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 DAVID KIMBRO, PH.D.

PAMELA JO BONDI
ATTORNEY GENERAL, STATE OF FLORIDA

JONATHAN L. WILLIAMS
DEPUTY SOLICITOR GENERAL
JONATHAN GLOGAU
SPECIAL COUNSEL
OFFICE OF THE ATTORNEY GENERAL

FREDERICK L. ASCHAUER, JR.
GENERAL COUNSEL
FLORIDA DEPARTMENT OF
ENVIRONMENTAL PROTECTION

GREGORY G. GARRE
Counsel of Record
PHILIP J. PERRY
CLAUDIA M. O'BRIEN
ABID R. QURESHI
JAMIE L. WINE
LATHAM & WATKINS LLP
555 11th Street, NW
Suite 1000
Washington, DC 20004
Tel.: (202) 637-2207
gregory.garre@lw.com

PAUL N. SINGARELLA
LATHAM & WATKINS LLP

CHRISTOPHER M. KISE
JAMES A. MCKEE
ADAM C. LOSEY
FOLEY & LARDNER LLP

MATTHEW Z. LEOPOLD
CARLTON FIELDS JORDEN BURT P.A.

ATTORNEYS FOR THE STATE OF FLORIDA

October 26, 2016

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A. Introduction and Overview

1. My name is David Kimbro and I am an Assistant Professor in the Department of Marine and Environmental Sciences at Northeastern University. I was trained as an experimental ecologist and I have several years of professional research and teaching experience. In my research, I use experiments and observations to understand the effects of the natural environment and human activities on nursery habitats in estuaries such as salt marshes, seagrasses, and oyster reefs. I am connected to this litigation because much of my research has focused on oyster reefs in estuaries on all three coastlines of the United States.

2. Specifically, I was asked by the State of Florida to conduct a four-year research study to determine the cause of the collapse of an oyster fishery (the Eastern Oyster, *Crassostrea virginica*) in Apalachicola Bay, Florida, which occurred around the summer of 2012.

3. From 2013-2016, I used a three-pronged approach to investigate this oyster fishery collapse: (a) observations, (b) experimentation, and (c) mathematical modeling.

4. I concluded that the cause of the oyster fishery collapse in 2012 was a reduction in freshwater from the Apalachicola River into Apalachicola Bay. This reduction allowed high salinity conditions to develop and in turn promoted oyster disease, oyster predators, and oyster recruitment failure. The abnormal abundance of predatory snails in Apalachicola Bay is illustrated below in Figures 1–2.

Figure 1. Photo taken by Dr. Kimbro on board a State of Florida research vessel to evaluate Apalachicola Bay's oyster population in October 2012. Mark Berrigan (left) and a typical oyster sample collected that day (center). Inset highlights sample with an abnormally high abundance of predatory snails and gaping oysters that had been eaten by the snails. Yellow oval highlights 1 of 8 snails in this sample.

Figure 2. Image taken by Dr. David Kimbro of predatory snails during an experiment in Apalachicola Bay. This experimental unit contained nine adult snails. In addition, it was covered by egg capsules laid by the snails (left portion of picture). Each capsule (100s per experimental unit) contained approximately 2,500 eggs. This image was common throughout all zones of Apalachicola Bay in May 2013.

5. Other scientists and scholars—including federal and state government scientists—reached similar conclusions.

a. For example, in September 2012, Dr. Laura Petes, a research scientist with the National Oceanic and Atmospheric Association (NOAA), concluded that the reduced freshwater input and "[c]onditions in 2011 and 2012 have primarily occurred within ranges that are moderately or extremely stressful for oysters, which typically lead to oyster mortality and increased predation pressure." Attached as FX-412 is a true and accurate copy of the research memorandum prepared by Dr. Petes in connection with her work at NOAA. I reviewed this memorandum in connection with my investigation of the 2012 collapse and it is the type of material that a research ecologist considers when conducting a study.

b. In August 2013, other NOAA scientists concluded that, "the physical (high salinity) and biological (increased predation and natural mortality) environmental issues have played a more central role in the declines to the oyster stock in this area." Attached as FX-413 is a true and accurate copy of the memorandum prepared by these scientists at NOAA. I reviewed this memorandum in connection with my investigation of the 2012 collapse and it is the type of material that a research ecologist evaluates when conducting a study.

c. In August 2013, the Florida Fish and Wildlife Conservation Commission prepared a report that evaluated the causes of the 2012 fishery collapse. The report concluded that, "The cause of the oyster decline is a lack of freshwater flow into rivers and estuaries. . . . Due to lack of freshwater input, salinities on oyster fishing grounds have significantly increased resulting in "poor" conditions for oyster growth and survival since May 2011. Prolonged relatively freshwater conditions, typical of estuaries have not been observed since at least February 2010, resulting in increased predator abundance, increased disease and decreased nutrition." Attached as JX-91 is a true and accurate copy of the Report prepared by FWC. I reviewed this Report in connection with my investigation of the 2012 collapse and it is the type of material that a research ecologist considers when conducting a study.

d. In 1992, Dr. Dara Wilber, a research scientist with the Northwest Florida Water Management District, published research that suggested low discharge of freshwater from the Apalachicola River reduced the commercial production of oysters two years later. Dr. Wilber hypothesized that this reduction was caused by elevated water salinity and the proliferation of oyster disease and predators.

e. In 2000, Dr. Robert Livingston, a professor at Florida State University, published research results that supported Dr. Wilber's research. When water salinity increased in Apalachicola Bay, Dr. Livingston observed significant mortality of oysters caused by predation and to a lesser extent disease.

f. I conducted research and analyses independent of these other scientists so that no conclusions were predetermined before I began.

6. In addition to being consistent with the findings of other scientists, my conclusions are consistent with the experience of a seafood business owner in Apalachicola, Florida, as explained in Mr. Tommy Ward's testimony. This individual owns oyster leases in Apalachicola Bay that have been profitable for generations and closed to the commercial fleet of oystermen. But in 2012, the oyster production of these private leases collapsed. Because these private leases were exposed to high salinity conditions and a large abundance of predatory snails

(also commonly referred to as conchs)—but not to the commercial fleet of oystermen—my overall conclusion can explain the simultaneous collapse of public and privately owned oyster reefs in Apalachicola Bay.

7. I predict that the oyster fishery in Apalachicola Bay can recover if a sufficient amount of freshwater is discharged from the Apalachicola River, because sufficient discharge prevents the prolonged periods of high water salinity that promote the proliferation of disease and predators. If a proper amount of discharge from the Apalachicola River is combined with additional restoration efforts (e.g., re-shelling of commercial oyster reefs), then I believe the oyster fishery in Apalachicola Bay can regain its status as one of the most productive oyster fisheries in the United States.

8. Below, I will first describe my professional background. I will then provide background on the oyster fishery in Apalachicola Bay and the importance of oyster reefs for the health of estuaries. Next, I will describe my research approach and the results that led me to my conclusions. Finally, I will discuss a solution to this environmental problem in Apalachicola Bay.

B. Professional Background

9. I am an Assistant Professor in the Department of Marine and Environmental Sciences at Northeastern University. At Northeastern University, I conduct ecological research, teach an undergraduate level course in Ecology, and teach a graduate-level course in Experimental Design and Statistical Analysis. I obtained a Masters of Science (2004) and a Ph.D (2008) in Ecology from the University of California at Davis, which was ranked #1 in the 2006 Graduate Program Rankings for Ecology and Evolution managed by the U.S. News and World Report (currently ranked as the #3 program).

10. Since 1998, I have used experimental and observational approaches to examine the effects of the environment and predators on estuarine habitats such as oyster reefs, salt marsh

meadows, and seagrass beds. As a result of this experience, I have authored 24 publications in some of the highest ranked journals in my field such as *Ecology Letters*, *Ecology*, and *Proceedings of the Royal Society of London B: Biological Sciences*. My research results have been used by the National Park Service (Point Reyes National Seashore in California and the Oceans Program Coordinator of the Southeast Region) to design oyster conservation and restoration strategies. In my short career, I have served on several scientific panels including the Alternate Ballast Water Exchange Areas: Physical and Biological Oceanographic Considerations (Pacific States Marine Fisheries Commission); the Florida State University panel on the impacts of the Deepwater Horizon oil spill (sponsored by the National Science Foundation); and the University of Florida Oyster Recovery Team (sponsored by Florida SeaGrant).

C. The Apalachicola Bay Oyster Fishery

11. For centuries, estuaries have contained oyster populations that provided many benefits to humans, known as ecosystem services. One of these services includes the commercial harvest of oysters, which is highlighted in Figure 3.

12. Oyster populations in the northern Gulf of Mexico have maintained the highest catch of wild oysters in the world. In the northern Gulf of Mexico, Apalachicola Bay, FL was one of only two U.S. estuaries estimated to have stable oyster biomass over the past 100 years.

13. The stability of the Apalachicola Bay fishery was attributed to the state's management of this natural resource, which is unique because it mandates that oysters can be harvested only by hand tongs on public oyster reefs. In contrast, other states' management agencies have allowed oysters to be harvested with more efficient and destructive methods such as patent tongs and mechanical dredges.

14. Oyster tongs are 12–18 feet long with a rake-like end that is composed of pointed "teeth." The pointed teeth are spaced approximately 1 inch apart so that smaller oysters and reef

material can fall through the teeth and back into the bay during the extraction of legal-sized oysters (3 inches).

15. Because oyster tongs are extremely heavy, harvesting oysters in Apalachicola Bay is a physically demanding procedure that limits harvesting efficiency and structural damage on oyster reefs.

16. Apalachicola oysters are a recognized commodity throughout the state and the nation. Apalachicola Bay has historically provided 90% of the total oyster catch in Florida, and 10% of the catch nationwide.

17. Apalachicola oysters have also been recognized for the quality of their taste. For instance, Apalachicola oysters have been featured on high-end restaurant menus throughout the southeast United States. News of Apalachicola oysters and its surrounding culture are also regularly reported in national media outlets such as the Washington Post, Garden and Gun magazine, Boston Globe, New York Times, Bangor Daily News, the Gravy podcast of the Southern Foodways Alliance at the University of Mississippi, and National Geographic.

D. The Ecological Significance of Oysters

18. In addition to being a species with a commercial harvest value, the Eastern oyster is a species that is critical for the maintenance of a healthy estuary ecosystem, as explained in the testimony of Dr. Glibert. Each of these services is illustrated in Figure 3.

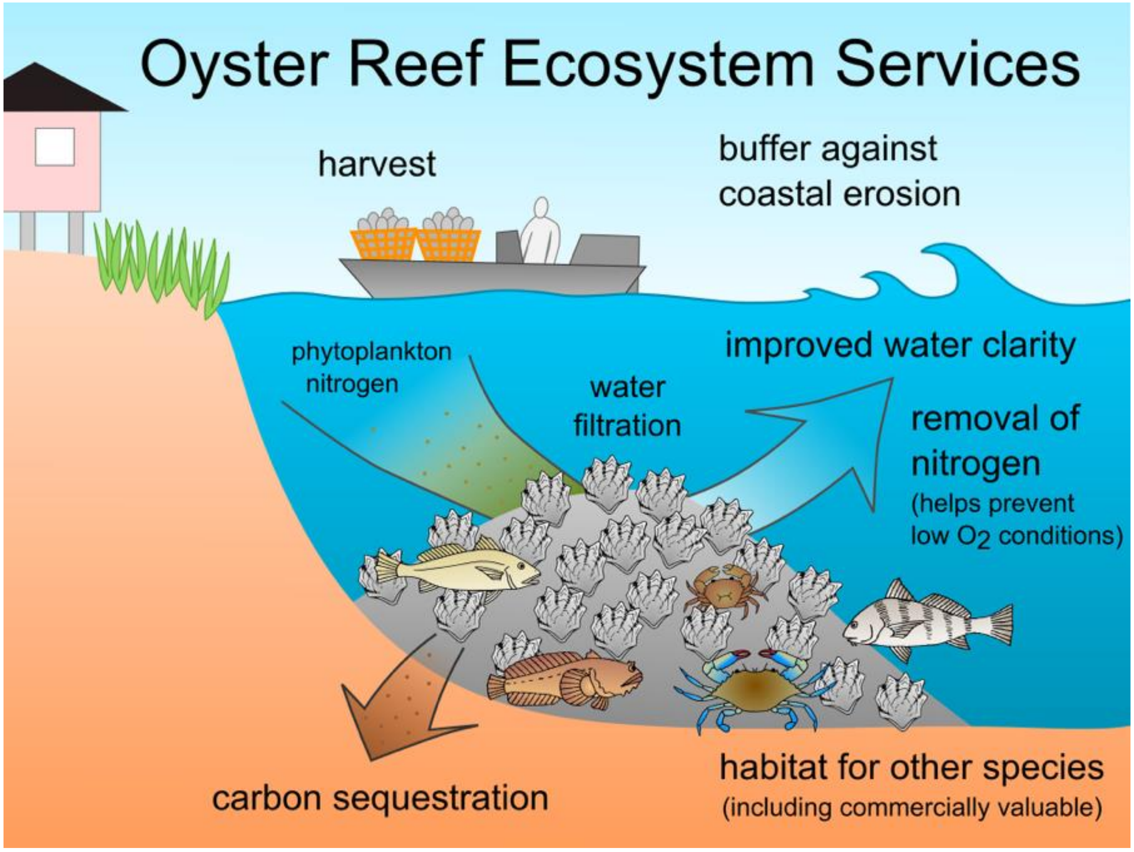


Figure 3. Schematic diagram of seven ecosystem services that oyster reefs provide to maintain healthy estuaries and to benefit human society.

