The Effects of Climate Change and Excess Nutrients on Hypoxia Levels and Eutrophication in Estuaries

Emma Zanfardino

TSEM 190: Honors Towson Seminar

Professor Elliott

May 17th, 2020

Introduction

Water is all around us. It keeps us alive, by growing our food and quenching our thirst, and helps us be productive, in our factories and homes. But before we as humans took control of our Earth's resources, the ecosystems were highly productive and provided a safe habitat for various species all over the world. One of the most productive ecosystems in the world is the estuary. An estuary is the area where freshwater and saltwater mix (Evers, 2012). Marine estuaries occur when a freshwater source, such as a river, empties into saltwater, such as the ocean. The estuary itself contains brackish water, which is a combination of freshwater and saltwater. One of the most common types of marine estuaries is the coastal plain estuary. These estuaries are located along the coast and are formed when the sea level from the ocean rises and flows into an already existing river valley. The largest coastal estuary in the United States is the Chesapeake Bay as the bay's watershed is around 64,000 square miles ("Where is the largest estuary in the United States?", n.d.). A body of water this big provides a tremendous amount of ecological services, or a natural process from healthy ecosystems that improve the overall ecosystem. Estuaries in particular are one of the most productive ecosystems as they provide a variety of ecological services including water filtration and habitat protection ("Basic information about estuaries", n.d.). If an estuary becomes polluted, they are no longer able to produce these benefits for the ecosystem or humans. Eutrophication, or a devastating algae bloom as a result of increased amounts of nutrients present, can cause dead zones from a lack of oxygen in the water, otherwise known as hypoxia ("Nutrients and eutrophication", n.d.). When these dead zones occur, they hinder the estuary's ability to provide habitat for a variety of species that use the area to raise offspring and ability to filter the water. In this paper I will be analyzing various studies to understand the effects of the overuse of fertilizers and climate change on estuaries. The main question I am studying is: what are the effects of climate change and the overuse of fertilizers on hypoxia in estuaries? Within the Literature Review, I discuss the methods used in the research from four different studies as well as the results found at the end of each study. In the Analysis, I break down the results and expand upon what these results mean in terms of estuarine health, as well as discussing the possible solutions mentioned in the studies. In analyzing this I find a strong correlation between fertilizer use and hypoxia levels, as well as climate change and hypoxia levels, and possible solutions and preventative measures to lessen any negative effects on the estuaries.

Literature Review

The study *Environmental response of an Irish estuary to changing land management practices* focused on an estuary located in Ireland called the Blackwater catchment and estuary. The estuary was originally declared eutrophic by the Environmental Protection Agency's Trophic Status Assessment Scheme (TSAS) but restoration projects began around 1990 to help restore the watershed to its natural form (Ní Longphuirt et al., 2015). Eutrophication occurs when an excess of nutrients, usually nitrogen or phosphorus, enters a body of water and causes an algal bloom, depleting the oxygen concentration in the water which then results in hypoxia or a "dead zone" where no organisms can survive in the body of water due to the lack of oxygen. The main goals of this research were to "to examine potential links between trends in calculated catchment nutrient loads, measured river loads and downstream estuarine concentrations, to determine the impacts of any changes on physio-chemical and biological parameters within the estuarine system, and to identify the measures that have been most effective in reducing nutrient loss from the catchment to the estuary" (Ní Longphuirt et al., 2015). The researchers collected data from 1990 to 2010 on the amount of both organic and inorganic fertilizers being used in the area, leaching of nutrients of other “landcover categories” such as urban areas or nearby forestry, and the amount of rural populations and industries without sewage which would allow nutrients to leach more easily. The results showed that between the years 1990 and 2000, there was “a slight (2%) increase in N load estimations” and “P loadings were reduced by 9%” and between the years 2000 and 2010, there was an 18% decrease in nitrogen (N) and a 20% decrease of phosphorus (P) (Ní Longphuirt et al., 2015). A cover load, sometimes known as a critical load, refers to "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (“Critical load”, 2018). Ireland, in an effort to decrease the amount of nutrient pollution and improve overall estuary health, introduced restrictions on many synthetic fertilizers (Ní Longphuirt et al., 2015). This worked, as the overall amount of excess nutrients found in the Blackwater catchment and estuary decreased drastically, proving that an excess of fertilizer use leads to the high nutrient pollution in an estuary.

