Utilizing Impounded Waters to Enhance Critical Habitat for Endangered Species of the Pascagoula River

Final Report

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Report on December Pascagoula River flow and Gulf Sturgeon survivability

This research explores a relatively unique potential benefit to impounding rivers. Specifically could a proposed impoundment be designed to restore natural flow regimes or hydrographs and improve critical habitat for threatened and endangered aquatic species. This study was limited to the effect such river flow management could have on the Gulf Sturgeon. Other threatened and endangered aquatic species are likely to have slightly different requirements, such as salinity control.

Background:

Randall and Sulak (2007) found that annual recruitment for Gulf sturgeon (Acipenser oxyrhynchus) in the Suwannee River is positively correlated with high mean monthly flows in September and December. Hypotheses for this correlation include 1) increased survivability under conditions of decreased salinity and/or high dissolved oxygen and 2) increased food supply and/or foraging area under high flows (Randall and Sulak 2007).

Flowers et al. (2009) found that Gulf sturgeon in the Apalachicola River spawn in areas of similar depth and velocity regardless of flow. The study showed that discharges less that 142 m3/s at the Jim Woodruff Lock and Dam reduced spawning habitat, which has the potential to affect recruitment. The authors suggest that managers consider the possible effects of low flows on Gulf sturgeon recruitment. However, there are important gaps in knowledge regarding the negative impacts from low flows and the potential positive impacts from augmented flows, which are only speculative (see Appendix 1 for information on select endangered species of the Pascagoula River).

This project evaluates the potential for an impoundment on a Pascagoula River tributary to supply water to supplement the River's flow to enhance the Gulf sturgeon's critical habitat and ultimate recovery (Figure 1). Specifically, a long record of daily flow data was used in a model to simulate daily flow on the Pascagoula River with water released from the impoundment when flow at the Merrill, MS gauging station reached or fell below 7934 Acre-Feet (A-F) per day in December. This number is based on the positive correlation found between December flows and Gulf Sturgeon spawning success in the Suwannee River near Ellaville, FL. In that study, a daily December flow rate of 100 m^3/s was determined to be optimal, and that flow rate is about the 70^{th} percentile of average December flows on the Suwannee River. The 70^{th} percentile for average December flow in the Pascagoula River at Merrill is about 113 m^3/s, very close to that of the Suwannee River.

