12-2009

CHARACTERIZATION OF GULF STURGEON DIEL AND SEASONAL ACTIVITY IN THE PENSACOLA BAY SYSTEM, FLORIDA

Beth Wrege
Clemson University, bwrege@clemson.edu

CHARACTERIZATION OF GULF STURGEON DIEL AND SEASONAL ACTIVITY IN THE PENSACOLA BAY SYSTEM, FLORIDA

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Wildlife and Fisheries Biology

---

by
Beth Marie Wrege
December 2009

Accepted by:
Dr. J. Jeffery Isely, Committee Chair
Dr. William W. Bowerman
Dr. Christopher J. Post
Dr. David C. Guynn

ABSTRACT

We assess temporal and spatial distribution and diel variability in activity of Gulf of Mexico sturgeon *Acipenser oxyrinchus desotoi* in the Pensacola Bay system, Florida, using stationary ultrasonic telemetry. Gulf of Mexico sturgeon (n = 54) migrated through the bay system in fall to wintering areas in the Gulf of Mexico and Santa Rosa Sound. In spring, sturgeon migrated back through the bay system to summering habitats in rivers. Gulf of Mexico sturgeon use East Bay and Escambia Bay primarily as migration routes between riverine areas used in spring and summer and the Gulf of Mexico used in winter. North Central Pensacola Bay was not routinely frequented. Gulf of Mexico sturgeon used specific areas within the Pensacola Bay system in summer and winter not previously documented as essential sturgeon habitat. Areas in southeastern Pensacola were used heavily during winter by a portion of the population. Gulf of Mexico sturgeon also exhibited long-term winter residency in Santa Rosa Sound. Interestingly, an area in northeastern Escambia Bay supported Gulf of Mexico sturgeon in summer. This observation was unexpected; however, the identification of Gulf of Mexico sturgeon in this area at this time has important ecological and management implications. Gulf of Mexico sturgeon exhibited a strong diel activity pattern. Gulf of Mexico sturgeon were more active at night than during day in all seasons but summer. The use of prepositioned arrays of acoustic receivers not only provides continuous data within a defined area, but provides insights into nocturnal behavior not previously examined.

ACKNOWLEDGMENTS

Funding was provided by the National Marine Fisheries Service (NMFS) Office of Protected Resources and the NMFS Panama City Laboratory. John Brusher, John Carlson, Andy David, Doug DeVries, Chris Gardner, and Steve Matthews provided valuable field assistance. Laboratory assistance was provided by Bob Jarvis, Greg Landry, Bo Sawyer, Joe Deppen, Alisha Lemons, Megan Witton, Debbie Figueroa, Chris Berry, Marta Ribera, Janice Hamm, and Consuela Williams. Constructive reviews were provided by Guy Davenport, Dr. William Bowerman, Dr. Christopher Post, Dr. Shawn Young, and Dr. David Guynn.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

The Gulf of Mexico sturgeon *Acipenser oxyrinchus desotoi* (hereafter referred to as Gulf sturgeon) is a subspecies of the Atlantic sturgeon *A. oxyrinchus* and is found throughout rivers, bays and shallow coastal waters of the Gulf of Mexico from western Florida to eastern Louisiana. Due to declines in Gulf sturgeon populations, the subspecies was listed as threatened in 1991 under the Endangered Species Act. In 2003, large expanses of bays and rivers in western Florida were designated as critical habitat for Gulf sturgeon. However, little is known with regard to the basic ecology and movement of the species. This dissertation reports the findings from studies of seasonal migrations and daily activity patters in Gulf of Mexico Sturgeon in the Pensacola Bay system, in northwest Florida. For presentation purposes, this body of work is separated into two chapters: Seasonal Distribution of Gulf of Mexico Sturgeon in the Pensacola Bay system, Florida; and Diel Activity of Gulf of Mexico Sturgeon in a Northwest Florida Bay.

SEASONAL DISTRIBUTION OF GULF OF MEXICO STURGEON IN THE PENSACOLA BAY SYSTEM, FLORIDA

INTRODUCTION

The Gulf of Mexico sturgeon *Acipenser oxyrinchus desotoi* (hereafter referred to as Gulf sturgeon) is a subspecies of the Atlantic sturgeon *A. oxyrinchus* (Vladykov 1955) and is found throughout rivers, bays and shallow coastal waters of the Gulf of Mexico from western Florida to eastern Louisiana (Davis et al. 1970; Huff 1975). Due to declines in Gulf sturgeon populations, the subspecies was listed as threatened in 1991 under the Endangered Species Act (Federal Register 1991). In 2003, large expanses of bays and rivers in western Florida were designated as critical habitat for Gulf sturgeon (Federal Register 2003).

In spring, Gulf sturgeon migrate into coastal rivers (Craft et al. 2001; Fox et al. 2000, 2002; Harris 2003) where they remain throughout summer (Wooley and Crateau 1985; Foster and Clugston 1997; Hightower et al. 2002). Gulf sturgeon use deep pools as thermal refuges during this period and do not feed (Mason and Clugston 1993). In fall, sturgeon emigrate from thermal refuges in rivers to bays and estuaries where they feed throughout the winter (Mason and Clugston 1993; Carr et al.1996; Foster and Clugston 1997; Fox et al. 2002). Gulf sturgeon show a preference for sandy estuarine shoreline and nearshore marine habitats during winter foraging periods (Parauka et al. 2001; Fox et al. 2002; Edwards et al. 2003). Accounts of winter habitat use are few and conclusions are often based on small sample size due to inherent difficulties in monitoring the movements of large fish in marine habitats.

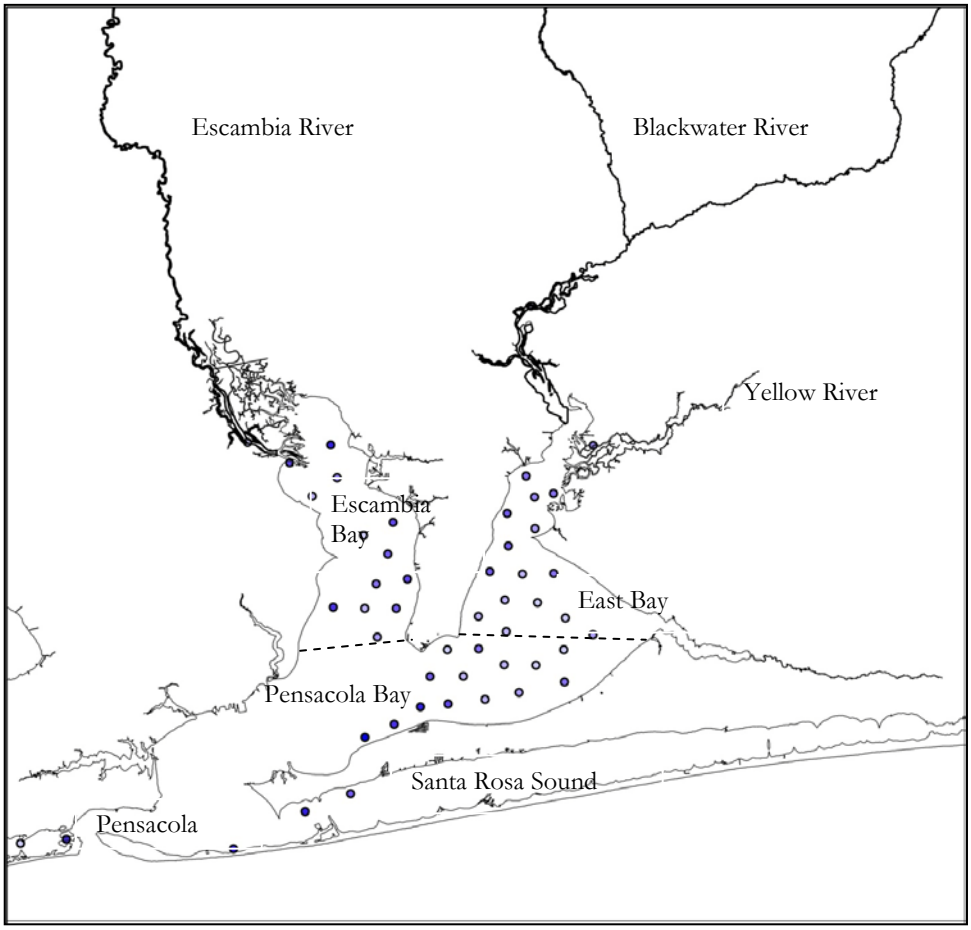
Four distinct populations have been identified in the northeastern Gulf of Mexico: the Pearl and Pascagoula rivers population; the Escambia, Blackwater, and Yellow rivers population; the Choctawhatchee River population; and the Apalachicola, Ochlockonee, and Suwannee rivers population (Stabile et al. 1996; Berg et al. 2004). Only a limited number of investigations have monitored movement within the Escambia, Blackwater, and Yellow rivers population (Craft et al. 2001; Hightower et al. 2002; Berg et al. 2004). Little information is known about the fine-scale movement of Gulf sturgeon within the Pensacola Bay system. However, during winter, Gulf sturgeon reside in specific areas within Pensacola Bay and adjacent Gulf of Mexico waters (Craft et al. 2001; Parauka et al. 2001; Fox et al. 2002). Fox et al. (2002) observed that wintering males predominately resided in the bay, while the majority of wintering females were located in the Gulf of Mexico.

