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Gulf sturgeon summer habitat use and fall migration in the Pascagoula River, Mississippi, USA

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Summary

The locations and habitat features of freshwater holding areas and the timing of fall migration are undocumented for Gulf sturgeon in the Pascagoula River drainage, Mississippi. Our objectives were to identify and characterize holding areas for Gulf sturgeon (*Acipenser oxyrinchus desotoi*), document their summer and fall movement patterns, and determine migration cues. To do this we captured, radio-tagged, and monitored movement of Gulf sturgeon in the Pascagoula River drainage and analyzed these data using geographic information systems. From May to November Gulf sturgeon congregate in a holding area in the lower portion of the Pascagoula River and Big Black Creek [river kilometers (rkm) 57–68] and near Cumbest Bluff (rkm 40), before they return to the Gulf of Mexico. While in the holding area, Gulf sturgeon were typically found in deep locations, either in or downstream from river bends. As found in other rivers, Gulf sturgeon in the Pascagoula River showed little movement within the holding area and often stayed within a single river bend; although we observed local movements by some individuals (under 10 rkm). In the Pascagoula River, Gulf sturgeon initiated their migration out of fresh water from late-September to mid-October, coincident with shorter day length, falling water temperature (mean = 23.7°C, range 21–26°C), and elevated river flow. Our work demonstrates that the lower Pascagoula River serves as a vital area for Gulf sturgeon.

Introduction

Gulf sturgeon, *Acipenser oxyrinchus desotoi*, are anadromous, with adults moving into rivers in the spring for spawning and migrating back to saltwater in the fall of the same year. They historically occurred in Gulf of Mexico drainages from Tampa Bay westward to the Mississippi River (Wooley, 1985). In the late spring, summer and early fall Gulf sturgeon remain at specific areas within rivers called holding or staging areas (Wooley and Crateau, 1985; Clugston et al., 1995). Spawning individuals migrate from saltwater to upstream spawning localities then move downstream to the holding areas, although some individuals remain near spawning areas for longer periods (Foster and Clugston, 1997; Heise et al., 2004). Non-spawning adults and subadults also migrate upstream from the coast to holding areas. Sturgeon arrive in these areas in late spring and movement into saltwater begins as water temperature decreases in the fall (Clugston et al., 1995; Foster and Clugston, 1997).

The Gulf sturgeon was listed as threatened in 1991 under the Endangered Species Act (United States Fish and Wildlife Service and Gulf States Marine Fisheries Commission 1995), and is state listed as endangered in Mississippi, (Mississippi Museum of Natural Science, 2001) although populations persist in the Pearl (Morrow et al., 1998) and Pascagoula River drainages (Heise et al., 2004). Because of their status throughout its range, details of their life history and habitat use are needed to facilitate their management and recovery. In the Pascagoula River drainage, Gulf sturgeon migrate to the Bouie River north of Hattiesburg for spawning (250 river kilometers (rkm) upstream from the mouth of the Pascagoula River) and likely spawn in the Chickasawhay River (Heise et al., 2004; Fig. 1), but the location and habitat features of summer holding areas are undocumented. Our objectives were to identify and characterize these areas, document summer and fall movement patterns of Gulf sturgeon, and determine migration cues.

Methods

Study area

The Pascagoula River lies within the Gulf Coastal Plain physiographic province and drains an area of about 25 123 km^2. Elevations in the watershed range from 0 to 198 m above sea level (United States Army Corps of Engineers, Mobile District, 1968) and land use is mostly forestry with some agriculture.

The Pascagoula River is unique and a recent survey of rivers in the northern third of the world indicated that it is the last large (> 350 m^3 s^{-1} virgin mean annual discharge) river system in the contiguous United States that does not have an impoundment on its main channel or is otherwise not strongly impacted (Dynesius and Nilsson, 1994). Because of this unique status, we can expect that the Pascagoula River has few alterations in flow patterns and temperatures and is an important river system for potential recovery of Gulf sturgeon.

Sampling

We captured Gulf sturgeon in gill nets during their freshwater residency period in the Pascagoula River drainage (Fig. 1)