19. The Eastern oyster is a "foundation species." This is a term used by ecologists to describe organisms that create habitat such as kelp forests and coral reefs. The presence and abundance of these organisms maintain the movement of energy, the cycling of nutrients, and the biodiversity of ecosystems.

20. For instance, oyster reefs provide habitat for a range of recreationally and commercially important estuarine fishes and invertebrates, including blue crabs, stone crabs, flounders, red drum, black drum, spotted seatrout, and sheepshead.

21. In addition to harboring a diverse community of animals, oysters filter large volumes of water and consequently help maintain water clarity.

22. Oysters also remove excess nitrogen from the water and filter down the abundance of harmful algae and microbes. This is important because a surplus of nitrogen can promote the production of too much floating algae (phytoplankton), which ultimately sinks to the bottom and is decomposed by bacteria. This bacterial decomposition depletes oxygen in the water, which can cause a loss of fish and invertebrates.

23. The structured reefs created by oysters also serve as a breakwater for waves and storm surge, helping to protect coastal habitats such as marshes and prevent erosion of valuable coastal property.

E. The Oyster Life Cycle

24. Oyster reefs have historically covered approximately 10% of the bottom of Apalachicola Bay.

25. Adult oysters spawn from late March through October. After being fertilized in the water column, eggs develop into a planktonic larva. Oyster larvae rely on floating algae (phytoplankton) for food and warm water temperature to further their growth and development. After approximately 14 days, oyster larvae attach to a hard substrate and become a sessile juvenile oyster (hereafter "spat").

26. In Apalachicola Bay, oysters are assumed to grow continuously throughout the year, reaching a marketable harvest size of 76 mm (3 inches) in approximately 18 months, considerably faster than more northerly oyster populations. However, our research demonstrated that oysters can reach marketable harvest size in less than one year in Apalachicola Bay.

27. The growth, reproduction, and survival of oysters depend on a range of factors including temperature, salinity, food availability (phytoplankton), sedimentation, predation, disease, pollution, harvesting, and physical disturbance. Of these, oysters are particularly sensitive to changes in water salinity, which primarily depends on the amount of freshwater

discharge from a river and is defined as the number of grams of dissolved salts in 1,000 g of seawater. An optimal range of water salinity has been described as between 12–25 ppt.

28. The oyster's sensitivity to salinity, however, is due less to the oyster's physiology, because oysters tolerate salinity levels from 0–35 ppt for extended for periods of time. Instead, the oyster's sensitivity to salinity is due more to the predators and diseases of oysters being unable to tolerate the low and fluctuating salinity levels of the brackish waters that oysters inhabit.

29. Given observations during the aquaculture of oysters and ecological theory, it is generally understood that oysters use brackish waters as a refuge from predation. In addition to excluding predators, low and fluctuating salinities protect oysters from oyster disease and shell erosion by parasitic sponges. When high salinity conditions are prolonged, the proliferation of oyster disease and predators causes significant oyster mortality. Thus, water salinity is a primary environmental condition that determines the health of oysters in Apalachicola Bay.

30. The amount of freshwater discharge from a river can also influence oyster nutrition and ultimately oyster populations, because the floating algae (phytoplankton) that sustains the growth, maintenance, and reproduction of oysters depends on nutrients, as explained in the testimony of Dr. Glibert. These nutrients are delivered to eastern and gulf coast estuaries by discharge of freshwater from rivers.

31. Of course, too much freshwater discharge for a sustained period of time can overwhelm the physiological tolerances of oysters and cause death. Thus, healthy and productive oyster reefs require the maintenance of water salinity that is neither too high nor too low (12–25 ppt).

F. The Collapse of the Apalachicola Bay Oyster Fishery in 2012

32. The decline in oyster abundance in many estuaries has led to precipitous declines in oyster fisheries. But oyster populations in the northern Gulf of Mexico remained intact through 2010, declining the least and maintaining the highest catch of wild oysters in the world. In addition, until the 2012 decline, Apalachicola Bay was one of only two U.S. estuaries estimated to have stable oyster biomass when comparing the 2000-2010 time frame to a baseline in 1900. The stability of the Apalachicola Bay fishery was attributed to the state management of this natural resource.

33. However, this historically productive fishery experienced a dramatic decline in the summer of 2012, when the Florida Department of Agriculture and Consumer Services (FDACS) survey found low harvestable stock. As a result of this decline, commercial harvest revenues declined by 43% and commercially marketed pounds of oyster meat declined by 58% from September 2012 – February 2013.

34. This decline in oyster production also occurred on private oyster leases in Apalachicola Bay, as explained in Mr. Tommy Ward's testimony.

35. The Florida Fish and Wildlife Conservation Commission's (FWCC) 2012-2013 Florida Gulf Coasts Oyster Disaster Report outlined this fishery decline in greater detail. The report also addressed potential causes of the decline, including: (i) negative effects of toxins from the Deepwater Horizon oil spill; (ii) negative effects of fishery management decisions in the wake of the Deepwater Horizon oil spill (i.e., opening the weekend harvest rule in summer 2010 for 26 extra days and the winter harvest area for 73 extra days); and (iii) reduced freshwater discharge from the Apalachicola River.

36. Freshwater discharge from the Apalachicola River was implicated because riverine discharge creates the most dominant environmental gradient in a classic estuary: water

salinity predictably decreases upstream and this strong environmental gradient organizes the distribution, abundance, and diversity of species based on differences among species in their physiological tolerance to fresh versus salty water.

37. The influence of salinity in estuaries is widely accepted and can be found in any marine biology textbook. Furthermore, in the five year period prior to the 2012 oyster fishery collapse in Apalachicola Bay, minimum river flows from the Apalachicola River occurred twice as often than in the period from 1989-2007, and ten times more often than historical records from 1923-1955, as explained in Dr. Hornberger's testimony.

38. After reviewing the FWCC report (JX-91) and additional independent data, the NOAA Climate Program Office concluded that the primary cause of the oyster fishery collapse was a multi-step process initiated by a severe drought. According to this report (FX-413), the severe drought reduced the discharge of freshwater from the Apalachicola River and this freshwater reduction increased water salinity in Apalachicola Bay. With prolonged conditions of high salinity, the abundance of oyster disease and predators increased to a degree that caused the oyster fishery collapse.

39. While the NOAA report acknowledged that commercial harvest also reduced oysters, NOAA concluded that the oyster fishery collapse would have occurred regardless the amount of harvest. As a result, the fishery was declared a Federal Disaster by the U.S. Commerce Department in May of 2013.

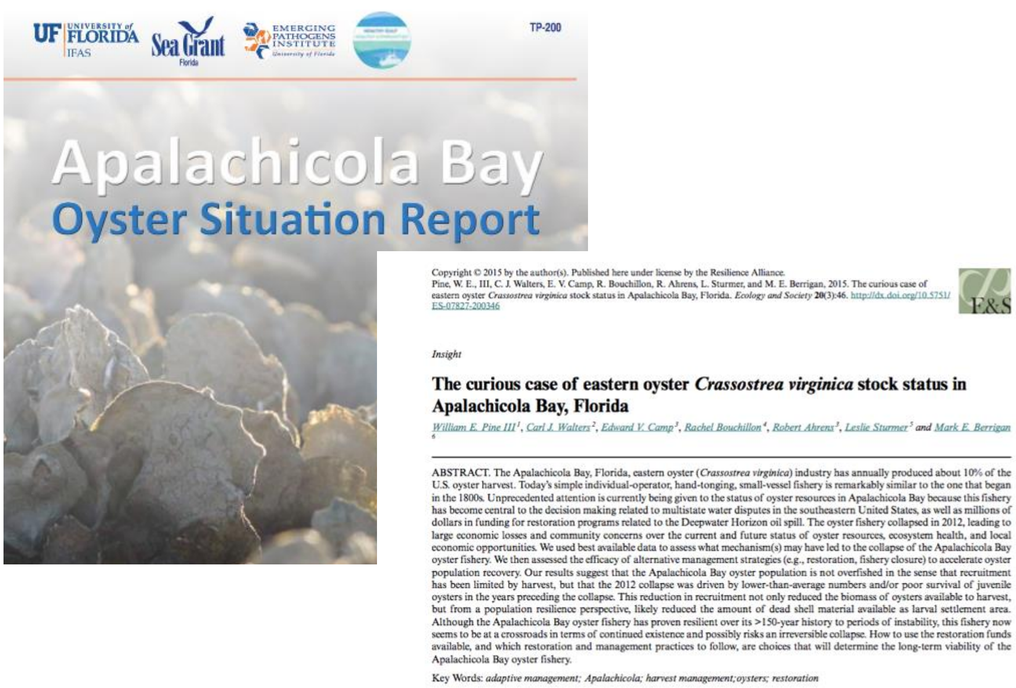
40. The source of freshwater for the Apalachicola River begins in the State of Georgia. According to the U.S. Geological Survey, the State of Georgia has increased its upstream withdrawal of freshwater over time. Therefore, it is reasonable to consider whether withdrawals of freshwater from the upper watershed of the Apalachicola River worsened the

effects of a natural drought and whether this additional stress pushed the oyster fishery into a state of collapse.

41. The effect of upstream water withdrawal, however, has been called into question because an independent scientific study by Dr. Pine, a professor at the University of Florida, did not find an association between river flow and oyster mortality in Apalachicola Bay. In addition, citizen and newspaper reports suggested that an increase in commercial harvest likely played a larger role in the 2012 collapse of the Apalachicola oyster fishery.

G. Previous Research

42. Numerous individuals have attempted to make sense of the various factors that could have caused the 2012 oyster fishery collapse in Apalachicola Bay, but none of these studies succeeded. Two of the most frequently referred to studies are illustrated in Figure 4.



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Pine, W. E., III, C. J. Walters, E. V. Camp, R. Bouchillon, R. Ahrens, L. Sturmer, and M. E. Berrigan. 2015. The curious case of eastern oyster *Crassostrea virginica* stock status in Apalachicola Bay, Florida. *Ecology and Society* **20**(3):46. http://dx.doi.org/10.5751/ES-07827-200346

E&S

Insight

The curious case of eastern oyster *Crassostrea virginica* stock status in Apalachicola Bay, Florida

William E. Pine III[1], Carl J. Walters[2], Edward V. Camp[3], Rachel Bouchillon[4], Robert Ahrens[3], Leslie Sturmer[5] and Mark E. Berrigan[6]

ABSTRACT. The Apalachicola Bay, Florida, eastern oyster (*Crassostrea virginica*) industry has annually produced about 10% of the U.S. oyster harvest. Today's simple individual-operator, hand-tonging, small-vessel fishery is remarkably similar to the one that began in the 1800s. Unprecedented attention is currently being given to the status of oyster resources in Apalachicola Bay because this fishery has become central to the decision making related to multistate water disputes in the southeastern United States, as well as millions of dollars in funding for restoration programs related to the Deepwater Horizon oil spill. The oyster fishery collapsed in 2012, leading to large economic losses and community concerns over the current and future status of oyster resources, ecosystem health, and local economic opportunities. We used best available data to assess what mechanism(s) may have led to the collapse of the Apalachicola Bay oyster fishery. We then assessed the efficacy of alternative management strategies (e.g., restoration, fishery closure) to accelerate oyster population recovery. Our results suggest that the Apalachicola Bay oyster population is not overfished in the sense that recruitment has been limited by harvest, but that the 2012 collapse was driven by lower-than-average numbers and/or poor survival of juvenile oysters in the years preceding the collapse. This reduction in recruitment not only reduced the biomass of oysters available to harvest, but from a population resilience perspective, likely reduced the amount of dead shell material available as larval settlement area. Although the Apalachicola Bay oyster fishery has proven resilient over its >150-year history to periods of instability, this fishery now seems to be at a crossroads in terms of continued existence and possibly risks an irreversible collapse. How to use the restoration funds available, and which restoration and management practices to follow, are choices that will determine the long-term viability of the Apalachicola Bay oyster fishery.

