Climate Change: Effects on Salinity in Florida's Estuaries and Responses of Oysters, Seagrass, and Other Animal and Plant Life[1]

Karl Havens[2]

Summary

Florida's economically important estuaries could be heavily impacted by sea-level rise and altered river flow, both caused by climate change. The resulting higher salinity, or saltiness of the water, could harm plants and animals, alter fish and bird habitat, and reduce the capacity of estuaries to provide such important services as seafood production and the protection of shorelines from erosion.

Introduction

Estuaries are one of the most productive kinds of ecosystems on earth, and they support a high diversity of fish, birds, and other kinds of plants and animals. Estuaries are bodies of water along the coastline that can be relatively enclosed bays or wide marshes at river mouths. They are places where fresh water from rivers mixes with saltwater from the sea, creating a place with intermediate salinity. On average, the salinity of the open ocean is 35 parts per thousand (ppt). The salinity of rivers can range from 0.1 to 5 ppt. In estuaries, salinity is highly variable because of tidal effects and because of variation in freshwater inflow from rivers (Figure 1). (While the term estuary is mostly used for coastal systems where salty and fresh water mix, since the 1970s it also has been used to describe drowned river mouths in the Great Lakes, where nutrient- and sediment-rich river water mixes with water from the open lake in a very similar manner. The Great Lakes even have small tides generated by wind, so water moves in and out much like it does in the ocean.)

Figure 1. Salinity, typically measured in units of parts per thousand (ppt), is the amount of salt that is present in water. In freshwater lakes, springs, and ponds it usually is near zero. In the ocean it averages about 35 ppt, and in estuaries it ranges from less than 1 to over 30 ppt. Organisms that live in water are sensitive to salinity and tend to occur only within a certain range.
Credits: Adapted from Peter Summerlin, Louisiana State University

1. This document is SGEF-218, one of a series of the Florida Sea Grant College Program, UF/IFAS Extension. Original publication date June 2015. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Karl Havens, director, Florida Sea Grant College Program, UF/IFAS Extension, Gainesville, FL 32611.

When freshwater inputs are low, an estuary can become as salty as the adjacent ocean. When freshwater inputs are high, an estuary can become entirely fresh. Even during times of normal river flow, salinity in an estuary varies between high and low tide. The salinity is higher during high tide because more ocean water is moving in. Salinity is lower at low tide because freshwater is moving out as the ocean level is receding.

Estuaries have a high economic value for Florida. About 80 to 90 percent of the commercial seafood species caught off Florida's coasts, including shrimp, crabs, oysters, lobsters, and certain groupers and snappers, depend on estuaries for at least part of their life cycles. Marine fisheries depend on the mangrove, marsh, and seagrass habitats in estuaries for spawning and for protection of juveniles. Those habitats also are places where food resources are plentiful. The grasses and mangroves around estuaries also provide habitat for millions of birds. Oyster reefs in estuaries serve as important wave breaks that help protect coastal communities during storms.

The organisms that live in estuaries (Figure 2 and Figure 3) are adapted to the variations in salinity. Typically, there is a gradient from species that prefer fresher water at the upstream river end of the estuary to species that prefer saltier water at the downstream ocean end.

Figure 2. Photographs of healthy beds of seagrass.
Credits: Paul Asman and Jill Lenoble

As examples, the freshwater plant *Vallisneria*, or wild celery, occurs at the upper end of estuaries and in rivers, and it prefers salinities in the range of 0 to about 5 ppt. It can tolerate salinities up to 18 ppt, but only for short periods of time (Doering, Chamberlain, and McMunigal 2001). Farther toward the ocean, plants like *Thallasia*, a common type of seagrass, prefer salinities in the 30 to 40 ppt range, but can tolerate lower salinities for short periods of time, such as when there is a large discharge of fresh water from a river into the estuary (Lirman and Cropper 2003).

Crassostrea virginica, the eastern oyster, has a preferred salinity range of 14 to 28 ppt (Shumway 1996), but it can tolerate short exposures to fresh water or ocean water.

