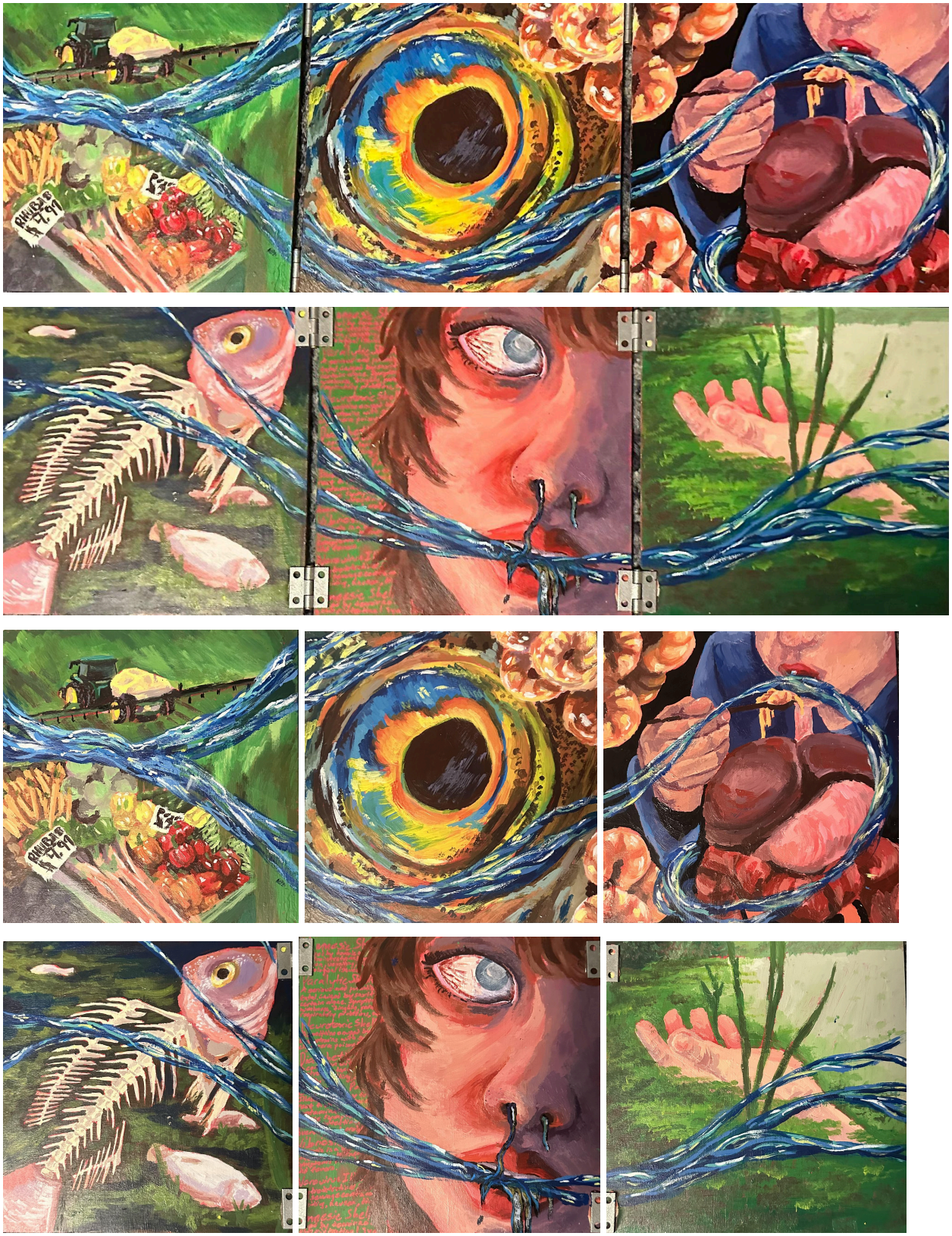

Term Project Summary

Rayna Popovic

Harmful Algal Blooms or HABS are a phenomenon where algae that releases toxins into the water to out compete other marine microorganisms increase rapidly in population size in a given area.[1] This rapid increase in recent years can be traced back to climate change,[2] as the warming waters are better for algae growth,[3] and to nutrient pollution, from the overuse of synthetic fertilizers in agricultural practices.[4] The extra fertilizer that isn't absorbed into the soil is picked up by rain water, or water from irrigation systems, and naturally flows down to nearby water reservoirs like rivers, lakes, or even coastal ocean waters. This natural return of excess water to surrounding water bodies is called run off.[5] This leads to an overabundance of nutrients called eutrophication or nutrient pollution. Eutrophication causes algal blooms as the nutrients from the synthetic fertilizer are actually one of algaes life limiting factors,[6] meaning that without these nutrients they can't survive. So their population size is directly dependent on the nutrients availability.[7] So when all of a sudden there is an increase in availability, to the point that it is always available, the algae population size explodes in a phenomenon described as a "bloom". This is incredibly harmful to the ecosystems that are affected because, although algae are producers of oxygen, if there is too much algae for primary consumers to keep up the rest that is missed dies and decomposes using up all of the oxygen in the water. This low level oxygen environment, known as anoxic conditions, decreases the amount of oxygen dependent organisms that are able to survive.[8]

If this wasn't bad enough some strands of algae produce toxins which give certain algal blooms the label of "harmful"[9] like mentioned above. The increase of algae in the water from the

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[1] Sellner, Kevin G., Gregory J. Doucette, and Gary J. Kirkpatrick. "Harmful algal blooms: causes, impacts and detection." Journal of Industrial Microbiology and Biotechnology 30 (2003): 383-406.
[2] "What is a harmful algal bloom? | National Oceanic and Atmospheric Administration." NOAA, 27 April 2016, https://www.noaa.gov/what-is-harmful-algal-bloom. Accessed 23 April 2025.
[3] Fraga, Santiago, and Andrew Bakun. "Global Climate Change and Harmful Algal Blooms: The Example of Gymnodinium catenatum on the Glacian Coast." Research Gate, Elsevier Science Publishers B.V., 1993.
