Appendix E. Instream flows for the Mobile-Tensaw River Delta and Mobile Bay Estuary

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Summary

Based largely on the findings of studies conducted elsewhere, where conditions are very different from those in Alabama, we know that the health and productivity of estuaries are determined by the maintenance of natural levels of freshwater inflow from upstream watersheds. As such, it is reasonable to hypothesize that alteration of the quality and quantity of freshwater inflow from the Mobile River Basin, and the 31 smaller coastal watersheds, could have strong negative effects on the ecological and economic health of coastal Alabama. Importantly, we know little about the strength of the relationship between freshwater inflow and the extraordinary biological diversity that currently characterizes our coastal waters. Given the probable increase in demands for water as our state's population and economy grow, and possible future losses due to interstate water disputes, we strongly recommend that studies of the relationship between the quantity and quality of freshwater inflow, from the Mobile River Basin and the 31 smaller coastal watersheds, and the health and productivity of Alabama's coastal waters start as soon as possible. These studies would allow us to provide data-driven recommendations to the future development of a statewide water conservation management plan.

Background

Coastal waters are inextricably linked to upstream ecosystems (i.e., terrestrial and freshwater) via the transport of inorganic and organic materials carried downstream by rivers and streams[1,2,3,4]. Conversely, coastal waters are also linked to the open ocean by tidal exchanges and the migration of marine organisms that enter low salinity waters to feed and reproduce[5,6]. Together, these distant sources of nutrients, food, recruits and reproductively active adults create diverse and highly connected food webs that support one of the most dynamic and productive ecosystems on earth: the estuary.

Nearly 40% of all U.S. citizens live within 100 miles of our nation's coast.

The quality of life and vitality of the services estuaries provide to humankind have led nearly half of the world's population to move within 90 miles of some coastline [5, 7]. In the United States, nearly 40% of all U.S. citizens were living within 100 miles of our nation's coastlines at the turn of the last century[7, 8]. Worldwide, human encroachment into coastal environments, and their reliance on the foods, waters and services they provide, has triggered dramatic changes in the structure and productivity of estuarine ecosystems. This demographic shift underlines the fact that water is closely coupled with human socioeconomic systems. It seems clear that strong economies require healthy environments to grow - an important point coastal Alabamians learned in the days following the Deepwater Horizon accident of 2010. As such, Alabama coastal communities will need to renew efforts to develop data-driven conservation plans that provide both for the wise stewardship of our resources for future generations should freshwater withdrawal begin in earnest while allowing for continued economic growth[5].

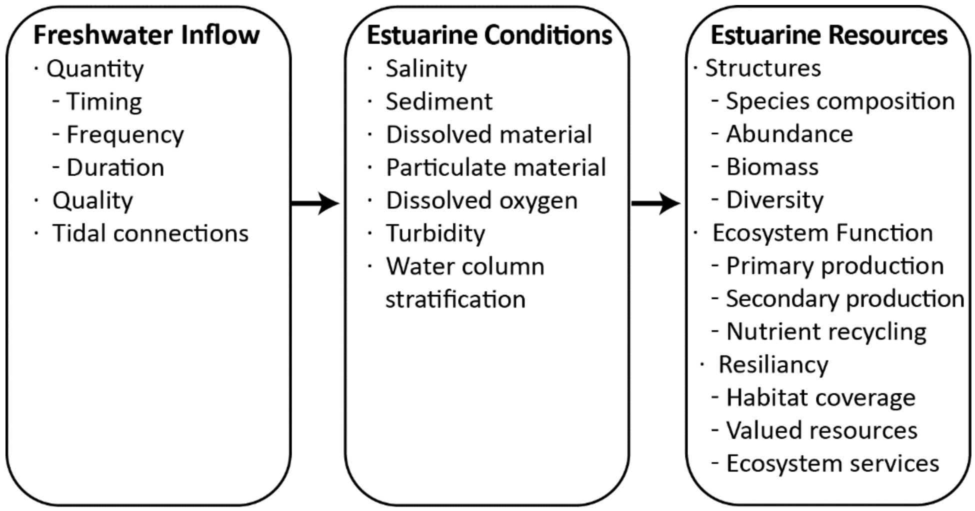

Figure 1. Conceptual model of inflow effects on Estuarine Resources, ***modified from Montagna et al., (2002)***

Despite the well-documented importance of this geographically broad inorganic and organic connectivity of inland and coastal ecosystems (Figure 1), environmental management today relies on static monitoring measures made on small spatial scales, rather than dynamic and integrated measures conducted at the scale of the ecosystem, to evaluate estuarine health[5]. This static approach does not adequately characterize the health of estuaries receiving highly variable quantities of freshwater inflow, or the strength of connections between watersheds, estuaries and the open ocean[9, 10]. Moreover, such an approach focuses heavily on the means derived from static measures of estuarine condition and not the ranges of environmental conditions (i.e., relative to species minimum and maximum tolerances) that play a key role in determining the biological diversity and productivity of estuaries[11, 12, 13,14,15].