Key Words: *adaptive management; Apalachicola; harvest management;oysters; restoration*

Figure 4. Examples of non-peer reviewed and peer reviewed research that evaluated the 2012 oyster fishery collapse in Apalachicola Bay, FL.

43. Both of these research efforts were unsuccessful because they relied primarily on two types of observational data: fisheries-dependent data and fisheries-independent data.

Examples of fisheries-dependent data include annual dockside landings of oysters and the amount of boat trips required to produce these landings. An example of fisheries-independent data is the surveying of commercial oyster reefs conducted by FDACS on roughly a semi-annual basis.

44. While fisheries-dependent and fisheries-independent data are useful, a researcher that uses only these observational data will be unable to conclusively identify the cause of the oyster fishery collapse. This is because the Apalachicola Bay ecosystem is too big and there are too many factors that could have individually or in combination caused the fishery collapse.

45. For instance, from 2005–2012, the minimum amount of freshwater discharged into Apalachicola Bay became lower and lower during the late summer months (May–October). This decrease in freshwater from the Apalachicola River is illustrated below in Figure 5.

46. In this warm season, a reduction in freshwater could have increased the abundance of oyster disease and predators. In addition, the reduction in freshwater could have been accompanied by a reduction in nutrients, which could have starved oysters by reducing the availability and quality of their food (phytoplankton), as explained in the Dr. Glibert's testimony. Furthermore, this reduction in freshwater discharge could have been caused by natural drought and/or upstream withdrawal of freshwater. Finally, by itself or in combination with the stress caused by freshwater reduction, the commercial harvest of oysters could have caused the collapse. Observational data alone cannot be used to simultaneously evaluate the relative importance of all these factors.

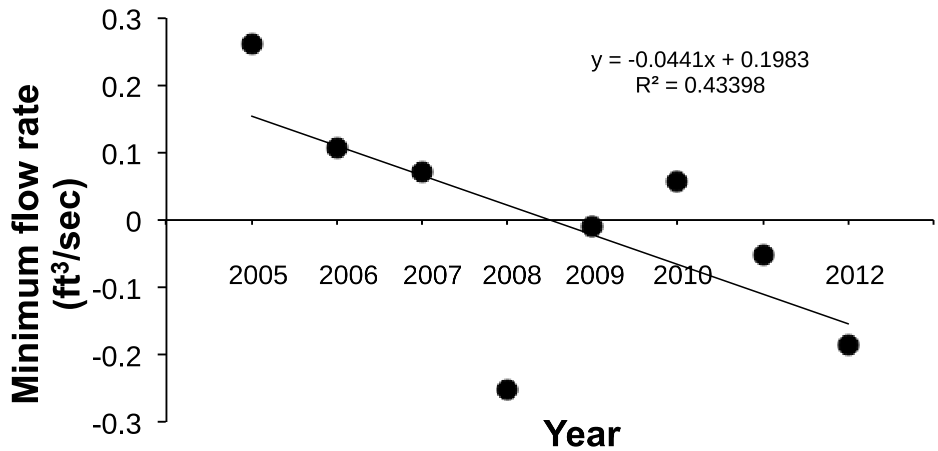


Figure 5. Minimum daily flow (ft³/sec) at Chattahoochee River during low-flow season (August–October) from 2005 to 2012 just prior to the oyster fishery collapse in Apalachicola Bay. Data are standardized to the overall mean of minimum flow from 2005–2012. Data clearly show that minimum flow rates during the low flow season have consistently decreased over time.

47. Dr. Pine and colleagues attempted to go beyond an observational approach by combining a mathematical model with the observational data. But as explained in detail below, this effort was unsuccessful because none of the researchers had first-hand experience with the study system and because the model was flawed. As a result, their research conclusions contradicted conclusions of previous research and the opinion of the researcher who generated the observational data, Mr. Mark Berrigan.

48. More specifically, Dr. Pine published a research article entitled, "The curious case of the eastern oyster *Crassostrea virginica* stock status in Apalachicola Bay, Florida". In this publication, Dr. Pine concluded the following: (i) the commercial harvest of legal and sub-legal size oysters did not play a role in the collapse; (ii) there was no relationship between freshwater discharge from Apalachicola River and the amount of oyster mortality estimated by his model;

and (iii) an un-identified factor caused a recruitment failure of oysters, which led to the 2012 fishery collapse.

49. But at the end of their publication about this research, Dr. Pine and colleagues stated that, "With the data currently available for Apalachicola Bay, we cannot be sure whether we are dealing with a small oyster population that has been subject to strong fishing impacts or a larger population that has been subject to strong environmental influences that have impacted the long-term carrying capacity."

50. Furthermore, at the beginning of their publication, Dr. Pine and colleagues stated, "Note that we did not study or reach any conclusions about any effect of water withdrawals affecting the Apalachicola River Basin or oyster populations in Apalachicola Bay. This is an area that warrants future research."

51. After reviewing Dr. Pine's publication, I agree that the data and model used in their study were incapable of identifying the cause of the 2012 oyster fishery collapse. The study by Pine and colleagues was inconclusive because it depended on a model that lacked key observational and experimental data. As a result, two key things were missing from their model.

a. First, the model lacked a component that allowed oyster disease and predators to increase their impact on oyster mortality when freshwater discharge from the Apalachicola River decreased and the water salinity in Apalachicola Bay increased. Without this component, the amount of oyster mortality predicted by their model was not allowed to change when the discharge of freshwater into Apalachicola Bay changed.

b. Second, the study did not address one of the major factors that may have caused the collapse, the upstream withdrawal of freshwater from the Apalachicola River watershed.

52. Because of these flaws, researchers cannot use the results or conclusions of the Pine study to identify the cause of the 2012 oyster fishery collapse.

53. In a subsequent publication, Dr. Pine, together with Dr. Camp and others, investigated the cause of the collapse to the Apalachicola Bay oyster fishery in 2012. I reviewed this publication in connection with my investigation of the 2012 collapse because it is the type of material that that a research ecologist evaluates when conducting a study. A true and accurate copy of this publication is JX-167. The publication states:

> "Why did the oyster fishery collapse in Apalachicola Bay Florida during 2012? Although a detailed assessment of the dependent and independent data was not able to identify a specific proximal cause (Pine et al. 2015), it is considered likely that a sequence of events occurred whereby: (1) low river flow led to increased salinity in Apalachicola Bay for a multiyear period; (2) which likely led to increases in oyster parasites, predators, or unknown pathogens; (3) causing elevated mortality, particularly among juvenile oysters; (4) which led to recruitment failure, potentially exacerbated by shell removal from fishing or environmental events; and then (5) population collapse of adult oysters."

54. Given the uncertainty about the cause of the oyster fishery collapse in Apalachicola Bay, I was asked by the State of Florida to design and implement a research program that could quantitatively identify the cause(s) of the collapse. This is precisely the sort of "future research" Pine et al. recommended.

H. My Research Approach

55. To understand the cause of the oyster fishery collapse in Apalachicola Bay, I needed the best available research approach. It is well accepted in the field of Ecology that the optimal research approach for complex questions—such as the oyster fishery collapse in Apalachicola Bay—requires a union of three separate approaches: observational, experimentation, and mathematical modeling. Before I discuss the specifics of my research, I will provide background on each of these research approaches.

56. First, standardized observations could be used to create hypotheses, guide the design of realistic experiments, interpret the results of experiments, and evaluate model predictions. But as I explained above, observations alone cannot establish cause and effect. For instance, two species of trees may not overlap in a forest. While this lack of overlap could be due to competition between the two tree species, this same pattern could also be caused by the tree species preferring different environmental locations. In short, observations can suggest a causal relationship between two factors, but observations cannot account for a "confounding" or hidden factor that may be the true cause of the pattern.

57. Second, experimentation has been a significant means of investigation in the field of Ecology since the 1960s, because it is the only approach that can address confounding factors, and consequently establish cause and effect relationships. This approach, however, has its own limitations because experiments are usually conducted at small spatial scales and for short time periods. Also, when more than one factor is considered, the appropriate experimental design quickly becomes logistically difficult to implement.

58. Third, model building allows ecologists to generalize to larger spatial scales and longer time periods by distilling nature into the few most important elements, exploring the bounds of hypotheses, and simultaneously evaluating multiple factors. However, without observations and experiments to guide model construction and to test model predictions, the modeling approach is limited.

59. In January 2013, I initiated a union of observations, experiments, and modeling to understand the ecology of the 2012 oyster fishery collapse in Apalachicola Bay. Each part of this multi-faceted approach had several components. For example, the observational approach consisted of quantifying water salinity and temperature on a monthly basis from 2013–2016,

quantifying oyster growth on a monthly basis from 2014–2016, consulting the FDACS fisheries independent monitoring of commercial oyster reefs, and conducting our own annual population census of oyster reefs throughout the entire bay from 2013–2016. Some of these components are illustrated in Figure 6.

Figure 6. Images of observational research in Apalachicola Bay. (A) Divers conducting surveys of oyster reefs underwater. (B) Researchers processing oyster samples that were collected in the survey. (C) Researcher using instrumentation to monitor water salinity and temperature.

60. My experimental approach also required several components because the different factors that may have caused the collapse operate on different spatial and temporal scales. For instance, changes in water salinity occur at the scale of the entire bay. Consequently, the salinity patterns of Apalachicola Bay may change very slowly over time. In contrast, the spatial scale at which predators of oysters operate is relatively smaller (1 m^2). In addition, predatory snails may alter their consumption rate of oysters over much smaller time periods.

61. Therefore, evaluating the influence of multiple factors in Apalachicola Bay requires repeating the same experiment across the large environmental gradient of interest (i.e., water salinity) and over time. This kind of experiment is called the "comparative-experimental approach" and it is a well-established method in the field of Ecology. In the Methods section below, I provide further detail about this approach.

62. Finally, the results of our observational and experimental approaches were integrated into a sophisticated mathematical model, as explained in Dr. White's testimony.

Methods and Results of Field Experiments in Apalachicola Bay

63. During the spring of 2013, I employed the comparative-experimental approach by conducting the same experiment in six different zones of Apalachicola Bay and at the same time. As described below, my experiments established a clear and causal relationship between increasing water salinity and increasing predation on oysters.

