No. 142, Original

In the

Supreme Court of the United States

STATE OF FLORIDA,
Plaintiff,
v.
STATE OF GEORGIA,
Defendant.

Before the Special Master
Hon. Ralph I. Lancaster

UPDATED PRE-FILED DIRECT TESTIMONY OF FLORIDA WITNESS PATRICIA GLIBERT, PH.D

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INTRODUCTION

1. My name is Patricia M. Glibert. I am an estuarine ecologist with a Ph.D. in biology from Harvard University, and am a tenured professor at the University of Maryland. Estuaries are ecologically rich environments where fresh water from a river meets salt water from the ocean, and are home to numerous species of plants and animals that thrive in this transition zone. In particular, estuaries can be nursery areas where the young of various species such as fish, crabs, and shrimp find a suitable environment to grow. Apalachicola Bay has historically been one of relatively few pristine, exceptional estuaries in North America, as the United Nations recognized when it designated the Apalachicola region a Biosphere Reserve. Apalachicola Bay has received a high degree of protection (*See* Figure 1, showing conservation lands around the Bay), but has suffered increasingly from reductions in freshwater flow that are changing the

Figure 1 *– A map of the Apalachicola River and Bay, highlighting the protected lands around both. This is a true and accurate copy of a figure from FDEP, which I used in my expert report and which is further described in the testimony of Mr. Jonathan Steverson. (FX-789, Fig. 1.2).*

character of the estuary, slowly turning it more marine-like—that is, an environment with water characteristics (including salt content) and species that resembles the Gulf of Mexico or the open ocean, rather than an estuary.

2. I have spent my career researching and advising on the health of estuaries. In particular, the overarching focus of my research is how the microscopic species in these estuaries serve as food for other species such as oysters, and how those larger species, in turn, feed other species. The microscopic species I study are known as phytoplankton (also called algae).[1] They form the base of the food web. They float in the water (the term planktos comes from the Greek meaning to wander, drift) and they use light energy to make their biomass (amount of biological or organic material) through the process of photosynthesis while absorbing chemical nutrients from the water.

3. Like many microscopic organisms (bacteria, for example), we may not think about them but they have major effects on our daily lives. Even phytoplankton have important effects on our lives, especially on our supply of seafood. Changes in plankton affect the total amount of species in the food web, the types of species found in the food web, and the feeding relationships among these species. As these change, so too does the availability of those species we prize.

4. Estuarine food webs are dependent on fresh water flow. Of most relevance here, (1) freshwater contains the nutrients phytoplankton need to grow; (2) without freshwater flow, plankton in Apalachicola Bay can accumulate to harmful degrees as they are not flushed away; and (3) without freshwater flow, the mix of fresh and salt water is impacted, and the food web of the estuary becomes more marine-like, as species that thrive in saltier conditions flourish, and important estuarine species decline.

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[1] In my testimony, the terms algae and phytoplankton are used interchangeably. Phytoplankton are one type of "plankton" (another type is zooplankton, the microscopic animal plankton). I use the term plankton throughout my testimony as well, primarily in reference to phytoplankton.

5. In this testimony, I evaluate the ecosystem of the Apalachicola Bay and how it has been affected by reductions in freshwater flow. I conclude that reduced freshwater flow is altering the ecosystem and food web of the Bay (including the mix of species), leading to declines in the abundance of plants and animals that grow in the Bay (defined here as "productivity"). One of the most prominent impacts has been significant harm to oysters, which have declined and not recovered in the past four years. If the trend of increased low flows continues, harm to the whole ecosystem will become increasingly difficult to reverse. Based on my review of Apalachicola-specific data and the broader literature, I reach the following findings, highlighted here and described more fully in this testimony:

a. Reductions in freshwater flow are changing the nature of the water in Apalachicola Bay. Freshwater flow brings in important nutrients like nitrogen and phosphorus, and mixes with the salt water to reduce the level of salt (salinity) in the Bay. Thus, at extremely low flows, the nutrient balance changes and salinities increase.

b. When nutrients change and salinity increases, estuarine species that normally live in the Bay are harmed. Beginning at the base of the food web, reduced flows affect phytoplankton. First, at lower flows different types of phytoplankton become more dominant. This is important because different types of plankton provide different types of nutrition to the food web. Changes in the mix of phytoplankton species affect all organisms in the food web, since those organisms grazing on phytoplankton will not grow and reproduce as fast on poorer quality food, which means they do not feed other species as well, and this process carries through up the food chain. A shift in phytoplankton species is like shifting a human diet from a balanced diet to a fast food diet – the phytoplankton consumers' health suffers, leading them to grow and reproduce less, in turn not feeding other species as well, with effects reverberating across the food web to other species. The reduction in freshwater flow also makes the Bay more hospitable to harmful algal species that can be toxic to other species in the Bay.

c. Second, at lower flows the phytoplankton can accumulate in the warmer water as they are not flushed out, especially in the East Bay area. When the phytoplankton accumulate and are not eaten, most die and subsequently decompose, a process which reduces dissolved oxygen in the water. Reduced levels of oxygen cause stress to all species in the Bay.

d. Reduced flows also harm the growth of larger underwater plants, the submersed aquatic vegetation, that grow on the bottom of the Bay and are an important food source and place for juvenile species (fish, crab, shrimp and others) to live. First, lower flow harms larger plants that normally grow in the fresher part of the Bay (East Bay) because the water is saltier under low flow conditions and these plants are less tolerant to salt. Second, submersed plants are harmed by the reduction in oxygen levels in East Bay that result when plankton accumulate and then decompose at low flows. And last, this plankton accumulation reduces the sunlight available to drive photosynthesis in the submersed vegetation on the Bay bottom, thus reducing their growth. One important species in the food web that has been significantly harmed by reduced flow is the oyster. The oyster filter feeds on phytoplankton (it eats by taking in – or filtering – all particles from the water). The changes in the composition of the plankton community at lower flow means that plankton oyster food becomes less and less nutritious. Some of the phytoplankton become directly toxic to the oysters' growth. Additionally, as discussed by Dr. Kimbro in his testimony, increased salinity as a result of reduced flow allows other organisms, including predators that eat oysters and parasites that cause oyster disease, to expand. The combined effect of poor oyster food and increased predators has resulted in the loss of oysters in the Bay. Because oysters are an important part of the ecosystem, as reef builders and filterers of the water, their loss has significant effects on the rest of the Bay ecosystem.

e. Further degradation as flows decrease in the future could lead to permanent harm to the Bay ecosystem, but such an outcome may still be avoided if these low flow trends are reversed. Increases in flow will allow the Bay ecosystem to become stabilized, and potentially recover to its historic state.

PROFESSIONAL BACKGROUND

6. I completed my Ph.D. at Harvard University in 1982, and have over 30 years of experience as a researcher, professor, advisor and consultant to government entities in the field of coastal and estuarine ecology, in particular in nutrients, phytoplankton and food web structures. I am currently a tenured Professor at the University of Maryland Center for Environmental Science (UMCES), Horn Point Laboratory, where I have been employed for 30 years. I also hold a Visiting Professor appointment at Zhejiang University, China.

7. I have extensive experience in researching and applying ecological principles to estuaries and estuarine food webs and my work is widely recognized and cited nationally and internationally. I have published more than 200 papers in scientific journals or book chapters. As detailed in my resume, I have received the highest award for research conferred by the University of Maryland System (2006), I am a Fellow of the American Association for the Advancement of Science (2012) and a Sustaining Fellow of the Association for the Sciences of Limnology[2] and Oceanography (2016). For my research in marine ecology, I have also been awarded an honorary doctorate from

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[2] Limnology is the study of freshwater bodies.

Linnaeus University, Sweden (2011) and a certificate of appreciation from the University of Kuwait (2012).

8. I have studied estuaries in the United States and throughout the world. I have specific expertise in the study of the lower food web, the nutrients that support the food web, and the factors that promote those algae that can become toxic or harm the food web, the 'harmful algal blooms' (termed HABs, and sometime called 'red tides'). At my Laboratory, located near the Chesapeake Bay, my colleagues extensively research oysters, and I have authored or co-authored a number of articles discussing the relationships between algae and oysters.

9. My current research at the University of Maryland centers around questions related to nutrient dynamics and algal blooms in coastal and estuarine systems, as well as understanding linkages between nutrient loading, HABs, and changes in aquatic food web structure. In addition to my research activities, I also have undertaken a number of advisory activities. For example, I recently co-chaired the US National Harmful Algal Bloom committee, which is advisory to the NOAA (the National Oceanic and Atmospheric Administration), as well as a global working group on HABs under the umbrella of UNESCO (the United Nations Educational, Scientific and Cultural Organization). In addition, governments from several countries have called on me to advise them on solutions to acute environmental threats posed by harmful algal blooms.

OPINIONS

I. OVERVIEW OF TESTIMONY: APALACHICOLA BAY AND RECENT CHANGES

A. *Definitions*

10. For ease of understanding, I begin by explaining several terms that I will be using throughout my testimony:[3]

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[3] For additional definitions and schematic illustrations, see the Glossary section of my report (FX-789).

a. **Estuary:** A semi-enclosed coastal water body where freshwater from a river meets with seawater. River-dominated estuaries, like Apalachicola Bay historically has been, tend to be highly "flushed" (*see* residence time, below) with freshwater. River-dominated estuaries can be highly productive because of the nutrients delivered with the freshwater, and they provide important habitats supporting a rich diversity of species. On the other hand, estuaries with low freshwater flow generally have less "flushing", less nutrient input, and as a result they are generally less productive than river-dominated systems.

b. **Food web:** The pathway through which all species – from microscopic plants to large mammals – are connected together, based upon what eats what. At the base of the food web are those species that do not need to feed on other living things to survive, such as microscopic algae, which grow using nutrients in the water and sunlight. Organic matter is transferred from these primary producers to higher "trophic levels," such as fish or invertebrates, through feeding.

c. **Water quality[4]:** The chemical, physical, and biological characteristics of water. It measures the condition of the water and can be used, among other purposes, to assess the health of the ecosystem. Some of the relevant characteristics, explained below, are nutrients, salinity, dissolved oxygen and chlorophyll-a.

d. **Inorganic and organic nutrients:** Inorganic nutrients are dissolved molecules in the water that can contain the basic building blocks for growth and be used directly by plants (including algae) as food. They can be compared to liquid fertilizer. The two most important nutrients are nitrogen (N) and phosphorus (P)

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[4] The term "water quality" can also refer to pollutant contamination, but Apalachicola Bay is not considered to suffer from a chemical pollutant problem. This is not surprising considering all of the preserved land surrounding the Apalachicola River and Bay.

and the most common “forms” for nitrogen are nitrate (NO_3) and ammonium (NH_4), while the most common form for phosphorus is phosphate (PO_4). Inorganic nutrients do not contain the element carbon (C). Organic nutrients are nutrients that are bound within molecules that contain carbon. Much of these nutrients come from dead life, such as broken down plant material called detritus. The “*nutrient load*” (inorganic and organic) is the total amount of a nutrient delivered to a waterbody like an estuary, whereas the “*nutrient concentration*” is the concentration of a nutrient in the water (*e.g.*, amount per liter).

e. **Salinity:** A measure of the salt content of water. Salinity is technically a dimensionless (or unitless) number, but is often expressed as parts per thousand (ppt). It can be thought of as the number of parts of salt relative to the number of parts of water, i.e., parts of salt per thousand parts of water. Freshwater (as in the non-tidal portion of the Apalachicola River) has a salinity around 0 ppt. The portion of the Bay closest to the mouth of the River has the lowest salinity, increasing gradually until the Bay meets the Gulf of Mexico where salinity exceeds 30 ppt.

f. **Dissolved oxygen:** A measure of the amount of oxygen dissolved in water. Aquatic plant and animal species require oxygen to live. Anoxia is a condition in which no oxygen is present in water (less than 0.1 mg dissolved oxygen per liter); hypoxia is a condition of low oxygen in the water (less than 2 mg dissolved oxygen per liter). Both conditions are stressful to aquatic plant and animal species, and prolonged periods of low oxygen can cause mortality.

g. **Residence time (flushing):** The amount of time it takes for a part of water to move through a system, or the amount of time it resides in a system like an estuary. Residence time increases when flow decreases. This effect is straightforward: when water enters the Bay more slowly from the River, the process of pushing (or "flushing") a given quantity of water out to the ocean slows. The rate at which a quantity of water is "flushed" out is called the "flushing rate."

h. **Detritus:** Nonliving particulate material in the water column, usually derived from the breakdown of plant or animal material.

i. **(Primary) Productivity:** Productivity is the rate of production of new biomass; that is, the reproduction and growth of plants and animals. Primary productivity is the rate at which plants (including phytoplankton) at the bottom of the food web grow (and accumulate)

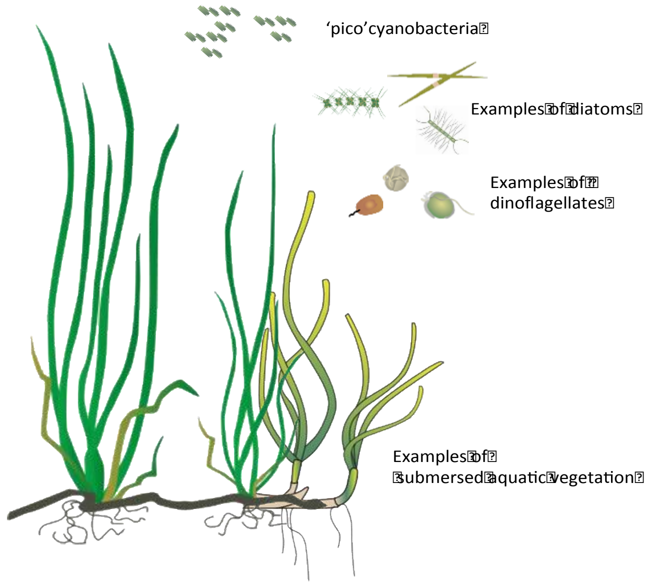

Figure 2*– Schematic drawings of the different types of microscopic algae and submersed vegetation that are considered 'primary producers'. Not drawn to scale (the picocyanobacteria, diatoms and dinoflagellates are not visible to the naked eye). I created this demonstrative drawing for my testimony based on generally scientifically accepted principles.*

within an ecosystem. The term “productivity” is also used here to denote the resulting amount of biomass of organisms.

j. **Phytoplankton or algae:** Microscopic plants or bacteria that use dissolved nutrients present in the water, combined with sunlight, to grow (photosynthesis) (*See* Figure 2). Phytoplankton form the base of the food web and are the dominant primary producers in estuaries. Even though most phytoplankton are single-celled organisms, they span a size range of many orders of magnitude (from cells smaller than 2 micrometer to cells that are 2,000 micrometer). There are many groups of phytoplankton, among which I concentrate on three main groups:

    i. **Diatoms:** Diatoms are one of the most common types of phytoplankton. Diatoms are generally the most nutritious food source for grazers (species that feed on other organisms), including oysters. They support efficient, productive food webs. They typically prefer to take their nitrogen from the water in the form of nitrate.

    ii. **Cyanobacteria:** Cyanobacteria, often called blue-green algae, are actually a form of bacteria, and are not true algae, but they are, nevertheless, an important member of the phytoplankton. Some species can be extremely small (picocyanobacteria). Cyanobacteria generally prefer nitrogen in the form of ammonium. Because of their small size and nutrient content, picocyanobacteria do not support food webs that are as productive as diatom-supported food webs.

    iii. **Dinoflagellates:** A class of algae, most of which are sustained through photosynthesis, but many of which can also eat other species of plankton. Various dinoflagellates are "harmful algae," and make toxins that can have severe impacts on human and animal health. Dinoflagellates also generally prefer to take their nitrogen as ammonium rather than as nitrate.

k. **Chlorophyll-a:** The pigment contained in plants (including plankton) that converts light energy into food. This pigment is often used as a measure of phytoplankton biomass.

l. **Photosynthesis:** The manufacture by plants of carbohydrates and oxygen from carbon dioxide, supported by chlorophyll and the presence of sunlight.

m. **Eutrophication:** The process of increased growth of the primary producers of an ecosystem, most often driven by increased nutrient inputs. Effects such as harmful algal blooms, fish kills, marine mortality events, loss of seagrasses and bottom habitat, development of hypoxia and loss of harvestable species are a common response to coastal eutrophication. In many estuaries, this is a result of increased nutrient loading, but in Apalachicola Bay it is primarily caused by less "flushing" of algae and nutrients during low flow, allowing more time for nutrients to be consumed by algae within the estuary. Because there are too many algae to be consumed, they die off and decompose, a process that reduces the dissolved oxygen in the water that aquatic species depend on. Eutrophication can occur regardless of the species of algae involved. Both normally "good" and nutritious algae can accumulate and overwhelm the system as well as those that are less nutritious or harmful. In Apalachicola Bay the less nutritious plankton (cyanobacteria) tend to accumulate, compounding the effects of eutrophication.

n. **Submersed aquatic vegetation (SAV):** Rooted vegetation that grows under water in shallow zones of the Bay where light penetrates. The term can refer to both marine and freshwater plant species. *Submersed* aquatic vegetation is also frequently called *submerged* aquatic vegetation. However, submersed is the preferred term because some plants may break through the water surface under some conditions (as for example, water lilies).

o. **Zooplankton:** A community of floating, often microscopic, animals that inhabit aquatic environments and generally feed on phytoplankton. They are an important food source for fish and crustaceans up the food web.

p. **Grazing and filter feeding:** Grazers are any species that feed on other organisms, and which are in turn eaten by predators. The common grazers at the microscopic level are copepods. Filter feeding is a particular way to graze, and is done by filtering food such as plankton out of the water column by letting water pass by a filtering structure. Oysters are an example of filter feeders.

q. **River gage**: Measurement stations in the River that measure the height (also known as stage) of the river. This is combined with information about the velocity of the river and a formula called a “rating curve” to develop measurements of streamflow. The Chattahoochee gage is furthest up the Apalachicola River and sits right below the Georgia-Florida line. The Sumatra gage is the gage nearest the Bay, and sits about 20 river miles upstream from the

Bay. In my testimony I primarily use Sumatra gage flow records, but I have confirmed some of my analysis using the Chattahoochee gage records.