The Mobile Bay Watershed is the 4th largest watershed in the U.S.

Here, we seek to inform our Alabama Water Agency Working Group (AWAWG) colleagues of the importance of maintaining strong linkages between all of Alabama's estuaries, and the Gulf of Mexico. The Mobile Bay watershed, whose river and streams span four states, is the fourth largest, in terms of freshwater inflow, in the continental United States and the primary source of water entering Mobile Bay (Figure 2). Additionally, freshwater inflow into Alabama's coastal waters comes from 31 smaller watersheds in Mobile and Baldwin Counties (Figure 3).

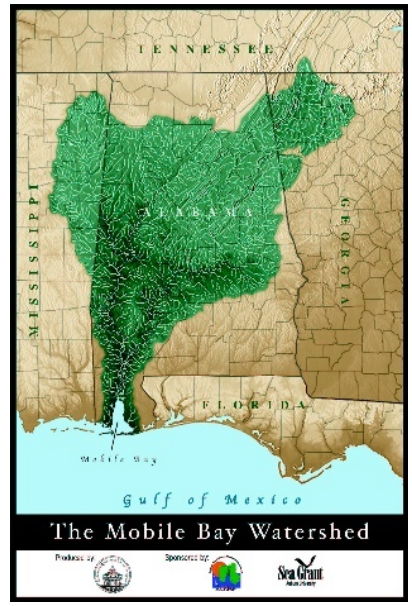

Figure 2. Geographic Setting of the Mobile-Tensaw River Delta

Importantly, we call our colleagues' attention to the fact that much of what we know about the importance of these linkages between watershed and estuarine health is based on studies conducted elsewhere (California, Georgia, Florida, and Texas), where hydrological and physiographic conditions are very different from those that currently exist in Alabama. Little has been published on the relationships between natural ranges of freshwater inflow and estuarine resiliency in coastal Alabama[5].

Estuarine salinity is impacted by freshwater inflow.

Of all the watershed inputs to coastal ecosystems, it is freshwater inflow, because of its effects on estuarine salinity, which is arguably of greatest importance (Figure 4). Alterations of freshwater inflow, due either to drought or water extractions, have been shown in other states (Georgia, Florida and Texas) to trigger important shifts in the location of ecologically-critical freshwater and salt water mixing zones within estuaries and alterations of water quality[1,7,13,17,18]. Moreover, it is the breadth of the physiological tolerance of estuarine organisms to temporal and spatial changes in salinity that plays a role in determining the structure and productivity of most coastal ecosystems. Because freshwater inflow can vary greatly on both seasonal and annual scales, the geographic location of these mixing zones can change dramatically. For these reasons, scientists have characterized estuaries according to the location of isohalines that are indicators of the relative strength of mixing between inputs from the watershed and those coming from the open ocean[19, 20].

Figure 3. Geographic locations of the 31 smaller watersheds of Mobile and Baldwin counties.

The structure and productivity of virtually every aquatic and marine ecosystem is the product of recovery following historical disturbances[21]. Depending on the frequency and intensity of perturbations within an ecosystem, the recovery pathways can be very different. Impacts from such events can have both negative and positive impacts in this regard. Estuaries are frequently impacted by both chronic and episodic disturbances[11, 12, 18]. When freshwater inflow is high, except in cases of extreme flooding, estuaries are characterized by a series of increasing gradients of salinity as one progresses from the rivers that feed into estuaries to the open ocean. During these times, estuarine food webs are comprised of a diverse array of freshwater, estuarine, and marine organisms, many of which are of either recreational or commercial importance[22,23,24,25].

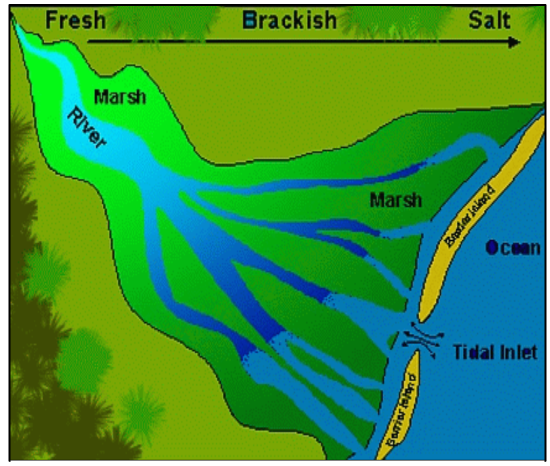

Figure 4. Conceptual model of the transition of salinity progressing from the watershed to the open ocean under normal spring inflow.