Information on Gulf sturgeon migrations and habitat preferences are based on roving telemetry (Parauka et al. 2001; Fox et al. 2002). Recent advances in acoustic telemetry increase the likelihood of relocation of fish by incorporating the use of data-logging receivers (Simpfendorfer et al. 2002; Heupel et al. 2004, 2005). The use of pre-positioned receiver arrays for continuous monitoring of acoustic transmitters has been successfully used to monitor the habitat use and movement of several marine species including shark *Carcharhinus spp.* (Simpfendorfer et al. 2002; Heupel et al. 2004, 2005), and green sturgeon *A. medirostris* (Moser and Lindley 2007). I assess temporal and spatial distributions of Gulf sturgeon in the Pensacola Bay system, Florida, using stationary ultrasonic telemetry.

METHODS

Study area.—The study area consists of the Pensacola bay system and associated rivers, and the Choctawhatchee River (Figure 1). Rivers draining into the Pensacola bay system include the Escambia, Blackwater, and Yellow rivers. The Escambia River originates in southern Alabama and extends 148 km into northwest Pensacola Bay (FDEP 1998). The Blackwater River originates in northern Florida and extends 107 km into northeast Pensacola Bay. The Yellow River originates in central Alabama and extends 150 km into northeast Pensacola Bay. The Choctawhatchee River originates in southern Alabama and extends 280 km into northeast Choctawhatchee Bay (Seaman 1988). The Pensacola Bay system is a 3,133 km^2-estuary composed of the Escambia, East, and Pensacola bays and Santa Rosa Sound (FDEP 1998). Santa Rosa Sound is bisected by the Gulf Intracoastal Waterway and connects Pensacola Bay and Choctawhatchee Bay.

Capture and Tagging.--- All fish for this study were tagged and released in the Florida portions of the Escambia, Blackwater, Yellow, and Choctawhatchee rivers where they were captured, and all acoustic monitoring occurred within the Pensacola bay system. Fish were captured and tagged at river kilometer (rkm) 24 in the Escambia River, at rkm 12 in the Blackwater River, at rkm 20 in the Yellow River, and at rkm 40 and 50 in the Choctawhatchee River. Gulf sturgeon were captured during June, July, September, and October 2005 using fixed and drift mono- and multi-filament gillnets ranging in lengths from 30.5 to 45.7 m, widths from 2.5 to 3.7 m, and stretched mesh sizes from 7.9 to 22.9 cm. Fixed gillnets were anchored perpendicular to the river bank in preferred habitats



.

Figure 1.---Study site of Pensacola Bay system which includes associated bays (Escambia, East and Pensacola) and rivers (Escambia, Blackwater and Yellow) located along the northeastern Gulf of Mexico. Dashed lines distingquish between each bay and locations of deployed VR2 receivers (black cirlcles).

.

such as river bends, deep holes, on sand and mud substrates. Drift gillnets were set in similar areas, but one end of the net was affixed to the boat and the net was then stretched across the river and allowed to drift with the current. Fixed gillnets were checked hourly and drift nets were allowed to drift for 30 minutes. All captured Gulf sturgeon were placed in an onboard re-circulating tank until processed.

Gulf sturgeon were measured for fork length (FL) and total length (TL) to the nearest 0.5 cm and weighed to the nearest 0.1 kg. Individual fish sex determination was not attempted during tagging, with the exception of three fish that were confirmed to be females upon discovery of eggs during surgery. Gulf sturgeon were scanned for previously-injected passive integrated transponder (PIT) tags and inspected for any external tags. If a PIT tag or other external tag was located, the tag number was recorded. Untagged sturgeon were injected in the base of the dorsal fin with a 14 × 2 mm PIT tag (model TX1411SSL; Biomark Inc., Boise, Idaho, USA). In addition, sturgeon received two 60-mm external T-bar tags (model FD-67 T-bar; Floy Tag, Seattle, Washington, USA). External tags were inserted through the base of each pectoral fin using a fastener gun (Tag Fast II; Avery Dennison Corporation, Fitchburg, Massachusetts, USA). Individually coded acoustic transmitters (models V9 and V13, 69.0 KHz; VEMCO, Halifax, Nova Scotia, Canada) weighted 2 and 6 g in water, measured 9 x 20 mm and 13 x 36 mm. Larger tags (V13) were used on fish ≥ 60 cm fork length and smaller tags (V9) were used on fish < 60 cm fork length. Battery life for acoustic tags was rated by the manufacturer as approximately 400 days (V9) and 700 days (V13), and each coded transmitter was set to cycle once every 60 seconds. Tags were surgically implanted, using the techniques described by Walsh et al. (2000). Briefly, an incision was made on the mid ventral line and the tag was inserted into the abdominal cavity.

The incision was then closed with absorbable sutures and surgical glue. Sex of individuals was not determined; however, three fish were confirmed as females upon discovery of eggs during surgery.

Gulf sturgeon location was monitored using fixed-station acoustic receivers (model VR2; VEMCO, Halifax, Nova Scotia, Canada) stationed throughout each bay (Figure 1). Receivers were anchored in location and positioned in the middle of the water column using a cable and float system. Acoustic receivers recorded transmitter number, date and time, and had an effective range of ~ 0.5 km. The array was deployed to provide maximum location data coverage of individuals throughout the study. Receivers were downloaded at monthly intervals using a magnetic probe and computer interface provided by the manufacturer.

Acoustic Receiver Locations.---During October 2005 through 21 June 2006, a total of 56 receivers were deployed at 59 locations in the four study bays. Forty-five were deployed within Escambia, East, and Pensacola bays. An additional receiver was placed in Santa Rosa Sound, the seaward arm of the Pensacola bay system from 31 October 2005 through 28 April, 2006. From 20 September 2006 through 2 August 2007, 45 receivers were redeployed in the Pensacola bay system at the same locations monitored during 2005 - 2006. Receivers were again located in Santa Rosa Sound. An additional 2 receivers were positioned in central Santa Rosa Sound from 2 August 2006 through 14 November 2007. Additional receivers were positioned further upstream in the Escambia, Yellow and Blackwater rivers. The Escambia River receiver was placed 0.6 km at rkm 2 from 2 August 2006 through 2 August 2007. The Yellow River receiver was placed at rkm 3 from 2 August 2006 through 11 June 2007. The Blackwater River receiver was placed at rkm 4 from 2 August 2006 through 25 March 2007.

Season Definition.---We divided the entire study period into eight seasons based on temperature changes. Seasons one and five consisted of October, November and December, 2005 and 2006 respectively. Seasons two and six consisted of January, February and March, 2006 and 2007 respectively. Seasons three and seven consisted of April, May and June, 2006 and 2007 respectively. Seasons four and eight consisted of July, August and September, 2006 and 2007 respectively.

Telemetry Data Analysis.---We used a threshold of 2 consecutive records of an individual to define presence near a specific hydrophone. Presence of each individual was defined on an hourly and daily basis, and then summarized to units of either fish hours or fish days for analysis purposes. I evaluated differences in mean fork length and mean weigh among Gulf sturgeon collected from different rivers using analysis of variance. Individual pair-wise differences I identified using a Student-Newman-Keuls multiple range test. Numbers of fish days in each season were combined across hydrophones within bays. Differences in the distribution of fish days per bay between seasons were evaluated using a Chi-square statistic. A probability level (P) = 0.05 was used as the threshold for significance. Data were analyzed using the Statistical Analysis System (SAS version 9.2; SAS Institute, Cary, North Carolina).

Latitude and longitude for each receiver position was converted into decimal degrees (dd) and input into Arc View GIS v 9.1 (ESRI Inc., Redlands, California) with extents (min X = -88 dd; max X = -86 dd; min Y = 31 dd; max Y = 30 dd). Seasonal predicted density of fish days was calculated using an inverse distance weighting procedure in (Geostatistical Analyst) obtained through the manufacturer with extents (North = 30.6500 dd; South = 30.3170 dd; West -87.3700 dd; East = -86.8400 dd) and a Datum (D_North_America_1983_HARN; ArcInfo 9.3.1 ESRI Inc., Redlands, California).