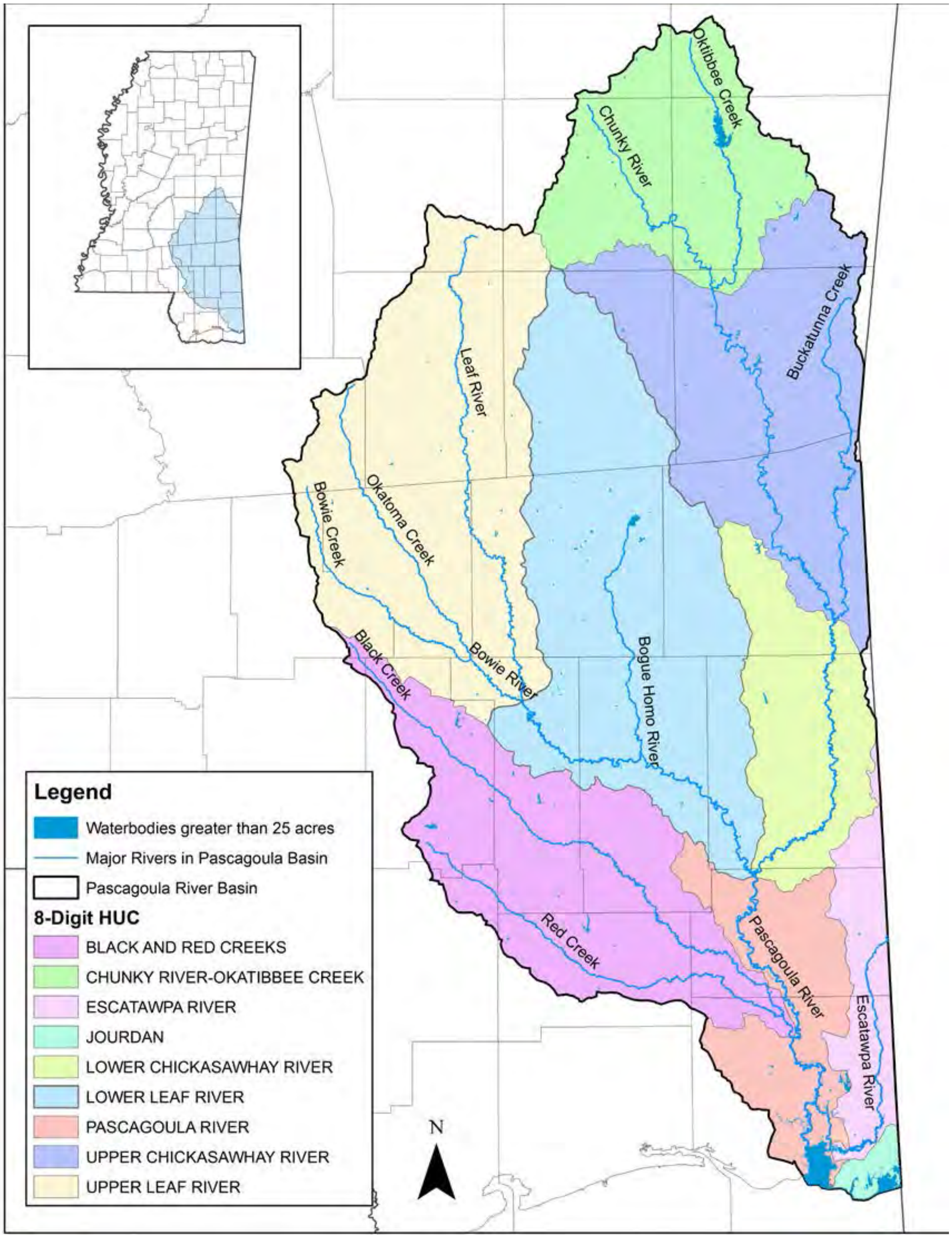

Figure 1. Pascagoula River Hydrologic Units

Procedures:

In previous studies (Pote, J.W., C.L. Wax, and M.L. Tagert, 2014), an impoundment was proposed and analyzed based on what would occur under the projected future climate and landscape in that location. Data sets constructed were Pascagoula river flow based on fifty years of data, and rainfall and evaporation from fifty years of serially complete and homogeneous climatological records. The site for the lake was not on the Pascagoula River itself but on a tributary downstream of the Merrell gage (Figure 2). The Big and Little Cedar Creek watershed was selected as the preferred site for the impoundment based on site-specific topographic, hydrologic and geologic assessments. A single large lake was not feasible because of commercial Big Cedar Creek Wetland Mitigation Bank in the watershed. However, the necessary water storage capacity was obtained by proposing two smaller lakes.

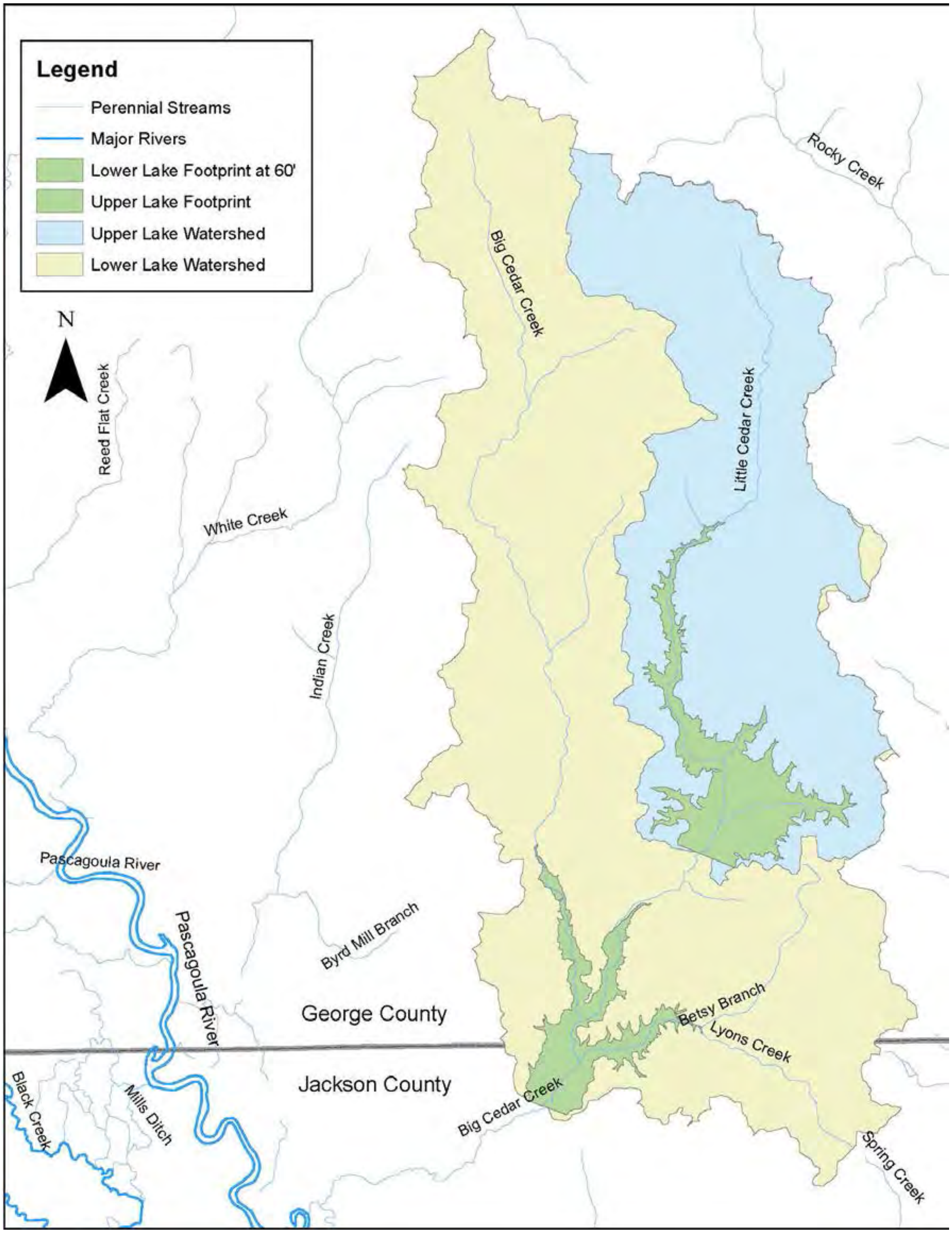

Figure 2. Proposed lake footprints and watersheds for proposed lakes.