During El Niños when river flow is high, estuarine salinity will be lower.

When freshwater inflow is reduced, as is often the case in late summer and fall, and during drought years, isohalines are fewer in number and estuaries become more uniformly marine and saltier in nature[23,24,25]. When this happens, marine organisms tend to dominate the ecological structure of an estuary. In other years, freshwater inflow from the rivers and streams of the southeastern United States can, at times, be extreme and driven by dynamic meteorological conditions that developed over distant waters of the Pacific and Atlantic oceans [26, 27, 28, 29,30]. For example, the El Niño and La Niña phases of El Niño Southern Oscillation (i.e., ENSO), and their interactions with conditions generated by decadal and multi-decadal climate phenomenon such as North Atlantic Oscillations, Pacific Decadal Oscillation, and Atlantic Multi-decadal Oscillation have been shown to strongly influence stream and river flow in the southeastern United States. During La Niña, precipitation can be lower, which, in all likelihood, can lead to lower freshwater inputs and higher salinities. These changes can provide enormous physiological challenges for freshwater and estuarine organisms and it is the variation in the amount of freshwater inflow, and the ability of estuarine organisms to tolerate this fluctuating environment, that allows an extraordinary mix of freshwater, estuarine, and marine organisms to coexist in our coastal ecosystems[2, 3, 4, 5].

Flood pulse concept: river communities depend on an annual inundation of broad plains and the subsequent recession of water levels into the main channel.

It should be noted that during periods of extraordinary freshwater inflow, connections between terrestrial and aquatic ecosystems increase greatly. When rivers overflow their banks and flooding occurs on adjacent terrestrial uplands, new aquatic environments are created that are several times larger than those that existed when rivers were constrained within their channels [31, 32]. These new lateral connections between terrestrial and aquatic ecosystems provide enhanced levels of food web supplements in the form of nutrients, prey, and detritus that are transported by floodwaters to downstream species (known by ecologists as the Flood Pulse Concept[33, 34]). In some cases, this flooding also benefits upstream wetlands as it prevents the recruitment of tree species.

Freshwater inflow also naturally carries modest quantities of sediments that play a key role in supporting the persistence of emergent tidal wetlands (Figure 5)[7]. These sediments can also determine the structure of benthic (bottom) communities whose organisms serve as prey (fish food) for most of the commercial and recreational species living in the northern Gulf of Mexico[2, 3, 5]. As such, it is important for water conservation planners recognize that episodic events are incredibly important determinants of the health of coastal communities and incorporate strategies that maintain the occurrence of these natural perturbations in future plans[2, 3]. Conversely, it should also be noted here that the absence of forested buffers zones along upstream riparian areas can lead to increased riverbank erosion and subsequent elevated turbidity levels in downstream estuaries.

Figure 5. Landsat Satellite image shows the dramatic output of sediments from the Mobile-Tensaw River Delta into Mobile Bay during one period of extreme freshwater inflow.

Alabama forests and wetlands serve to moderate runoff and purify water supplies.

Land use conversions frequently serve as precursors to the degradation of water quality in estuaries by multiple anthropogenic stressors[35]. The surrounding lands of the watersheds of Alabama currently comprise high proportions of intact forests and wetlands that are very effective at moderating runoff and purifying water supplies [36, 37]. The vegetation and soils of terrestrial and aquatic habitats possess a remarkable capacity to filter out unwanted contaminants, while reducing the erosion of sediments before they enter rivers and streams and eventually reach coastal waters. Watersheds without land conservation practices, adopted in conjunction with relevant water management plans, will inevitably result in the delivery of less clean water to coastal ecosystems.

Elevated turbidity resulting from uncontrolled sediment loading into a watershed can cloud waters and reduce light penetration to levels below the threshold needed to sustain photosynthesis for plants that drive the productivity of coastal food webs[38,39]. When this happens, the areal coverage of nursery habitat- forming plants (submerged aquatic vegetation) will be reduced. Concomitant with changes in the quality of water entering estuaries following land conversions along a watershed's rivers and streams are elevated inputs of nitrogen and phosphorus that frequently trigger macroalgal blooms that blanket critical nursery habitats[37], and increased incidences of summer-time hypoxia and anoxia in our nation's estuaries[40, 41,42]. These lower oxygen levels usually inhibit biological activities and greatly reduce estuarine and nearshore productivity.

