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Estuarine and Nearshore Marine Habitat Use by Gulf Sturgeon from the Choctawhatchee River System, Florida

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Abstract.—Although most species of anadromous sturgeons worldwide are threatened with extinction, information on the estuarine and marine components of their life history is generally lacking. During March 1997 to July 1999, we used ultrasonic telemetry to examine estuarine and marine habitat use of adult Gulf sturgeon *Acipenser oxyrinchus desotoi* from the Choctawhatchee Bay/River System, Florida. During winter and spring, telemetered Gulf sturgeon were distributed nonrandomly within Choctawhatchee Bay, with most relocations in nearshore areas 2–4 m deep. Within the bay, Gulf sturgeon occasionally moved long distances but usually remained in localized areas (<1 km^2) for several weeks. Areas where Gulf sturgeon remained for prolonged periods were characterized by sandy substrate harboring a benthic community dominated by crustaceans and annelids. Most male Gulf sturgeon remained exclusively in Choctawhatchee Bay during the winter and spring. In contrast, most females during this time were either relocated in the Gulf of Mexico or were absent at sampling locations, having last been detected at bay entrances. Declines in habitat quality in Choctawhatchee Bay and the Gulf of Mexico may hinder recovery of this species, since adult Gulf sturgeon rely on these areas for nourishment during periods of gonadal growth.

Introduction

Historically, Gulf sturgeon *Acipenser oxyrinchus desotoi* supported substantial commercial and limited recreational fisheries throughout much of its range, which extended from Tampa Bay, Florida west to the Mississippi River (U.S. Commission of Fish and Fisheries 1902; Burgess 1963; Lee et al. 1980). Abundance, however, has decreased substantially from historical levels due to overexploitation and habitat loss (USFWS, GSMFC, and NMFS 1995). The state of Florida prohibited harvest of Gulf sturgeon in 1984, and the species was designated as threatened by the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) in 1991.

According to the Gulf Sturgeon Recovery Plan, a critical step in the restoration process is identification of essential habitats in river basins, estuaries, and nearshore marine waters (USFWS, GSMFC, and NMFS 1995). Most studies have focused on freshwater habitat (e.g., Huff 1975; Zehfuss et al. 1999; Sulak and Clugston 1998; Foster and Clugston 1997), with few studies of estuarine and marine habitat requirements (Odenkirk 1989; Heise et al. 1999; Sulak and Clugston 1999). Much of our existing knowledge of marine and estuarine Gulf sturgeon distribution comes from

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incidental bycatch records provided by fishermen (Wooley and Crateau 1985). The recovery plan recommends the use of ultrasonic telemetry to monitor Gulf sturgeon movement patterns in estuarine and marine waters, where it is believed that most feeding and growth occurs (Mason and Clugston 1993; Clugston et al. 1995).

Previous attempts to characterize estuarine and marine habitat use have been largely unsuccessful as telemetered Gulf sturgeon have been lost after relatively short tracking periods (Odenkirk 1989; Carr et al. 1996; Sulak and Clugston 1999). This lack of tracking success was due to some of the inherent problems in marine telemetry work, such as weather related difficulties in tracking and large survey areas coupled with both financial and logistical constraints. Information collected to date suggests that Gulf sturgeon are capable of making large scale (>180 km) movements between river systems, although most adult Gulf sturgeon return to their natal river to spawn (Stabile et al. 1996). Bycatch collections (Odenkirk 1989) and limited telemetry results (Heise et al. 1999; Sulak and Clugston 1999) suggest that Gulf sturgeon inhabit the nearshore environment during periods of marine residency.

Our primary objective was to determine sex-specific information on migration and distribution of adult Gulf sturgeon in Choctawhatchee Bay, Florida and nearshore Gulf of Mexico waters. We tracked telemetered fish after their fall emigration from the Choctawhatchee River, until their subsequent return to the river. A secondary objective was to compare habitat utilized by Gulf sturgeon to that available within Choctawhatchee Bay, to ascertain if habitat selection was occurring. The Choctawhatchee River system is important because it supports a reproducing Gulf sturgeon population (Fox et al. 2000) that is genetically distinct from neighboring Gulf of Mexico river systems (Stabile et al. 1996). In addition, the Choctawhatchee River is one of the few remaining rivers in Florida without obstructions to migration and is relatively undisturbed.

Study Area

This study was conducted within Choctawhatchee Bay and nearshore Gulf of Mexico waters (Figure 1). Choctawhatchee Bay is 48 km long and averages 6 km in width. The primary freshwater input for the bay is the Choctawhatchee River, which

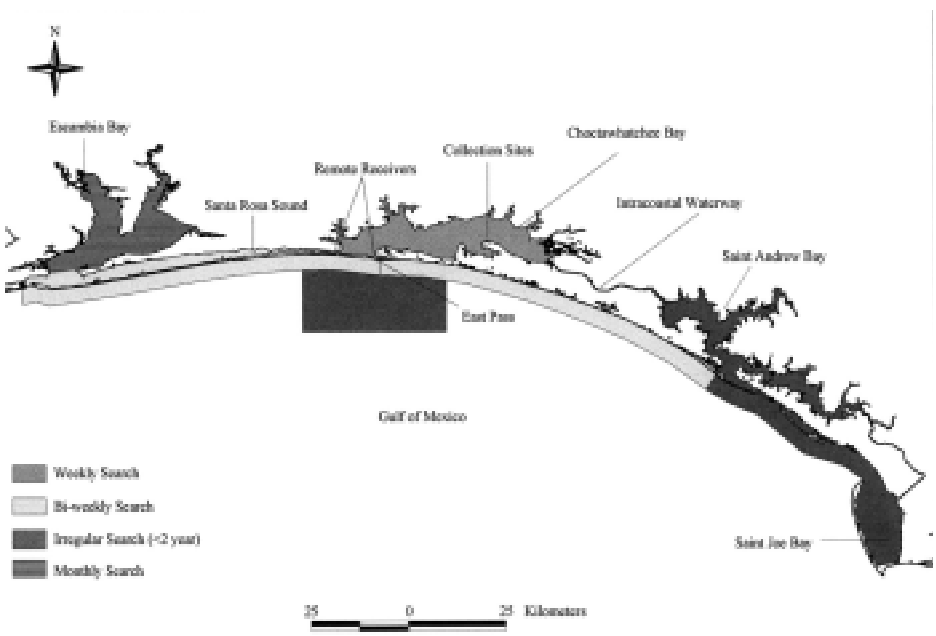


Figure 1. Locations of the study area and receivers used to detect movement of gulf sturgeon between Choctawhatchee Bay and other estuarine and marine waters. Shaded areas represent summarization of searches done within Choctawhatchee Bay and nearby waters to relocate telemetered gulf sturgeon.

is located in the eastern end of the bay, while the principal marine input is from East Pass at the opposite end of the bay. The Choctawhatchee River drains a mainly agricultural and forested watershed in excess of 12,000 km^2 (Bass et al. 1980) and is heavily loaded with silt and clay, which are deposited in the bay. Improper land use practices in the watershed have led to increased turbidity and sediment loads in the river, which are thought to be contributing factors in the decline of seagrass habitat in the bay (Livingston 1986). The benthic habitat of the bay is dominated by low relief sand and mud flats interspersed with oyster and seagrass beds. Bay sediments are composed of a wide (0.8 km) and shallow (<1.8 m) sand shoal along the edge of the bay, while the centrally located deeper portions of the bay are dominated by a fine clay sediment (Goldsmith 1966). Choctawhatchee Bay has two additional openings: the Intracoastal Waterway on its eastern edge and Santa Rosa Sound on the western border. All openings to the bay, except the Choctawhatchee River, are presently dredged by the U.S. Army Corps of Engineers for navigation.