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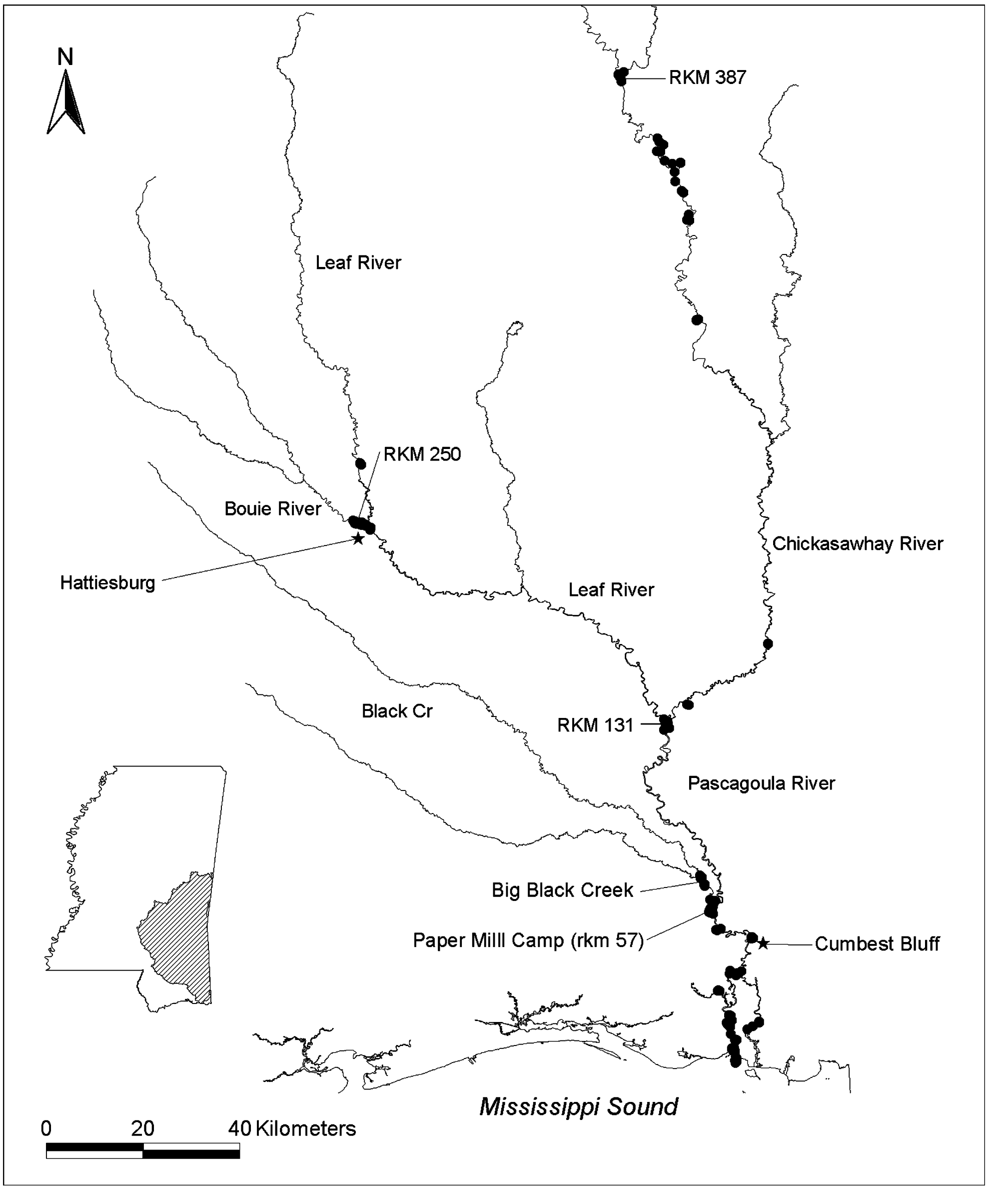

Fig. 1. Pascagoula River drainage with sampling locations indicated by dark circles. Lower inset represents the drainage area for the Pascagoula watershed in Southeast Mississippi

and handled them following guidelines developed by the United States Fish and Wildlife Service (USFWS, 1992). Gill nets were 15–91 m long × 2.4–3.1 m deep with 10–18 cm bar multifilament mesh and were fished during the day and evening. We set nets on the bottom and positioned them across or parallel to the primary channel or in eddies. We checked nets every 1–3 h to minimize stress on captured Gulf sturgeon. For each net set, water depth (m), water temperature (°C; surface and at 3 m), and dissolved oxygen (mg L^{-1}; at 3 m from surface) were measured with a Yellow Springs Instrument (YSI) meter. Geographic coordinates were obtained using a hand-held GPS unit. After capture, Gulf sturgeon were measured to the nearest centimeter in fork length (FL), total length (TL), and modified standard length (SL, measured to the posterior end of the last lateral scute; Bailey and Cross, 1954). Each sturgeon was tagged with an AVID® PIT-tag (passive integrated transponder) (Norco, CA, USA) placed in the muscle near the base of the dorsal fin and an external dart tag was placed near the base of the dorsal fin (1997–1999) or pectoral fin (2000–2002). Gulf sturgeon were placed in a mesh sling and weighed to the nearest kilogram and were equipped with a radio transmitter (Advanced Telemetry Systems Inc., Isanti, MN, USA). The tags were attached by drilling two holes in two adjacent dorsal scutes (i.e. 4th–5th or 5th–6th). Plastic-coated, stainless steel attachment cables that were built into the radio transmitter were then threaded through holes in the scutes and into the holes on a backing plate or sonic transmitter and secured by aluminum cable clamps. Sonic transmitters were used in a related study on saltwater habitat use. After processing, Gulf sturgeon were released near the point of capture.

Telemetry

We located radio-tagged Gulf sturgeon weekly by boat, weather permitting, each summer and fall from 1998 to 2000. We radio tracked twice a month during summer 2001–2002 and weekly during the fall migration. An Advanced Telemetry Systems receiver and a loop antenna were used to find the general location of a tagged Gulf sturgeon, then a more precise location was estimated based on changes in signal strength by using a paper clip antenna, which provided a reduced field of reception. For each relocation, water depth (m), water temperature (°C; surface and at 3 m), and dissolved oxygen (mg L^{-1}; at 3 m from surface) were measured with a YSI meter. Geographic coordinates were obtained using a hand-held GPS unit and plotted on maps using ARCVIEW software (Environmental Systems Research Institute, Redlands, CA, USA).

We analyzed Gulf sturgeon locations by calculating the distance along the Pascagoula River from each individual's geographic coordinate to rkm 0. A location includes both radio telemetry data and capture location data. The reference point (rkm 0) is located at the railroad bridge near the mouth of the West Pascagoula River. We calculated river distances using ARCVIEW 3.2a with an Avenue script (network distance). Individuals that were relocated on the East Pascagoula were calculated separately using a reference point (rkm 0) at the railroad bridge near the mouth of the East Pascagoula River. The distance from rkm 0 and associated environmental parameters for each location were summarized for each tracking and/or capture day (hereafter termed tracking period). If we tracked and/or captured Gulf sturgeon on more that 1 day during a week those data were combined into one tracking period. For combined data the mean date is reported for the tracking period.

