Assessment of the seasonal usage of the lower Pascagoula River estuary by Gulf sturgeon (Acipenser oxyrinchus desotoi)

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Summary
The Pascagoula watershed likely offers the greatest possibility for the survival of the Gulf sturgeon, Acipenser oxyrinchus desotoi, within Mississippi. Thus, understanding and preserving the connectivity between distant habitats in this region plays a major role in protecting and managing such anadromous fish populations. The focus of this project was to determine the within-river routes Gulf sturgeon take through the lower Pascagoula River downstream of the point where it splits (river kilometer 23) into two distinct distributaries. Sixty days were sampled throughout a two-year period with a total effort of 81 947 net-meter-hours and eight Gulf sturgeon were captured, ranging from 74 to 189 cm FL and weighing from 3.6 to 52.6 kg. Using an array of automated telemetry receivers, acoustically tagged Gulf sturgeon movements were monitored within the lower river and associated estuary. Estimated residence times (days) suggest Gulf sturgeon appear to prefer the eastern distributary upriver from Bayou Chemise as the primary travel corridor between freshwater habitats and marine feeding grounds. The western distributary mouth was more highly used by Gulf sturgeon during both seasonal migrations between upriver and offshore habitats. Thus, the western distributary appears to represent the main entrance point utilized by Gulf sturgeon to the Pascagoula River watershed and should be protected as the eastern distributary mouth has been altered from a natural marsh edge to one of hardened surfaces.

Introduction
The Gulf sturgeon, Acipenser oxyrinchus desotoi, occurs in drainages extending from the Suwannee River in Florida to the Pearl River in eastern Louisiana (Wooley, 1985; Rogilillo et al., 2007; Ross et al., 2009). Across the Gulf of Mexico, research has focused mainly on coarse-scale patterns of life history. Gulf sturgeon spawn in the early spring (Sulak and Clugston, 1998; Heise et al., 2004) and young-of-the-year (YOY) spend 9–10 months feeding in the river before they appear in the estuary in December–February (Sulak and Clugston, 1998). Juveniles (<6 years; except YOY) are believed to overwinter in the estuary (Sulak and Clugston, 1998, 1999; Sulak and Randall, 2002; Sulak et al., 2009). In Mississippi, sub-adult and adult Gulf sturgeon overwinter in the Mississippi Sound, congregating near the passes between barrier islands (Ross et al., 2009). The spring migration is segregated into spawners and non-spawners. Spawners enter the river in early spring and travel to the spawning grounds where they remain for discrete spawning events before they move downriver to the in-river holding area (Fox et al., 2000; Heise et al., 2004). In contrast, non-spawning late juvenile and sub-adult Gulf sturgeon migrate to in-river holding areas in late May–June (Foster and Clugston, 1997; Heise et al., 2005). It is clear that the role of the estuary in the life history of Gulf sturgeon changes with ontogeny from a foraging habitat to a travel corridor, linking vital spawning and summer holding habitats with both nearshore and offshore marine feeding locales. Alteration of this landscape-scale habitat connectivity pathway has negatively impacted other sturgeon populations (U.S. Fish and Wildlife Service and Gulf States Marine Fisheries Commission, 1995; Kreiser et al., 2008; Yi et al., 2009). Thus, maintenance and protection are particularly relevant for the Gulf sturgeon as it is listed as threatened under the Endangered Species Act (USFWS, 1991; U.S. Fish and Wildlife Service and Gulf States Marine Fisheries Commission, 1995) and is state listed as endangered in Mississippi (MMNS, 2001). The specific objective of this project was to assess small-scale estuarine migratory patterns of Gulf sturgeon into and out of the Pascagoula River watershed seasonally, among size classes, and among river (array) segments.

Materials and methods
Study area
The Pascagoula River, located in south-eastern Mississippi, USA, has a watershed draining about 24 844 km² and is the last large river system within the conterminous US with no dams or impoundments on the main channel (Dynesius and Nilsson, 1994). The river splits into two distributaries about 23 river kilometers (rkms) north of the mouth (Fig. 1) with the first 12 rkms of the eastern distributary having a regularly maintained dredged ship channel (shaded navigation channel, Fig. 1) and a large shipyard. In contrast, the western distributary is comparatively non-impacted shallow salt marsh habitat (Peterson et al., 2007). Bayou Chemise is a natural waterway tributary that joins the two distributaries at rkms 5 to the east and rkms 3 on the west; there are also two dredged connections, one located at Interstate 10 (I-10) and the other just north of Highway 90 (Hwy 90).