Methods

Telemetry

In March–April 1997 and March 1998, we set gill nets (91.4–121.9 m long, 20–36 cm stretch mesh) in Choctawhatchee Bay to collect fish that were large enough to be sexually mature (fork length > 1.3 m; Huff 1975). Interviews with retired commercial sturgeon fishermen led us to sample at one historical fishing site in Choctawhatchee Bay (Figure 1). The sampling site was a large sand shoal that extended into the bay approximately 1 km. Sampling was done in early spring to maximize catch rates of fish thought to be migrating to the Chocta-whatchee River. Nets were deployed perpendicular to the shoreline along the sand shoal at depths from 2 to 5 m, when water temperatures were between 12°C and 22°C. Soak times were limited to 4 h, and nets were fished during both day and night. Details of the fish-handling procedures are in Fox et al. (2000).

In 1997, both a radio (Advanced Telemetry Systems model 5A, 40–41 mHz) and an ultrasonic (Sonotronics model CHP-87-XL, 35–40 kHz) transmitter were implanted into the abdomen of selected fish (see Fox et al. 2000 for surgical procedures), but only ultrasonic transmitters were used in 1998. The ultrasonic transmitters had a guaranteed tag life of two years and an effective range of 3 km. The radio tags were used in a companion study to monitor spawning migration while these fish were in the Choctawhatchee River (Fox et al. 2000). The uniquely-coded ultrasonic transmitter signals were detected with a portable digital receiver (Sonotronics USR-5B) and a directional hydrophone (Sonotronics DH-4). To aid in the detection of individual Gulf sturgeon movement in and out of Choctawhatchee Bay, remote monitoring sites (Sonotronics USR-90 receivers) were established at the entrances to East Pass and Santa Rosa Sound during November 1997–June 1998 (Figure 1). An additional remote monitoring site was maintained in the lower portion of the Choctawhatchee River to document timing of outmigration to the bay, during October and November in 1997–1998. These remote monitoring receivers were checked weekly for relocation information and to change batteries.

We conducted biweekly searches of Choctawhatchee Bay during the spring of 1997 and in October–December of 1997. Beginning in early January 1998, the entire bay was searched at weekly intervals until mid-June (Figure 1). Biweekly searches of the bay resumed in late September 1998, followed by weekly searches that began in late December and continued until July 1999. During all searches, we listened for telemetered fish at 1–3 km intervals along transects that were spaced depending on listening conditions. At times of poor listening conditions (e.g., increased wind or boat traffic), a spare transmitter was used to assess tag range. We did not track fish during periods when the transmitter range was 0.75 km or less. On several occasions, we also lowered a spare transmitter into the deeper portions of the bay to determine if transmitter range was adversely affected by water depth. We detected no difference in transmission range, even at the deepest parts of the bay.

In an effort to document nearshore marine movement of Gulf sturgeon, searches were done at least biweekly from mid-December 1998 through mid-July 1999, between the entrances of Saint Andrew Bay and Escambia Bay (shoreline distance = 161 km; Figure 1). Using spare transmitters during search efforts, we estimated that these nearshore searches covered a conservative area of about 4 km from the beach. Florida Department of Environmental Protection (DEP) researchers conducted biweekly searches of Escambia Bay beginning in October 1997–1998 and continuing through the winter and spring months for the duration of this project. In coordination with these researchers, Santa Rosa Sound was also searched on at least a biweekly basis during this study (Figure 1). We also performed additional searches of surrounding bays (Saint Andrew and Saint Joe) and more distant Gulf of Mexico waters, when time and weather permitted. Since we limited our marine searches to periods of low wind and calm seas, the impact of surf noise interference was kept at a minimum.

Habitat Characterization

At each site where a telemetered Gulf sturgeon was relocated, we recorded latitude and longitude using either a handheld GPS unit (prior to December 1998) or a differentially-corrected GPS unit. Depth was recorded using a digital depth sounder. Temperature, salinity, and dissolved oxygen (surface and bottom or 7.6 m, whichever was less) were measured using an YSI multimeter (model 51-B). Prior to December 1998, substrate samples were collected with a Petite PONAR sampler. Substrate type was qualitatively categorized as mud, silt, sand, or oyster beds, and the presence or absence of any potential prey items was noted. Beginning in December 1998, a standard PONAR sampler was used to collect a sediment sample at each fish relocation site. A subsample (>100 g) was removed for grain-size analysis, and the remaining portion of the sample was sieved through a 500 μm mesh screen for invertebrate prey. All material remaining in the sieve was preserved in 5% buffered formalin. The formalin was replaced with 70% ethanol after one week, and samples were stained with Rose Bengal to ease sorting and identification of invertebrates. Grain-size analysis was conducted by separating the coarse fraction (sand) from the fine fraction (silt and clay) by wet sieving through a 0.063 μm screen. The mud fraction was then separated into silt and clay fractions by mixing the sample thoroughly in a graduated cylinder and pipetting (10 cm depth) at specified intervals based on settling times (Lewis and McConchie 1994). These subsamples were then oven dried and weighed to allow for estimates of grain-size distribution at Gulf sturgeon relocation sites.

Estimates of the amount of available habitat within Choctawhatchee Bay were made using geographic information system (GIS) software (ArcView version 3.2 and Arc/Info version 8.1, Environmental Systems Research Institute, Inc.). Information on habitat parameters (grain size, invertebrate abundance [#/m^2], species richness [species per location]) collected at most relocation sites from December 1998 through July 1999 were entered into a GIS database. To supplement our information on sediment types in Choctawhatchee Bay, we combined our grain-size information with historical data from Goldsmith (1966) and Livingston (1986). Goldsmith (1966) used a systematic grid sampling approach to characterize Choctawhatchee Bay, and a subset of 135 samples spaced approximately 1.0 km apart were available for us to use. Livingston (1986) divided the bay into major habitat types and sampled a total of 49 stations throughout Choctawhatchee Bay for sediment composition, invertebrate abundance, and species composition. We combined our data on invertebrate abundance and species richness at relocation sites with results from Livingston (1986) in constructing maps of invertebrate abundance and species composition. A bathymetry map was constructed using sounding data collected by NOAA-NOS (1998). An estimate of available habitat for each parameter (e.g., grain size, invertebrate abundance, species composition, and depth) was then made from the contoured data, by querying the GIS database. To increase the number of observations of utilized habitat, we used GIS software to assign sediment grain-size composition values for relocation sites in 1997–1998, when sediment type was not quantified. These values were derived from contoured maps and were assigned on a site-specific basis.

The amount of seagrass (*Halodule wrightii* and *Ruppia maritima*) habitat available for Gulf sturgeon in Choctawhatchee Bay was estimated by the Florida Marine Research Institute, using digital data from aerial surveys (FMRI 1998). Telemetered Gulf sturgeon were considered to be residing in seagrass habitat if the relocation position intersected the seagrass coverage. Since seagrass beds were almost entirely within water less than 2 m deep, analysis of used and available seagrass habitat was limited to these shallow waters.

To examine the duration of Gulf sturgeon estuarine/marine residence, we determined the date of fish entry into the Choctawhatchee River in 1997 and 1998. This date was estimated at the first contact with fish tagged the previous year, using a combination of radio and ultrasonic telemetry searches in the lower 110 km of the Choctawhatchee River. Searches within the river were conducted at least biweekly, from early February 1997 and early March 1998 until early July in each year. During 1999, two complete searches of the lower 110 km of the river were conducted in early June and mid-July, in addition to more numerous searches of the lower 40 km of the river. The search effort was not sufficient to document migration into the Choctawhatchee River during 1999.