For the purposes of the model, it was assumed that the two lakes would be used simultaneously. If water was needed, the Lower Lake would provide it, but water from the Upper Lake would be released until the elevation changes in the two lakes were equal.

Therefore, the simulations assumed the two lakes operated as one, with a combined water surface area of 2,868 A and geometry provided by GIS analysis using DEM data. This geometry provided a combined lake-full volume of 41,452 A-F. The drainage basin was assumed to be 39,743 A with a rainfall-runoff coefficient of 0.6 because of the nature of the basin's land cover and soil types.

A major change made in the model to accommodate the more realistic lakes was a recognition that as a lake loses volume, its area shrinks. Also, as the lake area decreases, the area of the watershed increases. In order to account for these changes, a series of elevations of the lakes were delineated to calculate the lake basin volume and area change for each ten feet of drop in the lake. Using regression analyses, equations were developed to match this sequence, producing equations in the form of Area = f(Volume). These were used in the model to establish changes in the area of the lakes and drainage basin on a daily basis.

These calculations were performed first for the Lower Lake and then the Upper Lake. Finally, since the two are treated in the model as a single lake in terms of drawdown, the specifications of the two lakes were combined and analyzed together, producing a single equation that predicted the lake area given the volume lost or gained daily (Table 1). Each day in the simulations, the calculated lake area is subtracted from the total watershed area to produce the land surface area draining into the lake. Climatological contributions to the water balance of the lake are thus applied to the constantly changing areas of the lake and drainage basin as calculated on a daily basis. The equations developed are shown in Table 2.

Table 1. Calculated lake elevations and surface areas.

Elevation	Upper Area	Volume	Lower Area	Volume	Combined Areas	Volume
0	1,715	31,428	1,153	10,024	2,868	41,452
-10	1,681	30,229	1,124	9,659	2,805	39,888
-20	1,647	28,639	1,097	8,583	2,744	37,222
-30	1,613	27,010	1,069	7,507	2,682	34,517
-40	1,579	25,822	1,042	7,085	2,621	32,907
-50	1,547	24,477	1,015	6,663	2,562	31,140

Table 2. Prediction equations for upper, lower, and combined lakes.

Area =	0.023667	Volume +	968.9136	Upper
Area =	0.03536	Volume +	790.628	Lower
Area =	0.027882	Volume +	1703.40	Combo

The predicted lake surface areas were graphed against the calculated lake surface areas to test goodness of fit of the equations. Figures 3, 4, and 5 show these results.

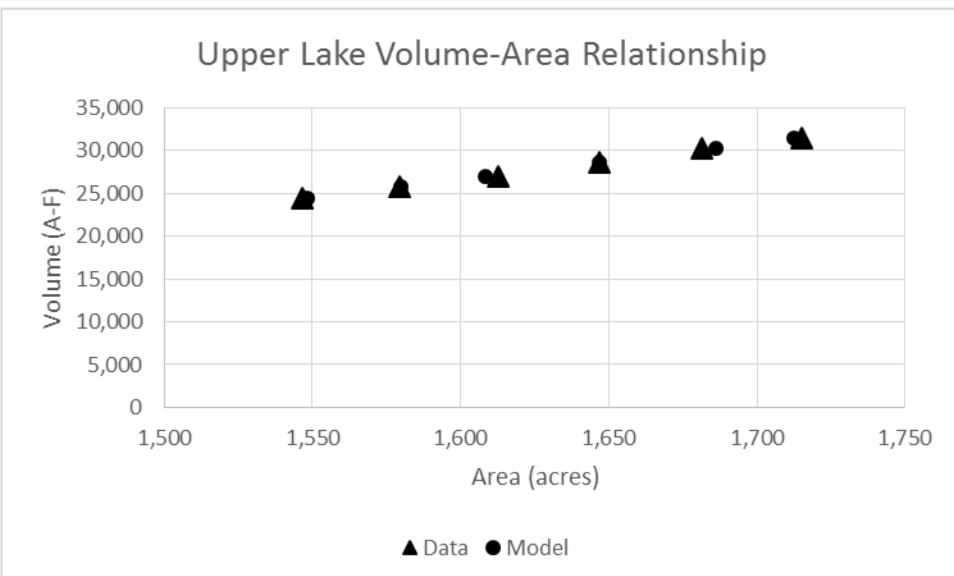

Figure 3. Calculated vs predicted lake areas, Upper Lake (R^2 = 0.997).