B. *Apalachicola Bay and Its Food Web*

11. The Apalachicola Bay (and its watershed) is unique among estuaries in the United States, and is heavily protected by a wide array of Florida and federal laws (*See* Figures 1 and 3). The Apalachicola River that feeds the Bay is also protected, and flows mostly through federal, state and private conservation lands in Florida. These protections are in place because both the Bay and River collectively comprise one of the least polluted and least developed estuarine systems in the United States, and they are home to a variety of ecologically and economically important species.

Figure 3 *– A view of Apalachicola Bay on October 2015, showing the city of Apalachicola and the East Bay Bridge, with East Bay (and the main channel of the River emptying into it) in the background. FX-266e is a true and accurate copy of this photograph, which is also publicly available on the official ANERR Facebook page. I have visited the Bay, and the photograph is a true and accurate depiction of this area.*

12. The United Nations, under the International Man and Biosphere Program, has designated the Bay a Biosphere Reserve, recognizing the importance and beauty of the Bay. Under federal law, the Bay has also been designated as one of only twenty-eight National Estuarine Research Reserves. Under Florida state law, it has been designated an Aquatic Preserve and Outstanding Florida Water. (*See* Direct Testimony of Jon Steverson) To ensure that the estuary remains protected and unpolluted, Florida has made extensive land purchases around the estuary in addition to enacting these protective designations. (*See* Direct Testimony of Jon Steverson)

13. Apalachicola Bay has different zones, and changes in flow affects them differently. Apalachicola Bay proper is in the center, East Bay is to the north, St. Vincent's Sound is in the west, and St. George's Sound is in the east. (*See* Figure 4) Since East Bay is at the mouth of the River, closest to freshwater flow, it is especially sensitive to changes in flow and water quality. East Bay is an area of particular significance: its lower salinity and greater nutrient availability render it an important nursery region for many fish and invertebrate species, and it historically contained an extensive amount of submersed aquatic vegetation. East Bay also plays an important role as an oyster refuge when salinities become high in the Bay proper, as Dr. Kimbro explains.

14. Apalachicola River delivers a very large percentage of the freshwater flow that reaches the Bay (most of the time, well over 90%). Basic principles of estuarine ecology establish that as freshwater flow changes, so does water quality, including factors such as dissolved nutrients, salinity, and dissolved oxygen. In response to these changes, the biology of the Bay changes as well, as measured by chlorophyll-*a* among other metrics. In my testimony I show how flow affects salinity and nutrients that in turn impact the Bay in many ways (*See* Figure 5, diagram of how flow links to changes in the Bay).

Figure 4 *– A map of Apalachicola Bay provided by ANERR, showing the two main communities on the Bay. This is an edited version of a map I presented in my expert report. (FX-789, Fig. 1.4)*

15. Apalachicola River flow is seasonal, with high flows in winter and spring, and lower flows in summer and early fall. This seasonality affects what species are dominant in the Bay during certain seasons, with some species more prevalent during high flows and others preferring lower flow conditions. However, when these low flow periods are exacerbated by further upstream water extractions, as described by Dr. Hornberger, the Bay's ecology is harmed by substantial changes in

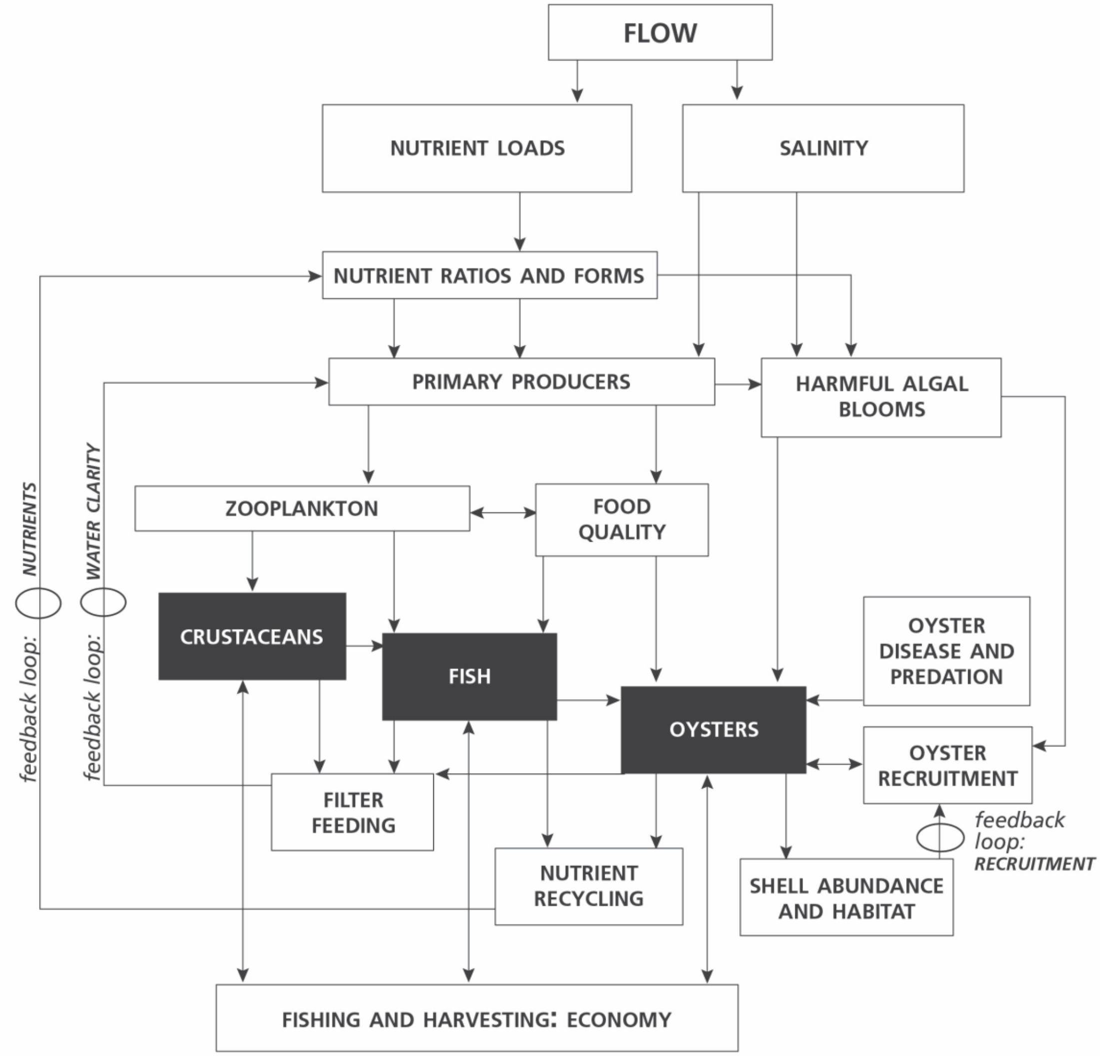

Figure 5 *– Conceptual diagram showing how flow affects Apalachicola Bay. Changes in flow affect salinity and nutrients, which in turn alter the Apalachicola Bay food web. I created this diagram based on my expertise and generally accepted scientific principles for use in my expert report. (FX-789, p. 6)*

water quality, leading to significant changes in biology.

16. Historically, Apalachicola Bay has been very productive, driven by the input of freshwater from the River. In this context I use the term "productivity" to mean a measurement of the total amount of fish, shellfish, plants, and other life supported in the Bay. Productivity of the Bay starts at the bottom of the food web, with primary producers (*See* Figure 5). The primary producers are the various forms of plant life that grow through photosynthesis. Phytoplankton (algae) are the most important primary producers in the water (*See* sketches, Figure 2 above). This microscopic life is generally eaten by microscopic animals (zooplankton), that filter the phytoplankton from the water. These "grazers," or consumers, in turn are eaten by predators up the food chain such as invertebrates and fish. Oysters alto filter the phytoplankton for their food. The amount of phytoplankton and the type – or "quality" – of phytoplankton set the trajectory for all of the food web; as their quality changes, the nutrition for the larger species changes. Data on freshwater flow and phytoplankton productivity show a strong correlation between the two.

17. Not all phytoplankton are beneficial to the food web or provide high quality food for grazers. Small plankton called cyanobacteria, and very small ones referred to as picocyanobacteria, do not provide food that is as nutritious for grazers. These small species can be difficult for grazers such as oysters to eat and may be rejected by them outright (*See* picoplankton sketch, Figure 2). Other phytoplankton species can, under some conditions, produce toxins that can alter ecosystems in many detrimental ways. These are the harmful algae that can create "harmful algal blooms," or HABs, a phenomenon often historically and/or locally referred to as "red tides." As I will discuss in more detail below, a particular concern in the Bay is that many of these harmful algae species increase in abundance under low-flow conditions, which have become more common in Apalachicola Bay with increased upstream consumption by Georgia, as explained in the testimony by Dr. Hornberger.

18. Submersed aquatic vegetation ("SAV"), as well as vegetation in marshes, are also primary producers in the food web. Aside from being a food source for many organisms, these plants also provide important refuge from predators and form nursery habitat for various species in the Bay, especially East Bay. The varieties of species that grow in saltier water are called seagrass, (*See* Figure 6). Reduced flows lead to increased salinity, which directly affects growth and survival of submersed aquatic vegetation in East Bay, where the vegetation predominantly prefers fresher water. When submersed aquatic vegetation are stressed or when plant growth decreases due to the effects of low flow, the available habitat for many species declines, and juveniles of many species (including commercially important blue crab and shrimp) lose the important areas to mature that are normally provided by the submersed aquatic vegetation.

Figure 6 *–A photo showing the seagrass growing underwater near the seaward side of Apalachicola Bay in August 2015. FX-266b is a true and accurate copy of this photograph, which is also publicly available on the official ANERR Facebook page, where it is described.*

19. The Bay has experienced a variety of impacts to the ecology in the most recent decades. I have found that changes and impacts are correlated to reduced freshwater inflow, which Dr. Hornberger and Dr. Flewelling have linked to increases in Georgia consumption. (*See* Testimony of Dr. Hornberger; Hornberger Expert Report (FX-785); Flewelling Expert Report (FX-786)) The recent crash of the oyster populations is the most concerning symptom, among others, of an increasingly unhealthy Bay as a result of reduced flows. As had been widely reported for many years, 90% of Florida's oysters came from Apalachicola Bay. This is no longer the case.

20. I have found that Apalachicola Bay is shifting to a state of lower productivity as reduced flows result in increased salinity and decreased nutrients, making the Bay more hospitable to marine species, including predators such as the oyster drill, a kind of predatory snail so named because it drills through the oyster shell, aided by secretions of sulfuric acid, to feed on the oyster meat, and conches, another oyster predator that thrives in higher salinity waters. The phytoplankton of the Bay have also changed, as the Bay is becoming a more suitable environment for picocyanobacteria and for some harmful algae. Based on my assessment, I conclude that the food web has experienced changes in form and function, beginning at the microscopic level, and this has led to ecological harm, including to economically and recreationally prized species.

21. Without a remedy, I conclude that continued stress on Apalachicola Bay as a result of decreases in flow attributable to increasing Georgia water consumption, will result in continued deterioration of the ecology of the Bay, a Bay that so many have done so much to protect. The Bay is in danger of further damage if upstream consumption continues to decrease water flows; this damage will only become increasingly more difficult to reverse.

II. REDUCED FRESHWATER INFLOW INCREASES SALINITY AND TEMPERATURE AND REDUCES THE AMOUNT OF HIGH QUALITY NUTRIENTS IN APALACHICOLA BAY, IMPAIRING THE FOOD WEB AND HARMING KEY SPECIES

22. Water quality in an estuary is directly linked to the amount of freshwater flow coming into the estuary, because freshwater flow both brings the nutrients that are derived from upstream and dilutes the salinity that comes in with the ocean water. In an estuary such as Apalachicola Bay, there is a gradient of water quality parameters with lower salinity and more nutrients near the river mouth, and higher salinity and fewer nutrients near the Gulf of Mexico. Water quality is important (among many other reasons) because it affects the type of food webs that can thrive; as freshwater input decreases, there is an expansion of marine-like organisms.

23. Water quality has been monitored in all the zones of the Bay since 2002 by the Apalachicola National Estuarine Research Reserve (ANERR) through a monthly sampling program. (*See* ANERR Data (JX-136)) At a few sites, there are also instruments in the water that continuously monitor some water quality parameters, taking recordings every 15-30 minutes (*See* Figure 7 for a map of these sites). I used these data to evaluate whether and how water quality has changed historically as freshwater flows have decreased.

Figure 7 *– Map of the sampling sites in the ANERR monitoring program, with the monthly sampling sites in green, and continuous monitoring sites in orange. This is a true and accurate copy of a figure I used in my expert report. (FX-789, Fig. 2.2) I made slight modifications to this figure, using generally scientifically accepted principles and methodology. The original figure which I downloaded is available online from ANERR at http://cdmo.baruch.sc.edu (JX-136).*

24. To evaluate the impacts of Georgia's consumption on several water quality parameters, I used three flow scenarios provided by Dr. Hornberger that represent: (1) a scenario without any Georgia consumption (i.e., the total extent of harm caused by Georgia, called the "unimpacted" scenario); (2) a very conservative scenario with reduced Georgia consumption (one of Dr. Hornberger's "remedy" scenarios); and (3) a scenario representing projected future increases in Georgia consumption without an equitable apportionment (the "future" scenario). I used statistical regression relationships, which are commonly used in my field, to estimate how water quality

parameters would change under these scenarios. I obtained these relationships by correlating River flow at the Sumatra gage with observed ANERR data on each parameter.

25. To examine the overall effects of changes in flow, I categorized all available data according to different ranges of flow from the 2002 to 2012 ANERR data set and flow at the Sumatra gage. For instance, from 2002 to 2012, there were 8 months in which the average monthly flows were below 6,200 cfs. For all of the months in that flow range (sometimes called a "bin"), I calculated the average water quality parameter, for instance, the level of nitrate. Then, using the regression relationships I established, I looked at those average flows and the corresponding water quality parameter, and calculated what the water quality parameter would be for the new flow values under Dr. Hornberger's scenario. For instance, I looked at the eight months in the "< 6,200 cfs" flow range under the unimpacted scenario, and calculated how the additional flow for those months, had there not been Georgia consumption, would improve water quality. I repeated this approach for the data in the next higher flow range (next "bin") and so on.

26. After my deposition, I evaluated ANERR data from 2012 to 2014 that were not initially available as I prepared my expert report to assure myself that there have been no changes in observed trends from my opinions. I found no such changes and therefore these data do not change my opinion in any way. I also evaluated correlations between flow at Chattahoochee Gage and nutrients, in case the Sumatra Gage had errors that affected my analysis. The relationships between flow and nutrients and other water quality parameters considered were equally robust regardless of the gage used.

