Activity patterns of Gulf Sturgeon (*Acipenser oxyrinchus desotoi*) in the staging area of the Pascagoula River during fall outmigration

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Abstract – Environmental cues that are associated with individual movement of threatened Gulf Sturgeon from upriver areas to nearshore and offshore winter feeding areas have been described throughout much of their range in the Gulf of Mexico. In this study, we focus on small-scale movement of Gulf Sturgeon between summer ‘holding’ areas and the fall staging area in the Pascagoula River system (Mississippi, USA). We evaluated a set of logistic regression models using Akaike’s Information Criterion and found that relative changes in barometric pressure, time of day, and water temperature were cues for small-scale Gulf Sturgeon movements during fall outmigration. Numerous environmental cues appear to drive the activity of Gulf Sturgeon in staging areas, indicating the complexity of abiotic factors affecting the observed staging patterns during emigration. The identification of the environmental drivers that are associated with Gulf Sturgeon movement is particularly important if these known saline transition zones change spatially annually with variable rainfall or due to water withdrawals and are used by Gulf Sturgeon making osmotic adjustments while moving downriver.

Key words: migration; physiochemical cues; threatened species; rheotaxis

Introduction

Gulf Sturgeon, *Acipenser oxyrinchus desotoi*, are a federally threatened subspecies of the Atlantic Sturgeon, *Acipenser oxyrinchus oxyrinchus*, and are native to northern Gulf of Mexico drainages from the Pearl River, Louisiana, to the Suwannee River, Florida (Wooley 1985; Randall & Sulak 2007), including the Pascagoula River, Mississippi. The Pascagoula River is unique because it is the largest naturally flowing river (structurally unaltered) system in the contiguous United States (Dynesius & Nilsson 1994) making it potentially the most important core river within Mississippi (Heise et al. 2004) and possibly within the Western limits of its range (Havrylkoff et al. 2012).

Gulf Sturgeon are anadromous, leaving the river in the fall to feed in the estuary and nearshore habitats and returning in the spring, when mature individuals spawn upriver. After returning to the river, Gulf Sturgeon spend the remainder of spring and summer (late May–September; Heise et al. 2004, 2005) within summer ‘holding’ areas. These holding areas are generally deep, near river bends, or upriver from sand shoals and generally located in the mid to lower reaches of main-stem rivers (Wooley & Crateau 1985; Foster & Clugston 1997; Sulak & Clugston 1999; Heise et al. 2005).

Environmental cues have been shown to affect the movement and behaviour of migratory species on a variety of spatial and temporal scales (Vøllestad et al. 1986; Avgar et al. 2013). Fall environmental cues such as decreasing day length, decreasing water temperature and increases in river discharge prompt the initiation of adult Gulf Sturgeon movement from holding areas to locations downriver (Heise et al. 2005). During the fall of 2000 (a drought year), Gulf
Sturgeon were found to remain in a ‘fall staging area’ downriver of the summer holding area for extended periods of days to weeks (Heise et al. 2005). Similar staging areas have been described in the Apalachicola River, Florida as areas just above the fresh/salt water interface. Here fish remain during a period of osmoregulatory adjustment (Wooley & Crateau 1985; Odenkirk 1989) as is the case with congeners such as juvenile Chinese Sturgeon (*Acipenser sinensis*). This species has been shown to use low salinity estuarine areas to acclimate to changing salinity regimes (Zhao et al. 2011). Low salinity estuarine ‘staging’ zones have also been shown to serve as important foraging grounds for young Atlantic Sturgeon in several studies in the northern Atlantic (Simons et al. 2006; Guilbard et al. 2007; Nellis et al. 2007). In fact, high fall discharge has been suggested to drive recruitment success of Gulf Sturgeon in the Suwannee River, Florida (Randall & Sulak 2007) by expanding low salinity areas for increased foraging opportunities.

Gaps in knowledge exist about the links of potential environmental cues and increased periods of activity of Gulf Sturgeon, as they pause their emigration from the lotic environment after leaving the summer holding area. Due to their rarity, sampling for Gulf Sturgeon is costly and time-consuming, especially in the Western portion of their range (Havrylkoff et al. 2012; Peterson et al. 2013). An effective sampling strategy would be adapted to correspond with periods when there is a high probability of increased Gulf Sturgeon activity. Our objective was to identify the environmental and hydrological conditions that trigger Gulf Sturgeon activity in the staging area of the Pascagoula River in order to enhance capture rates and to allow managers and resource specialists to address anthropogenic changes of these conditions, while not impacting important upriver migration cues for threatened Gulf Sturgeon.