Sampling
Sampling locations changed seasonally, reflecting the spring upriver and fall downriver movements of Gulf sturgeon (Fig. 1; Table 1). Spring sampling (2008 and 2009) was conducted in the lower Pascagoula River using anchored gill nets set parallel and perpendicular to flow in the western
Gulf sturgeon were weighed (nearest 0.1 kg) and measured to fork length (FL, cm), and assessed for previous capture by the presence of external tags and/or internal passive integrated transponder (PIT) tags. New captures were tagged with T-bar and PIT tags, as in Heise et al. (2004).

Fish were tagged externally with a uniquely coded low-powered acoustic tag (Model V9-2L; 69 kHz, 10 month battery life with a 60 s random delay; Vemco, Canada) at the base of the dorsal fin (see Sulak et al., 2009; Apalachicola pilot project). Tagging wounds were treated with Stress Coat (Aquarium Pharmaceuticals, Inc.) prior to release. Captured Gulf sturgeon were categorized as adult (>1250 mm FL), sub-adult (891–1250 mm FL), and late juvenile (304–890 mm FL; Parauka et al., 2011), and released at a moored telemetry receiver to record the release time. Sampling effort was calculated as net-meters-hours (net-m-hrs) as described in Peterson et al. (2008).

Automated telemetry arrays
Automated VR2W receiver arrays (Vemco, Canada; hereafter ‘array’) were used to track all tagged Gulf sturgeon. Receivers were anchored using concrete blocks (68 kg) within the river as a series of gates (Fig. 1, receivers 1–6, 11), to monitor movement between distributaries through Bayou Chemise (Fig. 1, receivers 3 and 4), and along the mouths of the distributaries forming curtains of detection (Fig. 1, receivers 7–10, 12–14). Receivers were positioned at the surface in a top down orientation (Sulak et al., 2009), with an assumed detection radius between 600 and 750 m (Havrylkoff, 2010; Mike Randall, USGS, pers. comm.).

The arrays were deployed from October 2008 to December 2009. The fall 2008 array consisted of 15 VR2W receivers (Fig. 1, I-IV and 1–11). Receivers 1–11 remained in place throughout the study period and receivers II–IV were relocated to positions 12–14 (Fig. 1) from January 2009 to December 2009. Receiver I was lost. This array was divided spatially into north (receivers I–IV, fall 2008), middle (receivers 1–5, entire study), and south (receivers 6–11, 2008, and 6–14, 2009) segments for descriptive and analytical purposes (Fig. 1).

Automated telemetry analysis
The automated array was divided in the estuarine area north and south of Hwy 90 (spring 2009; fall 2008, 2009). For the fall 2008 and 2009 collections, the pooling of data was based on the fact that the hydrology was similar between those years (National Drought Mitigation Center; http://drought.unl.edu/). Fall was defined as between October and November; spring was defined as between March and May. Residence period (days; sensu Chittenden et al., 2008) within each segment of the array (i.e. north, middle, south) was

Table 1
Seasonal gill net sampling effort

<table>
<thead>
<tr>
<th>Sampling year</th>
<th>Month range</th>
<th>Days</th>
<th>Sets</th>
<th>Total Net-m-hrs</th>
<th>Number of Gulf sturgeon</th>
<th>Gulf sturgeon CPUE</th>
<th>Net bar mesh size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Feb – Apr</td>
<td>16</td>
<td>62</td>
<td>25 987</td>
<td>1</td>
<td>3.85E-05</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Oct – Nov</td>
<td>18</td>
<td>54</td>
<td>26 646</td>
<td>5</td>
<td>1.88E-04</td>
<td>5.1, 12.7, 20.3</td>
</tr>
<tr>
<td>2009</td>
<td>Jan – Apr</td>
<td>18</td>
<td>59</td>
<td>24 680</td>
<td>1</td>
<td>4.05E-05</td>
<td>5.1, 12.7</td>
</tr>
<tr>
<td></td>
<td>May – Sept</td>
<td>9</td>
<td>13</td>
<td>4634</td>
<td>1</td>
<td>2.16E-04</td>
<td>12.7, 20.3</td>
</tr>
</tbody>
</table>
calculated 1) when the fish moved sequentially through one segment (e.g. north or south) into the other segment, or 2) when the movement pattern observed was non-continuous; that is, when the detections were not considered spatially or temporally sequential. In order to calculate residence time in the second case, the last known detection within the north segment, for example, was subtracted from the first within the north segment and the last detection within the middle segment was subtracted from the first detection within the middle segment. Absences of ≥7 days were not included in calculation of residence times.