The study *Growth, Condition, and Maturity Schedules of an Estuarine Fish Species Change in Estuaries Following Increased Hypoxia due to Climate Change* was conducted in Australia. The estuaries focused on were the Moore River Estuary, Swan River Estuary, Peel-Harvey Estuary, Blackwood River Estuary, Walpole-Nornalup Inlet, Wilson Inlet, Beaufort Inlet, and the Wellstead Estuary (Cottingham et al., 2018). Data on the average rainfall between 1990 and 2015 for the area surrounding each of these bodies of water were collected from nearby weather stations, as well as data on the annual freshwater discharge in order to test if there was a significant relationship between the two (Cottingham et al., 2018). The results found a positive correlation between them, meaning that when annual rainfall decreases, freshwater discharge decreases as well. Next, the researchers created a box model, highlighting the relationship between oxygen concentration within the water and the amount of freshwater discharge into the estuary. The results showed as freshwater discharge declined, the levels of hypoxia increased (Cottingham et al., 2018). Since hypoxia is caused by a lack of dissolved oxygen, the study found there was a positive correlation between freshwater discharge and dissolved oxygen concentrations, as they both declined. Dissolved oxygen is the measure used to determine how much oxygen is present in the water and therefore available to organisms in the water ("Dissolved oxygen and water", n.d.). The results showed that various estuaries, the Moore River, Swan River, and Wellstead estuaries as well as the Walpole-Nornalup Inlet, located in different areas with different biochemical components, and water depths all experience the same correlation (Cottingham et al., 2018). Although the watersheds with shallower areas don't show as drastic of a decrease in dissolved oxygen concentration compared to those that reach much deeper depths, the presence of any decrease in dissolved oxygen concentration when there is a decrease in freshwater discharge supports the positive relationship between the two.

The goal of the study *Modelling Climate Change Impacts on Nutrients and Primary Production in Coastal Waters* was to establish a projection of "the impacts of climate change on freshwater inputs, nutrient loadings and the effect on the phytoplankton community of the receiving waterbody…" (Pesce et al., 2018). Phytoplankton are essential to ocean and freshwater basin ecosystems as they are a group of small, oftentimes microscopic, plankton made up of bacteria, protists, and single-celled plants or algae that can undergo the process of photosynthesis and sometimes chemosynthesis to produce oxygen within these aquatic environments. Since phytoplankton are able to convert solar energy into a usable form for many of these aquatic ecosystems, they are essential primary producers as well as playing an essential role in many biogeochemical processes like the oxygen, carbon, and nutrient cycles. Phytoplankton levels in an ecosystem are limited by environmental drivers such as “water temperature, light penetration, tides, salinity, and nutrient availability” which is then highly influenced by the effects of climate change (Pesce et al., 2018). The study itself took place in the lagoon of Venice, Italy and focused heavily on the Zero river basin and the salt-marsh of Palude di Cona in order to cover two different bodies of water that are affected by different things. The Zero river basin, for example, is located near land that is mostly used for agriculture, growing crops such as corn, soy, and wheat as well as raising livestock, with the rest being mostly urban and industrial areas (Pesce et al., 2018). The proximity of this development increases the risk of any chemicals and fertilizers entering the waterway due to runoff, which can throw off the nutrient composition of the water and have a negative effect on the phytoplankton. On the other hand, the Palude di Cona is a salt-marsh with much shallower water than the Zero water basin which makes the water temperature mirror the air temperature, as the shallow water can heat and cool to match the air around it much quicker, making it highly susceptible to the changing temperatures that climate change may bring (Pesce et al., 2018). Researchers ran various models to project future impacts temperature and precipitation will have on the freshwater discharge and nutrient levels and found that there was a projected increase of both freshwater discharge and precipitation during the winter months, while in the summer both declined (Pesce et al., 2018). This in turn caused an overall increase in nutrient loadings annually, but with an increase of nutrients during the winter and a decrease during the summer.

