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Movements of Gulf Sturgeon (*Acipenser oxyrinchus desotoi*) in Nearshore Habitat as Determined by Acoustic Telemetry

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Gulf sturgeon were tagged with telemetry tags and were tracked and relocated in fall and early winter of 1996 and 1998 to determine migration patterns and winter feeding habitats after they emigrated from the Suwannee River, Florida, into the Gulf of Mexico. We hypothesized that their migration would generally follow the drowned Suwannee River channel across the West Florida shelf. Fish left the river in late Oct. or early Nov., about the time river water temperatures fell below 20 C. Tracked and relocated fish moved slowly and remained offshore of Suwannee Sound in nearby shallow (<6 m) marine–estuarine habitats until at least mid or late Dec. The relatively small area (~115 km^2) within which fish were consistently relocated in 1998 probably is a critically important feeding habitat because adult Gulf sturgeon, which do not feed while in the river, occupy it for up to half their short (4–5 mo) marine residency. The fish left the area in late Dec. or early Jan., most likely in response to powerful cold front–generated weather conditions (under which, boat-based acoustic tracking is infeasible). A large (1,760 km^2) adjacent area was searched for sonic-tagged sturgeon in early Jan. 1999, but only one was relocated (~50 km northwest of the Nov.–Dec. area). Although we were unable to address the hypothesis that their migration follows the Suwannee paleochannel, the results do indicate that Gulf sturgeon move to yet unknown, distant, late-winter feeding areas of the Gulf of Mexico before returning to the river in spring.

The Gulf sturgeon (*Acipenser oxyrinchus desotoi*) is anadromous, entering the Suwannee River from the Gulf of Mexico from mid-Feb. to May (Foster and Clugston, 1997; Sulak and Clugston, 1999), moving upriver to spawn primarily in March and April (Sulak and Clugston, 1998), probably in response to both water temperature (Fox et al., 2000) and spring high tides (Sulak and Clugston, 1999). Gulf sturgeon remain in the river until late fall but do not feed while in freshwater (Mason and Clugston, 1993; Gu et al., 2001). Adults begin moving down the river around Sep. and enter the Gulf by early Dec. (Carr et al., 1996; Foster and Clugston, 1997), where they feed intensively during winter (Wooley and Crateau, 1985; Clugston et al., 1995). Juveniles [less than 1,000 mm in total length (TL), less than age 6 yr] remain in the river or nearby estuarine environments during winter (Foster and Clugston, 1997; Sulak and Clugston, 1999).

Before our study, very little was known about Gulf sturgeon movements or habitats once they leave Gulf Coast rivers. One Gulf sturgeon was tracked in 1989 for 72 hr in Apalachicola Bay (U.S. Fish and Wildlife Service, 1989); four sonic-tagged Gulf sturgeon were relocated within Suwannee Sound about 7 km south of the East Pass river mouth on 1 or 2 d (one fish relocated once and the others twice) of the last 10 d of Oct. 1991 (A. M. Foster, pers. comm.); and 16 other sonic-tagged sturgeon were relocated within Suwannee Sound approximately 3–4 km south of the river mouth (Carr et al., 1996; details not provided). Gulf sturgeon, from the Choctawhatchee River, were acoustically relocated during 1997–99 in Choctawhatchee Bay (Fox et al., 2002).

To determine fall movement and emigration patterns, we tagged and released adult sturgeon temporarily held in tanks near the mouth of the Suwannee River. We hypothesized that the released fish would respond to environmental cues and begin emigrating. By tracking these fish, we planned to determine migratory directions, paths, and destinations. At the same time, we also planned to relocate other adult sturgeon that previously had been fitted with tags and immediately released without being held. We also hypothesized that emigrating sturgeon would generally follow the Suwannee River paleochannel (Wright, 1995) across the continental shelf as they retraced a migration route (that has very gradually lengthened as sea level has risen) to deep-water habitats. Preliminary analysis of 1996 results led us to modify our 1998 strategy. In 1998, sturgeon were collected using gill nets as they migrated down the Suwannee River, and all were immediately released after being tagged. The fish were to

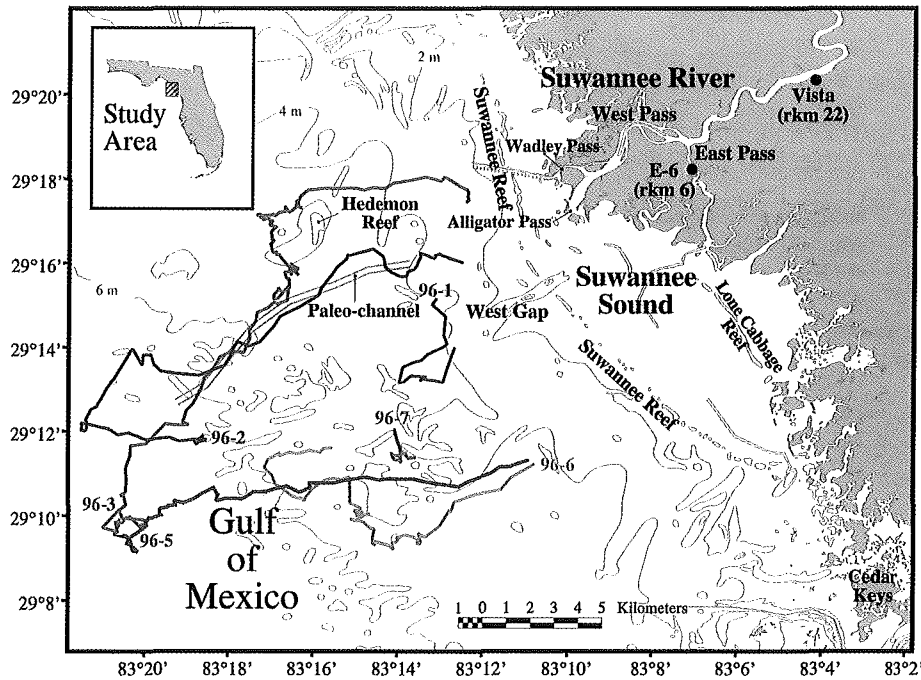

Fig. 1. Study area: Suwannee River, Suwannee Sound, Suwannee Reef, and nearshore Gulf of Mexico. Also shown are 1996 tracks (excluding 96-4), location of paleochannel (from Wright, 1995), and automatic detection stations E-6 (rkm 6) and Vista (rkm 22). Tracks are labeled near start points.

be later relocated in the lower river or nearshore estuarine areas and would be tracked once migration commenced.