One of the major determinants of the effects of nutrient loading, in addition to the losses of forests and marshes, is the timing and magnitude of freshwater inflow[36, 37]. Reductions of inflow can dramatically increase water transit time (i.e., flushing rate) through an estuary[17]. Increases in estuarine transit time reduce the ability of an estuary to flush materials of all kinds out into the ocean[18]. As transit times increase, concentrations of nutrients, contaminants, and pathogens can increase. Reductions in freshwater inflow can also change the hydrodynamic regime of an estuary, leading to changes in the relative importance of tides on circulation patterns as well as the formation and strength of water column stratification. When stratification occurs during summer the formation of extensive dead zones is more likely in coastal waters[41, 42].

Watersheds are critical guardians for coastal cultures and economies.

Estuarine health is a key determinant of coastal states' economic and cultural health. For this reason, the potential for political conflict between upstream users and coastal resource managers could be great[19]. Withdrawals from rivers and streams can support, for example, the irrigation of crops, industrial and commercial growth, and residential activities. As long as the rate of water extraction for these purposes (either via interbasinal transfer, water withdrawals to support either industrial or urban growth, or irrigation for crops) does not exceed the rate of replenishment, rivers and streams can continue to serve as sustainable sources of water for economic growth and downstream ecosystem health[35]. In many cases, extracted waters can be returned to rivers and streams following proper treatment, thus maintaining adequate freshwater supplies for downstream ecosystems[3, 37]. It should be noted that in the case of agriculture, about half of the water that is diverted from a watershed for crop irrigation can be lost from the watershed during the warm growing season through evapotranspiration and thus is not available for use further downstream. Based on lessons learned from Georgia, Florida, and California, during drought years when demand is great, significant reductions in the volume of freshwater inflow into coastal waters can occur. When a deficit occurs, as has been seen in Apalachicola Bay, Florida, alteration of the quantity, quality, and timing of the freshwater inflow has been correlated a reduction in estuarine health and productivity. Watersheds also provide many nonextractive economic cultural benefits to our society including protection from flooding, transportation, hydroelectric power, and fishing, hunting, and boating.

Situation and Need

Maintaining sufficient freshwater quantities is becoming one of the most critical issues of the 21st century.

We are living in an era of unprecedented and rapid ecological change. It is now the view of many scientists and conservationists that maintenance of sufficient quantities of high quality freshwater[35] and its subsequent delivery into coastal waters is becoming one of the most critical issues of the 21st century. Two major forces are reshaping freshwater flows into estuaries worldwide: changing demographics and increasing levels of hydrological engineering. Water conflicts, such as the ongoing negotiations over the requested transfer of water from Alabama-Coosa-Tallapoosa (ACT) to the Apalachicola-Chattahoochee-Flint (ACF), when coupled with elevated water withdrawals used for irrigation, serve as important examples of future water disputes in our humid, wet region of the world[7]. These examples serve as a harbinger of future times when freshwater inflow may not be limitless.

Water use in Alabama has almost quadrupled over the last 40 years.

Water use in Alabama has increased dramatically since the 1960s and there is no reason to think this rate will decrease as Alabama grows and prospers (Figure 6)[43, 44]. Freshwater will undoubtedly be needed for continued municipal, industrial, and agricultural growth throughout the watersheds emptying into coastal Alabama which could mean less water will reach estuaries without a comprehensive water management strategy or a clear plan to manage the sustainable growth of industry and cities within Alabama. Moreover, the sustained droughts in the western U.S. have led to dramatic conflicts among water users for an ever-diminishing supply of this resource, leading some to suggest that the agricultural industry may need to move to the southeastern U.S. If these predictions end up as reality, then it is reasonable to predict that populations of estuarine organisms, which function best in lower salinity waters, will be at greater risk.

What is at risk? The extraordinary biodiversity of coastal Alabama estuaries

One of the signature characteristics of our healthy estuaries is the rich biological diversity these systems support (Figure 7). Much evidence suggests that estuarine resistance and resiliency to disturbances are determined in large part by biological diversity[45, 46, 47, 48]. The biological diversity of the estuaries of the north-central Gulf of Mexico (GoM) rivals that of most coastal locations in the northern hemisphere[49, 50]. The combination of extraordinary productivity, driven by the plentiful nutrients supplied by some of the nation's largest watersheds, and an abundance of critical nursery habitats have led many to characterize the estuaries of the northern GoM as the nation's "Fertile Crescent" [51, 52]. The convergence of these ecologically critical factors has established this region as home for many of the nation's economically-important fin and shellfish. Regrettably, only a few characterizations of living resources in the Mobile Bay estuary exist, and most are dated and found in unpublished environmental impact assessments[53]. Even fewer studies have examined the importance of watershed inputs in maintaining the productivity of coastal Alabama. This largely unpublished evidence suggests that the biodiversity of our coastal waters is extraordinary, and that freshwater may well drive the structure and function of ecological communities within this estuary.