Calculations of time spent in each distributary (i.e. west vs east) exclude any time spent within Bayou Chemise. Use of Bayou Chemise as a conduit was determined based on sequential detection at both the east (receiver 3) and west end (receiver 4; Fig. 1) of the bayou. All calculations described above are conservative estimates of residence time. The means (±SE, standard error) of total time per distributary (east vs west) for each size class were plotted to display how use varied among segments of the telemetry array seasonally. The fall north (2008) and all spring graphs display the results of a single season. The middle and south segment fall graphs represent the pooled results from two fall seasons (2008 and 2009).

Residence time (days) among Gulf sturgeon size classes was compared within array and season and between east vs west distributaries within size class, where possible, with either a Students t-test or one-way ANOVA, after examining data for normality and homogeneity of variance. For ANOVA, a Sidak or Games-Howell (unequal variance) post-hoc test was used to separate means if the overall model was significant (P < 0.05).

Results

Sampling occurred at a number of localities within the watershed. Effort was similar between spring (mean effort: 25 333 net-m-hrs) and fall seasons (26 646 net-m-hrs), but reduced in the summer season (4551 net-m-hrs). Spring estuarine sampling resulted in the capture of one sub-adult Gulf sturgeon, both from Bayou Chemise. Fall upriver sampling resulted in capturing and tagging two adult, one sub-adult and two late juvenile Gulf sturgeon. Summer upriver sampling resulted in the capture of one sub-adult within the summer holding area. Details regarding seasonal sampling effort can be found in Table 1. Size of captured sturgeon ranged from 74–189 cm FL, with weights ranging from 3.6 to 52.6 kg (Table 2).

Table 2
Summary data, captured Gulf sturgeon, Pascagoula River watershed

<table>
<thead>
<tr>
<th>Capture</th>
<th>FL (cm)</th>
<th>Weight (kg)</th>
<th>Age category</th>
<th>Fish tag #</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Apr 2008</td>
<td>78</td>
<td>3.6</td>
<td>LJ</td>
<td>9468</td>
</tr>
<tr>
<td>14 Oct 2008</td>
<td>189</td>
<td>52.6</td>
<td>A</td>
<td>9466</td>
</tr>
<tr>
<td>24 Oct 2008</td>
<td>87</td>
<td>6.4</td>
<td>LJ</td>
<td>9464</td>
</tr>
<tr>
<td>28 Oct 2008</td>
<td>110</td>
<td>11.9</td>
<td>SA</td>
<td>9469</td>
</tr>
<tr>
<td>28 Oct 2008</td>
<td>157</td>
<td>31.7</td>
<td>A</td>
<td>9459</td>
</tr>
<tr>
<td>28 Oct 2008</td>
<td>74</td>
<td>4.4</td>
<td>LJ</td>
<td>9463</td>
</tr>
<tr>
<td>11 Mar 2009</td>
<td>96</td>
<td>6.0</td>
<td>SA</td>
<td>9460</td>
</tr>
<tr>
<td>9 Sept 2009</td>
<td>135</td>
<td>17.7</td>
<td>A</td>
<td>9474</td>
</tr>
</tbody>
</table>

LJ, late-juvenile; SA, sub-adult; A, adult; FL, fork length.

Fall movements

The north segment of the array was only in place during the fall 2008 migration. During this time, six tags were active and detected within this array segment from 14 October to 7 November 2008. Five sturgeon representing all size classes were detected migrating to the estuary within the eastern distributary. Only a single late juvenile used the western distributary during this period of fall migration. Mean time (days) to traverse this segment (eastern distributary) was negatively correlated with fish size. The time late juveniles spent in this segment of the array did not differ between distributaries (Fig. 2a, Table 3; P > 0.05).