27. I have found that water quality in Apalachicola Bay has changed directly as a result of reductions in freshwater flow, which Dr. Hornberger has described are caused by an increase in Georgia's consumption. These changes are especially harmful because the greatest impact of

increased consumption comes at the time when low flow naturally occurs, during summer and fall, when the estuary is already experiencing some natural stress. With reduced freshwater flow, over increasingly large areas of the Bay water quality becomes more like the Gulf of Mexico with higher salinities and less beneficial delivery of nutrients. Dr. Robert Livingston, one of the most preeminent Apalachicola Bay researchers, reached the same conclusion in his analysis of river flow effects on Apalachicola Bay – even before the most severe low flow years (2011-2012) occurred. (*See* Livingston 2008 (FX-379)). As he said, “Without adequate river water input, the Apalachicola estuary, one if the most prolific in North America, would be transformed into a much less productive system.” In the testimony that follows, I will describe how the evidence supports this finding.

A. *Reduced Freshwater Inflow Reduces High Quality Nutrients in the Bay*

28. The most important nutrients in an estuarine system are the inorganic nutrients dissolved in the water—mainly nitrogen and phosphorus. These nutrients can be considered the liquid fertilizers for the primary producers that grow in the water. The Apalachicola River is the major source of these dissolved nutrients in the Bay, because these nutrients come from upstream sources. There are other sources of nutrients—for example, the decomposing leaves and plant material (detritus) that come from the floodplain forest or from the sediment floor. These different nutrient sources provide different quality nutrients for phytoplankton growth, in turn altering the community of phytoplankton due to their nutrient preferences. Less nutritious plankton become more prevalent when flows are low, in part because the River brings in fewer nutrients overall, but also because the proportion of dissolved inorganic nutrients changes—there is less nitrogen, and the dominant “form” of nitrogen shifts from nitrate to ammonium. Not only do less nutritious plankton become more common, but detritus becomes a more prevalent food source for those species that can eat it.

Detritus is less nutritious overall and when it becomes a proportionately larger source of food, the food web has less high quality food.

29. As noted earlier, both nitrogen and phosphorus come in different forms, which can be thought of as different "flavors" for the phytoplankton, with most significant inorganic forms of nitrogen being nitrate[5] (NO_3) and ammonium (NH_4), while the most significant inorganic form of phosphorus is phosphate (PO_4). Just as garden plants require nitrogen and phosphorus as fertilizer, so too do the microscopic aquatic plants, the algae, although they must obtain their nutrients from natural sources—that is, the water. Also, just as different formulations of fertilizer are best for the

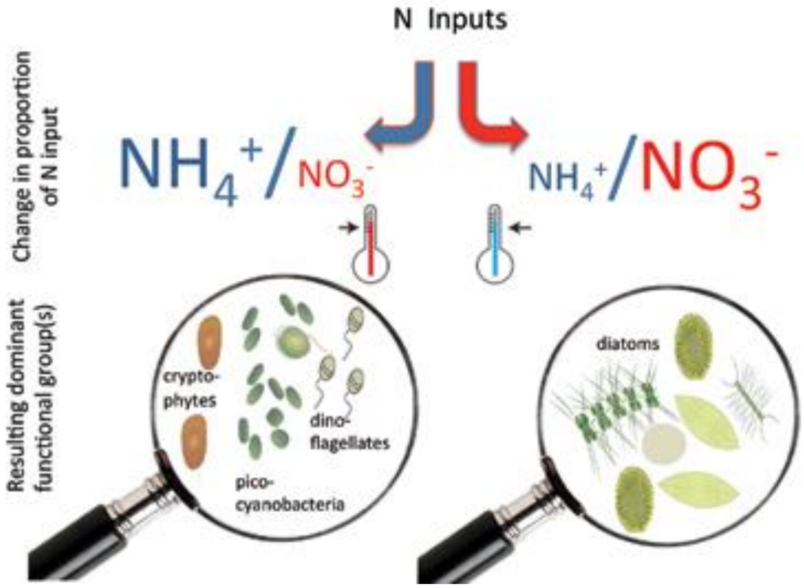

Figure 8 *– Conceptual schematic showing the effects of changes in the proportion of ammonium (NH_4) and nitrate (NO_3) on the types of phytoplankton that develop. When ammonium is the dominant form (low flow condition, on the left side of the figure), and when waters are naturally warmer (summer low flow period), dinoflagellates and cyanobacteria (less productive plankton) are more common. In contrast, when nitrate is the dominant form (under high flow, cooler water conditions, on the right side), diatoms are the dominant form of phytoplankton. This is a true and accurate copy of a figure I created based on generally scientifically accepted principles and methodology, and included in my expert report. (FX-789, Fig. A4.2)*

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[5] Another chemical form of inorganic nitrogen is nitrite (NO_2), but this is generally a minor constituent in water. The use of the term "nitrate" in my testimony actually denotes the sum of nitrate plus nitrite.

growth of different garden plants (tomatoes *vs* roses, for example), so too do different species of algae thrive on different proportions of nutrients or different flavors of the same nutrient. (*See* Figure 8) Nitrate is generally the preferred and most nutritious form of nitrogen for diatoms, which are the most important phytoplankton type in Apalachicola Bay. Ammonium is the form of nitrogen used preferentially by a less nutritious type of plankton, the cyanobacteria, and by many dinoflagellates, among which are some types of harmful (often toxic) algae. These differences in the use of various forms of nitrogen by different types of phytoplankton have been well established in the scientific literature. And, different phytoplankton also prefer different ratios of phosphorus to nitrogen or change their rate of growth when the proportion of nitrogen to phosphorus changes, as described later in my testimony.

30. My analysis shows that nitrate (the preferred and most nutritious form of nitrogen for diatoms) is strongly correlated to river flows, and accounts for 97% of the inorganic nutrient load from the River. Thus, a decrease in River flows leads to a decrease in nitrate loads, in turn decreasing nitrate concentration in the water of the Bay. (*See* Figure 9) Ammonium and phosphate are also correlated to Apalachicola River flow, but less strongly so. This is because ammonium and phosphate can also come from the decomposition of plant matter (the detritus mentioned above) and other sediment sources and processes. A comparison of data collected by scientists from 1992-1994 relative to that collected during the 2002-2012 period, shows a substantial drop in inorganic nitrogen loads in the latter period. (*See* Mortazavi et al. 2001 (JX-11)) During the lowest flows in 2011-2012, inorganic nitrogen loads were 50% lower than the loads measured in 1992-1994.

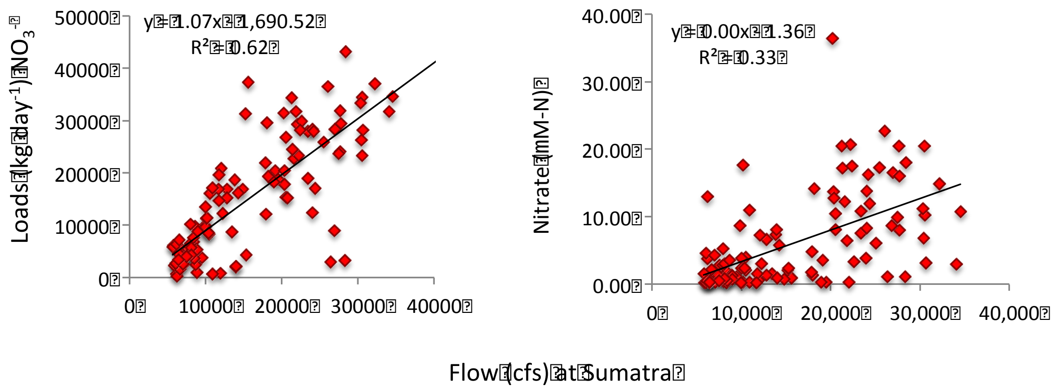


Figure 9 *–The left panel shows a plot of nitrate loads against observed flows at the Sumatra Gage (<40,000cfs), using data from 2002-2012. The right panel shows the resulting nitrate concentrations at one site in the Bay, Cat Point. Note that higher loads and concentrations occur with higher flows. I have also run these regressions for observed flows at the Chattahoochee Gage, with the same results. These gages are located at different points along the River and therefore were compared to avoid any potential bias in one gage or another. These figures were created by me, using generally scientifically accepted principles and methodology, using ANERR data (JX-136) and Sumatra gage flow data (JX-128), and were produced in my expert report. (FX-789, Fig. 2.3 (slightly edited), Fig. 2.9)*

31. In the absence of Georgia consumption, with increased flow carrying more nutrients into the Bay, I estimate that concentrations of nitrate, the preferred nutrient for the nutritious diatoms in the food web, would be about three times higher in East Bay and Cat Point (one of the major oyster bars). For Dry Bay (another major oyster bar), the difference would be about four times greater. (*See* Figure 10, bar chart)

32. To show how the Bay could be improved by a remedy, I compared the "remedy" scenario to the "future" scenario – two potential trajectories the Bay could take, depending on whether consumption is capped. The difference between these two reflects the potential impact of the remedy on nutrients in the Bay. Improvements in nitrate availability would be quite substantial for all sites. The example sites here suggest improvements of 62% to greater than 500% for the months that experienced the lowest flows (summer months in dry years). Even for months in the medium flow categories when the impacts of Georgia's consumption is not as pronounced, a 30% increase

would be observed. (*See* Table 1 under Figure 10) With such an improvement in nitrate availability, the Apalachicola Bay ecology benefits because this increase changes the “flavors” of inorganic nitrogen (more nitrate relative to ammonium) to those forms preferred by nutritious diatoms, the algae more supportive of productive food webs.

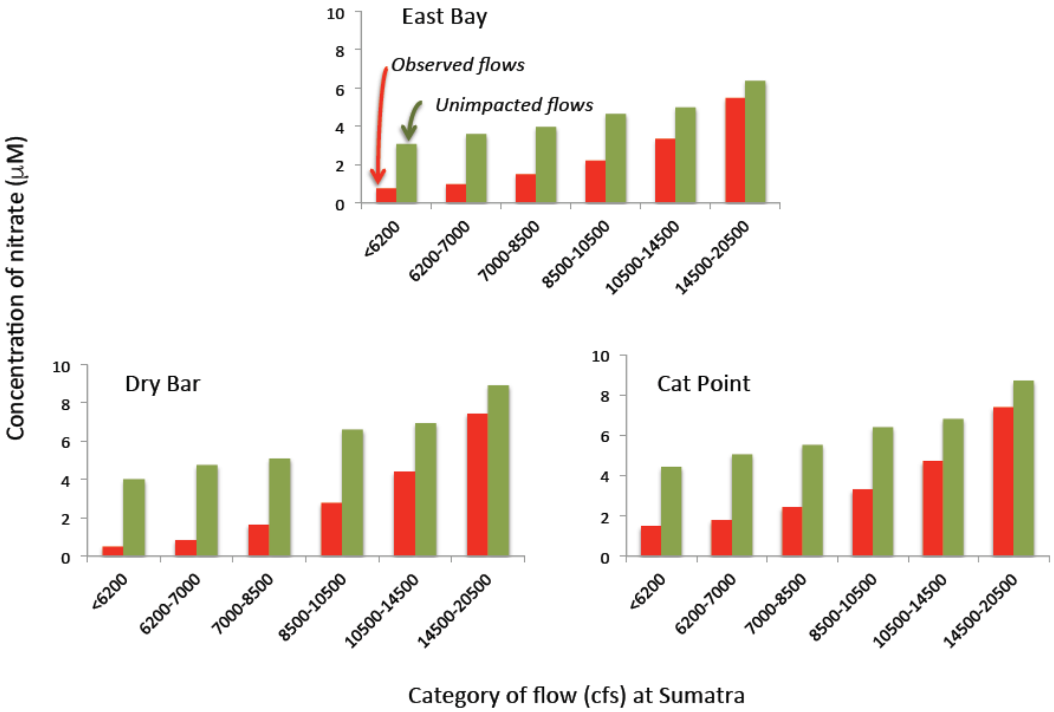


Figure 10 *–Bar charts showing improvements in nitrate concentration between observed and unimpacted flows, averaged for each "bin" or category of flow. The top panel is East Bay, left is Dry Bar and right is Cat Point. As shown, Georgia's consumption has the highest impacts on months with the lowest observed flows. I created this chart, using generally scientifically accepted principles and methodology, for my report and testimony. It reflects data originally contained in tabular form in my report. (FX-789, Table 2.2) I added Dry Bar as an additional illustration of harm, calculated based on the same data and equations shown in my report. (FX-789, Fig. A3.6)*

Flow Category (cfs)	**East Bay**	**Cat Point**	**Dry Bar**
<6200	111	62	>500
6200-7000	67	42	160
7000-8500	50	37	83
8500-10500	33	27	47
10500-14500	21	18	26
14500-20500	11	10	16

Table 1 *– Table showing the percent improvement in nitrate concentration that would be expected at each of these sites if the remedy were imposed, relative to expected future condition. Similarly, "bins" of flows that had very low flow would benefit greatly from imposition of a remedy, whereas changes are lower for those periods that already saw high flows. I created this table, using generally scientifically accepted principles and methodology, for my report and testimony. It reflects simple calculations based on data originally contained in tabular form in my report, or calculated from data and equations provided in my report. (FX-789, Table 2.2, Fig. A3.6)*

B. *Reduced Freshwater Inflow Increases Salinity and Water Temperature in the Bay*

33. Reduced freshwater flows also lead to increased salinity in the Bay because there is less dilution of the seawater. Dr. Greenblatt's testimony discusses salinity in more detail—put simply, when there is less freshwater coming into the Bay, salt water is less diluted, leading to higher levels of salinity. Increased salinity in the Bay results in more ammonium and phosphate being released from the sediment (by direct chemical effects and by biological activity), further contributing to a shift in the nutrient composition in the Bay towards more ammonium relative to nitrate.

34. I also assessed the impact of reduced freshwater inflow on water temperature. Longer residence times, the time a portion of water spends within the Bay before getting flushed out into the open Gulf, caused by low River flow results in higher water temperatures. At lower flow, there is less of the cooler River water to begin with. And as the water sits in the Bay for a longer time before being flushed to the Gulf, it has more time to warm in the Florida sun.

C. *The Changes in Nutrients, Salinity and Temperature Caused by Flow Reductions Change Phytoplankton Community Composition in the Bay, Impairing the Food Web*

35. I found that flow reductions cause a change to the species composition of phytoplankton—the important base of the Apalachicola Bay food web—in a number of ways. As I have emphasized, different types of phytoplankton species prefer different nutrient forms and proportions. (*See* Figure 8 above) As my analysis has shown, when flow is reduced from 20,000 to <7,000 cfs, the proportion of ammonium to nitrate increases by a factor of more than 100 and the proportion of nitrogen to phosphorus decreases by a factor of more than 100. (*See* Figure 11 & Expert Report (FX-789, Figs. 2.5, A3.9, A3.10)) The shift in nutrients in Apalachicola Bay I describe above, including increased ammonium relative to nitrate favors different types of phytoplankton—less nutritious cyanobacteria rather than more nutritious diatoms. Just as a major change in diet affects the metabolism of humans, this change in the quality of nutrients at the base of the food web has

significant and complex impacts on the grazers that feed on these phytoplankton. It changes the ecology of the Bay.

36. Similarly, when nitrogen–to-phosphorus proportions change, the proportion of different types of phytoplankton also changes and the shift can also change their rate of growth. The amount of nitrogen and phosphorus available to organisms higher in the food web also changes because they graze on food with different nutrient content.

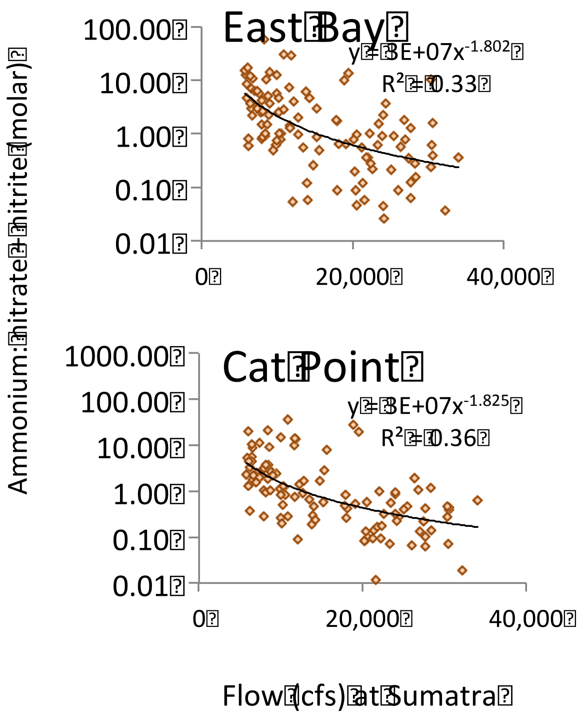


Figure 11– *Graphs showing the change in the proportion of ammonium to nitrate as a function of flow. Note the steep rise in this ratio at low flows (note also the Y axis is plotted on a logarithmic scale). Shown are examples of this ratio for East Bay (top panel) and Cat Point (bottom panel). I created these figures, using generally scientifically accepted principles and methodology, for my report and testimony. They are based on ANERR nutrient data (JX-136) and Sumatra gage flows (JX-128), and these figures are true and accurate copies of figures appearing in my report. (FX-789, Fig. A3.10)*

37. Changes in the phytoplankton community are also due to increasing salinity: as River flows decrease, the plankton species typically found in higher salinity ocean environments proliferate at the expense of the species that historically flourished in Apalachicola Bay with its freshwater influx from the River. Finally, warmer temperatures as a result of flow reductions also contribute to a harmful shift in types of phytoplankton in the Bay because the less nutritious cyanobacteria prefer warmer water, while more nutritious diatoms prefer cooler water.