We determined that a radio-tag was shed if the fish was not tracked migrating out of the river and if for each tracking period the position of the tag varied by no more than 0.2 rkm (not an overwintering fish). Data associated with shed tags were excluded from the database once we determined that the position of the tag did not vary more than 0.2 rkm. Associated data recorded prior to this position were included in subsequent analyses. We used principal components analysis (PCA) to examine the relationship between environmental variables during each tracking period (streamflow, temperature, depth, dissolved oxygen and day length) and the timing of fall migration. The river discharge reported for each tracking period was the mean of the discharge for the tracking day through the previous 4 days (USGS station 2479310 at rkm 55). Day length for each tracking period was calculated in the same manner. We used SPSS (SPSS® Base 9.0, Chicago, IL, USA) to ordinate the tracking period data according to environmental variables using a correlation matrix with varimax rotation. A screen test was used to determine the number of meaningful components. We then plotted standardized factor scores for each tracking period against the meaningful components, superimposing letters for when Gulf sturgeon were exhibiting the holding behavior (h) or were conducting their fall downstream migration (m). Following Matthews (1985) and Ross and Doherty (1994), we considered any variable that loaded on a component at an absolute value of ≥0.40 to make a significant contribution to interpreting that component. To test the null hypothesis of no difference in environmental parameters between groups of Gulf sturgeon showing migratory and holding behaviors, we first generated a similarity matrix using Euclidean distances based on a $\log(x + 1)$ transformation of the environmental variables, followed by testing group differences using ANOSIM, a non-parametric analysis of similarities (PRIMER version 5.19; Clarke and Green, 1988; Clarke and Warwick, 2001). ANOSIM generates a test statistic (R) reflecting the difference between the two groups, then recomputes the test statistic for 10 000 permutations of the sample labels (i.e. individual fish).

Results

Description and use of the holding area

From 1998 to 2002, our summer sampling resulted in 54 Gulf sturgeon captures from Big Black Creek and 145 from the Pascagoula River for a total 199 captures (includes within and among year recaptures). The mean size of Gulf sturgeon, only including new captures (n = 149), was 143 cm FL (range = 61.5–204.0 cm) and the mean mass was 32 kg (range = 1.3–90.7 kg). Based on FL, the majority of individuals were adults (n = 131), 11 were sub-adults and 7 were juveniles. From May to October (prior to downstream migration) of 1998–2002 we recorded 812 telemetry relocations from 132 transmitters; 74% of these relocations were from the Pascagoula River between 'Paper Mill Camp' (near rkm 57) and the confluence with and including 'Dead Lake' (the last 1.5 km of Big Black Creek; Fig. 2). In addition, a deep river bend in Big Black Creek ('English turn', at rkm 67.5) was used occasionally during the study (Fig. 2). For all summer tracking periods, the mean distance (equal weighting by year) from rkm 0 was rkm 58.7 (SD = 7.6, range = 27.9–85.4). The holding area has been used consistently by Gulf sturgeon each summer and fall since we identified the area in 1998. Both spawning and non-spawning individuals arrived in the holding area in early to mid-May. Telemetry and capture data indicate that Gulf sturgeon move between Big Black Creek and the Pascagoula River and to a lesser extent downriver to Cumbest Bluff (Fig. 2). About 8% of the summer relocations were located near Cumbest Bluff, at rkm 40.5. Movement patterns during the summer were generally localized, with fish staying within a 1.0 rkm area throughout the summer. When individuals did move, it was usually < 10.0 rkm and between areas where other Gulf sturgeon were present. For example, Gulf sturgeon moved between Paper Mill Camp (rkm 57.5), Dead Lake (rkm 61) and English turn (rkm 67.5; Fig. 2).

Prior to migration, the mean water depth (equal weighting by year) was 5.6 m (SD = 3.0, range = 1.0–13.7). Relocations were typically in deep holes along river bends, although Gulf sturgeon were also located in a straight section of the river (about 3 m deep) between Paper Mill Camp and Dead Lake. The mean water temperature at 3 m was 28.4°C (SD = 2.0, range = 17.6–31.8) and the mean dissolved oxygen was 6.3 mg L^{-1} (SD = 0.6, range = 3.9–8.1). Yearly habitat parameters (equal weighting by tracking period) for the holding area were similar (Table 1). Based on all years of recorded data, the monthly mean discharge for the Pascagoula River at rkm 55 (USGS Station 2479310) ranged from 2726 $m^3 s^{-1}$ in May to 895 $m^3 s^{-1}$ in October. The mean discharge for May–October was 1734 $m^3 s^{-1}$. The approximate monthly mean discharge for Big Black Creek (combining USGS Stations 2479160 and 2479300), ranged from 668 $m^3 s^{-1}$ in May to 297 $m^3 s^{-1}$ in October. The mean discharge for May–October was 420 $m^3 s^{-1}$.