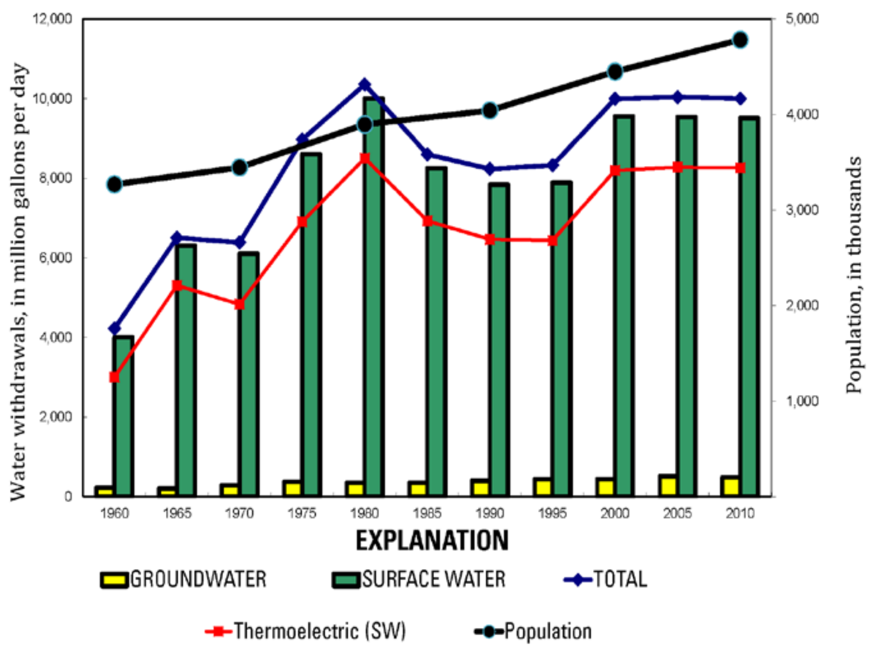

Figure 6. Freshwater withdrawals in Alabama, 1960-2010, Estimated Use of Water in Alabama in 2010 Report, ADECA Office of Water Resources.

Roughly 80% of Alabama's estuarine fish can be found in coastal fisheries.

Roughly, 80% of Alabama's estuarine fishes support important coastal fisheries[54]. Over 240 species of fishes occur here[54, 55], and about 165 species, such as Spotted Sea Trout (*Cynoscion nebulosus*), Red Drum (*Sciaenops ocellatus*), Southern Flounder (*Paralichthys lethostigma*), Atlantic Croaker (*Micropogonias undulatus)*, Gulf Menhaden (*Brevootia patronus)*, Spot (*Leiostomus xanthurus*), and Bay Anchovy (*Anchoa mitchilli*), are estuarine-dependent consumers[55] that play an important role in determining the structure of our coastal food webs. Many freshwater fishes, including Channel Catfish (*Ictalurus punctatus*), Largemouth Bass (*Micropterus salmoides*), Bluegill (*Lepomis macrochirus*), Redear Sunfish (*Lepomis microlophus*), Spotted Sunfish (*Lepomis punctatus*), and several species of Gar (*Atractoseus spatula*, and *Lepisosteus* spp.), are also common in the northern reaches of this estuary [55]. Surveys of freshwater fishes collected within the lower reaches of the Mobile-Tensaw River Delta indicate that largemouth bass, catfish, and gars diets can be highly variable, feeding extensively on estuarine-dependent fishes (e.g., anchovies and menhaden), crabs, and shrimp in some years and on freshwater prey in other years[56]. An analysis of a 25-year-long record of fish collections made by the Alabama Department of Conservation and Natural Resources indicates their relative abundances have changed little in recent decades[57]. The coexistence of these marine and freshwater organisms suggests strong trophic interactions between two widely divergent ecosystems are important to the health of this estuary[4]. There can be little doubt that the strength of this connectivity would be reduced if freshwater inflow dropped to the point where freshwater organisms no longer co-occurred with marine organisms in coastal Alabama. While it is possible that these species would simply move upstream, the much narrower reaches of the upstream watershed would, in all likelihood, mean there would be less available area for aquatic organisms to live and thus reduce their population sizes.

Figure 7. The Mobile-Tensaw River Delta supports an extraordinarily rich biodiversity, including a number of threatened and endangered species that make the Mobile Bay Estuary their home.