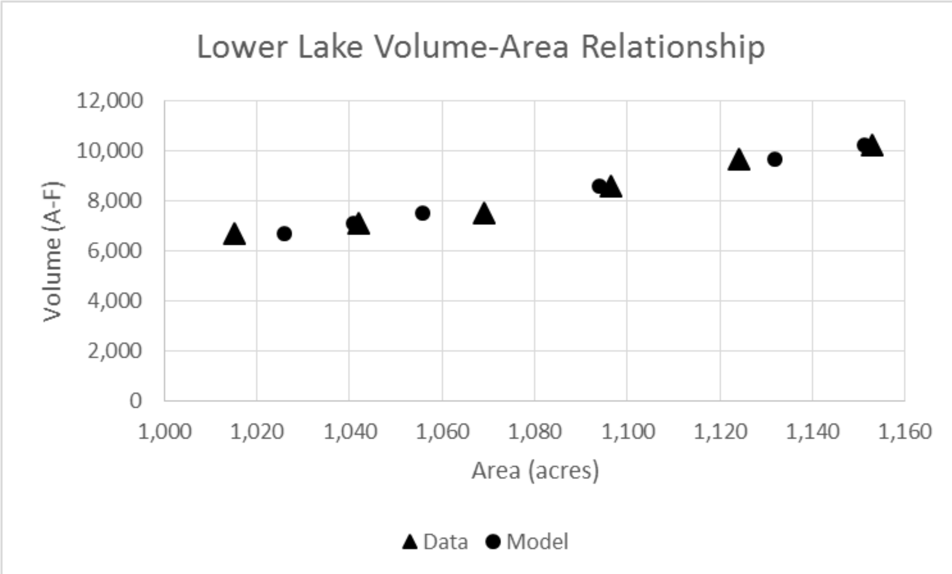

Figure 4. Calculated vs predicted lake areas, Lower Lake (R^2 = 0.972).

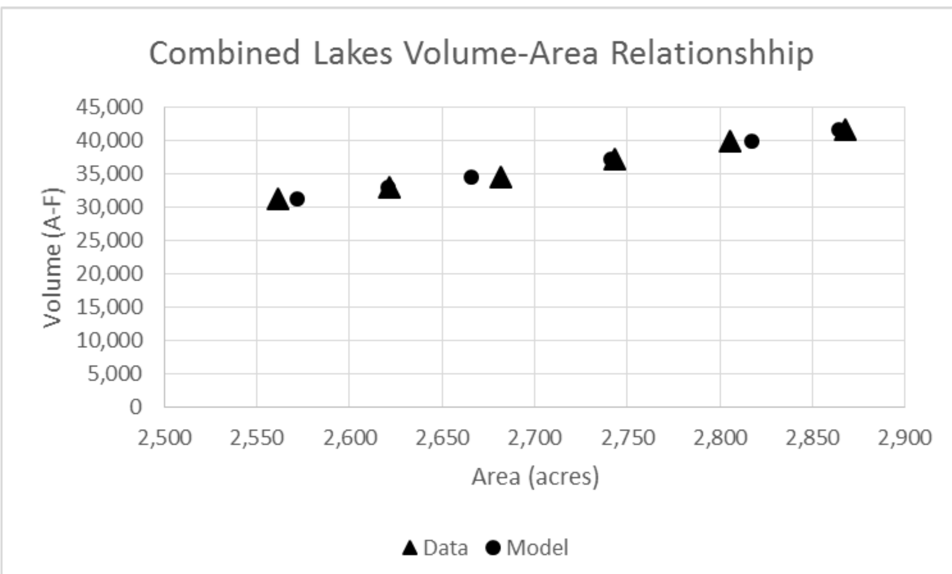

Figure 5. Calculated vs predicted lake areas, combined lake (R^2 = 0.992).

With these changes, the procedure was much like that used in Phase One. The method of analysis is a daily simulation of the lakes' volume if they had been operated over the fifty-year period 1961-2010 using climate and river flow data recorded over that period. The simulation of the lake volume uses the following inputs and outflows:

- Inputs: Runoff from rain in the watershed and rain directly into the lakes.
- Losses: Evaporation when greater than precipitation (P-E), infiltration, overflow, and management water used to supplement river flow.
- Rules of operation: When the river falls below the 7Q10 (917 cfs, 1,819 A-F/d), sufficient volume is released from the lakes to raise the river flow back to that level. This does not stop until the lakes have lost all of their volume.

The analysis required several data sets. These included information on the soils and hydrogeology, rainfall data for fifty years, evaporation data for the same period, and river stage records for the same location for the same fifty year period. The following were available:

- Rainfall: Precipitation was taken from the National Weather Service Cooperative climate record at Merrill, MS, the nearest climate record site. The data were checked for accuracy and completeness of record.
- Evaporation: The nearest two sites were Fairhope, AL and Starkville MS. These were compared and were very close in value, with Fairhope having a slightly lower cumulative value because of its coastal location. Since evaporation changes rapidly from the coast to more inland environments, and the lake location is several miles inland, the Starkville data were used, making the simulation slightly more conservative (higher evaporation rates than likely exist in reality).
- Soil and geo-hydrology: Dr. Darrel Schmitz, who developed much of this information, performed all of the analyses necessary to provide such factors as percent of lake volume lost to infiltration and percent runoff from the basin.
- River stage and flow rates: Two locations with very complete records were available. One (Merrill) was near the lake location, the other (Graham Ferry) was nearer Mobile. Since the Merrill site is nearer the point where demand is most critical, it was selected as the location which would trigger supplemental water from the lake.