The study *Societal Phosphorus Metabolism in Future Coastal Environments: Insights from Recent Trends in Louisiana, USA* was conducted in the Upper Pontchartrain Basin in parts of Louisiana and Mississippi, but focused mainly on the levels of phosphorus (P) that travel through the watershed as runoff and eventually enter the Lake Pontchartrain estuary. The paths taken by the P were split into the categories "...agricultural, forested/wetland, and urban/developed landscapes" and calculated. Since P is a biochemical cycle, it is recycled through the environment through the phosphorus cycle and the researchers allowed some room for error to account for the recycling of P (Roy et al., 2014). This study specifically recorded data of the price of fertilizer in the US from 1985 until 2010 as well as the amount of fertilizer purchased in the Upper Pontchartrain Basin area from 2000 to 2010. What researchers noticed was that "DAP prices began to increase gradually at first and then rapidly between 2006 and 2008 to 3.5 times the 1985–2002 mean" meaning the DAP, or diammonium phosphate, fertilizer was being priced so high that eventually, people couldn't afford it and there was a substantial decrease in the amount of fertilizer being purchased and used between 2006 and 2010 (Roy et al., 2014). This may be one of the reasons that led to the rapid decline of P levels in the Lake Pontchartrain estuary and surrounding watershed. Another reason may be changes in the food production system located within the basin area. Raising cattle, whether for milk or beef, is taxing on the environment as cattle require large amounts of feed, which is grown with fertilizers to speed up the process and increase yield. Raising dairy cows especially adds excess nutrients through their manure as they produce large quantities of manure in their lifetime that can then be carried through the watershed into the nearby estuary through runoff. Between 2001 and 2010, there was a large reduction in milk production in the area, with the industry instead shifting to animals that graze on pastures instead of using large quantities of feed (Roy et al., 2014).

Collectively, these studies show the negative impacts of nutrient pollution and climate change on hypoxia in estuaries. Cottingham et al. (2018) and Pesce et al. (2018) both focus on the impact of climate change, focusing heavily on its effects on annual rainfall, temperature, freshwater discharge, and dissolved oxygen concentrations within and around the estuary. On the other hand, Ní Longphuirt et al. (2015) and Roy et al. (2014) focus on the effects of nutrient pollution on hypoxia and eutrophication levels in estuaries. All of this research combined, helps people become more aware of the negative effects on estuaries and encourages them to implement new practices and solutions, some of which I will discuss further in my Analysis.

Analysis

These studies provide a lot of research with important ramifications that I will highlight in this section. First, the focus on the impact of fertilizers on nutrient levels in bodies of water in both Ní Longphuirt et al. (2015) and Roy et al. (2014) have provided research showing that levels of nitrogen (N) and phosphorus (P) in excess have a negative impact on both estuaries and other bodies of water and provided potential solutions on how to manage the use of fertilizers sustainably. Ní Longphuirt et al. (2015) found that calculated and measured N and P levels had begun to reduce and they attributed this to the recent decrease in agriculture byproducts and waste that spreads from the original farms. I agree with this attribution because if there are less nutrients, N and P, being used in excess then there isn’t as much nutrient waste running off into the surrounding areas, negatively impacting local waterways. It is important to note, however, that even though individual farms may not feel as if they are using fertilizers in an excess that would impact waterways, every farm along a watershed contributes to the total amount of nutrients in a body of water. This is why it is important to ensure that every farm, not just one or two, is aware and consciously trying to limit the use of synthetic fertilizers.

Regulation measures put into place by local or national governments are also important in holding agricultural businesses accountable. The Good Agricultural Practice regulations were put into place in 2009 to limit the "...magnitude, application, timing, rates, storage and placement of inorganic fertilizers and organic manures containing Nitrogen and Phosphorus" and the Local Government (Water Pollution) Act 1977 (Water Quality Standards for Phosphorus) Regulations 1998[1] was created to inform local authorities the best ways to plan the management of nutrient levels and improve water quality in the local area (Ní Longphuirt et al., 2015). These measures are good first steps to improving public awareness about the need to limit excess of nutrients, but in order to prevent eutrophication of estuaries and other bodies of water, there need to be measures that are tailored to each estuary. Restrictions that work in a small agricultural center that isn't near an estuary, won't work in an area that relies on agriculture heavily and is right upstream from an estuary.

