B	4230333C3D	25	148*	156	Estuarine	Unknown	Choctawhatchee	Missing	153	N/A
8/14	08-08	6H B	423051212D	37	171*	177	Marine	Marine	Choctawhatchee	Choctawhatchee	187	163
8/14	08-09	6H B	420B310F7C	49	184*	188	Marine	Marine	Choctawhatchee	Choctawhatchee	145	138
9/9	08-10	6H B	423053D1B	49	179*	184	Marine	Marine	Choctawhatchee	Choctawhatchee	187	156
9/9	08-11	6H B	48754F6871	46	178*	182	Marine	Missing	Choctawhatchee	Missing	208	N/A
9/9	08-12	6H B	4876445F3C	42	187*	191	Marine	Missing	Choctawhatchee	Missing	156	N/A
10/12	08-13	6H B	4876452B36	54	187*	191	Marine	Marine	Choctawhatchee	Choctawhatchee	170	173
10/25	08-14	6H B	42303F1D46	23	155*	162	Marine	Missing	Choctawhatchee	Missing	163	N/A
10/26	08-15	6H B	486A6C0C1C	28	160*	167	Unknown	Missing	Missing	Missing	N/A	N/A
10/26	08-16	6H B	486A474F41	43	180*	185	Unknown	Missing	Choctawhatchee	Missing	N/A	N/A

Table 1-3. Capture dates, transmitter type, PIT Tag ID, weight (kg) fork length (cm) and assigned habitat use during study period for individual Gulf sturgeon captured in 2009. In the Fork Length column, * denotes estimated fork lengths derived from Von Bertelannfy growth estimates (Flowers et al. 2010). In the River column, * denotes an individual that returned to the east of Choctawhatchee Bay but was not detected in Choctawhatchee River. River column indicates the river that each Gulf sturgeon was documented in the spring and summer of that year.

Capture Date	ID	Transmitter Type (V16)	PIT Tag ID	Weight (kg)	Fork Length (cm)		Habitat Use		River		Days of Overwinter Occupancy	
					2009–2010	2010–2011	2009–2010	2010–2011	2010	2011	2009	2010
10/5	09-01	6H	486A297209	12	117	129*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	156	122
10/5	09-02	6H	422F363634	23	145	154*	Marine	Unknown	Choctawhatchee	Choctawhatchee	161	162
10/6	09-03	6H	4230425970	30	156	163*	Marine	Marine	Choctawhatchee	Choctawhatchee	154	146
10/6	09-04	6H	42027C2074		146	155*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	150	138
10/6	09-05	4H	47065D3828	14	113	126*	Marine	Marine	Choctawhatchee	Choctawhatchee	164	146
10/6	09-06	4H	470D617517	15	118	130*	Marine	Marine	Choctawhatchee	Choctawhatchee	178	180
10/6	09-07	4H	4709532A1B	14	119	131*	Marine	Marine	Choctawhatchee	Choctawhatchee	174	184
10/7	09-08	6H	486A6C195B	29	155	163*	Marine	Marine	Choctawhatchee	Yellow	155	N/A
10/7	09-09	4H	4706423C76	21	135	145*	Marine	Marine	Escambia	Choctawhatchee	N/A	N/A
10/7	09-10	4H	4820753953	18	126	137*	Unknown	Estuarine	Choctawhatchee	Choctawhatchee	N/A	177
10/7	09-11	6H	470644353	20	138	148*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	136	146
10/7	09-12	4H	47041E254C	14	118	130*	Estuarine	Marine	Choctawhatchee	Escambia	163	N/A
10/7	09-13	6H	4705167E29	15	132	142*	Marine	Marine	Choctawhatchee	Choctawhatchee	163	152
10/7	09-14	4H	470635050B	16	129	140*	Marine	Marine	Yellow	Blackwater	N/A	N/A
10/7	09-15	4H	467B5F375A	12	116	128*	Marine	Marine	Choctawhatchee	Apalachicola	186	N/A
10/7	09-16	6H	47076D1151	25	147	156*	Marine	Marine	Choctawhatchee	Choctawhatchee	168	149
10/7	09-17	4H	48756E0A36	9	103	117*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	167	138
10/7	09-18	6H	46184D7A6E	31	157	164*	Marine	Marine	Choctawhatchee	Choctawhatchee	163	138
10/7	09-19	6H	47080C167B	36	156	163*	Marine	Marine	Choctawhatchee	Choctawhatchee	163	154

(Table 1-3 Cont.)

Capture Date	ID	Transmitter Type (V16)	Pit Tag ID	Weight (kg)	Fork Length (cm)		Habitat Use		River		Days of Overwinter Occupancy	
					2009–2010	2010–2011	2009–2010	2010–2011	2010	2011	2009	2010
10/7	09-20	4H	47095B7F72	17	134	144*	Estuarine	Marine	Choctawhatchee	Choctawhatchee	130	134
10/7	09-21	4H	4709284D52	17	129	140*	Marine	Missing	Missing	Missing	N/A	N/A
10/7	09-22	6H	465B3F5A5A	43	174	179*	Marine	Marine	Escambia	Choctawhatchee	N/A	N/A
10/7	09-23	4H	9704290E1A	4	89	105*	Marine	Estuarine	Choctawhatchee	Choctawhatchee	167	149
10/7	09-24	6H	422F3C6F66	27	144	153*	Marine	Marine	Choctawhatchee	Apalachicola	163	N/A
10/7	09-25	4H	486B257844	7	97	112*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	171	128
10/7	09-26	6H	470D731E37	29	155	163*	Marine	Marine	Choctawhatchee	Yellow	163	N/A
10/7	09-27	6H	47094D6357	61	194	197*	Marine	Marine	Choctawhatchee	Choctawhatchee	165	200
10/7	09-28	4H	4706542F18	11	111	124*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	170	149
10/7	09-29	6H	470C593C43	25	153	161*	Marine	Marine	Choctawhatchee	Yellow	139	N/A
10/7	09-30	6H	460E03159	19	143	N/A	N/A	N/A	Choctawhatchee	N/A	N/A	N/A
10/7	09-31	6H	48752C6616		175	180*	Unknown	Marine	Choctawhatchee	Choctawhatchee	N/A	203
10/7	09-32	4H	47042B190E	14	121	133*	Marine	Marine	Choctawhatchee	Choctawhatchee	191	165
10/7	09-33	4H	4876730240	11	109	122*	Marine	Unknown	Yellow	Escambia	N/A	N/A
10/7	09-34	4H	470518207A	5	91	106*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	154	123
10/8	09-35	4H	4709332C43	18	130	141*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	166	165
10/8	09-36	6H	470B412015	52	183	187*	Marine	Marine	Choctawhatchee	Bay*	179	N/A
10/8	09-37	4H	471A156A5D		127	138*	Estuarine	Marine	Choctawhatchee	Choctawhatchee	149	131
10/8	09-38	6H	4821057112	45	180	N/A	N/A	N/A	Choctawhatchee	N/A	N/A	N/A
10/8	09-39	6H	4876347E06	11	114	127*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	161	186
10/8	09-40	4H	486B077E1A	7	102	116*	Estuarine	Estuarine	Choctawhatchee	Choctawhatchee	162	117

Table 1-4. Capture dates, transmitter type, PIT Tag ID weight (kg), fork length (cm), and assigned habitat use for individual Gulf sturgeon captured in 2010. Bay* denotes an individual that returned to the east of Choctawhatchee Bay but was not detected in Choctawhatchee River. Choctawhatchee* denotes an individual that was documented in both Choctawhatchee River and Bay during the summer months. River column indicates the river that each Gulf sturgeon was documented in the spring and summer of that year.

Capture Date	ID	Tag Type (V16)	Pit Tag ID (New)	Pit Tag ID (Old)	Weight (kg)	Fork Length (cm)	Habitat Use	2011 River	Days of Occupancy
6/3	10-01	6H A	3D9.1C2D9BA82E		15	129	Marine	Choctawhatchee	171
6/3	10-02	6H A	3D9.1C229BBE76		15	128	Estuarine	Choctawhatchee	198
6/3	10-03	6H A	3D9.1C2D9B3A60		22	139	Estuarine	Choctawhatchee	142
6/3	10-04	6H A	3D9.1C229B5F98		18	133	Marine	Choctawhatchee	151
6/3	10-05			467D263A57	14	130			
6/3	10-06	6H A	3D9.1C2D9B8232		23	138	Estuarine	Choctawhatchee	129
6/3	10-07		3D9.1C2D9B36D0		6	89			
10/9	10-08	6H	3D9.1C2CC994B0		54	188	Marine	Choctawhatchee	158
10/9	10-09	6H	3D9.1BF20FAC91		23	140	Estuarine	Choctawhatchee	148
10/9	10-10	6H	3D9.1C2CBE60E6		21	139	Estuarine	Choctawhatchee	165
10/9	10-11	4H	3D9.1C2C57FC6B	470C394D12	14	126	Estuarine	Choctawhatchee	142
10/9	10-12	4H	3D9.1BF18A8374	48206D7832	12	121	Marine	Choctawhatchee	149
10/9	10-13	4H	3D9.1C2CC9DC96	486A3B3661	11	114	Estuarine	Choctawhatchee	129
10/9	10-14	6H	3D9.1C2CC965A3	461334081E	22	138	Estuarine	Choctawhatchee	114
10/9	10-15	4H	3D9.1BF2110043		5	89	Estuarine	Choctawhatchee	126
10/9	10-16	6H	3D9.1C2D0BCF76	423035265A	38	172	Marine	Choctawhatchee	209
10/9	10-17	4H	3D9.1BF20F7376	470C641028	13	118	Estuarine	Choctawhatchee	152
10/11	10-18	6H	3D9.1BF20F4770	423052024A	48	173	Marine	Choctawhatchee	161
10/11	10-19	6H	3D9.1C2D09F6E6		20	140	Estuarine	Choctawhatchee	150
10/11	10-20	6H	3D9.1C2C57F7E0	4821262814	20	136	Marine	Blackwater	N/A
10/11	10-21	6H	3D9.1C2CC96574	48241B460A	42	172	Marine	Choctawhatchee	161

(Table 1-4 Cont.)

10/11	10-22	6H	3D9.1C2CC9FEF0		54	186	Marine	Choctawhatchee	141
10/11	10-23		3D9.1BF20F79D9	486B077E1A	10	108			
10/11	10-24	6H		42332701D	20	136	Estuarine	Choctawhatchee	131
10/11	10-25	6H	3D9.1C2C57F1EC		47	169	Marine	Choctawhatchee	152
10/11	10-26	4H	3D9.1C2CCA3CEA	42327D250C	10	111	Estuarine	Choctawhatchee	126
10/11	10-27	6H	3D9.1BF211189D		17	131	Marine	Choctawhatchee	142
10/11	10-28	6H	3D9.16F20F4A9D	4203423510	22	147	Estuarine	Choctawhatchee	123
10/11	10-29	6H	3D9.1C2D0B080A	4229044029	29	144	Marine	Missing	N/A
10/12	10-30	6H A	3D9.1C2CC96C15		21	131	Marine	Choctawhatchee	132
10/12	10-31	4H	3D9.1C2D0A072B		16	128	Estuarine	Choctawhatchee	143
10/12	10-32	6H A	3D9.1C2C57FC90		20	133	Marine	Blackwater	112
10/12	10-33	6H A	3D9.1C2CCE434B	4230433542	21	135	Marine	Choctawhatchee	112
10/12	10-34	4H	3D9.1BF210F611		14	125	Marine	Choctawhatchee	138
10/12	10-35	6H A	3D9.1C2CC95AA4	42302F502C	42	167	Marine	Yellow	N/A
10/12	10-36	6H A	3D9.1BF20F4A9A		57	181	Marine	Choctawhatchee	133
10/12	10-37	6H A	3D9.1C2CC96329	487536013D	26	140	Estuarine	Choctawhatchee	117
10/12	10-38	6H A	3D9.1C2CBE6F19		20	136	Marine	Choctawhatchee	151
10/12	10-39	6H A	3D9.1C2C59B933	423C544E04	32	152	Estuarine	Choctawhatchee	129
10/12	10-40	4H	3D9.1C2D0D7AF6		19	126	Marine	Choctawhatchee*	157
10/12	10-41	6H A	3D9.1BF2110088		23	143	Marine	Choctawhatchee	129
10/12	10-42	6H A	3D9.1C2D0A0F80		54	185	Marine	Choctawhatchee	217
10/13	10-43	6H A	3D9.1BF20FA701		42	165	Marine	Choctawhatchee	153
10/13	10-44	4H	3D9.1C2CC961E4		13	120	Estuarine	Choctawhatchee	120
10/13	10-45	6H A	3D9.1C2CC96C57	4707756740	42	160	Marine	Choctawhatchee	144
10/13	10-46	6H A	3D9.1C2CBE3671	470810030B	25	132	Estuarine	Choctawhatchee	159
10/13	10-47	4H	3D9.1BF210FB87		25	127	Estuarine	Choctawhatchee	160
10/13	10-48	6H A	3D9.1BF210FA8D		28	147	Marine	Choctawhatchee	144

(Table 1-4 Cont.)

10/13	10-49	6H A	3D9.1C2CC94252	470C7A541B	50	177	Marine	Bay*	N/A
10/13	10-50	4H	3D9.1C2C57F680		12	105	Estuarine	Choctawhatchee	140
10/13	10-51		3D9.1C2CC9D7CF	487552185C	30	143			
10/13	10-52	4H	3D9.1C2C9BDC80		14	125	Marine	Choctawhatchee	139
10/13	10-53		3D9.1C2C9BB8F5		48	158			
10/13	10-54	4H	3D9.1C2CCC5D89		13	125	Estuarine	Choctawhatchee	147
10/13	10-55		3D9.1BF210F6BC		42	160			
10/13	10-56	4H	3D9.1C2CC95282		8	105	Estuarine	Choctawhatchee	130
10/13	10-57	4H	3D9.1C2CC9F55C		15	126	Marine	Choctawhatchee	149
10/13	10-58		3D9.1C2CC96673		25	132			
10/13	10-59		3D9.1C2D12178D	420342567D	62	183			
10/13	10-60		3D9.1C2C57F77D		24	140			
10/13	10-61		3D9.1C2D0A072A		22	136			
10/14	10-62	4H	3D9.1C2D136FA5		7	99	Estuarine	Choctawhatchee	125
10/14	10-63		3D9.1C2D0AF375		34	155			
10/14	10-64	4H	3D9.1C2CCB40E	467C057348	19	118	Estuarine	Choctawhatchee	131
10/14	10-65		3D9.1BF210F7AE		25	136			
10/14	10-66	4H		486A324412		104	Marine	Choctawhatchee	140
10/14	10-67	4H	3D9.1BF210EA70		11	113	Estuarine	Choctawhatchee	124
10/14	10-68		3D9.1C2CFD39C7		49	173			
10/14	10-69		3D9.1C2D0AF97E		73	194			

Table 1-5. Mean (range) date of arrival, departure, and duration, mean ±SE km distance spent from midline of Choctawhatchee Bay and Choctawhatchee River mouth for estuarine-dependent and marine resident Gulf sturgeon telemetered in Choctawhatchee River by year with results of analysis between years and habitat use classification. The midline refers to the geographic center used in examination of distributions throughout Choctawhatchee Bay. Est-Mar refers to analyses comparing estuarine-dependent and marine individuals. *denotes $P < 0.05$ indicating a significant difference.

	Estuarine		Marine		Estuarine	Marine	2009	2010
	2009	2010	2009	2010	P-value (2009–2010)	P-value (2009–2010)	P-value (Est-Mar)	P-value (Est-Mar)
Day of Arrival	Oct 28 (Oct 18–Nov 5)	Nov 12 (Oct 6–Dec 29)	Oct 26 (Oct 6–Nov 11)	Nov 6 (Oct 1–Dec 4)	$P < 0.0001$*	$P < 0.0001$*	$P < 0.32$	$P < 0.04$*
Day of Departure	Apr 3 (Mar 5–Apr 23)	Apr 3 (Mar 3–Apr 26)	Apr 13 (Mar 6–May 18)	Apr 10 (Mar 5–Jun 6)	$P < 0.96$	$P < 0.61$	$P < 0.04$*	$P < 0.06$
Duration (days)	157 ±3.5	141.1 ±3.6	169 ±2.5	157 ±3.3	$P < 0.01$*	$P < 0.004$*	$P < 0.005$*	$P < 0.002$*
Distance from River Mouth (km)	15.9 ±0.6	20.3 ±1.3	20.1 ±0.9	22.3 ±0.8	$P < 0.003$*	$P < 0.08$	$P < 0.0004$*	$P < 0.20$
Distance from Bay Midline (km)	2.1 ±0.4	1.0 ±0.3	-0.7 ±0.2	-.84 ±0.2	$P < 0.02$*	$P < 0.63$	$P < 0.0001$*	$P < 0.0001$*

Table 1-6. Mean residency index of estuarine-dependent Gulf sturgeon as derived by documented habitat use each year. n=number of Gulf sturgeon.