Data Analyses

The distribution of Gulf sturgeon relocations was compared with available habitat area for bathymetry, grain-size composition, infaunal invertebrate species richness and abundance, and seagrass coverage using an individual-based chi-square test at $\alpha = 0.05$ (White and Garrott 1990). We tested the null hypothesis that the frequency of Gulf sturgeon relocations would be equal to predicted frequencies based on the amount of available habitat estimated by our contoured data. In order to meet sample size requirements of the chi-square test, we combined both sampling seasons in our analyses of selection for depth and grain-size composition, and we also excluded fish without at least 15 relocations. We limited our tests of habitat selection for invertebrate species richness and abundance on fish with greater than 10 observations in the 1998–1999 sampling season, as this was the only season that invertebrate samples were collected. One requirement of the chi-square test is that the individual observations on an animal must be independent (White and Garrott 1990). In an attempt to reduce the dependence among successive observations, we limited the relocations used in our analyses to the first relocation per day for an individual fish. Although we collected habitat data for additional parameters (e.g., salinity, temperature, and dissolved oxygen), we were unable to characterize available habitat for these, since they can fluctuate on a short temporal scale.

Results

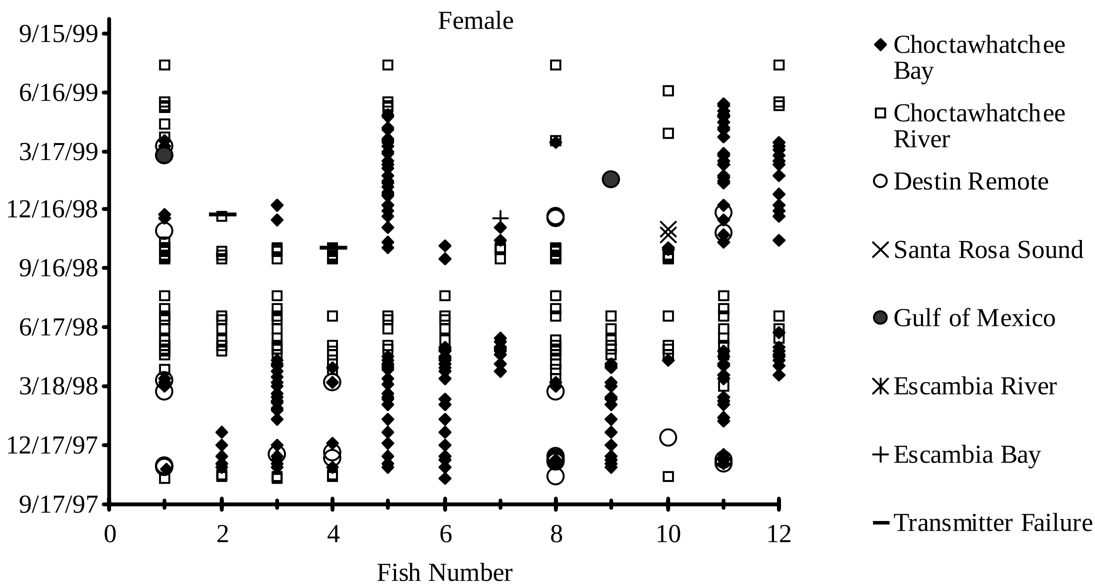
Transmitters were implanted in twenty Gulf sturgeon (7 males and 13 females) during March–April 1997. An additional two fish (one male and one female) received an ultrasonic transmitter during March 1998. Most telemetered fish dispersed throughout the bay or into the river shortly after tagging. Based on tag movement, there were no known tag expulsions or postsurgical mortalities during 1997. One male Gulf sturgeon (Fish #20; Figure 2) that received an ultrasonic transmitter in 1998 continued to move after the date of tagging (27 March) until 15 May. Relocations after this date were at a single site until the completion of the study. It seems likely that this fish either died or expelled its transmitter, and consequently, it was excluded from the analyses.

Movement Patterns

Telemetered Gulf sturgeon were located 200 times during the 1997–1998 sampling season (Figure 3). Of the 20 individuals that were tagged during the spring of 1997, 18 (90%) individuals were relocated during the following 1997–1998 sampling season. During the 1998–1999 field season, 200 relocations were made of 17 telemetered individuals. Sixteen (80%) of the original twenty Gulf sturgeon tagged during 1997 were relocated in 1998–1999. Two of the fish (Fish #'s 2 and 4; Figure 2) that we tracked during the 1997–1998 season apparently had nonworking ultrasonic transmitters during the 1998–1999 season. These fish were relocated using radio telemetry in the Choctawhatchee River during the summer of 1998, and we were able to determine that the ultrasonic transmitter had failed.

We relocated three telemetered Gulf sturgeon in the Gulf of Mexico during searches conducted west of the entrance to Choctawhatchee Bay (Figure 3). Two of the fish were relocated south of the barrier island that separates the Gulf of Mexico from Santa Rosa Sound and were 0.8–2.0 km offshore in shallow water (mean = 8.0 m) with a sand substrate (mean > 99% sand). Both fish appeared to be returning to Choctawhatchee Bay from the west and were in the bay within one week of being relocated in the Gulf of Mexico. One of these fish (Fish #15; Figure 2) had been located during summer 1998 in the Escambia River, and a second fish (Fish #1; Figure 2) was previously relocated in Choctawhatchee Bay during mid-December 1998. This second fish was relocated in the Gulf of Mexico in mid-March 1999 and returned to the bay the following week. The third fish (Fish #9; Figure 2) relocated in the Gulf of Mexico was found at the Escambia Bay entrance channel (depth = 12.7 m) in late January 1999 and was not relocated again during this study.

Based on prolonged periods of absence (i.e., more than 6 weeks of search effort) and relocations at the Choctawhatchee Bay entrance via remote receiver stations, we hypothesize that additional telemetered Gulf sturgeon migrated into the Gulf of Mexico. For example, during the 1997–1998 sampling season, 9 of the 20 fish tagged in the spring of 1997 (45%; Fish #'s 1, 4, 7, 8, 10, 11, 13, 15, and 18) appeared to have utilized gulf waters for extended periods. These fish were not relocated in weekly searches of Choctawhatchee Bay for periods of six weeks or more and, in some cases, were relocated at the remote receiver site located at the entrance of Choctawhatchee Bay. Eight of these nine fish were eventually relocated



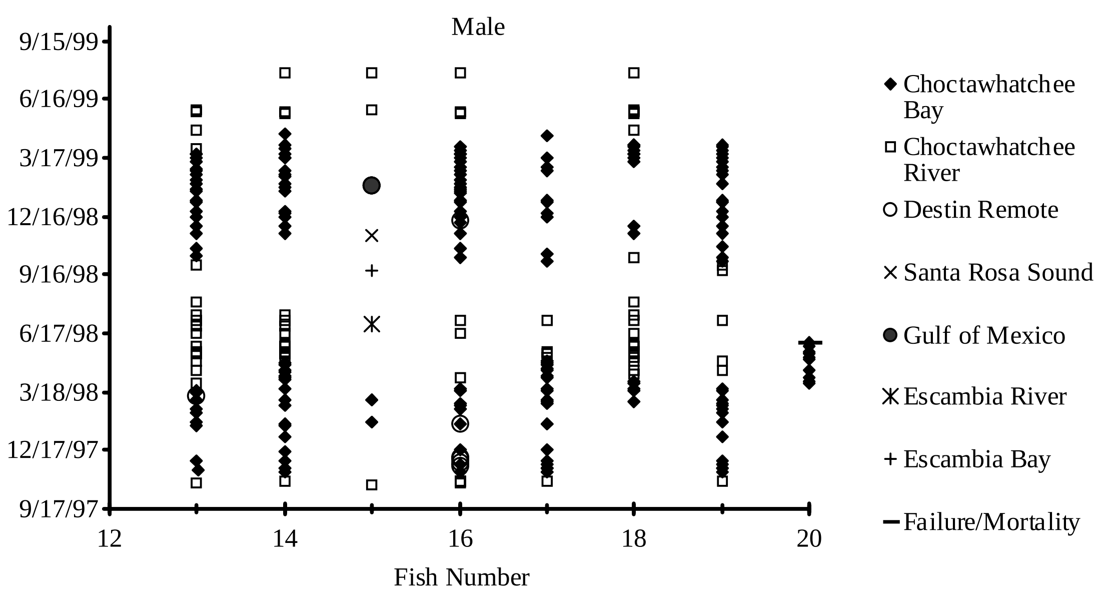


Figure 2. Timing and area of relocation for telemetered gulf sturgeon during 1997–1999.