Study Site

The study was conducted in the Suwannee River, Suwannee Sound, and adjacent nearshore areas of the Gulf of Mexico (Fig. 1). Near its mouth, the Suwannee River branches into East Pass and West Pass. A channel continues from the mouth of East Pass and ends in mid-Suwannee Sound. Sturgeon adults mainly use East Pass for emigration and immigration (K. Sulak, unpubl. data). West Pass divides into two primary channels, Wadley Pass and Alligator Pass. Wadley Pass is connected to the Gulf by a straight, dredged channel across the northern portion of the sound. Alligator Pass is connected to the Gulf by an undredged, natural channel that leads to West Gap, a natural channel through Suwannee Reef. The deeper western portion of this channel traverses an area of infilled paleochannel incisions that are similar in morphology to the branching pass system formed by the modern Suwannee delta (Wright, 1995). An infilled paleochannel similar to the present Suwannee River channel begins near West Gap and heads southwest across the inner shelf (Wright, 1995). Suwannee Sound is shallow (typically less than 2 m) estuarine (salinity, 15–25 ppt) basin enclosed seaward by Suwannee Reef—an approximately 27-km-long arc of oyster reefs and shoals. Suwannee Sound is about 18 km long and about 8 km wide at its widest point. Ecologically, we include the narrow northwestern arm of the sound confined to seaward by Suwannee Reef (Fig. 1). Nearshore areas immediately seaward of Suwannee Sound are characterized by soft organic-rich sediments derived from outflow of the river.

Methods

Studies to determine migratory patterns and marine habitats were conducted in two segments: late 1996 to early 1997 and 1998 to early 1999. In 1996 we captured sturgeon as they migrated down river and either tagged and released them immediately or held them in tanks near the river mouth, where adults normally delay or stage (Wooley and Crateau, 1985; Carr et al., 1996) before migrating into the Gulf of Mexico. Tank-held fish were telemetry tagged and released just offshore in the Gulf when other sturgeon were emigrating from the Suwannee.

TABLE 1. Tag code, total length (TL), weight, and track number for Gulf sturgeon tagged with transmitters in 1996 and 1998.

1996				1998		
Tag code	TL (cm)	Weight (g)	Track	Tag code	TL (cm)	Weight (g)
18	153	19,750		237	164	24,000
21	136	13,500		255	166	24,500
23	151	18,750	96-6	275	172	36,500
25	151	20,400		284	200	56,000
28	140	22,800		293	174	39,250
29[a]	158	22,000		336	182	41,500
41	152	23,500		337	185	37,000
42/64	149	19,000		345	148	30,000
44	139	15,500		364	197	46,000
45	139	13,800		444	180	41,000
54/66	127	12,750		545	177	36,000
65	150	19,600		2226	186	42,300
70	136	14,500		2235	188	46,500
77/512[a]	154	19,500		2334	197	42,500
78	121	9,500	96-7	3445	180	47,500
79/267[a]	154	25,900	96-2	3535	201	62,000
80/533[a]	192	51,500	96-5	4477	178	38,000
94/294[a]	166	23,500	96-4	4567	159	36,000
100/348[a]	157	24,000	96-3	4666	191	46,000
105/375[a]	181	29,000	96-1			
285	159	22,800				
2444	163	21,500				
2453	145	21,500				

[a] Archival tag also attached.

Adult sturgeon were collected with set and drift gill nets (20- to 30-cm stretch mesh) during fall of 1996 and in late summer and fall of 1998. Collecting methodology is detailed by Sulak and Clugston (1998, 1999). Transmitter tags were attached to adult sturgeon using monel wire (2.5-mm diameter) that was inserted through holes drilled through the anterior dorsal scutes along the middorsal crest and crimped on the opposite side (Wooley and Crateau, 1985; Foster and Clugston, 1997). Fish were also tagged with t-bar tags (Floy Tag Inc., # FD-94) in both pectoral fins.

Three types of transmitter tags were used during the studies: 1) 12-mo, audibly coded (sequence of pulses and intervals) acoustic tags (Sonotronics CT-82-2); 2) 6-mo, algorithmic-coded acoustic tags (Lotek CAFT-3), and 3) 6-mo, algorithmic-coded acoustic/radio tags (Lotek CART-3). Some fish were equipped with two types of tags (e.g., Lotek CART or CAFT + Sonotronics) in 1996. Audibly coded acoustic tags were used exclusively in 1998.

Twenty-three Gulf sturgeon (1,214–1,920 mm TL, 9.5–51.5 kg) were equipped with telemetry tags in 1996 (Table 1). Ten fish were released immediately after being captured and tagged, and 13 fish were transported to holding tanks (4-m diameter, 1.5 m deep) near the mouth of the river and were held there for 27–45 d (mean = 34 d) until they were released. Water was supplied by continuous flow-through circulation of ambient river water. Five of the 13 fish were sequentially transported to a release site in a live-well boat, immediately tagged, released at 4, 14, 18, 85, and 18 km offshore from West Gap at depths of 5, 8, 9, 24, and 9 m, and tracked. The remaining fish were sequentially released but not initially tracked.