RESULTS

Tagging and detection.---We tagged 54 Gulf sturgeon within the Escambia (n=26), Yellow (n=8), Blackwater (n=12), and Choctawhatchee Rivers (n=12) in June, July, September, and October 2005. Of those, 18 fish contained PIT or T-bar tags from previous studies. Tagged Gulf sturgeon ranged in length from 78.0 cm to 200.0 cm fork length (142.5 ± 33.5; mean ± SD) and weighed from 3.4 kg to 70.7 kg (mean = 28.0 ± 16.5; mean ± SD). On average, Gulf sturgeon collected from the Yellow and Choctawhatchee rivers were longer (F = 5.41; df = 3, 54; P = 0.0025) and heavier (F = 6.29; df = 3, 54; P = 0.001) than those collected from the Escambia River.

Fifty-four Gulf sturgeon were detected at least once during seasons 1 through 4, and 42 fish were detected at least once during seasons 5 through 8. Four fish were not detected during the two-year study. A total of 425,700 fish hours, or 17,164 fish days were recorded. Individuals were observed during 8,347 ± 33.5 hours (mean ± SD) or 367 ± 7.2 (mean ± SD) days. Cumulative number of observations of individuals on independent hydrophones ranged from 134 to 73,1630 hours or 13 to 2,059 days. Three fish accounted for 48% of all observations. Individual hydrophones recorded observations of fish during 5,528 ± 26.1 hours (mean ± SD) or 367 ± 8.4 (mean ± SD) days. Cumulative number of observations per hydrophone ranged from 1 to 217,795 fish hours or 1 to 2,350 fish days. Two hydrophones accounted for 50% of all observations. Fish 857 exhibited a high degree of fidelity to the area adjacent to hydrophone 47 in Santa Rosa Sound. Records of this fish at this hydrophone accounted for 18% of all fish hours and 12% of all fish days.

Season One.---A total of 46 Gulf sturgeon were detected on 48 hydrophones representing a total of 837 fish days in Pensacola bay system during fall 2005 (Figure 2). The majority of fish resided in the southwestern portion of Pensacola Bay and western Santa Rosa Sound. Sturgeon were also concentrated in the upper portion of the Escambia Bay and present in East Bay. Sturgeon did not occupy the eastern portion of the Pensacola Bay during season one.

Season Two.---A total of 37 Gulf sturgeon were detected on 35 hydrophones representing a total of 448 fish days in Pensacola bay system during winter 2006 (Figure 2). The majority of fish resided in western Santa Rosa Sound. Sturgeon did not occupy the eastern portion of Pensacola Bay during season two and rarely occurred in East Bay. The concentration of sturgeon decreased from season one to two and shifted south toward the Gulf of Mexico.

Season Three.---A total of 33 Gulf sturgeon were detected on 26 hydrophones representing a total of 334 fish days in Pensacola bay system during spring 2006 (Figure 2). The majority of fish resided in northern portion of Escambia Bay. Sturgeon were also present in southern East Bay. No sturgeon were observed in southern Pensacola Bay or western Santa Rosa Sound. The concentration of sturgeon decreased from season two to three and shifted north.

Season Four.---A total of 6 Gulf sturgeon were detected on 11 hydrophones representing a total of 68 fish days in Pensacola bay system during summer 2006 (Figure 2). Fish resided in the northern portion of Escambia Bay. Sturgeon were also present in western Pensacola Bay and northern Escambia Bay.

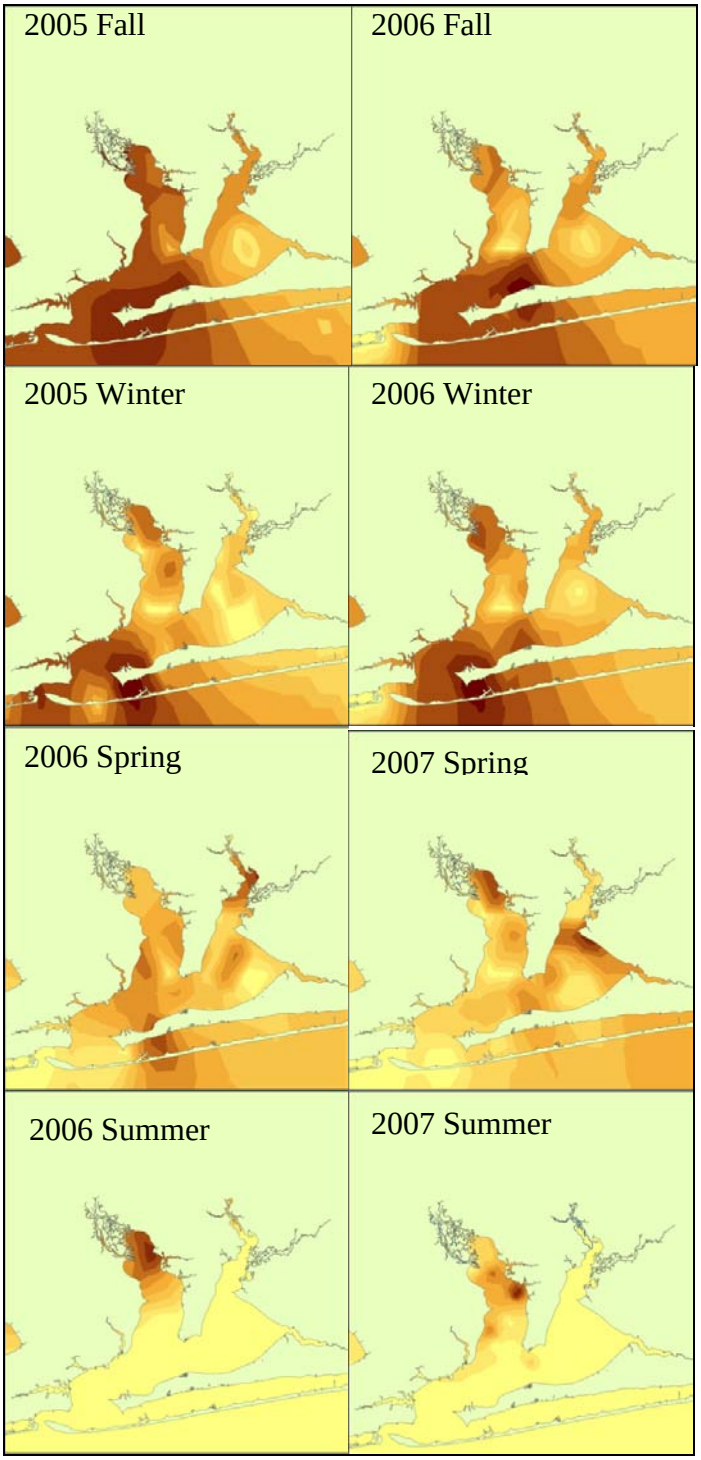


Figure 2.---Gulf sturgeon predicted density throughout Penasacola Bay system during fall 2005 (1), winter 2006 (2), spring 2006 (3), summer 2006 (4), fall 2006 (5), winter 2007 (6), spring 2007 (7) and summer 2007 (8). Contours represent percentiles in increments of 10 of the maximum density during that season.

Season Five.---A total of 54 Gulf sturgeon were detected on 49 hydrophones representing a total of 996 fish days in Pensacola bay system during fall 2006 (Figure 2). The majority of fish resided in the southwestern portion of Pensacola Bay and western Santa Rosa Sound. Sturgeon were also concentrated in the upper portion of Escambia Bay and present in East Bay. Sturgeon did not occupy the eastern portion of the Pensacola Bay during season one. When compared to season one, sturgeon were more concentrated in western Pensacola Bay and less concentrated in northern Escambia Bay.

Season Six.---A total of 42 Gulf sturgeon were detected on 44 hydrophones representing a total of 644 fish days in Pensacola bay system during winter 2007 (Figure 2). The majority of fish resided in western Santa Rosa Sound. Sturgeon were also present in western Pensacola Bay and northern Escambia Bay. Sturgeon did not occupy the eastern portion of the Pensacola Bay during season six and rarely occurred in East Bay. The concentration of sturgeon remained similar from season five to six and shifted south toward the Gulf of Mexico. When compared to season two, sturgeon concentration was similar.