**Materials and methods**

**Sampling**

Sampling efforts on the Pascagoula River took place from 2010 through 2012, during the Gulf Sturgeon fall outmigration period (September–November); efforts were focused between river kilometre (rkm) 24 and 38 (Fig. 1) in the fall staging area (Heise et al. 2005). We were interested in capturing Gulf Sturgeon of any size class and used various sized anchored gill net sets during the day and night. Net location, surface and bottom water temperature (°C), dissolved oxygen (mg L⁻¹), salinity, and specific conductivity (µS) were recorded at the midpoint of each net following deployment, and nets were checked every 2 h. We assume that increased catch-per-unit-effort indicates increased ‘activity’ of Gulf Sturgeon in the fall staging area. Captured Gulf Sturgeon were secured onboard the sampling vessel, standard body metrics were recorded, and fish were acoustically tagged following standard procedures (USFWS 1993; Kahn & Mohead 2010).

**Data collection and treatment**

Physiochemical data were obtained from multiple sources and extrapolated to assess abiotic conditions.
within the sampling area. Barometric pressure (mbar) was obtained hourly from weather station DKCM6-8741501, Pascagoula, Mississippi. Stream velocity (m·s⁻¹) and discharge (m³·s⁻¹) were obtained from United States Geological Survey (USGS) station 02479310 at Graham Ferry, Mississippi, 24 rkms upriver of our sampling site. Tidal height (m, converted to cm) recorded at 6-min intervals and hourly water temperatures were both obtained from National Oceanic and Atmospheric Administration (NOAA) station 08741533, Pascagoula, Mississippi.

Change in tidal height in relation to mean lower low water was used to represent the relative tidal influence upriver as follows. Change in water-levels downriver (station 08741533) took approximately 3 h to have an effect on the water-levels upriver as determined with a YSI (model 6600; Yellow Springs Instruments, Yellow Springs, Ohio, USA) equipped with a pressure sensor. Data from station 08741533 adjusted for the 3-h lag were used to approximate the change in the water height (positive or negative) from the time the nets first entered the water to the time the nets were removed (about 2 h). Water temperature data from station 08741533, recorded hourly, were adjusted to reflect the water temperature observed in the upriver sampling area at the appropriate time period. This was a three-step process: (1) we calculated a daily mean value from all in-situ water temperature data recorded at the midpoint of each anchored gill net (surface and bottom pooled); (2) we obtained water temperature values from station 08741533 for the closest net-set time point and estimated a standard deviation (SD) between the in-situ daily mean of the net-set and the gage value; and (3) we either added or subtracted the SD from all hourly water temperature values (station 08741533) corresponding in time with the total sampling period for that day to create site-adjusted hourly water temperature values upriver. Lunar calendars were obtained from http://www.almanac.com for Pascagoula, Mississippi and the per cent (%) visible moon for each date sampled was used in the models. Time of day (TOD) was coded categorically as day (1.0), evening crepuscular (0.25) or night (0.0) to assign a relative light level and directionality for statistical analyses. The evening crepuscular period was defined as 1 h before and after sunset and a net-set was coded likewise if any portion of the soak time occurred during the defined 2 h period.

Statistical analyses

We constructed a set of candidate logistic models (n = 227) to determine the likelihood of the presence of Gulf Sturgeon given a set of independent predictor variables. Logistic regression models were constructed and evaluated in R (ver. 3.0.2, R Foundation for Statistical Computing, Vienna, Austria.). The dichotomous outcome, Gulf Sturgeon presence or absence for each 2 h net-set, was determined using a set of predictor variables. Predictor variables included the calculated mean values for water temperature (°C), barometric pressure (mbar), discharge (m³·s⁻¹), stream velocity (m·s⁻¹), per cent (%) visible moon, change in tidal height (cm) for each net-set, and the categorical TOD. If the complete suite of water quality and environmental data were not available for a particular record, it was removed from the analysis. Prior to logistic regression analysis, we tested the direction and magnitude of each pair-wise combination of predictor variables using Pearson’s product–moment correlation (r) using SPSS (ver. 20, Statistical Programs for Social Sciences, Armond, NY, USA.). If the pairwise r-value was |≤0.60| then only one of the predictors was used in the regression model and the others were removed from further analysis.