[4] "What is a harmful algal bloom? | National Oceanic and Atmospheric Administration." NOAA, 27 April 2016, https://www.noaa.gov/what-is-harmful-algal-bloom. Accessed 23 April 2025.(link)
[5] Sellner, Kevin G., Gregory J. Doucette, and Gary J. Kirkpatrick. "Harmful algal blooms: causes, impacts and detection." Journal of Industrial Microbiology and Biotechnology 30 (2003): 383-406. (link pdf)
[6] Tedengren, Michael. "Eutrophication and the disrupted nitrogen cycle: this article belongs to Ambio's 50th anniversary collection. theme: eutrophication." Ambio 50.4 (2021): 733-738.
[7] Smith, Val H., and David W. Schindler. "Eutrophication science: where do we go from here?." Trends in ecology & evolution 24.4 (2009): 201-207.
[8] "What is a harmful algal bloom? | National Oceanic and Atmospheric Administration." NOAA, 27 April 2016, https://www.noaa.gov/what-is-harmful-algal-bloom. Accessed 23 April 2025.
[9] "What is a harmful algal bloom? | National Oceanic and Atmospheric Administration." NOAA, 27 April 2016, https://www.noaa.gov/what-is-harmful-algal-bloom. Accessed 23 April 2025.

increase in algal blooms has overall increased the amount of algae producing toxins and the toxins themselves in recent years. Unlike general knowledge on algal blooms and their ability to deprive marine environments of oxygen the increase in algal toxins is a subject with even less awareness. However, these toxins may be one of the more directly harmful consequences of algal blooms to human health. The toxins from algal blooms can be harmful to humans who come into direct contact with it, usually people living on the coasts of water bodies experiencing algal blooms,[10] however the toxins don't just stay in one place. Algal toxins have the ability to travel up the food chain. For example a shrimp that eats algae producing these toxins can end up with the toxins in its system. If this shrimp is then harvested and used as a source of food a human could eat it and be affected by that same toxin. Unfortunately this toxin can be super harmful causing skin irritation, gastrointestinal issues, or even neurological conditions. And what's worse is that there is evidence that supports this connection between the increase in algal blooms and the increase in human exposure to algal toxins.[11] Synthetic fertilizer runoff unfortunately does not know the difference between wild ecosystems and human-made so even our fisheries are not safe from potentially harmful algal blooms. Algal blooms happening in fisheries can decrease the amount of fish they are able to produce as well as poison the ones they do put out. If this goes unchecked people can get sick from this seafood.