Season Seven.---A total of 25 Gulf sturgeon were detected on 45 hydrophones representing a total of 599 fish days in Pensacola bay system during spring 2007 (Figure 2). The majority of fish resided in northern portion of East Bay. Sturgeon were also present in western Santa Rosa Sound and also in southern Escambia Bay. Some sturgeon were observed in eastern Pensacola Bay. The concentration of sturgeon decreased from season six to seven and shifted north. When compared to season three, sturgeon concentration shifted from Escambia Bay to East Bay.

Season Eight.---A total of 1 Gulf sturgeon was detected on 13 hydrophones representing a total of 32 fish days in Pensacola bay system during summer 2007 (Figure 2). This fish

resided in the eastern portion of Escambia Bay. Sturgeon were not detected in any other locations. The concentration of sturgeon decreased from season seven to eight and shifted from East Bay to Escambia Bay. When compared to season four, sturgeon concentration was similar.

The highest number of detections of tagged fish occurred in Santa Rosa Sound. This group included 4 fish tagged and released in Choctawhatchee River, 7 fish from Blackwater River, 10 fish from Escambia River, and 1 fish from Yellow River. The receiver averaged 5,725 hits per fish (range = 2 to 73,163 hits) and during 2005 - 2006. In 2007 - 2007, the receiver recorded 92,072 hits, including 12 fish from the previous year and 3 fish not recorded during study period 1. This group included 5 fish tagged and released in Blackwater River, 8 fish from Escambia River, and 2 fish from Yellow River. The receiver averaged 6,138 hits per fish (range = 1 to 47,904 hits) during 2006 - 2007. During Seasons 2 and 5, 2 fish each season remained in Santa Rosa Sound for 61 to 80 consecutive days. A total of 21 fish was recorded in Santa Rosa Sound in Seasons 5 and 6 (3,606 hits). This group included 2 fish tagged and released in Choctawhatchee River, 6 fish from Blackwater River, 10 from Escambia River, and 3 fish from Yellow River.

The majority of the fish were last detected within the bays in April each year; however, 8 fish in 2006 and 4 fish in 2007 remained in the bay until June before migrating into nearby rivers. Atypical behavior was observed in one fish tagged in the Choctawhatchee River that traveled to and remained in upper Escambia Bay during the summer of 2006 for 32 days. Although not continuously detected, the fish was detected on 10 days in June, 2 days in July, 11 days in August, and 9 days in September. This fish returned the following year to a site

in upper Escambia Bay for 7 days from 11 June through 24 July 2007 and was last detected in lower Escambia Bay on 30 July 2007.

DISCUSSION

Four fish were not detected during the two year study, either as a result of tag failure, rejection, or mortality, and one fish died as a result of an independent study conducted in 2006 on the Escambia River (F. Parauka, personal communication). Movement out of the study area may account for fish that were not detected during 2006 – 2007 that were detected during 2005 - 2006.

In general, Gulf sturgeon implanted with sonic transmitters in rivers discharging into the Pensacola Bay system migrated through the bay system in fall to wintering areas in the Gulf of Mexico and Santa Rosa Sound. In spring, Gulf sturgeon migrated back through the bay system to summering habitats in rivers. Gulf sturgeon use East Bay and Escambia Bay primarily as migration routes between riverine areas used in spring and summer and the Gulf of Mexico used in winter. Similar patterns in migration were observed in Apalachicola Bay (Wooley and Crateau 1985) and Choctawhatchee Bay (Hightower et al. 2002). North-central Pensacola Bay was not routinely frequented by Gulf sturgeon. A consistent pattern of Gulf sturgeon distribution in the Pensacola bay system across years suggests this pattern is typical for this population.

An area in northeastern Escambia Bay supported Gulf sturgeon in summer. In 2005, three fish and in 2007, one fish spent an extended period during summer in this area. This behavior has not previously been documented. Gulf sturgeon normally spend the summer months in deeper, cooler water in the rivers (Wooley and Crateau 1985; Hightower et al. 2002) and, to my knowledge, have not been previously observed spending the summer

period in marine waters. It is possible that cool temperatures or high concentrations of food in this area resulted in bay residence during summer months.

Gulf sturgeon used specific areas within the Pensacola bay System in summer or winter not previously documented as essential sturgeon habitat. Areas in southeastern Pensacola Bay and Santa Rosa Sound were used heavily during winter by a portion of the population. Gulf sturgeon also exhibited long-term winter residency in Santa Rosa Sound. Long-term residency has been observed in other studies and was associated with sandy substrate with abundant benthic organisms (Paruaka et al. 2001; Fox et al. 2002). Previously, Santa Rosa Sound was identified as a migration corridor for Choctawhatchee River Gulf sturgeon, but did not support long-term winter residency (Parauka et al. 2001). However, Craft et al. (2001) observed fish residing in deep holes in nearby Pensacola Pass during winter. Although stomach contents were not examined, the high density of Gulf sturgeon in Santa Rosa Sound during winter suggests the availability of prey. It is possible that recent hurricane activity changed the substrate and distribution of benthic prey, changing the preferred winter habitat of Gulf sturgeon in this area.

Although other areas within the Pensacola bay system were identified as important, they did not support long-term residency. These areas likely represent migration routes. In Pensacola Bay, receivers positioned off the peninsula between Escambia and East Bays were rarely frequented by sturgeon. During dive operations to recover receivers in this area, divers noted strong currents and hydrogen sulfide-rich sediments. In contrast, receivers in southwestern Pensacola Bay detected relatively large numbers of both sub-adult and adult sturgeon. Divers reported high visibility in this area and an abundance of benthic organisms. Craft et al. (2001) also noted high use of a nearby area in Pensacola Bay.

Sturgeon exhibited high fidelity to source rivers. However, some study fish migrated across population boundaries. I also observed a shift in spring high densities from Escambia Bay in 2006 to East Bay in 2007. Although previous studies documented migration between river systems (Carr et al. 1996; Fox and Hightower 1998; Fox et al. 2002), the cross population-boundary movement I observed was atypical. Craft et al. (2001) and Berg et al. (2004) observed that sturgeon moved freely among the Escambia, Yellow, and Blackwater Rivers. Berg et al. (2004) suggested that these river populations interbreed and switch rivers if optimal spawning conditions were not present in a particular river. Although interbreeding within bay systems may be common, the genetic designation of four distinct population segments (Stabile et al. 1996; Berg et al. 2004) suggests movement between bay systems is limited. Movement I observed between distinct population segments may be a function of common wintering or summering habitat independent of spawning.

The designation of Gulf sturgeon critical habitat not only has a spatial, but a temporal component. The temporal component allows for human activity at times when sturgeon are not present. I identify two new combinations of time and area of Gulf sturgeon habitat use in the Pensacola bay system not previously reported. Gulf sturgeon use the area in western Santa Rosa Sound extensively during winter. The large proportion of study fish in this area suggests this may be an important wintering area for the Escambia, Blackwater, and Yellow rivers population. Gulf sturgeon also use northeastern Escambia Bay during summer. This observation was unexpected. Identification of Gulf sturgeon in this area at this time has important ecological and management implications.

REFERENCES CITED

Berg, J., M. Allen, and K. Sulak. 2004. Population assessment of the Gulf of Mexico Sturgeon in the Yellow River, Florida. Masters Thesis. The University of Florida, Gainesville, Florida.

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.

Craft, N. M., B. Russell, and S. Travis. 2001. Identification of Gulf Sturgeon spawning habitats and migratory patterns in the Yellow and Escambia River systems. Final Report to the Florida Marine Research Institute, Fish and Wildlife Conservation Commission, Tallahassee, Florida.

Davis, J. T., B. J. Fontenot, C. E. Hoenke, A. M. Williams, and J. S. Hughes. 1970. Ecological factors affecting anadromous fishes of Lake Ponchartrain and its tributaries. Louisiana Wildlife and Fisheries Commission Bulletin 9: 1-63.

Edwards, R. E.. K. J. Sulak, M. T. Randall, and C. B. Grimes. 2003. Movements of Gulf sturgeon (*Acipenser oxyrinchus desotoi*) in nearshore habitat as determined by acoustic telemetry. Gulf of Mexico Science 2003 (1): 59-70.

Federal Register. 1991. Endangered and threatened wildlife and plants; Threatened status for the Gulf sturgeon; Code of Federal Regulations, Title 50, P.L. 17. Federal Register 56(189): 49653-49658.

Florida Department of Environmental Protection (FDep). 1998. Pensacola Bay watershed management guide: An integrated ecosystem action plan. Florida Department of Environmental Protection, Tallahassee, Florida. 268pp.

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.