In most coastal zones in the Gulf, terrestrial, aquatic, and marine organisms frequently interact. In comparison, the strength of trophic interactions among these organisms while likely remain unstudied for coastal Alabama, perhaps because the management of terrestrial, aquatic, and marine resources frequently falls under different governmental jurisdictions. Over 300 bird species also rely to some extent or other on the productivity of the Mobile Bay estuary[58], in particular fishes and crustaceans for food. Of these, about 70 species are year-round residents, and another 100 bird species winter here[54]. Active nesting sites include Cat Island, Sand Island, and Gaillard Island[59]. About 20 duck species have been reported from the delta and account for approximately 95% of the total yearly abundance of waterfowl within the state[60]. A single evaluation of winter surveys conducted in the Mobile–Tensaw River Delta has documented a 96% decline in waterfowl populations from over 100,000 birds in 1939 to about 4000 birds in 1999[61]. The reasons for this decline are unknown, but it is likely that a combination of habitat loss and hunting pressure have contributed to this decline.

More than 70 species of reptiles and 40 species of amphibians live near the waters of the Mobile Bay.

The terrestrial borders of the Mobile Bay estuary support a number of reptiles and amphibians who also seem to rely, in part, on the bay for their existence. More than 70 species of reptiles and at least 40 species of amphibians live near the waters of this estuary[62]. Five species of sea turtles are found offshore, and two of these, the Green (*Chelonia mydas*) and the Kemp's or Atlantic Ridley (*Lepidochelys kempii*), may at times enter the estuary[54]. About 57 species of mammals can be found in coastal Alabama and surrounding waters. Among them, Bottlenose (*Tursiops truncatus*) and Spotted Dolphins (*Stenella frontalis*) are quite common in Alabama waters.

Habitat Diversity within Coastal Alabama Estuaries

Salt marshes and SAV act as refuges for vulnerable organisms and contribute to the nutrients and carbon budgets of Mobile Bay.

Habitat diversity is great within our state's coastal waters and includes a broad array of oligohaline (low salinity) and euryhaline (widely varying salinities) habitats. Salt marshes and submerged aquatic vegetation (SAV) are found along the margins of most Alabama estuaries (Figure 8) [63, 64]. We know little about the functional roles of these habitats as either refuges for vulnerable organisms or their contributions to the overall nutrient and carbon budgets of Mobile Bay [65, 66, 67]. However, based on studies conducted elsewhere along the northern Gulf, and similarities in the compositions of habitat-forming species, our submerged vegetation and salt marshes are expected to be key determinants of the productivity of this estuary[56, 68].

Figure 8. Mobile-Tensaw River Delta supports a remarkable diversity of emergent marsh and submerged aquatic vegetation species.

Surrounding the delta are lowland forests that are episodically flooded by coastal rivers. This flooding should provide an avenue for the transfer of leaf litter and nutrient exports from these forests to the delta and beyond [32]. As such, emergent marshes in oligohaline deltas and bordering upland forest probably represent important export sites for substantial external inputs of energy to consumers in Mobile Bay. Assessments of the effects of upstream silviculture and agriculture on lands adjacent to these waters are limited in the published literature [36, 37].

A diverse array of structurally complex habitats can be found within the delta. Tens of thousands of acres of open water, freshwater-mixed marshes, swamps, and mixed bottomland forest exist (see below for a more detailed description of delta habitats). Areal coverage of macrophytes (both emergent and submerged) and lowland forests is extensive in the northern reaches of this estuary, but is markedly reduced just south of the Mobile Bay causeway [64, 65,66]. Still, the SAV of the lower delta is diverse, with 24 reported species [57,61].

Oligohaline SAV Habitats

Over 50% of Alabama's SAV is located in the lower Mobile-Tensaw River Delta.

The Mobile-Tensaw River Delta, found at the head of Mobile Bay, supports a high diversity of freshwater and low salinity estuarine habitats that are critical to the environmental sustainability of Mobile Bay. The Mobile–Tensaw River Delta has been characterized by extraordinarily high plant biomass (in the form of emergent and submerged macrophytes) [3,65,67,69]. Over half of Alabama's areal coverage of SAV is located in the lower Mobile-Tensaw River Delta. Species richness is high with some 24 species of SAV occurring in this region[64]. Because most of these species are intolerant of higher salinities, all of these habitat-forming species would be at risk if extractive water uses or droughts become excessive. There is no data to suggest that they would be able to simply migrate upstream.

Only a few surveys have documented SAV coverage in Mobile Bay[57, 65, 67, 69]. Survey methods and reporting methods varied greatly among studies. Although the total coverage and relative abundances of SAV varied among surveys, three freshwater species (*Myriophyllum spicatum, Ceratophyllum demersum,* and *Vallisneria americana*) have consistently contributed the greatest proportion of SAV. An invasive SAV species, Eurasian water milfoil (*Myriophyllum spicatum)*, has been the most abundant species recorded in the surveys (occupying about 85% of shallow-water areas surveyed and covering about 33% to 80% of surveyed areas) [65, 67]. Interestingly, one study failed to find that the areal predominance of this invasive species was the result of competitive exclusion of native SAV species in the delta[70].