Roy et al. (2014) focused on what causes decreases in fertilizer use other than legislation. The study found that "...fertilizer economics can have a profound impact on societal P metabolism at a regional/basin spatial scale" (Roy et al., 2014). This makes sense because if fertilizers are too expensive then farmers won't be able to afford it or will decide the investment isn't worth it. In years when the fertilizer prices spiked, there was a decrease in the amount of excess nutrients found in the nearby waterways and because of this there was less overall hypoxia of the local water. Roy et al. (2014) propose that, as a way to lessen eutrophication and encourage more efficient nutrient use among farmers, "future price increases for inorganic P fertilizer could be driven intentionally by policy…". This is a policy that could work in theory, although there definitely would be pushback. This would somewhat work because if the prices are too high, the farmers won't buy and apply the fertilizer, which would lessen runoff and

[1] There are two dates within this title because the original legislation, the Local Government (Water Pollution) Act, 1977 has been revisited and revised with new amendments over the years. Each time it is revisited, the newly amended legislation carries both the original title, Local Government (Water Pollution) Act, 1977, and a new one, (Water Quality Standards for Phosphorus) Regulations,1998, added on.

overall hypoxia. However, larger agricultural farms may be able to still afford to buy fertilizer and larger farms tend to use more fertilizers than smaller farms, so raising the price might not control the larger corporations. Another issue is the backlash; if the prices are dramatically increased overnight, there will be a lot of public outcry especially from the smaller farms who won’t be able to afford any and because their crop yield will suffer if they don’t have an alternative fertilizer immediately. I believe that a gradual increase or a tiered price system would work better at mitigating a strong outcry and would give the public more time to learn about more organic sources of P, such as poultry litter.

Both studies by Pesce et al. (2018) and Cottingham et al. (2018) focus on the impact of climate change on nutrient and hypoxia levels and their impact on the estuary’s health. Pesce et al. (2018) recorded that increased temperatures in the winter increase the amount of rainfall. More rain in winter leads to greater amounts of runoff because there aren’t as many plants that can absorb the water before it runs into a stream or estuary as well as other negative impacts on the ecosystem, such as erosion or mudslides. Pesce et al. (2018) also concluded that higher temperatures in summer will disturb the typical ranges of N that are influenced by temperature and soil water content and that overall temperature increases will lead to increased hypoxia. I agree that increased temperatures will cause hypoxia because oxygen’s solubility is most efficient at specific temperatures, typically lower temperatures. If the temperatures continue to rise, then the dissolved oxygen concentration of estuaries and other bodies of water will begin to decrease drastically as the oxygen is escaping the water, causing hypoxic conditions that prevent organisms from living in the water. Cottingham et al. (2018) studied the effects of climate change and increased hypoxia on the growth of the *A. butcheri*, or the southern bream as it’s more commonly called, and determined that difference in temperatures and salinity levels “...are not primarily responsible for the large variations in the growth of *A. butcheri* among estuaries in south-western Australia”. I agree with this conclusion because increases in hypoxia and eutrophication, both of which negatively impact the growth of organisms who live in the estuary, can be caused from a variety of factors including amount of rainfall or the dissolved oxygen concentration of the estuary, and a combination of some or all of these factors is more likely to cause a disturbance in growth patterns than just one. Both Pesce et al. (2018) and Cottingham et al. (2018) conduct thorough experiments with large amounts of data that support the idea that climate change’s effects cause increased levels of hypoxia and eutrophication which negatively impact the organisms within the estuary ecosystem. However, neither study provides suggestions for solutions or plans to mitigate these negative effects determined in the data, unlike Ní Longphuirt et al. (2015) and Roy et al. (2014) which provided multiple possible solutions to the issues brought on by excess fertilizer use. Some ways that have been proven to help mitigate the effects of nutrient pollution include providing natural defenses against runoff and other sources of nutrients in excess. Planning a strategic layout of farms in the watershed of an estuary can prevent excess nutrients from entering the water (Massachusetts Wildlife Climate Action Tool, n.d.). This could range from planting crops that require more fertilizers as far away from the water as possible or even planting a ‘buffer zone’ by planting bushes or trees around the perimeter of the crops to help prevent runoff. These buffer plants prevent runoff by absorbing much of the excess water from the crops through their roots. More sustainable farming practices such as rotating crops, using livestock as natural fertilizers, and planting more polyculture plots are more effective in lessening farming’s negative impact on estuary health (Massachusetts Wildlife Climate Action Tool, n.d.). Rotating crops and polyculture plots are more diverse and prevent a single crop from using all the natural nutrients out of the soil, whereas livestock grazing on fields would fertilize the fields with manure in a more sustainable fashion.