Fox, D. A., J. E. Hightower, and F. M. Parauka. 2002. Estuarine and nearshore marine habitat use by Gulf Sturgeon from the Choctawhatchee River system, Florida. American Fisheries Society Symposium 28: 111-126.

Harris, J. E. 2003. Distribution of Gulf of Mexico sturgeon (*Acipenser oxyrinchus desotoi)* in relation to environmental parameters and the distribution of benthic invertebrates in the Suwannee River Estuary, Florida. Master's Thesis. The University of Florida, Gainesville, Florida.

Heupel, M. R., C. A. Simpfendorfer, and R. E. Hueter. 2004. Estimation of shark home ranges using passive monitoring techniques. Environmental Biology of Fishes 71: 135-142.

Heupel, M. R. and C. A. Simpfendorfer. 2005. Quantitative analysis of aggregation behavior in juvenile blacktip sharks. Marine Biology 147: 1239-1249.

Hightower, J. E., K. P. Zehfuss, D. A. Fox, and F. M. Parauka. 2002. Summer habitat use by Gulf Sturgeon in the Choctawhatchee River, Florida. Journal of Applied Ichthyology 18: 595-600.

Huff, J. A. 1975. Life history of Gulf of Mexico sturgeon, *Acipenser oxyrhynchus desotoi,* in the Suwannee River, Florida. Florida Marine Resources Publication. No. 16. Tallahassee, Florida. 32 pp.

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.

Parauka, F. M., S. K. Alam, D. A. Fox. 2001. Movement and habitat use of subadult Gulf Sturgeon in Choctawhatchee Bay, Florida. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 55: 280-297.

Seaman, W., JR. 1988. Florida aquatic habitat and fishery resources. Florida Chapter of the American Fisheries Society, Eustis, Florida. 543 pp.

Simpfendorfer, C. A., M. R. Heupel, and R. E. Hueter. 2002. Estimation of short-term centers of activity from an array of omnidirectional hydrophones and its use in studying animal movements. Canadian Journal of Fishery and Aquatic Sciences 59: 23-32.

Stabile, J., J. R. Waldman, F. Parauka, and I. Wirgin. 1996. Stock structure and homing fidelity of Gulf sturgeon (*Acipenser oxyrinchus desotoi).* Genetics 144: 767-775.

Vladykov, V. D. 1955. A comparison of Atlantic sea sturgeon with a new subspecies from the Gulf of Mexico *(Acipenser oxyrhynchus desotoi).* Journal of the Fisheries Resource Board of Canada 12: 754-761.

Walsh, M. G., K. A. Bjorgo, and J. J. Isely. 2000. Effects of implantation method and temperature on mortality and loss of simulated transmitters in hybrid striped bass. Transactions of the American Fisheries Society 129: 539-544.

Wooley, C. M. and E. J. Crateau. 1985. Movement, Microhabitat, Exploitation, and Management of Gulf of Mexico Sturgeon, Apalachicola River, Florida. North American Journal of Fisheries Management 5: 590-605.

DIEL ACTIVITY OF GULF OF MEXICO STURGEON IN A NORTHWEST FLORIDA BAY

INTRODUCTION

The Gulf of Mexico sturgeon *Acipenser oxyrinchus desotoi* (hereafter referred to as Gulf sturgeon) is a subspecies of the Atlantic sturgeon *A. oxyrinchus* (Vladykov 1955) and is found throughout rivers, bays and shallow coastal waters of the Gulf of Mexico from western Florida to eastern Louisiana (Davis et al. 1970; Huff 1975). Gulf sturgeon migrate into coastal rivers in spring (Fox et al. 2000, 2002; Craft et al. 2001; Harris 2003) where they remain throughout summer (Wooley and Crateau 1985; Foster and Clugston 1997; Hightower et al. 2002). In fall, Gulf sturgeon emigrate to bays and estuaries where they feed throughout the winter (Mason and Clugston 1993; Foster and Clugston 1997; Fox et al. 2002).

Although the seasonal migrations of sturgeon are well documented, little information is available pertaining to daily variation in activity levels. Patterns in the activity of fish over a 24-hour period have been well documented. Diel activity has been related to light intensity, temperature, food availability, and predation (see for example reviews by Helfman 1993; and Reebs 2002). Haynes and Gray (1981) observed white sturgeon *A. transmontanus* movement from deep to shallow water and from fast to slow current in evening, and inversely related activity to light level. Paragamian and Duehr (2005) observed a change in depth used by white sturgeon related to spawning. Parsley et al. (2008) report increased activity and movement of white sturgeon into shallow areas at night.

Information on Gulf sturgeon migrations and habitat preferences are based on roving telemetry (Parauka et al. 2001; Fox et al. 2002). Recent advances in acoustic telemetry increase the likelihood and frequency of relocation of fish by incorporating the use of data-logging receivers (Simpfendorfer et al. 2002; Heupel et al. 2004, 2005). The use of prepositioned receiver arrays for continuous monitoring of acoustic transmitters has been successfully used to monitor the habitat use and movement of several marine species including dusky shark *Carcharhinus spp.* (Simpfendorfer et al. 2002; Heupel et al. 2004, 2005), and green sturgeon *A. medirostris* (Moser and Lindley 2007). I assess temporal variability in activity of Gulf sturgeon using prepositioned data-logging ultrasonic telemetry.

METHODS

The study area consists of the Pensacola Bay system in northwest Florida (Figure 1). Rivers draining into the Pensacola Bay system include the Escambia, Blackwater, and Yellow rivers. The Pensacola Bay system is a 3,133 km^2-estuary composed of the Escambia, East and Pensacola bays and Santa Rosa Sound (FDEP 1998). Santa Rosa Sound is bisected by the Gulf Intracoastal Waterway and connects Pensacola Bay and Choctawhatchee Bay. The Pensacola bay system is an important migratory route and wintering ground for Gulf sturgeon.

All Gulf sturgeon used in this study were captured, tagged and released in the Florida portions of the Escambia, Blackwater, Yellow and Choctawhatchee rivers. Gulf sturgeon were captured during June through October 2005 using fixed and drift mono- and multi-filament gillnets ranging in lengths from 30.5 to 45.7 m, widths from 2.5 to 3.7 m, and stretched mesh sizes from 7.9 to 22.9 cm. Gillnets were fished perpendicular to the river bank in preferred habitats. Gillnets were checked every 30 - 60 minutes. All captured Gulf sturgeon were placed in an onboard re-circulating 400-L live well until processed.

Gulf sturgeon were weighed (0.1 kg), measured (0.5 cm fork length) and inspected for internal and external tags. A PIT tag (model TX1411SSL; Biomark Inc., Boise, Idaho, USA) was injected into untagged sturgeon in the base of the dorsal fin. In addition, two external T-bar tags (model FD-67 T-bar; Floy Tag, Seattle, Washington, USA) were inserted through the base of each pectoral fin. Sex of individuals was not determination; however, three fish were confirmed to be emales upon discovery of eggs during transmitter