Twenty-one vascular plant species representing 11 taxonomic families were recorded during the 2008 and 2009 field surveys. The presence of eight species not encountered in the 2002 baseline survey was documented in 2008 and 2009. Most of the identified species were minor components of the SAV community and were not included in the broad classification of species categories in the mapping process. Only sago pondweed (*Stuckenia pectinate*) occurred in significant enough densities and locations in 2009 to be mapped as a monospecific category.

As in 2002, most habitats in 2009 contained mixtures of species typically found in northern Mobile Bay and the delta. The most extensive habitat was a mixture of Eurasian watermilfoil (*Myriophyllum spicatum*), southern naiad (*Najas guadelupensis*), and wild celery (*Vallisneria neotropicalis*). Eurasian watermilfoil and wild celery were the most common species encountered. Other common fresh and brackish water species included coon's tail, southern naiad, and water stargrass[70].

Several areas of the Delta that had supported large SAV beds in 2002 were devoid of submerged vegetation in 2008 and 2009, in particular the northernmost part of the study area. The dynamics of SAV occurrence in the delta are poorly known, and reasons for the decline of SAV in these areas are not clear.

Oysters

Oysters provide an important habitat for vulnerable marine and aquatic organisms in deeper waters.

Oyster populations and reefs provide a suite of ecosystem services, such as habitat for benthic macrofauna, enhanced nutrient cycling, and shoreline stabilization. Although published data are lacking for Alabama, oysters have been shown to provide important habitat for vulnerable marine and aquatic organisms in deeper waters in other locations [71, 72]. A comprehensive compilation of the types and areal coverages of the dominant habitats of this estuary can be found on the Mobile Bay National Estuarine Program Web site (www.mobilebaynep.com). Unlike recent declines in harvest on the East Coast, the Mobile Bay oyster fishery remains stable. However, rigorous comparisons of historical abundances of oyster populations (past to present) are difficult because (1) methods used to document oyster density varied greatly among studies, (2) harvest is not an accurate estimate of oyster production because size limitations restrict oyster harvest, and (3) the number of fishermen participating in the fishery has changed over the years. Alabama oyster reefs have been assessed only 7 times between 1896 and 1995[73]. The surveys examined the population and oyster health condition in two of the surveys, while the other five surveys examined populations, condition, and the configuration of reefs. Because the surveys used different methods and varied in their interpretations, it is difficult to compare their results quantitatively.

In addition to threats from pollution and overfishing, Alabama oysters are vulnerable to sedimentation and salinity changes.

Both natural and anthropogenic activities affect the oyster population in Mobile Bay. The current natural activities are similar to those that occurred in the past: natural predators, diseases, and weather phenomena (i.e., hurricanes). The oyster drill (*Stramonita haemastoma*), a predator that can consume up to 95% of the smaller oysters in coastal Alabama, severely restricts the distribution of oysters in Alabama, especially during periods of low freshwater inflow. Anthropogenic activities that may affect oyster populations in this estuary have increased over time. Not only does pollution, overfishing, and exposure to organochloride pesticides (i.e., DDT and metabolites, DDE, DDD, and dieldrin) decrease oyster populations, many other activities are also detrimental to oysters. Oyster populations are vulnerable to sedimentation from dredging, eutrophication, toxins (i.e., heavy metals), and salinity changes due to hydrologic alterations and habitat loss due to development in in our watersheds. With all these activities potentially having negative effects on oyster populations in Mobile Bay, efforts are underway to preserve this natural resource[5].

Wetlands

Summaries of surveys conducted within the area estimated nearly 440,000 acres of wetlands, of all types, were present in the Mobile Bay estuary[74]. Of these, 176,000 acres of wetlands were found below the 10-foot contour regulated by the Alabama Coastal Area Management Program (ACAMP) [74]. Most of the brackish or saline marshes were below 10 feet in elevation, but about half of the freshwater marshes and one-third of the forested wetlands occurred in areas above 10 feet [74]. Plant species compositions and probably the functions of freshwater marshes and forested wetlands above and below the 10-ft contour differed. Freshwater marshes within the 10-ft contour comprise mostly emergent species, while those found above this elevation were mostly pitcher plant bogs or pitcher plant bogs mixed with scrub-shrub wetland. Lower-elevation forested wetlands were mostly of a bottomland hardwood type, while those above 10 ft. are usually either pine savannas or tupelo–bay forests [74].