Conclusion

Overall, the main question I set out to answer in this research paper is: what are the effects of climate change and an overuse of fertilizers on hypoxia in estuaries? In analyzing the four well conducted studies, I concluded that both climate change and nutrient pollution have widespread negative effects on estuaries such as low levels of dissolved oxygen and high levels of runoff with excess nutrients, both of which lead to high levels of hypoxia and eventually eutrophication. Estuaries are an important part of the ecosystem as they provide habitat and serve as a nursery ground for various organisms. If they become hypoxic, the organisms will lose their habitat, which may lead to the endangerment or extinction of organisms that we rely on for food or their benefits towards the overall health of the ecosystem. Everyone benefits from an estuary, whether it's through the fish we eat or the recreational activities we enjoy. If estuaries become hypoxic and eutrophic it will disrupt the benefits we receive from them. If I had more time to focus on this topic, I would next research the impact of organic fertilizers, such as manure, to determine if they are a more sustainable alternative to synthetic fertilizers. Another topic that would be important to research is if there is a specific plant that would work as the best buffer and prevent the most amount of runoff from farms and other areas that release excess nutrients into the environment. These plants can then be planted around farms and other industrial areas to filter out the nutrients before they reach a large body of water, such as an estuary. Until then, it is important to work towards reducing climate change as well as becoming more sustainable in our fertilizing habits in order to help keep our estuaries safe, healthy, and productive.

Sources

1. Cottingham, A., Huang, P., Hipsey, M. R., Hall, N. G., Ashworth, E., Williams, J., & Potter, I. C. (2018). Growth, condition, and maturity schedules of an estuarine fish species change in estuaries following increased hypoxia due to climate change. *Ecology & Evolution (20457758)*, *8*(14), 7111–7130. https://doi-org.proxy-tu.researchport.umd.edu/10.1002/ece3.4236

2. EPA. (n.d.). *Basic information about estuaries.* Environmental Protection Agency website. https://www.epa.gov/nep/basic-information-about-estuaries

3. Evers, J. (2012, Oct. 9). *Estuary.* National Geographic Society. www.nationalgeographic.org/encyclopedia/estuary/.

4. Massachusetts Wildlife Climate Action Tool. (n.d.). *Adaptation strategies and actions restore affected estuaries: Reduce nutrient pollution.* Climate action tool. https://climateactiontool.org/content/restore-affected-estuaries-reduce-nutrient-pollution

5. Ní Longphuirt, S., O'Boyle, S., & Stengel, D. B. (2015). Environmental response of an Irish estuary to changing land management practices. *Science of the Total Environment*, *521*, 388–399. https://doi-org.proxy-tu.researchport.umd.edu/10.1016/j.scitotenv.2015.03.076

6. NOAA. (n.d.). *Where is the largest estuary in the United States?* National Ocean Service website. https://oceanservice.noaa.gov/facts/chesapeake.html

7. NOAA. (n.d). *Estuaries: why are estuaries important? Ecological services.* National Ocean Service website. https://oceanservice.noaa.gov/education/kits/estuaries/estuaries03_ecosystem.html

8. Pesce, M., Critto, A., Torresan, S., Giubilato, E., Santini, M., Zirino, A., Ouyang, W., & Marcomini, A. (2018). Modelling climate change impacts on nutrients and primary production in coastal waters. *Science of the Total Environment, 628,* 919–937. https://doi-org.proxy-tu.researchport.umd.edu/10.1016/j.scitotenv.2018.02.131

9. Roy, E. D., White, J. R., & Seibert, M. (2014). Societal phosphorus metabolism in future coastal environments: Insights from recent trends in Louisiana, USA. *Global Environmental Change Part A: Human & Policy Dimensions*, *28*, 1–13. https://doi-org.proxy-tu.researchport.umd.edu/10.1016/j.gloenvcha.2014.05.009

10. USGS. (n.d.). *Dissolved oxygen and water*. USGS. Retrieved May 13, 2020, from https://www.usgs.gov/special-topic/water-science-school/science/dissolved-oxygen-and-water?qt-science_center_objects=0#qt-science_center_objects

11. USGS. (n.d.). *Nutrients and eutrophication.* United States Geological Survey. https://www.usgs.gov/mission-areas/water-resources/science/nutrients-and-eutrophication?qt-science_center_objects=0#qt-science_center_objects

12. Wikipedia contributors. (2018, August 9). *Critical load*. In *Wikipedia, The Free Encyclopedia*. Retrieved 23:05, May 13, 2020, from https://en.wikipedia.org/w/index.php?title=Critical_load&oldid=854180057