Fall migration

From 1998 to 2002, radio-tagged sturgeon initiated downstream migration in late-September to mid-October (Fig. 3 and 4). The mean water temperature during the first tracking

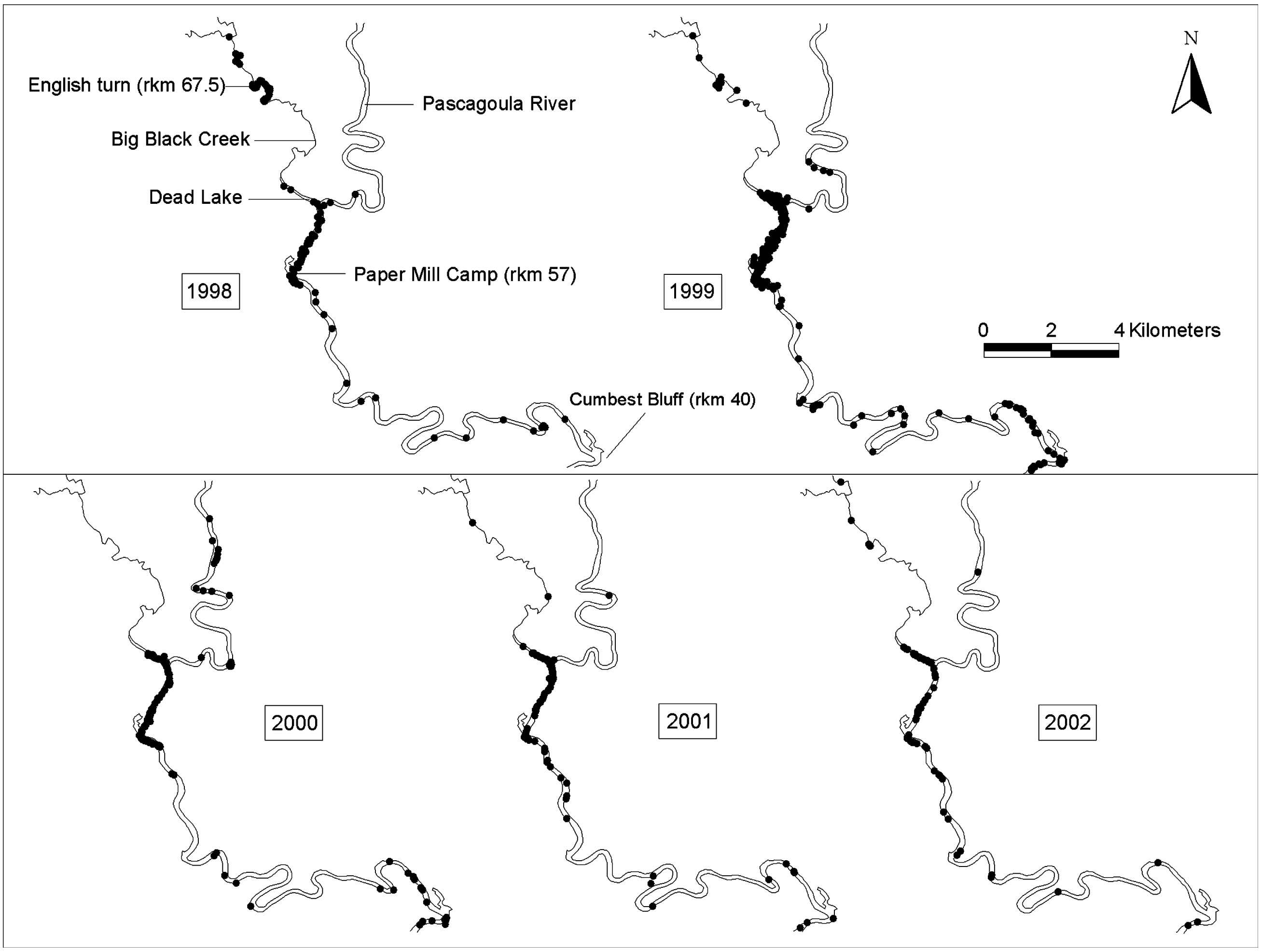

Fig. 2. Telemetry and capture locations for Gulf sturgeon from the holding area in the lower Pascagoula River from 1998 to 2002

Table 1
Summary of habitat parameters from Gulf sturgeon relocations recorded at the holding area prior to fall migration from 1998 to 2002

Year	Distance (rkm)	Depth (m)	Water temperature (°C)	DO (mg L^{-1})
1998	61.1 (6.1)	5.0 (2.6)	28.9 (0.6)	6.3 (0.2)
	28.7–69.3	1.2–12.6	24.8–32.4	4.5–8.2
1999	58.5 (6.6)	5.1 (2.7)	27.7 (0.5)	6.7 (0.3)
	28.6–87.3	1.0–14.3	22.0–32.2	5.4–8.2
2000	58.2 (8.2)	5.2 (3.0)	27.8 (0.5)	6.7 (0.3)
	30.3–132.8	1.0–13.3	16.3–33.5	4.8–9.3
2001	56.0 (7.8)	7.3 (2.8)	27.1 (0.4)	5.9 (0.4)
	23.3–69.1	1.2–15.6	23.5–30.4	4.1–7.6
2002	59.0 (4.7)	5.1 (2.0)	28.4 (0.6)	6.1 (0.3)
	28.7–68.5	1.6–12.7	26.4–30.5	5.0–7.2

The mean and standard deviation (in parentheses) are above the range. Distance = distance from rkm 0, the mouth of the Pascagoula River. Water temperature recorded at 3 m from the surface. DO, dissolved oxygen.

period where fish exhibited a decrease in the mean distance from rkm 0 was 23.7°C (SD = 1.8, range = 21.0–26.0). In all years, excluding 2000, river exit occurred during elevated streamflow (higher than summer conditions) with a mean of 579.1 $m^3\ s^{-1}$ (SD = 531.8, range = 194.6–1344.2; Figs 3 and 4). In 2000, a severe drought year, migration started at a mean streamflow of 32.7 $m^3\ s^{-1}$ (Fig. 4). After initial movement downstream, some Gulf sturgeon remained in a section of the Pascagoula River between rkm 24 and 38 for several weeks then exited the river by early November (Figs 3 and 4).