Year	Mean	Standard Error
2009 (n = 15)	0.89 (0.78–0.96)	0.01
2010 (n = 38)	0.78 (0.47–0.92)	0.02

Student's *t*-test; $P = 0.0001$

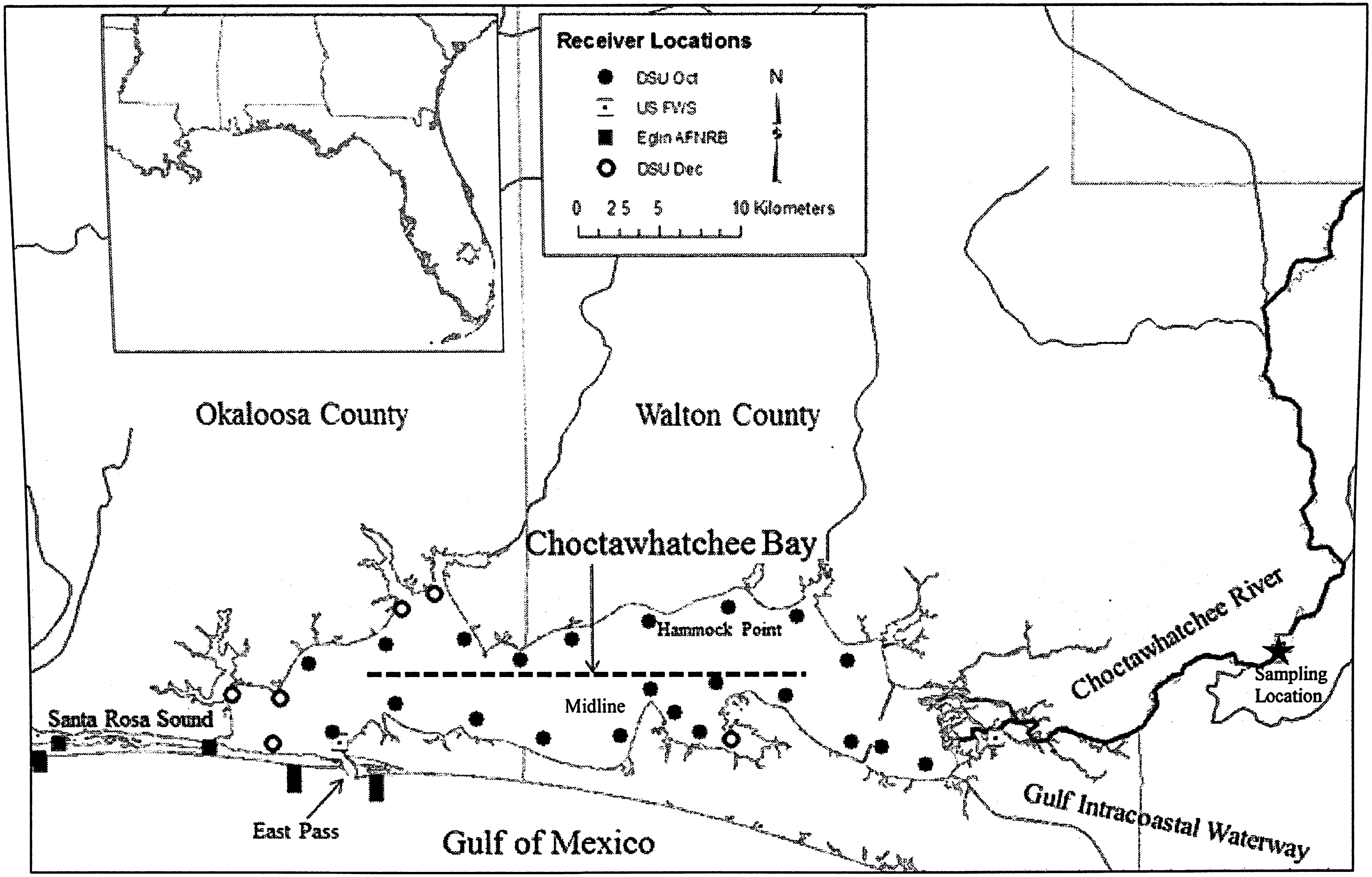

Figure 1-1. Study site with passive telemetry array for assessment of Gulf sturgeon habitat utilization and residency in Choctawhatchee Bay, Florida (October 2009–May 2010, and October 2010–June 2011). Closed circles were deployed in October 2009, while open circles were deployed in December 2009. In 2010 all receivers were deployed in October. The midline refers to the geographic center used in examination of distributions throughout Choctawhatchee Bay.

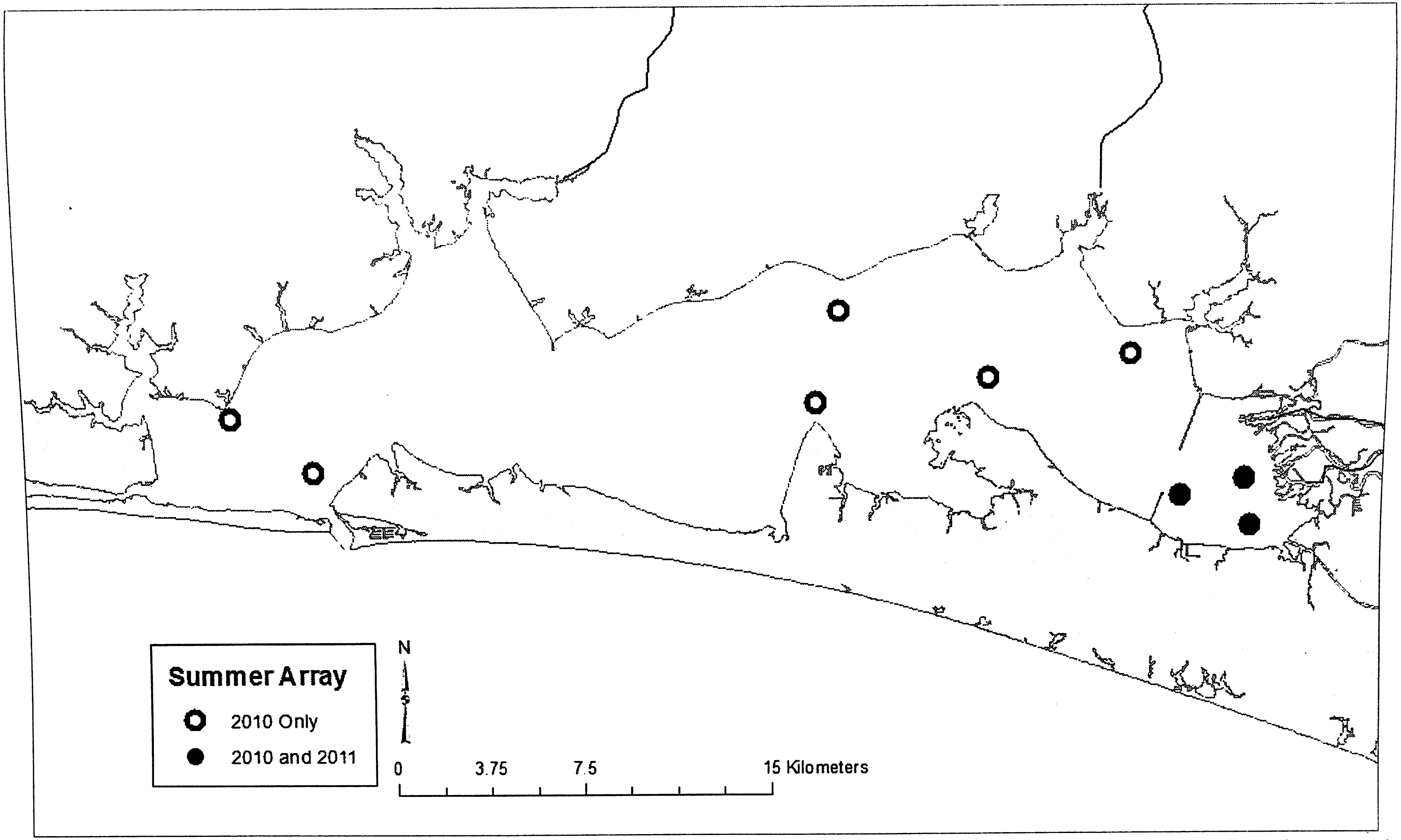

Figure 1-2. Locations of passive acoustic receivers deployed in Choctawhatchee Bay, Florida during summer months of 2010 and 2011. Closed circles denote receivers that were deployed both years, and open circles denote receivers that were deployed in 2010 only.

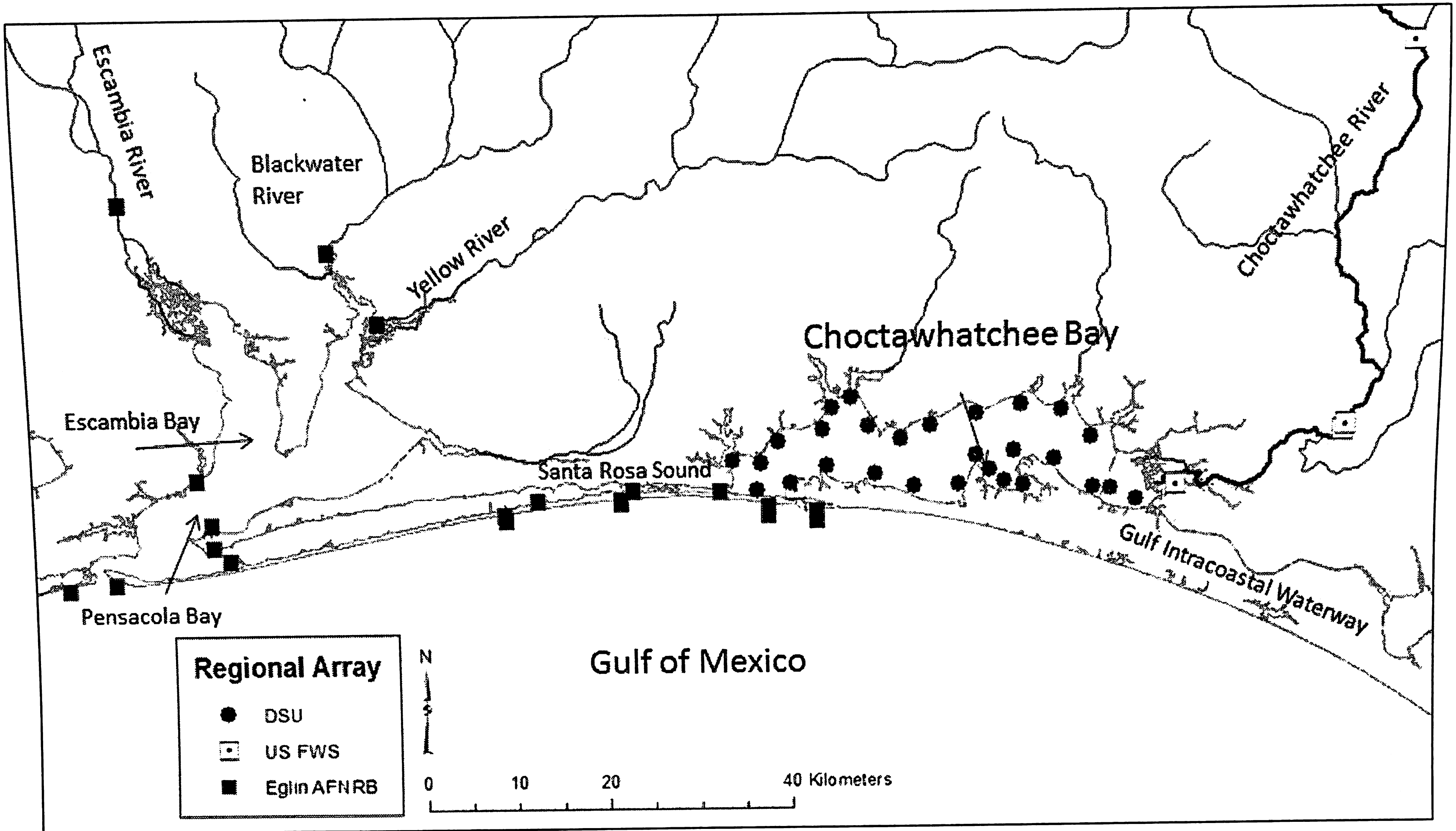

Figure 1-3. Locations of passive telemetry array in Choctawhatchee Bay, Florida and receivers deployed in neighboring systems by the U.S. Fish and Wildlife Service and Elgin Air Force Natural Resources Branch. Closed circles denote receivers deployed by Delaware State University, closed squares denote receivers deployed by Eglin Air Force Natural Resources Branch, and open squares denote receivers deployed by the U.S. Fish and Wildlife Service.

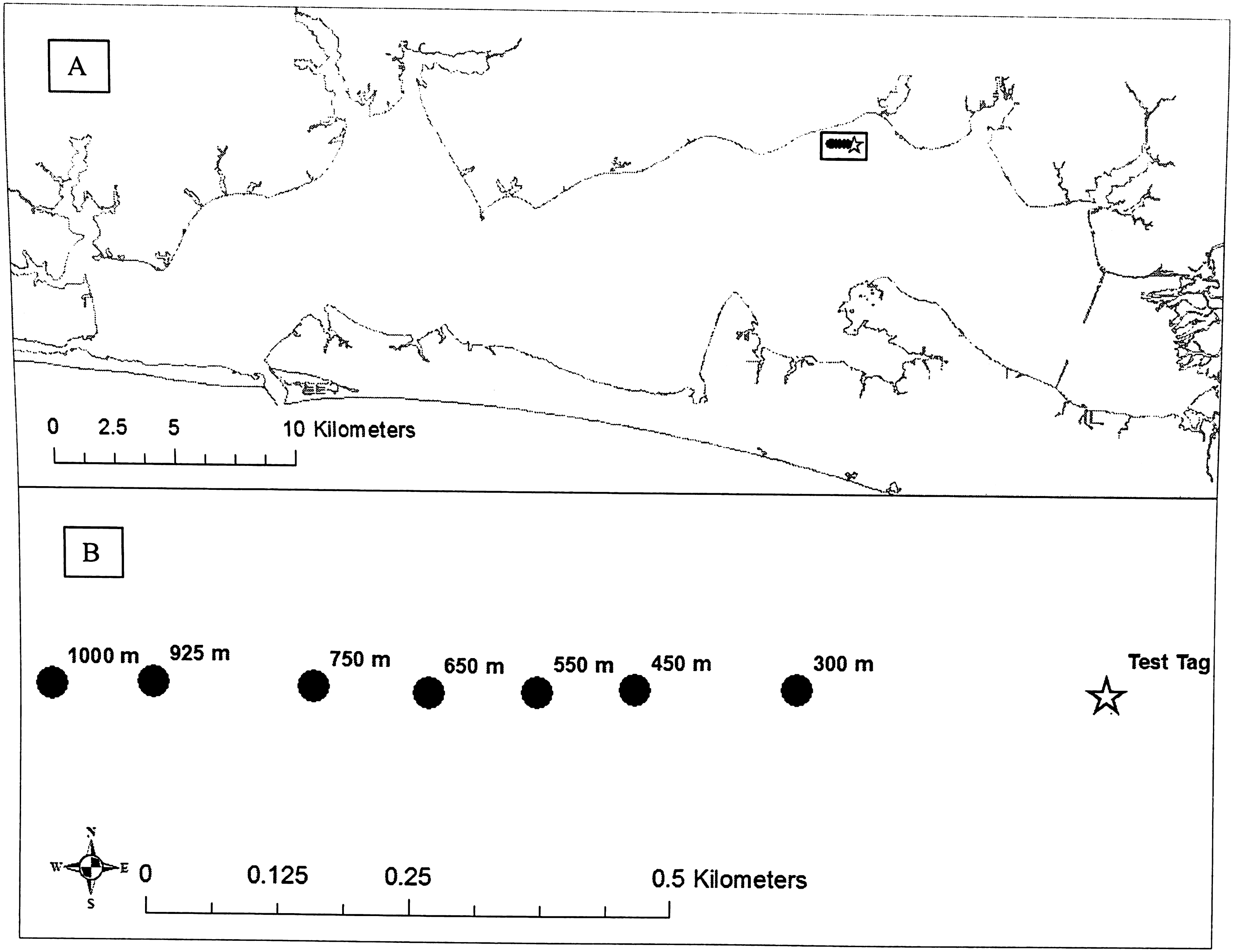

Figure 1-4. Location, configuration and distances of the range test array for passive acoustic receivers deployed in Choctawhatchee Bay, Florida. Panel A depicts the location of the range test array, and Panel B depicts the configuration and distances.