Results:

The analyses showed that using this system of letting the lake supplement river flow as specified when needed, there were 654 days over the 50-year period when water was added. 457 (70%) of these days were in December. The analyses also showed that the lake volume was reduced to zero on 158 days of the 18,250 days in the 50-year period (0.9% of the days). The temporal occurrence of these events are shown in Figure 6.

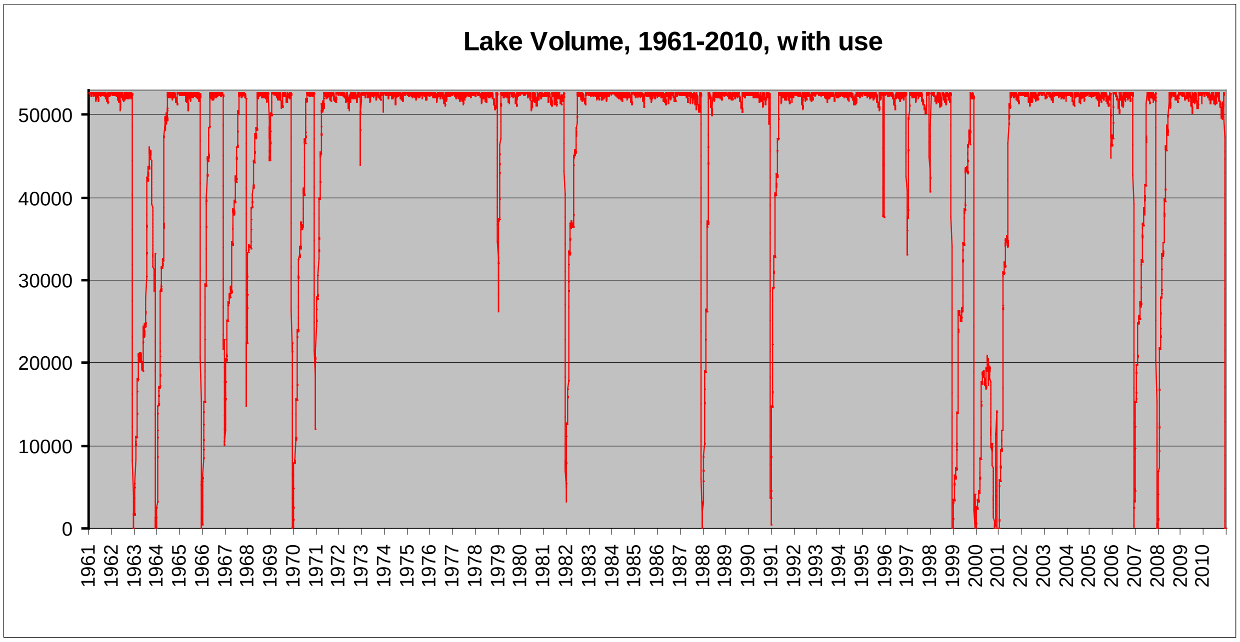

Figure 6: Daily lake volume, 1961-2010, showing days water was added and days the lake dried up when flow was maintained at 7934 A-F/d

These results indicate that the idea of a lake supplementing the river flow to provide daily December flow of 7934 A-F/d is sound. In this simulation, the climate of the region sustained the lake full enough to provide the needed supplemental water on all but 0.9% of events. However, keeping the December daily flow so high negatively impacted the volume, and thus the elevation of the lake. This may not be an acceptable situation.

An additional simulation was conducted to see how much the lake volume and elevation changes would be reduced by lowering the amount of the December daily river flow to a minimum of 6000 A-F/d. Results showed there were 525 days over the 50-year period when water was added, and 305 (58%) of these days were in December. Also, the number of days the lake dried up was reduced from 158 to 34 (0.001% of days) over the 50-year period (Figure 7).