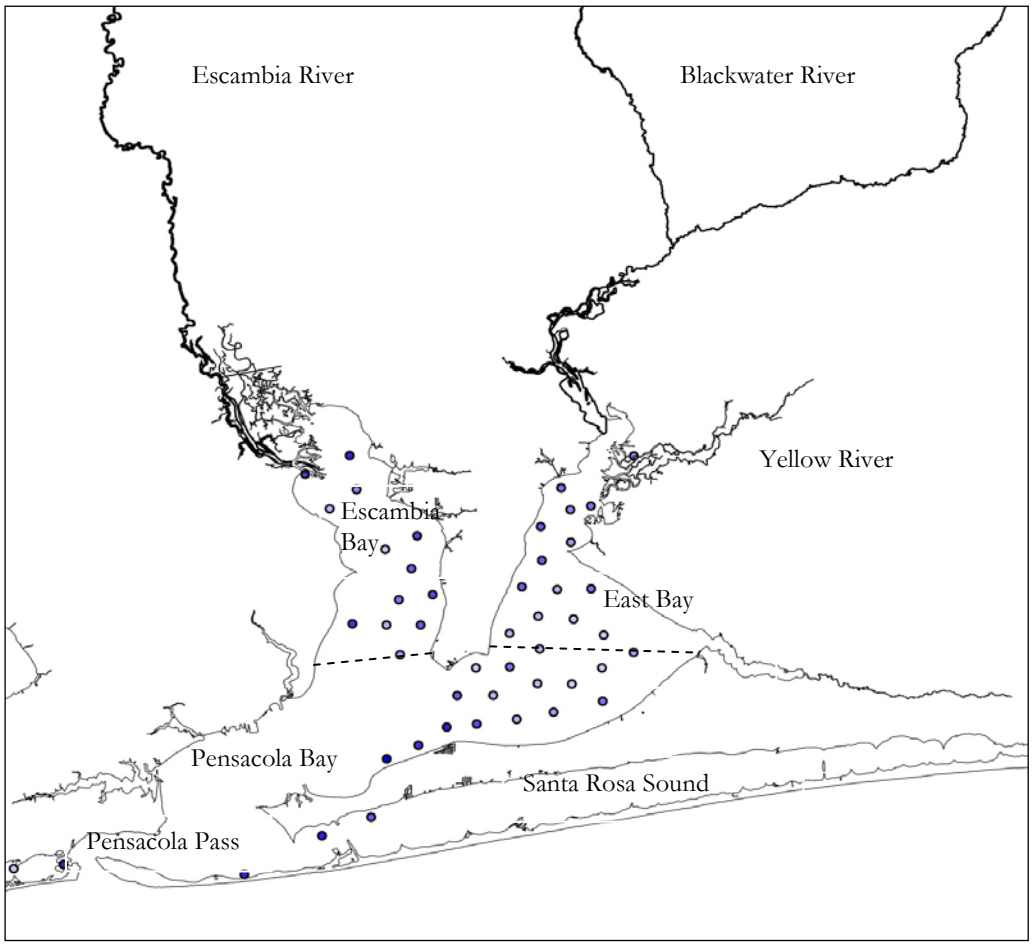


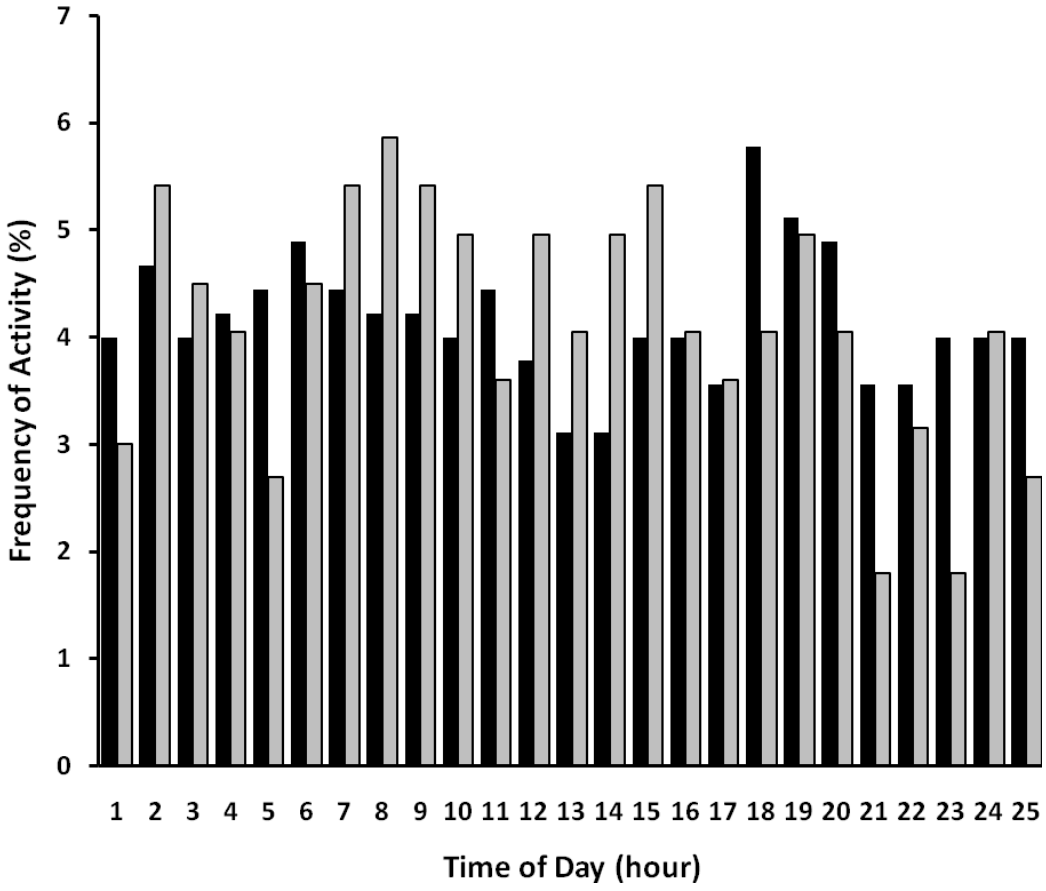
Figure 3.---Pensacola Bay system study site located along the Gulf of Mexico in northeasternFlorida, USA. Pensicola Bay system includes Escambia Bay, East Bay Pensacola Bay and Santa Rosa Sound. Rivers discharging into the Pensacola Bay system include the Escambia River, Blackwater River and Yellow River. Solid circles indicate locations of acoustic receiviers used to evaluate diel activity and movement of Gulf sturgeon.

f implantation. Individually coded acoustic transmitters (models V9 and V13; VEMCO, Halifax, Nova Scotia, Canada) were surgically implanted, using the techniques described by Walsh et al. (2000). Briefly, an incision was made on the mid ventral line and the tag was inserted into the abdominal cavity. The incision was then closed with absorbable sutures. Transmitters weighted 2 and 6 g in water, measured 9 x 20 mm and 13 x 36 mm, and had a battery life of approximately 400 and 700 d. Large tags were used on fish ≥ 60 cm fork length and small tags were used on fish < 60 cm fork length. Battery life for acoustic tags was rated by the manufacturer as approximately 400 days and 700 days, and each coded transmitter was set to cycle once every 60 seconds.

Gulf sturgeon location was monitored using an array of 56 fixed-station acoustic receivers (model VR2; VEMCO, Halifax, Nova Scotia, Canada) stationed throughout the Pensacola bay system (Figure 3). Receivers were anchored in location and positioned in the water column using a cable and float system. Acoustic receivers recorded transmitter number, date and time, and had an effective range of ~0.5 km. Data were recovered monthly using a magnetic probe and computer interface provided by the manufacturer. Most receivers were deployed from October 2005 through June 2006, and from September 2006 through August 2007. However; 3 receivers were allowed to record additional data from June 2006 through September 2006. I divided the study period into: fall (October – December), winter (January – March), spring (May – July) and summer (August – October) of each study year (2005 – 2007). I evaluated the effect of time-of-day on detection probability by examining observations of fixed transmitters. I anchored transmitters 300 and 500 m from two fixed receivers and evaluated the daily periodicity over a 7-d period. The relationship between frequency of fixed transmitter observations recorded and time of day

(day: 07:00 – 19:00, and night:19:00 – 07:00) at 300 and 500 m was not significant (300 m: n = 460, $\chi^2 = 0.0340$, $P = 0.8521$; 500 m: n = 222, $\chi^2 = 0.0180$, $P = 0.8932$; Figure 4).

We used a threshold of two records of an individual within a one-hour period to define presence near a specific hydrophone. Presence of each individual was defined on an hourly basis to reduce the impact of repeated observations on frequently encountered individuals. A fish was determined to have moved when it was recorded on independent hydrophones within a two-hour period. Differences in the hourly distribution of presence and movement within seasons were evaluated using a Chi-square statistic. A probability level (P) = 0.05 was used as the threshold for significance. Data were analyzed using the Statistical Analysis System (SAS version 9.2; SAS Institute, Cary, North Carolina).



.

Figure 4.---Relation between mean frequency (%) of observations of fixed position transmitters recorded on two acoustic receivers across a 7-day period and time of day (hour) indicating probability of reception at 300 (solid bars) and 500 (shaded bars) meters.

RESULTS

We tagged 58 Gulf sturgeon within the Escambia (n=26), Yellow (n=8), Blackwater (n=12), and Choctawhatchee Rivers (n=12) in June, July, September, and October 2005. Tagged Gulf sturgeon ranged in length from 78.0 cm to 200.0 cm fork length (142.5 ± 33.5; mean ± SD) and weighed from 3.4 kg to 70.7 kg (mean = 28.0 ± 16.5; mean ± SD).

Fifty-four Gulf sturgeon were detected at least once during the study. Individuals were observed over a total of 425,700 fish hours representing an average of 2,350 ± 33.5 (mean ± SD) hours per fish on 367 ± 33.5 (mean ± SD) days per fish. Cumulative number of observations per hydrophone ranged from 1 to 217,795 fish hours. Three fish accounted for 48% and two hydrophones accounted for 50% of all observations. One fish on one hydrophone accounted for 22% of all observations. In order to better evaluate consistent patterns among fish, this fish - hydrophone combination was eliminated from further analyses.