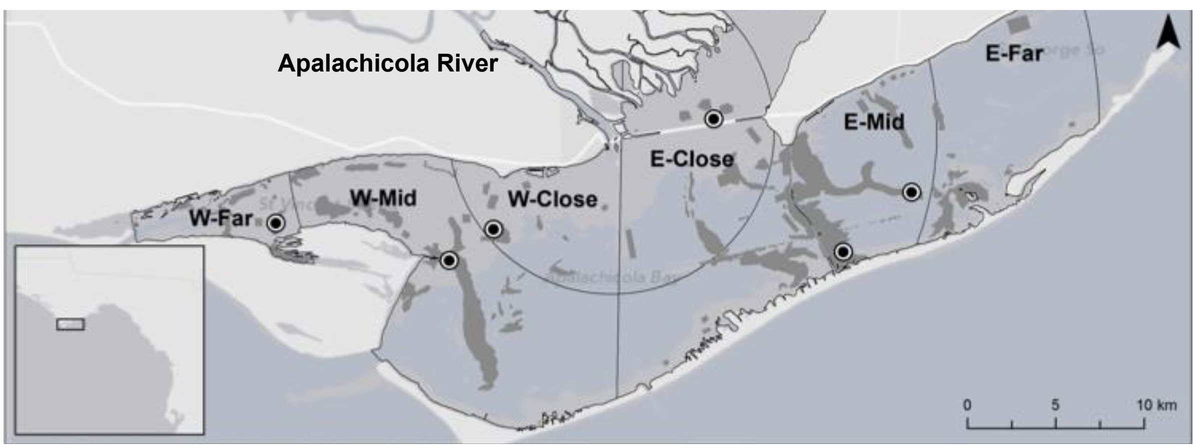


Figure 7. Map of Apalachicola Bay, Florida. Dark shading illustrates oyster reefs. Concentric circles illustrate proportional distance (Close, Mid, Far) of reefs from the Apalachicola River. Black circles show location of experiments within each zone (Close, Mid, Far). Zones were further labeled with a W or E in order to distinguish between zones that are westward or eastward of the Apalachicola River.

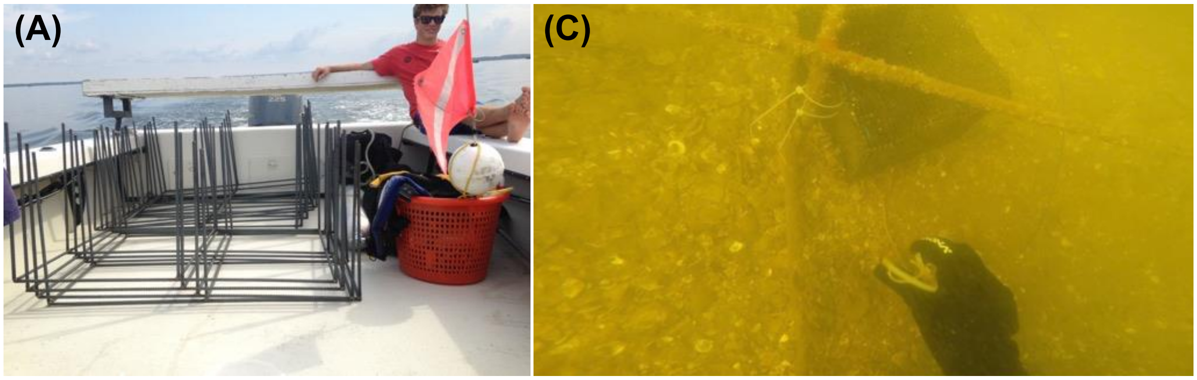
64. These six zones were used in order to obtain the same type of experimental results from areas of the bay with different water salinity and abundance of predatory snails. These six zones are illustrated in Figure 7.

65. To a large extent, river input determines the environmental conditions of the bay by controlling water salinity. As a result, I suspected that water salinity and snail abundance may increase with increasing distance from the river in either the east or west direction. This is why the two zones closest to the river are referred to as “Close”, the two zones farthest from the river are referred to as “Far”, and the remaining two zones were referred to as “Mid” (Fig. 7).

66. To fully implement the comparative-experimental approach, I also monitored the water temperature, water salinity, and predator abundances in each zone throughout the experiment.

67. In each of the six zones, I randomly selected one oyster reef on which to conduct the experiment. On each of these six reefs, I deployed nine protective rebar frames (1.21 m x 0.91 m x 0.61 m), which were made out of ½” rebar. The rebar frames were used to prevent disturbances from harvesting and boating activities. This design resulted in the deployment of 54 rebar frames throughout Apalachicola Bay.

68. Figure 8A illustrates the transport of frames to oyster reefs in Apalachicola Bay. Figure 8B illustrates a schematic diagram of a rebar frame. Figure 8C illustrates a rebar frame on an oyster reef and a research diver attaching our experimental material to a rebar frame.



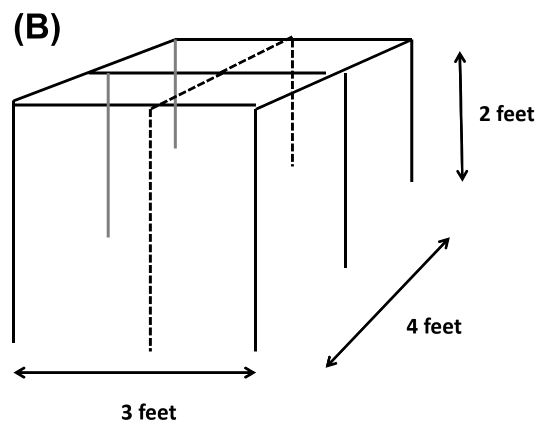


Figure 8. (A) Image of rebar frames used in experiments to protect oysters from boating and harvesting activities. (B) Diagram of rebar frame with dimensions. (C) Image of oysters in an experimental cage made of wire mesh that was attached to one rebar post with plastic cable ties.

69. Next, I attached three different experimental treatments to three posts on each rebar frame.

70. The three experimental treatments included a cage treatment, a cage-control treatment, and a control treatment. Images of these three treatments are presented in Figure 9.

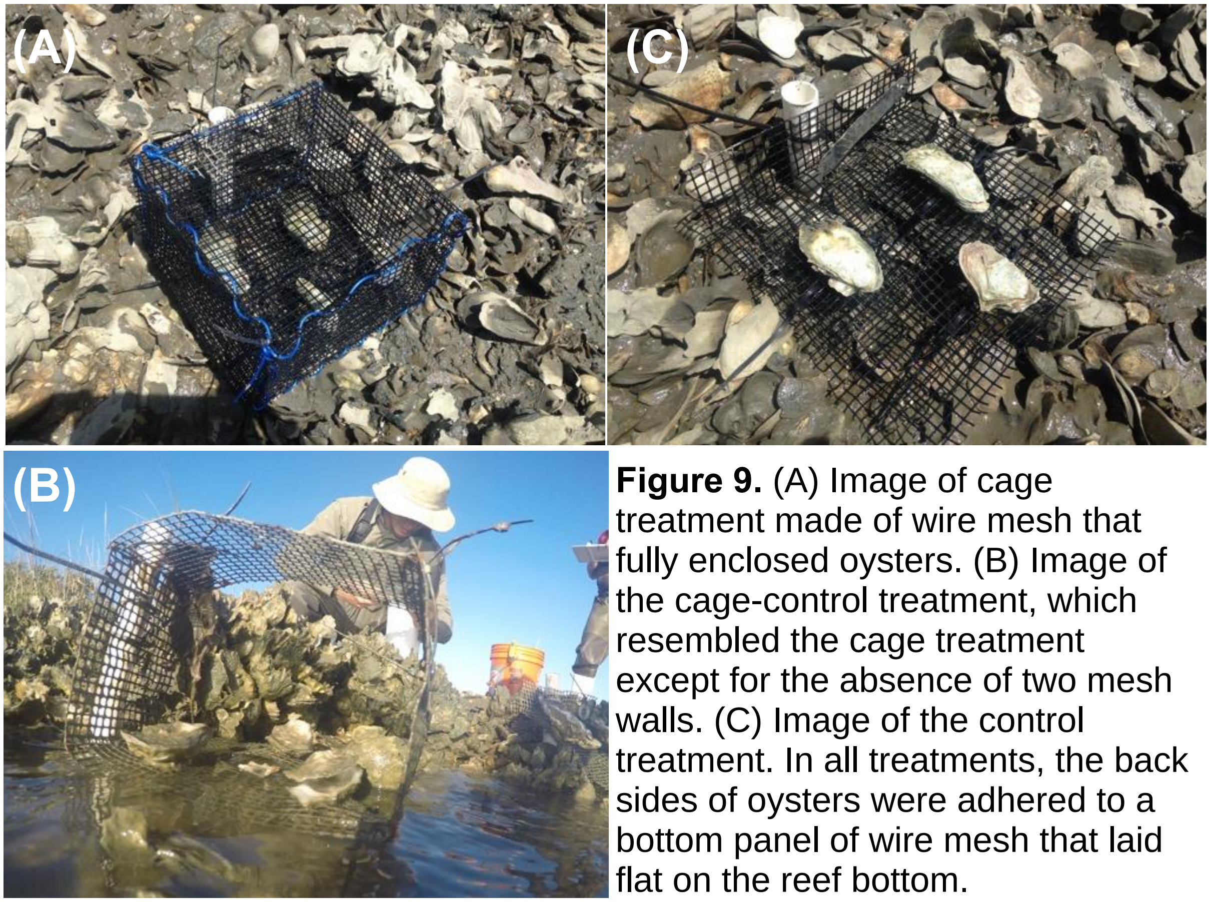


Figure 9. (A) Image of cage treatment made of wire mesh that fully enclosed oysters. (B) Image of the cage-control treatment, which resembled the cage treatment except for the absence of two mesh walls. (C) Image of the control treatment. In all treatments, the back sides of oysters were adhered to a bottom panel of wire mesh that laid flat on the reef bottom.

71. All three experimental treatments were constructed of vinyl-coated wire mesh (5 mm × 5 mm) panels with dimensions of 0.3 m × 0.3 m. The cage and cage-control treatments contained walls and a roof, which increased their dimensions to 0.3 m × 0.3 m × 0.5 m. In each experimental treatment, the backsides of four oysters were attached to the bottom panel of wire mesh. This panel was positioned flat on the ground and the panel was attached to the rebar frame with a cable tie.

72. The cage treatment contained four oysters that were fully enclosed by the wire mesh (Fig. 9A). As a result, oyster survivorship in the cage treatment was influenced by environmental factors such as water salinity and disease, but not predators. Survivorship also could have been affected by artifacts from the wire mesh such as altered water flow or accumulation of sediment.

73. The control treatment contained four oysters that were fully exposed to the environment and predators (Fig. 9C).

74. The cage-control treatment contained four oysters that were not fully enclosed by the wire mesh (Fig. 9B). To mimic any artificial effects of the wire mesh, this treatment resembled the cage treatment except for the absence of two walls. As a result, oyster survivorship could have been influenced by the environment, predators, and/or artifacts from the wire mesh.

75. On a weekly to monthly basis, the following data were collected from each of the six zones: oyster survivorship from each treatment, water salinity, water temperature, and the abundance of predatory snails.

76. At the end of the experiment, I tested for the influence of "procedural artifacts" on our results by comparing oyster survivorship in the control treatment to oyster survivorship in the cage-control treatment. If oyster survivorship did not differ statistically between the two treatments, then I concluded that the experiment lacked artifacts due to the presence of the wire mesh material. In other words, our results could not be explained by the presence of artificial caging material. This is a common technique and test used in the field of Ecology. In the Apalachicola Bay experiments, I never detected an artifact.

77. At the end of the experiment, I also tested for the strength of predation. I calculated the strength of predation by subtracting the survivorship of oysters in the control treatment from the survivorship of oysters in the cage treatment. I then standardized this difference by the survivorship in the cage treatment. This metric [(cage – control)/cage] is widely used in the field of Ecology.