Seven sonic-tagged fish also were equipped with archival data tags (Vemco Model-TDR or Northwest Marine Technology Model-NMT) in 1996 (Table 1). Archival tags were attached to dorsal scutes using the same methods as for telemetry tags. Archival tags record information from temperature and pressure (depth) sensors several times a day and archive these data in memory.

Automatic detection–identification stations operated in the fall of 1996 from 18 Oct. to 19 Nov. at East Pass (E-6) at river kilometer (rkm) 6 and from 18 Oct. to 29 Oct. at Vista at rkm 22 (Fig. 1). Two receiver–datalogger instruments (Lotek Model SRX 400) were set up at E-6; one connected to a yagi antenna and configured to detect radiosignals (from Lotek CART tags) and the other connected to a hydrophone (Lotek LHP 1) to detect ultrasonic signals from Lotek CAFT and Lotek CART tags (when the latter were transmitting in the sonic mode). A similar receiver–datalogger was deployed in the radiomode at Vista Landing (rkm 22). Effective range within which hydrophones could identify coded tags was measured to be between 100 and 200 m, although noise from nearby boat motors could interfere with identification and in some instances produce spurious detection and identification. A tag was considered to have been positively detected and identified only if more than 10 detections–identifications (hits) were recorded in a discrete time period (<15 min).

In 1996, acoustic-tagged fish were tracked from the National Marine Fisheries Service research vessel RV *Caretta* (18-m length, converted shrimp trawler) rigged with a stereophonic tracking system (Edwards, 1999) using two hydrophones (Sonotronics DH-2, one on each side of the vessel) and two receivers (Sonotronics USR-4D). Detection range was consistently greater than 1.2 km in open water deeper than 3 m. An additional hydrophone (Lotek LHP 1, with directional reflector) and receiver (Lotek SRX 400) were used to identify Lotek transmitter tags detected while tracking. Tracked sturgeon movement speeds were calculated from straight-line distance between positions determined by differential global positioning system (GPS) and time (usually 15 min) between positions. Smoothed speeds were calculated for each position by dividing the summed distance intervals by the summed time intervals to the present and immediately previous positions. Because of uncertainty about the ability to track acoustically, the first two fish that were tracked in 1996 were initially tethered with 50 m of Spiderwire fishing line (20-kg breaking strength) tied to a float (15-cm diameter × 20 cm long) carrying a radiotransmitter. Tethering was discontinued for the remaining fish because acoustic tracking was found to be reliable.

Nineteen Gulf sturgeon (1,484–2,100 mm TL, 24.0–62.0 kg) were captured from 5 Aug. to 24 Nov. 1998, between rkm 0.5 and 200, equipped with sonic transmitters, and immediately released (Table 1). Searches were conducted from 4 Nov. through 22 Dec. to relocate and plot movements of tagged sturgeon as they moved from the river into Suwannee Sound and further into the adjacent Gulf. Most initial searches were conducted from either a 3-m outboard skiff or a 7-m net skiff that stopped approximately every 0.8 km. A directional hydrophone (Sonotronics DH-4) connected to an ultrasonic receiver (Sonotronics USR-4D) was used to scan for tagged fish. When a signal was detected, the boat was moved in the direction of the tagged fish until the tag code could be determined and its location could be estimated by GPS at the closest approach. Movements of some noticeably moving fish were monitored for up to 5 hr. Daily net movement for each fish was calculated by dividing the distance between first and last relocation points by number of days between those relocations. Because of weather conditions and staff schedules, relocation activities were suspended from 22 Dec. 1998 until 6 Jan. 1999.

Large areas were searched from 6 Jan. to 28 Feb. 1999 in an attempt to relocate sonic-tagged sturgeon. The boat was moved from point to point on a grid of stations located about 1.9 km apart. Any transmitter within these grids should have been detectable with a 1.2-km minimum effective radius of detection at each point. Searching was done from the US Geological Survey (USGS) RV *G. K. Gilbert* (16-m, shallow-draft research vessel), except on 6 Jan. and 19 Jan.–25 Feb. from a 3-m outboard, and on 7 and 14 Jan. from the University of Florida RV *Overtime* (8-m inboard). On 27–28 Feb. 1999, deep (40–50 m) soft-substrate areas just offshore of the Florida Middle Ground (Fig. 2) were searched aboard the FV *Lady Rover* (10-m commercial fishing vessel) to address the possibility of sturgeon using this area of known winter congregation of many bottom-fish species (Darnell and Kylypas, 1987). Area searched was estimated using a 1.2-km radius of detection for each search point. Areas of polygons enclosing these radii were measured using ArcView GIS and were summed to estimate total area searched.

RESULTS

The automatic detection stations detected three telemetry-tagged fish in Oct. and Nov. 1996. The first (tag code 54/66) was detected at Vista (rkm 22) on 18 Oct. (3 d after release at rkm 37) and at E-6 (rkm 6) on the next day. The second (42/64) was detected at Vista on 20 Oct., 5 d after capture and subsequently at E-6 only 4.3 hr later. It was again detected at E-6 4 d later and on the same day was detected upriver at Vista 8.7 hr later. It was detected again at Vista 2 and 3 d later and finally at E-6 on 9 Nov. The third fish (code 23) was de-