A two-step process was used for model selection and evaluation. In the first step, candidate models were constructed that included both lower order main effects and higher order two-way interaction effects. We considered these models to be hierarchically well formulated (HWF, Jaccard 2001). The relative fit of the candidate logistic models were evaluated using Akaike’s Information Criterion (AICc), adjusted for small sample size (Burnham & Anderson 2002). The model with the lowest AICc value is considered the model with the best explanatory power and the $\Delta$AICc value was determined for each competing model by calculating the difference between that model’s AICc and the AICc value of the best fit (lowest AICc value) model. Thus, the value $\Delta$AICc is a criterion of comparison among models relative to the model that is considered to best fit the data. To remove the many models that had poor explanatory power but also to minimise the risk of discarding useful models, we only selected models with $\Delta$AICc units ≤ 3 (Burnham & Anderson 2002; Richards 2005; Grossman et al. 2006).

The second step in the model selection process was to evaluate the reduced subset of candidate models, those with $\Delta$AICc units ≤ 3 from the full candidate set, to determine whether any two-way interaction effects present in the models were ‘trivial’ (Jaccard 2001). Trivial interaction terms were detected using two criteria. The first criterion was to determine whether the difference in model fit to the data of the nested submodel and the HWF model was inconsequential (Jaccard 2001). The difference in model fit was determined by comparing the AICc of the nested submodel (without interaction terms) and the AICc of the HWF model (with interaction terms). We considered the fit of the nested submodel to be equivalent to that of the HWF if the difference in AIC values
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was ≤ 3. The second criterion was to determine whether the interaction terms in the HWF were statistically significant (α = 0.05) using a Wald test. We considered the interaction terms to be trivial in a candidate model if their exclusion did not result in substantially decreased model fit and if they were not different from zero. Following this evaluation of the interaction effects, the reduced set of candidate models were reformulated to include only main effects, where appropriate.

The statistical significance of the reduced set of candidate models and their associated parameters was evaluated. To test the ability of a candidate model to determine the presence of Gulf Sturgeon, we evaluated the difference of the residual deviance of the model with predictors and the residual deviance of the associated null model. This test statistic is distributed χ² and the critical value is determined with degrees of freedom (d.f.) equal to the difference in the d.f. of the model with predictors and the d.f. of the null model. The statistical significance of each model parameter was determined using a Wald test (α = 0.05). The 95% confidence interval of each mean model parameter was determined by a profile likelihood approach. The relative model weight, wi, of the K models examined was determined for each of the reduced set of candidate models using ΔAICc of each candidate model for each of i models:

\[ w_i = \frac{e^{-\frac{1}{2}\Delta AIC_{ci}}}{\sum_{j=1}^{K} e^{-\frac{1}{2}\Delta AIC_{cj}}} \]

The determination of the weight of each model enabled us to qualitatively describe the relative importance of each model parameter, summarised across all models in the reduced set of candidate models (Anderson et al. 2012). We determined the relative importance of a parameter by summing the weight of all models (reduced set) containing that parameter.

Results

Data collection and treatment

There were no significant pair-wise correlations between independent variables used in the regression analyses. Each pair-wise Pearson’s product–moment correlation r-value was ≤ 0.60 and the independent variables that were included in the top five candidate models had r-values < 0.40. There were 1095 complete records with 42 records of Gulf Sturgeon presence. These records were comprised of 30 unique individuals ranging in total length from 36.0 to 147.2 cm. The recapture of previously tagged individuals were considered an independent presence if the fish had been at-large for at least 24 h. The grand mean (±SD, standard deviation) for barometric pressure, water temperature, discharge, and stream velocity and means (±SD) for change in tidal height, TOD, and % visible moon are shown in Table 1 and are presented as a guide for predicting conditions under which Gulf Sturgeon appear more active.

In the first step of model selection from the exhaustive list of potential candidate models (n = 227), we found five models that had ΔAICc ≤ 3. These five models accounted for 52.25% of the total model weight of the set of candidate models. These five models comprise the reduced model set and each had one (n = 3) or three (n = 2) two-way interactions present. We evaluated the statistical significance of these two-way interactions and none were significant at α = 0.05 (P-values of interaction terms in the five candidate models ranged from 0.095 to 0.548). The model-specific evaluation of the difference in the AICc value of the full model (main effects and interaction effects) and the AICc of the parsimonious nested model (no interaction terms included) allowed us to understand relative model fit. We found that the difference in the AICc value for each of the five candidate models to range from −0.78 to 2.49 when the

Table 1. Summary statistics for water height change, TOD, and % visible moon (mean values) and barometric pressure, water temperature, discharge, and stream velocity (grand mean values) and standard deviations for physiochemical variables included in predictive models split by presence and absence of Gulf Sturgeon.