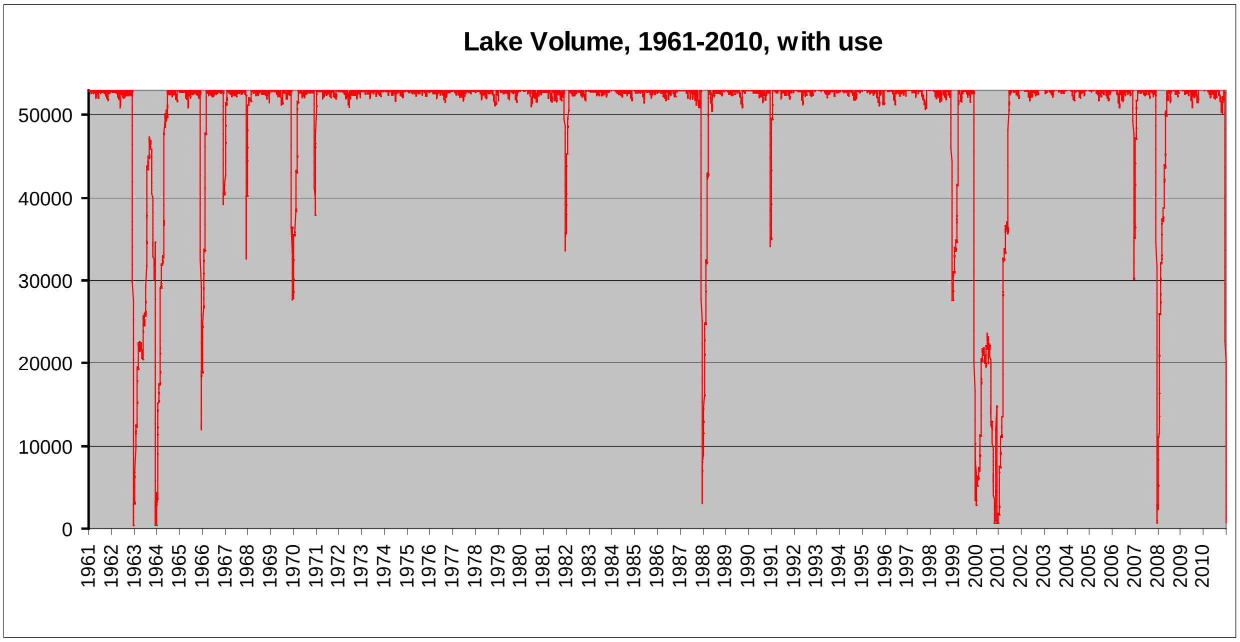

Figure 7: Daily lake volume, 1961-2010, showing days water was added and days the lake dried up when flow was maintained at 6000 A-F/d

Conclusions:

The outcome of these simulations clearly indicates that an impoundment can serve not only to maintain the river flow regime to meet instream flow requirements, but can also be used to manipulate the river flows to enhance critical habitat for endangered species. It should be noted, however, that data on the specific water needs of the Gulf Sturgeon, or other endangered species, is very limited and poorly tested. The two simulations in this study, the first using the prescribed 7934 A-F/day and the second one using approximately 75% of that amount, may or may not be sufficient to satisfy specific species needs.

Future research should include precise examination of species water quantity and flow rate needs and the ability of an impoundment to supply those requirements effectively. It is evident from the second simulation that using the smaller 6000 A-F/day threshold of river flow maintains the lake volume far better. More studies may show that the lower threshold has no significant impact on the viability of the Gulf Sturgeon in the Pascagoula River. In short, regulatory instream flows and even historic natural hydrographs may not be ideal for the recovery and protection of threatened and endangered species. Potentially, impoundments can be a valuable tool to protect natural landscapes from the impacts of projected climate variability by supplementing natural flows when necessary to protect or enhance the recovery of threatened and endangered species.

APPENDIX 1

Pascagoula Species of Study

Introduction

The following is a summary of the status and habitat requirements for four threatened or endangered fish species with critical habitat in the Pascagoula River Basin that may be impacted by an impoundment in the system. The species are: Gulf sturgeon (*Acipenser oxyrinchus desotoi*), peal darter (*Percina aurora*), saltmarsh topminnow (*Fundulus jenkinsi*), and Alabama shad (*Alosa alabamae*). These species were selected based on a literature review and discussions with scientists at the Mississippi Museum of Natural Science. The Gulf sturgeon is the most studied of these species. However, there are important gaps in our knowledge regarding each of these species. First, the negative impacts from low flows and the potential positive impacts from augmented flows are only speculative (though documented for the Gulf sturgeon). And second, while a new impoundment will certainly impede fish passage there is little to no data describing how or if these species actually use the tributaries proposed for impounding. As such, we need more data to better understand how fishes utilize the river and tributaries and these species specific habitat requirements to make specific management recommendations. The following describes the four fishes of concern in the study area and a preliminary description of their habitat requirements.

Gulf Sturgeon (*Acipenser oxyrinchus desotoi*)

The Gulf sturgeon is listed as Critically Imperiled in Mississippi (Mississippi Department of Wildlife Fisheries and Parks 2005) as is Threatened according to the Federal Threatened and Endangered Species List (US Fish and Wildlife Service 2014).

Gulf sturgeon are anadromous fish migrating in fall from the Gulf of Mexico to spawn in freshwater rivers. Critical habitat for the Gulf sturgeon includes the Gulf of Mexico and major rivers draining into the Gulf from the Suwanee River to the Mississippi River, including the Pascagoula River drainage system. In the Pascagoula system, Gulf sturgeon arrive in early to mid-April when the water temperature is 19.0-22.8 °C, mean stream flow is 5.2-15.7 m^3/s (USGS gauging station 2472500 at river kilometer 283), and dissolved oxygen is 6.2-8.0 mg/L (Heise et al. 2004). Though spawning is generally thought to occur in spring (Carr et al. 1996; Clugston et al. 1995; Foster and Clugston 1997; Sulak and Clugston 1998) evidence of autumn spawning has been documented in the Suwanee River, Florida (Randall and Sulak 2012). After spawning most individuals return to the Gulf of Mexico. However, long-term and overwintering individuals have been recorded in the Pascagoula drainage system (Heise et al. 2004). Juveniles remain in freshwater habitat until the age of 2, after which they begin the cycle of anadromous migration.