in the Choctawhatchee River System during the spring or summer of 1998. Although most telemetered fish returned to the Choctawhatchee River, one male (Fish #15) was relocated in the Escambia River (>100 km from Choctawhatchee Bay) during the summer of 1998 (Figure 2), and one female (Fish #7) was relocated in Escambia Bay in December 1998 but not subsequently relocated in the Choctawhatchee River System. Two additional female fish, tagged in the spring of 1997,

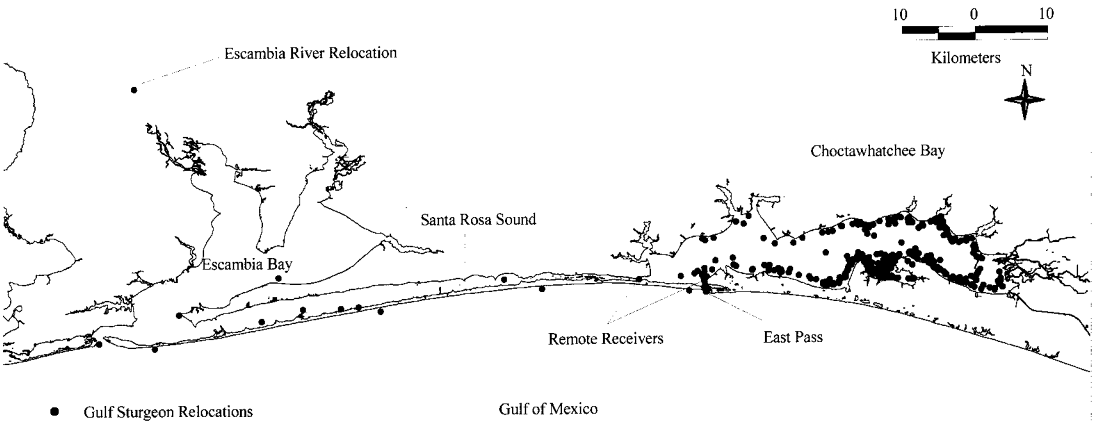


Figure 3. Relocation sites of telemetered adult gulf sturgeon within Choctawhatchee Bay and adjacent estuarine and marine waters.

were not relocated after being detected in the river during the fall of 1997. These fish were excluded from the analyses and are not shown on Figure 2. These two fish could have migrated out of the Choctawhatchee River/Bay system and not returned or experienced failure of both ultrasonic and radio transmitters.

During the 1998–1999 field season, it appeared that 8 out of 19 (45%; Fish #'s 1, 7, 8, 9, 10, 11, 15, and 18) telemetered fish used Gulf of Mexico waters (Figure 2). Three of the eight fish were relocated in the Gulf of Mexico, while the remaining five were hypothesized to be using the marine environment based on relocation patterns (i.e., absent from Choctawhatchee Bay for more than six weeks followed by relocation within the bay). A total of 8 out of 12 females (66%), and 3 out of 7 males (42%) were inferred to have entered marine waters during the course this study.

Habitat Associations

Weekly searches of Choctawhatchee Bay provided information on Gulf sturgeon estuarine habitat use. Fish relocations in deep water (>4 m) were infrequent; Gulf sturgeon appeared to use only the deeper bay waters for movement between shoreline areas (Figure 4). Gulf sturgeon occasionally moved long distances rapidly (as evidenced by relocations of fish on consecutive days) but often remained in localized areas (<1 km^2) for prolonged (i.e., several weeks) periods. The median depth at relocation sites was 2.4 m in 1997–1998 and 2.6 m in 1998–1999. Based on water depths at relocation sites, we determined that Gulf sturgeon were not distributed according to the amount of available depth ranges. We found significant differences for Gulf sturgeon distribution when depth was considered ($\chi^2 = 259.83$, df = 22, P < 0.05). Gulf sturgeon typically were found in water 2–4 m depth and used depths shallower than 1 m and greater than 4 m, less than expected based on availability (Figure 4). The 2–4 m deep habitats where Gulf sturgeon were typically relocated had sediments with a high percentage (>80%) of sand (Figure 5). Based on available habitat, Gulf sturgeon were relocated more frequently than expected ($\chi^2 = 297.45$, df = 18, $P < 0.05$) in areas with a high (>80%) sand composition (Figure 5).

Abundance (#/m^2) and richness (# of species/site) of infaunal invertebrates were greatest in the western portion of Choctawhatchee Bay near the Gulf of Mexico entrance and generally declined towards the Choctawhatchee River and the eastern edge of the bay (Figures 6–7). Gulf sturgeon were not distributed in proportion to invertebrate abundance and species richness. Based on available habitat, we found significant differences in the distribution of invertebrate density ($\chi^2 = 28.44$, df = 10, $P < 0.05$) and species richness ($\chi^2 = 138.37$, df = 8, $P < 0.05$) when Gulf sturgeon relocation sites were compared with invertebrate distribution in the bay as a whole. Gulf sturgeon were typically relocated at sites with the lowest invertebrate abundance (0–1000/m^2; Figure 6) and at sites with relatively few species (Figure 7). Annelids and crustaceans were the dominant (numerically) taxonomic groups at Gulf sturgeon relocation sites during 1998–1999.

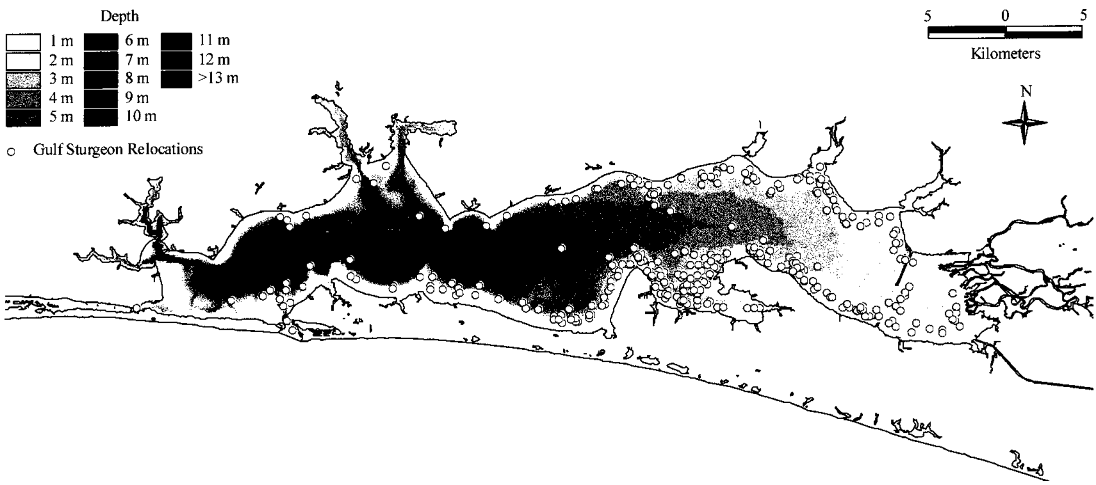


Figure 4. Bathymetric contour map of Choctawhatchee Bay with relocation sites of telemetered gulf sturgeon.