38. To evaluate the changes in phytoplankton composition resulting from changes in water quality, I accessed data on phytoplankton in Apalachicola Bay from the Florida Fish and Wildlife Research Institute (FWRI), available published papers and dissertations, and other literature sources. In particular, I analyzed trends in the phytoplankton community in Apalachicola Bay based on various phytoplankton field collections reported in the three available studies that identified these species as well as other data sources described below. (Estabrook Thesis 1973 (JX-142); Putland Thesis 2005 (JX-16); Viveros Bedoya Thesis 2014 (JX-15)) I also reviewed a report that became available very recently after preparation of my report that summarizes the results of field investigations done by various estuarine researchers at Florida State University, discussing phytoplankton composition including the critical 2011-2012 years. (Phlips Report 2016 (FX-359)) The 2011-2012 data, representing the very low flow years, were not previously included in the prior analysis (Viveros Bedoya Thesis 2014 (JX-15)). I primarily focused my analysis on three major groups of phytoplankton (*See* Figure 2 in the beginning of this document): preferred nutritious diatoms, less nutritious cyanobacteria, and dinoflagellates (many of which are harmful algae species).

39. First, my analysis shows that during low flows there is a shift in the community to increasing abundance of less nutritious cyanobacteria (especially the picocyanobacteria) relative to more nutritious diatoms. (*See* Figure 12) This trend is expected from accepted estuarine science, since most cyanobacterial species prefer warmer water and ammonium as the dominant nitrogen form—both of which increase as flows decrease. The author of the data from which these data were derived, Dr. Viveros Bedoya, drew the same conclusion. (Viveros Bedoya Thesis 2014 (JX-15)) During periods of critical low flow, such as in 2011 and 2012, I therefore expected that very high cyanobacteria would be observed. In fact, this trend was reaffirmed in the recent report by Dr.

Phlips et al. (FX-359)) in which the top 40 types of phytoplankton were reported for the years 2008-2012 (*i.e*, including the driest years of 2011-2012). In East Bay, North Bay and West Mid-Bay cyanobacteria (especially picocyanobacteria) were numerically dominant among that top 40, with diatoms rarely reported for the years 2011-2012.

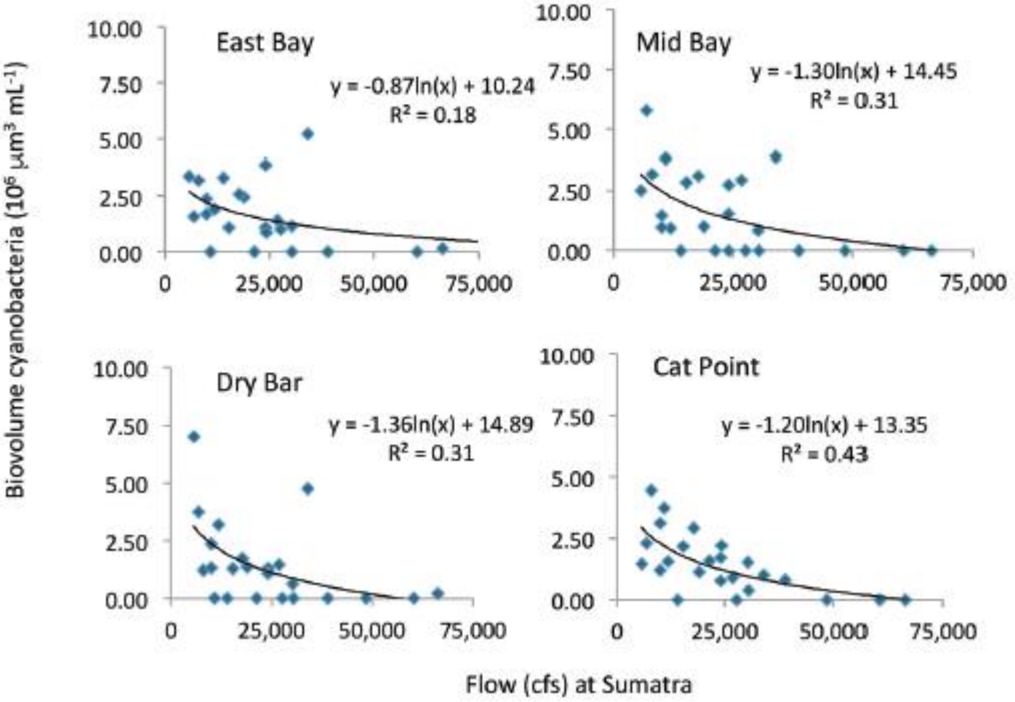


Figure 12 *– Relationships between measured biovolume of cyanobacteria and flow at the Sumatra gage. I replotted this data from the Viveros Bedoya thesis, using generally scientifically accepted principles and methodology. (JX-15) All regressions are statistically significant, indicating that cyanobacteria levels increase at lower flows throughout the Bay. These figures are true and accurate copies of figures presented in my expert report. (FX-789, Fig. 3.5)*

40. Second, I compared the species of phytoplankton reported in a 1973 study with a 2014 study to determine if there had been a change in the common phytoplankton types (Estabrook Thesis 1973 (JX-142); Viveros Bedoya Thesis 2014 (JX-15)). This comparison shows that various freshwater phytoplankton species observed in 1973, the era prior to significant increases in Georgia consumption (*see* Dr. Hornberger Testimony), were rarely observed or not seen at all in 2014.

Conversely, the 2014 study observed some marine species that were not observed in 1973. The communities were clearly different during the period of these two studies.

D. *Harmful Algal Blooms Are Exacerbated by Low Flows*

41. The changes in phytoplankton species composition caused by increased low flow and the resulting changes in salinity and nutrients include an increase in harmful algal blooms (commonly abbreviated as HABs). These are species of phytoplankton that can produce toxins which can cause fish kills and human health problems, and which cause detriment effects to the food web in myriad ways. Among the HABs are also species that, when detected at levels of concern, trigger closures of shellfish harvesting areas.

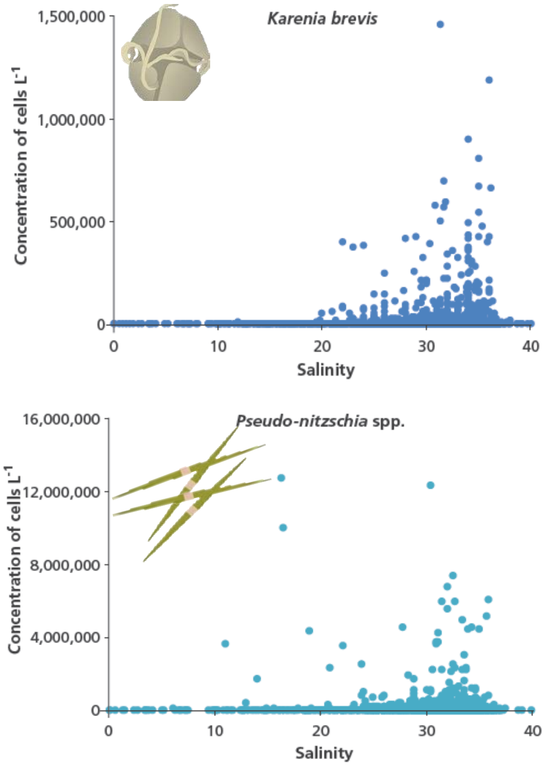


Figure 13 *– Relationships between the abundance of two common harmful algae species in Apalachicola Bay and salinity. Note that these species are more abundant under higher salinities. The image in the corner of each graph is a sketch of these different species. I plotted these graphs based on FWRI data, using generally scientifically. Aside from the sketches they are true and accurate copies of graphs contained in my expert report. (FX-789, Fig. 3.9)*

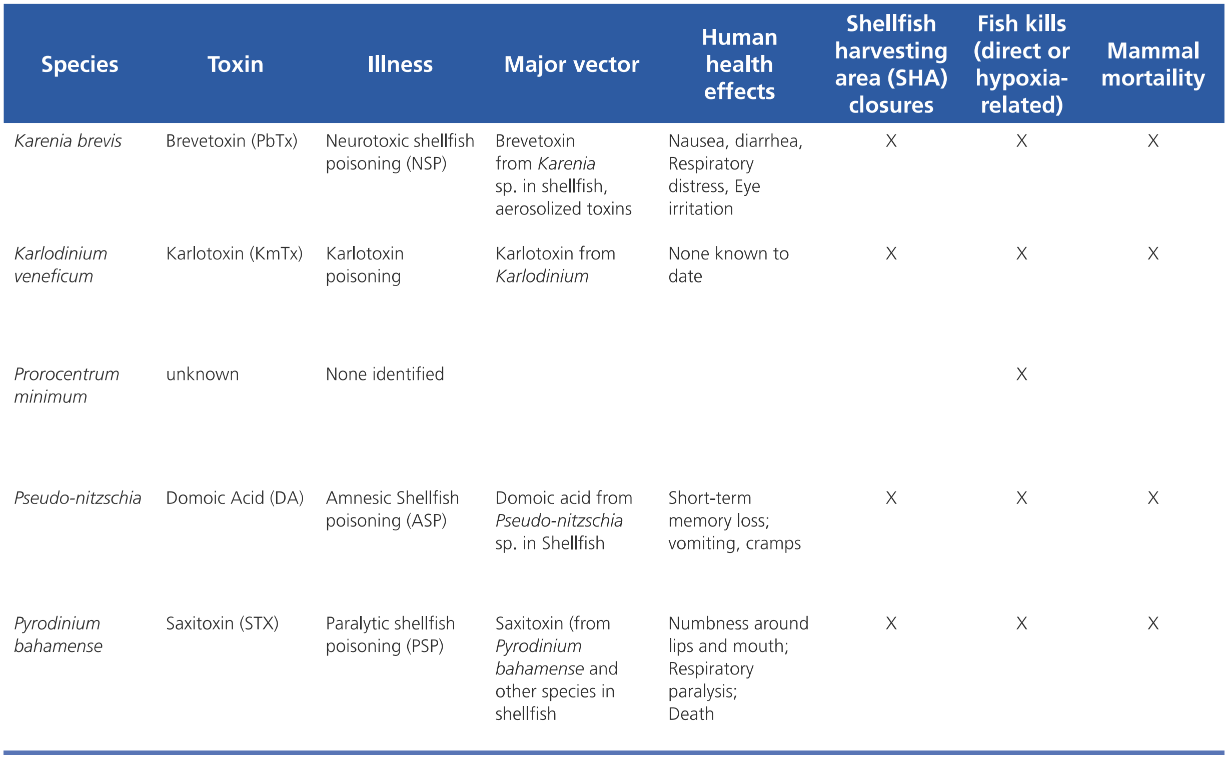
42. In addition to HAB species reported in the studies mentioned in my discussion of the shift in phytoplankton composition above, there are other sets of HAB data on which I have drawn. The Florida Fish and Wildlife Research Institute (FWRI) collects HAB data whenever a harmful bloom event is reported,

and I have used these data to analyze the frequency of reported occurrences with time and salinity preferences of several specific HABs in Apalachicola Bay.

43. The most well-known HAB in Florida, often referred to as the "Florida red tide," is *Karenia brevis*, which causes severe human health issues; the detection of its toxin at certain levels triggers commercial shellfish area closures. This HAB originates offshore and is marine in nature. Although its introduction in the near-shore area of Apalachicola Bay and other estuaries in the Panhandle is determined by a complex suite of factors, including offshore physics, winds, and other environmental factors, it can only thrive in environments with relatively high salinities. (*See* Figure 13) Extremely low flows exacerbated by water consumption can increase the risk for a *Karenia brevis* bloom to take hold and expand within the Bay.

44. While not as well-known as the "Florida red tide", there are other HAB species in Apalachicola Bay, including *Prorocentrum minimum, Pseudo-nitzschia* spp. and *Karlodinium veneficum*. The impacts of these species on the food web – and oysters specifically – are many, and some also have significant human health impacts when consumed in seafood. (*See* Table 2)

45. Changes in flow and salinity change the abundance and distribution of these HAB species. As shown above, *Karenia and Pseudo-nitzschia* prefer saltier water (*See* Figure 13 above), but the HAB species *Prorocentrum minimum* and *Karlodinium veneficum* commonly bloom in mid-salinity reaches of the Bay. Reduced flows increase the risk of these HABs expanding into the normally less saline East Bay, causing harm in this nursery environment.



Species	Toxin	Illness	Major vector	Human health effects	Shellfish harvesting area (SHA) closures	Fish kills (direct or hypoxia-related)	Mammal mortaility
Karenia brevis	Brevetoxin (PbTx)	Neurotoxic shellfish poisoning (NSP)	Brevetoxin from *Karenia* sp. in shellfish, aerosolized toxins	Nausea, diarrhea, Respiratory distress, Eye irritation	X	X	X
Karlodinium veneficum	Karlotoxin (KmTx)	Karlotoxin poisoning	Karlotoxin from *Karlodinium*	None known to date	X	X	X
Prorocentrum minimum	unknown	None identified				X	
Pseudo-nitzschia	Domoic Acid (DA)	Amnesic Shellfish poisoning (ASP)	Domoic acid from *Pseudo-nitzschia* sp. in Shellfish	Short-term memory loss; vomiting, cramps	X	X	X
Pyrodinium bahamense	Saxitoxin (STX)	Paralytic shellfish poisoning (PSP)	Saxitoxin (from *Pyrodinium bahamense* and other species in shellfish	Numbness around lips and mouth; Respiratory paralysis; Death	X	X	X

Table 2 *– Associated toxins, human health syndromes and potential environmental impacts of HAB species present in Apalachicola Bay. I created this table for my report and testimony based on information I reviewed, my expert knowledge, and generally scientifically accepted principles. It is a true and accurate copy of a table produced in my expert report. (FX-789, Table A5.1)*

46. The very recent report that became available describing the distribution of HABs from 2008-2013 shows an astonishing increase in these HAB species relative to the previously available data. (Phlips Report 2016 (FX-359)) These data list the highest cell densities of *Pseudo-nitzschia* spp. and *Karlodinium veneficum* to be *five to six times* higher than any value in the FWRI database,

showing the large potential for these HABs in Apalachicola Bay. *Karlodinium* was only documented in the FWRI database in 2011, and the values reported by Dr. Phlips clearly place it within a range that can harm oysters, as I discuss below. The summary by Dr. Phlips also shows that dinoflagellates were more than 3-fold more abundant and cyanobacteria were more than double overall in 2012 compared to 2009 at the Cat Point oyster bar site. He documented the same trend in dinoflagellate abundance in 2012 at the East Bay Bridge site and at Dry Bar. In these regions, the relative abundance of diatoms remained the same from year to year. These data confirm my previous prediction of increased cyanobacteria and dinoflagellates with low flow.

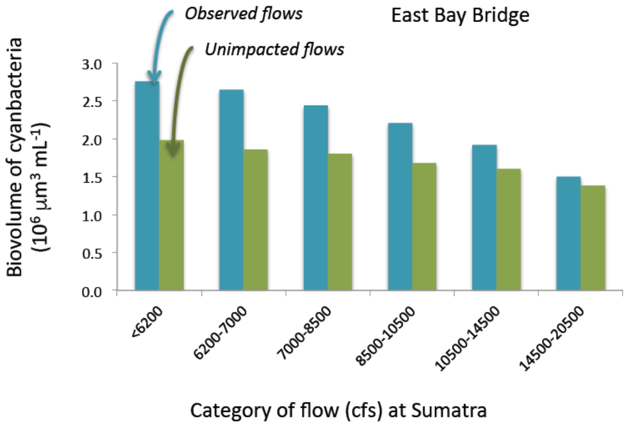
47. As noted above, when flow declines, the ratio of nitrogen-to-phosphorus decreases, mostly due to a reduction in nitrogen delivered to the Bay through River flow. Such a shift appears to particularly favor one of the HAB species, *Pseudo-nitzschia.* It has much higher abundances under lower nitrogen-to-phosphorus conditions that come with lower flow.