Gulf sturgeon utilize different areas of the river system for various reasons and during different times of the year. Currently, the Bouie River is the only known location for spawning within the Pascagoula River drainage system (Heise et al. 2004). However, this does not discount spawning in other locations. In the Pascagoula River, Gulf sturgeon were found to prefer the western distributary mouth as their main point of entrance into the Pascagoula River and the eastern distributary, upstream from Bayou Chemise, as a corridor between fresh and saltwater habitats (Havrylkoff et al. 2012). Holding areas in the Pascagoula River and Big Black Creek are important for spawning and non-spawning adults between May and November (Heise et al. 2005). Spawning adults migrate from these holding areas upriver and then return to the holding area after spawning (Heise et al. 2005). The selection of the holding areas may be influenced by tide and salinity (Heise et al. 2005).

A number of other studies in various locations on several species of sturgeon cite flow, water temperature, and salinity as influencing recruitment (i.e. the addition of young fish to a stock). Randall and Sulak (2007) found that annual recruitment for Gulf sturgeon in the Suwannee River is positively correlated with high mean monthly flows in September and December. Hypotheses for this correlation include 1) increased survivability under conditions of decreased salinity and/or high dissolved oxygen and 2) increased food supply and/or foraging area under high flows (Randall and Sulak 2007).

Flowers et al. (2009) found that Gulf sturgeon in the Apalachicola River spawn in areas of similar depth and velocity regardless of flow. The study showed that discharges less that 142 m^3/s at the Jim Woodruff Lock and Dam reduced spawning habitat, which has the potential to affect recruitment. The authors suggest that managers consider the possible effects of low flows on Gulf sturgeon recruitment.

A positive correlation between year-class strength and average water flows in June was found for lake sturgeon (*Acipenser fulvescens*) in the St Lawrence River, US indicating that year class strength is influenced by hydrological conditions in the first few months of life (Nilo et al. 1997). Similarly, a positive correlation between fall flow and recruitment was found for juvenile Atlantic sturgeon (*Acipenser oxyrinchus*) in the Altamaha River, Georgia (Schueller and Peterson 2010).

Reasons for recruitment failure of white sturgeon (*Acipenser transmontanus*) in the Kooteni River, British Columbia, which was dammed in 1972, include water temperature, flow, habitat availability, water quality in reservoirs, entrainment, angling, and the downstream export of larvae (Jager et al. 2002). In this river water temperature and river stage were found to be the best predicative variables for the migration of female white sturgeon into spawning grounds (Paragamian and Kruse 2001). Here, flows above 630 m^3/s were found to be optimal (Paragamian and Wakkinen 2002). These sturgeon were also shown to spawn in areas of relatively high velocity and depth (McDonald et al. 2010; Paragamian et al. 2009). In the same river, studies show that velocities have been reduced by dam construction, which has resulted in sediments burying spawning grounds (Paragamian et al. 2009). The sturgeon are still spawning in the same areas as before dam construction; however, these areas are now unsuitable habitat.

Salinity levels are also an important factor in the habitat suitability for Gulf sturgeon at different life stages. Altinok and Grizzel (Altinok and Grizzle 2001) found that juvenile Gulf sturgeon (< 6 months) had better growth rates, food conversion, and energy absorption in salinities of 3 and 9 ppt compared to that of freshwater. These authors did not test higher levels of salinity. Altinok et al. (1998) also found that small juvenile Gulf sturgeon have low survivability rates when directly transferred from freshwater to saltwater at 30 ppt or higher.

Jacobson and Galat (2008) describe a process by which stakeholders met to design a more naturalized flow regime for pallid sturgeon (*Scaphirhynchus albus*) in the Lower Missouri River. In this case the specific hydrologic requirements for the species were unknown and so the design process was based on characteristics of the natural flow regime. They hypothesized that pulse-flows in the spring can clean off spawning substrate.

Dams present a major impediment to Gulf sturgeon migration and are the main reason implicated in their Threatened state (US Fish and Wildlife Service 2009). Dams block the passage of sturgeon to historical spawning grounds (US Fish and Wildlife Service 2009). It is important that thorough surveys be conducted to ensure that new impediments are constructed upstream from Gulf sturgeon habitat. Other threats to Gulf sturgeon include water withdrawals and flow alterations, dredging, pollution, climate change (changing water temperature and flows), bycatch, disease and predation, the inadequacy of regulations, hurricanes, boat collisions, red tide, and aquaculture (F.M. 2006; US Fish and Wildlife Service 2009).

Pearl darter (*Percina aurora*)

The Pearl darter is listed as Critically Imperiled in Mississippi (Mississippi Department of Wildlife Fisheries and Parks 2005) and is a Candidate Species on the Federal Threatened and Endangered Species List (US Fish and Wildlife Service 2014).

The Pearl darter was historically found in the Pearl and Pascagoula River drainage basins but is assumed extirpated from the Pearl and now only exists in the Pascagoula River (Kreiser et al. 2013; Ross 2001) with a decrease in range of approximately 55% (US Fish and Wildlife Service 2010).