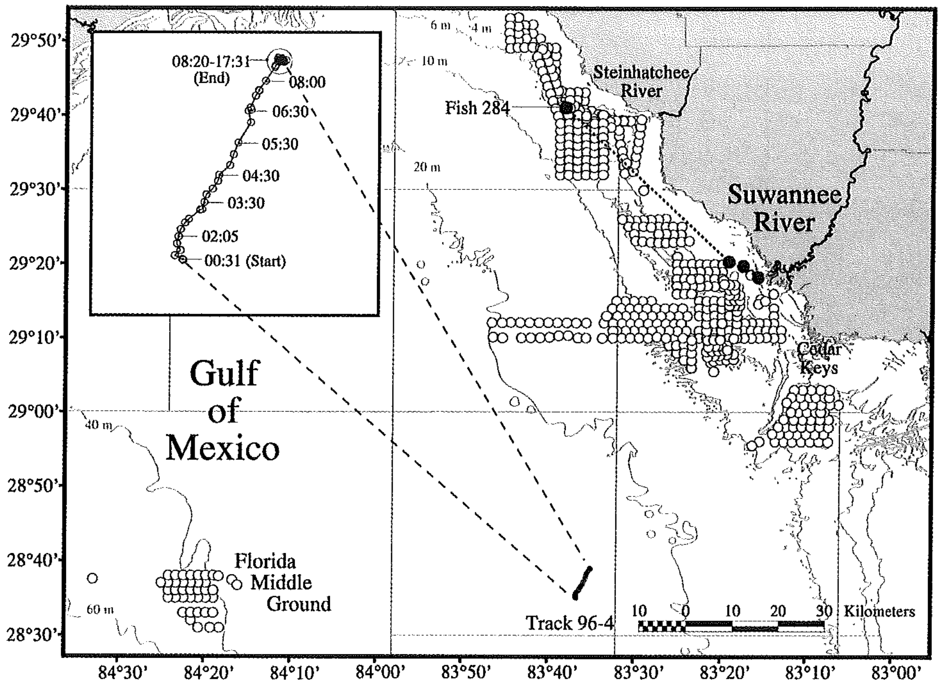

Fig. 2. Track 96-4, details of track 96-4 (inset), 1998–99 large-area surveys (open circles—radius = 1.2-km minimum detection range), fish-284 relocations (filled circles) 17 Nov.–10 Dec. 1998 and 16 Jan. and 19 Jan. 1999 relocations (off Steinhatchee), and offshore survey 27–28 Feb. 1999 (points near the Florida Middle Ground).

tected at E-6 (rkm 6) only on 10 Nov., 26 d after capture and tagging.

Seven fish were tracked in the Gulf of Mexico in Nov. and Dec. 1996 (Table 2). Tracks of these fish are shown in Fig. 1, except for track 96-4 that was located 85 km southwest of the other tracks (Fig. 2). In the first two tracks (96-1 and 96-2), the tether broke during the early portion of the track. Subsequent tracking showed that a tether was unnecessary.

All the four fish (96-1, 96-2, 96-3, and 96-5) that were released within 20 km offshore of Suwannee Reef eventually moved inshore. Initial movement in 96-1 and 96-2 was offshore for about 6 and 14 hr, before the fish began moving shoreward. Tracks 96-3 and 96-6 had shorter periods (2 and 3 hr) of initial looping before movement became shoreward. Track 96-3 differed from the others by virtue of meandering and looping that began about halfway along its shoreward segment, although movement was directly and consistently shoreward for 6 hr before reaching the offshore edge of Suwannee Reef.

TABLE 2. Track length, duration, and speed of Gulf sturgeon tracked in 1996.

Track	Length[a] (km)	Duration (hr)	Overall speed[b] (km/hr)	Mean speed[c] (SD) (km/hr)	N
96-1	8.9	12.3	0.7	0.8 (0.4)	21
96-2	35.0	35.9	1.0	0.8 (0.5)	82
96-3	39.7	43.6	0.9	1.0 (0.6)	155
96-4	10.3	17.0	0.6	0.7 (0.6)	52
96-5	19.5	16.1	1.2	1.3 (0.7)	61
96-6	24.9	24.6	1.0	1.0 (0.7)	96
96-7	3.6	5.9	0.6	0.6 (0.4)	25

[a] Sum of N straight-line segments.
[b] Track length/duration.
[c] Mean for segments.

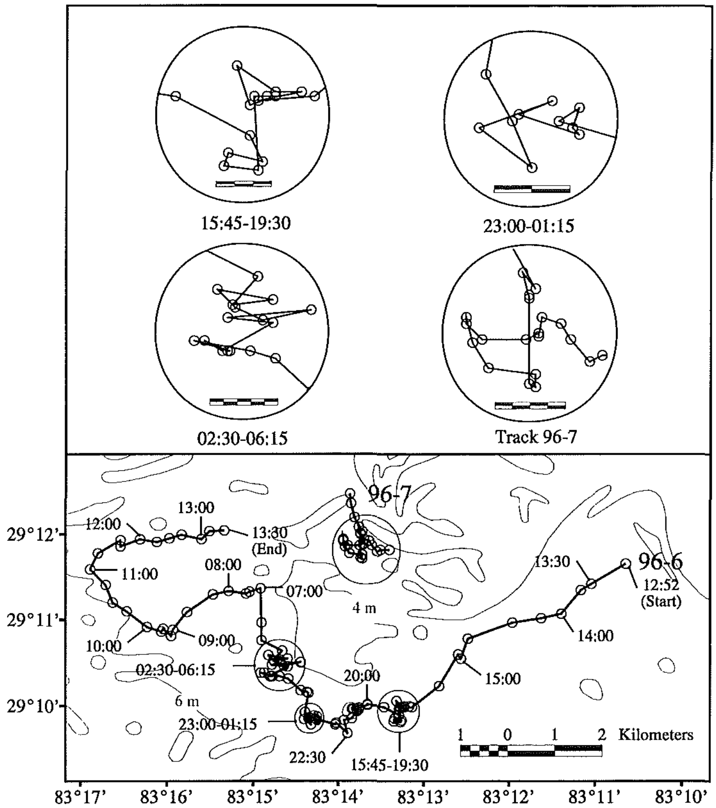

Fig. 3. Tracks 96-6 and 96-7, and details of 96-6 and 97-7 movements within small areas (1 scale division = 0.1 km).