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>Present (n = 42)</th>
<th>Absent (n = 1053)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barometric press (mbar)</td>
<td>1014.7 ± 5.3 (1007.7; 1014.5)†</td>
<td>1016.6 ± 4.3 (1015.3; 1016.4)</td>
</tr>
<tr>
<td>Water height change (m)</td>
<td>0.026 ± 0.09 (−0.53; 0.03)†</td>
<td>−0.007 ± 0.08 (0.02; 0)</td>
</tr>
<tr>
<td>TOD (0, 0.25, 1.0)</td>
<td>0.57 ± 0.44 (1.0; 0.62)</td>
<td>0.74 ± 0.40 (1.0; 1.0)</td>
</tr>
<tr>
<td>Water temperature (°C)</td>
<td>21.6 ± 3.2 (17.4; 21.7)†</td>
<td>22.1 ± 3.0 (23.5; 23.0)</td>
</tr>
<tr>
<td>Visible moon (%)</td>
<td>45.7 ± 38.6 (0; 50)</td>
<td>52.6 ± 34.0 (50; 50)</td>
</tr>
<tr>
<td>Discharge (m³·s⁻¹)</td>
<td>76.90 ± 30.54 (61.45; 69.38)</td>
<td>84.53 ± 47.80 (58.05; 69.23)</td>
</tr>
<tr>
<td>Stream velocity (m·s⁻¹)</td>
<td>0.59 ± 0.36 (0.20; 0.51)†</td>
<td>0.55 ± 0.34 (0.37; 0.46)†</td>
</tr>
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</table>

Time of day (TOD) categorical codes: 1.0 = day, 0.25 = evening crepuscular, 0 = night. Modes followed by medians are shown in parentheses.

†Multiple modes exist; smallest value shown.
interaction terms were removed. Three models (Model 1, Model 4, and Model 5; Table 2) had improved explanatory power when interaction terms were removed; the reduction of the AICc ranged from 1.43 to 2.49. Two models (Model 2 and Model 3) exhibited a poorer fit when interaction terms were removed, but the difference was slight, ranging from 0.69 to 0.78.

The multimodel analysis of the prevalence of model parameters and relative model fit allowed us to make inferences about the utility of predictor variables. Barometric pressure occurred in all candidate models and was a negatively correlated predictor of Gulf Sturgeon presence in each model with cumulative Aikake weights across all models of 1. The predictor variable TOD occurred in three candidate models (1, 2, 5) and accounted for a cumulative weight of 0.83 and was also a negative predictor. Water temperature (negative predictor) occurred in only two candidate models (1, 4) and accounted for a total weight of 0.73. Finally, the predictor variable tide change (negative; total weight = 0.09) and % moon (positive; total weight = 0.09) occurred in models 3 and 5 respectively. The predictors discharge, stream velocity, and year were not included in any of the reduced model set.

Discussion

We have shown significant correlations between a subset of predictor variables considered in our study and activity of Gulf Sturgeon present in staging areas. All of the top-ranked multivariable models exhibited statistically significant and consistent patterns in the correlations between Gulf Sturgeon activity and independent abiotic variables. These abiotic drivers may not be the only important ones, as factors affecting activity of Gulf Sturgeon in staging areas are likely complex and conditionally dependent on annual fluctuations in a large suite of physiochemical drivers, some of which have been suggested to influence Gulf Sturgeon emigration. For example, increasing river discharge, water temperature, and decreasing day length have been identified as large-scale adult emigration cues (Heise et al. 2005). However, studies to elucidate Gulf Sturgeon staging and the short-term environmental drivers are greatly lacking, although the behaviour has been generally described (Wooley...
The model results we report here imply that complex and multivariate environmental relationships likely drive Gulf Sturgeon activity on a fine spatial scale. As barometric pressure was found to be a strong predictor variable in all models (its cumulative sum of weights was greatest of all variables), it is likely that factors associated with fluctuations in barometric pressure affect the timing of Gulf Sturgeon migration. During the time of this emigration, the Gulf Coast region is characterised by the passage of frontal weather systems.