Gulf sturgeon were not found frequently in areas containing seagrass. Seagrass areas were concentrated in the western portion of the bay along the 0–2 m isobath, while Gulf sturgeon utilized primarily the eastern portions of the bay. Relocations occurred significantly less often in waters less than 2 m with seagrass than expected ($\chi^2 = 7.55$, df = 1, $P < 0.05$) based on the amount of seagrass habitat in the 0–2 m isobath.

With the exception of bottom salinity, measured physical parameters (temperature and oxygen concentrations) at Gulf sturgeon relocation sites did not vary much between sampling seasons. The median bottom temperature during the 1997–1998 field season was 16.7°C (10th and 90th percentiles; 13.4–23.2), while in 1998–1999 it was 17.9°C (10th and 90th percentiles; 14.8–23.0). Bottom oxygen concentration had a median value of 8.2 mg/L (10th and 90th percentiles; 6.3–10.2) during 1997–1998 and 8.12 mg/L (10th and 90th percentiles; 5.1–10.0) in 1998–1999. Salinity levels at relocation sites were much lower in 1997–1998 (median value = 6.0 ppt; 10th and 90th percentiles; 1.8–17.7), when compared with measured

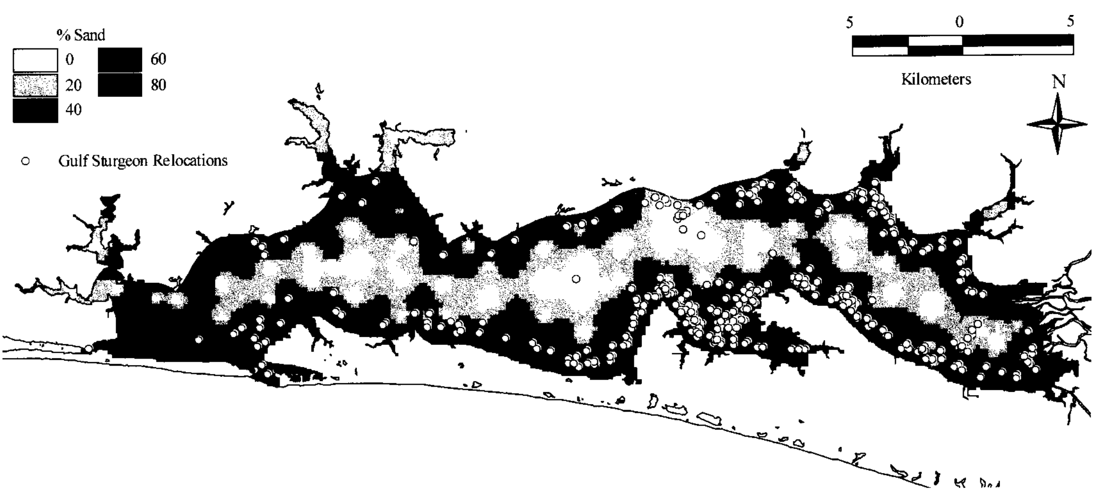


Figure 5. Grain-size contour map of Choctawhatchee Bay with relocation sites of telemetered adult gulf sturgeon.

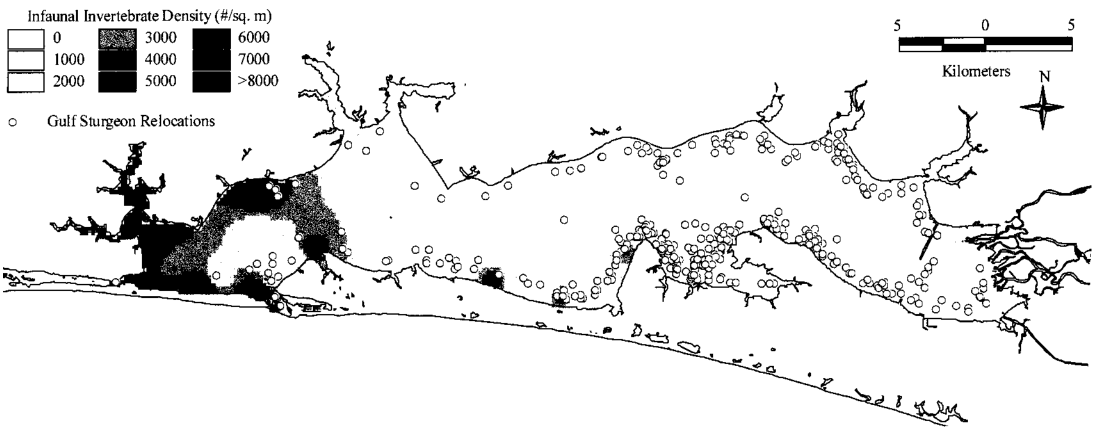


Figure 6. Infaunal invertebrate density (#/m[2]) contour map of Choctawhatchee Bay with relocation sites of telemetered adult gulf sturgeon.

values in 1998–1999 (median value = 18.4 ppt; 10th and 90th percentiles; 9.9–24.8).

Migration Timing

The timing of Gulf sturgeon movement from the estuary into the Choctawhatchee River varied among individuals and years. Fish typically entered the river in April–May and returned to the bay in September–October (Figure 2). Five of six males and six of ten females entered the river earlier in 1997 than in 1998 (Figure 8). During the 1998 field season, we also observed two females (Fish #4 and #11) moving between the river and the bay on several dates (Figure 2). One of these fish (Fish #11) moved from the bay to the river on at least three separate occasions from mid-March through mid-June and encountered salinity changes of 10.2–26.4 ppt within 1–7 d.

Discussion

Gulf sturgeon in Choctawhatchee Bay primarily occupied shoreline areas between 2 and 4 m of depth characterized by low relief sand substrate. Telemetry results indicate that Gulf sturgeon do not frequent the deeper portions of the bay but,

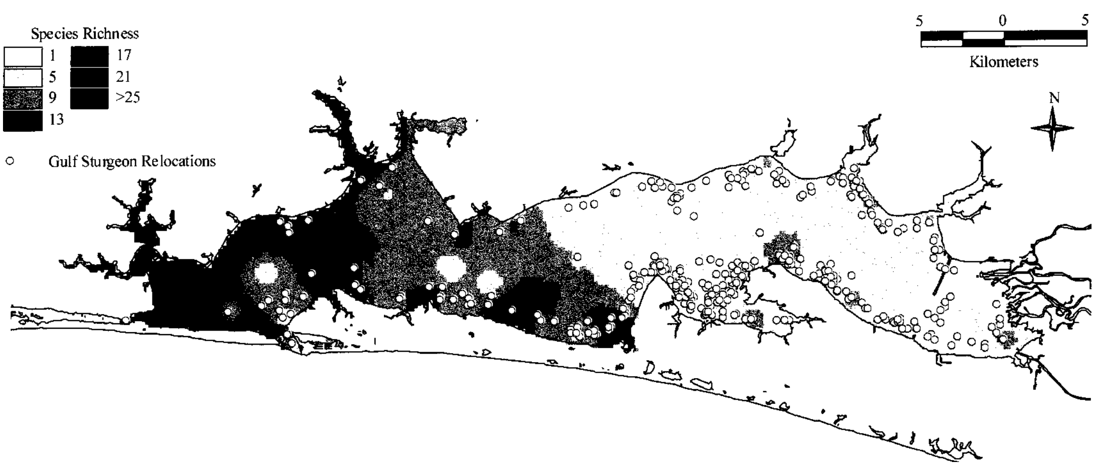


Figure 7. Infaunal invertebrate species richness (# species/site) contour map of Choctawhatchee Bay with relocation sites of telemetered adult gulf sturgeon.