78. This experiment was repeated seven times from 2013–2016.

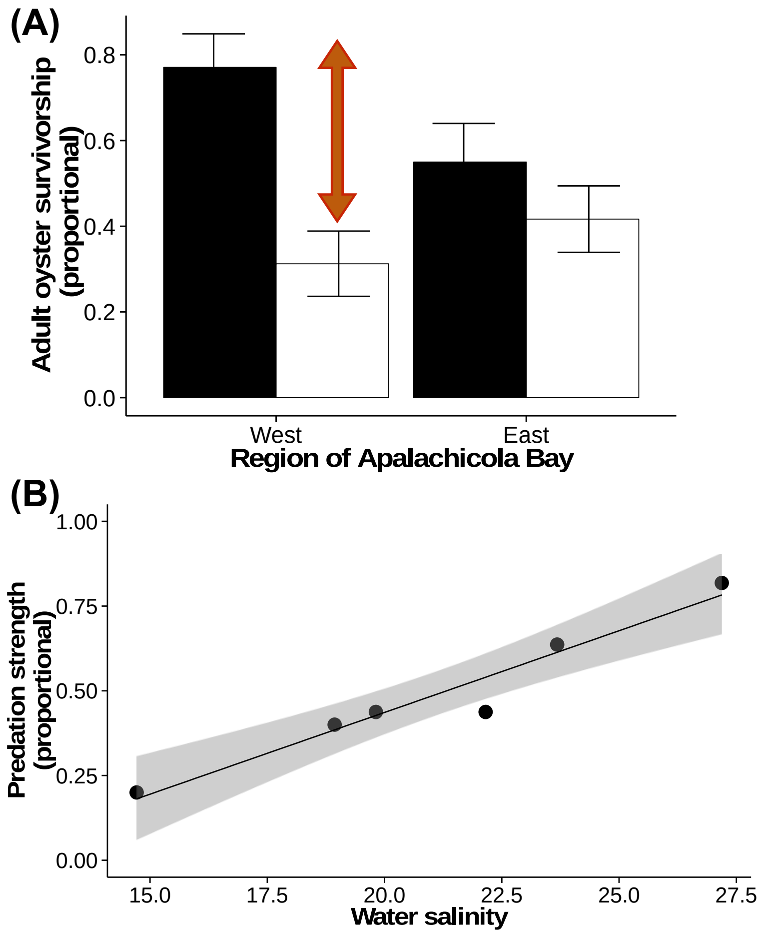


Figure 10. (A) Results of the first Apalachicola Bay experiment in May 2013. Black bars represent survivorship of oysters in cage treatments on reefs westward and eastward of the Apalachicola River. White bars represent survivorship of oysters in control treatments. The red arrow reflects the difference between the cage and control treatments and this difference estimates the strength of predation on oysters. (B) Predation on oysters in the six zones of Apalachicola Bay became stronger with increasing water salinity. Inset shows image of a snail eating an oyster.

79. During the first experiment in May 2013, oysters in western Apalachicola survived in the cage treatments (black bars, Fig. 10A), but not in the control treatments (white bars, Fig. 10A). The difference in survivorship between the cage and control treatments illustrates the strength of predation (length of red arrow in Fig. 10A).

80. In East Apalachicola, many oysters in the protected cages died most likely because of high water salinity and disease.

81. When I calculated the average strength (±95% Confidence Interval) of predation for each of the six zones, I found that predation on oysters outside of cages became significantly stronger as water salinity increased (Fig. 10B). In this experiment, water salinity increased with

increasing distance from the Apalachicola River. In addition, ~ 95% of the predation was due to predatory snails.

82. In accordance with the comparative-experimental approach, we repeated this experiment over time in order to understand how large-scale environmental change alters predation on oysters. For instance, in July of 2013, Apalachicola Bay experienced an intense amount of local precipitation that significantly reduced water salinity relative to salinity conditions in our first experiment. This reduction in water salinity also reduced the abundance of predatory snails throughout the bay.

83. The reduction in water salinity caused two main effects on oysters. First, reduced salinity improved the survivorship of oysters in protective cages, presumably by decreasing the abundance of oyster disease. Inside the cage treatments, oyster survivorship improved by 16% on western reefs and by 76% on eastern reefs. Second, reduced salinity unequivocally reduced the abundance of predatory snails and consequently predation on oysters, except on reefs far from the river in western Apalachicola. During the first experiment, 5 out of 6 sites (83% of sites) had strong predation on oysters outside of protective cages (strength > 0.40). But during the second experiment, only 2 out of 6 sites (33% of sites) contained strong predation on oysters outside of protective cages (strength > 0.40).

84. Together, the results of the first two experiments established a clear and causal relationship between increasing water salinity and increasing predation on oysters.

85. In all of our experiments, ~ 95% of the predation on oysters was caused by a predatory snail.

86. By repeating this experiment for nearly 4 years, we also demonstrated that snail predation only occurs in months with warm temperatures because snails undergo dormancy during winter months.

87. Thus, over a relatively short and long time scale, predation on oysters consistently intensified with increasing water salinity during non-winter months. Given that the water salinity of Apalachicola Bay increased significantly before the 2012 oyster fishery collapse, it was reasonable for us to question whether the oyster fishery collapse was caused by an increase in water salinity and outbreak of predatory snails.

88. Before discussing further the results of my experiments, I will address some criticisms of my research. Dr. Lipcius, an Expert Witness for the State of Georgia, criticized these experiments for two main reasons.

89. First, Dr. Lipcius criticized the predation results of my experiment as artificial. He reasoned that the rebar frames and wire mesh could have attracted predatory snails because snails like structure and there was little oyster reef structure at the study sites (i.e., the Close, Mid, and Far zones). If the experimental materials did attract the snails, then the strong predation on oysters in my experiments would be due to the rebar frames and mesh materials, not differences in water salinity.

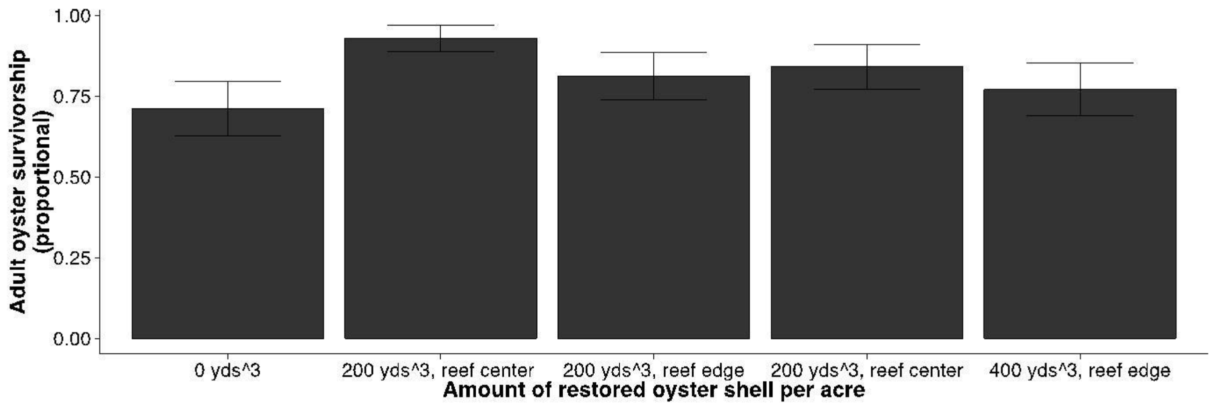


Figure 11. Results of experiment on restored reefs in Apalachicola Bay. The x-axis represents the five different areas where the experiment was simultaneously conducted in the Fall of 2015. Our original study location (0 yds^3), which did not receive any new shell substrate is on the left side of the x-axis. In this experiment, predation occurred but it was not stronger on the restored reefs when compared to our original unrestored site. On each restored reef, the experiment was conducted in the center and on the edge of the reef.

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a. To evaluate this criticism, I re-evaluated the results of an experiment that was initiated in Fall of 2015. In the Mid zone on the west side of Apalachicola Bay, the State of Florida restored a section of the oyster reef with 200 yds^3/0.25 acre. Approximately 100 m away on the same oyster reef, the State of Florida restored another section with 400 yds^3/0.25 acre. In this zone, I now had access to the original study location, which contained little reef structure, and two other reefs with more reef structure. These reefs gave me the ability to repeat my experiment across a gradient in reef structure, while holding water salinity relatively constant.

b. In this experiment, predation occurred. But oyster survivorship due to predation did not differ among the reefs. Figure 11 (FX-842a) is a graph I created using generally accepted scientific principles and methodology, and it is an accurate representation of the data I collected from my reef restoration experiment. As illustrated in Figure 11, the survivorship of oysters was relatively constant across the different types of reefs. Therefore, the amount of background reef structure does not influence the degree to which snails consumes oysters in my experiments.

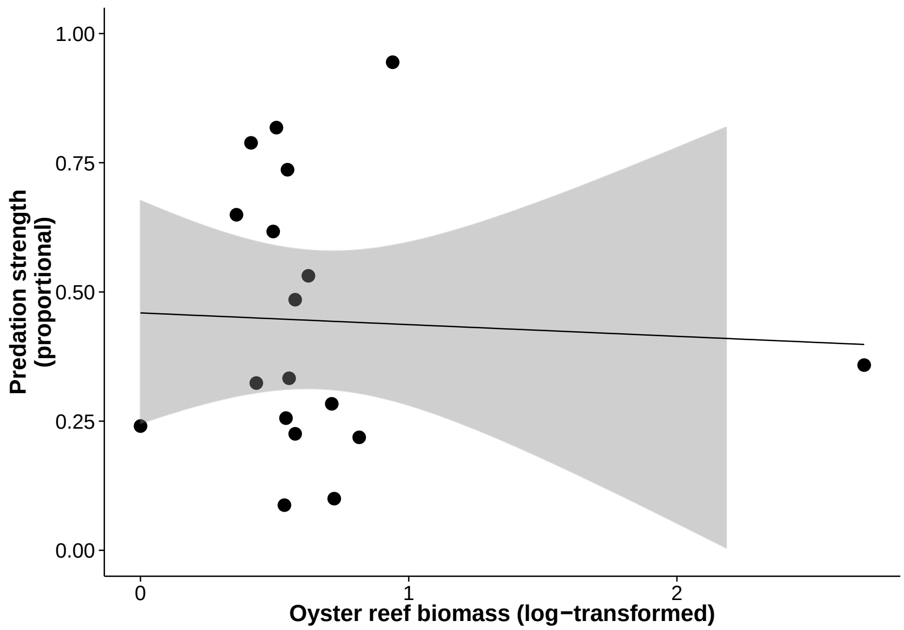

Figure 12. The linear relationship (±95% Confidence Interval, gray area) between strength of predation in our experiments over four years and background biomass of oyster reef material in each zone. The reef biomass data were collected in our annual population surveys. Clearly, the strength of predation does not increase or decrease with a change in the amount of background reef material.

c. To further test Dr. Lipcius' first criticism, I used my annual survey data of oyster reefs to calculate the amount of reef structure (biomass) per unit area in each zone (Close, Mid, and Far). I then evaluated whether the strength of predation over four years of experiments depended on the amount of reef structure in each zone. Figure 12 (FX-841) is a graph I created using generally accepted scientific principles and methodology, and it is an accurate representation of the data I collected from my annual population surveys and predation experiments. As Figure 12 illustrates, the strength of predation on oysters did not change with an increase or decrease in reef structure.

d. Based on the results of these two different tests, Dr. Lipcius' first criticism is not valid.

e. Nevertheless, it is important to realize that Dr. Lipcius has used the same materials and procedures in his own published research: Long, C.W., R. Seitz, B. Brylawski, and **R.N. Lipcius** (2014). Individual, population, and ecosystem effects of hypoxia on a dominant benthic bivalve in Chesapeake Bay. *Ecological Monographs* 84: 303–327. Like myself, Dr. Lipcius used these methods because they are widely accepted in the field of experimental Ecology and have been so since the 1960s.

90. Second, Dr. Lipcius criticized the conclusions of my report about predatory snails, because he believed that fisheries independent data (e.g., FDACS surveys) did not show elevated numbers of "box" oysters in 2012. In oyster research, a "box" oyster refers to a dead oyster gaping open without any tissue in between the two valves of the oyster. When a predatory snail eats an oyster, it leaves behind a box and the number of box oysters can be used as a means to estimate predation due to snails.

a. While I agree that box oysters can be used to estimate predation strength on oysters, I disagree that the FDACS data can be used to address this point. This is because FDACS did not consistently or rigorously quantify box data. I confirmed the absence of these data by inspecting the FDACS data set and conferring directly with FDACS employees.

b. Therefore, Dr. Lipcius' conclusion that predatory snails were in low abundance during the 2012 fishery collapse is not supported by any valid scientific data.

c. In addition, on commercial oyster reefs, the ability to use boxes as an estimate of predation on oysters is compromised because tonging activity separates oyster valves. Consequently, on an oyster reef with significant snail predation, tonging can eliminate the existence or reduce the amount of boxes.

d. As part of this second criticism, Dr. Lipcius also stated that the conclusions of my report about predatory snails were invalid because my annual surveys of oyster populations demonstrated a minuscule abundance of predatory snails. Furthermore, he suggested that I withheld data on drill abundances from my expert report.

e. But Dr. Lipcius is mistaken because Figure 9 of my Expert Report clearly illustrated that the abundance of predatory snails differed throughout Apalachicola Bay and that these differences changed over time.

f. This figure is reproduced here as Figure 13. These data were collected during my experiments in Apalachicola Bay and they show much higher snail abundances at the beginning of our research (2013). These data also show that snail abundance increased with increasing distance from the river and that snail abundance has decreased over time. Therefore, the basis for this component of Dr. Lipcius' second criticism is invalid.