Track 96-4 (Fig. 2) started 85 km south-southwest of West Gap, about 65 km offshore of the coastline and was characterized by consistent movement to the northwest for 6 hr until just before daylight. However, about 0.5 hr before daylight, the fish was observed swimming at the surface at the edge of the area illuminated by the vessel's deck lights. At that time, the lights were turned off, the vessel was moved about 0.5 km away at high speed, and tracking was continued while the vessel was kept at a distance of at least 0.3 km from the fish. Movement continued toward the northwest for 2 hr and then suddenly ceased. The track was terminated at that same location 9 hr later. Water depth in this track was 20–25 m.

Two of the tracks (96-6 and 96-7) (Fig. 3) were of fish that were encountered after they had been at liberty for many weeks and are shown in closer detail in Figure 3 insets. As track 96-5 was approaching Suwannee Reef, the signal from another acoustic tag was detected. Track 96-5 was terminated, and track 96-6 was started because it offered the opportunity to track a fish that had been at liberty for 57 d after being captured and equipped with a sonic tag. Movement in track 96-6 was generally offshore for 22.5 hr before it completed a clockwise loop and then began moving shoreward in a generally eastward course for 2 more hr until it was lost when receiver batteries failed unexpectedly. After unsuccessfully searching for 96-6 for 3 hr, another free-ranging, tagged fish (tagged 46 d earlier) was detected, and track 96-7 was begun. Movement in 96-7 (Fig. 3) was generally southward for 2.5 hr, after which the fish slowly looped clockwise and was moving shoreward when tracking was discontinued (because of scheduled cruise termination) after 6 hr. Water depth in these two tracks was 4–6 m.

Speed of movement of the seven tracked fish (examples given in Fig. 4) was highly variable, ranging from 0.0 to 3.7 km/hr, averaging 0.6–1.2 km/hr (Table 2). Speed was not obviously related to time of the day, with highest speeds at night in tracks 96-2 and 96-4 and highest speeds during daylight hours in 96-5 and 96-6. Track 96-2 speed was relatively high the first night but was low the second night, increasing

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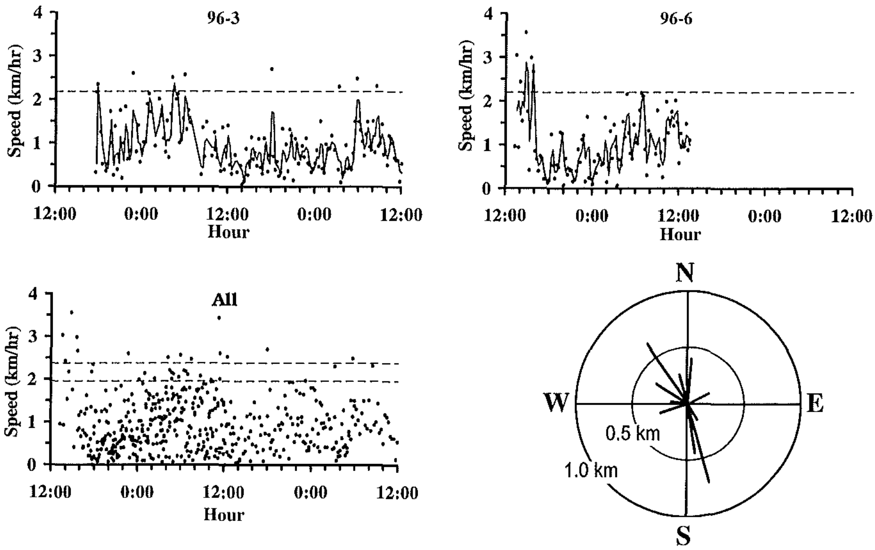

Fig. 4. Tracking speeds for tracks 96-3 and 96-6. Points are speeds calculated between positions, and solid lines are smoothed (sum of distance/sum of time for two most recent positions). Dashed lines are theoretical sustained speeds based on fish size (Weihs, 1977). Data points for all fish and theoretical sustained speeds for smallest and largest fish (dashed lines) are plotted together in the last panel (all). Also shown (lower right panel) are daily net displacements (net movement/d) of fish relocated in Nov.–Dec. 1998.

again after the second night. Tracks 96-1 and 96-7 were short and did not include comparable day and night periods. All tracks included intermittent periods of very low (<0.5 km/hr) speed, particularly within confined activity areas (e.g., Fig. 3 insets).

None of the archival tags deployed in 1996 were recovered in 1997 or 1998. Three of the fish (identified from t-bar tags as corresponding to tag codes 105, 77, and 29) were recaptured 869, 1,260, and 1,665 d after release but no longer carried their archival tag.

Eighteen of the 19 sturgeon tagged in 1998 were relocated (56 individual relocations) in Nov. and Dec. 1998 (Fig. 5), with individuals relocated from one to six times each during periods of up to 45 d between first and last relocation. Water depth at the relocation points ranged from 0.5 to 5 m (mean = 2.64, SE = 0.156) (Fig. 6). We planned to track sturgeon in 1998 only when they appeared to be emigrating from the area, but periodic relocation of acoustic-tagged fish indicated that most relocated fish were moving very little as late as 22 Dec. On that date, one fish was tracked to determine whether its movement was indicative of emigration. At the end of 5.1 hr, the fish was within 0.7 km of its initial position.