A total of 46 Gulf sturgeon were detected on 48 hydrophones representing a total of 837 fish-days in the Pensacola Bay system during fall 2005 (Table 1). Peaks in observations on an hourly and daily basis occurred in fall and winter of each calendar year. Most hydrophones were not deployed during summer resulting in fewer observations of fewer individuals. On average, individual Gulf sturgeon were detected on 10.12 – 32.0 independent days each season.

The relationship between frequency of Gulf sturgeon observations recorded on all acoustic receivers and time of day for all seasons combined indicated a strong diel

Table 1.--- Sample size descriptions relative to year and season related to diel activity of Gulf of Mexico sturgeon in a northwest Florida bay in 2005 - 2007.

Season	Hydrophones deployed	Hydrophones with detections	Gulf sturgeon	Days	Hours	Days per fish	Hours per hydrophone
Fall	56	48	46	837	63,349	18.20	1131.23
Winter	43	35	37	448	68,851	12.11	1601.19
Spring	34	26	33	334	2856	10.12	84.00
Summer	14	11	6	68	396	11.33	28.29
Fall	37	37	54	996	48,694	18.44	1316.05
Winter	39	39	42	644	59492	15.33	1525.44
Spring	37	37	25	599	9388	23.96	253.73
Summer	18	13	1	32	1037	32.00	57.61

activity pattern (Figure 5). Although significant when observations were combined across seasons (Table 2), the relationship was not consistent between seasons. In fall, winter and spring, Gulf sturgeon were more active at night than during day (Table 2). However, during summer, Gulf sturgeon were more active during day than at night.

Fifteen percent of the time, consecutive hourly observations indicating lateral movement of Gulf sturgeon between independent acoustic receivers. When compared to diel activity, the relationship between frequency of movement and time of day for all seasons combined indicated a week nocternal movement pattern (Figure 6). Although significant when observations were combined across seasons (Table 3), the relationship was again not consistent between seasons. The ratio of night to day movement frequency was significantly different from uniform only in winter. In spring, apparent increased activity during night was not significant. In fall and summer, apparent increased activity during day was not significant.

.

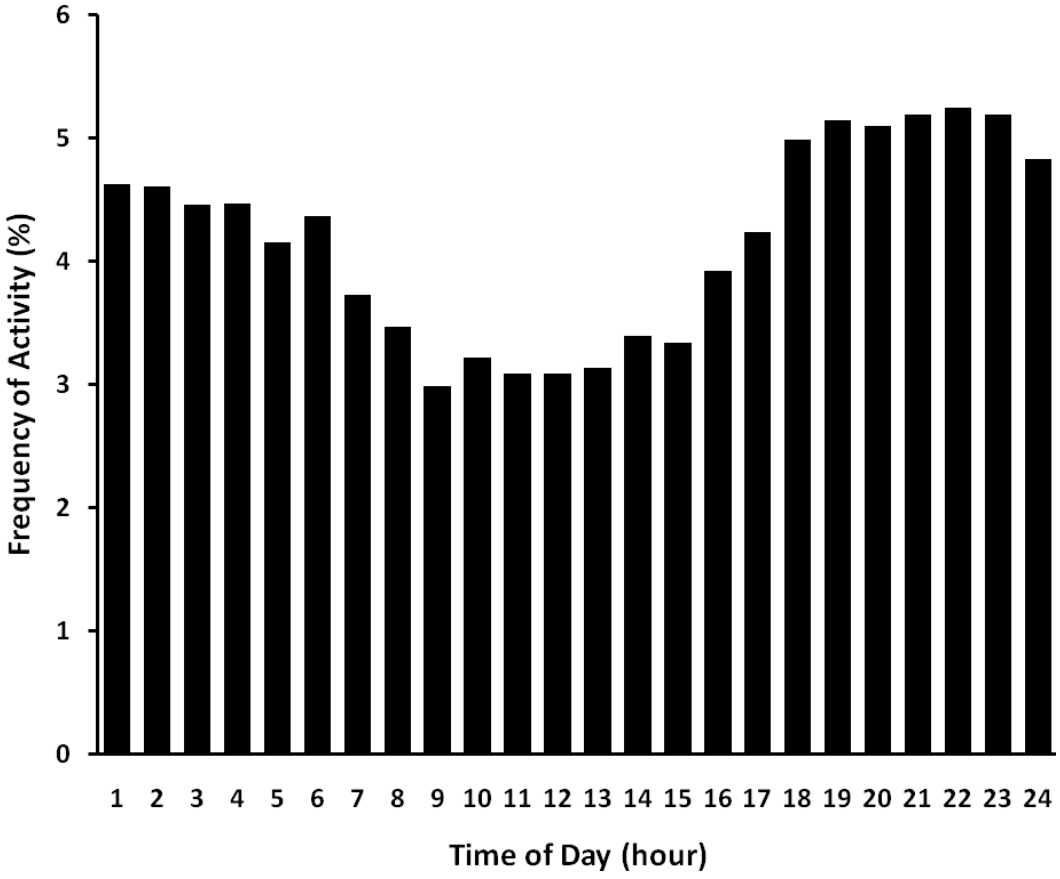


Figure 5.--- Relation between frequency (%) of Gulf sturgeon observations recorded on all acoustic receivers and time of day (hour) across all seasons indicating activity.

.

Table 2.--- Percentage of total activity of Gulf of Mexico sturgeon in a northwest Florida bay during night (18:00 – 06:00 hours) and day (06:00 – 18:00 hours), total number of observation (*N*), χ^2 statistic testing for uniformity in the distribution of activity between night and day, and the probability of rejecting the null hypothesis.

Season	Night	Day	*N*	χ^2	*p*
Fall	52.49	47.51	6458	3.96	0.046
Winter	56.02	43.98	5829	111.17	0.001
Spring	54.87	45.13	1684	16.36	0.001
Summer	20.45	79.55	239	13.52	0.001
Combined	54.34	45.66	14210	40.21	0.001

.

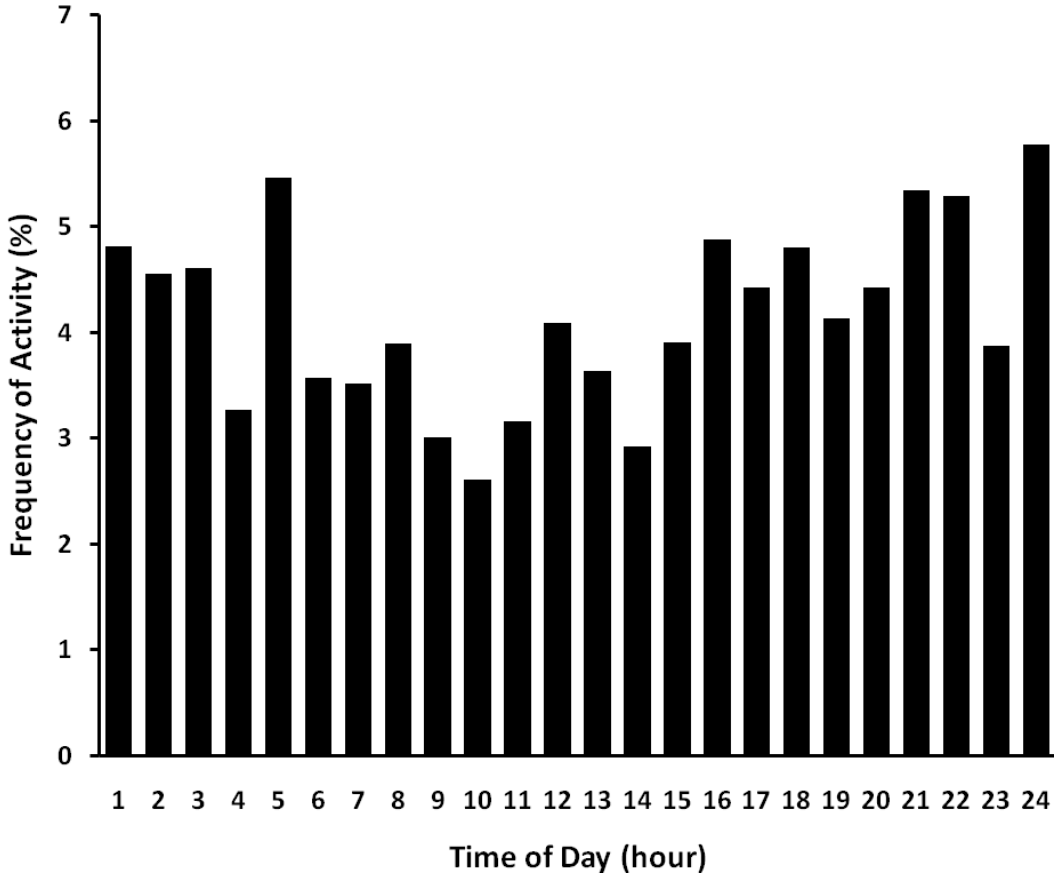


Figure 6.--- Relation between cumulative frequency (%) of Gulf sturgeon observations recorded on independent acoustic receivers within a 1-hour period and time of day (hour) across all seasons indicating movement.