Total time spent by each fish per segment (i.e. middle or south segment of the array) for both fall seasons (2008, 2009) were pooled within size classes to compare how use of the distributaries varied within segments (Fig. 2b,c). Movements within the middle and south segments were monitored from fall 2008 to fall 2009. Increased variation among size classes was noted in residence time, path, and percent time spent (see Table 3) within each distributary during year one within the fall middle segment. Less variation was observed in year two when only two Gulf sturgeon (an adult and a sub-adult) had active tags (Table 3). Gulf sturgeon were detected within the middle fall segment between 26 October and 16 November 2008 and 18–20 October and 13–14 November 2009. Mean residence time within this segment in year 1 ranged from 0.46 to 5.56 days (mean = 2.2 days) and in 2009 ranged from 0.5 to 2.1 days (mean = 1.3 days; Table 3) but neither sub-adult nor adult residence time differed between distributaries (P > 0.05; Fig. 2b). Two fish (one adult #9466 and one late juvenile #9468; 2008) were detected migrating solely within the eastern distributary. Two fish (one late juvenile #9464, 2008, and one adult #9474, 2009) were detected migrating solely within the western distributary. Four fish (one adult #9459, two sub-adults #9469, 2008 and #9460, 2009 and one late juvenile #9463, 2008) were detected migrating downriver within the eastern distributary only as far as Bayou Chemise, before crossing over and continuing the remainder through the western distributary.

Tagged Gulf sturgeon were detected within the south fall segment (Fig. 2c) of the array between 28 October and 16 November 2008 and 20 October to 22 November 2009. Mean residence time within this segment ranged from 0.003 to 6.79 days (mean = 1.9 days) in 2008 and from 7.8 to 17.7 days in 2009 (mean = 12.7 days; Table 3) but did not differ (P > 0.05) between size classes (Fig. 2c). Movements within the south segment during fall 2008 migration showed that fish of all size classes used the west river mouth more so than the east river mouth. One adult (#9466) was detected briefly at the eastern river mouth. One fish was not detected within the south segment in 2008 (late juvenile #9468). Five fish representing all size classes were detected moving solely within the western south segment during fall migrations (#9459, 9474, 9469, 9463, and 9464; Fig. 2c). Sub-adult #9460 moved widely throughout the western south segment before being detected very briefly at the eastern river mouth.

Spring movements

Four tagged Gulf sturgeon were detected within the middle spring segment of the array between 11 March and 27 May 2009. Residence time within the middle segment ranged from 3.9 to 30.5 days (mean = 12.7 days; Table 3), but there was
no difference ($P > 0.05$) in residence time between late juveniles and sub-adults in the east distributary, nor adults between east and west distributaries (Fig. 2d). Three fish tracked during fall 2008 were detected during the spring upriver migration (late juveniles #9463, 9464, and sub-adult #9469). Of the two late juveniles, both were detected migrating north out of the middle segment of the array via the same distributary they used during the fall migration. Three fish (#s 9460, 9469 and 9464, two sub-adults and late juvenile, respectively) were observed to use both distributaries during this time. One late juvenile (#9463) was detected solely within the eastern distributary. A sub-adult (#9460) used Bayou Chemise to travel between the distributaries; the other sub-adult (#9469) is assumed to have used the man-made channel located immediately north of Hwy 90 to travel from the eastern to the western river mouth during this time. One late juvenile (#9464) used each distributary river mouth to separately access each of the distributaries.

Four tagged Gulf sturgeon were detected within the south spring segment of the array between 12 March and 21 April 2009 (Fig. 2e); residence time within the south segment ranged from 0.17 to 15.4 days (mean $= 4.6$ days; Table 3). Three of these fish had been tracked during the fall 2008 migration. The movement of these three (#s 9463, 9464, and 9469), two late juveniles and a sub-adult, respectively, were pooled with the movements recorded for the one sub-adult captured during spring 2009 sampling (#9460; Table 3). Late juvenile #9463 is assumed to have entered the eastern distributary via the eastern river mouth, but was not detected on any receivers within the south segment of the array. Both sub-adults (#9469 and 9460) were detected solely using the western distributary south segment of the array (Table 3).