After relocation activities were resumed on 6 Jan. 1999, we did not relocate any sturgeon in the first 7 d of large-area searching. On 16 Jan., fish 284 was relocated (outside the main Nov.–Dec. activity area shown in Fig. 5) 64 km northwest of West Gap, offshore of Steinhatchee (Fig. 2), where water depth was 5 m and middepth temperature was 14.3 C. Fish 284 was again relocated on 19 Jan. less than 1 km from the 16 Jan. relocation point. At that time, a large sturgeon was observed to jump out of the water; hence it was concluded that one or more sturgeon were in the area. In continued searching of nearshore areas, we failed to locate other sturgeon. However, on 5 Feb. we did observe another large sturgeon jump less than 3 km northwest of where fish 284 had been relocated, and a jumping sturgeon was observed 17 d earlier. We did not relocate any sturgeon in searches of offshore areas (159 km^2) near the Florida Middle Ground on 27–28 Feb. (Fig. 2). A total of 1,760 km^2 was searched in 17 trips between 6 Jan. and 28 Feb.

Discussion

Gulf sturgeon move relatively slowly (Fig. 4) while in nearshore marine habitats. Speed averaged 0.6–1.2 km/hr (Table 2). Fish 96-6 and 96-7 swam at average speeds of 1.0 and 0.6 km/hr. Because they had been at liberty for 57 and 46 d, respectively, their speed can be considered representative of normal behavior. Fish

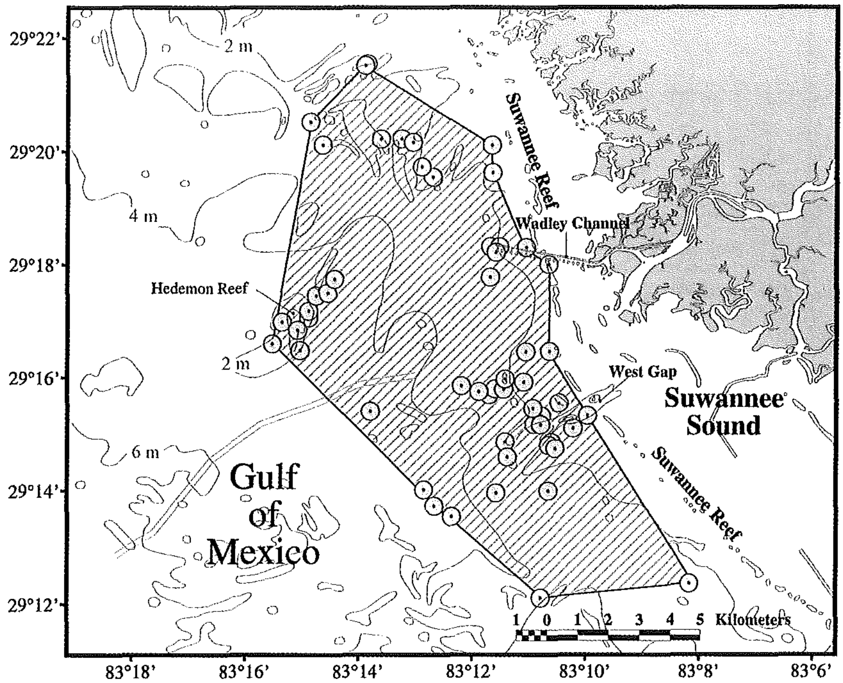

Fig. 5. Relocation positions Nov.–Dec, 1998. Hatched polygon area is 115 km².

96-6 was considerably larger than 96-7 (151 cm vs 121 cm TL), perhaps accounting for its higher speed. Movement patterns were punctuated by periods of slow movement within small areas (Fig. 3), suggesting foraging.

These average speeds are well below optimal sustained speeds of 1.9–2.4 km/hr predicted from body lengths (Weihs, 1977), and predicted optimal speeds were rarely attained even over short periods (Fig. 4). Webb (1986) suggested, based on 2-min critical swimming speeds of juvenile (15.7 cm TL) lake sturgeon (*A. fulvescens*), that sturgeon kinematics were similar to those of teleosts. Long (1995) found that a 1.3-m white sturgeon (*A. transmontanus*)

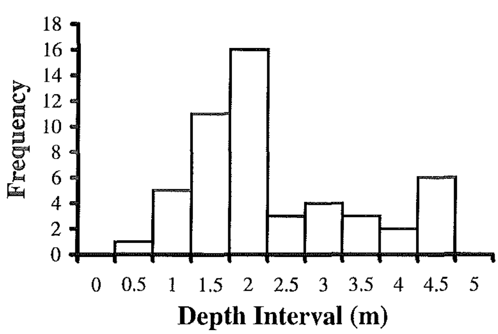

Fig. 6. Frequency of 1998 relocation depths by 0.5-m interval, lower bound indicated.

exhibited two modes of swimming—a slow mode and a fast mode in which the speed was more than two times that of the slow mode without changes in tail beat frequency. Assuming that the Gulf sturgeon tracked in this study were swimming in a slow mode, they could more than double their speeds to near-predicted optimal speeds by shifting into the fast mode.

Minimum average swimming speeds of 1.1–3.7 km/hr were determined from times of detection at automatic detection stations. The latter speed was downstream, in a river where currents have been measured to be up to 4.3 km/hr at rkm 215 (Sulak and Clugston, 1998) and 2.7 km/hr at rkm 6 (Tillis, 2000). These speeds are comparable to mean speeds from tracks 96-6 and 96-7 (1.1 and 0.6 km/hr). Similarly low average speeds have been reported for other Gulf sturgeon and shortnose sturgeon (*A. brevirostrum*). Foster and Clugston (1997) tracked a Gulf sturgeon at a daily mean speed of 1.6 km/hr downstream in the Suwannee River. Moser and Ross (1995) reported shortnose sturgeon daily mean speeds of 0.5–1.1 km/hr in the Cape Fear River, North Carolina, and McCleave et al. (1977) found that shortnose sturgeon moved at a mean speed of 0.3–1.2 km/hr in a Maine estuary.