The movement of a variety of animals is thought to be associated with the changes in barometric pressure (Sproat 1967). For example, Heupel et al. (2003) found that Blacktip Shark (Carcharhinus limbatus) leave shallow Florida bays until after the passage of the storm. Likewise, Gulf Sturgeon moved offshore of the Suwannee River, Florida nearshore area during periods of strong cold fronts (Edwards et al. 2003; Sulak et al. 2009).

The importance of TOD as a predictor of Gulf Sturgeon activity is supported by the total sum of weights among three candidate models and indicated that Gulf Sturgeon were more likely to be captured at night or during the evening crepuscular period. In fact, nocturnal movement of early developing Gulf Sturgeon (Kynard & Parker 2004), adult Gulf Sturgeon (Wrege et al. 2011), and 15-day-old Atlantic Sturgeon (Gessner et al. 2009) have been observed in field and laboratory studies. Diel changes in movements and activity (diel plasticity) of anadromous fishes may be a common strategy when moving along habitat gradients. For example, Chinook (Oncorhynchus tshawytscha) and Steelhead (Oncorhynchus mykiss) Salmon smolts changed diel migration tactics while emigrating from the Sacramento/San Joaquin watershed. This behaviour implied that encountering new habitat types as they moved downstream fish would change daily migration tactics as a means to avoid predation pressure, increase foraging success, and other vital requirements in new environments (Chapman et al. 2013). The concept of diel plasticity (e.g. Kynard & Parker 2004; Gessner et al. 2009) as a way to deal with a range of ecological scenarios may be similar in many anadromous species leaving a freshwater river, travelling through an estuary, and eventually entering the marine environment. As Gulf Sturgeon leave the river and prepare to enter the estuary, we assume diel movement patterns could potentially be changing within the staging area of the river as it is likely fish may have encountered the fresh/salt water interface (Peterson et al. 2007) and have started to adjust physiologically to enter estuarine/marine waters (Altinok et al. 1998; Altinok & Grizzle 2001).

Our study indicated decreasing water temperature was important in models 1 and 4, accounting for a reduced total sum of weights compared to barometric pressure and TOD. We speculate that while it is possible fish may be simply passing through the staging area from holding areas after water temperature falls, it is also possible that decreasing water temperature may be one of the environmental cues responsible for the initiation of Gulf Sturgeon movement of the staging area. Decreasing water temperature has been noted as an important driver of Gulf Sturgeon emigration in other studies (Clugston et al. 1995; Foster & Clugston 1997) but it has not been identified as an important factor in influencing fish activity in more transitional staging areas. Wooley & Crateau (1985) suggested that fish remained in the staging areas until environmental cues (they proposed water temperature) spurred their movement towards the estuary. As water temperature has been identified as an important driver initiating Gulf Sturgeon emigration from the summer holding areas (Heise et al. 2005), we predict it could also be an important driver of movement downriver away from the staging areas as well.

Tidal change was positively related with activity when included in model 3 accounting for only a small sum of weights as was % visible moon (negatively correlated) which also occurred in only one model and accounting for a small sum of weights compared to other variables. Lunar and tidal cycles have long been shown to affect the movements of many fish species and decapod crustaceans (Forward & Tankersley 2001; Reeds 2002; Hare et al. 2005; Keefer et al. 2013) and generally are co-dependent on one another. Kelly & Klimley (2012) noted Green Sturgeon (Acipenser medirostris) swimming into the current while maintaining position just off the bottom which likely allows them to more efficiently maintain buoyancy while swimming. Thus, it is possible that flow conditions experienced during a rising tide caused Gulf Sturgeon to change their swimming behaviour in a way which made them more susceptible to capture in the anchored gear.