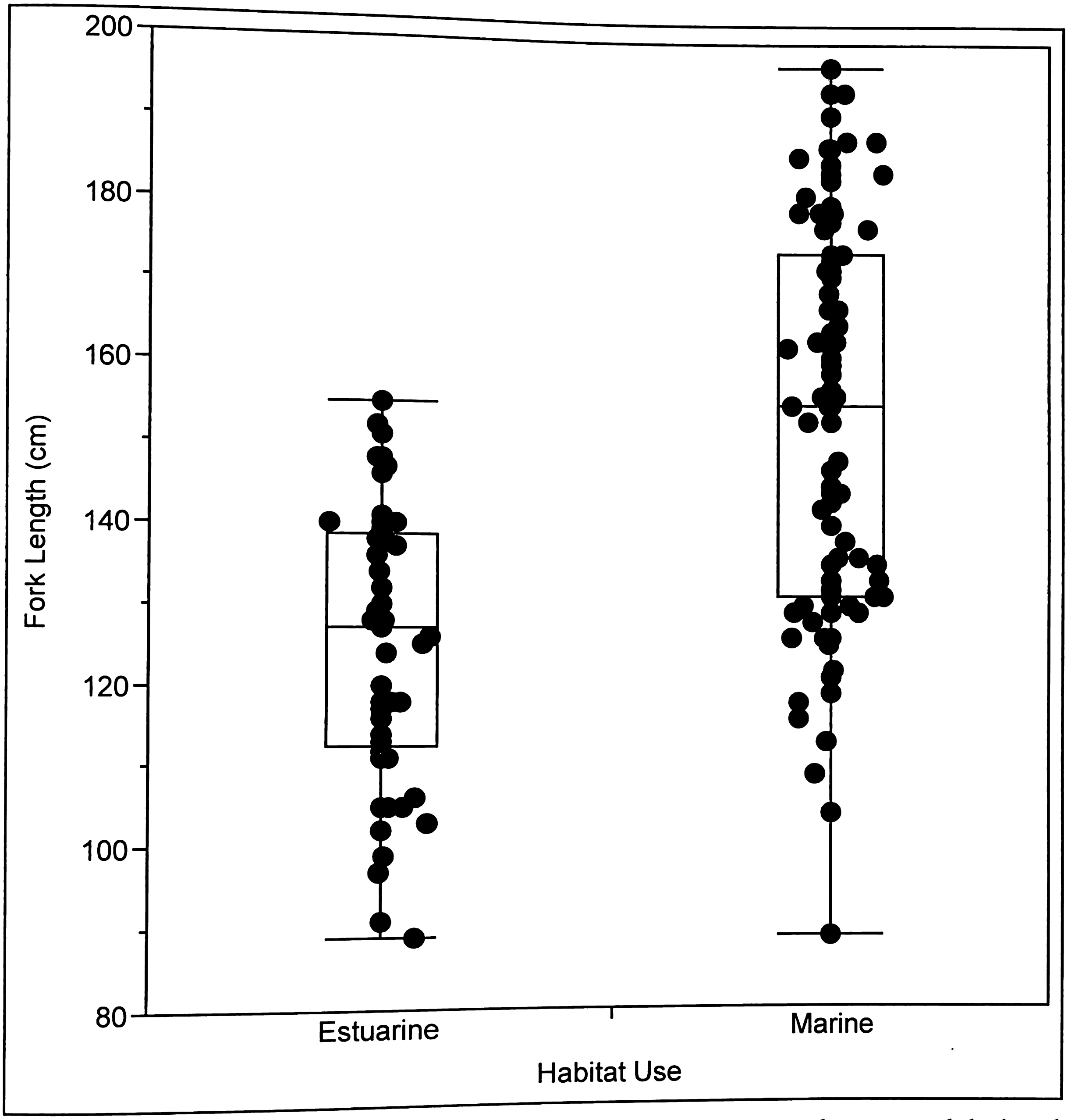

Figure 1-5. Length of Gulf sturgeon according to residency status documented during the 2009–2010 and 2010–2011 overwinter periods. Box plots display a statistical summary of length by residency status showing the mean, 25-75th quartiles, min and max.

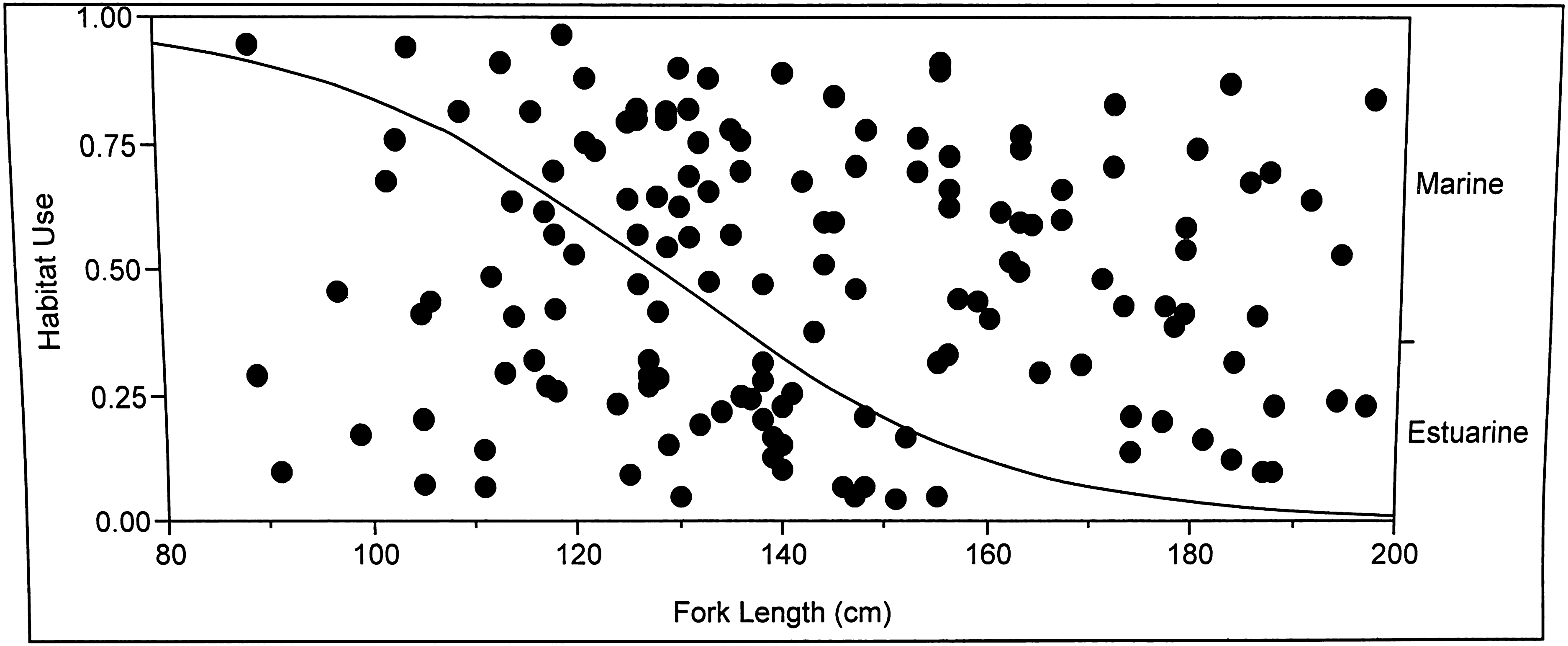

Figure 1-6. Results of logistic regression comparing Gulf sturgeon habitat use (estuarine vs. marine) by fork length. Circles plotted above the line represent Gulf sturgeon that have utilized the Gulf of Mexico and circles plotted below the line represent Gulf sturgeon that remained within Choctawhatchee Bay. For each fork length, the probability scale in the y direction is partitioned into probabilities for categorized residency groups. The probabilities are measured as the vertical distance between the curves (Total Y = 1.0).

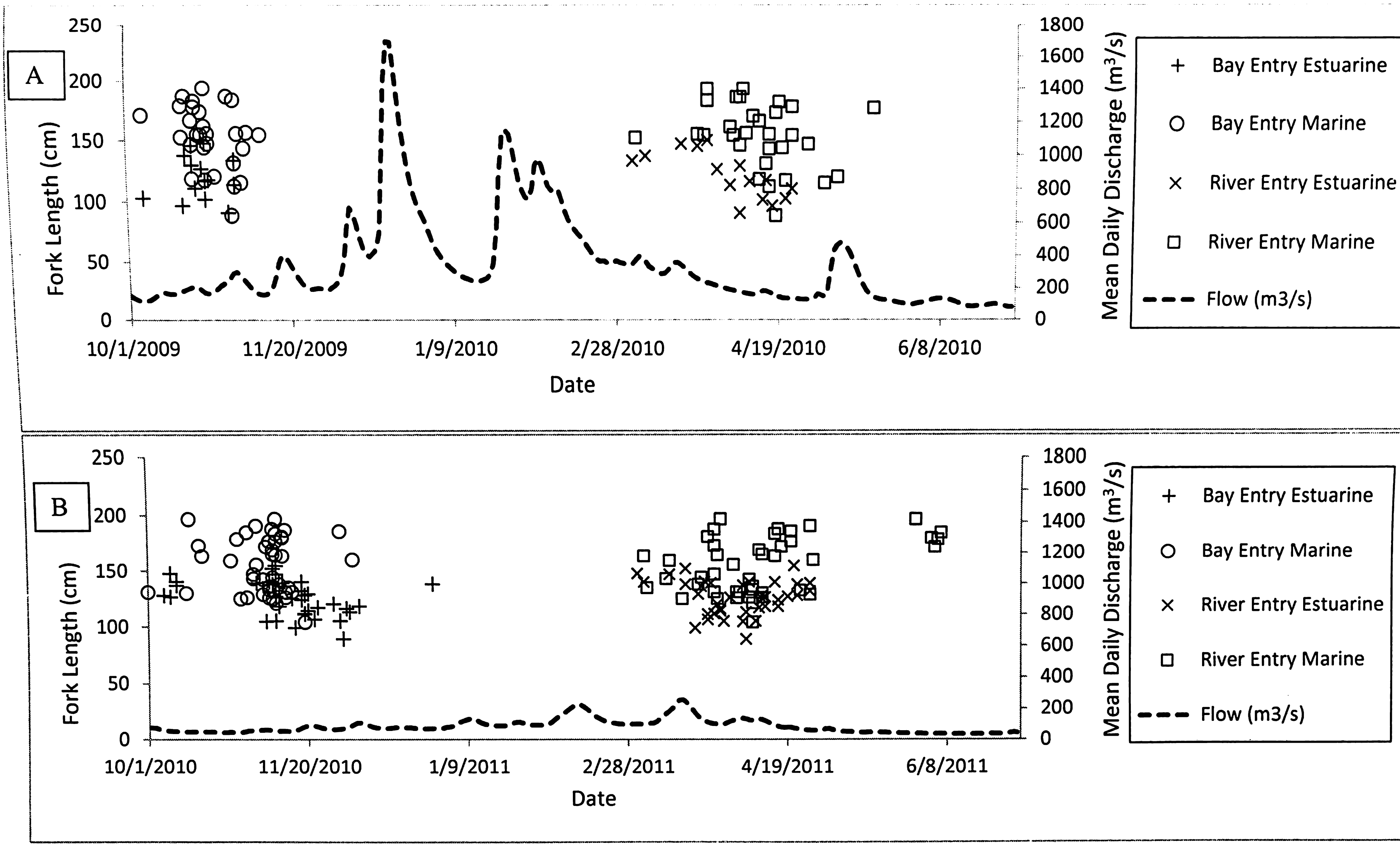

Figure 1-7. Timing of fall emigration and spring immigration of telemetered Gulf sturgeon from and to the Choctawhatchee River, Florida during the study period associated with river flow (m^3/s). Panel A depicts 2009–2010 dates of migration and flow and Panel B depicts 2010–2011 dates of migration and flow.

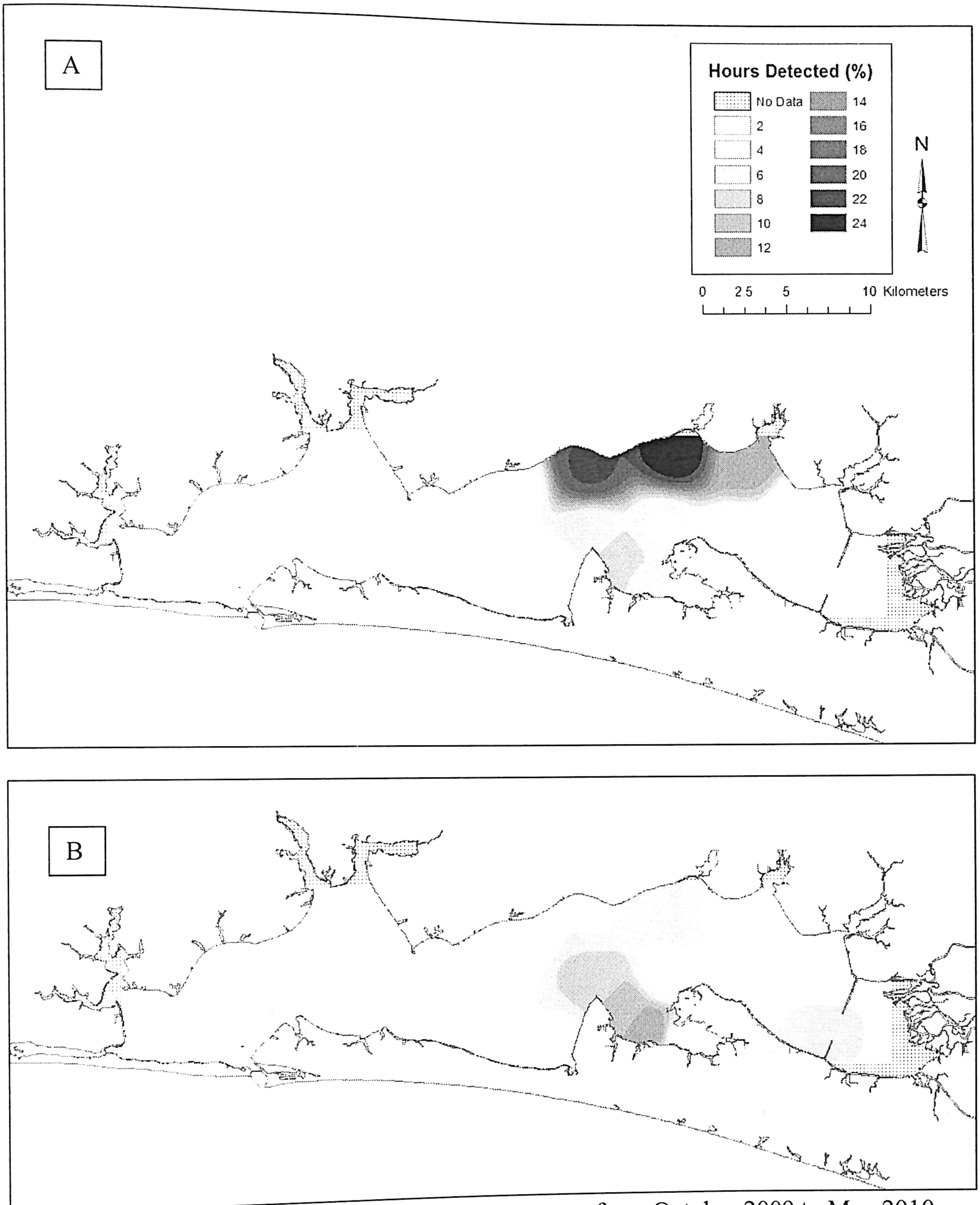

Figure 1-8. Distribution of telemetered Gulf sturgeon from October 2009 to May 2010. Panel A depicts distribution of estuarine-dependent residents and panel B depicts distribution of individuals that utilized the Gulf of Mexico for a portion of the overwinter period.