D. *Phytoplankton Changes Attributable to Georgia Consumption*

48. I used the same flow scenarios provided by Dr. Hornberger as described above to evaluate changes to phytoplankton abundance and community. I first focus on abundance of cyanobacteria and estimate the improvement that would be seen when flows are improved. In this case, as in my water quality analysis, I based my analysis here on correlation (regression) relationships I derived, but here I used the 2014 study data and projected abundances for flow categorized in certain ranges. I use data from the East Bay Bridge and East Bay site as examples.

49. The overall biovolume (one measure of abundance) of cyanobacteria is 35% higher under observed conditions than it would be under unimpacted conditions. (*See* Figure 14) The "remedy" scenario also shows meaningful improvements, with a reduction of cyanobacterial abundance of 10% (as compared to a future with increased consumption) that would be expected at the lowest

flows in the example of East Bay Bridge site. (*See* Tables 3 associated with Figure 14) Similar improvements are seen for the important oyster bar sites, Cat Point and Dry Bar. In short, improvements in flow will help reduce the amount of cyanobacteria and, in turn, improve food quality in the Bay.



Flow Category (cfs)	East Bay Bridge	East Bay surface
<6200	-10	-7
6200-7000	-8	-6
7000-8500	-9	-6
8500-10500	-8	-6
10500-14500	-7	-5
14500-20500	-6	-4

Figure 14*– Chart showing improvement in cyanobacteria between observed and unimpacted flows, averaged for each "bin" or category of flow. The chart gives the example for East Bay Bridge. I created this chart using generally scientifically accepted principles and methodology, for my testimony. It visually represent data contained in my expert report in tabular form. (FX-789, Table 3.4)*

Table 3 *– Estimates of the percent reduction in cyanobacteria abundance using the East Bay Bridge and East Bay sites as examples, showing each category of flow with the remedy scenario in relation to the future scenario. I created this chart using generally scientifically accepted principles and methodology, for my report and testimony. It represents data contained in my expert report in tabular form, and data calculated using the same methodology, data, and equations presented in my expert report for East Bay Surface . (FX-789, Table 3.4, Fig. 3.5, Fig. 3.10)*

E. *Reduced Freshwater Inflow Can Cause Excessive Levels of Phytoplankton, Resulting in Harmful Levels of Dissolved Oxygen*

50. In addition to reducing nutrient loads, low flows also increase residence time, the time a portion of water spends within the Bay before getting flushed out into the open Gulf. With reduced

freshwater flow, flushing rates are reduced and water, including its nutrients and phytoplankton, is less likely to move from the river to the sea.

51. When nutrients and algae do not move with flow along the natural flushing trajectory from the River to the Gulf, there is more time for algae to “grow in place.” These algae can accumulate to a harmful degree in the relatively stagnant water as they are exposed to more sunlight and the nutrients that are not flushed away. Algae only require about a day to double in biomass when they have access to sufficient nutrients for growth. In my data analysis, I found, and others have similarly reported, that there are statistically significant relationships between algal abundance and flow. When flow is low, there is more chlorophyll-*a*, a measure of total phytoplankton biomass in the water. Beyond the harm cause by an increase in the type of phytoplankton that are less nutritious for grazers, excessive increase in phytoplankton biomass can be harmful regardless of the type of phytoplankton.

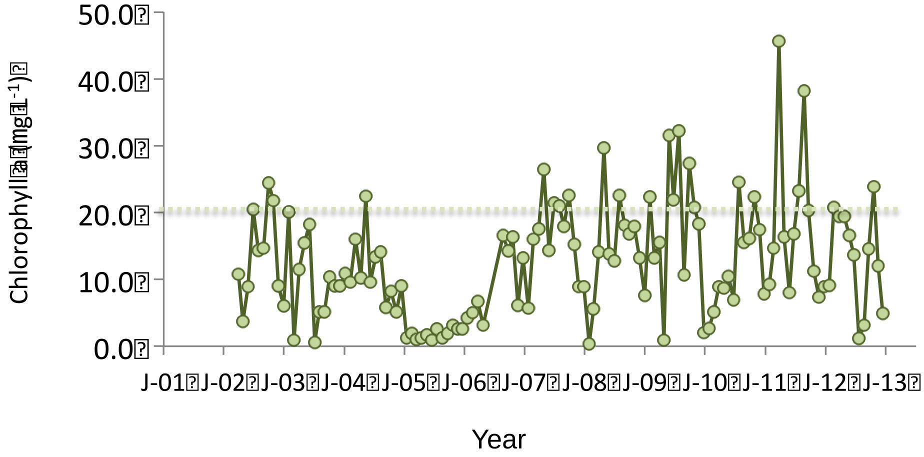


Figure 15 *– Changes in chlorophyll-a per liter (μg L^{-1}) in East Bay based on data by ANERR (JX-136). Time scales on the graph starts January 2001. The dashed line is drawn at 20 μg L^{-1} to allow identification of the periods when this value was exceeded. As shown, chlorophyll-a has peaked in recent dry years. I created this chart for my report and testimony using generally scientifically accepted principles and methodology. (FX-789, Fig. 3.3) One line has been added to the figurecontained in my expert report to create this figure.*

52. The ANERR data show that at lower flows, values of chlorophyll-*a* begin to approach and may even exceed levels set by the Florida Department of Environmental Protection to ensure the health of the Bay--20.7 μg chlorophyll-*a* per liter (daily average). For comparison, in the recommended values of water quality for estuaries established by NOAA, as reaffirmed for Georgia estuaries (Sheldon and Alber 2011 (FX-360)), a value of 20 μg chlorophyll-*a* per liter is considered to be "high" and associated water quality is considered to be "fair/poor." As shown in Figure 15, this value was hit more frequently in the past decades, especially during the dry years.

53. The data for East Bay show that during very low flow periods, these excessive phytoplankton can accumulate to harmful levels that cause "eutrophication," a process that can deprive Bay life of the oxygen necessary to survive. Since virtually all aquatic species require oxygen to survive,[6] reductions in oxygen to low levels (*hypoxia*) or near zero (*anoxia*) are extremely stressful to the submersed plants, invertebrates, fish, and oysters, even if the episodes of hypoxia or anoxia are relatively brief. Such stress can reduce growth and spawning, and even increase mortality, harming the ecosystem. As I explained earlier, the reduction in oxygen comes about by bacterial decomposition of this excessive phytoplankton accumulation.

54. Episodes of low oxygen occur particularly at night. At that time, the phytoplankton are not producing oxygen because there is no sunlight for them to carry out photosynthesis. At night, therefore, the process of consuming oxygen exceeds that of photosynthesis, which produces oxygen. In eutrophic conditions, the large amount of algae that is decomposed by microbes means that substantial amounts of oxygen are consumed. This leads to large swings in dissolved oxygen, with significant nighttime reductions in dissolved oxygen that can harm many species in the ecosystem, including fish, invertebrates and oysters.

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[6] The exception are some bacteria, especially those that undertake the decomposition process.

55. My review of the ANERR dissolved oxygen data confirms that these pronounced reductions in dissolved oxygen occur primarily at night in Apalachicola Bay and that these swings are greater during periods of low flow. (*See* Figure 16 for examples of oxygen swings during a late August period in 2011) While not all low flow periods lead to hypoxia, there is a statistically significant relationship between the occurrence of hypoxia (< 2 mg/L dissolved oxygen) and reductions in river flow. Hypoxia occurs more frequently as river flow is reduced. Anoxia (<0.1mg/L dissolved oxygen) also occurs more frequently as flows decline, especially as flows measured at the Sumatra gage decline below 10,000 cfs. (*See* Figure 18, further below)

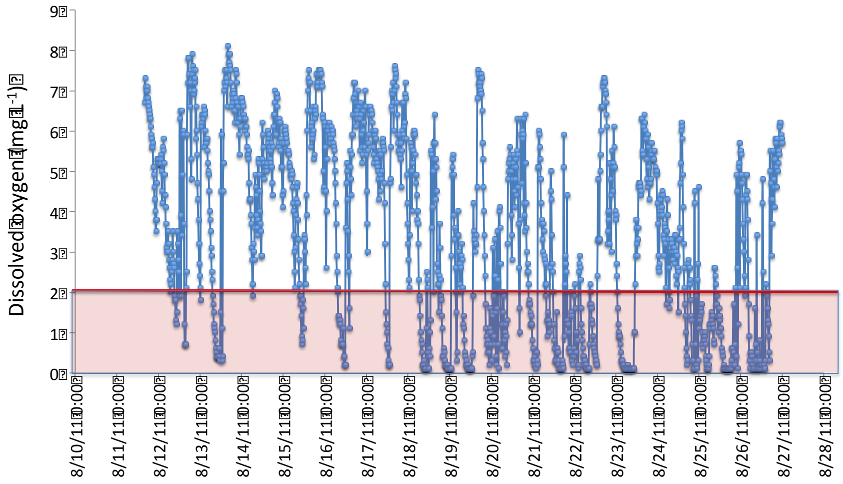


Figure 16 *– Example of changes in dissolved oxygen at East Bay during a few day period in August of 2011. The points that fall in the red zone are periods during which hypoxia occurred (the red line delineates oxygen values of 2 mg* L^{-1}*). Note that hypoxia or anoxia occurred night after night and often lasted hours. I created this figure for my report and testimony using generally scientifically accepted principles and methodology. A longer time course showing that this pattern occurred (June to November 2011) is given in a figure I created from ANERR data (JX-136) for my Expert Report.(FX-789, Fig. 2.7)*

56. Another way of assessing the data to determine the impact of low flows on the organisms of Apalachicola Bay is to compare the percent of time East Bay experiences salinities of 18 or 25 ppt—the higher salinities seen in lower flow periods—and the percent of time hypoxia or anoxia occurs in

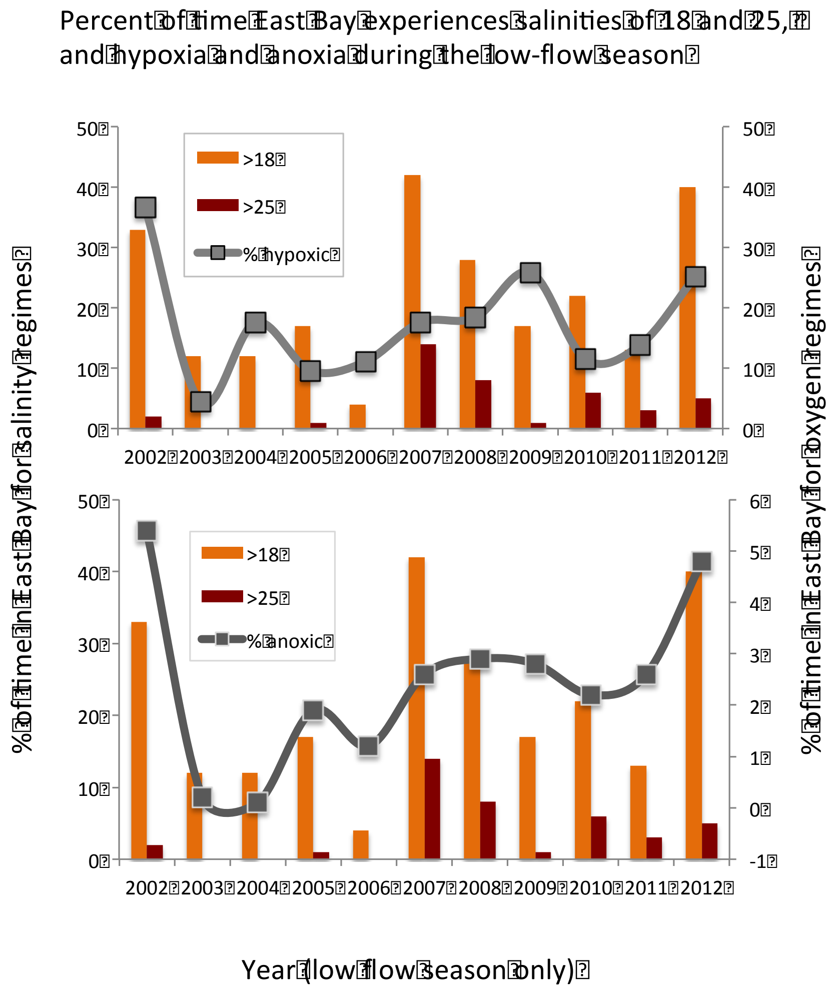


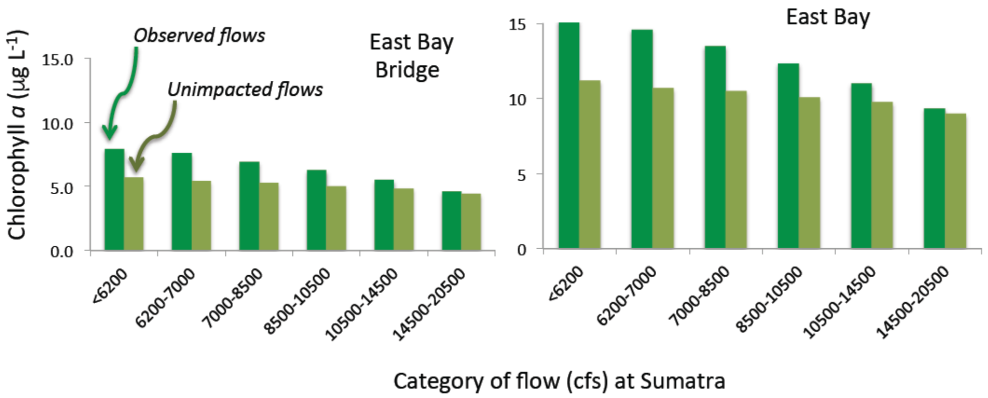
Figure 17 – Comparison, by year, of the percent of time that East Bay experiences salinities of 18 (orange bars), 25 (red bars) and the associated amount of time it also experiences hypoxia (gray line; upper graph) and anoxia (gray line, lower graph). These are observed data from the East Bay ANERR station (JX-136). Note that the left Y axis is the scale for the bars showing salinity results, while the right Y axis is the scale for the gray line showing oxygen results, and also note the scale of the right-hand axis differs between the top and bottom panels Anoxia occurred about 3-5% of the time in recent dry years, and hypoxia about 15-30% of the time. This graph is a simple plot of ANERR data, which I created for my testimony using generally scientifically accepted principles and methodology, and based on data which I presented in various other ways throughout my expert report. (See FX-789, Fig. 2.8, Table A3.2, A3.6, A3.7)

the low flow season. Year after year, when salinities are more frequently in this higher zone, the Bay also experiences more frequent episodes of severe hypoxia and anoxia. As shown in Figure 17, in recent dry years anoxia occurred about 3-5% of the time and hypoxia about 15-30% of the time.

57. Moreover, as water warms as a result of lower flow, oxygen becomes less soluble in water. This is an indisputable fact of physics: oxygen solubility decreases as temperatures warm. In other words, at warmer temperatures, the water holds less oxygen, so less oxygen is naturally available to aquatic organisms. During very low flow periods, this physical phenomenon combines with the effects of algae growth and its decomposition to reduce oxygen levels even further. Clearly, periods of low oxygen occur when flows are low, and the processes of eutrophication, warming and physical solubility collectively act in the same direction, intensifying the harm to aquatic organisms.