The PCA extracted two axes with Eigenvalues > 1.0, which accounted for 71.3% of the total variance after rotation (Table 2). We interpret PC-I as a seasonal effect because of high loadings of day length and water temperature. PC-II reflects discharge, with high loadings of streamflow and dissolved oxygen (in the Pascagoula River, low dissolved oxygen is generally associated with high discharge). Overlaying the behavior of Gulf sturgeon (holding or migration) on the factor scores shows the association of migratory behavior with shorter days and lower water temperatures (Fig. 5). Migratory behavior was generally associated with increased discharge, although not during drought years. Groups of Gulf sturgeon, as defined by migratory or holding behavior, differed significantly (ANOSIM, $R = 0.61$; $P < 0.0001$).

Our 5-year study on Gulf sturgeon in the lower Pascagoula River has given us the opportunity to observe fall migration under extremes of flow conditions. High flows occurred in September 1998 (Fig. 3) due to Hurricane Georges (Category 2) which made landfall 24 km to the west of the mouth of the Pascagoula River. One week after Hurricane Georges, three out of five radio-tagged fish that were in the holding area had migrated downstream to the Gulf of Mexico. Streamflow

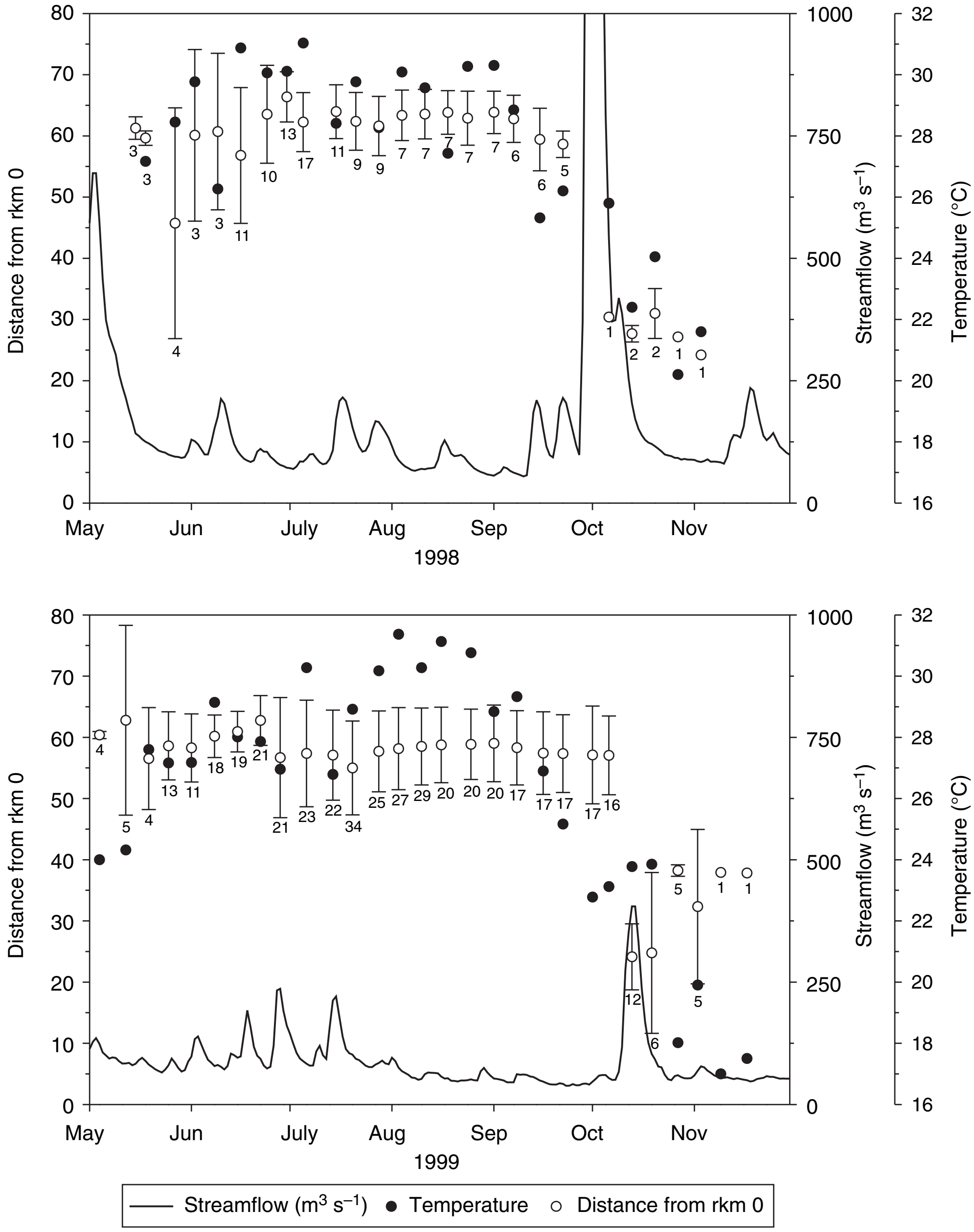

Fig. 3. Mean distance from rkm 0 and water temperature for Gulf sturgeon relocations during each tracking period, and stream discharge for the Pascagoula River during 1998–1999 (in streamflow). Vertical bars are standard deviation and the numbers below are a count of telemetry relocations (shed tags removed, see Methods) plus any captures during that tracking period. Discharge data are from USGS station number 02479310

peaked on 10 October at 2517 m^3 s^{-1} (USGS station 2479310). By 3 November, the remaining two radio-tagged Gulf sturgeon had migrated to the Gulf of Mexico. During the severe drought of 2000, the mean distance from rkm 0 during migration declined at a slower rate than in other years (Fig. 4) although all radio-tagged fish were out of the river by early November.