Both in 1996 and 1998, most sturgeon prob-

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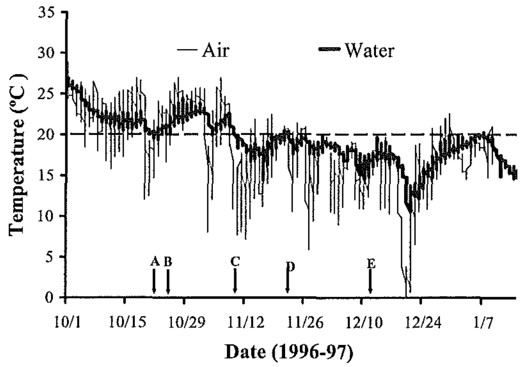

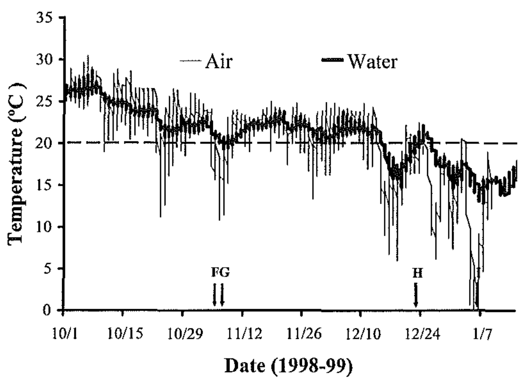

Fig. 7. Water and air temperature (2-hr intervals) in 1996–97 and 1998–99. Water temperature (middepth) was measured at East Pass rkm 6 (E-6, Fig. 1) (Tillis, 2000; G. Tillis, pers. comm.). Air temperature was measured at Cedar Key, Florida, 18 km south-southeast of E-6 (Fig. 1) (Source: NOAA C-MAN Station CDRF1 29.14°N 83.03°W). Arrows indicate events. 1996–97: (A) Two fish detected at lower (rkm 6) station and water temperature falling to 20 C. (B) One fish returns to upper (rkm 22) station (remains for 3 d), and water temperature increasing above 20 C. (C) Two fish detected at lower station (10 hr apart), and water temperature falling below 20 C. (D) Track 96-1. (E) Tracks 96-6 and 96-7 indicating that previously tagged fish remain in nearshore area. 1998–99: (F) No fish relocated in surveys of Suwannee Sound and nearshore areas and water temperature 21–22 C. (G) First relocation off Suwannee Sound and river water temperature falling to 20 C. (G, H) Fish present and relocated in nearshore area. (H) Relocation efforts suspended. (I) Relocation efforts restarted immediately after major cold front; no fish found in previous area.

ably left the river in early Nov. at about the time when river water temperature fell below 20 C (Fig. 7). Carr et al. (1996) similarly found that sturgeon left the river when water temperature reached 19–21 C. In 1996, the automatic detection station data showed that two of the three detected fish (23 and 42/64) passed the lower station (E-6 at rkm 6) on 9 and 10 Nov., on which dates water temperature at E-6 had fallen to 20.2 C and 18.4 C. Movements of fish 42/64 are noteworthy in that they seem to indicate an earlier period of emigration delay or staging (Wooley and Crateau, 1985), perhaps influenced by temperature. This fish had been detected at rkm 22 on 20 Oct., near the river mouth at rkm 6 on 24 Oct., and then as it moved 16 km back upriver to rkm 22 in less than 9 hr. This movement corresponded to a period when water temperature was falling to 19.5 C at E-6 on 22 Oct. before increasing back to 24.4 C on 28 Oct. We did not detect any fish moving into or out of the river after 10 Nov. In 1998, relocation surveys on 4–6 Nov. failed to detect tagged sturgeon in Suwannee Sound or nearshore Gulf of Mexico areas. Fish were first relocated in nearshore Gulf areas on 7 Nov., on which date river water temperature at E-6 fell to as low as 19.4 C.

Sturgeon remained in nearshore Gulf areas adjacent to Suwannee Sound for protracted periods. In 1996, our fieldwork ended on 12 Dec. as a result of research vessel schedules. However, all released fish headed back inshore toward Suwannee Reef. Two at-liberty fish relocated and tracked (96-6 and 96-7) remained in the general area and demonstrated that some sturgeon were still in the area as late as 12 Dec. In 1998, fish were consistently relocated over a period of 46 d, until field operations were suspended after 22 Dec. Daily net movement (Fig. 4) was only 0.15–0.72 km/d and showed little directional pattern. Largest displacements were parallel to the coast and in the direction (northwest–southeast) of tidally cycling, alongshore currents. All 1998 relocations were in areas inshore of those where fish 96-6 and 96-7 had been relocated and tracked, perhaps due to temperatures being substantially higher in 1998 (Fig. 7). The fall movement of Suwannee River Gulf sturgeon from the river to the nearshore Gulf of Mexico differs greatly from that of Choctawhatchee River Gulf Sturgeon, many of which (particularly males) remain and overwinter in Choctawhatchee Bay (Fox et al., 2002), which is much larger (48 km long × 6 km wide) and deeper (maximum depth of >12 m) than Suwannee Sound.