Figure 3. The oyster bed is photographed at low tide when the animals are exposed to the air. These are called inter-tidal oyster beds. In some places in Florida, where the water is deeper in the estuary, the oysters always are underwater. These are called sub-tidal oyster beds.
Credits: UF/IFAS photo

Plants and animals in estuaries are harmed when unusually high salinities persist for prolonged periods of time. Harm also can occur during periods of high freshwater inputs from rivers. In both cases, extreme events are the issue.

The higher salinity, reduced nutrient input, and reduced sediment inputs associated with extreme low river inflow can stress or kill plants and animals; diminish productivity due to lack of nutrients; and kill marshes due to reduced sediment input. With extreme high river inflow, on the other hand, low estuary salinity kills marine organisms; high nutrient inputs contribute to algal blooms; and increased sediment input smothers sea grasses and oysters.

Examples of Stress from Extreme High Salinity

The following are examples of harm caused to estuaries due both to periods of high salinity from extreme low freshwater input, and to periods of low salinity from extreme high freshwater input.

In 1987, a massive amount of seagrass died in Florida Bay, which is located at the southernmost end of the Florida peninsula. The cause of the die-off was the subject of a considerable amount of research. Hypotheses about the die-off included (no : needed): an overabundance of nutrients that stimulated algae blooms, stirring up of sediments by a hurricane, and high salinity.

For several years after 1987, salinity in Florida Bay went into the hyper-saline range, which means much saltier than sea water, at more than 46 ppt. Earlier studies conducted in Biscayne Bay indicated that at 40 ppt salinity, there was reduced seagrass growth. It is thought that the die-off in Florida Bay and the switch to an algae-dominated ecosystem was due in part to the hyper-salinity (Zieman, Fourqurean, and Frankovich 1999).

In the fall of 2012, Apalachicola Bay, located in the Big Bend region of Florida next to the northeast corner of the Gulf of Mexico, experienced a rapid decline in its oyster population. It coincided with salinities as high as the adjacent ocean, caused by two successive years of record low river inflows. It also coincided with high levels of oyster predators, such as crabs and conchs; parasites, such as worms, snails, and sponges (Figure 4); and pathogens, such as *Perkinsus*, a group of single-cell organisms that infect certain marine animals. Research documented that the sudden collapse of the oyster population was associated with a die-off of juvenile oysters (Havens et al. 2013). It is not known which specific factor (e.g., physiological stress from high salinity, predators, parasites, or pathogens) caused that response. It may have been a perfect storm of conditions harmful to oysters that resulted from the low inputs of fresh water and resulting high salinity.

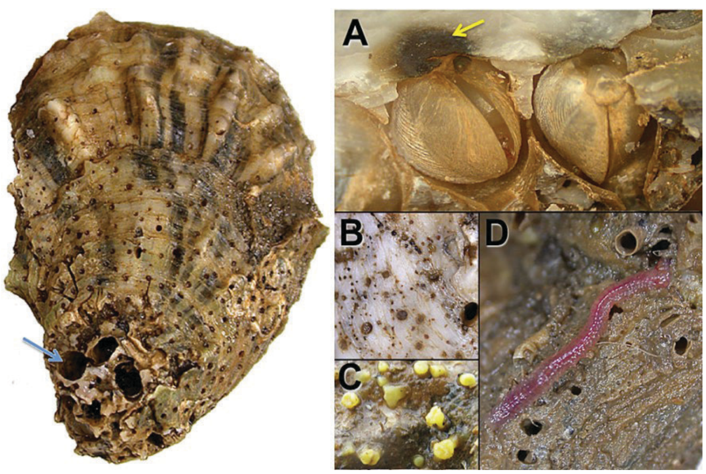

Figure 4. This image shows the condition of oysters two years into a severe drought, low river inflow, and high salinity. The images show how oysters have been parasitized. Panel A shows a parasitic clam that bores a hole into the oyster shell to feed (at the place of the yellow arrow). Panel B shows smaller holes made by boring sponges, and Panel C shows the live sponges on a shell. Panel D shows a boring worm and some of the holes it makes when feeding. The larger image on the left shows large holes left in an oyster shell by boring clams (the blue arrow).
Credits: Andrew Kane, University of Florida

An earlier decline in oysters in Apalachicola Bay was documented by Petes, Brown, and Knight (2012). They also found that during a time of reduced freshwater inflows and elevated salinities, oysters experienced mortality. They attributed the deaths to *Perkinsus* pathogens and suggested that the growth of *Perkinsus* populations was enhanced by the high salinity. The study also identified a situation seen in other research, namely that there was a synergistic negative effect of high salinity and high water temperature on oyster health.