Discussion

From May to November Gulf sturgeon congregate in a holding area comprising the lower portion of the Pascagoula River and Big Black Creek (rkm 57–68) and near Cumbest Bluff (rkm 40), before they return to the Gulf of Mexico. In the Suwannee River, Foster and Clugston (1997) and Clugston et al. (1995) found that from June to November Gulf sturgeon congregate at five major areas (each about 4–8 km long). These were centered around rkm 40.0, 55.5, 71.0, 93.2 and 200.2. In the Apalachicola River, Wooley and Crateau (1985) reported that from May to September Gulf sturgeon congregated below the Jim Woodruff Lock and Dam (rkm 171). This area may be the best alternative habitat available to these Gulf sturgeon because upstream migration is blocked by the dam. In the Choctawhatchee River, Hightower et al. (2002) reported that summer telemetry relocations for mature fish (72.6%) and immature fish (38.1%) were located between rkm 40 and 50. Hightower et al. (2002) also indicated that a few summer relocations of mature Gulf sturgeon were found between rkm 130 and 150; these individuals migrated to the area in the spring to spawn. We also relocated some individuals near a

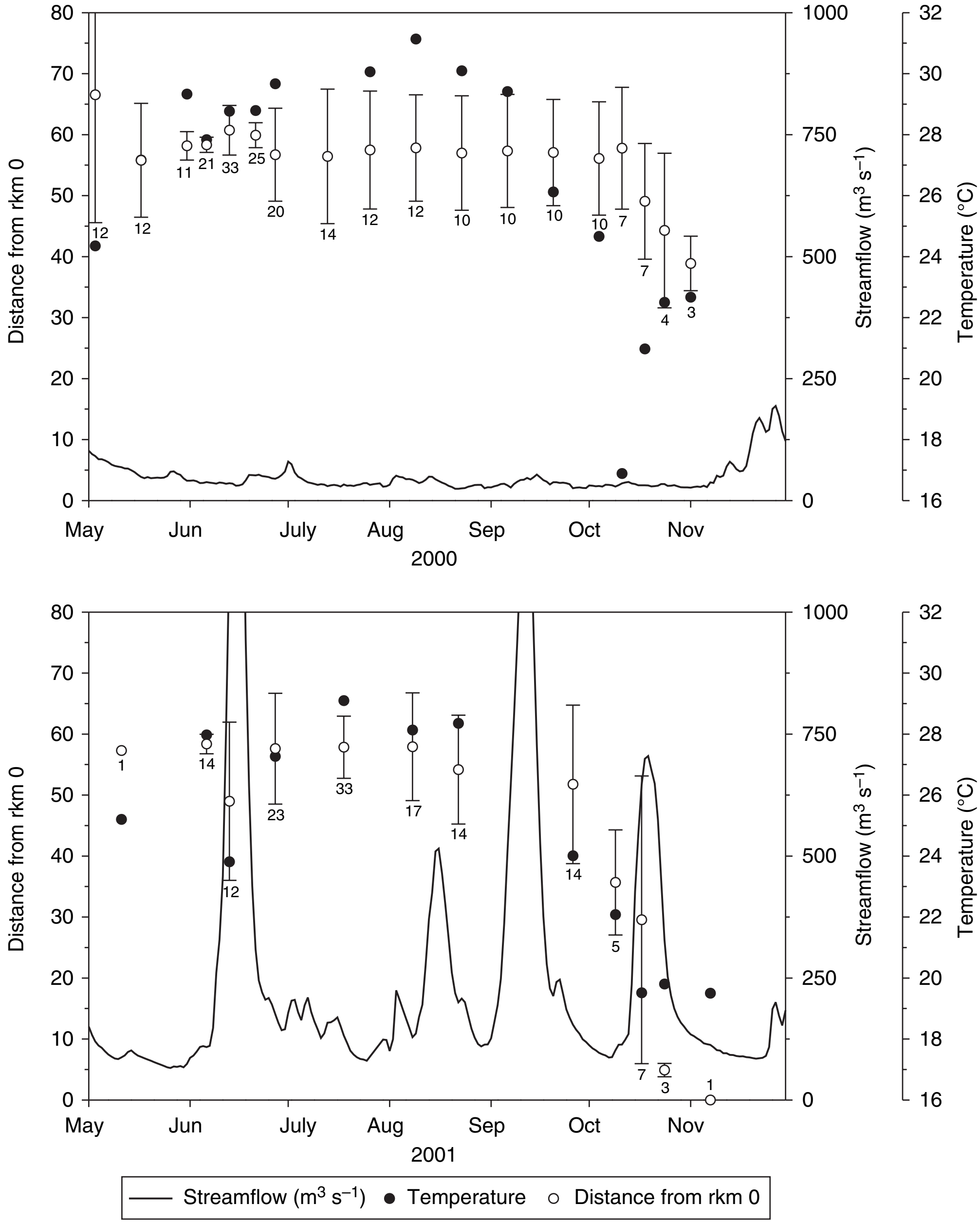

Fig. 4. Mean distance from rkm 0 and water temperature for Gulf sturgeon relocations during each tracking period, and stream discharge for the Pascagoula River during 2000–2001 (in streamflow). Vertical bars are standard deviation and the numbers below are a count of telemetry relocations (shed tags removed, see Methods) plus any captures during that tracking period. Discharge data are from USGS station number 02479310

Table 2
Variable loadings on principal components I–II, following varimax rotation

Variable	PC-I	PC-II
Day length	0.934	−0.098
Water temperature	0.934	−0.023
Streamflow	−0.210	0.904
Dissolved oxygen	−0.278	−0.819
Depth	0.385	0.227
Percent of variance accounted for	40.3	31.0

spawning area near rkm 250 throughout the summer (Heise et al., 2004).