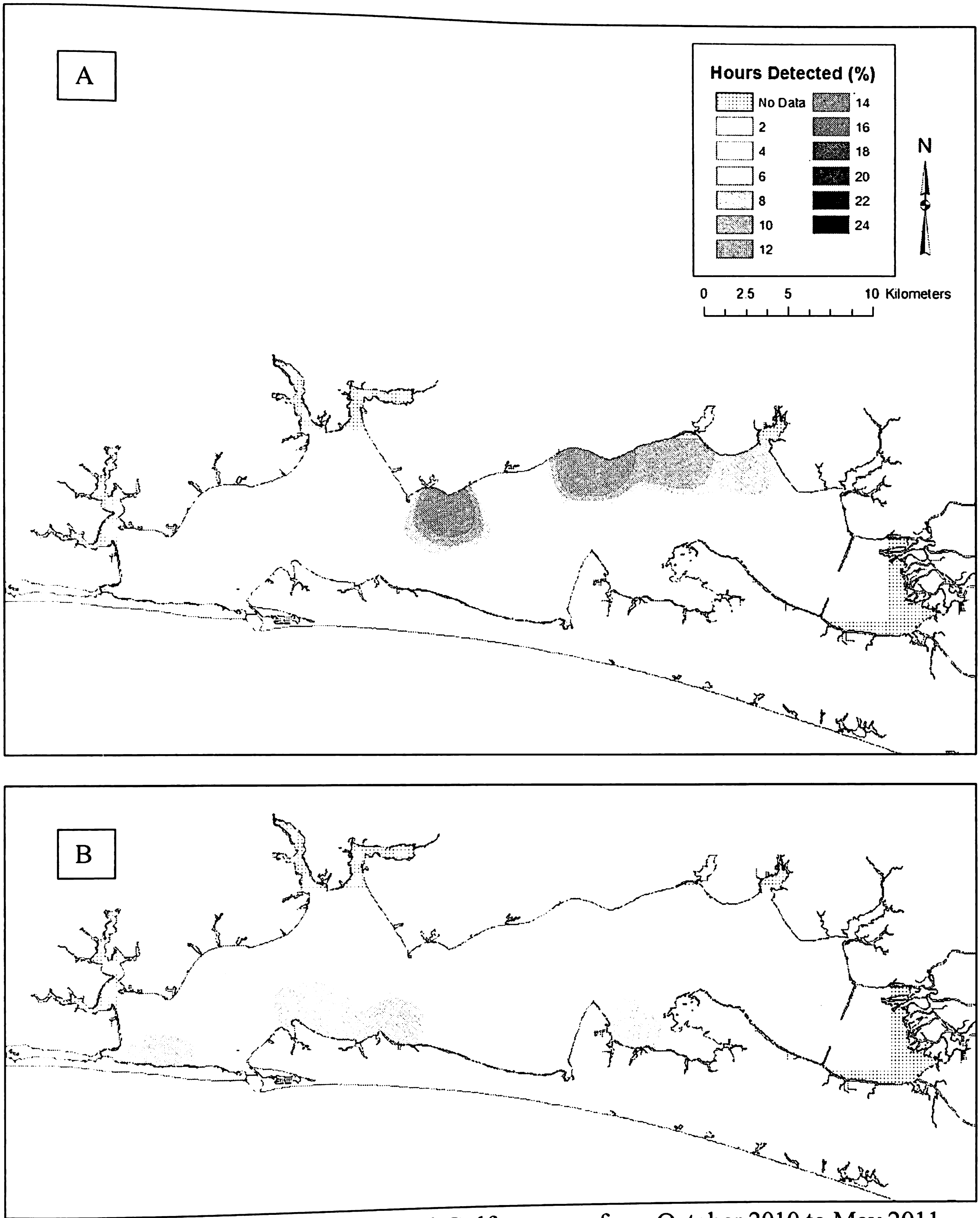

Figure 1-9. Distribution of telemetered Gulf sturgeon from October 2010 to May 2011. Panel A depicts distribution of estuarine-dependent residents and panel B depicts distribution of individuals that utilized the Gulf of Mexico.

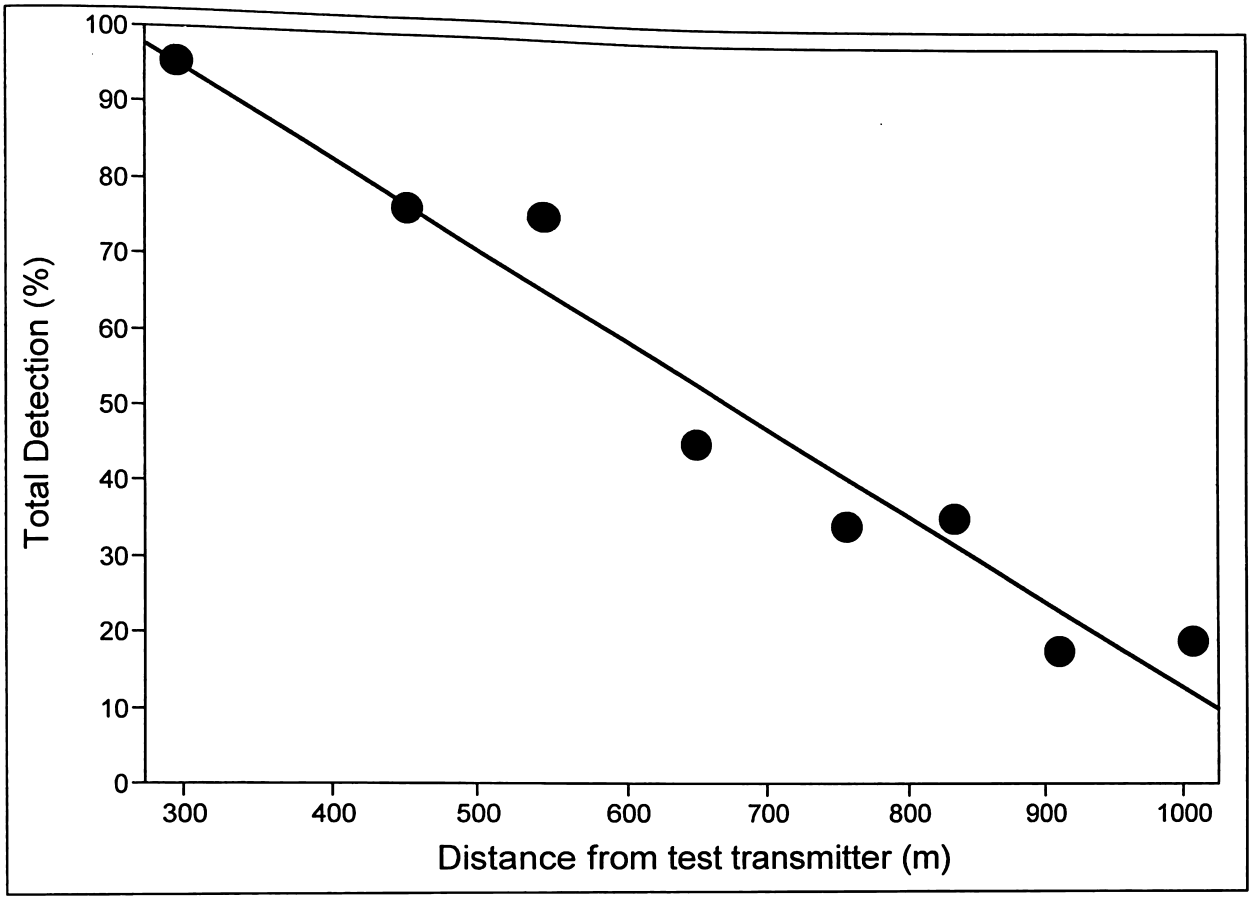

Figure 1-10. Detection efficiencies documented during range testing conducted in Choctawhatchee Bay, Florida from June 5–August 8, 2010. The percent of total possible detections recorded at each receiver distance in the range test is plotted. The total possible detections were estimated according to the random delay time of the test transmitter. The linear regression (y = 0.12x + 129.86) suggests that 50% detection efficiency occurred at 685 m.

Chapter 2

Relationship between Gulf sturgeon *Acipenser oxyrinchus desotoi* overwinter habitat use and potential prey in Choctawhatchee Bay, Florida

Introduction

Gulf sturgeon *Acipenser oxyrinchus desotoi* are a slow growing anadromous species listed as threatened under the U.S. Endangered Species Act, largely due to overfishing and habitat degradation (USFWS et al. 1995). Gulf sturgeon are believed to spend the first three years of life in freshwater environments (Mason and Clugston 1993), undergoing ontogenetic changes in salinity tolerance (Altinok et al. 1998). Larger juveniles and adults migrate to estuarine and marine waters during the winter months to feed mostly on benthic invertebrates before returning primarily to their natal rivers during the warmer months (Huff 1975, Mason and Clugston 1993). Aside from larval (Kynard and Parker 2004) and early juveniles (Mason and Clugston 1993), Gulf sturgeon are not believed to feed while in rivers as evidenced by apparent fasting and weight loss (Wooley and Crateau 1985, Carr et al. 1996) and further supported through carbon stable isotope analysis (Gu et al. 2001). As such, adult and larger juvenile Gulf sturgeon are reliant on estuarine and marine foraging habitats for growth and gonadal recrudescence (Carr et al. 1996, Fox et al. 2002).

Unfortunately these critical estuarine overwinter habitats are facing continued modification (EPA 1999) and are a concern for managers tasked with Gulf sturgeon recovery (USFWS and NOAA 2003). In Florida, eight counties surround estuarine systems known to support reproducing populations of Gulf sturgeon. From 1950 to 2010, seven of these counties experienced over 100% increases in human population growth (USCB 2010). Such population growth was associated with habitat transitions from rural/forested to urban/suburban and has led to management concerns regarding degradation of water quality and benthic communities (EPA 1999); Watersheds subjected to urban land use are generally characterized by lower water quality and poor benthic condition (Dauer et al. 2000, Snyder et al. 2003, Bilkovic et al. 2006).

The Choctawhatchee River supports a relatively healthy reproducing population of Gulf sturgeon (Fox et al. 2002), which may be due to unobstructed access to the majority of historic habitats (USFWS et al. 1995). However, the majority of changes in this watershed have occurred in nearshore environments commonly used by Gulf sturgeon (Parauka et al. 2001, Fox et al. 2002) and were recognized several decades ago as a potential factor in degrading water quality (Long et al. 1997, Thorpe et al. 2002). Anthropogenic impacts in Choctawhatchee Bay are compounded by eutrophication due to limited exchange of water through flushing, increased water temperature, and longer algal-growing seasons (Livingston 1986). Additionally, it is unknown how climate change and sea level rise may impact Gulf sturgeon habitats, (USFWS et al. 1995, USFWS and NMFS 2009), but these impacts are predicted to be particularly profound in estuarine environments, as they may experience habitat losses due to alterations in salinity, and dissolved oxygen (Kennedy 1990, Ray 1997), exacerbated by rising temperature (Scavia et al. 2002).

Given the threats that face critical forage habitats for Gulf sturgeon, a better understanding of Gulf sturgeon behavior as it relates to foraging is needed (USFWS and NOAA 2003). Gut contents analysis has provided initial insights to food resources consumed by Gulf sturgeon (Huff et al. 1975, Mason and Clugston 1993, Carr et al. 1996), and biotelemetry has been increasingly employed to characterize habitats utilized by Gulf sturgeon (Fox et al. 2002, Harris et al. 2005, Ross et al. 2009, Sulak et al. 2009). Manual tracking efforts in the Suwannee River Estuary, Mississippi Sound, and

Pascagoula River Estuaries have identified sandy estuarine and marine habitats containing large numbers of prey items such as lamp shells, amphipods *Ampelisca spp.*, and brittle stars (families Amphiuridae and Ophiactidae), as important foraging habitats (Harris et al. 2005, Ross et al, 2009). In the Choctawhatchee Bay, manual tracking efforts linked Gulf sturgeon to sandy nearshore shelf habitats characterized by lower densities and abundance of invertebrates than predicted based on available habitat (Fox et al. 2002). Gulf sturgeon in this system were primarily believed to be feeding on estuarine ghost shrimp, a prey item not easily sampled with the collection gear used in a habitat use study conducted in 2002 (Fox et al. 2002), likely due to the shrimp's ability to burrow at depths > 1 m (Felder and Lovett 1989). Juvenile Gulf sturgeon in Apalachicola Bay, Florida were found in areas with fewer invertebrates as well, suggesting that foraging may have been restricted by either salt water intrusion or foraging on unreported prey items not collected through directed sampling (Sulak et al. 2009). While these previous studies have assessed Gulf sturgeon habitat utilization, the underlying mechanisms which mediate behavior remain poorly understood.

Passive telemetry offers an opportunity to monitor a portion of an aquatically-based population simultaneously over extended periods of time, eliminating many of the logistical and resource constraints associated with manual tracking techniques (Heupel et al. 2004). However, statistical approaches to analyze these telemetry data have not evolved as quickly as technological advances (Heupel et al. 2006). Meanwhile researchers commonly utilize telemetry data to examine residence periodicity or migratory periods, identify home range and activity areas, and attempt to correlate environmental variables such as tidal state, water depth, water temperature and salinity (see Heupel et al. 2006 for a review). Less commonly, researchers have also associated habitat use to physical habitat characteristics (Humston et al. 2005, Huff et al. 2011) and potential prey distributions (Sulak et al. 2009) with movement patterns.

Passive telemetry can improve the understanding of habitat use, and through identification of parameters, model selection can answer questions that are of particular biological interest (Johnson and Omland 2004). Specifically, Generalized Linear Models (GLMs) are often appropriate in fisheries science because they accommodate non-normal distributions of response variables (Venables and Dichtmont 2004) that commonly occur in ecological communities (Hoef and Bovang 2007). Recently GLMs were developed to relate habitat use patterns to physical habitat characteristics among green sturgeon *A. medirostris*, providing insights to behavior as it relates to habitat components (Huff et al. 2011).

In this study, I adapted the GLM framework to describe the relationship between Gulf sturgeon habitat use and benthic invertebrates in Choctawhatchee Bay (Huff et al. 2011). Through my effort, I hoped to understand how the distribution and abundance of potential prey resources influenced Gulf sturgeon habitat use as a measure of time spent in a given area. This will allow mangers to understand how changes to habitats within estuarine systems may affect Gulf sturgeon behavior and recovery.

Methods

Study Locale:

Gulf sturgeon were collected for acoustic telemetering in the Choctawhatchee River; passive acoustic monitoring was conducted in the surrounding bay (Figure 2-1). The Choctawhatchee River is one of the largest undammed systems remaining in the Gulf of Mexico, flowing from its headwaters in Alabama approximately 280 km before discharging into the east end of Choctawhatchee Bay. The Choctawhatchee River provides the bay with ≈95% of its freshwater (Blaylock 1983). Choctawhatchee Bay is approximately 45km in length and averages 6 km in width providing a semi-enclosed area protected from most storm events (FDEP 2003). Depth in the eastern bay averages 3 m and increases to an average of 10 m in the west (FDEP 2003). Benthic sediments are mostly silt and clay in the deeper areas and in many of the bayous, and sandy in the peripheral shelf-slope areas (Livingston 1986). East Pass, in the southwest corner of the bay, provides the only direct marine input from the Gulf of Mexico. Choctawhatchee Bay connects with the Gulf Intracoastal Waterway to the east and to the west.