All tagged fish, except a late juvenile (#9463), spent more than 90% of their time within a single distributary (sub-adult #9469 in east, and sub-adult #9460 and late juvenile #9464 in the west; Table 3). One late juvenile (#9464) is assumed to have used the man-made connection located at I-10 to travel between the distributaries. None of the fish that used Bayou Chemise during the fall migration were observed using it again during spring. One fish from each of the size classes represented during this season was detected migrating north out of the array via each distributary (#s 9463 and 9460 via east, and #s 9464 and 9469 via west).

**Discussion**

Data gathered by the telemetry arrays indicated that Gulf sturgeon movements through the estuary are highly varied. For example, in-river movements varied most within the region between I-10 and Hwy 90 and some fish traveled upriver and downriver rapidly through this region, whereas other fish were detected seasonally moving upriver (spring) or downriver (fall). Moreover, a single fish was observed to hold for three days in the east mouth of Bayou Chemise while other fish moved rapidly through as they traveled both upriver and downriver. Similar upriver and downriver movement patterns have been reported in the Suwannee River (Sulak and Clugston, 1999). The significance of this bidirectional behavior is unknown, as other fish were only detected traveling in a unidirectional manner.

Telemetry results have identified Bayou Chemise and the eastern distributary (north of Hwy 90) as previously unknown travel corridors connecting upriver freshwater habitat with estuarine nearshore and offshore habitats associated with the western distributary within the lower Pascagoula. Previous telemetry studies (Heise et al., 2004, 2005) within this drainage had comparatively few relocations of tagged Gulf sturgeon within the eastern distributary and it was subsequently believed that the western distributary was the primary travel corridor. One possible explanation of the movement patterns associated with the two distributaries is an avoidance of the highly impacted area around the eastern distributary mouth, which includes significant industrial/commercial traffic and a large shipyard (Peterson et al., 2007; Partyka and Peterson, 2008). However, total avoidance of this area was not observed, as an adult and late juvenile were
observed to travel through the eastern distributary during fall and spring migrations, respectively. Furthermore, several late juvenile and sub-adults went undetected through the south segment of the array and were last detected within the eastern distributary. Manual tracking (see Havrylkoff, 2010) throughout the array south of I-10 failed to relocate those fish and the most parsimonious route out of the array would have been through the eastern distributary mouth.

Juvenile, sub-adult, and adult Gulf sturgeon tagged during our study generally spent the same amount of time in the fall arrays in estuarine waters (middle and south arrays), although small sample sizes influence these results. However, more recent research by the present authors suggests that adults spend less time there compared to juveniles and sub-adults (M. S. Peterson, unpublished data). Several studies have found that adults and sub-adults remain for several weeks in nearshore estuarine waters of Florida following the fall downriver migration (Carr et al., 1996; Sulak and Clugston, 1999). The present study has produced evidence of prolonged and extensive use of the Pascagoula River mouth and immediate adjacent coastal habitats associated with the western distributary in April and May by four Gulf sturgeon detected within the arrays during seasonal migrations. Previous manual tracking activity within this system did not detect any tagged Gulf sturgeon, regardless of size, within the coastal nearshore environment between April and September despite regular and persistent manual tracking (Ross et al., 2009). The use of automated receivers acting as anchored tracking stations that were monitoring continuously allowed for expansion of knowledge of Gulf sturgeon estuarine use while reducing manpower.

Management of Gulf sturgeon and their continued survival in Mississippi requires protection of areas where Gulf sturgeon feed in winter, spawn in spring, and hold during summer months. The maintenance of this connectivity between these major habitats and protecting critical habitat vulnerable to ongoing anthropogenic coastal development (Peterson and Lowe, 2009) are vital to sustaining Gulf sturgeon populations. Moreover, it is also important to protect natural flow cycles within the drainage as they set migratory cues (fall and spring) (Fox et al., 2000; Parauka et al., 2001; Heise et al., 2004, 2005) and protect available spawning habitat (Heise et al., 2004; Randall and Sulak, 2007; Kreiser et al., 2008; Flowers et al., 2009). Development projects that reduce water flow within coastal rivers can directly affect recruitment and survival within the drainage, remove natural migratory cues, and lead to habitat loss in the form of low salinity coastal waters rich in potential prey and should therefore be avoided. Data presented in this study illustrates the importance of connectivity, highlights new areas used by the Pascagoula population during migration and estuarine residency, and provides a launching point for future research.

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