While in holding areas, Gulf sturgeon are typically found in deep locations, either in or downstream from river bends, or upstream from long sand shoals (Foster and Clugston, 1997; Sulak and Clugston, 1999; this study). In the Suwannee River, Gulf sturgeon were found in areas that were 1–2 m deeper than the main channel (Foster and Clugston, 1997). In the Choctawhatchee River, however, mean depths for telemetry relocations at the holding area were shallower and outside of the main channel (Hightower et al., 2002). In the Pascagoula River, mean water temperature at the holding areas was 3.5 and 2.1°C higher than in the Suwannee and Choctawhatchee rivers, respectively.

The spatial selection of the holding area in the Pascagoula River may be influenced by the tide and salinity. During summer flow conditions, the lower half of the Pascagoula River, including all of the holding area, is tidally influenced. In extreme conditions, tidal effects can extend upstream to about rkm 68 (Rebich and Landers, 1990). In addition, the

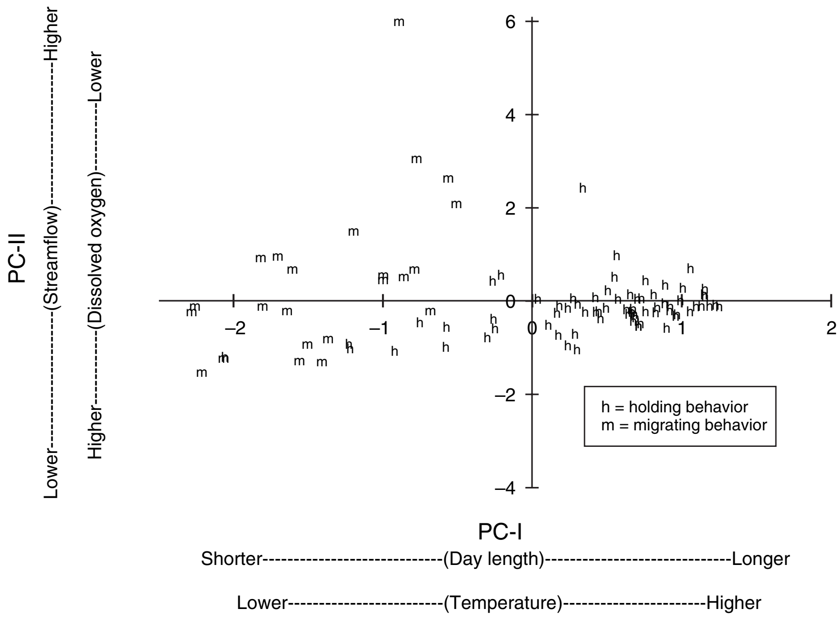

Fig. 5. Scatterplot indicating the behavior of the Gulf sturgeon (holding or migration) overlaid on the factor scores from PCA, illustrating potential migration cues

lower reaches experience a typical 'salt wedge' of saline water intrusion from the Mississippi Sound. Rebich and Landers (1990) indicated that the maximum extent of saline water is located about rkm 27 at extreme low flows and high salinities in the Mississippi Sound. In 1999 and 2000 drought conditions occurred in the Pascagoula River drainage (National Climate Data Center, 2002). During a short-term study in September 2000, Plunkett et al. (2001) found saline water as far upstream as rkm 29. The lower boundary of the holding area extends downstream near Cumbest Bluff (rkm 40), but is beyond the upstream extent of salt water. The upper boundary may include the upstream extent of tidal influence (Table 1).

Similar to other populations, Gulf sturgeon in the Pascagoula River showed little movement within the holding area and often stayed within a single river bend. The mean distance from rkm 0 remained stable throughout each summer prior to migration, although we observed local movements by some individuals (under 10 rkm) within the holding area. In the Suwannee River, individuals moved on average within 0.6 km upstream or downstream during the summer (Clugston et al., 1995). In the Apalachicola River, the mean distance moved during the summer was 0.4 km (Wooley and Crateau, 1985).

Initiation of fall migration is associated with seasonal (decreasing day length and lowered water temperature) and discharge cues. Once seasonal conditions are appropriate, increases in flow may trigger migratory responses. In both the Suwannee and Apalachicola rivers, water temperature was reported as an important factor in the initiation of migration. In October and November, radio-tagged Gulf sturgeon in the Suwannee River moved downstream when the water temperature decreased from about 26.0 to 17.0°C; the mean for all years was 21.3°C (Clugston et al., 1995; Foster and Clugston, 1997). By early December, Gulf sturgeon had departed the Suwannee River and returned to the Gulf of Mexico. Gulf sturgeon initiated migration in the Apalachicola River after river water temperature dropped to 23.0°C in late September (Wooley and Crateau, 1985).

In the Apalachicola River, after leaving the Jim Woodruff Lock and Dam, Gulf sturgeon temporarily halted their downstream movement at the confluence of the Brothers River at rkm 19 (Wooley and Crateau, 1985). Gulf sturgeon then moved 4 rkm up the Brothers River and remained at this staging area for up to 24 days before returning to salt water. This river is the last large tributary of the Apalachicola River above saltwater intrusion. In the Pascagoula River, after initial movement downstream, some Gulf sturgeon remained in the mainstem of the river between rkm 24 and 38 for several weeks before leaving the river. However, this staging pattern for Gulf sturgeon in the Pascagoula River is less pronounced than in the Apalachicola River. Wooley and Crateau (1985) suggested that increased water flow combined with decreasing water temperature may be the stimulus to resume downstream migration from the Brothers River.