Flows within Choctawhatchee Bay have been described as a two layered system with slow moving higher saline waters traveling eastward up the deeper central and southern sections, and lower saline waters flowing westward along the surface (Blaylock 1983, Jones and Huang 1994). Mean surface salinities are generally highest along the northern shore of the bay with the water column highly stratified during much of the year dependent on winds and discharge from Choctawhatchee River (Jones and Huang 1994). Dissolved oxygen, like salinity, is vertically stratified in the bay, with hypoxic conditions occurring at depth, particularly in the central and western portions of the bay during various times throughout the year (Livingston 1986).

Collection of Specimens:

In October 2009, I captured adult (fork length ≥ 130 cm; Huff 1975) and juvenile (fork length < 130 cm; Huff 1975) Gulf sturgeon in the lower portions of Choctawhatchee River (rkm 40–50) prior to their outmigration into Choctawhatchee Bay and surgically implanted VEMCO Ltd. V-16 acoustic transmitters. Netting operations, surgical procedures and telemetry efforts were detailed in Chapter 1.

Telemetry:

Concurrent with the collection of Gulf sturgeon, a passive acoustic array of 29 VEMCO Ltd. VR2-W receivers was deployed in the nearshore habitats of Choctawhatchee Bay to monitor Gulf sturgeon habitat (Figure 2-1).

Habitat Sampling

I manually searched for telemetered Gulf sturgeon in Choctawhatchee Bay by using a hydrophone according to previously established protocols, (Fox et al. 2002), using updated telemetry equipment (VEMCO Ltd. VR100 receiver and VH165 and VH110 hydrophones). Tracking efforts took place as resources and weather allowed; typically the entirety of Choctawhatchee Bay on a monthly basis. Whenever a Gulf sturgeon was relocated, depth (m), bottom salinity (ppt), dissolved oxygen (mg/l), bottom water temperature (°C) were documented, and a benthic sample was collected using a petite PONAR grab (total sampling area of 231 cm^2) (Figure 2-2).

Benthic samples were taken at random locations throughout Choctawhatchee Bay from May 7–19, 2010, using a petite PONAR grab. Random sampling locations were selected using Hawth's tools random point generator in ArcView ArcGIS 9.3 (Beyer 2004). Sampling sites (n = 225) were stratified according to depth ($\geq$1.8, 1.8–3.8, < 3.8 m), with 75 sampling locations per depth strata (Figure 2-2). These depth strata were modified from previously used depth strata (NOAA 1998, Fox et al. 2002) to assess Gulf sturgeon habitat.

Benthic Sample Processing

Benthic samples were collected, processed, and invertebrates were identified to the lowest practical taxonomic level (McLelland and Heard 2011) according to previously established protocols (Fox et al. 2002). I then cataloged families of benthic invertebrates identified from gut contents of both Gulf sturgeon and the closely related Atlantic sturgeon *A. o. oxyrinchus* documented in the following literature: Vladykov and Greely 1963, Huff 1975, Mason and Clugston 1993, Moser and Ross 1995, Carr et al. 1996, Johnson et al. 1997, Haley 1998, Fox 2000, Secor et al. 2000, Murie and Parkyn 2001, cited by Harris et al. 2005, Savoy 2007 (Table 2-1). I cross-referenced the invertebrates collected in in my study with the list compiled from literature. Families of invertebrates that had been documented in previous literature were categorized as "documented prey" (Table 2-2). Invertebrates were also classified as documented prey based on high densities and conspicuous biomass at Gulf sturgeon relocation sites taken during this study (J. McLelland, University of Southern Mississippi, personal communication).

Habitat Characterization

I interpolated invertebrate data collected through benthic sampling efforts via standard kriging methodology using ArcView ArcGIS 10 Software (ESRI Inc., Redlands CA). I calculated several common ecological indices for interpolation: total invertebrate abundance; the Shannon-Weiner Diversity Index (H'), which is a mathematical expression of species richness and evenness commonly used in ecological investigations (Washington 1984) including benthic monitoring studies:

$$H' = -\sum \rho i \log(\rho i))$$

where pi is the proportion of the total number of species i expressed as a proportion of the total number of species for all species in the population; and abundance/m^2 of five taxonomic groups of invertebrates. Frequency of occurrence was considered when choosing taxonomic groups for interpolation to reduce error associated with the inclusion of rare taxa in bioassessments (Ostermiller and Hawkins 2004). I included: abundance/m^2 of the polychaete subclass Scolecida, the polychaete orders Aciculata and Canalipalpata, the arthropod order Amphipoda, and the bivalve order Veneroida. Two values were calculated for each habitat variable: the first was based on all invertebrates identified, and the second was based on invertebrates designated as documented prey only. This resulted in 14 total habitat values.

Interpolations of these 14 habitat characteristics were used to describe habitats surrounding the acoustic monitoring stations (ArcView ArcGIS 10 spatial analyst) (Figure 2-2). The scope of habitat characterization was based on range testing conducted within the system (as described in Chapter 1), which indicated more than half (57%) of the detections occurring within 600 m would have been successfully captured by the receiver. I converted raster data into polygons, and then calculated mean habitat values for each acoustic receiver location. Whenever an acoustic receiver was placed < 600 m from shore, I standardized values to a 600 m radius by using a weighted average according to the area of each polygon within the buffer zone.

Gulf Sturgeon Habitat Use

From passive telemetry data, I quantified the total cumulative hours that a Gulf sturgeon was detected within the vicinity of each receiver (Huff et al. 2011). For inclusion in my analyses, detections from Gulf sturgeon were required at least once every ten minutes for a minimum of six cumulative hours on an individual receiver, without being detected on another receiver. Because documented swimming speeds of Gulf sturgeon in estuarine and marine environments are relatively slow, with individuals moving 1 km/hr or less (Edwards et al. 2003, Parkyn et al. 2007), restricting data to those every ten minutes improved confidence that Gulf sturgeon were utilizing an area instead of simply passing through. Gulf sturgeon data that did not meet these criteria were excluded from further analyses.

Using a recently developed metric of marine habitat use (Huff et al. 2011) for green sturgeon, I calculated habitat component values of each habitat type for individual Gulf sturgeon. This was calculated by weighting each receiver's habitat values according to the total cumulative time that an individual Gulf sturgeon was recorded utilizing a particular region in relation to the total time spent on all receivers as depicted through the following equation:

$$\hat{v}_k = \sum_{i=1}^{n} y_{ik} x_i \Big/ \sum_{i=1}^{n} y_{ik}$$

Where x is the environmental variable of interest; x_i is the value of the environmental variable of interest (e.g. abundance/m^2, H') at receiver I; and y_{ik} is the amount of time spent by individual Gulf sturgeon k at receiver i (Huff et al. 2011).

Analysis

GLMs were developed, with predictor variables that included the habitat values calculated for individual Gulf sturgeon, residency group (estuarine or marine resident as defined in chapter 1), and the total cumulative hours that each Gulf sturgeon accrued throughout the entire array was the response (Huff et al. 2011). The GLMs were constructed using a quasi-Poisson error distribution to allow for over-dispersion in inferences and a log link, which is the natural link function for Poisson distributions; log link is often utilized in quasi-Poisson models (Venables and Dichmont 2004, Hoef and Boveng 2007). Non-parametric regression models for each predictor and the response variable were screened by calculating leave-one-out-jackknifed R^2 for predicted output versus observed data and the best models were identified based on the highest values. In addition to the resident categorical predictor, a single predictor variable from each habitat grouping (e.g. Amphipoda/m^2 or Amphipoda/m^2-documented prey) was selected for the final GLMs, based on which habitat variable generated a greater R^2 during the screening process. As a result, eight candidate predictor variables could be selected for the final GLM. All predictor variables were log transformed, except for H', and pair plots and dot charts were constructed to visually examine relationships and identify collinearity among predictor variables identified in the screening process. All possible model combinations of candidate predictor variables were considered, with a limitation of four variables in any given model to avoid model over-fitting (Huff et al. 2011). Models were run using R (version 2.15.1) software, and ranked according to the quasi-Akaike information criterion (qAIC) value (Burnham and Anderson 2002). An Akaike weight, which explains the relative likelihood of the model given the data, was generated with each model combination and used to assist in model selection (Johnson and Omland 2004). Marginal model plots were created to evaluate model fit using the car package in R (Fox and Weisberg 2011). A regression function for each plot was fitted using a lowess smooth function for the data and the fitted value (Cook and Weisberg 1993). Analysis of deviance was conducted on the final GLM to identify habitat parameters that influenced the model.

If resident grouping was included in the final GLM, a multi-response permutation procedure (MRPP) was conducted using Bray-Curtis distance measure to assess variation in the habitats utilized across two resident groups (McCune et al. 2002). The first resident group consisted of estuarine resident Gulf sturgeon; the second group was comprised of marine residents based on movements into the Gulf of Mexico during the overwinter period. MRPP provides a probability estimate to evaluate if observed differences are due to chance ($P \leq 0.05$), as well as describes the effect size independent of the sample size with A, an agreement statistic that describes the within group homogeneity in comparison to what is expected by chance (McCune et al. 2002). Estimates of A can range from 0 to 1 with a value of A = 1 signifying the two groups are equal, an estimate of $A = 0$ signifies random occurrence, and $A < 0$ when heterogeneity occurs within groups greater than expected by chance (McCune et al. 2002). In community ecology, an A value of 0.3 is considered high (McCune et al. 2002). When sample sizes are small, a significant P value must be accompanied by a correspondingly high A value to confirm biological significance (McCune et al. 2002).

I used Non-metric multi-dimensional scaling (NMS) to graphically represent relationships among sturgeon (Clark and Ainsworth 1993, McCune et al. 2002) to independently assess the validity of GLM results. An ordination plot illustrating the relationship among telemetered Gulf sturgeon and receivers was created with PC-ORD software (McCune et al. 2002). Average Euclidean distances were calculated using the cumulative presence of telemetered individuals on passive acoustic receivers to create the ordination following previously established NMS selection criteria (described in Huff et al. 2011). Predictive habitat variables, according to the selected GLM, were then fit to the NMS plot, represented as a contour gradient overlaid on the individual sturgeon scores (Salemmaa et al 2008, Huff et al. 2011) using R software (Oksanen 2004). Ordination scores for individual receivers were calculated by the weighted averaging individual sturgeon ordination values. General additive models (GAM, Gaussian error distribution with identity link) were developed to fit habitat contours constructed with non-parametrically smoothed surfaces (Wood 2000). Similar contour plots were constructed using NMS ordination scores based on the cumulative hours that Gulf sturgeon accrued at each site (Huff et al. 2011).

In the GLM, MRPP, and NMS analyses, the total number of days that an individual Gulf sturgeon accrued at each receiver was weighted according to the length of time each receiver was deployed, with receivers deployed for the longest periods of time having the greatest influence on the model.

Results

Collections and Monitoring

Gulf sturgeon were collected from October 5–8, 2009 with mean water temperature of 23.8°C. A total of 19 juvenile and 21 adult Gulf sturgeon were collected, ranging from 89–194 cm FL (mean = 135 cm, SE = 4.1) and 4–61 kg (mean = 21 kg, SE = 2.1). Details of collection activities are provided in Chapter 1. Gulf sturgeon telemetered in 2008 that were later documented in Choctawhatchee Bay during my study ranged from 138–191 cm FL (mean = 164, SE = 4.3) and 23–54 kg (mean = 37 kg, SE = 2.8) in weight at the time of capture.

The majority (n = 22) of acoustic receivers were deployed between October 6–October 10, 2009 concurrent with specimen collection. Additional acoustic receivers were deployed on October 15, 2009 (n = 1) and between December 16–19, 2009 (n = 6), as resources became available. All receivers were removed from the system in early June, several weeks after returning Gulf sturgeon had migrated into the Choctawhatchee River, except for one receiver that was not downloaded after April 19, 2010 (Figure 2-1).

A total of 54 telemetered Gulf sturgeon were documented on this array during the 2009–2010 overwinter period: 38 individuals in 2009 and 16 in 2008. Of the 54 individuals, 15 remained within the estuary (mean = 122 cm FL) and were smaller than the 35 Gulf sturgeon documented moving into the Gulf of Mexico (mean = 152 cm FL) as described in Chapter 1. I was not able to determine the location of four Gulf sturgeon that were presumed to have exited the bay but were not detected in the Gulf of Mexico. It is possible that these four individuals departed the bay via Santa Rosa Sound or the Gulf Intracoastal Waterway. Two individuals classified as marine residents were not included in subsequent analysis because they did not accrue at least six cumulative hours on at least one receiver within the array.

Habitat Use

Mean cumulative hours within the passive array was greater for the Gulf sturgeon classified as estuarine-dependent (mean = 263 cumulative hours, SE = 29.5) compared to the marine residents (mean = 83 cumulative hours, SE = 23.5). Habitat use appears to vary geographically according to the two groups, with estuarine-dependent individuals accruing the most time along the north central embayments in the middle and eastern portions of Choctawhatchee Bay, and the marine residents distributed more widely throughout the bay and accruing the most time in a large southern bayou (Figure 2-3).

Eight candidate predictor variables were included in the GLMs: log(abundance-documented prey), H'-documented prey, log(Amphipoda), log(Aciculata-documented prey, log(Veneroida), log(Canalipalpata), log(Scolecida), and resident group. A total of 164 GLMs were generated to identify indicators of Gulf sturgeon habitat use in Choctawhatchee Bay. Three of the 164 model outputs had markedly lower qAIC scores than the remaining 161. Output from the first model was determined to be most representative as it had both the lowest qAIC score, the greatest Akaike weight, and included information about two potential prey items (i.e. Amphipoda and Scolecida) (Table 2-3).

The presence of the order Amphipoda and resident grouping, led to substantial reductions in model deviance (Table 2-4). The marginal model plots suggest a relationship wherein Gulf sturgeon habitat use increases with amphipod abundance (Figure 2-4). Gulf sturgeon habitat use decreased in areas of high abundance of Scolecida. Gulf sturgeon habitat use initially increased then decreased with increasing species diversity (Figure 2-4), but this parameter had the least impact on the model (Table 2-4).

The MRPP indicated that the averaged habitat values of five taxa utilized in the GLM varied significantly among the estuarine (n = 15) and marine (n = 31) ($P < 0.001$, $A = 0.07$) residents, however the A value was very low, suggesting that observed differences may not be biologically significant (McCune and Grace 2002). Given the small sample size (n = 46), I chose not to attempt to assess Gulf sturgeon habitat use according to residency grouping.

The GLM results indicated that abundance of Abundance of Amphipoda was chosen for NMS analysis because the GLM indicated it had the strongest positive relationship with Gulf sturgeon habitat use documented in Choctawhatchee Bay. Gulf sturgeon habitat use throughout Choctawhatchee Bay was also plotted. Stress for the final two-dimensional solution was 3.5 according to model selection criteria described in Huff et al. 2011. When comparing the NMS ordination plots, it appears that individual Gulf sturgeon which spent the most time in Choctawhatchee Bay did so in areas of greatest amphipod abundance, corroborating the GLM results (Figure 2-6).

Discussion

My findings suggest that the abundance of amphipods serves as a strong predictor of Gulf sturgeon habitat use in Choctawhatchee Bay. Previous benthic sampling efforts in the Choctawhatchee Bay have indicated that high abundance of amphipods occur within the system and have been hypothesized to be an important prey resource for juvenile Gulf sturgeon (Heard et al. 2002). Similarly, amphipods have consistently been found in the gut contents of juvenile Gulf sturgeon captured in the mouth of the Suwannee River Estuary (Huff 1975, Mason and Clugston 1993), leading to their designation as an important prey item for juveniles (Brooks and Sulak 2005). Amphipods have also been identified as important prey for juvenile Atlantic sturgeon in the Hudson River Estuary (Haley 1998).