The St. Lucie Estuary, located along the Atlantic coast of Florida, periodically receives large discharges of fresh water from Lake Okeechobee via a canal that was built between the lake and estuary in the 1960s. When this happens, a variety of negative effects occurs (Sime 2005), including reduced transparency, loss of submerged plants, impacts to oysters, and sometimes algae blooms.

Freshwater inputs also bring large amounts of nutrients. Usually these do not stimulate blooms of algae because the water is moving too fast for them to proliferate (Phlips et al. 2012), but under certain conditions blooms, have occurred. For example, in the summer of 2005, there was a large bloom of the toxic blue-green alga *Microcystis aeruginosa* in Lake Okeechobee. A discharge of water from the lake carried a massive quantity of algae into the St. Lucie Estuary. The estuary water, including that in marinas and the boat-mooring areas in front of people's homes and condominiums, was pea green and foul smelling for weeks (Figure 5).

Figure 5. The summer 2005 blue-green algae bloom in the St. Lucie estuary.
Credits: Ed Phlips, University of Florida

Projected Changes in Climate That Could Affect Salinity in Estuaries

Climate change is expected to cause two major responses that will directly affect the salinity of estuaries: (1) altered river flow, and (2) a continued rise in sea level. The Intergovernmental Panel on Climate Change (IPCC 2013) projects that global average sea level will rise between 1 and 3 feet during this century, and that it is "virtually certain" that sea level will continue to rise after 2100. If global warming passes a certain threshold, projected to be between 2°F and 3°F, there could be near-complete loss of the Greenland Ice Sheet, causing a global mean sea-level rise of over 23 feet.

At the same time that sea levels are rising, climate change is expected to influence the pattern of rainfall and drought. Wuebbles et al. (2014) ran 40 climate models and found that they all gave common predictions for the future: warming of the atmosphere and soil, lower relative humidity across the United States, and an increase in the duration, frequency, and intensity of droughts. Murray, Foster, and Prentice (2012) ran several climate models, and they all predicted that in this century, climate change and population growth will result in increased global water stress. Sheffield and Wood (2008) projected that there will be a doubling in the frequency of droughts lasting 4 to 6 months and a three-fold increase in the frequency of droughts lasting longer than a year.

What do these changes—altered river flow and continuing sea level rise—mean for estuaries and their salinity? In regard to river flow, there will be prolonged periods of low flow during droughts and then short periods of extreme high flow. Because the interaction of the ocean and river water is what creates the intermediate salinity of estuaries, the expected outcome is long periods of higher estuarine salinity interrupted for short periods with a flush of fresh water. Higher sea level will exacerbate the high salinity during low-flow periods (Figure 6).

How Changes May Affect Estuarine Plants and Animals

A future in which sea-level rise causes more salty ocean water moving into estuaries and longer-lasting droughts causing periods of reduced freshwater input could stress estuarine organisms. The range of salinity may exceed what is optimal for their growth and even exceed what they can tolerate (Figure 7). Species that cannot swim might be greatly reduced in numbers. Others might be able to migrate farther upstream into the rivers that feed the estuary to reach a place where they can tolerate the salinity.

One problem is that most of Florida's estuaries, with the exception of Florida Bay, are fed by rivers that are much narrower than the estuary and often are kept deeper for boat traffic, so there is much less space for estuary organisms to exploit, and the sediments may not support their growth.