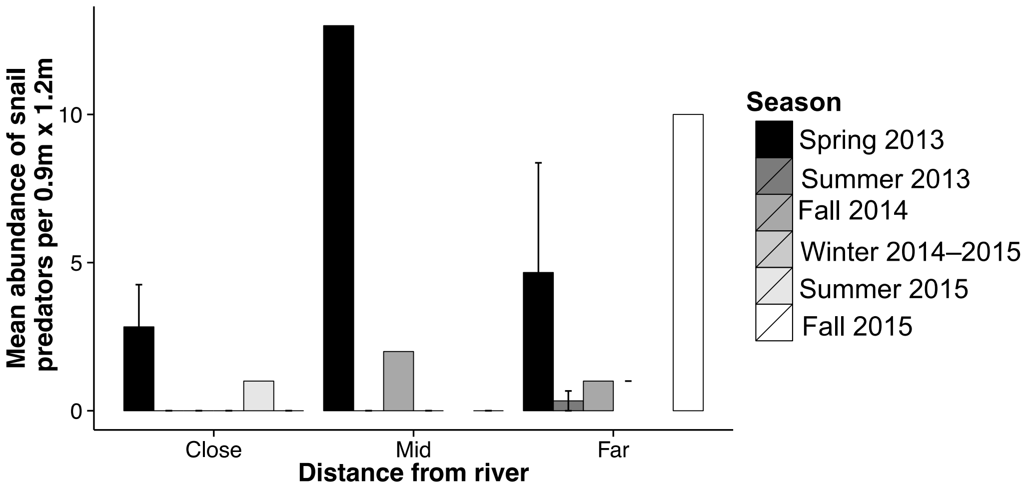

Figure 13. Reproduction of Figure 9 from Kimbro Expert Report, which illustrates the mean (±SE) count of snail predators per unit area during each Apalachicola Bay experiment. On the x-axis, data are grouped into three categories, which represent the proportional distance of the study location from the Apalachicola River (Close, Mid, Far). Two main results emerged: in 2013 (black bars), snail abundance was high and it was highest on reefs farther from the river; snail abundance decreased over time and most recently (white bars) snails were abundant only on reefs farthest from the river.

g. Furthermore, these data should be interpreted as a measure of relative snail abundance across sites and over time, rather than absolute snail abundance. This is because the waters of Apalachicola Bay can be extremely turbid (i.e. cloudy), inhibiting our ability to accurately assess the true abundance of snails.

h. Finally, in the fall of 2012, I accompanied FDACS on a research trip to assess the status of oyster reefs in Apalachicola Bay. During this research, I observed an anomalously high abundance of snails. An image of this observation is presented in Figure 1.

Methods and Results of Field Experiments in Apalachicola Bay and Ochlockonee Bay

91. Although our research clearly linked elevated water salinity to predation on oysters, this result could have been due to a natural phenomenon such as regional drought. To test whether the results in Apalachicola Bay were due solely to a regional environmental condition, we conducted experiments simultaneously in Apalachicola Bay and in nearby Ochlockonee Bay.

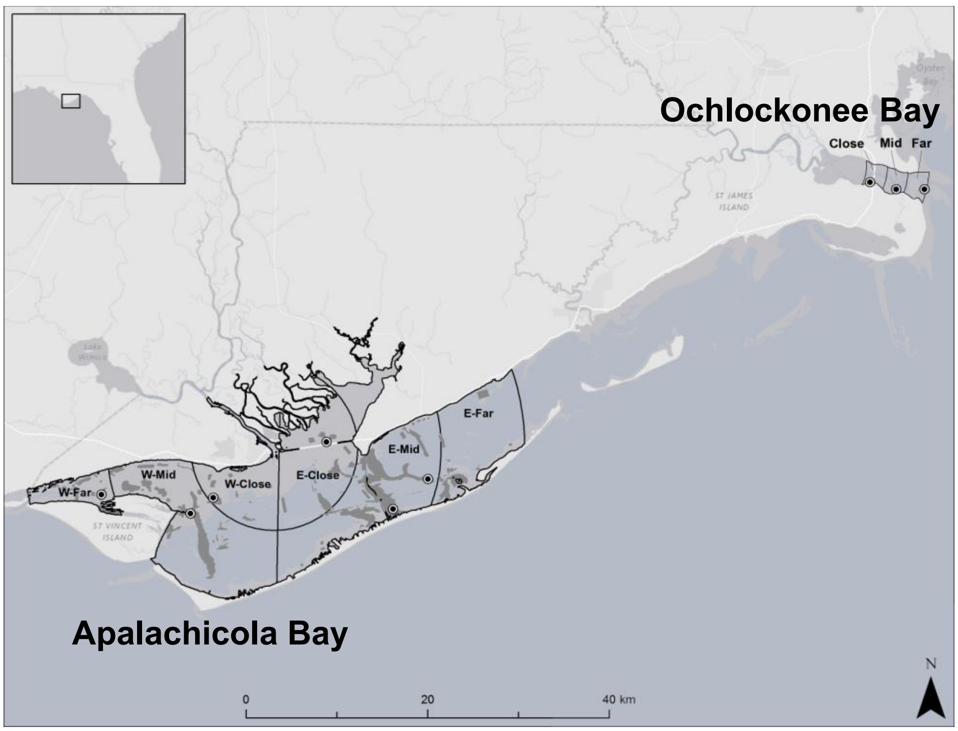

Figure 14. Map of Apalachicola Bay and Ochlockonee Bay. In Apalachicola, dark shading illustrates oyster reefs. In both bays, concentric circles illustrate proportional distances of oyster reefs from the natal river. In Apalachicola, proportional distances extend west and east of the Apalachicola River.

92. As the map in Figure 14 illustrates, Ochlockonee Bay is 30 kilometers east of Apalachicola Bay. While both bays have oyster reefs that always remain underwater ("subtidal"), the Ochlockonee watershed is separate from the watershed of Apalachicola Bay. The watershed of the Ochlockonee River originates in SW Georgia and is 1/8 the size of the Apalachicola River watershed. As result, environmental conditions of Ochlockonee Bay primarily reflect localized

meteorological conditions. Thus, similar results from both bays would imply that a regional factor (e.g., drought) increased water salinity and predatory snails. Conversely, different results between the two bays, in particular, stronger predation on oysters in Apalachicola Bay, would indicate that something unique to Apalachicola Bay is important.

93. In both bays, oyster survival in cages was high, which is illustrated in Figure 15 by the solid lines being close to the proportional value of 1.0 (high survivorship) throughout both bays. In Ochlockonee Bay, predation became important (significant difference between solid and dashed lines) in the most seaward 20% of the oyster reefs. In Figure 15, predation strength is illustrated by the difference between the solid line (survivorship in cages) and the dashed line (survivorship in control treatments). But in Apalachicola Bay, predation was significant on all of the oyster reefs, even on those reefs closest to the river. Thus, freshwater input provided many of the reefs in Ochlockonee Bay—but not in Apalachicola bay—with a refuge from predation.

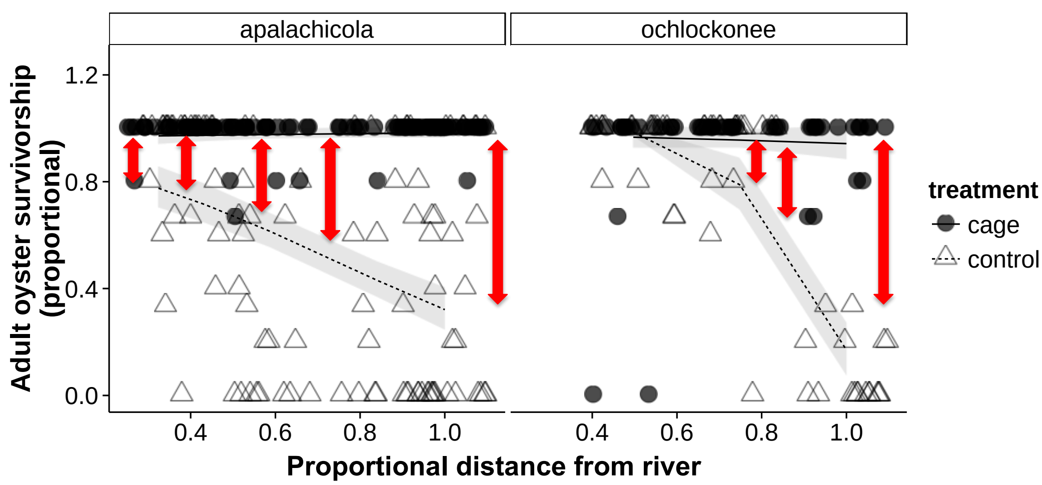

Figure 15. Results of experiments conducted simultaneously in Apalachicola Bay (left panel) and Ochlockonee Bay (right panel). Survivorship of oysters in the protective cage treatment is represented by circles and solid line. Oyster survivorship in the control treatment is represented by triangles and dash line. The difference between solid and dash lines represents predation strength on oysters (red arrows).

94. This between-bay difference in oyster predation was clearly linked to differences in water salinity. Figure 16 (FX-855) is a graph that I created using generally accepted scientific principles and methodology, and it is an accurate representation of the data collected from my Apalachicola Bay and Ochlockonee Bay experiments. In Figure 16, I plotted the strength of predation on oysters from all zones of each bay on the y-axis. The salinity of each zone is then referenced on the x-axis of the graph. This graph clearly shows that an increase in water salinity leads to an increase in the strength of predation.

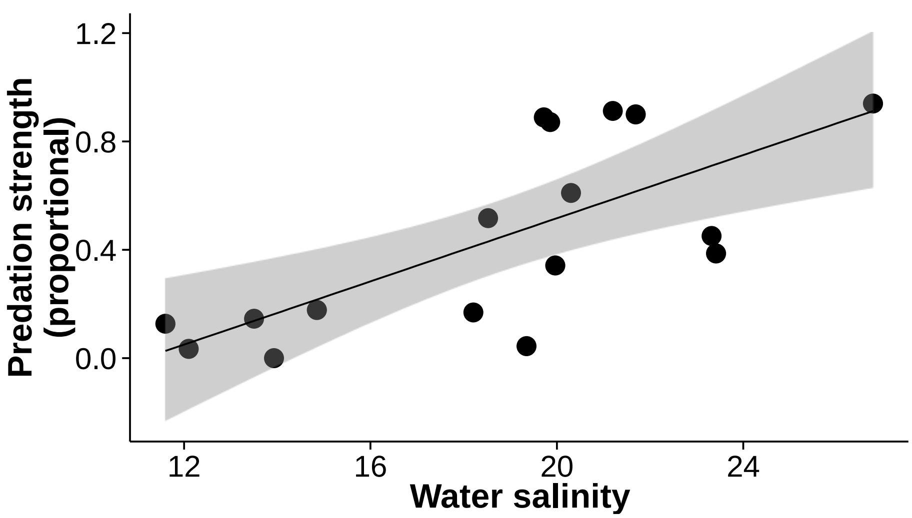

Figure 16. Results of experiments that were simultaneously conducted in Apalachicola Bay and Ochlockonee Bay. Graph illustrates the strength of predation from each zone (Close, Mid, Far) of both bays and the water salinity of each zone. This result clearly shows that an increase in water salinity leads to an increase in predation strength in both bays.

95. Furthermore, the difference in salinity between the two bays can be explained by differences in freshwater discharge between the two bays. Unlike the discharge of the Ochlockonee River, the minimum flow rate of the Apalachicola River during the low-flow

season (Aug-Oct) has declined consistently over the past 10 years. This trend was illustrated in Figure 5.

96. In summary, the experiments that I simultaneously conducted in Apalachicola Bay and Ochlockonee Bay demonstrated that salinity-induced predation on oysters is intensified in Apalachicola Bay. This intensification is linked to a factor(s) unique to Apalachicola Bay.