While amphipods are known as an important prey resource for juvenile Gulf sturgeon (Heard et al. 2002), anecdotal evidence has included ghost shrimp as important prey item for adult Gulf sturgeon in Choctawhatchee Bay (Fox et al. 2002); Gut content analysis of a Gulf sturgeon that died in sampling in the Choctawhatchee identified estuarine ghost shrimp as the most dominant invertebrate, along with smaller number of commensal forceps shrimp and over 100 amphipods (Fox et al. 2000, Heard et al. 2002). Although the GLM and NMS analysis presented a strong relationship between amphipods and Gulf sturgeon habitat use, these findings do not discount previous hypotheses that ghost shrimp are important prey for Gulf sturgeon. Because ghost shrimp are not easily captured using benthic sampling grabs due to the shrimp's burrowing nature (Posey 1986) it is possible they were not captured in the petite PONAR grab used in this study. Generally the habitat of both amphipods and ghost shrimp is characterized by sandy substrates in mesohaline environments of northern Gulf of Mexico (Heard et al. 2002). In this study, amphipods were distributed in sandy shelf habitat where estuarine ghost shrimp have previously been documented in high densities (Heard et al. 2002, McLelland and Heard 2011). The co-occurrence of amphipods and ghost shrimp may account for the strong signal of this predictor for Gulf sturgeon habitat use in Choctawhatchee Bay as evidenced by the results of the GLM.

It appears that Gulf sturgeon avoid areas where polychaetes of the order Scolecida occur in high abundances. While Scolecida are a known prey item of Gulf sturgeon (Mason and Clugston 1993), polychaetes have not historically been considered particularly important prey for Gulf sturgeon according to gut content analysis or through inferences drawn from manual tracking efforts in estuarine environments (Huff et at.

1975, Mason and Clugston 1993, Fox et al. 2002, Harris et al. 2005). However, polychaetes were the dominant prey item consumed by Atlantic sturgeon captured in the Long Island Sound and Connecticut River (Savoy 2007), the Minas Basin, Nova Scotia (McLean et al. 2013), and juvenile common sturgeon *A. sturgio* (range = 63–116 cm FL) in the Gironde Estuary, France (Brosse et al. 2000). While it is unknown what prey items were available in the first two studies, the Gironde Estuary was found to be largely dominated by polychaetes (Scolecida and Canalipalpata) and it was hypothesized that the common sturgeon may have been foraging on polychaetes simply due to their predominance (Brosse et al. 2000). As such, while Gulf sturgeon are known to consume Scolecida, they may be avoiding areas with high densities of Scolecida in Choctawhatchee Bay because alternative prey exists in areas that may provide more optimal environmental conditions, such as sediment type, salinity, and dissolved oxygen.

Polychaetes are often utilized as indicators for ecological health given their abundance, high reproductive rates that allow for rapid response to environmental changes, and sessile nature ensuring continued exposure to environmental conditions (Dean 2008). One of the most dominant species of Scolecida documented in the bay was an opportunistic, infaunal sub-surface deposit feeding polychaete *Mediomastus ambiseta,* often found in fine silt substrates (McLelland and Heard 2011), low dissolved oxygen (Dauer 1993, McLelland and Heard 2011) and mesohaline environments (Billheimer et al. 1997). High densities of Scolecida may be an indicator for undesirable Gulf sturgeon habitat due to the presence of silt sediments and/or hypoxic conditions. Hypoxia has been attributed to the reduction in habitat that has contributed to the overall decline and lack of recovery of Atlantic sturgeon in Chesapeake Bay (Secor and Gunderson 1998).

While it is unsurprising that marine residents utilize the bay habitats less than the estuarine residents, this result supports the validity of the selected GLM and provides further support that an ontogenetic habitat shift occurs in Gulf sturgeon, as larger individuals utilize the Gulf of Mexico, presumably to access higher quality prey available in marine environments (Sulak and Randall 2002). Gulf sturgeon habitats utilized within the bay by marine residents may simply be areas found along migration corridors, or individuals may be staging before returning to the river for the summer. Staging behavior at river mouths, in which Gulf sturgeon aggregate presumably for osmoregulation, has been documented prior to spring migrations to natal rivers in the Apalachicola (Wooley and Crateau 1985) and Suwannee River Estuary (Sulak and Clugston 1999, Harris et al. 2005). Marine resident Gulf sturgeon may be occupying southern shoreline as a mechanism for osmoregulation, although Gulf sturgeon have been known to transition rapidly from estuarine to riverine habitats in this system (Fox et al. 2002). Alternatively, Gulf sturgeon may simply be feeding along migratory pathways while waiting for environmental cues such as water temperature (Sulak and Clugston 1999). When fish migrate, they use a number of mechanisms to create spatial maps, allowing them to reach seaward destinations as well as return to natal rivers (e.g. physical landmarks, olfactory cues, and external compasses like the sun; see Braithwaite and de Perera 2006 for a review). Perhaps Gulf sturgeon that overwinter in the Gulf of Mexico utilize habitats in Choctawhatchee Bay in ways that allow them to migrate between the Gulf and the river.

In addition to invertebrate distribution, sediments, water quality, other factors may influence relationships with prey that were not captured in my study, such as competition or predator avoidance behaviors. A number of demersal feeders hypothesized to compete with Atlantic sturgeon feeding in estuaries (Greene 2009) have been documented in Choctawhatchee Bay (Livingston 1986). While little to no information exists regarding predation on Gulf sturgeon in overwinter habitats, a number of Atlantic sturgeon predators have been documented or reported, included sea lampreys *Petromyzon marinus* , long nose gar *Lepisosteus osseus,* birds, seals, and sharks (see Greene 2009 for a review). Large sharks have been found in habitats utilized by Gulf sturgeon (D. Fox, Delaware State University, personal communication). The presence of predators and competitors could potentially influence Gulf sturgeon habitat use, although the potential for predation and competition is thought to be lowest during the winter months when Gulf sturgeon inhabit estuarine environments (Sulak and Randall 2002).

Through the combination of an extensive passive acoustic array, benthic sampling efforts, and utilization of a recently developed modeling technique (Huff et al. 2011), I have improved our understanding of Gulf sturgeon behavior as it relates benthic invertebrates in Choctawhatchee Bay, Florida. This work corroborates previous research in Choctawhatchee Bay that characterized habitats where Gulf sturgeon were documented through manual tracking efforts (Fox et al. 2002) and refines it by improving our understanding of the factors that mediate habitat use. As a next step, gastric lavage studies that identify actual prey consumed by Gulf sturgeon found in the Choctawhatchee Bay would strengthen the link between the indicators of habitat use documented in my study and foraging. Overall, my work provides managers with information that allows them to anticipate how changes to habitat quality and availability may influence Gulf sturgeon behavior and ultimately their recovery. Further, my findings may serve as a model for Gulf sturgeon habitat use in the estuarine systems found in the middle portion of their range (i.e. Mobile, Escambia, and Apalachicola Bays) as these systems share a constrained geography that may give rise to similar habitat conditions.

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Table 2-1. List of documented Gulf sturgeon prey according to gut contents analysis of Gulf sturgeon or the closely related Atlantic sturgeon. Invertebrates identified as likely prey based on data collected in Choctawhatchee Bay are included. Letters correspond to sources. A = Huff 1975, B = Mason and Clugston 1993, C = Carr et al. 1996, D = Fox et al. 2000, E = Murie and Parkyn 2001, cited by Harris et al. 2005, F = Heard et al. 2002, G = McLelland Personal Communication, H = Vladykov and Greeley 1963, I = Moser and Ross 1995, J = Johnson et al. 1997, K = Haley 1998, L = Secor et al. 2000, M = Savoy 2007

Phylum	Class	Order	Family	*A.o. desotoi*							*A o. oxyrinchus*					
				A	B	C	D	E	F	G	H	I	J	K	L	M
Annelida	Oligochaeta	Tubificida	Tubificidae		X						X					
	Polychaeta	Aciculata	Glyceridae										X			
			Lumbrineridae										X			
			Nereididae		X						X					
			Oenonidae										X			
			Onuphidae										X			
			Phyllodocidae										X			
			Pilargidae							X						
			Sigalionidae										X			
		Canalipalpata	Ampharetidae										X			
			Cirratulidae										X			
			Oweniidae							X						
			Sabellidae		X											
			Spionidae										X	X		X
			Flabelligeridae										X			X
		Eunicida	Lumbrineridae										X			
		Sclocida*	Arenicolidae		X				X							
			Capitellidae		X								X			
			Maldanidae										X			X
			Opheliidae							X						
			Orbiniidae		X											
			Paraonidae							X						
Arthropoda	Insecta	Coleoptera	Opalinidae										X			
		Diptera	Ceratopogonidae		X											
			Chironomidae	X	X											
		Ephemeridae	Ephemeridae								X					

(Table 2-1 Cont.)

Phylum	Class	Order	Family	*A.o. desotoi*							*A o. oxyrinchus*					
				A	B	C	D	E	F	G	H	I	J	K	L	M
		Ephemeroptera	Baetidae		X											
	Malacostraca	Amphipoda	Ampeliscidae		X								X			X
			Corophiidae		X								X			X
			Gammaridae		X											X
			Haustoriidae	X	X				X							
			Ischyroceridae		X											
			Liljeborgiidae							X						
			Oedicerotidae											X		
			Phoxocephalidae		X											
		Cumacea	Bodotriidae							X						
			Diastylidae		X											
		Decapoda	Alphidae				X									
			Callianassidae	X	X	X	X	X	X							X
			Crangonidae								X		X			X
			Palaemonidae		X											
			Pinnotheridae													X
			Portunidae	X			X									
			Squillidae													X
			Upogebiidae													X
			Xanthidae		X											
		Isopoda	Anthuridae	X	X			X				X			X	
			Cirolanidae										X			
		Mysidacea	Mysidae		X											X
		Stomatopoda	Nannosquillidae										X			
Bacillariophyta	Bacillariophyceae	Naviculales	Pleurosigmataceae		X											
Brachiopoda	Inarticulata	Lingulida	Lingulidae		X	X			X							
Chordata	Actinopterygii	Perciformes	Ammodytidae								X					
		Anguilliformes	Moringuidae	X												
	Leptocardii	Amphioxi	Branchiostomidae		X	X		X	X							
Chromista	Bacillariophyceae	Cymbellales	Gomphonemataceae		X											
Echinodermata	Echinoidea	Clypeasteroida	Mellitidae		X											
	Holothuroidea	Molpadiida	Caudinidae									X				

(Table 2-1 Cont.)

Phylum	Class	Order	Family	*A.o. desotoi*							*A o. oxyrinchus*					
				A	B	C	D	E	F	G	H	I	J	K	L	M
	Ophiuroidea	Ophiurida	Amphiuridae					X								
			Ophiactidae					X								
Hemichordata	Enteropneusta		Ptychoderidae						X							
Mollusca	Bivalvia	Veneroida	Cardiidae		X											
			Corbiculidae		X											
			Mactridae							X						
			Mesodesmatidae							X						
			Pharidae							X						
			Solecurtidae						X							
			Sphaeriidae								X					
			Tellinidae		X								X			
			Veneridae										X			
	Gastropoda	Basommatophora	Physidae		X											
		Cephalaspidea	Scaphandridae							X						
		Neogastropoda	Muricidae										X			
			Nassariidae							X						
			Hydrobiidae							X						

Table 2-2. List of invertebrates present at Gulf sturgeon relocations sites (October 10, 2009–April 25, 2010) and random habitat stations in Choctawhatchee Bay (May 7–19, 2010).DP = Documented Prey (designated by gut contents analysis), HS = Habitat stations, GS = Gulf sturgeon sampling sites. *Denotes a sub-class of polychaetes once belonging to a taxonomic order that no longer exists.

Phylum	Class	Order	Family	DP	HS	GS
Annelida	Oligochaeta	Tubificida	Tubificidae	X	X	X
	Polychaeta	Aciculata	Amphinomidae		X	
			Glyceridae	X	X	X
			Goniadidae	X	X	X
			Hessionidae	X	X	X
			Nereididae	X	X	X
			Onuphidae	X	X	X
			Phyllodocidae	X	X	X
			Pilargidae	X	X	X
			Sigalionidae	X	X	
			Syllidae		X	X
		Canalipalpata	Ampharetidae	X	X	X
			Chaetopteridae		X	X
			Cirratulidae	X	X	X
			Oweniidae	X	X	X
			Pectinariidae		X	X
			Sabellidae	X	X	X
			Spionidae	X	X	X
			Terebellidae		X	X
		Scolecida*	Capitellidae	X	X	X
			Cossuridae		X	X
			Maldanidae	X		X
			Opheliidae	X	X	X
			Paraonidae	X	X	X
Arthropoda	Insecta	Diptera	Chironomidae	X	X	
	Malacostraca	Amphipoda	Ampeliscidae	X	X	X
			Ampithoidae		X	X
			Aoridae		X	X
			Corophiidae	X	X	
			Gammaridae	X	X	
			Haustoriidae	X	X	X
			Hyalellidae		X	
			Ischyroceridae		X	
			Liljeborgiidae	X		X
			Oedicerotidae	X	X	X
		Cumacea	Bodotriidae	X	X	X
			Diastylidae	X	X	X
			Nannastacidae		X	
		Decapoda	Hippolytidae		X	X
			Nannastacidae		X	
			Paguridae		X	
			Panopeidae	X	X	
			Pasiphaeidae			X
			Penaeidae		X	X
			Pinnotheridae	X		X
			Portunidae	X		X
		Isopoda	Anthuridae	X	X	X

(Table 2-2. Cont.)

Phylum	Class	Order	Family	DP	HS	GS
			Hyssuridae		X	X
			Idoteidae		X	X
			Munnidae			X
			Sphaeromatidae		X	
		Mysidacea	Mysidae	X	X	X
		Ostracoda			X	X
		Tanaidacea	Kalliapseudidae		X	X
			Paratanaidae		X	
	Maxilllopoda	Sessilia	Balanidae		X	X
Brachiopoda	Inarticulata	Lingulida	Lingulidae	X		X
Bryozoa	Gymnolaemata	Cheilostomata	Bugulidae		X	
			Membraniporidae		X	X
			Walkeriidae		X	
		Ctenostomata	Vesiculariidae			X
Chordata	Leptocardii	Amphioxi	Branchiostomidae	X	X	X
Cnidaria	Anthozoa	Actiniaria	Edwardsiidae		X	
	Hydrozoa	Hydroida	Campanulariidae		X	
			Lovenellidae		X	X
Echinodermata	Echinoidea	Clypeasteroida	Mellitidae	X		X
	Ophiuroidea	Ophiurida	Amphiuridae	X	X	
			Ophiactidae	X	X	X
Mollusca	Bivalvia	Arcoida	Arcidae			X
		Mytiloida	Mytilidae		X	X
		Nuculoida	Nuculanidae		X	X
		Pholadomyoida	Lyonsiidae		X	
		Veneroida	Lucinidae		X	X
			Mactridae	X	X	X
			Mesodesmatidae	X	X	X
			Montacutidae		X	X
			Semelidae		X	X
			Solenidae	X	X	X
			Tellinidae	X	X	X
			Veneridae	X	X	X
	Gastropoda	Cephalaspidea	Bullidae		X	X
		Cephalaspidea	Scaphandridae	X	X	X
		Heterostropha	Pyramidellidae			X
		Mesogastropoda	Calyptraeidae		X	
			Cerithiidae		X	X
			Epitoniidae			X
			Naticidae			X
			Vitrinellidae		X	X
		Neogastropoda	Columbellidae			X
			Nassariidae	X	X	X
		Neotaenioglossa	Aclididae		X	
			Caecidae		X	X
			Hydrobiidae	X	X	X
Phoronida		Pyramidelloida	Phoronidae		X	X
Porifera	Demospongiae	Hadromerida	Clionaidae		X	
Sipuncula	Sipunculida	Golfingiaformes	Phascolionidae		X	X

Table 2-3. Top 5 ranked Generalized Linear Models (GLM) comparing habitat parameters to hours accrued for telemetered Gulf sturgeon within the passive acoustic array deployed in Choctawhatchee Bay, Florida in October 2009– May 2010, with qAIC, Delta, Weight, and R^2. * Denotes final GLM chosen.

qAIC	Delta	Weight	R^2	Model Terms
50.38	0	0.084	0.43	*H'-documented prey + log(Amphipoda) + log(Scolecida) + resident group
50.46	0.07	0.081	0.47	H'-documented prey + log(Amphipoda)+ log(abundance-documented prey) + resident group
50.48	0.10	0.0794	0.40	Log(Amphipoda) + log(Abundance-documented prey) + resident group
51.68	1.30	0.044	0.38	log(Amphipoda) + log(Scolecida) + resident group
52.01	1.63	0.037	0.48	H'-documented prey + log(Abundance-documented prey) + log(Aciculata-documented prey) + resident group

Table 2-4. Analysis of deviance for telemetered Gulf sturgeon (n = 48) habitat use in Choctawhatchee Bay, Florida during October 2009–May 2010. Includes parameters described in selected model, deviance, residual df, residual deviance, F, and Pf(>F).