This study identified holding areas in the lower Pascagoula River that serve as critical habitat for Gulf sturgeon during the summer and fall. The importance of these areas is heightened by recent findings that individuals located here represent multiple genetic stocks (Dugo et al., 2004). Most large rivers in the continental US are impounded or are greatly altered, which has contributed to the decline of diadromous species. The results of this study highlight the importance of natural streamflow and water temperature for Gulf sturgeon to complete their life history and the importance of free-flowing rivers for migratory species.

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References

Bailey, R. M.; Cross, F. B., 1954: River sturgeons of the American genus *Scaphirhynchus*: characters, distribution, and synonymy. Pap. Mich. Acad. Sci. Arts Lett. **39,** 168–208.

Clarke, K. R.; Green, R. H., 1988: Statistical design and analysis for a 'biological effects' study. Mar. Ecol. Prog. Ser. **46,** 213–226.

Clarke, K. R.; Warwick, R. M., 2001: Change in marine communities: an approach to statistical analysis and interpretation, 2nd edn. Natural Environment Research Council, Plymouth Marine Laboratory, Plymouth, UK.

Clugston, J. P.; Foster, A. M.; Carr, S. H., 1995: Gulf sturgeon, *Acipenser oxyrinchus desotoi*, in the Suwannee River, Florida, USA. In: Proc. 2nd international symposium on sturgeon (September 1993, Moscow). A. D. Gershanovich and T. I. J. Smith (Eds). VNIRO Publishing, Moscow, pp. 215–224.

Dugo, M. A.; Kreiser, B. R.; Ross, S. T.; Slack, W. T.; Heise, R. J.; Bowen, B. R., 2004: Conservation and management implications of fine-scale genetic structure of Gulf sturgeon in the Pascagoula River, Mississippi. J. Appl. Ichthyol. **20,** 243–251.

Dynesius, M.; Nilsson, C., 1994: Fragmentation and flow regulation of river systems in the northern third of the world. Science **266,** 753–762.

Foster, A. M.; Clugston, J. P., 1997: Seasonal migration of Gulf sturgeon in the Suwannee River, Florida. Trans. Am. Fish Soc. **126,** 302–308.

Heise, R. J.; Slack, W. T.; Ross, S. T.; Dugo, M. A., 2004: Spawning and associated movement patterns of Gulf sturgeon in the Pascagoula River drainage, Mississippi. Trans. Am. Fish Soc. **133,** 221–230.

Hightower, J. E.; Zehfuss, K. P.; Fox, D. A.; Parauka, F. M., 2002: Summer habitat use by Gulf sturgeon in the Choctawhatchee River, Florida. J. Appl. Ichthyol. **18,** 595–600.

Matthews, W. J., 1985: Distribution of midwestern fishes on multivariate environmental gradients, with emphasis on *Notropis lutrensis*. Am. Midland Nat. **113,** 225–237.

Mississippi Museum of Natural Science (MMNS), 2001: Endangered species of Mississippi. Mississippi Department of Wildlife, Fisheries and Parks, Museum of Natural Science, Jackson, Mississippi.

Morrow, J. V., Jr; Kirk, K. P.; Killgore, K. J.; Rogillio, H.; Knight, C., 1998: Status and recovery potential of Gulf sturgeon in the Pearl River system, Louisiana-Mississippi. North Am. J. Fish. Manage. **18,** 798–808.

National Climate Data Center, 2002: Climate division drought data. Available from the internet: http://lwf.ncdc.noaa.gov/oa/ncdc.html.

Plunkett, M. L.; Morris, F., III; Turnipseed, D. P., 2001: Water resources data, Mississippi, water year 2000. United States Geological Survey report number USGS-WDR-MS-00-1.

Rebich, R. A.; Landers, M. N., 1990: Upstream extent of saline water in the Pascagoula River. In: Proc. XX. Annual Mississippi water resources conference, 10–11 April 1990, Jackson, Mississippi. B. Jean Daniel (Ed.). Mississippi Water Resources Research Institute, Mississippi State University, Mississippi, pp. 98–104.

Ross, S. T.; Doherty, T. A., 1994: Short-term persistence and stability of barrier island fish assemblages. Estuarine Coast. Shelf Sci. **38,** 49–67.

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

United States Army Corps of Engineers, Mobile District, 1968: Pascagoula River comprehensive basin study. Summary Report, Mobile, Alabama.

United States Fish and Wildlife Service, 1992: Standard operating procedures for sturgeon. Panama City Field Office, Panama City, Florida.

United States Fish and Wildlife Service and Gulf States Marine Fisheries Commission, 1995: Gulf sturgeon recovery plan. US-FWS and GSMFC, Atlanta, Georgia.

Wooley, C. M., 1985: Evaluation of morphometric characters used in taxonomic separation of Gulf of Mexico sturgeon, *Acipenser oxyrhynchus desotoi*. In: North American sturgeon: developments in environmental biology of fishes, vol. 6. F. Binkowski and S. I. Doroshov (Eds). Dr W. Junk, Dordrecht, The Netherlands, pp. 97–103.

Wooley, C. M.; Crateau, E. J., 1985: Movement, microhabitat exploitation and management of Gulf of Mexico sturgeon, Apalachicola River, Florida. North Am. J. Fish Manage. **5,** 590–605.

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