F. *Changes in Phytoplankton Abundance and Dissolved Oxygen in East Bay Attributable to Georgia Consumption*

58. Using Dr. Hornberger's scenarios, as described above, I evaluated the impact of flow on chlorophyll-*a* (a measure of the total abundance of phytoplankton) and dissolved oxygen concentrations (one of the results of high plankton abundance) in Apalachicola Bay. First, compared to flows unimpacted by Georgia consumption, average chlorophyll-*a* concentrations are 40% higher at low observed flows that include Georgia consumption, showing the impact of Georgia's consumption on eutrophication in the sensitive East Bay area. Similarly, compared to a future with increased consumption, a remedy would improve chlorophyll-*a* concentration by up to 10% at the lowest flows, reducing the risk of eutrophication in East Bay. (See Figure 18 and accompanying Table 4)



Flow Category (cfs)	East Bay Bridge	East Bay
<6200	-6	-10
6200-7000	-2	-8
7000-8500	-3	-8
8500-10500	-3	-7
10500-14500	-5	-6
14500-20500	-8	-4

Figure 18 *– Bar charts above showing improvement in chlorophyll-a between observed and unimpacted flows averaged for each "bin" or category of flows. The examples shown are East Bay Bridge and East Bay. I created this graph for testimony using generally scientifically accepted principles and methodology. It represents in graphical form data presented in tabular form in my expert report. (FX-789, Table 3.3) I added East Bay as an additional illustration of harm, calculated based on the same data and equation shown in my report. (FX-789, Fig. A4.4)*

Table 4 *– Estimates of the percent reduction in chlorophyll-a for the East Bay Bridge and East Bay sites for each category of flow with the remedy scenario in relation to the future scenario. I created this chart for my testimony using generally scientifically accepted principles and methodology. It represents data contained in my expert report in tabular form, and data calculated using the same methodology, data, and equations presented in my expert report for East Bay. (FX-789, Table 3.3, Fig. A4.4)*

59. I also estimated the 'worst case' dissolved oxygen conditions-*i.e.*, the upper bound of the time period during which anoxia (no oxygen) or hypoxia (low oxygen) would be observed. Without Georgia consumption, East Bay would experience the worst periods of low oxygen much less frequently, especially for the lowest flow regimes. A remedy scenario would meaningfully reduce

low oxygen periods as well, especially at low flows. Improvements in the periods of hypoxia or anoxia by more than 10% would be seen (*See* Figure 19a & Figure 19b and accompanying Table 5).

60. Water temperature is lowered with increasing freshwater inflow, a directional change favorable of more oxygen dissolved in water. Temperature would also experience meaningful improvement under a remedy scenario. (*See* Expert Report (FX-789), Table 2.4)

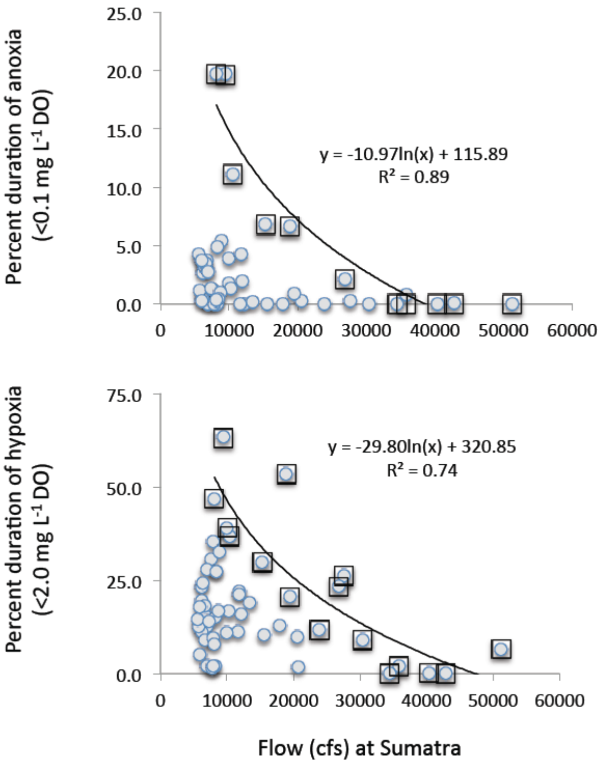
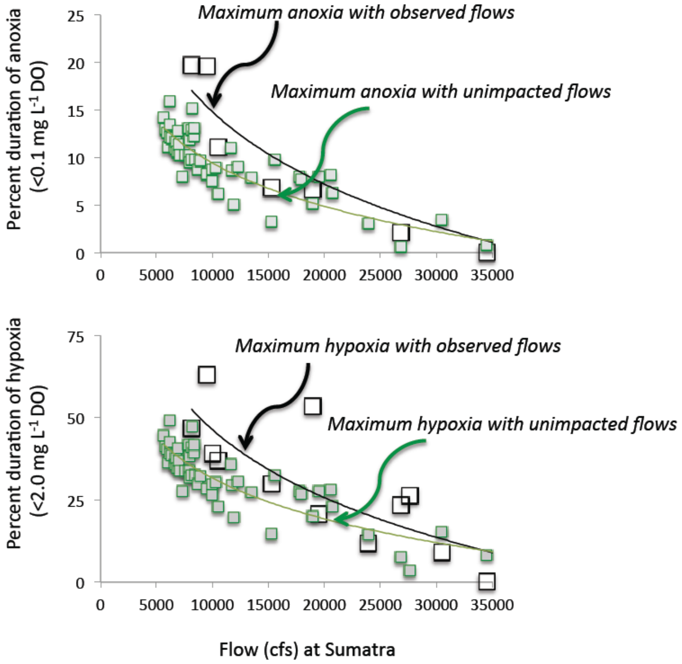


Figure 19a *– Figures showing the relationship between the most severe episodes of anoxia and hypoxia (squared dots) and flow, based on the ANERR data (JX-136) and Sumatra flow (JX-128). Data represent low flow months only (June through October). I created this figure for my report and testimony using generally scientifically accepted principles and methodology. This is a slight modification of a figure presented in my expert report. (FX-789, Fig. 2.8)*



Flow Category (cfs)	Anoxia	Hypoxia
<6200	-13	-11
6200-7000	-11	-10
7000-8500	-10	-9
8500-10500	-13	-11
10500-14500	-15	-12
14500-20500	-10	-8

Figure 19b *– Figures showing the improvements in maximum anoxia (above) or hypoxia (below) at East Bay under observed and unimpacted flow conditions, based on the equations in Figure 19a and calculated using the same methodology and data as results previously presented in my report (FX-789, Table 2.3). While natural conditions of anoxia or hypoxia exist, as shown, Georgia' consumption in months with the lowest flows significantly increases the risk of severe low oxygen conditions. I created these figures for my testimony using generally scientifically accepted principles and methodology.*

Table 5 *–Table showing the percent reduction in periods of anoxia or hypoxia that would be expected if the remedy scenario used were imposed, relative to future conditions. I created this chart for my testimony using generally scientifically accepted principles and methodology. It is based on the modified equations, using the same methodology used to present results in tabular form in my expert report. (FX-789, Table 2.3)*

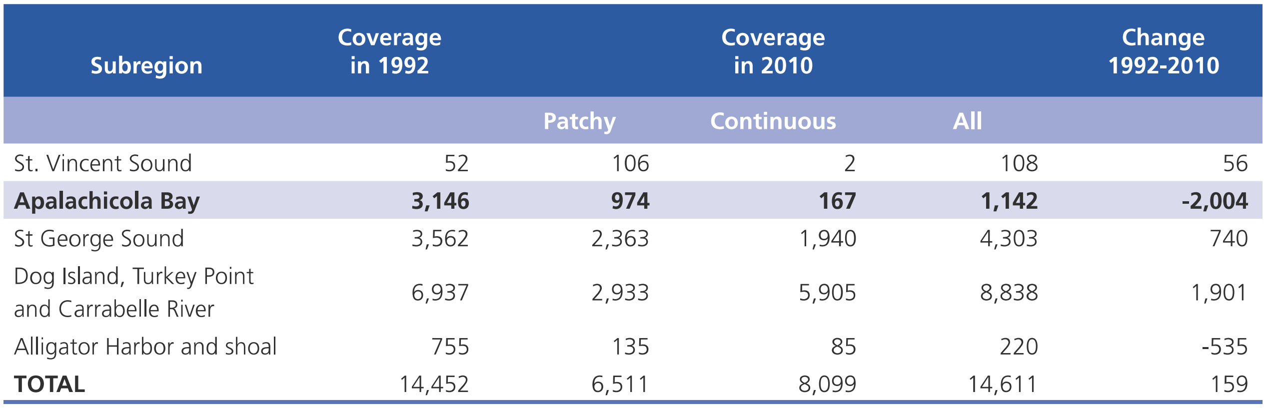
G. *Submersed Aquatic Vegetation (SAV) Also Declines With Flow Reductions*

61. Water quality effects from low flow that result in a change in total chlorophyll-*a* and a shift in phytoplankton composition in Apalachicola Bay also impact submersed aquatic vegetation—the other important primary producer at the base of the Apalachicola Bay food web.

62. Submersed aquatic vegetation, or SAV, are often used as indicator species of environmental conditions, especially freshwater inflow, because these rooted plants cannot move, and some species are very sensitive to changes in water quality. It is well established in the literature that SAV are an important nursery habitat for many species of fish and invertebrates and one key source of primary production. Its loss can directly impact the survival and growth of a number of species that rely on its abundance.

63. In Apalachicola Bay, loss of freshwater SAV in the East Bay region has been substantial and ongoing for some time. In 1984 it was estimated that East Bay alone had 3,541 acres of SAV and the Bay proper had an additional 2,778 acres. Substantial loses of SAV were seen during the 1999-2001 drought. (Edmiston 2008 (JX-29)) This indicates that low flows and increased salinity affected those freshwater SAV species – consistent with a wide array of literature on the impact of salinity to certain SAV species.

64. Large losses of SAV in East Bay were further observed as a result of the storm surge associated with Hurricane Dennis in 2005. This SAV did not recover for many years as flows remained relatively low, including during the drought year of 2007. (Livingston FDEP 2008 (FX-379)) By 2010, when an aerial survey was performed, SAV remained notably absent in East Bay as compared to prior surveys despite the fact that it had been five years since the hurricane. (*See* Table 6 and Yarbro & Carlson 2014 (FX-871)) Although salt-tolerant vegetation in areas further away from the River recovered to levels comparable to or beyond 1992 abundance, the SAV in Apalachicola Bay and especially East Bay, which cannot tolerate high salinities, did not see sustained recovery. Species in Apalachicola Bay suffer without the nursery habitat this SAV provides.



Subregion	Coverage in 1992	Coverage in 2010			Change 1992-2010
		Patchy	Continuous	All	
St. Vincent Sound	52	106	2	108	56
Apalachicola Bay	**3,146**	**974**	**167**	**1,142**	**-2,004**
St George Sound	3,562	2,363	1,940	4,303	740
Dog Island, Turkey Point and Carrabelle River	6,937	2,933	5,905	8,838	1,901
Alligator Harbor and shoal	755	135	85	220	-535
TOTAL	14,452	6,511	8,099	14,611	159

Table 6 *– Change in SAV coverage in acres in various surveyed regions of Franklin County, with Apalachicola Bay (which consists of East Bay and the central portion of Apalachicola Bay) highlighted. Note that Dog Island, Turkey Point and Carrabelle River sites, which saw expansion of SAV, are not directly influenced by flow from the Apalachicola River. The table is taken from Yarbro & Carlson 2014 (FX-871), and this is a true and accurate copy of the version presented in my report. (FX-789, Table 3.1)*

65. I am not surprised by this variation in recovery between the surveyed regions, especially since they vary in salinity. A difference in recovery between salt-tolerant species and the less tolerant species that inhabit Apalachicola Bay is expected. There are multiple factors that affect SAV growth and survival, but salinity is a key factor. It is well established in the scientific literature that high salinity will cause significant stress for some of the SAV species found in East Bay, the important nursery area. For instance, two studies have established that when daily average salinity values are over 18 (parts per thousand or ppt) reduced growth is observed in *Vallisneria americana*, the key freshwater plant in East Bay (Mazzotti et al. 2008 (JX-27)), and daily average values over 25 ppt can cause *Vallisneria* mortality (Moore 2012 (JX-32)). There is even evidence that salinities as low as just over 10 ppt can impact *Vallisneria* growth. As described above, in earlier years there was evidence of observed impacts to SAV tied to high salinity. The observed ANERR data show that in recent dry years salinity ranges increase to levels that likely cause significant impacts to SAV: the East Bay station shows salinities exceeding 18 ppt throughout the summer growing season for all

of 2011 and 2012 (shown in Figure 17, above). These high salinities not only inhibit growth, but they also inhibit seed germination and seed viability of the SAV species, the growth of which is important for a population to recover. Decreases in salinity, then, will provide relief from the extreme stresses SAV experience in the driest years.

66. Harm to the SAV in East Bay and the reduced possibility for recovery of these species is also compounded by several other factors related to the increases in phytoplankton biomass (chlorophyll-*a*) that I have established occur under low flow, as I describe above. The increase in phytoplankton biomass harms SAV in two main ways:

a. First, it reduces penetration of sunlight to the bottom of the estuary. Chlorophyll-*a* in the water absorbs light as it grows. By doing so, it reduces the total light that penetrates the water, reducing the amount of light that SAV can get at the bottom of the Bay. With less light, the submerged plants carry out photosynthesis more slowly and grow less. The levels of chlorophyll-*a* that are observed in East Bay during very low flows are at a level that established literature proves is detrimental to SAV (more than 15 $\mu g\ L^{-1}$). This effect is compounded by high salinities, which reduces the efficiency of photosynthesis in SAV.

b. Second, the reduced oxygen conditions resulting from low flows (described below) further impact SAV growth, including the rate at which seeds germinate and are viable. Seed germination is inhibited under low dissolved oxygen just as it is inhibited with high salinities. Thus, when SAV is lost due low flow, it faces many impediments to recovery. If seeds do not germinate or grow, neither do the plants.

67. As I describe above, all of these conditions (chlorophyll-*a,* dissolved oxygen and SAV growth) would improve with reductions in Georgia consumption.

III. CHANGES AT THE BASE OF THE FOOD WEB IMPACT SPECIES FURTHER UP IN THE FOOD WEB, INCLUDING OYSTERS

A. *Basic Estuarine Science Establishes that Changes in Nutrition Affect the Entire Food Web*

68. From basic nutrition science, we know that the nutrients we consume impact our metabolism. Basic ecological principles state that changes at the base of the food web reverberate up the food chain. Changes in primary producers, like phytoplankton, can change the quality and quantity of food for those species that eat those primary producers and they, in turn, may see reduced growth and reproduction. Species that, in turn, eat those species may decline as well. This is the effect of reduced flows on the Apalachicola Bay: the “upper trophic levels,” that is, higher-level, larger predators such as various fish and invertebrates, change as the microscopic food changes and salinity increases. Since food quality and salinity are both affected by flow (*see* Figure 5, above), and as Dr. Hornberger testifies Georgia’s consumption has a significant impact on flow, I expect Georgia’s consumption to have a significant impact on the entire food web.

69. Species at higher trophic levels, i.e., higher in the food web, are affected by changes in phytoplankton community composition in a number of ways:

a. First, different phytoplankton species have different chemical properties such as lipid composition, key fatty acids, and other chemical constituents which affect the nutrition obtained by the organisms that eat the phytoplankton. Some cyanobacteria are notably lacking some of these constituents so an increasing fraction of cyanobacteria in the diet can affect the growth of those organisms using these phytoplankton as food.

b. Second, different phytoplankton species have different proportions of the critical elements of nitrogen, phosphorus and carbon. Cyanobacteria have much more carbon relative to phosphorus than do diatoms; eating cyanobacteria is more of a “junk food” diet. Similarly, when decomposing plant material (detritus) serves as a significant food source rather than nutritious phytoplankton, the diet is high in carbon but proportionately lower in nutrients like nitrogen and phosphorus. This alters the metabolism and therefore growth rates of the grazers. There is a metabolic cost to a sustained poor diet. Just as it is more difficult for us to run a marathon on a diet of mostly Twinkies, so it is more difficult for oysters to survive on the "junk food" diet that occurs at low flow. In fact, fish that consistently eat detritus consume the least nutritionally balanced food and thus have lower growth rates than those fish that eat plankton or those that eat other fish.

c. Third, different phytoplankton species are of different sizes. Shifts to smaller and smaller-sized algae (picoplankton including picocyanobacteria), which is associated with low flows, shift the food to a size that many grazers simply cannot eat.

d. Fourth, the presence of toxins in harmful algae, many species of which proliferate at lower flows, can harm predators directly, altering their feeding rate, and, as described specifically for oysters below, the development and growth of larvae.

e. Fifth, different nutrient quality in the food can affect various life stages of species differently. Species' growth and survival are affected by changes in food quality: nutrition matters. Developing larvae and juveniles may have different nutritional needs than adults. For example, copepods, a type of grazing zooplankton that generally eat phytoplankton and that are abundant in Apalachicola Bay, require good quality food not only for their growth but for that of their young. Changes in the proportions of nutrients have effects on egg production or the viability of those eggs once they hatch. Declines in the copepod population can have severe impacts on higher trophic level species. Changes in the quality of food (as plankton or detritus) can also occur because flow affects the timing of when species occur in the estuary. Predator-prey interactions are also altered when food quality changes, and this can provide an advantage to one species over another. Mismatches between food availability and food quality affect the entire food web.