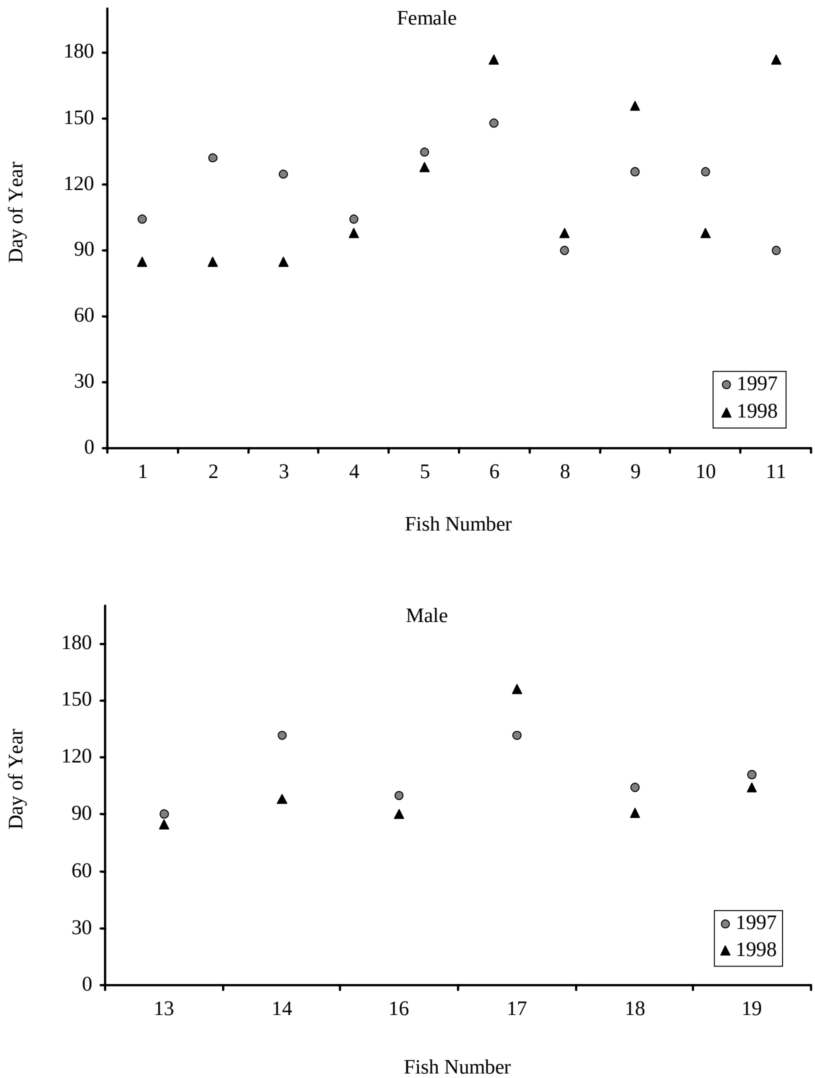


Figure 8. Dates of river entry in 1997 and 1998 for telemetered gulf sturgeon tagged in 1997 that returned to the Choctawhatchee River in 1998.

instead, appear to use these deeper waters only to move from one shallow shoreline habitat to another. Fish relocated in deep waters on one occasion were subsequently relocated in shallow waters in all cases. Individual fish often remained in localized areas (<1 km^2) for extended (>2 weeks) periods of time then moved rapidly to another area where localized movements occurred again. Our observations are in agreement with Findeis (1997) who described sturgeons (Acipenseridae) as exhibiting evolutionary traits adapted for benthic cruising. Similar results have been found for adult Gulf sturgeon in the Suwannee River (Sulak and Clugston 1999) and for juvenile Atlantic sturgeon *A. o. Oxyrinchus* in North Carolina (Moser and Ross 1995; Armstrong and Hightower 1999). Although there were differences in telemetry methods between our project (i.e., weekly searches) and the work of Sulak and Clugston (1999) (i.e., continuous tracking of individual fish), similarities in behavioral patterns exist between both studies. We hypothesize that individual fish move over an area until they encounter suitable prey type and density, at which time they stop to forage for extended periods.

Within Choctawhatchee Bay, Gulf sturgeon are generally found in the lower-salinity middle and eastern portions, which are low in infaunal invertebrate abundance and diversity when compared with the western end of the bay. They also do not frequent seagrass habitats that are located primarily in the western end of the bay, even though seagrass habitats typically support higher levels of both invertebrate abundance and diversity (Livingston 1986; Heck et al. 1995). This pattern of Gulf sturgeon distribution seems counterintuitive, given that growth of Gulf sturgeon occurs primarily during these periods of estuarine and marine residence (Mason and Clugston 1993; Clugston et al. 1995; Carr et al. 1996). We hypothesize that Gulf sturgeon in Choctawhatchee Bay are feeding primarily on other prey, such as ghost shrimp *Lepedophthalmus louisianensis* and an associated commensal shrimp *Leptalpheus forceps*, that were not available to our sampling gear because they burrow to depths greater than 1 m. Burrowing by ghost shrimp likely explains why Livingston (1986) collected few during his study. The ghost shrimp is an oligohaline burrower typically found along intertidal and subtidal substrates ranging from sandy mud to organic silty sand (Felder and Lovett 1989). Abundance estimates for ghost shrimp populations are often made on the basis of burrow counts (Posey 1986), since other sampling strategies either can be ineffective or labor-intensive. We occasionally observed Gulf sturgeon actively foraging on the sand flats, and sediments in those areas contained numerous burrows similar to those occupied by ghost shrimp. Additionally, the digestive tracts of two adult Gulf sturgeon that died during netting operations exclusively contained numerous ghost shrimp and L. forceps (Fox et al. 2000). This result is similar to that of Carr et al. (1996), who determined that 32% of adult Gulf sturgeon (N = 157) undergoing spring migration into the Suwannee River had foraged exclusively on ghost shrimp and brachiopods. Mason and Clugston (1993) found that subadult Gulf sturgeon in the Suwannee River fed on ghost shrimp, isopods, and amphipods, whereas adults concentrated on nearshore coastal shelf organisms. Additional evidence for Gulf sturgeon foraging on ghost shrimp in Choctawhatchee Bay has been provided by Heard et al. (2000). Using a combination of underwater survey techniques specifically designed for estimation of ghost shrimp abundance, Heard et al. (2000) determined that ghost shrimp densities (up to 100 individuals/m^2) were greatest in nearshore shallow (<2 m) areas along the middle and eastern portions of Choctawhatchee Bay, which were frequented by telemetered adult Gulf sturgeon.

Although we are unable to provide conclusive evidence for a link between Gulf sturgeon habitat utilization and foraging, a link between the two has been established for other sturgeon species. Research conducted on the estuarine distribution for both juvenile Atlantic sturgeon and European sturgeon A. sturio indicates a link between distribution and prey availability (Moser and Ross 1995; Armstrong and Hightower 1999; and Rochard et al. 2001). Shortnose sturgeon *A. brevirostrum* frequent areas along the freshwater-saltwater interface and other low-energy sections of the river that are high in prey abundance (Buckley and Kynard 1985; Hall et al. 1991). Shovelnose sturgeon Scaphirhynchus platorynchus in the upper Mississippi River tend to occur around wing and closing dams that have been linked to greater densities of food organisms (Hurley et al. 1987). Juvenile lake sturgeon *A. fulvescens* distribution is positively correlated with substrate type in Northern Ontario rivers, and these associations with substrate have been linked to foraging preferences and associated prey abundance in these river systems (Chiasson et al. 1997).