.

Table 3.--- Percentage of total movement between hydrophones of Gulf of Mexico sturgeon in a northwest Florida bay during night (18:00 – 06:00 hours) and day (06:00 – 18:00 hours), total number of observation (*N*), χ^2 statistic testing for uniformity in the distribution of activity between night and day, and the probability of rejecting the null hypothesis.

Season	Night	Day	N	χ^2	P
Fall	48.45	51.55	1158	1.11	0.290
Winter	69.56	30.44	473	72.36	0.001
Spring	54.41	45.59	454	3.52	0.061
Summer	39.73	60.27	73	3.08	0.079
Combined	54.07	45.93	2160	14.34	0.001

DISCUSSION

Gulf sturgeon migrate through the Pensacola Bay system in fall to wintering areas in the Gulf of Mexico and Santa Rosa Sound, then migrate back through the bay system to summering habitats in rivers in spring (Wrege Chapter 1, this volume). Similar patterns in migration were observed in Apalachicola Bay (Wooley and Crateau 1985) and Choctawhatchee Bay (Hightower et al. 2002). I observed a strong diel pattern in Gulf sturgeon activity. Gulf sturgeon were more active at night than during day in all seasons but summer. Although diel patterns in the activity of fish have been well documented (Helfman 1993; Reebs 2002), diel behavior of sturgeon has not been well described. Haynes and Gray (1981) related depth and location of white sturgeon inversely to light level. Parsley et al. (2008) documented that white sturgeon move into shallow water at night. I believe the relationship between the frequency of Gulf sturgeon detections and time of day that I observed was related to a nocturnal vertical migration. The detection of an acoustic signal requires an uninterrupted line of sight between the transmitter and the receiver (Clements et al. 2005). As sturgeon are primarily demersal (Ferguson and Duckworth, 1997), slight changes in benthic topography may interrupt reception. Vertical movement of Gulf sturgeon increases detection probability and explain the observed periodicity.

The detection of a few summer residents in Pensacola Bay system was unexpected. Gulf sturgeon normally spend summer in deeper, cooler water in rivers (Wooley and Crateau 1985; Hightower et al. 2002) and have not been previously observed spending the summer period in marine waters. These summer residents were located near shallow water. White

sturgeon are known to move into shallow water at night (Parsley et al. 2008). Due to the limited number of acoustic receivers deployed in summer, I believe Gulf sturgeon may have moved out of the range of detection of the array at night, resulting in apparent low activity and movement in summer.

Previous studies of Gulf sturgeon movement and migration have been based on roving telemetry (Parauka et al. 2001; Fox et al. 2002). These studies have been conducted exclusively during daylight hours. The use of prepositioned arrays of acoustic receivers not only provides continuous data within a defined area (Simpfendorfer et al. 2002; Moser and Lindley 2007), but provides insights into nocturnal behavior not previously examined. The designation of Gulf sturgeon critical habitat not only has a spatial, but a temporal component to allow for human activity at times when sturgeon are not present. The use of prepositioned acoustic arrays may provide additional insight into behavior that may have important ecological and management implications.

REFERENCES CITED

Berg, J., M. Allen, and K. Sulak. 2004. Population assessment of the Gulf of Mexico Sturgeon in the Yellow River, Florida. Masters Thesis. The University of Florida, Gainesville, Florida.

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.

Clements, S., D. Jepsen, M. Karnowski, and C. B. Schreck., 2005., Optimization of an acoustic telemetery array for detecting transmitter-implanted fish. North American Journal of Fisheries management 25: 429-436.

Craft, N. M., B. Russell, and S. Travis. 2001. Identification of Gulf Sturgeon spawning habitats and migratory patterns in the Yellow and Escambia River systems. Final Report to the Florida Marine Research Institute, Fish and Wildlife Conservation Commission, Tallahassee, Florida.

Davis, J. T., B. J. Fontenot, C. E. Hoenke, A. M. Williams, and J. S. Hughes. 1970. Ecological factors affecting anadromous fishes of Lake Ponchartrain and its tributaries. Louisiana Wildlife and Fisheries Commission Bulletin 9: 1-63.

Edwards, R. E., K. J. Sulak, M. T. Randall, and C. B. Grimes. 2003. Movements of Gulf sturgeon (*Acipenser oxyrinchus desotoi*) in nearshore habitat as determined by acoustic telemetry. Gulf of Mexico Science 2003 (1): 59-70.

Federal Register. 1991. Endangered and threatened wildlife and plants; Threatened status for the Gulf sturgeon; Code of Federal Regulations, Title 50, P.L. 17. Federal Register 56(189): 49653-49658.

Ferguson, M. M. and G. A. Duckworth. 1997. The status and distribution of lake sturgeon, Acipenser fulvescens, in the Canadian provinces of Manitoba, Ontario and Quebec: a genetic perspective. Environmental. Biol. Fish. 48: 299–309.

Florida Department of Environmental Protection (FDep). 1998. Pensacola Bay watershed management guide: An integrated ecosystem action plan. Florida Department of Environmental Protection, Tallahassee, Florida. 268pp.

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.

Fox, D. A., J. E. Hightower, and F. M. Parauka. 2002. Estuarine and nearshore marine habitat use by Gulf Sturgeon from the Choctawhatchee River system, Florida. American Fisheries Society Symposium 28: 111-126.

Harris, J. E. 2003. Distribution of Gulf of Mexico sturgeon (*Acipenser oxyrinchus desotoi)* in relation to environmental parameters and the distribution of benthic invertebrates in the Suwannee River Estuary, Florida. Master's Thesis. The University of Florida, Gainesville, Florida.

Heupel, M. R., C. A. Simpfendorfer, R. E. Hueter. 2004. Estimation of shark home ranges using passive monitoring techniques. Environmental Biology of Fishes 71: 135-142.

Heupel, M. R. and C. A. Simpfendorfer. 2005. Quantitative analysis of aggregation behavior in juvenile blacktip sharks. Marine Biology 147: 1239-1249.

Hightower, J. E., K. P. Zehfuss, D. A. Fox, and F. M. Parauka. 2002. Summer habitat use by Gulf Sturgeon in the Choctawhatchee River, Florida. Journal of Applied Ichthyology 18: 595-600.

Huff, J. A. 1975. Life history of Gulf of Mexico sturgeon, *Acipenser oxyrhynchus desotoi,* in the Suwannee River, Florida. Florida Marine Resources Publication. No. 16. City, State. 32 pp.

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.

Parauka, F. M., S. K. Alam, D. A. Fox. 2001. Movement and habitat use of subadult Gulf Sturgeon in Choctawhatchee Bay, Florida. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 55: 280-297.

Seaman, W., JR. 1988. Florida aquatic habitat and fishery resources. Florida Chapter of the American Fisheries Society, Eustis, Florida. 543 pp.

Simpfendorfer, C. A., M. R. Heupel, and R. E. Hueter. 2002. Estimation of short-term centers of activity from an array of omnidirectional hydrophones and its use in studying animal movements. Canadian Journal of Fishery and Aquatic Sciences 59: 23-32.

Stabile, J., J. R. Waldman, F. Parauka, and I. Wirgin. 1996. Stock structure and homing fidelity of Gulf sturgeon (*Acipenser oxyrinchus desotoi).* Genetics 144: 767-775.

Vladykov, V. D. 1955. A comparison of Atlantic sea sturgeon with a new subspecies from the Gulf of Mexico *(Acipenser oxyrhynchus desotoi)*. Journal of the Fisheries Resource Board of Canada 12: 754-761.

Walsh, M. G., K. A. Bjorgo, and J. J. Isely. 2000. Effects of implantation method and temperature on mortality and loss of simulated transmitters in hybrid striped bass. Transactions of the American Fisheries Society 129: 539-544.

Wooley, C. M. and E. J. Crateau. 1985. Movement, Microhabitat, Exploitation, and Management of Gulf of Mexico Sturgeon, Apalachicola River, Florida. Nort American Journal of Fisheries Management 5: 590-605.