70. Oysters are particularly and continually challenged to maintain their nutrient balance, depending on the available nutrients in the water. Grazers such as oysters that take in their food simply by filtering water particles (the "filter feeders") are especially susceptible to changes in food quality. They have limited ability to selectively pick that which they want to eat. They cannot swim to a new reef to try to find better food. They have poor efficiency of capturing food of very small size. If the phytoplankton shift to a community without the appropriate nutrient balance, the oysters' physiology will experience stress. Oysters can reject food that they do not want by producing "pseudo-feces"; it is the oyster's way of spitting out food they do not like, and they primarily reject cyanobacteria and some dinoflagellates ("poor" food) and retain diatoms ("good" food). They also can release undigested or unpalatable food in their feces. Clearly, any food that is rejected, regardless of its nutrient content, cannot support growth.

71. Thus, food webs are not merely a reflection of the total amount of "food" available, but are an outcome of the quantity and quality of the food and the balance of nutrients therein. In the presence of increased salinity and more marine-like phytoplankton, I expect to see increases in the presence of marine fish and crustaceans. Not only has the habitat changed as flow has changed, for example there is less submersed aquatic vegetation in East Bay, but the changes in the overall phytoplankton composition have affected the overall quality of the food for the whole food web. As Dr. Livingston has explained, he has observed these kinds of changes in the food web during low flow years. (Livingston FDEP 2008 (FX-379)) A more recent study of fish and invertebrate species also concluded that flow and salinity are strongly tied to what type of community is observed in the

Bay. (Garwood et al. 2016 (FX-401)) There are numerous other studies that show that upper food web species change as flow changes. (*E.g.*, Gandy et al. (FX-402))

72. The interacting effects I describe early in my testimony underscore that effects due to nutrient and food quality changes are synergistic with stresses due to changes in salinity. (*See* interactions shown in Figure 5 above) The nutrient effects on species are exacerbated by changes in salinity that are a result of changes in flow. For instance, copepods, the zooplankton I describe above, require the right nutrients, but they also require the right salinity range for optimal egg production. (Putland 2007 (JX-23)) As the salinity regime changes due to Georgia consumption, as shown in Dr. Greenblatt's testimony, some species of zooplankton will be less able to thrive and others will flourish, changing the nature of the food web. Thus, reductions in flow cause not just stresses due to nutrients or stresses due to salinity, but these stresses occur in tandem, compounding the negative effects.

B. *Oysters Are Particularly Harmed by Multiple Environmental Changes Caused by Flow Reductions*

73. Oysters have been among the species most severely affected by flow reductions in the Apalachicola Bay. As Dr. Kimbro shows, the increases in salinity caused by Georgia consumption have caused increases in oyster predation and, to a lesser extent, disease, which stresses oysters. Any change in predation by its very definition is a change in the food web, and one that is particularly harmful given the importance of oysters to the ecology and economy of Apalachicola Bay. Oysters are also stressed by increases in temperature, which are similarly caused by reductions in freshwater flow.

74. Low flow causes additional stress to oysters through food web effects, described above. Oysters' rejection of poor quality food costs energy, affects metabolism, and so reduces oyster growth and reproduction. It is well-established through a variety of studies on Eastern oysters (*Crassostrea virginica*, the species found in Apalachicola Bay), including research undertaken by myself and colleagues, that oysters are selective feeders and reject poor quality food without digesting it. Studies have shown that oysters fed cyanobacteria have slower growth rates. Accordingly, data from Apalachicola Bay show that oyster spat production is lower following periods of low flow when cyanobacterial abundance is high. (*See* Figure 20)

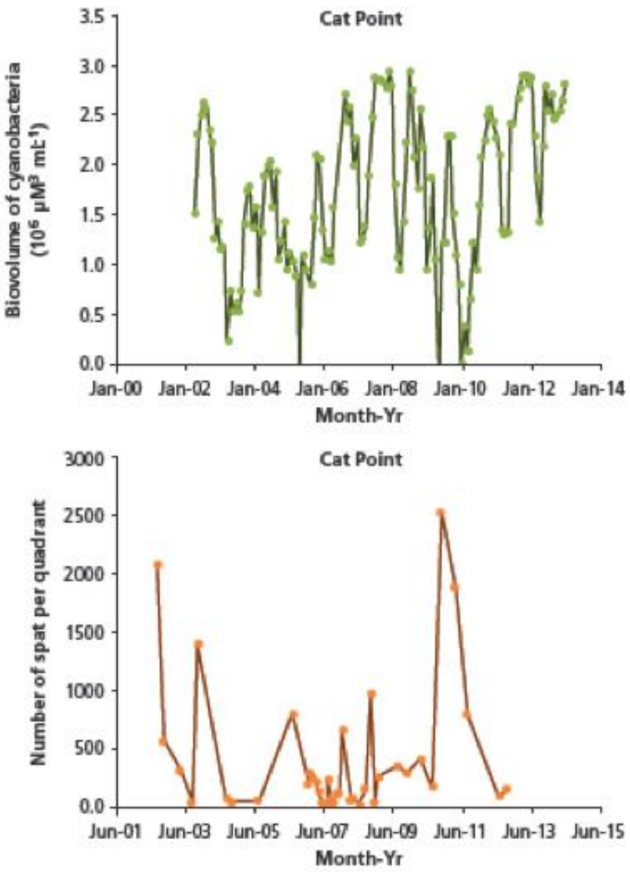


Figure 20 *– The estimated abundance of cyanobacteria at Cat Point, created using my calculated regression between flow and cyanobacteria, and the observed number of oyster spat (the tiny oyster young) from FDACS data. Note that there is generally an inverse relationship (with a time delay): when flows are low and cyanobacterial abundance is high, spat is low and vice versa. I created this figure for my report and testimony using generally scientifically accepted principles and methodology. This is a true and accurate copy of the figure presented in my expert report. (FX-789, Fig. 5.2)*

75. In addition to effects due to food quality, research, including some that I performed (Glibert et al. 2007 (FX-358)), has established that certain harmful algae toxins have severe effects on oyster larvae. Each of the major HAB species in Apalachicola Bay has been shown in laboratory studies to have direct effects on oyster feeding, oyster spawning or larval development. *Karenia brevis* and

Karlodinium veneficum toxins both cause larvae to become deformed and die because the toxins eat away at the cell membranes. (*See* Figure 21) The maximum concentration of *Karlodinium* cells reported by Dr. Phlips (Phlips Report 2016 (FX-359)) is certainly in the range where these effects have been observed under laboratory conditions. Additionally, when *Prorocentrum minimum* are abundant, again in the range of values reported by Dr. Phlips for 2011-2013, oyster spawning may not occur and such densities may also reduce the growth of larvae and juvenile oysters. As I have discussed above, the risk of these harmful algae proliferating in the Bay increases as flows decrease, and their maximum abundances in the recent data is many-fold higher than previous records have indicated. Even the toxic *Pseudo-nitzschia*, which too has increased during the very low flow years, affects oysters, which increase their pseudofeces production in response, costing them additional energy and harming their growth.

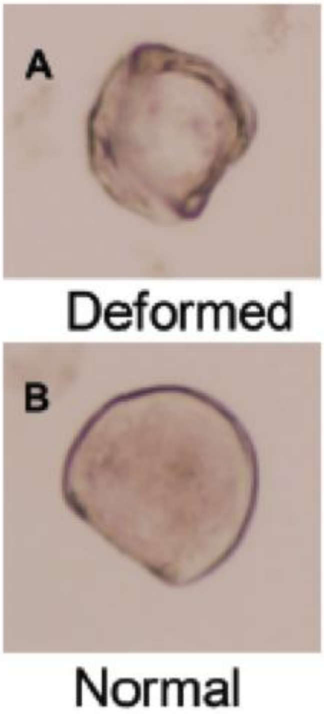


Figure 21 *– Photomicrograph of oyster larvae (*Crassostrea virginica*, the same species found in Apalachicola Bay) exposed immediately after spawning to the toxic algae species* Karlodinium venificum *at 10,000 cells per liter for 48 hours. The bottom image shows a normal "D-hinged" larva not exposed to the toxin. This figure is a true and accurate copy of a figure from Glibert et al. 2007 (FX-358) and my expert report (FX-789, Fig. A6.1).*

76. Lastly, when oyster growth is slowed due to poor nutrition, it increases the susceptibility to additional stressors. Larvae may take longer to develop. Disease resistance is reduced. In all, oysters become increasingly stressed as flow decreases; stress begets stress. As I have explained above, increased flows would (in addition to reducing salinity) reduce

the amount of “bad” food in the water, as well as reduce the risk of toxic algae – and so reduce the stress on oysters.

IV. THE LOSS OF OYSTERS CONTRIBUTES TO FURTHER ECOLOGICAL DEGRADATION

77. The oyster is a foundational species for the Apalachicola Bay; its importance is disproportionate to its abundance. It is an ecological engineer, and by that I mean that it is so important in the ecosystem that it ‘engineers’ many aspects of the ecology. The oyster population offers a variety of important ecosystem services to Apalachicola Bay, and its rapid decline in 2012 and failure to recover reinforces the negative effect of flow reductions through negative feedback interactions.

78. First, oysters help maintain water clarity by filtering high volumes of water. Without oysters, particulate material in water, including phytoplankton, is not filtered out. Rather, it accumulates, which – as I have described above – leads to reductions in light penetration, and reductions in dissolved oxygen as phytoplankton die off and are decomposed rather than consumed. With fewer oysters in the Bay, harmful accumulations of phytoplankton are expected to occur even more frequently, especially as Georgia’s consumption increases and flows are reduced further.

79. Second, oysters play an important role in nitrogen cycling. They remove nutrients, and oyster reefs promote conditions that allow excess nitrogen to be removed as gas, a favorable process termed denitrification. (*See* Figure 22) Without this pathway, more nitrogen remains in the system that is then used by phytoplankton to grow and bloom, leading again to eutrophication, shading, and low dissolved oxygen, as explained above. Oysters help to maintain the right balance of nutrients through their associated microbial processes, and while too little nutrients can limit production, too much reinforces eutrophication.

80. Third, oysters, by their very shells, create hard substrate oyster reefs. Oyster reefs are important substrate for oyster larval settlement, and they provide habitat for many other species—in Apalachicola Bay, those include mussels, barnacles, macroalgae, shrimp, crabs, and fish such as flounder and sea bass. Moreover, the enhanced accumulation of phytoplankton in the water column, a consequence of reduction in filter feeding and of changes in growth due to low-flow conditions, leads to deposition of dead plankton material on the bottom, silting over available substrate for the oyster settlement of the next generation. Without sufficient oyster reefs, larvae have more difficulty settling, and negative effects on the population are self-reinforcing.

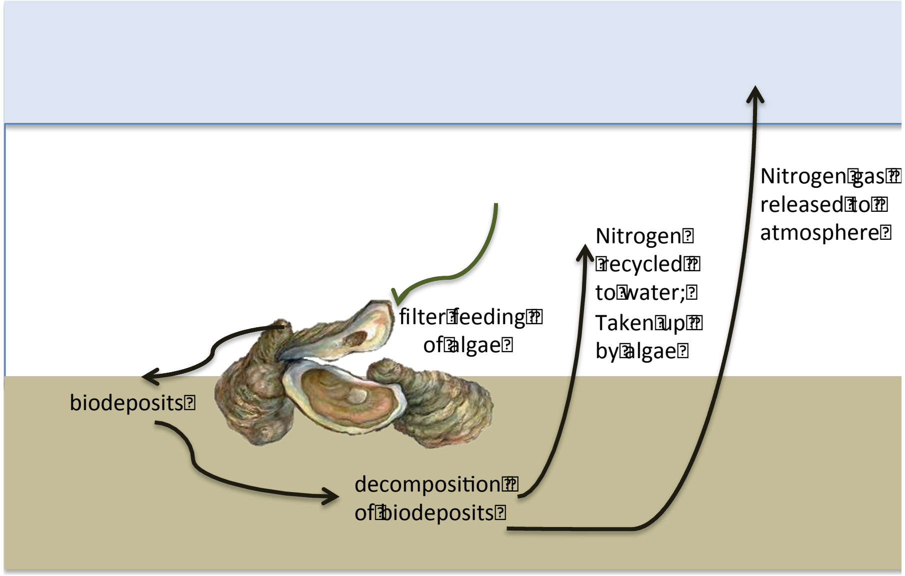


Figure 22 *– Diagram of oyster-related nitrogen cycling in the water, sediment and atmosphere. Oysters filter feed algae, release some of this food as biodeposits (feces and pseudofeces). Bacteria decompose these biodeposits, converting some of the nitrogen back to a form (mostly ammonium) that is again used by algae, but some is released to the atmosphere as nitrogen gas, the favorable process of denitrification. I created this conceptual diagram or my report and testimony based on generally scientifically accepted principles. It reflects a simpler version of figures presented in my report. (FX-789, Fig. 6.2-Fig. 6.3)*

V. DEGRADATION OF THE APALACHICOLA BAY COULD LEAD TO PERMANENT HARM, BUT INCREASED FLOWS WILL AVOID THIS OUTCOME AND HELP RESTORE ECOSYSTEM HEALTH

81. The evidence I have evaluated from Apalachicola Bay, including evidence on flow, water quality, phytoplankton, and oyster spat, as well as literature on estuarine ecology, all show that Apalachicola Bay is an estuary that is in decline as flows have been declining. The Bay has been in a less productive state in the recent years of critically low flow. Its ecology is being altered substantially by reduced flows, and it has become less productive and less able to sustain fisheries, especially during low flows that are exacerbated by Georgia. As Dr. Hornberger shows, low flows of longer duration and lower magnitude are predicted to continue to occur, and occur more frequently, in a future with unchecked Georgia consumption. If that happens, the Bay will decline further and show increasingly more characteristics of a low-flow estuary.

82. Harm to the Bay from reduced flows, as I have described here, includes harm resulting from increases in residence time; increases in salinity; changes in chemical nutrients, especially nitrate declines (absolutely and relatively); increases in hypoxia and anoxia in East Bay; changes in the phytoplankton community to less nutritious cyanobacteria; increased habitat suitability for harmful algae; loss of submersed aquatic vegetation and its nursery habitat; changes in the upper food web towards more marine species; and the loss of oysters and their ecosystem services. (*See* summary Figure 23) These changes, caused in large part by Georgia's consumption, are not isolated, but rather reinforce each other, meaning that even relatively small declines in flow can have disproportionately large effects.