During the tracking period in both 1996 and 1998, sturgeon were concentrated in a relatively small area offshore of Suwannee Sound. In 1998, 18 of 19 sonic-tagged sturgeon, previously tagged over an 80-d period at locations from rkm 0.5 to 200, were relocated within a 115-

km^2 polygon (Fig. 5), indicative of the overall population distribution. Accordingly, we hypothesize that a large portion of the Suwannee River adult population uses this nearshore marine environment area for extended periods of time after leaving the river in the fall. The ratio of 18:19 tagged sturgeon relocated in this area yields an estimate [95% binomial confidence interval (Zar, 1984)] that 74–99.9% of the adult population used this area in late 1998. Frequent sightings, during the tracking and relocation surveys, of large sturgeon jumping [a typical behavior pattern (Sulak et al., 2002)] confirmed that a number of sturgeon were present in the relocation area.

Because adult and subadult sturgeon feed only during the 4- to 5-mo marine phase (Clugston et al., 1995; Gu et al., 2001), the initial feeding period of up to 2 mo in nearshore waters must be of great importance to sturgeon that had fasted for the preceding 7–8 mo. Accordingly, the nearshore areas adjacent to Suwannee Sound and extending to the north and south should be considered essential feeding habitat for Suwannee River Gulf sturgeon. Because our relocation work did not systematically search all adjacent areas, full delineation of nearshore habitats would require additional work.

We did not determine the late-winter feeding grounds of Suwannee River Gulf sturgeon, and tracking and relocation data were not adequate to address the hypothesis that sturgeon emigration would follow the Suwannee River paleochannel. However, this study provides important new information about Gulf sturgeon marine habitat and movements. We now know, for example, that migration or dispersion does not occur immediately after sturgeon leave the river. Instead, Suwannee River Gulf sturgeon remain in nearshore marine areas for up to 2 mo. Whether they later migrate to specific winter-feeding grounds or whether they disperse widely remains unknown. The relocation of fish 284 on 16 Jan. and 19 Jan. 1999 about 50 km northwest of Suwannee Sound provides our only information on later movements. This fish, instead of moving offshore as we hypothesized or moving south as suggested by others (U.S. Fish and Wildlife Service and Gulf States Marine Fisheries Commission, 1995) remained in shallow water (5 m) and moved north.

As previously noted (Sulak and Clugston, 1999), movements of Gulf sturgeon during the initial nearshore fall feeding period display a characteristic pattern of long intervals of slow, steady directional progression covering several kilometers, alternating with long intervals of randomly directed, brief small-scale movements within confined areas (Fig. 3). The overall pattern corresponds to the general predictions for a Lévy search pattern (Viswanathan et al., 1996), where the search direction is chosen at random and adhered to until a patch of prey is detected (i.e., the distance searched is not constant; instead step lengths follow a power-law distribution). Such a search pattern assumes that the prey is patchily distributed and that the foraging organism lacks both advance knowledge of the location of prey patches and a distant prey-location sensory capability (e.g., olfaction to home in on distant prey). Such a directed-random foraging strategy is more efficient in prey location than a totally random search. One might also predict for Gulf sturgeon that once nearshore patches are exhausted, or once environmental cues trigger searching in deeper water, that the feeding population would disperse in random directions and to variable distances, until suitable prey patches are encountered. Recaptures of conventionally tagged Suwannee River sturgeon have been recorded (USGS, unpubl. data) from as far north as the Apalachicola River and as far south as Tampa Bay (i.e., up to 180 km from the Suwannee River mouth). Such documented long-distance excursions can be speculated to reflect movements of winter migrants seeking prey patches by a random-direction, scale-independent Lévy search. Much of the substrate of the eastern Gulf of Mexico shelf is hard carbonate rock or sponge bottom; areas of extensive soft substrate are sparsely distributed at wide intervals. Furthermore, because the sequential directions of movement in a Lévy search are chosen at random, it can be further speculated that some individual Gulf sturgeon head west (to similar distances as documented for tag recaptures) and ultimately arrive at deep, offshore, soft-substrate areas favorable to dense benthic prey populations (e.g., the plateau immediately west of the Florida Middle Ground). This hypothesis is reinforced by knowledge that the cognate subspecies Atlantic sturgeon (*A. o. oxyrinchus*) occurs at depths as great as 110 m in the Atlantic Ocean (Timoskin, 1968) and that other anadromous sturgeon species routinely forage at depths as great as 30–100 m (Khodorevskay and Krasikov, 1999) during the marine feeding period of the annual life cycle.

Our telemetry relocation data are not robust enough to enable a test of mathematical correspondence of step lengths with a power-law distribution as predicted for a Lévy search pattern (Viswanathan et al., 1996) vs a Poisson distribution indicative of conventional random walks. However, if sturgeon ultimately prove to use scale-independent, directed-random searches to locate prey patches while in the Gulf of Mexico, the ecological implication would be that Gulf sturgeon do not school or congregate during late-winter feeding. Instead, we would predict that they are broadly and individually dispersed without a predictable distribution center while foraging.

Movement of Gulf sturgeon away from the Suwannee River nearshore Gulf areas probably occurs during periods of strong cold fronts, such as those around 21 Dec. 1996 and 4 Jan. 1998 (Fig. 7). Wind and sea conditions preceding, during, and immediately after major cold fronts preclude at-sea operations and tracking. Hence, it is unlikely that migration or dispersal can be directly assessed using continual, boat-based sonic tracking. More information about late-winter habitats could be obtained by relocation surveys such as that used to relocate fish 284, but the large area that would have to be searched and the associated time and expense makes that approach impractical. It is likely that different and new approaches and techniques will have to be used to obtain further information. Identification of main carbon sources by stable-isotope analysis (Best and Schell, 1996) is a promising technique for distinguishing inshore and offshore feeding during the winter (USGS, in progress). Standard archival tags are difficult to recover and provide location data on inadequate precision (Welch and Eveson, 1999) for determining sturgeon movements. However, satellite pop-up archival tags have been developed (Lutcavage et al., 1999; Block et al., 2001) and can provide precise location information.

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