So their toxins harm organisms like people, fish, shellfish, marine mammals and birds, they remove oxygen, and they can block the sun from other marine plant life.[12] Overall too much algae disrupts the ecosystem. And unfortunately if an ecosystem isn't functioning it isn't providing humans with its ecosystem services either.[13] Unfortunately this has an economic cost as we would need to expend a lot of money in order to replicate them manually or when cleaning up after the consequences of not having them. It is safe to say that the storm and climate regulation nutrient pollution, and food,[14] like shellfish that are dying to toxins instead of being able to be harvested or play their part in their ecosystem,[15] could potentially cost us a fortune to replicate on our own.[16]

Additionally those who live near these ecosystems and rely on their ecosystem services more directly will be experiencing an environmental injustice by losing them. Whether that be local fishermen that rely on the waters to feed their families or those who just live in the area and

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[10] Hallegraeff, G. M. "Harmful algal blooms: a global overview." Manual on harmful marine microalgae 33 (2003): 1-22.
[11] Hallegraeff, G. M. "Harmful algal blooms: a global overview." Manual on harmful marine microalgae 33 (2003): 1-22.
[12] Hallegraeff, G. M. "Harmful algal blooms: a global overview." Manual on harmful marine microalgae 33 (2003): 1-22.
[13] Landsberg, Jan H. "The effects of harmful algal blooms on aquatic organisms." Reviews in fisheries science 10.2 (2002): 113-390. (link)
[14] Sanseverino, Isabella, et al. "Algal bloom and its economic impact." (2016).
[15] Landsberg, Jan H. "The effects of harmful algal blooms on aquatic organisms." Reviews in fisheries science 10.2 (2002): 113-390. (link)
[16] Sanseverino, Isabella, et al. "Algal bloom and its economic impact." (2016).

passively rely on the area's natural storm protection for their homes. Everyone benefits from affordable easy to access food however is it really fair to benefit from it at the detriment to their livelihood? Not to mention that because they live so close to these ecosystems they are also more likely to come into contact with harmful algal toxins and experience the health effects that come with them.[17]

Sadly it isn't as simple as just cutting off synthetic fertilizer use. Synthetic fertilizers are cheaper than organic fertilizers. They are also easier to get and have better results as they act right away instead of needing extra time for the nutrients to break down into the soil like organics do. Farmers get a better yield of plants for their money[18] which means the costs of produce can remain fairly affordable for the consumer despite the incredibly high demand from the growing population.[19] They are an invention that has helped to partially eliminate one of humanity's own life limiting factors, again a resource that caps a population size as without it the organisms can't survive, food. This is why they are so heavily relied upon.[20] Getting rid of synthetic fertilizers, especially without an alternative that works as well as them, would limit the amount of food we are able to produce and supply[21] and because the demand stays the same the price of food will most likely skyrocket. This isn't justified either, just because you have a lower paycheck doesn't mean you should't deserve to eat. Synthetic fertilizers are not inherently bad either, it is their frequent overuse at one given time in one given area that seems to be causing more of the problem,[22] too much of a good thing can become bad. This makes the answer way more complicated. A way that could make a solution more achievable despite this complexity is more general public awareness.[23]

My creative project is made to be an experience and not just an artwork you observe because this is a problem that is experienced, almost encouraging the viewer to not just sit back and observe the problem. It achieves this "experimental" nature via the intimacy that is involved with holding it and physically flipping through the "book". You control the pace of the story and therefore you are part of the story. However, the message is made to change depending on who is holding it and experiencing the work. It is mainly made for 3 types of people all of which are capable of understanding the complexity of the situation so teenagers to adults is the target. Therefore it should most likely be displayed in either an art gallery or even a library where it can be easily digested by these groups. It should target high agricultural and coastal communities, both sides of the coin those doing the affecting and the affected. The closer the display is the

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[17] Sanseverino, Isabella, et al. "Algal bloom and its economic impact." (2016).
[18] Sabry, A. K. "Synthetic fertilizers; role and hazards." Fertil. Technol 1 (2015): 110-133.
[19] Tedengren, Michael. "Eutrophication and the disrupted nitrogen cycle: this article belongs to Ambio's 50th anniversary collection. theme: eutrophication." Ambio 50.4 (2021): 733-738.
[20] Sanseverino, Isabella, et al. "Algal bloom and its economic impact." (2016).
[21] Sabry, A. K. "Synthetic fertilizers; role and hazards." Fertil. Technol 1 (2015): 110-133.
[22] Tedengren, Michael. "Eutrophication and the disrupted nitrogen cycle: this article belongs to Ambio's 50th anniversary collection. theme: eutrophication." Ambio 50.4 (2021): 733-738.
[23] Paerl, Hans W., Timothy G. Otten, and Raphael Kudela. "Mitigating the expansion of harmful algal blooms across the freshwater-to-marine continuum." (2018): 5519-5529.