83. The changes that I have described are not unexpected. Not only are they a direct result of fundamental biological and chemical changes, but such pathways of change have long been known from fundamental ecology. In fact, such changes were foretold decades ago by Mr. Robert Estabrook (1973) in his research on phytoplankton in the Bay, when he stated, "…further controls on restricting the water exchange of the Apalachicola River could result, not only in increased salinities which would adversely affect the oyster industry, but decreased flushing rates with the resultant possibility of a build-up of a high phytoplankton biomass. . . . But the problem lies in the fact that excessive

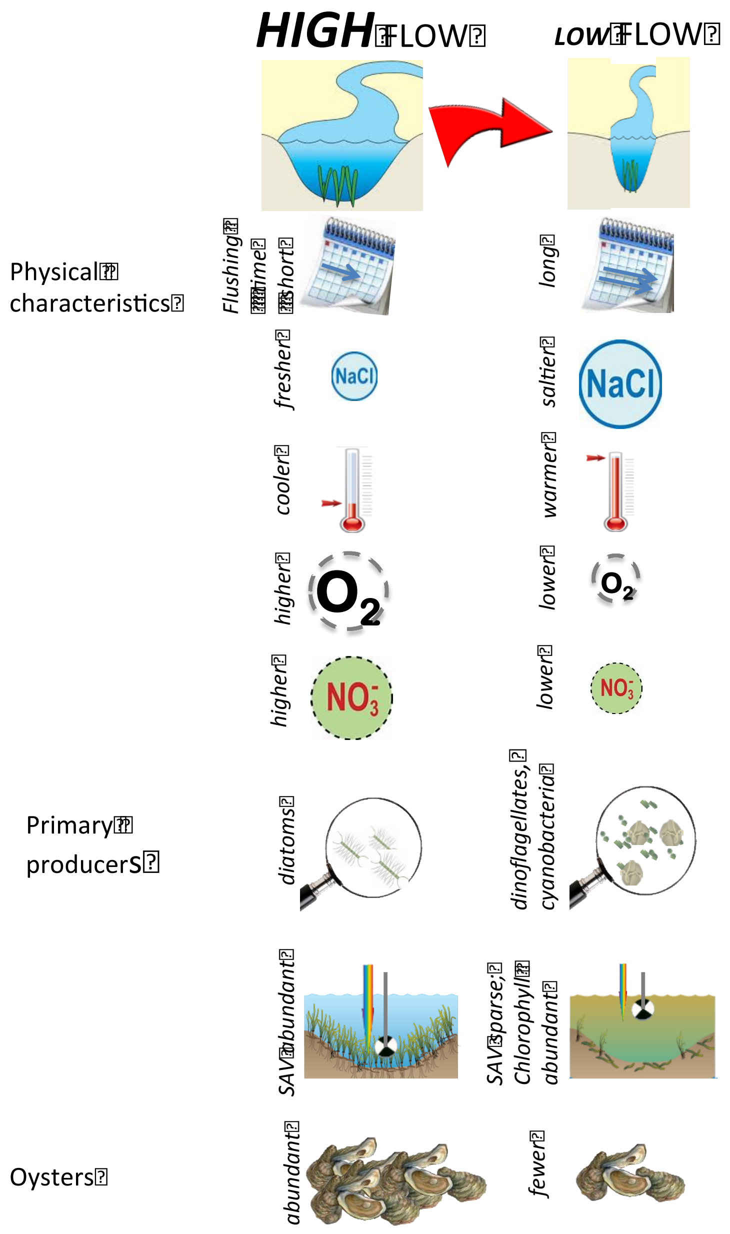


Figure 23 *– Summary conceptual sketch of the major changes in physical factors, primary producers and oysters when flow is reduced. I created this summary figure for my testimony based on generally scientifically accepted principles. It is based on graphics and symbols used in my report (FX-789).*

concentrations of nutrients often leads to a succession in phytoplankton from diatoms to greens and blue–greens [cyanobacteria].” (JX-142) The intervening decades have shown this prediction to be borne out. The collective data are robust, and the magnitude of the changes, especially of flow, are great. While estuaries are dynamic and resilient, there is a limit to estuarine resiliency. Since the key characteristic of an estuary is the meeting of freshwater and salt water, reductions in freshwater change the nature of an estuary. When naturally stressful periods of low flow are exacerbated by human consumption, as here, an estuary can be stretched beyond its capacity and experience disproportionately large effects such as the oyster crash observed in Apalachicola Bay. As noted in a paper co-authored by Georgia’s expert, Dr. Menzie, “[r]esponses to stressors can be nonlinear” and “[t]olerance (both physiological acclimation and evolution) needs to be considered” when evaluating an ecosystem’s response to stressors. (Landis et al. 2013 (FX-632)) In East Bay especially, the data show that eutrophication, hypoxia, and anoxia occur during extreme low flows, indicating that there are harmful ecological changes during low flows exacerbated by Georgia consumption. And, the longer stressful low-flow conditions are maintained as a result of upstream consumption, the more difficult it comes for Apalachicola Bay to stabilize and recover. Thus, this degradation and shift in character of the Bay could lead to permanent harm to the Bay ecosystem.

84. Additional flows would help avoid permanent damage and restore ecosystem health by improving nutrient loads, decreasing residence time, and improving the phytoplankton community composition. Just like negative changes can cause negative feedback loops, positive changes can also combine to synergize to provide large improvements even with relatively small increases in flow. For instance, even modest improvements in flow may be sufficient to reduce the phytoplankton accumulation and low dissolved oxygen in East Bay, allowing for improved establishment and growth of submersed aquatic vegetation that will help to restore East Bay’s

nursery function. Improvements in flow will also alter the proportion of different forms of nitrogen, favoring the growth of nutritious diatoms over cyanobacteria.

VI. DR. MENZIE'S ANALYSES DO NOT CAST DOUBT ON MY WORK

85. As part of the preparation of my testimony, I reviewed the work of Georgia's ecological expert, Dr. Charles Menzie, who has raised various criticisms about my evaluation in his expert report. In this section, I will explain why his analyses are incorrect and do not undermine my analyses.

86. On nutrients, Dr. Menzie has said that the floodplain is an important source of nutrients for the Bay, in the form of particulate organic matter and decomposing plant matter (detritus). While there is no doubt that this organic matter and other food sources play a role in the food web, they cannot replace the importance of dissolved nutrients that are delivered with River flow and the primary production that depends on these nutrients. As I described in Section II, the decomposing plant matter is not the preferred source of nutrients for many key species, and it is less nutritious.

87. Dr. Menzie also opined that dissolved oxygen reductions are not caused by phytoplankton blooms during low flow periods, pointing to his own observations on a single day at two creeks in Tate's Hell. However, Dr. Menzie did not take into consideration the change in dissolved oxygen between day and night, and merely sampled at a single point in time during a high-flow season. Thus, Dr. Menzie's sampling does not yield any insight into these important dynamics. Dr. Menzie in his report then attempts to use this single sampling trip to suggest that these observed reductions in dissolved oxygen are not primarily caused by low flows, but rather by low-oxygen water coming in from the Tate's Hell marshland around East Bay. He suggests that because the water from Tate's Hell is rich with humic material (colored organic matter, such as decaying plant debris), it is that

bacterial degradation of this material, not material from the excessive algae growth, that results in low oxygen. There are several flaws with this logic.

a. First, although Tate's Hell may be a source of humic material during high flow periods, much less humic material would be delivered to East Bay during low flow. During my visit to East Bay, for example, I observed no evidence of humic, or tea-stained water, as Dr. Menzie found during his visit during a comparative high flow period. Hypoxic and anoxic waters are predominantly recorded during the late, low-flow season—which is not the time during which most of the humic water comes in.

b. Dr. Menzie only measured hypoxic water in the upper Tate's Hell creeks and his measurements did not show associated low oxygen water simultaneously in East Bay. For that low oxygen water to reach East Bay, it would have to flow out from the creeks. In that process the water would likely be re-oxygenated as it meanders and mixes through the creeks.

c. Dr. Menzie's hypothesis that the freshwater creeks are a source of low dissolved oxygen would also suggest that when there are episodes of lower dissolved oxygen, there is more flow from those creeks, which would result in lower salinity. However, as I showed in the data presented above (*See* Figure 17) the opposite is the case: when low dissolved oxygen occurs at the East Bay station, salinities are *higher* than average, not lower, which means there is a lack of freshwater flow from either the creeks or the River.

d. The data show large dissolved oxygen swings between day and night, consistent with a pattern of eutrophication. Because this time-of-day variation is shown at all stations in the Apalachicola Bay (but to a greater extent in East Bay), it is clearly unrelated to runoff from Tate's Hell, which flows both during the day and at night. Dr. Menzie does not consider in his report the effect of these nighttime sags in dissolved oxygen.

88. Although Dr. Menzie does not deny that phytoplankton accumulation occurs, he opines that there is no evidence that phytoplankton accumulation has caused shading. This opinion, however, contradicts fundamental laws of light absorption (the physics of photosynthesis): if there are more phytoplankton, they absorb more light, and less light is left for the submersed aquatic vegetation. Since Dr. Menzie does not deny that there are more phytoplankton at lower flows, it is contrary to physics to claim there would not also be reduced light for the vegetation on the bottom.

89. While Dr. Menzie opines that cyanobacteria are not dominant at low flows, his own analyses of these data show the same trends as mine. Dr. Menzie, too, found there are more cyanobacteria at low flows. Dr. Menzie puts this very succinctly himself when he states that "diatoms will typically bloom in spring and early summer when water temperatures are still relatively low… In the summer, temperatures are highest and river flow is typically at its lowest. … cyanobacteria tend to dominate as they are suited to warm temperatures and low nutrient levels." It follows that Georgia's consumption, exacerbating the effects of low flows, will unnaturally increase the amount of cyanobacteria. This is indeed what was observed in recent studies. (*See* Viveros Bedoya Thesis 2014 (JX-15) and Phlips Report 2016 (FX-359))

90. Dr. Menzie critiqued my phytoplankton historical analysis in his report, but in so doing revealed that he has only limited knowledge of phytoplankton taxonomy. He highlighted that the 1973 study observed a freshwater species of *Asterionella formosa* and then mistakenly stated that the presence of a different species observed in 2014, *Asterionella glacialis,* is evidence that this freshwater phytoplankton species continued to be found. However, *Asterionella glacialis* is a marine species, and its presence (among other marine species) in recent years – but absence in the

1970s – is, in fact, evidence of a shift to more marine species that one would expect with rising salinity due to lower flows.

91. Dr. Menzie has stated he has not found evidence of harmful algae in Apalachicola Bay that can be tied to lower flows. However, his analysis of harmful algae in Apalachicola Bay focused exclusively on *Karenia brevis*, the “Florida red tide.” This suggests that he failed to consider the complexity and diversity of the harmful algae problem that has developed in the Bay as flows have been reduced, including for instance blooms of *Pseudo-nitzschia*.

CONCLUSION

92. In sum I have shown that changes in flow affect numerous physical features important to Bay ecology, including residence time, salinity, temperature, dissolved oxygen and nutrient concentrations and forms. (*See* Figure 23 above) These in turn affect the primary producers, including the phytoplankton and the SAV. Their abundance and composition affect the entire food web, including the prized oyster populations. Reductions in flow have caused, and further reductions in flow will cause, significant harm to the food web. Improved flows will help stabilize and restore the Apalachicola Bay ecosystem closer to its historic state.

93. If Georgia consumption is not curbed, the ecology and food web of the Bay will continue to see declines in productivity and will likely be harmed permanently. However, restoration of flows will provide meaningful ecological benefits, in particular to East Bay, the important nursery area. Just as ecological damage due to reduced flows is multipronged and synergistic, so too can be the positive effects with restored flows. Effects at the bottom of the food web, both positive and negative, reverberate throughout the system.

ATTACHMENT – LIST OF EXHIBITS CITED

- JX-11: This is a true and accurate copy of an article on nitrogen in Apalachicola Bay by Behzad Mortazavi and others, titled *Dissolved organic nitrogen and nitrate in Apalachicola Bay, Florida: spatial distributions and monthly budgets*, published in 2001 in the journal *Marine Ecology Progress Series*, a journal regularly relied upon by marine biologists and ecologists. This article is publicly available, and I relied upon this article to inform my opinions.

- JX-15: This is a true and accurate copy of a doctoral dissertation on phytoplankton in Apalachicola Bay, titled *The Impacts of Temporal Shifts in River Discharge on Phytoplankton Biomass in Apalachicola Bay, FL*, written by Dr. Paula Viveros Bedoya in 2014, as produced to Georgia by Florida. This thesis contains data and analysis frequently relied upon by marine biologists and ecologists, and I relied upon this article to inform my opinions.

- JX-16: This is a true and accurate copy of a doctoral dissertation on plankton in Apalachicola Bay, titled *Ecology of Phytoplankton,* Acartia tonsa*, and Microzooplankton in Apalachicola Bay, Florida*, written by Dr. Jennifer Putland in 2005, as produced to Georgia by Florida. This thesis contains data and analysis frequently relied upon by marine biologists and ecologists, and I relied upon this article to inform my opinions.

- JX-23: This is a true and accurate copy of an article on zooplankton, titled *Ecology of* Acartia tonsa *in Apalachicola Bay, Florida, and implications of river water diversion*, by J.N. Putland and R.L. Iverson, published in 2007 in the *Marine Ecology Progress Series*, a journal regularly relied upon by marine biologists. This article is publicly available, and I relied upon this article to inform my opinions.

- JX-27: This is a true and accurate copy of a 2008 University of Florida article, titled*Stressor* Response *Model for Tape Grass* (Vallisneria Americana), by Frank J. Mazzotti and others discussing *Vallisneria americana*, and is part of a series of published papers by University researchers, which are typically relied upon by experts in my field. This article is available online at http://edis.ifas.ufl.edu/pdffiles/uw/uw28100.pdf, and I relied on it to further support my opinions.

- JX-29: This is a true and accurate copy of an official 2008 Apalachicola National Estuarine Research Reserve (ANERR) report by Lee Edmiston, titled *A River Meets the Bay*, available online at http://www.dep.state.fl.us/coastal/downloads/management_plans/ A_River_Meets_the_Bay.pdf. This work contains biological data and summaries typically relied upon by biologists and ecologists, and I relied upon this document to inform my opinions.

- JX-32: This is a true and accurate copy of an Appendix on submerged aquatic vegetation to an official Florida government (St. Johns Water Management District) report from 2012, titled *Appendix 9.B. Submerged Aquatic Vegetation (SAV) in the Lower St. Johns River and the Influences of Water Quality Factors on SAV*. This report is available online at http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ2012-1_Appendix09-B.pdf. It contains biological data typically relied upon by experts in my field, and I relied on it to further support my opinions.

- JX-128: This is a true and accurate copy of the gage data from near Sumatra, FL, published by the United States Geological Survey (USGS). Such data is typically relied upon by experts in my field, and I relied upon it to inform my opinions.

- JX-136: This exhibit is an online database containing official Apalachicola National Estuarine Research Reserve (ANERR) water quality data, including salinity, nutrients, and chlorophyll-a. I downloaded various data on different parameters, dates, or stations from the link provided, http://cdmo.baruch.sc.edu/, at various dates between August 2015 and January 2016, as well as between June and July 2016. Such data is typically relied upon by experts in my field, and I relied upon it to inform my opinions.

- JX-142: This is a true and accurate copy of a master's thesis on phytoplankton in Apalachicola Bay, titled *Phytoplankton Ecology and Hydrography of Apalachicola Bay*, written by Mr. Robert Estabrook in 1973, as produced to Georgia by Florida. This thesis contains data and analysis frequently relied upon by marine biologists and ecologists, and I relied upon this article to inform my opinions.

- FX-266b: Described in text.

- FX-266e: Described in text.

- FX-358: This is a true and accurate copy of an article, titled *Harmful Algae Pose Additional Challenges for Oyster Restoration*, authored by myself and others, published in 2007 in the *Journal of Shellfish Research*, a publication regularly relied upon by marine biologists. This article is publicly available, and I relied upon this article to inform my opinions.

- FX-359: This is a true and accurate copy of a 2016 report, titled *Mass Oyster Mortality and Phytoplankton Composition in Apalachicola Bay: Is There a Link?*, by Dr. Edward Phlips and others on phytoplankton in the Bay, which I understand came into the possession of Florida in the summer of 2016 and which Florida subsequently produced to Georgia. It contains data and analysis typically relied upon by marine biologists, and I relied upon it to further support and confirm my opinions.

- FX-360: This is a true and accurate copy of an article, titled *Recommended Indicators of Estuarine Water Quality for Georgia*, discussing estuarine water quality in Georgia by Joan E. Sheldon and Merryl Alber, published in the *Proceedings of the 2011 Georgia Water Resources Conference*, a publication regularly relied upon by experts in my field. This article is publicly available, and I relied upon this article to inform my opinions.

- FX-379: This is a true and accurate copy of an official 2008 Florida Department of Environmental Protection report by Dr. Robert Livingston, titled *Importance of River Flow to the Apalachicola River-Bay System*, as produced to Georgia by Florida, containing biological data and analyses. Such reports are frequently relied upon by experts in my field, and I relied upon it to inform my opinions.

- FX-401: This is a true and accurate copy of a 2016 article by Jason Garwood and others of the Apalachicola National Estuarine Research Reserve, titled *Season, Salinity, and Bottom-Type Characterize Nekton Communities in Apalachicola Bay, Florida*, pending publication, as produced to Georgia by Florida. This article contains biological data and analysis typically relied upon by marine biologists and ecologists, and I relied upon it to inform my opinions.

- FX-402: This is a true and accurate copy of an official 2011 Florida Fish and Wildlife Conservation Commission (FWC) report, titled *Review of the Biology and Population Dynamics of the Blue Crab,* Callinectes sapidus*, in Relation to Salinity and Freshwater Inflow*, by R.L. Gandy and others. It is available online at http://www.swfwmd.state.fl.us/projects/mfl/reports/Chass_Appendices/Section_11.16.pdf, and I relied upon it to further support my opinions.

- FX-632: This is a true and accurate copy of an article titled *Ecological Risk Assessment in the Context of Global Climate Change*, by Wayne G. Landis and others, published in 2013 in the journal *Global Climate Change*. This is a publication typically relied on by experts in my field, and I relied on this article to further support my opinions.

- FX-785: This is a true and accurate copy of Dr. George Hornberger's report as submitted by Florida to Georgia on February 29, 2016. Marine biologists and ecologists frequently cooperate with and rely upon hydrologists, and I relied upon Dr. Hornberger's work to inform my opinions.

- FX-786: This is a true and accurate copy of Dr. Sam Flewelling's report as submitted by Florida to Georgia on February 29, 2016. Marine biologists and ecologists experts frequently cooperate with and rely upon hydrologists, and I relied upon Dr. Flewelling's work to inform my opinions.

- FX-789: This is a true and accurate copy of the expert report that I prepared for this case, as submitted by Florida to Georgia on February 29, 2016.