Figure 6. Conceptual illustration showing current conditions of river inflow and ocean water incursion to an estuary (left) compared to a future situation with reduced river flow and increased ocean water incursion due to higher sea levels (right). The estuary of the future is saltier, except at times of extreme rainfall and high river inflow. Rainfall is predicted to be heavier in the future because with a warmer atmosphere that can hold more moisture, storms will be more intense.
Credits: Florida Sea Grant

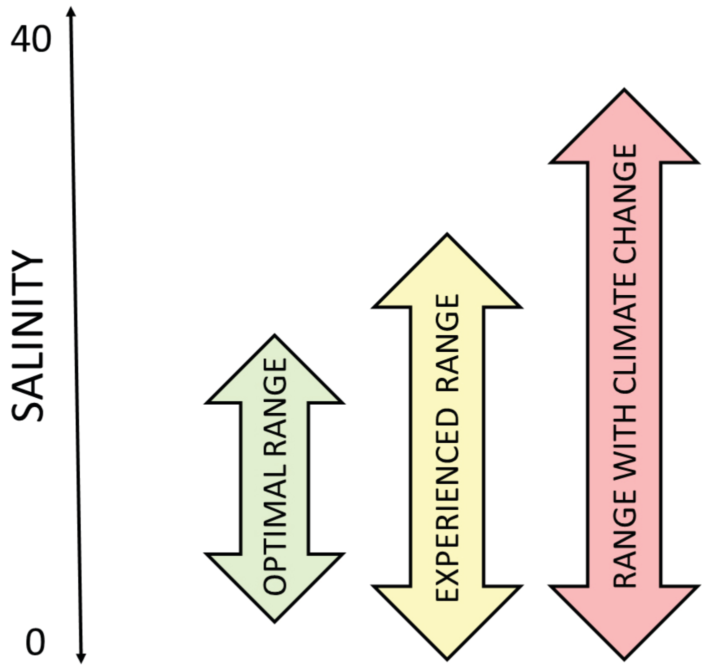

Figure 7. Conceptual illustration of salinity ranges experienced by plants and animals in estuaries. This figure compares the optimal range for growth, the range they actually experience, which includes some periods of drought and flood, and the range they might experience with climate change when there is higher sea level and prolonged droughts.
Credits: Florida Sea Grant

There is a rich scientific literature on the relationship between freshwater inflow and subsequent commercial landings of fish and shell fish. Catch is generally reduced in response to interruptions in freshwater supply caused by droughts. The expectation is that that with climate change and the increased frequency of droughts, production of many species of commercially important fish will decline. In addition, the higher frequency of extremes (very high and very low flows) will change both species composition and patterns of energy flow.

If the salinity of places like Biscayne Bay, Apalachicola Bay, and Tampa Bay increases into the 35 ppt range, ocean-dwelling predators, parasites, and pathogens will be able to thrive in the estuaries and eat oysters. Wild celery and other low-salinity-adapted species of plants at the upper end of the estuary may be constrained to a smaller space or may not be able to which could affect the estuary food web. It is unclear how these changes will affect the productivity of economically important fisheries, but estuaries are likely to become very different.

Mitigating Climate Change Effects

One of the big unknowns that will affect river flow into estuaries is the use of fresh water by people. It is critical now and especially in a future with increased droughts that water be used in as conservative a manner as possible for power generation, which is the largest user of water in the United States, and for urban and agricultural areas.

Florida's water management districts have protocols and plans to minimize wasteful use of fresh water, and they need to be followed. The average person in Florida may think that we are a state with plentiful water. Yet, the reality is that our aquifers are being drawn down. We also have networks of coastal canals that quickly discharge water to the ocean during the rainy season to protect our buildings and crops from flooding. That water is essentially wasted because it no longer is available in the dry season. This also affects coastal ecosystems because when water is quickly discharged in the rainy season, it causes harm to salt-tolerant species. In the dry season, there often is not enough freshwater flow to sustain species that cannot tolerate high salinity.

This management scheme needs to change and may require costly water storage facilities to capture some or all of that water for later use when rainfall is scarce. More broadly, Floridians can be aware of global actions needed to reduce carbon emissions to the atmosphere so that global warming does not exceed a threshold where catastrophic effects occur, not only to estuaries, but also to our coastal cities and economies.

Other Effects of Climate Change on Estuaries

This fact sheet focused on effects of climate change resulting from altered salinity in estuaries. It did not consider some of the other substantive changes that may occur and that will be addressed in other fact sheets.