Mathematical Modeling approach

97. The third prong of my research approach consisted of a mathematical model. The detailed description of this model can be found in Dr. White's Expert Opinion and in his Direct Testimony. Below, I will summarize this modeling approach.

98. Dr. White used the most recent type of mathematical model in the field of Ecology to understand how populations change over space and time. The model was parameterized with the following information:

a. An increase in salinity caused an increase in the incidence and severity of an oyster disease (DERMO), which is caused by *Perkinsus marinus*. This information came from published research by Dr. Eileen Hoffman, a professor at Old Dominion University.

b. An increase in salinity caused an increase in snail predation on oysters. This relationship was verified by our outdoor experiments. But the specifics of this relationship were informed by our controlled laboratory experiments, which were conducted at the University of South Florida.

c. Laboratory results demonstrated that a five-day (or longer) decrease in water salinity of 5–15 ppt caused a temporary cessation of predation, which improved oyster survivorship. Results also demonstrated that a water salinity reduction of 20 ppt killed a majority of the predatory snails and this improved oyster survivorship. These results also allowed us to understand how incremental reductions in water salinity reduced snail predation on oysters. These results were integrated into Dr. White's model on a weekly timescale.

d. An increase in water salinity altered oyster births. The specific relationship was obtained from the published literature.

e. After settling onto hard substrate and becoming spat, the growth rate of oysters was calibrated according to our experiments with juvenile oysters in Apalachicola Bay. The methods and results of these experiments are described below.

f. The model used weekly mean estimates of salinity and temperature for 1992-2012. For the period 1992-2006, salinity and temperature data were obtained from the dataset collected at Cat Point by the Apalachicola National Estuarine Research Reserve. For 2007-2012, salinity and temperature were obtained from hydrodynamic model simulations described in the Greenblatt Expert Report for the hydrodynamic model nodes closest to the Cat Point observation stations.

g. Given the observed water salinity and temperature data, the model predicted the biomass of oysters per unit area.

h. To evaluate the model's performance, the predicted oyster biomass was compared to the observed oyster biomass at Cat Point and Dry Bar, which were obtained from fisheries-independent data set (FDACS surveys). The model's performance was good.

i. The model produced an estimate of commercial harvest, recruitment, and mortality.

j. After running the model with observed water temperature and salinity conditions, the model was run again with different salinity and temperature conditions. These conditions, which were provided by Dr. Greenblatt, were referred to as “unimpacted” conditions, because they reflected water salinity and temperature conditions if freshwater withdrawals had not occurred in the upper watershed of the Apalachicola River.

99. The results of the model demonstrated that the commercial harvest of oysters has not changed significantly over the past 30 years. The model also predicted that the oyster population would have declined in 2012 because of natural stressors, but it would not have collapsed. According to the model, the fishery collapse would not have occurred if the State of Georgia had not removed freshwater from the Apalachicola River and increased the water salinity of Apalachicola Bay.

100. Dr. Lipcius criticized this modeling approach stating that the model relied on unrealistic growth data. Specifically, the growth data in the model allowed the maximum size of oysters to occur at ~ 65 mm, which is less than the market size of oysters (75 mm).

a. While these growth data were not perfect, the data were realistic because they came from real oyster reefs in Apalachicola Bay.

b. For example, I collected oysters from the six different zones in Apalachicola Bay. Next, I counted the number of bands in a portion of the oyster shell. Previously published research demonstrated that one part of the band represents oyster growth in warm summer months, and another part of a band represents oyster growth in cold winter months. Thus, each band of summer and winter growth can be inferred to represent one year of growth and one year of age. For example, an oyster with five bands can be referred to as a five-year old oyster.

c. If the age of an oyster is plotted on the x-axis of a graph and then size of the oyster is plotted on the y-axis, an estimate of growth patterns can be statistically determined.

d. My sample of oysters lacked oysters larger than 70 mm because there were no oysters this large in Apalachicola Bay at the time of sampling. As a result, I lacked growth information for oysters that were larger than 70 mm.

e. According to the research results I outlined above, the lack of large oysters in my data set and in Apalachicola bay was due to snail predators and disease killing all of the large oysters.

f. Therefore, our original growth data were not unrealistic; they simply lacked information about oysters > 70 mm in length.

g. Because I anticipated this problem, I began a field experiment with juvenile oysters in the fall of 2014. Juvenile oysters were produced from 25 adult oysters that were collected from Apalachicola Bay. At a hatchery, the adult oysters were spawned and the resulting larvae were held in the hatchery until they settled (~3 weeks).

h. These spat represented a cohort of juvenile oysters of the same age and origin.

i. I attached 10 spat (8 mm in shell length) to a ceramic tile and I enclosed each tile inside a protected cage made of wire mesh (see description above).

j. In each of the six zones of Apalachicola Bay, I attached one spat tile to each rebar frame. Every month, the size of each oyster spat was measured.

k. Because this experiment was conducted from October 2014–June 2016, we have site-specific information on how oysters grow from spat into adulthood.

l. In Figure 17 below, a photo image is presented to illustrate the deployment of this experiment in Apalachicola Bay. It also shows a close-up image of spat that were attached to a ceramic tile.

Figure 17. (A) Screen shot of a video file created during the deployment of an experiment with juvenile oysters in Apalachicola Bay. (B) Inset in top right corner shows the juvenile oysters attached to a ceramic tile. By following the change in size of these oysters every month, we created the highest quality data set on oyster growth that exists.

m. To evaluate the consistency of these growth data, I repeated the experiment from July 2015–June 2016. Until now, such high quality data about the growth of oysters in Apalachicola Bay have never existed.

n. These data were not available when my Expert Report was submitted. However, Dr. White's model was reanalyzed with these higher quality growth data and the model's performance improved significantly. Therefore, Dr. Lipcius' first criticism of the model is no longer applicable.

I. My Overall Research Conclusions

101. Given my overall research approach of observations, experiments, and modeling, I conclude that (i) an increase in water salinity caused an increase in predation on oysters in

Apalachicola Bay. (ii) Furthermore, processes unique to Apalachicola Bay—as opposed to regional drought—increased water salinity and predation beyond levels seen in a nearby bay. (iii) The commercial harvest and natural abundance of oysters in Apalachicola Bay would have declined in 2012 as a result of natural drought and natural reductions in freshwater discharge from the Apalachicola River. (iv) But the fishery collapse of 2012 would not have occurred if freshwater had not been removed from the upper watershed of the Apalachicola River, because this additional stressor prolonged high salinity conditions in Apalachicola Bay and because prolonged high salinity conditions caused the proliferation of oyster disease and predators, as well as the failure of oyster recruitment.

102. Dr. Lipcius developed five arguments against my overall conclusions. First, Dr. Lipcius used the fisheries-independent data (FDACS survey of commercial oyster reefs) to evaluate the abundance of oysters on commercial and non-commercial reefs both before and after the fishery collapse in 2012. Because oyster abundance declined on the commercial reefs, but not on the non-commercial reefs, Dr. Lipcius concluded that commercial harvest caused the collapse. But Dr. Lipcius is mistaken because the water salinity around commercial oyster reefs is typically higher than the water salinity around non-commercial oyster reefs, as explained in Dr. White's testimony. This environmental difference between the two types of oyster reefs fundamentally inhibits Dr. Lipcius' use of the FDACS data set to support his conclusion.

a. More specifically, Dr. Lipcius' conclusion is fundamentally flawed because oyster reef status (commercial or non-commercial) is confounded by a hidden factor of water salinity. In other words, differences in water salinity between the two types of reefs can explain why oyster biomass decreased on commercial reefs but not on non-commercial oyster reefs during the fishery collapse of 2012.

b. Thus, Dr. Lipcius failed to realize the limitations of an observation-only research approach; it's a well-accepted principle in the field of Ecology that observational data cannot be used to establish a cause and effect relationship.

103. In his second argument, Dr. Lipcius reasoned that if overharvest caused oyster fishery collapses in multiple bays, then the primary role of overharvest in the 2012 fishery collapse in Apalachicola Bay would be confirmed. To support his argument, Dr. Lipcius presented oyster pounds landed in Wakulla County and the number of trips that were required to produce these oyster landings (i.e., fisheries-dependent data). Wakulla County refers to bays east of Apalachicola Bay. Because oyster landings in 2012 also decreased in Wakulla County, Dr. Lipcius concluded that the oyster fishery of Wakulla County also collapsed in 2012. Then, he used this conclusion as evidence to argue that the fishery of Apalachicola Bay collapsed because the State of Florida regionally mis-managed oysters in all bays, not because of a unique scenario of increasing water salinity within Apalachicola Bay. But once again, Dr. Lipcius' conclusion cannot be supported by the available data because a hidden or confounding factor can also explain the same trend in the fisheries-dependent data.

a. The fisheries-dependent data from Wakulla County are suggestive of a landings decline around 2012. As Dr. Lipcius interpreted, these data could also be interpreted to represent a fisheries collapse in Wakulla County.

b. However, Dr. Lipcius' conclusion is fundamentally flawed because he lacked fisheries-independent data from Wakulla County. Without these data, it cannot be confirmed that an oyster-landing <u>decline</u> in Wakulla County represented a <u>fishery collapse</u> in Wakulla County.

c. It is also well accepted in the field of Ecology that fisheries-dependent data (landings, trips) cannot be assumed to represent the true abundance of an organism. With respect to Dr. Lipcius' second argument, conclusions from fisheries-dependent data are tenuous because high landings of oysters prior to 2012 could simply be the result of more oysters on reefs leading to more oyster landings.

d. Dr. Lipcius also believed overharvest was the primary cause of a regional decline in oyster landings because he observed an increasing number of trips made by the commercial fleet prior to 2012. The number of harvest licenses sold by the State of Florida also increased.

e. However, trip and license data are not reliable indicators of effort because harvesters do not accurately report their number of trips. In addition, there is reason to suspect that the purchasing of licenses increased during the Deep Water Horizon oil spill around 2010 in order to establish a form of residency within the fishery, which may facilitate receiving compensatory payment, even though the new license holders likely harvested little to no oysters.

f. Therefore, the conclusions based on these effort data are not robust.

g. It is worth nothing that Dr. Lipcius' second overall criticism represents his second instance of solely using observational data to make a conclusion about a cause-and-effect relationship. This goes against best practices in the field of Ecology.

h. Finally, Dr. Lipcius attempted to create further support for his second argument by referring to newspaper reports of overharvesting and lack of regulation enforcement, which were based solely on rumor. Without quantitative evidence, it is impossible to evaluate the degree to which enforcement was present or absent. Therefore, this finding is not scientifically defensible.

i. Before discussing Dr. Lipcius' third overall argument against my research, I need to discuss further the danger of using fisheries-dependent data to interpret the 2012 fishery collapse in Apalachicola Bay.

j. Dr. Lipcius highlighted a coincidence of increasing effort and decreasing landings of oysters in Apalachicola Bay just prior to the 2012 collapse. Dr. Lipcius concluded that the increasing effort caused landings to decline, and declining landings represented a fishery collapse.

k. However, Dr. Lipcius did not consider the alternative scenario: because oyster reefs began to decline as a result of increasing water salinity, the harvesters spent more effort to harvest whatever was left. In this scenario, the reduced harvest efficiency is a result of the crash, not a cause of the crash.

l. This interpretation is supported by the trend in Catch Per Unit Effort (CPUE), which is defined as the amount of oyster landings divided by the number of trips. While the CPUE trend declined steeply during periods of low flow and high salinity (i.e., 2007-2009 and 2012-2014), CPUE was stable during a period of higher flow and reduced water salinity (i.e., 2010-2011). Thus, fluctuations in freshwater discharge from the Apalachicola River and the subsequent fluctuations in the water salinity of Apalachicola Bay can explain the CPUE trends.

m. This dual interpretation of the same observational data underscores the notion that causation in a complex system such as Apalachicola Bay cannot be established without a research approach that integrates observations, experiments, and modeling.