Our results indicate that a considerable fraction of the adult Gulf sturgeon in the Choctawhatchee River system overwinters in Choctawhatchee Bay before migrating upriver the following spring or summer. Fish that leave Choctawhatchee Bay during the winter and spring appear to use a combination of surrounding bays (Escambia and Santa Rosa Sound) and the Gulf of Mexico. Some adult Gulf sturgeon undertake substantial (>100 km) migrations into the marine environment. Although our sample sizes were limited, a majority of females (8 out of 12) were either relocated in the Gulf of Mexico or were absent from Choctawhatchee Bay for at least 6 weeks following relocation at the entrance to the bay. In contrast, a majority of males (4 out of 7) remained in Choctawhatchee Bay during the winter and spring. Some females captured in our nets had remoras (remora family: Echeneidae) attached when captured, providing further evidence that they recently inhabited marine waters. We hypothesize that two additional female Gulf sturgeon from our group of tagged fish remained in marine waters for two consecutive years or moved to a surrounding river system and were not relocated, although it is possible that these fish died elsewhere or experienced failure of both sonic and radio transmitters. Residence in marine waters for more than one year has also been suggested for Atlantic sturgeon (Bain 1997). Although male Gulf sturgeon are capable of spawning in consecutive years, females appear to require more than one year between spawning events for gonadal recrudescence (Huff 1975; Fox et al. 2000). This same pattern of spawning frequencies for males and females has been observed for the closely-related Atlantic sturgeon (Smith 1985). Migration into marine waters could, therefore, be more important for female Gulf sturgeon that need to obtain the nutrients necessary for gonadal development.

The location of Gulf sturgeon foraging grounds in the Gulf of Mexico remains unknown. The three telemetered Gulf sturgeon that we relocated in marine waters were found in nearshore (<2 km offshore) waters west of the entrance to Chocta-whatchee Bay. Consecutive relocations for two of the fish showed a pattern of easterly movement toward the entrance of Choctawhatchee Bay. One fish (#15) showed a net movement speed of 1.54 km/h over a 40-hr period. We hypothesize that Gulf sturgeon foraging offshore may begin their return to Choctawhatchee Bay by migrating toward the shoreline, at which point they may detect olfactory or chemical cues of the Choctawhatchee River system. A similar two-step approach to migration and homing has been documented in some species of salmon that use magnetic cues for general direction (Walker et al. 1997) until they get close enough for olfactory mechanisms to aid in finer scale movements (Healey and Groot 1987; Hansen et al. 1993).

Homing fidelity in Gulf sturgeon is thought to be high (Wooley and Crateau 1985; Stabile et al. 1996; Foster and Clugston 1997), and this high degree of natal stream fidelity is proposed as the primary mechanism generating the observed genetic differences among remaining Gulf sturgeon populations (Stabile et al. 1996). Our tagged fish that was located in the Escambia River in the summer of 1998 was a ripe male when captured in Choctawhatchee Bay during 1997. In the spring of 1997, it was located in the upper Choctawhatchee River on confirmed spawning grounds during periods of spawning (Fox et al. 2000). After being relocated in the Escambia River, the fish was subsequently found in both Escambia Bay and Santa Rosa Sound before returning to the Choctawhatchee River via the Gulf of Mexico and Choctawhatchee Bay in the spring of 1999. Prior records of straying among Gulf sturgeon populations were between the Apalachicola and Suwannee rivers in Florida (Carr et al. 1996). The straying between these systems is thought to be the cause of their high degree of genetic similarity (Stabile et al. 1996). Alternatively, the documented straying between those systems may be due to the relatively high research effort in both the Apalachicola and Suwannee rivers in comparison to other systems. Our work suggests that straying may be more common than previously recognized, although Stabile et al. (1996) estimated that there was very little (0.45 females per generation) maternally mediated gene flow between the Choctawhatchee and the Escambia/Yellow River Complex.

During their movement from estuarine and marine waters into rivers, Gulf sturgeon may require a period of physiological acclimation to changing salinity levels. To aid in this acclimation, it is thought that Gulf sturgeon remain in specific staging areas during periods of migration both into and out of coastal rivers (Wooley and Crateau 1985; Carr et al. 1996; Foster and Clugston 1997). Our results indicate that adult Gulf sturgeon require little time for such physiological acclimation. During the spring of 1997 and 1998, we recorded two adult Gulf sturgeon moving from upstream spawning grounds (>river kilometer 120; Fox et al. 2000) back into the bay in less than four days. These two fish remained in the bay for up to a month before they returned to the river. It appears that Gulf sturgeon can move through the river/ bay interface rapidly and require little if any time for acclimatization. These findings support Altinok et al. (1998), who determined that, by age one, Gulf sturgeon have developed an active mechanism for osmoregulation and ion balance in a euryhaline environment.

Although overexploitation, habitat loss, and degradation have been linked to Gulf sturgeon declines (Huff 1975; Wooley and Crateau 1985), we know little about the role of anthropogenic impacts on Gulf sturgeon while in estuarine and gulf waters. In Chesapeake Bay, hypoxic events have increased in the last century and are now being linked to the degradation of nursery habitat for Atlantic sturgeon (Secor and Gunderson 1997). Poor water quality is a major concern in the Gulf of Mexico (Malakoff 1998) and surrounding estuaries, where hypoxic events have had negative impacts on the marine benthic community. An additional source of concern for Gulf sturgeon recovery in Choctawhatchee Bay is the rapid development of shoreline areas for housing and recreation. Gulf sturgeon utilize nearshore estuarine habitats almost exclusively while residing in the bay; thus care should be taken to not only protect this physical habitat but to ensure that the benthic community is not negatively impacted by degradations in water quality. In addition, Gulf sturgeon telemetry studies are needed, using innovative approaches such as archival or pop-up tags, to delineate offshore feeding grounds. Once offshore distributional patterns have been characterized, they can be coupled with information on the estuarine distributions, possibly leading to predictions on how declines in habitat quality will affect recovery efforts for this species.

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References

Altinok, I., S. M. Galli, F. A. Chapman. 1998. Ionic and osmotic regulation capabilities of juvenile Gulf of Mexico sturgeon, *Acipenser oxyrinchus desotoi*. Comparative Biochemistry and Physiology 120(A):609–616.

Armstrong, J. L., and J. E. Hightower. 1999. Movement, habitat selection and growth of early-juvenile Atlantic sturgeon in Albemarle Sound, North Carolina. Final report to the U.S. Fish and Wildlife Service and Virginia Power. North Carolina Cooperative Fish and Wildlife Research Unit, North Carolina State University, Raleigh, North Carolina.

Bain, M. B. 1997. Atlantic and shortnose sturgeons of the Hudson River: common and divergent life history attributes. Environmental Biology of Fishes 48:347–358.

Bass, G. D., D. M. Yeager, and V. G. Hitt. 1980. Ecology of the Choctawhatchee River system, Florida. Northwest Streams Research Project. Florida Game and Freshwater Fish Commission, Tallahassee, Florida.

Burgess, R. F. 1963. Florida sturgeon spree. Outdoor Life (March):44.

Buckley, J., and B. Kynard. 1985. Yearly movements of shortnose sturgeon in the Connecticut River. Transactions of the American Fisheries Society 114:813–820.

Carr, S. H., F. Tatman, and F. A. Chapman. 1996. Observations on the natural history of the Gulf of Mexico sturgeon (*Acipenser oxyrinchus desotoi* Vladykov 1955) in the Suwannee River, southeastern United States. Ecology of Freshwater Fish 5:169–174.

Chiasson, W. B., D. L. G. Noakes, and F. W. H. Beamish. 1997. Habitat, benthic prey, and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Canadian Journal of Fisheries and Aquatic Sciences 54:2866–2871.