Model	Deviance	Residual df	Residual deviance	F	Pr(>F)
Null		47	7337.8		
H'-documented prey	98.10	46	7239.7	1.0316	0.3156
log(Amphipoda)	1931.57	45	5308.2	20.3123	*$P < 0.001$
log(Scolecida)	249.25	44	5058.9	2.6211	0.1129
Resident group	1564.46	42	3494.5	8.2259	*$P < 0.001$

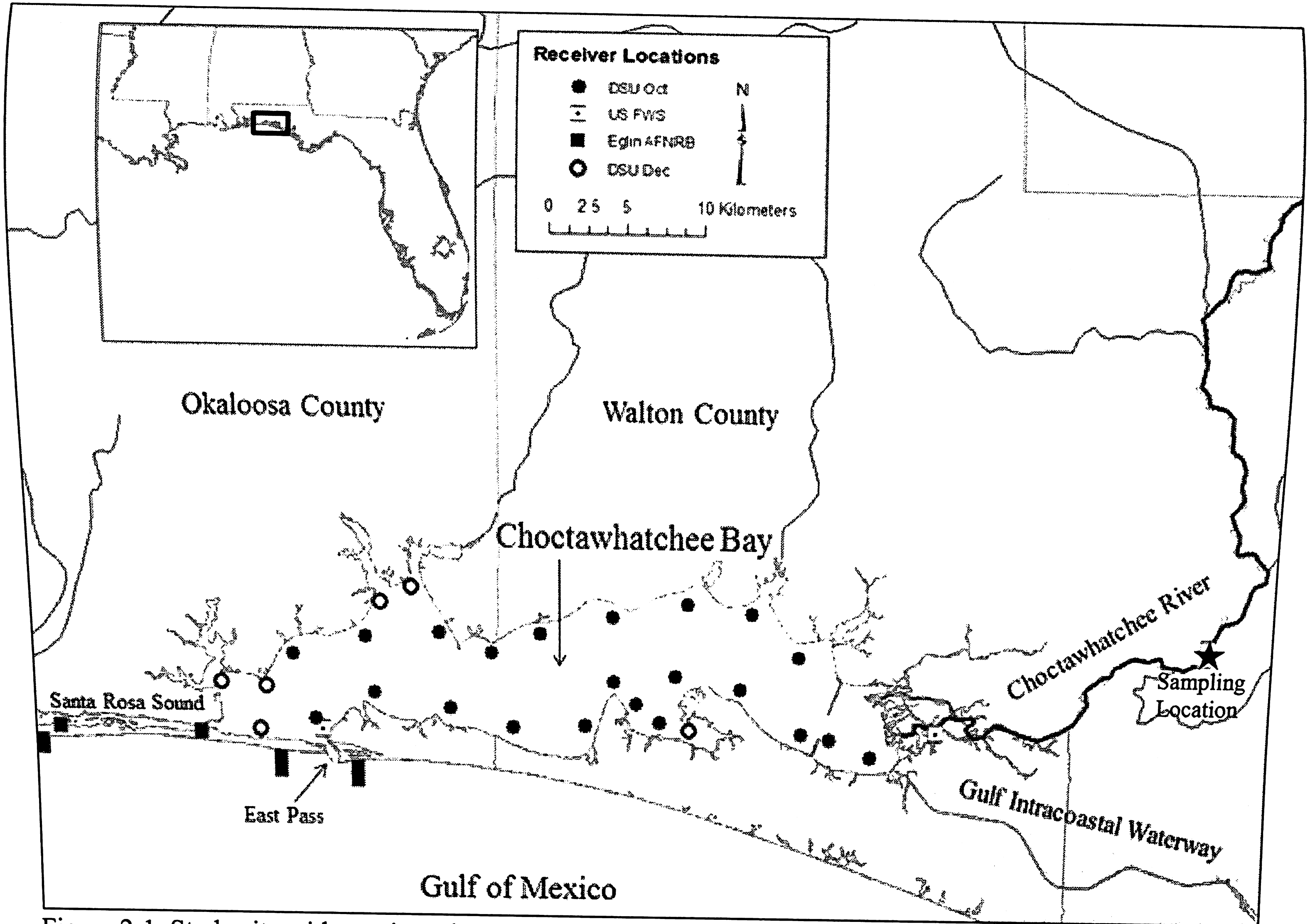

Figure 2-1. Study site with passive telemetry array for assessment of Gulf sturgeon habitat utilization and residency in Choctawhatchee Bay, Florida (October 2009–May 2010). Closed circles were deployed in October 2009, while open circles were deployed in December 2009. * identifies the receiver that was not downloaded after April 19, 2010.

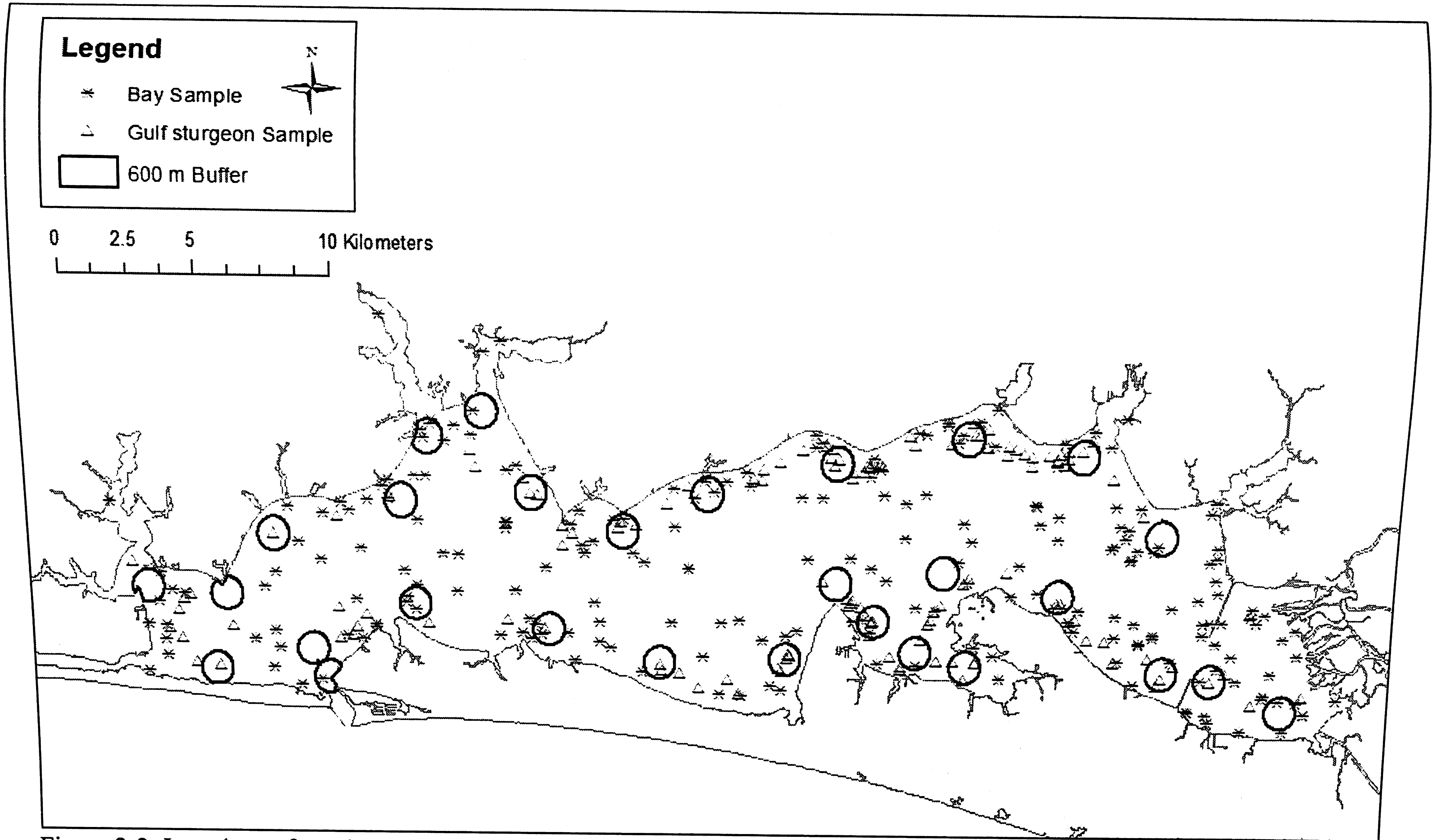

Figure 2-2. Locations of passive receivers with 600 m buffers and benthic sampling sites in Choctawhatchee Bay, Florida (October 2009–May 2010). Bay samples refer to benthic samples taken at random sampling locations, and Gulf sturgeon samples refer to benthic samples taken at Gulf sturgeon relocation sites identified through manual telemetry.

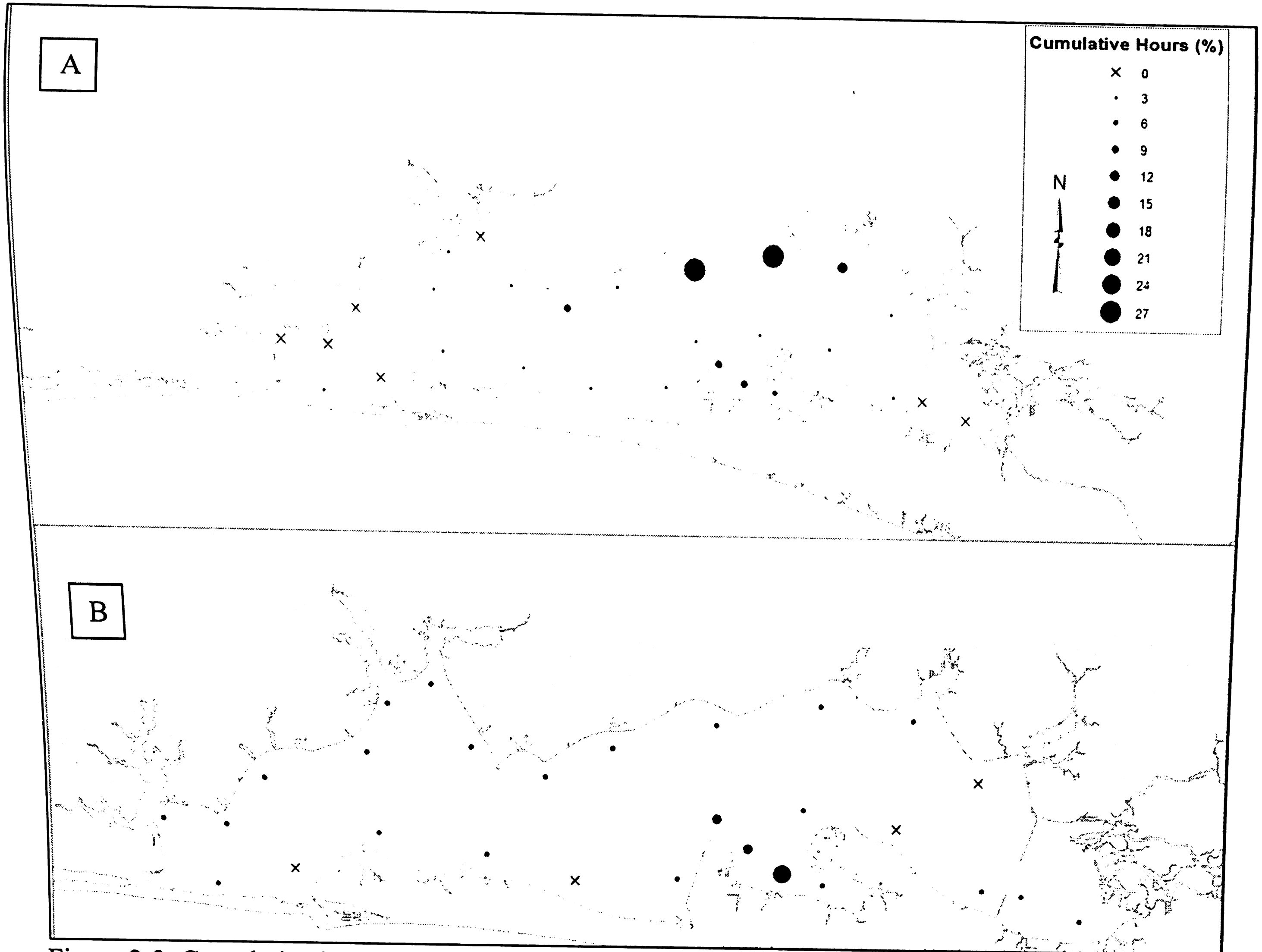

Figure 2-3. Cumulative hours (%) that Gulf sturgeon accrued at receivers deployed in Choctawhatchee Bay Florida (October 2009 – May 2010). Panel A depicts hours accrued by estuarine-dependent individuals (n=15) and Panel B depicts hours accrued by marine residents (n=31).

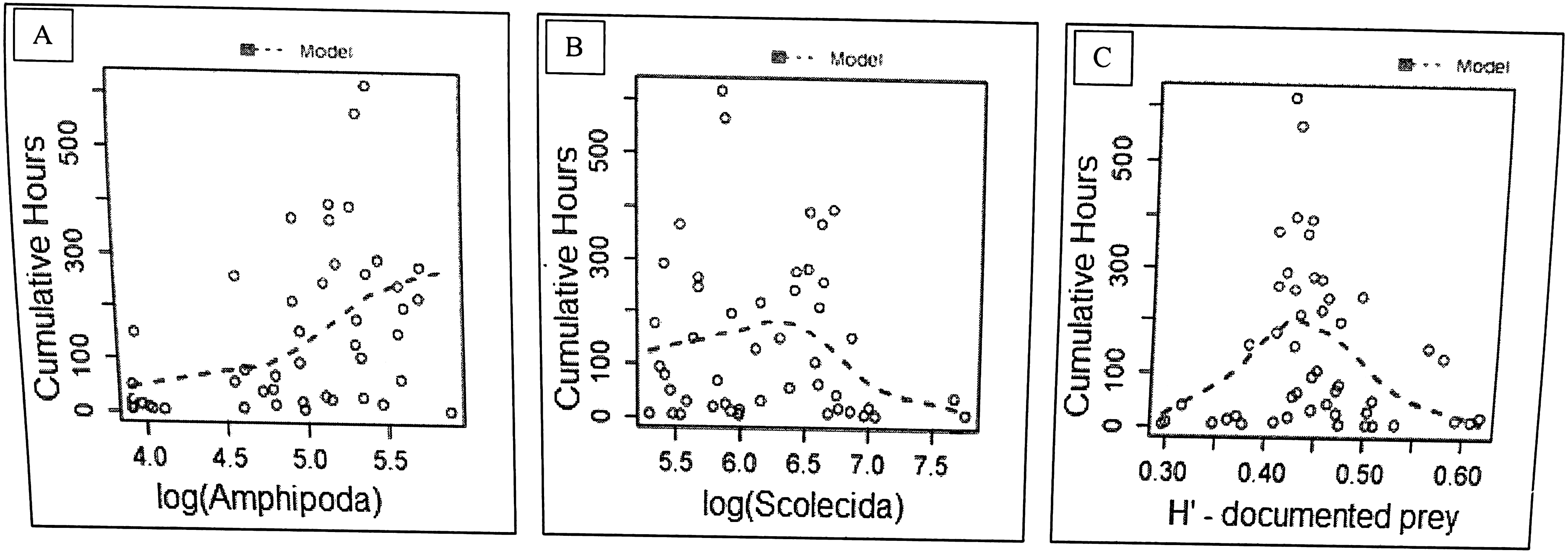

Figure 2-4. Marginal model plots for Gulf sturgeon detection data captured during October 2009 – May 2010 showing the response variable (total hours accrued on the passive acoustic array) on the vertical axis and the horizontal axes denote numeric predictor values (plotted points) in the final GLM model. Panel A depicts cumulative hours predicted according to abundance of log(Amphipoda), Panel B depicts cumulative hours predicted according to abundance of log(Scolecida), and Panel C depicts cumulative hours predicted according to species diversity (Shannon-Weiner diversity index).