A multivariate analysis conducted by Kreiser et al. (2013) in the Pascagoula River system found that the Pearl darter is most commonly associated with larger rivers and depositional habitats and disassociates from clean, sandy substrates, smaller rivers, and estuarine systems. In the Pascagoula system the Pearl darter historically inhabited the main channels of larger tributaries and rivers including the Pascagoula River, Black Creek, Leaf River, Okatoma Creek, Chickasawhay River, Bouie River, and Chunky Creek (NatureServe 2014b).

Threats to the Pearl darter include non-point source pollution, urbanization, changes in river geomorphology, head cutting, gravel mining, bank erosion, and excessive sedimentation (NatureServe 2014b; US Fish and Wildlife Service 2010). Brine and dioxin discharges in the Pascagoula are also a concern (NatureServe 2014b; US Fish and Wildlife Service 2010). Brine could produce toxic conditions where salinity is higher than the physiological tolerance (US Fish and Wildlife Service 2010). The Pearl darter's genetic diversity has likely declined because of fragmentation and the separation of populations. Therefore, conservation efforts needs to focus on multiple local populations (NatureServe 2014b).

The confluence of the Bouie and Leaf rivers, in the Pascagoula drainage system, may provide important habitat for the Pearl darter (US Fish and Wildlife Service 2010). It is important to maintain a constant water flow free of impoundments to prevent habitat fragmentation in this area (US Fish and Wildlife Service 2010).

Salt marsh topminnow (*Fundulus jenkinsi*)

The saltmarsh topminnow is state listed in Mississippi as Vulnerable to Extirpation or Extinction (Mississippi Department of Wildlife Fisheries and Parks 2005). Its habitat extends from Galveston Bay, Texas, to the western portion of the Florida panhandle (Peterson et al. 2003).

Seasonal abiotic signals such as water temperature, salinity, and turbidity influence abundance (Lopez et al. 2011). Spawning beginnings in spring and early summer (Lopez et al. 2010). More species were collected during the spring and summer compared to the winter, many of which were juveniles (Lopez et al. 2011). Saltmarsh topminnows have been found in salinities ranging from 0 to 20 ppt. Lopez et al. (2011) found that they were most common in salinities < 16 ppt and Peterson et al. (2003) found them to be most common in salinities < 12 ppt. Fresh water flows may also be important for the saltmarsh topminnow because of the sustainable salinity gradient that they create (Lopez et al. 2011). Reproduction and diet have been linked to access to medium and high marsh (Lopez et al. 2010). When nested on the seasonal/spatial axis factors such as water depth (<0.5 cm), bank slope ($<15^0$), and stem density (<25 stems/0.25 m^2) may positively affect abundance and distribution (Lopez et al. 2011; Peterson et al. 2003).

Threats to the saltmarsh topminnow include dredge and fill, shoreline hardening, coastal development, oils spills, climate change, and alterations to freshwater flows (Sutter and Hayes 2011). Optimal habitat for the saltmarsh topminnow is maintained through consistent flows of fresh water into salt marshes with shallow depths (Lopez et al. 2011; Peterson et al. 2003; Sutter and Hayes 2011). This flow may come from rivers or through groundwater.

Conservation efforts should focus on increasing the knowledge of the biology of the species, developing strategies on how to restore saltmarsh habitat, limiting and mitigating dredging and filling, alternative shoreline hardening methods, protecting groundwater and coastal freshwater flows, increasing the knowledge of those freshwater inputs affect saltmarsh topminnow habitat, and reducing the stress from coastal development on marsh areas (Sutter and Hayes 2011). Because of the habitat that it uses, small, interconnected, dendritic, intertidal saltmarsh creeks should be the focus of conservation efforts. (Lopez et al. 2010).

Alabama shad (*Alosa alabamae*)

The Alabama shad is state listed in Mississippi as Critically Imperiled (Mississippi Department of Wildlife Fisheries and Parks 2005). The IUCN has classified the species as Data Deficient and research is urgently needed to quantify its rates of range and population declines (NatureServe 2014a).

The Alabama shad is an anadromous species that lives in the Gulf of Mexico and travel up freshwater rivers to spawn. Juveniles spend the summer and fall in freshwater before traveling to The Gulf of Mexico in the late fall or winter (Barkuloo et al. 1993). Habitat type and physiochemical parameters have been found to predict the presence of Alabama shad in the Pascagoula drainage system (Mickle et al. 2010). The species was found mainly in sandbars early in the year declining in June and in channels and banks over the summer (Mickle et al. 2010). In the Pascagoula drainage system spawning likely occurs in the upper reaches of the Chickasawhay and Leaf Rivers (Mickle et al. 2010).

The species has been extirpated from much of its historical range including the Pearl River drainage system (Gunning and Suttkus 1990; NatureServe 2014a). In Mississippi it is now only found in the Pascagoula River (Gunning and Suttkus 1990). The main factor implicated in the decline of the Alabama shad is the impoundments blocking migration to spawning grounds (Mickle et al. 2010; NatureServe 2014a). Habitat fragmentation and degradation through siltation, declining water quality, and the dredging of sandbars as well as prolonged droughts and the construction of impoundments on major tributaries present additional threats to the species

(Mickle et al. 2010; NatureServe 2014a). Alabama shad have been found to successfully pass through the Jim Woodruff Lock and Dam and Lake Seminole, located on the Apalachicola River (NatureServe 2014a).

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