Those changes include loss of wetland habitat. Mangroves and salt marshes in the shallow water of estuaries may be affected by large rises in sea level, which could result in these plants and the important habitat they provide for fish and birds moving upstream. At some point, however, the plants may run out of places to move because the estuary constricts at a deep river entry point and because many of our estuaries are surrounded by residential and urban development with hardened sea walls.

Another change that may occur because of warming water is the intensification of toxic algae blooms and of disease-causing microorganisms. Increased temperature stimulates faster growth of those organisms and leads to a greater amount of them in the water—with potential negative effects on fish, oysters, clams, and people who recreate in or live near the water. This particular topic is covered in Climate Change and the Occurrence of Harmful microorganisms in Florida's Ocean and Coastal Waters (http://edis.ifas.ufl.edu/sg136), available on EDIS. by Havens (2015).

For additional general information on estuaries, see the following online from NOAA:

http://oceanservice.noaa.gov/education/tutorial_estuaries/welcome.html

Literature Cited

Doering, P.H., R.H. Chamberlain, and M. McMunigal. 2001. Effects of simulated saltwater intrusions on the growth and survival of wild celery, *Vallisneria Americana*, from the Caloosahatchee Estuary (South Florida). *Estuaries* 24: 894–903.

Havens, K.E. 2015. *Climate change and the occurrence of harmful microorganisms in Florida's ocean and coastal waters*. Florida Sea Grant Program, University of Florida Institute of Food and Agricultural Sciences. http://edis.ifas.ufl.edu/sg136.

Havens, K.E., M. Allen, E. Camp, T. Irani, A. Lindsey, J.G. Morris, A. Kane, D. Kimbro, S. Otwell, W. Pine, and C. Walters. 2013. Apalachicola bay oyster situation report. Florida Sea Grant, University of Florida, TP-200, 30 pp.

IPCC 2013. Working group I contribution to the IPCC fifth assessment report. Climate change 2013: the physical science basis. Intergovernmental Panel on Climate Change.

Lirman, D., and W.P. Cropper, Jr. 2003. The influence of salinity on seagrass growth, survivorship, and distribution within Biscayne Bay, Florida: experimental and modeling studies. *Estuaries* 26: 131–141.

Murray, S.J., P.N. Foster, and I.C. Prentice. 2012. Future global water resources with respect to climate change and water withdrawals as estimated by a dynamic global vegetation model. *Journal of Hydrology* 448: 14–29.

Petes, L.E., A.J. Brown, and C.R. Knight. 2012. Impacts of upstream drought and water withdrawals on the health and survival of downstream estuarine oyster populations. *Ecology and Evolution* 2: 1712–1724.

Phlips, E.J., S. Badylak, J. Hart, D. Haunert, J. Lockwood, K. O-Donnell, D. Sun, P. Viveros, and M. Yilmaz. 2012. Climatic influences on autochthonous and allochthonous phytoplankton blooms in a subtropical estuary, St. Lucie Estuary, Florida, USA. *Estuaries and Coasts* 35: 335–352.

Sheffield, J., and E.F. Wood. 2008. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. *Climate Dynamics* 31: 79–105.

Shumway, S. 1996. Natural environmental factors. In: V.S. Kennedy , R.I.E. Newell and A.F. Eble (eds). The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant, University of Maryland, College Park, MD, pp. 467–513.

Sime, P. 2005. St. Lucie Estuary and Indian River Lagoon conceptual ecological model. *Wetlands* 25: 898–907.

Wuebbles, D., G. Meehl, K. Hayhoe, T.R. Karl, K. Kunkel, B. Santer, M. Wehner, B. Colle, E.M. Fischer, R. Fu, A. Goodman, E. Janssen, V. Kharin, H. Lee, W. Li, L.N. Long, S.C. Olsen, Z. Pan, A. Seth, J. Sheffield, and L. Sun. 2014. CMIP5 climate model analysis: climate extremes in the United States. *Bulletin of the American Meteorological Society* 95: 571–583.

Zieman, J.C., J.W. Fourqurean, and T.A. Frankovich. 1999. Seagrass die-off in Florida Bay: long-term trends in abundance and growth of turtle grass: *Thalassia testudinum*. *Estuaries* 22: 460–470.