Clugston, J. P., A. M. Foster, and S. H. Carr. 1995. Gulf sturgeon Acipenser oxyrinchus desotoi in the Suwannee River, Florida, USA. Pages 215–224 *in* A. D. Gershanovich and T. I. J. Smith, editors. Proceedings Second International Symposium on the Sturgeon. VNIRO Publishing, Moscow, Russia.

Felder, D. L., and D. L. Lovett. 1989. Relative growth and sexual maturation in the estuarine ghost shrimp *Callianassa louisianensis* Schmitt, 1935. Journal of Crustacean Biology 9:540–543.

Findeis, E. K. 1997. Osteology and phylogenetic interrelationships of sturgeons (Acipenserids). Environmental Biology of Fishes 48:73–126.

FMRI. 1998. Florida atlas of marine resources. CD–ROM. St. Petersburg, Florida.

Foster, A. M., and J. P. Clugston. 1997. Seasonal migration of Gulf sturgeon in the Suwannee River, Florida. Transactions of the American Fisheries Society 126:302–308.

Fox, D. A., J. E. Hightower, and F. M. Parauka. 2000. Gulf sturgeon spawning migration, and habitat in the Choctawhatchee River System, Alabama-Florida. Transactions of the American Fisheries Society 129:811–826.

Goldsmith, V. 1966. The recent sedimentary environment of Choctawhatchee Bay, Florida. Master's thesis. University of Florida, Gainesville.

Hall, J. W., T. I. J. Smith, and S. D. Lamprecht. 1991. Movements and habitats of shortnose sturgeon (*Acipenser brevirostrum*) in the Savannah River. Copeia 3:695–702.

Hansen, L. P., N. Jonsson, and B. Jonsson. 1993. Oceanic migration in homing Atlantic salmon. Animal Behaviour 45:927–941.

Healey, M. C., and C. Groot. 1987. Marine migration and orientation of ocean-type chinook and sockeye salmon. Pages 298–312 in M. J. Dadswell, R. J. Klauda, C. M. Moffitt, R. L. Saunders, R. A. Rulifson, and J. E. Cooper, editors. Common strategies of anadromous and catadromous fishes. American Fisheries Society, Symposium 1, Bethesda, Maryland.

Heard, R. W., J. L. McLelland, and J. M. Foster. 2000. Benthic invertebrate community analysis of Choctawhatchee Bay in relation to Gulf sturgeon foraging: an overview of year 1. Interim report: year 1 to the Florida Fish and Wildlife Conservation Commission. Department of Coastal Sciences, University of Southern Mississippi, Ocean Springs, Mississippi.

Heck, K. L., K. W. Able, C. T. Roman, and M. P. Fahay. 1995. Composition, abundance, biomass and production of macrofauna in a New England estuary: comparisons among eelgrass meadows and other nursery habitats. Estuaries 18:379–389.

Heise, R. J., S. T. Ross, M. F. Cashner, and W. T. Slack. 1999. Gulf Sturgeon (*Acipenser oxyrinchus desotoi*) in the Pascagoula Bay and Mississippi Sound. Unpublished report to the U.S. Fish and Wildlife Service.

Huff, J. A. 1975. Life history of Gulf of Mexico sturgeon, *Acipenser oxyrinchus desotoi*, in Suwannee River, Florida. No. 16. Florida Department of Natural Resources, Marine Research Laboratory.

Hurley, S. T., W. A. Hubert, and J. G. Nickum. 1987. Habitats and movements of shovelnose sturgeon in the upper Mississippi River. Transactions of the American Fisheries Society 116:655–662.

Lee, S. D., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer. 1980. Atlas of North American freshwater fishes. Publication No. 1980-12. North Carolina Biological Survey.

Lewis, D. W., and D. McConchie. 1994. Analytical sedimentology. Chapman and Hall, New York.

Livingston. R. J. 1986. Choctawhatchee River Bay System. Final report. Volumes 1–4. Florida State University Center for Aquatic Research and Resource Management, Tallahassee, Florida.

Malakoff, D. 1998. Death by suffocation in the Gulf of Mexico. Science 281:190–192.

Mason, W. T., and J. P. Clugston. 1993. Foods of the Gulf sturgeon in the Suwannee River, Florida. Transactions of the American Fisheries Society 122:378–385.

Moser, M. L., and S. W. Ross. 1995. Habitat use and movements of shortnose sturgeon and Atlantic sturgeon in the lower Cape Fear River, North Carolina. Transactions of the American Fisheries Society 124:225–234.

NOAA-NOS. 1998. Choctawhatchee Bay bathymetric digital elevation models at 3 arc second resolution. Silver Spring, Maryland.

Odenkirk, J. S. 1989. Movements of Gulf of Mexico sturgeon in the Apalachicola River, Florida. Proceedings of the Annual Conference, Southeastern Association of Fish and Wildlife Agencies 43:230–238.

Posey, M. H. 1986. Changes in a benthic community associate with dense beds of a burrowing deposit feeder, *Callianassa californiensis*. Marine Ecology Progress Series 31:15–22.

Rochard, E., M. Lepage, P. Dumont, S. Tremblay, and C. Gazeau. 2001. Downstream migration of juvenile European sturgeon *Acipenser sturio L.* in the Gironde Estuary. Estuaries 24:108–115.

Secor, D. H., and T. E. Gunderson. 1997. Effects of hypoxia and temperature on survival, growth, and respiration of juvenile Atlantic sturgeon, *Acipenser oxyrinchus*. Fisheries Bulletin 96:603–613.

Smith, T. I. J. 1985. The fishery, biology, and management of Atlantic sturgeon, *Acipenser oxyrhynchus*, in North America. Environmental Biology of Fishes 14:61–72.

Stabile, J., J. R. Waldman, J. Hart, F. Parauka, and I. Wirgin. 1996. Stock structure and homing fidelity in Gulf of Mexico sturgeon (*Acipenser oxyrinchus desotoi*) based on restriction fragment length polymorphism and sequence analyses of mitochondrial DNA. Genetics 144:767–776.

Sulak, K. J., and J. P. Clugston. 1998. Early life history stages of Gulf sturgeon in the Suwannee River, Florida. Transactions of the American Fisheries Society 127:758–771.

Sulak, K. J., and J. P. Clugston. 1999. Recent advances in life history of Gulf of Mexico sturgeon, *Acipenser oxyrinchus desotoi*, in the Suwannee River, Florida, USA: a synopsis. Journal of Applied Ichthyology 15:116–128.

U.S. Commission of Fish, and Fisheries. 1902. Report of the commissioner (part XXVII) for the year ending June 30, 1901. U.S. Government Printing Office, Washington, D.C.

U.S. Fish and Wildlife Service, Gulf States Marine Fisheries Commission, and National Marine

Fisheries Service. 1995. Gulf Sturgeon (*Acipenser oxyrinchus desotoi*) Recovery/Management Plan. Atlanta, Georgia..

Walker, M. M., C. E. Diebel, C. V. Haugh, P. M. Pankhurst, J. C. Montgomery, and C. R. Green. 1997. Structure and function of the vertebrate magnetic sense. Nature(London) 390:371–376.

White, G. C., and R. A. Garrott. 1990. Analysis of wildlife radiotracking data. Academic Press, San Diego, California.

Wooley, C. M., and E. J. Crateau. 1985. Observations of Gulf of Mexico sturgeon *Acipenser oxyrhynchus desotoi* in the Apalachicola River, Florida. Florida Scientist 45:244–248.

Zehfuss, K. P., J. E. Hightower, and K. H. Pollock. 1999. Abundance of Gulf sturgeon in the Apalachicola River, Florida. Transactions of the American Fisheries Society 128:130–143.