104. In his third argument against my overall conclusions, Dr. Lipcius reasoned that elevated water salinity could not have caused the 2012 fishery collapse in Apalachicola Bay because such a thing has never occurred in similar ecosystems in the Gulf of Mexico (e.g., Louisiana and Texas). To support this argument, he cited several publications of scientific research. But Dr. Lipcius' argument is simply not supported by these specific citations.

a. In particular, Dr. Lipcius relied on a publication by Dekshenieks et al. (2000). Dr. Lipcius' use of this publication represents the misuse of published research or the failure to fully read and comprehend the relevant research for three key reasons:

   i. The abstract of this study states that, "In general, the simulations show that salinity is the primary environmental factor controlling the spatial extent of oyster distribution within the estuary." In short, this quote means that water salinity is very relevant to setting limits on where oysters occur in a Texas bay.

   ii. In the Dekshenieks et al. (2000) publication, the authors wrote, "There are several processes which produce the band of high oyster density spanning the central regions of Galveston Bay. The population is limited in the southwestern reaches of the Bay by *P. marinus*, which is the primary source of oyster mortality in Galveston Bay, has its greatest impact in high salinity environments." To interpret, the authors stated that the number one cause of oyster mortality in this Texas bay is disease and disease is promoted by high water salinity conditions. The authors then pointed to research results from another citation by Soniat et al. 1989, which claimed that high salinity conditions promote disease and disease can cause a condition of low oyster abundance in a very large section of a Texas bay. In summary, the publications cited by Dr. Lipcius both suggest that oysters cannot thrive in high salinity conditions because of the proliferation of oyster disease.

iii. In the publication by Dekshenieks et al. (2000), the overall conclusion is that flood events and very low salinity conditions also cause a decline in the abundance of oysters. When water salinity increases after extreme flood events, the abundance of oysters increases. However, this statement does not mean that Dekshenieks et al. (2000) examined the fate of oysters when water salinity becomes excessively high. In fact, the highest water salinity levels addressed by this study were 18.7 ppt, 15.3 ppt, and 23.3 ppt. Consequently Apalachicola Bay, which has experienced salinities up to 30 ppt, exceeds the scope of the research addressed by Dekshenieks et al. (2000).

105. In his fourth argument against my research approach, Dr. Lipcius faulted my Expert Opinion report for not addressing whether the lack of re-shelling by the State of Florida contributed to the 2012 oyster fishery collapse in Apalachicola Bay. Dr. Lipcius argued that sustainable management of an oyster fishery requires the management of shell substrate and that the State of Florida did not deploy enough shell substrate, especially just prior to the 2012 fishery collapse. To support his argument, Dr. Lipcius provided a time series on bushels of oyster substrate deployed in Apalachicola Bay, FL from 1949–2013. Dr. Lipcius arbitrarily partitioned the time series into unequal time bins and plotted the time bins. Based solely on the plot, Dr. Lipcius concluded that the time period before the collapse was the lowest amount of shelling ever observed, and therefore, the resource was mismanaged by the State of Florida. But this

conclusion is not robust because it depends on Dr. Lipcius' arbitrary organization of the data and lack of a rigorous analysis.

a. As a result, I conducted a more rigorous analysis of the same data. I obtained a data set that consisted of the annual amount of shell deployed (yds^3) in Apalachicola Bay by the state of Florida from 1970–2015. I was not able to locate data prior to 1970.

b. Next, I divided the data set into five-year time bins. For each 5-year bin, I generated a mean and 95% Confidence Interval of the amount of shell deployed by the State of Florida.

c. The 2012 oyster fishery collapse in Apalachicola Bay was represented in the 5-year bin of 2010–2014. The 2015 data point was excluded from this analysis because there were no other data in this bin and a measure of variance in the data of this bin could not be calculated.

d. Next, I calculated a forty-year average of shell deployment from 1970–2009. If the mean (95% CI) amount of shell deployed in 2010–2014 was statistically less than the 40-year average, then Dr. Lipcius' argument would be supported. But if the mean (95% CI) amount of shell deployed in 2010–2014 did not differ statistically from the 40-year average, then Dr. Lipcius' argument would not be supported.

e. Figure 18 (FX-438) is a graph I created using generally accepted scientific principles and methodology, and it is an accurate representation of the shelling data described above. Figure 18 shows the mean (±95% CI) amount of shell deployed for each time bin as well as the long-term average (horizontal line). Because the 2010–2014 mean and its 95% CI overlapped with the long-term average, the amount of shell deployed in 2010–2014 does not differ statistically from the long-term average. Consequently, it is invalid for Dr. Lipcius to conclude that the years just prior to and during the 2012 collapse represent a period of anomalously low shelling by the State of Florida.

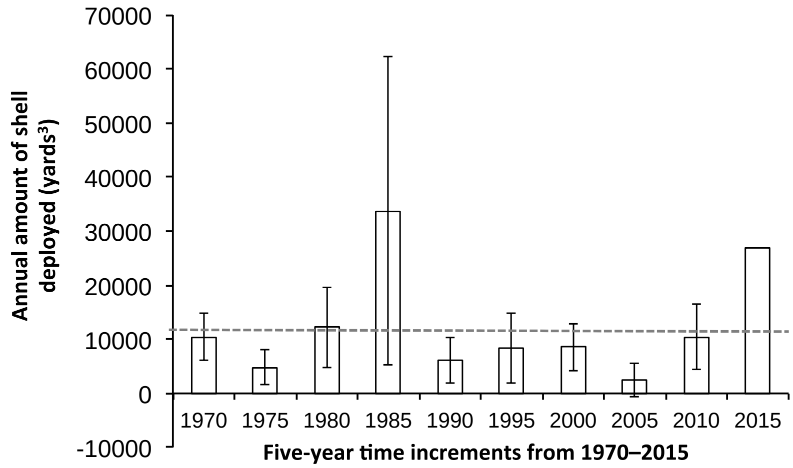

Figure 18. The results of a statistical test used to evaluate whether the amount of shell deployed into Apalachicola Bay by the State of Florida was anomalously low just prior to the 2012 oyster fishery collapse. The horizontal dash line represents the 40-year average (without the data from 2010–2015) amount of shell deployed. Because the mean and 95% Confidence Interval of the time period prior to and during the fishery collapse (2010–2014) overlaps with the 40-year average, this time period does not contain a significantly low amount of shell deployment by the State of Florida.

f. Regardless, even if the 2010–2014 mean and 95% CI had been anomalously low, Dr. Lipcius still could not conclude that a statistically significant deficiency of shelling caused the 2012 fishery collapse. Such a conclusion can only be reached by combining observational data with experiments and mathematical models.

106. Dr. Lipcius' final argument against my research concerns the timing of my experiments. Because my experiments were not conducted prior to the 2012 fishery collapse, during the collapse, and after the collapse, he argued that I could not use a Before-After-Control-Impact (BACI) design and analysis. Without a BACI analysis, he argued that I could not establish causality between elevated water salinity and the 2012 collapse of the oyster fishery.

But Dr. Lipcius is mistaken because the application of a three-pronged research approach to establish causality about complex historical patterns is not a novel scientific endeavor. In fact, the utility of such an approach has been highlighted in Ecology textbooks. Furthermore, the BACI design by itself would not work perfectly in the case of the Apalachicola Bay oyster fishery.

a. In a more simplified setting, the results of a BACI can be used to rigorously evaluate the environmental damage caused by disturbance events such as an oil spill or the installation of a nuclear power plant.

b. But as I explained above, the 2012 oyster fishery collapse in Apalachicola Bay is a much more complex scenario. As a result, it would be almost impossible to find a 'control' bay that was the same as Apalachicola Bay in all respects except for the salinity changes. For example, assuming hypothetically for comparison purposes that we used a BACI approach by beginning my experiments in Ochlockonee Bay and Apahachicola Bay in 2011, before the fishery collapse. If the results of this BACI demonstrated that predation and disease increased in Apalachicola Bay—but not Ochlockonee Bay—during 2012, then I would have concluded that something such as a change in salinity caused the difference in results. However, Dr. Lipcius and the State of Georgia could still have argued that something else differed (e.g., harvest effort) between these two complicated bays, which are not the same ecosystems. Thus, BACI design and analysis is only effective if there is only one different variable between the two places of interest, and if the researcher is aware of this single-variable difference ahead of time.

c. To understand the complex Apalachicola Bay system, a researcher must establish how changes in water salinity affect oyster survivorship, growth and births. This can be done with short-term experiments and observations. But the fishery collapse of 2012 involved a population of oysters, which is made up of many generations of oysters that all experienced different levels of water salinity and thus different levels of survivorship, growth and births over an extended time frame. Furthermore, the oyster population has fluctuated considerably over the past 30 years.

d. In order to evaluate if freshwater reductions in the upper watershed of the Apalachicola River caused the fishery collapse by elevating water salinity, we needed more than a BACI. More specifically, we needed a mathematical model that included real processes, which could be verified by experiments and observations in the real world. For instance, our experiments demonstrated that an increase in water salinity caused a certain amount of oyster mortality and this process was built into the model. With a validated model, it would be possible to examine how multiple factors (e.g., harvest, natural drought, freshwater withdrawals, predation) contributed to fluctuations in the oyster population over a long time period.

e. This ideal research approach of observations, experimentation, and modeling is not brand new. In fact, it is highlighted in basic Ecology textbooks. For example, the textbook that I use for my undergraduate Ecology course is shown in Figure 19. In chapter 14, the textbook introduces a data set that shows the cycling (regular boom and busts periods) of snowshoe hare populations in Canada over the last 200 years.

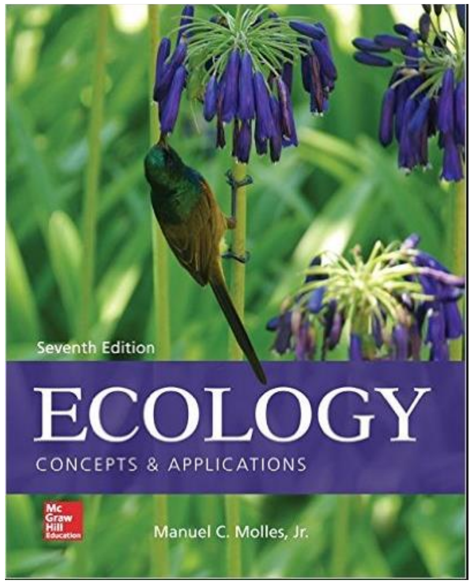

Figure 19. Image of text book that is used in Dr. Kimbro's undergraduate level course in Ecology at Northeastern University. Chapter 14 of the textbook highlights a well-known example of research that used observations, experiments, and modeling to understand what causes populations of Canadian lynx (predator) and snowshoe hare (prey) to cycle over a 200-year time frame. These conclusions were reached and accepted even though experiments were not conducted 201 years ago.

f. The textbook explains that this long-term cycling of snowshoe hare abundance could be caused by boom and bust periods in the abundance of predators (Canadian lynx) and/or fluctuations in the food supply for snowshoe hare.

g. To evaluate the cause of the snowshoe hare cycling, researchers conducted an 8-year experiment outdoors that controlled the abundance of lynx and the food supply for snowshoe hare.

h. The results of the experiment demonstrated that both predators and food supply may be important to the cycling in different ways. But to fully test this experimental conclusion, the researchers had to construct a mathematical model that included real processes confirmed by the experiments. Only with the use of this validated model were the researchers able to conclude that fluctuations in snowshoe hare populations are caused both by fluctuations in lynx abundance and the food supply for the snowshoe hare.

i. More recently, a research team updated the mathematical model with additional processes that they learned from more recent observations and experiments. This updated model provided further insight into the causes of long-term fluctuations in the abundance of the snowshoe hare population. This research was published in one of the most prestigious scientific journals in our nation: *Proceedings of the National Academy of Sciences of the United States of America*.

j. In summary, the application of a three-pronged research approach to establish causality about complex historical patterns is not a novel scientific endeavor. In fact, I suspect that all professional Ecologists and undergraduate Ecology students are aware of the application of this approach.

J. The Path Forward

107. The oyster reefs of Apalachicola are not healthy, but this degraded state is not irreversible. But without a sustained increase in freshwater from the Apalachicola River, however, any restoration efforts will be undermined by prolonged periods of high salinity and the proliferation of oyster disease, predators, and recruitment failure. A well-accepted concept in the field of Ecology is that all species have their unique environmental and biological requirements, which is referred to as the species' ecological niche. If a species is placed outside of its ecological niche, then it will not persist. The Eastern oyster in Apalachicola Bay is no different.