One feature of our study is the rarity in the number of captures. Therefore, the data we analysed was unbalanced (numerous zero’s) which can influence the logistic regression slope and Y-intercept coefficients (King & Zeng 2001) but because we were only interested in the direction of the slope (+, −) and not its magnitude, we feel the normal procedure is appropriate. This coupled with the fact that logistic regression only requires meeting the independence of samples and linear relationship assumptions indicates the approaches we used are appropriate for our data set (Field 2013).
Conclusion

It has been proposed that staging behaviour allows fish to adjust osmoregulatory function before entering estuarine and/or marine environments. Heise et al. (2005) only noted this behaviour in a drought year (2000) during their study in the Pascagoula River but has also been found in both the Suwannee River (Siegel et al. 1996; Randall & Sulak 2007) and the Apalachicola River, Florida (Sulak et al. 2009). In non-drought years, Heise et al. (2005) found the Gulf Sturgeon left the river quickly following increases in river discharge and spent little time in the described staging area. We believe the dynamically changing abiotic habitat in the Pascagoula River estuary (Peterson et al. 2007) may serve as an important area for Gulf Sturgeon to slowly acclimate to increasingly saline waters.

We recognise the data are unbalanced in terms of the number of records for which we have activity, but we have observed multiple catches of Gulf Sturgeon commonly during favourable conditions. As Gulf Sturgeon need to spend time in areas to adjust osmotically, we suggest annual fluctuations in rainfall and discharge (although not a good predictor of Gulf Sturgeon activity while exhibiting staging behaviour) during large-scale emigration movements may dictate where within the river these holding and staging zones occur. By examining trends in prediction variables included in the various models, the importance and conditional-dependence of environmental factors becomes clear when attempting to better predict the activity level of Gulf Sturgeon within staging areas. Furthermore, our unpublished acoustic data indicate that Gulf Sturgeon of all size classes make directed movements both upstream and downstream within the lower portions of the staging area defined by Heise et al. (2005). Closer examination of these data suggests that while adult Gulf Sturgeon may use portions of the staging area in the fall to presumably acclimate themselves to the estuarine/marine waters, immature fish may actually use the previously defined staging area as a holding area throughout at least portions of the late spring and summer. Although preliminary, acknowledging the potential for size-specific differential use of particular areas along the river axis is important to the conservation and recovery of Gulf Sturgeon and therefore requires further research.

A better understanding of the links between suites of environmental drivers and corresponding Gulf Sturgeon life-history cues will provide natural resource managers and stakeholders additional insight when making conservation and management decisions, particularly those involving water use policies. Water management for local municipalities and industries is of paramount concern, especially in coastal areas of the south-eastern United States where population levels have increased dramatically over past decades (Crossett et al. 2004; Cooke et al. 2012). These concerns have been further heightened as drought conditions, in some cases, and have threatened local and regional water supplies (i.e. Atlanta water wars: Apalachicola-Chattahoochee-Flint rivers; http://www.atlantaregional.com/environment/tri-state-water-wars). Future reductions in available surface water could potentially impact the linear position of salinity gradients within coastal watersheds and ultimately influence the availability of Gulf Sturgeon holding and staging areas.

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References


Hare, J.A., Thorrold, S., Walsh, H., Reiss, C., Valle-Levinson,
Grossman, G.D., Ratajczak, R.E., Petty, J.T., Hunter, M.D.,
Forward, R.B. & Tankersley, R.A. 2001. Selective tidal-
Field, A. 2013. Discovering statistics using IBM SPSS statis-
Edwards, R.E., Sulak, K.J., Randall, M.T. & Grimes, C.B.
Crossett, K.M., Culliton, T.J., Wiley, P.C. & Goodspeed, T.R.
Forward, R.B. & Tankersley, R.A. 2001. Selective tidal-
geon co-occurring in the St. Lawrence estuarine transition zone. American Fisheries Society Symposium 56: 85–104.
Heise, R.J., Slack, W.T., Ross, S.T. & Dugo, M.A. 2005. Gulf Sturgeon summer habitat use and fall migration in the Pasca-
ing before the storm: blacktip sharks respond to falling barometric pressure associated with Tropical Storm Gabri-
Kynard, B. & Parker, E. 2004. Ontogenetic behavior and migration of Gulf of Mexico Sturgeon, Acipenser oxyrinchus desotoi, with notes on body color and development. Envi-
Peterson, M.S., Havrylkoff, J.-M., Grammer, P.O., Mickle, P.F., Slack, W.T. & Yeager, K.M. 2013. Macrobenthic prey and physical habitat characteristics in a western Gulf Stur-
Randall, M.T. & Sulak, K.J. 2007. Relationship between recruitment of Gulf Sturgeon and water flow in the Suwan-
lands: the Suwannee River estuary. Final Report, St. Peters-
burg, FL: Department of Marine Science, University of South Florida. 127 pp.
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