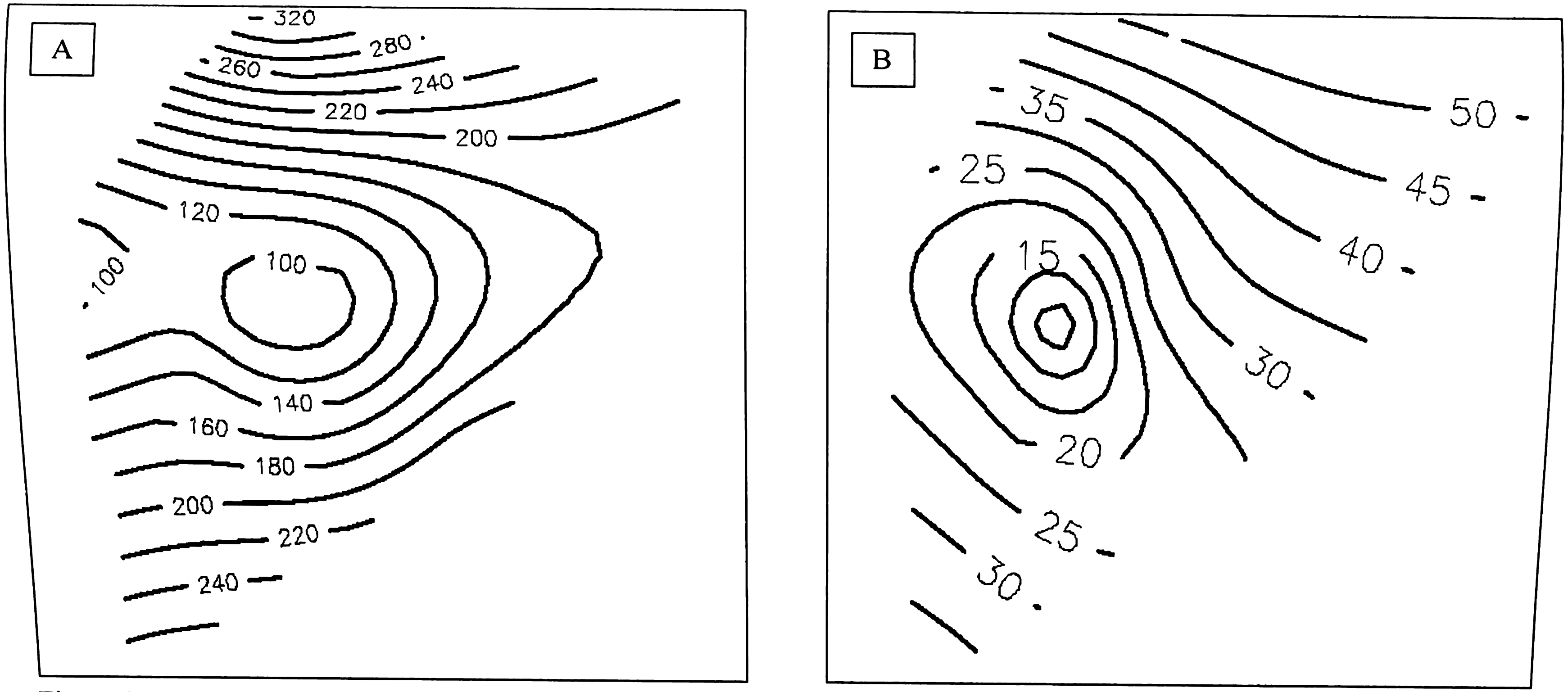

Figure 2-5. Non-metric multidimensional scaling (NMS) ordination plots depicting the responses of Gulf sturgeon habitat use to abundance of amphipods and total detection hours. Panel A depicts the amount of time spent in areas of varying levels of amphipod abundance, and Panel B depicts the areas where habitat use hours were accrued. Isolines represent the predicted smooth trends by general additive model (GAM) between variables and plot scores.

Curriculum Vitae

Katherine M. Fleming

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EDUCATION

Master of Science in Natural Resources, Sep. 2009 – May 2013 | 4.0 GPA
Delaware State University, Dover, Delaware, USA.

- Field work conducted at NOAA-NMFS Panama City Laboratory, Florida

Master of Conservation Biology, Jul. 2008 – Jun. 2009 | 3.8 GPA
University of New South Wales and Victoria University of Wellington (joint program)
Sydney, Australia and Wellington, New Zealand

Bachelor of Arts, International Affairs, Sep. 2000 - May 2004 | 3.7 GPA
George Washington University, Washington, D.C., USA

Continuing Education:

- Facilitation Skills for Planning Meetings (2012 State of Delaware Statewide Training and Development)
- Statistical Concepts and Tools for Fisheries Biologists (2011 American Fisheries Society)
- Telemetry Techniques (2011 World Sturgeon Conservation Society North American Chapter)
- Sturgeon Osmoregulation (2011 World Sturgeon Conservation Society, North American Chapter)
- Mapping Habitat of Aquatic Systems using Low-Cost Side Scan Sonar (2010 American Fisheries Society)
- Writing for Public Relations and Marketing (2006 United States Department of Agriculture Graduate School)
- Introduction to Environmental and Occupational Health, (2005 George Washington University, Graduate School of Public Health and Health Services)

PROFESSIONAL EXPERIENCE

NOAA Coastal Management Fellow, DNREC, Delaware Coastal Programs, Dover DE
Sep. 2012 – Present
Tridec Technologies

- Developing a marine spatial plan for Delaware's estuarine and marine waters.
- Managed implementation of public participatory mapping workshop to collect recreational use information for marine spatial planning efforts. Collaborated with state and federal partners to ensure regional consistency, compiled and processed ArcView GIS data layers utilized as base information for workshop participants, developed Delaware coast recreational use stakeholder list, communicated workshop goals to stakeholders.

- Provided staff support to additional mid-Atlantic-based Recreational Use Mapping Workshops. Facilitated workgroups through recreational use mapping process, and learned participatory mapping process to implement in Delaware.
- Identifies, compiles, and processes spatial data sets to use for planning purposes.
- Provides program support to ocean planning efforts through the Mid-Atlantic Council on the Ocean.
- Conducts federal consistency reviews of fisheries-related federal activities. Coordinates with DNREC and other state agencies, identifies enforceable policies as necessary and issues federal consistency determinations to ensure project compliance.

Delaware State University, Dover DE
Graduate Research Assistant *September 2009 – August 2012*

- Assessed Gulf sturgeon habitat utilization in Choctawhatchee Bay, FL using passive and active telemetry techniques. Surgically implanted acoustic transmitters into Gulf sturgeon, deployed and maintained a large scale passive acoustic array, manually relocated telemetered individuals, and collected benthic samples at relocation sites for habitat characterization.
- Managed acoustic telemetry array and facilitated data sharing across Gulf of Mexico. Created and managed relational databases of over 2.5 million records using Microsoft Access; statistically analyzed residency patterns using SAS JMP9, R 2.13.0, ArcGIS ArcView 10, Microsoft Excel; Employed model selection techniques to identify benthic invertebrates as indicators for Gulf sturgeon habitat use.
- Assisted ongoing telemetry projects on sand tigers, American eels, and Atlantic and shortnose sturgeons in Delaware River Estuary, DE and Hudson River Estuary, NY. Captured and processed American eels and sand tigers in nearshore coastal habitats and maintained passive acoustic receivers deployed in high energy conditions.
- Assisted NOAA-NMFS Panama City Laboratory with offshore reef fish survey. Deployed camera equipment for habitat characterization and traps, and processed captured reef fish.
- Assisted NOAA-NMFS Panama City Laboratory to process a variety of hard parts (vermillion snapper otoliths; gray triggerfish spines, fin rays) for age and growth analysis used in Southeast Data Assessment and Reviews.

Atlantic Coastal Cooperative Statistics Program (ACCSP), Washington, D.C.
Outreach Coordinator *September 2006 – May 2008*

- Conducted outreach activities for ACCSP, including coordinating in-person meetings, conference calls, and action items for Outreach and Fisheries Industry Committees. Collaborated with state and federal fisheries managers and industry stakeholders to reach consensuses that impacted statistics used to make management decisions.
- Coordinated and co-authored ACCSP Outreach Strategic Plan to promote program to state and federal marine fisheries partners and constituents
- Wrote monthly articles for Atlantic States Marine Fisheries Commission's *Fisheries Focus;* issued press releases
- Represented ACCSP as a scientific party member aboard 2008 NOAA Cooperative Winter Tagging Cruise.

Association of Schools of Public Health, Washington, D.C.

Project Coordinator *August 2005 – September 2006*

- Coordinated efforts of four collaborative expert groups to develop topic specific training guides. Coordinated monthly meetings, related Centers for Disease Control (CDC) -issued guidance, conducted research to contribute to final workgroup products, and managed logistics
- Staff liaison to nine member centers. Conducted informal site visits, communicated network services, addressed inquiries and suggestions for network improvements

Project Assistant, CPHP

February 2005 – August 2005

- Developed brochure describing CPHP Network activities and services, developed and maintained in-house library of educational resources, maintained rosters and workgroup database for CPHP expertise groups

Administrative Assistant

May 2004 – February 2005

- Researched and maintained database of 37 member schools' degree programs for ready access by prospective students, university faculty and other interested parties; provided administrative assistance as needed

Partnerships for Finance and Development Group, LLC, Washington, D.C.

Business Development Assistant *October 2003 – May 2004*

- Conducted research for international contractors seeking World Bank Project procurement activities
- Coordinated client visits with World Bank Program Leaders

Office of U.S. Senator Charles E. Schumer, Washington, D.C.

Congressional Intern *Fall 2001*

- Conducted research and summarized government briefings for Legislative Assistants and inquiring constituents

Lockheed Martin Systems Integration, Owego, NY

Procurement and Contract Administrator Intern *Summer 2001, Summer 2002*

- Tracked status and gave frequent briefings of ongoing department procurement/subcontracting efforts
- Analyzed complex contracts for reconciliation and obtained customer concurrence

VOLUNTEER EXPERIENCE

- DNREC Atlantic Sturgeon young-of-the-year sampling in Delaware River (2011).
- Gulf Sturgeon Tagging Workshop – assisted in efforts to teach methods for surgical implantation of acoustic transmitters to Gulf sturgeon researchers across the Gulf of Mexico region (2010).
- U.S. Army Corps of Engineers Gulf sturgeon young-of-the-year trawl survey in Apalachicola River, FL (2010).
- St. Andrew's Bay Resource Management Association Volunteer: seagrass surveys, water quality analysis (2009).

- Assisted NMFS and partners in emergency response to process >1500 thermally stunned sea turtles (2009).
- Ornithological Society of New Zealand Volunteer: passerine bird species population assessments (2008).
- Volunteer Education Docent at Washington D.C. National Aquarium (2006 – 2007).

CERTIFICATIONS, TRAININGS AND SKILLS

- Knowledge and experience using ArcGIS ArcView 10 (spatial analysis of residency, habitat characterization, land use analysis, general maps); SAS JMP 9.0; Microsoft Access, Excel, Word, PowerPoint; Adobe Acrobat
- Training from NOAA-NMFS personnel on trailering and operation of small boats
- Advanced Open Water SCUBA Certification (PADI)
- Extensive knowledge of VEMCO telemetry equipment and VUE software used for tracking fish movements

AWARDS AND MEMBERSHIPS

Awards

- Best in Section at Delaware State University's Graduate Student Symposium (2012)
- North American Chapter World Sturgeon Conservation Society Annual Meeting Student Travel Award (2011)

Memberships

- North American Sturgeon and Paddlefish Society - student member (2010 – 2013)
- American Fisheries Society – student member (2009 – 2013)
- American Fisheries Society Mid-Atlantic Chapter – student member (2011 - 2013)

PRESENTATIONS

- Fleming K.M. Participatory GIS to capture use data for ocean planning. April 2013. State of Delaware's GIS Users Group. Dover, DE.
- Fleming K.M. Mapping Recreational Use in Delaware's Atlantic Coast and Bay. January 2013. Delaware's Recreational Use Mapping Workshop. Lewes, DE.
- Fleming K.M. Why habitat matters: overwinter habitat use of Gulf sturgeon in Choctawhatchee Bay, Florida. August 2012. Master's Thesis Defense. Dover, DE.
- Fleming K.M, S.K. Bolden, D.A. Huff, D.A. Fox. August 2012. A look through time: Gulf sturgeon habitat quality and availability in Choctawhatchee Bay, Florida. American Fisheries Society 142nd Annual Meeting. St. Paul, MN.
- Fleming K.M, S.K. Bolden and D.A. Fox. November 2011. Looking back to look forward: Gulf sturgeon habitat use in Choctawhatchee Bay, FL. Annual Gulf Sturgeon Meeting. Niceville, FL.
- Fox, D.A., M.J. Oliver and K.M. Fleming. November 2011. Distribution and migratory behavior of Choctawhatchee River Gulf sturgeon in nearshore Gulf waters. Annual Gulf Sturgeon Meeting. Niceville, FL.
- Willett N.W., Fleming, K.A. and Fox D.A. November 2011. Using passive acoustic telemetry to assess fish behavior in shallow wind-driven estuarine systems. Annual Gulf Sturgeon Meeting. Niceville, FL.

- Fleming K.M, S.K. Bolden and D.A. Fox. October 2011. Changing environments, changing behaviors: Gulf sturgeon residency in Choctawhatchee Bay, FL. Mid-Atlantic American Fisheries Society Annual Meeting, Barnegat, NJ.
- Fleming K.M, S.K. Bolden and D.A. Fox. September 2011. Can humans and sturgeon co-exist? Linking Gulf sturgeon habitat utilization and human development in Choctawhatchee Bay, FL. American Fisheries Society 141st Annual Meeting, Seattle, WA.
- Fleming K.M, S.K. Bolden and D.A. Fox. July 2011. Life in a dynamic environment; Gulf sturgeon habitat use in the face of environmental change. North American Chapter of the World Sturgeon Conservation Society Annual Meeting. Nanaimo, BC.
- Fleming K.M., S.K. Bolden and D.A. Fox. April 2011. Investigating a potential roadblock to recovery: Human development and habitat utilization of Gulf sturgeon overwintering in Choctawhatchee Bay, FL. Association of Research Directors (Inc.) 16th Biennial Research Symposium. Atlanta, GA.
- Fleming K.M. and D.A. Fox April 2011. Understanding Gulf sturgeon habitat selection and residency patterns in Choctawhatchee Bay. 4th Annual Mattie Kelly Environmental Symposium on the Choctawhatchee Basin. Niceville, FL.
- Fleming K.M. and D. A. Fox. November, 2010. Recovery challenges for Gulf sturgeon in Choctawhatchee Bay, Florida: Linking habitat use and human development. Annual Gulf sturgeon meeting. Baton Rouge, LA.
- Fleming, K. M., D. A. Fox, J. M. Nunley, and F. M. Parauka. September, 2010. Who pays the price of progress: Gulf sturgeon habitat utilization and residency in Choctawhatchee Bay, FL? American Fisheries Society 140th Annual Meeting. Pittsburgh, PA.
- Fleming, K. M., D. A. Fox and F.M. Parauka. April, 2010. Understanding the impact of over-winter habitat degradation on Gulf sturgeon habitat use and patterns of residency in Choctawhatchee Bay. 3rd Annual Mattie Kelly Environmental Symposium on the Choctawhatchee Basin. Niceville, FL.
- Fleming, K. M., D. A. Fox and F.M. Parauka. February, 2010. Who pays the price of progress: Gulf sturgeon residency and habitat use in Choctawhatchee Bay, FL? 30th Annual Meeting of the Florida Chapter of the American Fisheries Society. Altoona, FL. (Poster)
- Fleming, K. M. and D. A. Fox. November, 2009. Linking landscape-level changes to Gulf sturgeon estuarine habitat use in Choctawhatchee Bay, Florida. NOAA-USFWS Gulf Sturgeon Working Group Annual Meeting. Cedar Key, FL. (Poster)