There is only one available analysis of wetlands change in the Mobile Bay estuary area[69]**.** Of the marsh losses that occurred between 1955 and 1979, 48% were attributed to human activities in this study. The remainder of the losses were attributed to "natural" processes such as erosion, subsidence, and natural community succession. Major human activities causing changes to wetland coverage were residential and commercial development (61% of fresh marsh and 68% of forested wetlands) and industrial navigation (24% of brackish or saline and 28% of scrub–shrub wetlands). Though quantification of recent changes and trends are not available for this estuary (a new assessment is currently being developed by MBNEP and ACAMP), national assessments of wetland changes provide insights into probable recent trends in Alabama. Dahl and Johnson (1991) indicated that wetland losses slowed nationally from the mid-1980s to 1995 [75, 76]. Reductions in rates of wetland losses were probably due to changes in the public perception of their ecological value as well as federal and state efforts to protect these critical habitats.

Ecosystem Services

In 2014, almost 13% of Alabama's population was living in the two coastal counties.

Sustainability of natural resources requires a balancing of exploitation and conservation, enabled by management based on the best available scientific and economic information. Valuation of ecosystem goods and services is an important tool for prioritizing restoration efforts, recognizing the economic importance of conserving natural capital, and raising public awareness about the contribution of healthy ecosystems to social welfare, now and for future generations. In 2014, almost 13% of the state's population was living in our two coastal counties. Given that these counties represent just 5.6% of the state's land, the density of people is quite high on the coast. Many of these citizens moved to coastal Alabama because of the quality of life provided by our states coastal resources. As such, it is reasonable to project that this growing concentration of people along our coast make important contributions to our state's economy.

Data provided in the State of the U.S. Ocean and Coastal Economies report issued in 2016 by the National Ocean Economics Program support this hypothesis[77]. The coastal economy of Alabama encompasses six key industrial sectors: marine transportation, tourism and recreation, living marine resources, marine construction, ship and boat building, and mineral extraction. These six industries generated 12% ($23.4 billion) of the gross domestic product of the state.

Recommendations:

It is important to note that much of what we have reported here is based on older studies conducted in coastal Alabama or elsewhere. Few of these studies were focused on the temporal and spatial impacts of variation in freshwater inflow on our coastal waters. For these reasons, we recommend the State take a number of initial steps that can provide us with the opportunity to quantify the impact of coastal freshwater inflow on the productivity of Alabama's coastal waters. First is the establishment of an ecosystem-based monitoring program that can establish base line conditions in Alabama's coastal waters. Monitoring is one openly accessible and publically accountable method of guaranteeing to the taxpayers that their dollars are being successfully used for the wise stewardship of Alabama's aquatic resources. Importantly, such data would be available to document effects of future natural and human-induced alterations, such as could occur should another large disaster happen in nearby Gulf waters.

Initial Steps:

1) Quantify the short- and long-term relationship between the volume of freshwater inflow into coastal Alabama estuaries and climate variability (precipitation and temperature) throughout our State's watersheds;

2) Conduct an analysis of the adequacy of currently established river flow gauges in estimating freshwater inflow into our estuaries from the watersheds of coastal Alabama;

3) Both modernize Alabama's Coastal Observatory Stations and use automated sampling vehicles to map the location of isohaline zones throughout coastal Alabama to model the geographic relationship between these zones and freshwater inflow volume;

4) Develop mathematical models that can provide a more rigorous description of the relationship between freshwater inflow and heterogeneity of isohaline locations throughout the waters of coastal Alabama;

5) Develop ecosystem models that describe the relationship between the Department of Conservation and Natural Resources' data collected by the Fisheries Assessment Monitoring Program and freshwater inflow;

6) Develop mathematical relationships that describe how conversion of forests to farmlands could alter natural ranges of

freshwater inflows, turbidity, and nutrient exports in Alabama's coastal waters;

7) Establish Sentinel Stations that can be used to conduct detailed monitoring of how the ecology of coastal Alabama is affected by variation in the natural cycle of freshwater inflow;

8) Require taxpayer supported collected data be deposited in a publically accessible data management center for future assessments.

Summary

Clearly, water is the one natural resource that links the citizens of the State of Alabama together. It is a large part of our cultural heritage and an important driver of our state's economy. As such, water, and the extraordinary biological diversity of life it supports, provides our citizens with an exceptional quality of life. To date, consideration of the importance of freshwater inflow for our coastal resources has been limited. Based on lessons learned from other states, however it seems reasonable to predict that increasing demands for water will have important impacts on the health of our state's economically important coastal resources. As the population and economy of Alabama increase, it seems reasonable to expect that demands for water, along with the conversion of forests to agricultural and urban growth, will only increase. Given the importance of links between terrestrial, aquatic, and estuarine ecosystems, the potential for unanticipated consequences for the health of coastal resources could be great. For these reasons, there is a clear need to develop an adaptive statewide Alabama comprehensive water management strategy that considers the potential impacts of a wide range of extractive uses from our states watersheds on coastal resources and provides for the establishment of an ecosystem-based monitoring program that documents the effectiveness of the plan.

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