better. The first demographic is those like myself who are incredibly anxious about the changes happening to our ecosystems and our climate in general, being able to experience this work is supposed to be cathartic especially for those who experience eutrophication and its negative effects first hand. Secondly, it's for those that are more hesitant about making changes to preserve what we have, this work is supposed to be a wake up call. Yes it can get this bad, yes we should do something about it now. Even just being aware of the fact that it is happening and it is this bad is a step forward, which brings me to the last perspective that will benefit from this work, those who are still in disbelief that this is happening. Although I think in recent years, thankfully, we see less and less of them, there are still people who are in denial of all the negative changes that are happening while still guiltlessly benefiting from the causes of those changes. When they look at this work it should inspire them to become aware of the environment around them they are taking for granted, instead of again just sitting back and observing. It should at the very least garner empathy from them towards those who are worried about the situation. Overall, the imagery is designed with an unsettling nature in mind. This unsettling feeling is relatable for those who are anxious and a wake up call to those who don't care enough, calling attention to the fact that this is one of the very real and threatening things happening to our planet. If we keep going without any changes there is a potential that we will lose these super important ecosystems as well as the organisms that call them home. We caused this problem and therefore we have to be the solution.

In order to achieve this response this work will mix both more symbolic imagery meant to be interpreted, specifically in regards to the feelings of anxiety and stress involved in the topic, as well as more representative narrative imagery. The narrative imagery should be the first thing you notice about the panels following the story and cycle of nutrients as they are applied to an agricultural field. On the same panel connected to this field is both a surplus of fresh produce as well as a surplus of algae, located directly under a fertilizing tractor. The composition of these elements should make the connection between application of synthetic fertilizers and substantial food production to a degree of impossibility that is made nearly impossible without them. This connection should address the concept that we are reliant on synthetic fertilizers in our agricultural practices in order to provide enough food for our population. However, on the other hand the algae is located right next to the food. This connects the use of synthetic fertilizer to algal growth as well showcasing the concept that the excess nutrients from synthetic fertilizers are directly responsible for the increase in algal blooms in recent years. After this the narrative follows the algal toxins through the food chain as it makes its way up to humans. It should address the concept that although the use of synthetic fertilizers is necessary in order to feed the world's population its overuse can cause negative impacts on the environment as well as human health. It should look almost like a collage on the "outside" panels. On top of the narrative imagery is what looks to be flowing water resembling the runoff that carries the nutrients to the water bodies to cause the algal bloom in the first place.This continuous runoff connects to the concept that flowing water is what allows the excess nutrients from synthetic fertilizers to enter coastal ecosystems further explaining that they, the synthetic fertilizers, are the cause to algal

blooms even if applied far away. The runoff also should provide a sense of movement and direction between the images guiding the audience's eye through the “story” segments of the piece.

On the “inside” of the panels there is the representative imagery that is more personal and more connected to feelings I find common to have when regarding these big complicated issues like HABS. Specifically they are feelings I often associate when thinking of the economic struggles that often surround environmental and ecological issues we face. Problems that seem so far out of our control. This part of the work should be the more interpretive and unsettling side that you have to actually look into to really understand and empathize. This deeper understanding needed is almost emphasized by the fact that it is not as easily “accessible” as it is on the opposite side of the piece. Together both sides showcase the consequences that come from fertilizer overuse and the potential disasters it can, and already is, leading to if no effort to find a solution is taken.

Annotated Bibliography:

1. Fraga, Santiago, and Andrew Bakun. “Global Climate Change and Harmful Algal Blooms: The Example of Gymnodinium catenatum on the Glacian Coast.” Research Gate, Elsevier Science Publishers B.V., 1993.

   Algal blooms are known to have an effect on their ecosystem directly, however it is suspected that with increasing algal blooms in bigger and bigger areas we can start to see a global environmental change, mostly worsening the climate crisis. Not only are warmer water more ideal for HABS but the rapid and drastic change of temperature on earth's surface also affects the weather and wind of our atmosphere. As the currents and strength of the wind changes the water currents, and their strength, changes as well. Specifically certain areas have been, and will continue to have even more, increasing frequencies of upwelling where warm coastal waters are pushed away allowing nutrients from the depth to rise. This process is necessary but the increased frequency has been leading to full blown algal blooms instead of just increased algae growth for a short period of time.

2. Hallegraeff, G. M. "Harmful algal blooms: a global overview." *Manual on harmful marine microalgae* 33 (2003): 1-22. (pdf)

   Marine organisms that live in environments with HABS are just as and in some cases even more susceptible to health effects by HABS. The most common risk of course is deoxygenation however the more harmful effects for humans are the illnesses and diseases that start to pop up in the organisms in which we commonly ingest. Specifically the article focuses on the increase in incidents of shellfish poisoning in human populations as harmful algal blooms increase in shellfish ecosystems, linking the two to each other as cause and effect.

   - What are the effects of HAB and why do they seem to be appearing more and more, four potential explanations to this and then evidence to find the true culprit(s).
   - There are a lot of other health problems associated with HABS in humans not related to eating marine animals from the environment. Just their direct exposure to being around HABS can also cause nausea, skin irritation, brain problems and in extreme cases potential brain damage, and more. And as harmful algae adapts there is the potential for more dangerous strands to appear based on adaptation in order to become the dominant strand. Competition leads to adaptation.

3. Paerl, Hans W., Timothy G. Otten, and Raphael Kudela. "Mitigating the expansion of harmful algal blooms across the freshwater-to-marine continuum." (2018): 5519-5529. (link)
    - Solutions in order to mitigate algal blooms,
        - We can combat what we have already done by removing algal blooms and trying to rebalance ecosystems
        - We can decrease synthetic fertilizer use without causing mass starvation by finding more natural ways to supply nutrients
        - Fix algal blooms as fast as we can: we have so many environmental problems already that need our attention. This is a problem that is not yet irreversible. We need to solve it quickly and efficiently before it gets to the point where we are going to lose no matter what (like climate change).
        - Ways to prevent runoff from the synthetic fertilizers we do have to use
    - The “hopeful” solution mindset: we now know why everything is dying, how we can save it and why we should.
4. Landsberg, Jan H. "The effects of harmful algal blooms on aquatic organisms." Reviews in fisheries science 10.2 (2002): 113-390. (link)

    The loss of certain species has an incredibly negative effect on the food web in their own ecosystem and even the ones surrounding them. Each species serves a role in their food web. The more specific the role, most of the time, the more important the role tends to be. Unfortunately the more specific the more reliant the species is on a stable, unchanging environment. When that environment changes rapidly the specific species has no time to adapt and starts to die out. We see it in climate change and in algal blooms. For example shellfish are really affected by HABS. Shellfish are filter feeders and carbon sequestration. So not only are they important food sources for a lot of animals, even animals benefit from them being around because they clean up the environment. The lack of that cleaning would affect animals in their environment that have no interaction with their predatory chain at all.

    - Effect of algal blooms on organisms
        - More an individual level of ecosystem effects
        - A more specific article about how algal blooms affect their direct ecosystem and why that is bad for certain, already vulnerable, species.
5. Sabry, A. K. "Synthetic fertilizers; role and hazards." *Fertil. Technol* 1 (2015): 110-133. (link)

    This article explores how human society is dependent on synthetic fertilizers that resupply the soil with vital nutrients, mainly nitrogen and phosphorus, that would otherwise run out leading to our population size not having enough food in order to survive. Without nutrients like nitrogen and phosphorus plants can’t grow meaning the amount in the soil is a limiting factor putting a cap onto their population size. However, humans are also limited by plants as they are the start to the food chain we need to survive. So if there is a cap on their population size there would also be a cap on ours, a lot of our population would succumb to starvation. We have found a way to uncap ourselves with technology but the environment was never prepared to handle it.

    - Difference between natural and why it is cheaper and more efficient to use synthetic.
    - Fertilizer pollution and what that means for the environment (not just eutrophication)
6. Sanseverino, Isabella, et al. "Algal bloom and its economic impact." (2016). (downloaded pdf)

    Algal Blooms have a lot of connections to the modern economy. For example the main reason algal blooms even occur is because of our reliance on synthetic fertilizers. There does exist more natural ways of providing the soil with the limiting nutrients they need, whether these be modern or even ancient practices.

However producing synthetic fertilizers provides an incredibly cheap and fast way in getting these nutrients. The “real deal” is always more expensive, the same goes to organic fertilizers.

    - Economic impacts of algal blooms: we use synthetic fertilizers because it is cheaper (basically because of the economy) and yet algal blooms, the product of this, also cost us a lot of money. Is the money we are saving by going synthetic worth the money and ecosystem services we are losing because of the consequences?

Fixing algal blooms costs us a lot of money. In order to keep on top of them to prevent losing coastal ecosystems, which we rely on, we need to spend money in order to research ways to restore a balance to the systems they are happening in. Sometimes that even means putting in money and effort to physically remove this algae, which depending on the algae has harmful health effects. These harmful health effects then cost money to treat.

Ecosystem services are also potential money. The services ecosystems provide for free could potentially cost a fortune to replicate, food and resources, storm/climate regulation, nutrient cycling, etc. Algal blooms have enough of a negative effect that if we allow them to go unregulated they could potentially wipe out a lot of coastal ecosystems in total. Without the ecosystem we have to spend the money to try and replicate their services.

- Also there is a huge amount of food waste, which is equivalent to nutrient waste if you think about it. (over consuming and overproducing leads to the waste of resources)
- Human health effects, how we are affected by algal blooms and also HABs. Why should everyday humans care about something that may “not affect them directly” because you can get nausea, food poisoning, skin irritation and burning, and even neurological illnesses from being around them. The more HABS the more likely it is you will be exposed.

7. Sellner, Kevin G., Gregory J. Doucette, and Gary J. Kirkpatrick. "Harmful algal blooms: causes, impacts and detection." *Journal of Industrial Microbiology and Biotechnology* 30 (2003): 383-406. (link pdf)

   This article talks about how certain coastal ecosystems are more vulnerable to algal blooms than others due to their warmer temperatures and closer relation to agricultural, and sometimes recreational like golf courses, areas using synthetic fertilizers. The warmer temperatures are ideal for algae to grow and survive and the runoff from nutrients allows them to have excessive nutrients in order to do so. So areas like the Gulf of Mexico sees more HABs than the Baltic Sea. Additionally the Baltic Sea, which is not prone to algal growth, has seen an increase due to more agricultural activities around the area, showcasing an extremely clear connection between the rise in one leading to the rise of the other.

   - How is the runoff from major agricultural areas ending up in coastal ecosystems:
     - Most of the time it seems that eutrophication follows the rivers. Most rivers in America flow south so it can be assumed that a lot of algal blooms happen South of major agricultural areas.

8. Smith, Val H., and David W. Schindler. "Eutrophication science: where do we go from here?." *Trends in ecology & evolution* 24.4 (2009): 201-207. (link pdf)

   In addition to the cause and effects of HABS this article also provides potential solutions and ways to recover from current nutrient causes eutrophication. For example this article proposes controlling the food chain with a man-made trophic cascade, purposely overfishing the top predators to allow more plankton-eating fish to manage the increased population before the algae has a chance to have negative effects on the ecosystem. Overall though the article argues that in order to see recovery in lakes we have to find a way to prevent this nutrient imbalance. Whether that be decreasing or eliminating run off from

synthetic fertilizers, providing physical barriers or switching to more natural ones, or experimenting with elements that naturally affect the nutrient balance like iron.

- Agriculture practices that lead to it, which agricultural practices are the worst when it comes to causes eutrophication and therefore algal blooms.
- What agricultural practices cause HABs.

9. Tedengren, Michael. "Eutrophication and the disrupted nitrogen cycle: this article belongs to Ambio's 50th anniversary collection. theme: eutrophication." Ambio 50.4 (2021): 733-738. (link)
    - 4 different studies on eutrophication
        - Increased algal blooms
        - Environment studies
    - Direct response to increase in synthetic fertilizers, we need the increase because of rapid population increases (7.4% increase in the last 10 years) demanding more food, to grow more food you need more fertilizer. Also we always grow more than we need. It is cautionary but also it leads to food waste.
    - Nitrogen cycle thrown off balance
    - From when the interest (more like worry) of the nitrogen cycle first started to happen so this is a different perspective of the scientific community before what we know now.

“What is a harmful algal bloom? | National Oceanic and Atmospheric Administration.” NOAA, 27 April 2016, https://www.noaa.gov/what-is-harmful-algal-bloom. Accessed 23 April 2025.(link)

This article discusses that an algal bloom is a colony of algae that has grown out of hand and that they are occurring in greater frequencies in U.S. coastal ecosystems and the great lakes due to increased nutrient pollution and the warming global temperatures. It also specifies that what makes certain algal blooms “harmful” is that there are some species of algae that produce toxins that can have harmful effects on marine organisms, birds, as well as people.

Photos of Creative Work: