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Human Population's Impact on Ocean Acidification and Consequences

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Abstract

This paper examines how exponential human population growth, and the induced intensification required to sustain that growth, contribute to and accelerate the process of ocean acidification, a critical yet overlooked consequence of anthropogenic activities. Utilizing the theoretical lens of induced intensification from Robbins et al.'s *Environment and Society*, alongside peer-reviewed research, this paper connects global food waste and unconscious consumption to the continuing issue of increased greenhouse gas emissions and ever declining marine biodiversity. Case studies, including Japan's food imports and waste patterns and the ecological vulnerabilities of marine species like the pteropod and Pacific cod underscore how unsustainable consumption habits lead to significant environmental and economic costs. While innovations like golden rice address nutritional deficits, they often do so at the expense of ecosystem services and biodiversity. Ultimately, as we are shown, there is an irony to current human-environment interactions: if we are to meet the demand of exponentially growing populations, we are to simultaneously degrade the very ecosystems that sustain said life. To mitigate this issue of accelerated ocean acidification and dwindling biodiversity, it is critical we as a collective global community practice more conscious and sustainable approaches to consumption and food systems.

Keywords: ocean acidification, induced intensification, biodiversity loss, population growth, unsustainable consumption, anthropogenic greenhouse gases, food waste, marine ecosystems.

Introduction

Ocean acidification is both a natural and anthropogenic process where ocean waters experience a decrease in pH (potential of hydrogen) due to the dissolution of carbon dioxide (CO₂) in seawater. The current rate of acidification has not been seen throughout recorded geologic history, causing concern. As pH goes down, a liquid's acidity increases, and a rise in a body of water's acidity causes a plethora of problems. For example, rising acidity interferes with the formations of calcium carbonate (CaCO₃). CaCO₃ is essential for the formation of certain organisms, which comprise the basis of a marine food chain as a food source for many other life forms, many of which are important to humans. Without these organisms being formed properly, we could see a domino effect throughout the marine food chain where many other species could die off or populations could be significantly impacted.

Acidification will also further increase sea surface temperatures (SST) due to increased CO₂ and other greenhouse gas (GHG) concentrations, which decrease available oxygen within our waters, an essential component indeed that will have impacts on non-calcareous species. Calcareous, in the context of marine biology, refers to the composition of calcium carbonate (CaCO₃) within a body of water, essential for the formation of species like those within the Foraminifera and Pteropoda orders that often serve as essential bases for marine food webs ("Definition of Calcareous"). Non-calcareous species, then, are those lacking calcium carbonate composition. These combined processes will eventually culminate in mass negative impacts on humans in terms of our wellbeing and our economic standing.

A correlation can be drawn between an exponentially increasing global human population and the rising levels of consumerism globally. This is due to a concept called "induced intensification", which is an artificial increase in food production

(usually through scientific innovations) to sustain exponential population growth. Additionally, unconscious consumption leads to an excessive ecological footprint (the level of human demand on natural resources), resulting in the rising acidification levels of waters which we are seeing. This correlation can be supported by using Malthusian theory, which states, “the capacity of population to grow is greater than the power of the Earth to provide resources” (Robbins et al. 17). Malthus essentially is saying that humans reproduce faster than our own Earth can sustain said reproduction. He theorized and attempted to rationalize this in his *An Essay on the Principle of Population* (1798).

Yet due to the period in which this essay was written, Malthus relies on outdated ideas. In the words of Robbins et al., he first mentions how events like war, famine, destitution and disease are all “natural limits to growth and keep the population in check”. He follows up by claiming that “second ... policies promoting the welfare of the poor are counterproductive ... they ... encourage unnecessary reproduction and resource waste ... Third ... the key to averting periodic and inevitable resource crisis is a moral code of self-restraint” (Robbins et al. 17). Thus, according to Malthus, the poor and those whom he thinks lack moral restraint are “reliant on handouts ... [are] bad managers of time and money, and that they are given to irrational procreation” (Robbins et al. 18). We clearly see some of the outdated ideas Malthus used at the time to rationalize his theory, and yet we will still utilize his essential premise without pitting blame on those “lacking” moral constraint or onto any marginalized group. Nor shall we rely on the idea that we have exceeded a global carrying capacity (an idea of how many humans can live or be sustained on Earth), as this view can lead to draconian decision making.

Our correlation is also supported by Ehrlich and Holdren's I=PAT equation, which stipulates that one's environmental impact (I) can be calculated by multiplying a state's (nation's) population (P) by its affluence levels (A) and finally by its technological advancement (T). This provides a mathematical identity, showing us that various environmental problems (in this case ocean acidification) are indeed related to the exponential growth of certain societal factors like food production or populations ("The 'IPAT' Equation" 2). Using these theories, we can attribute rising levels of consumerism globally (i.e., induced intensification of food production without conscious consumption, leading to too high of an ecological footprint) to the increased acidification of waters. This study further utilizes concepts from Robbins et al.'s *Environment and Society*, alongside academic studies and research on both global food consumption/waste and ocean acidification to show how high populations and the forced increase in food production that follows is having both direct and indirect impacts on oceans. These human activities impact the physical and chemical properties of the very water that we, and the life within said waters, are so reliant on, via increased acidification and GHG emissions.

Robbins et al. and Their Work as Our Foundational Source

Paul Robbins, coauthor of *Environment and Society: A Critical Introduction*, is a professor and dean of the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison and holds research interests in understanding human-environmental systems, the influence that non-humans have on human behavior and organization, and the implications the prior hold for the health of an ecosystem, local communities and social justice overall ("Robbins, Paul"). Our other two authors are John G. Hintz and Sarah A. Moore. Hintz is a professor of environmental, geographical and geological sciences at Bloomsburg University of

Pennsylvania. His research interests include the politics of public lands management, mapping protected areas, and sustainable agriculture. Sarah A. Moore is an associate professor of geography at the University of Wisconsin-Madison, where her research includes political, economic and social dimensions of waste management on several different scales (local to international). Given our three authors' deep expertise around the interdisciplinary nature of studying human-environment systems, environmental sciences and sustainability, geography, and social justice, Robbins et al.'s work serves as a critical framework for concepts that will allow us to establish a link between human behaviors and actions and the increased rates of ocean acidification.

Robbins et al. utilize several disciplines in addition environmental ethics. They draw on political economy—the study of how economic systems are impacted via political systems, which in our context means the implications of political systems on the wellbeing of our environment—and social construction—the idea that a certain thing, category or condition is understood to have such characteristics because people socially agree it does. Robbin's et al. use these varied concepts to make connections to global and contemporary environmental issues.

Perspective of Robbins et al.'s *Environment and Society*

Diving into Robbins et al., we see that exponential population growth for humans has dire consequences on our ability to be more sustainable. This is especially shown when the rate of food production, one of the things we need to survive, keeps pace only artificially with the rapid rate of population growth. The response, however, must not be advocating for genocide or draconian policies to keep food production and population growth at the same rate, or reverting to full-fledged Malthusian theory by pitting blame on the poor. Instead, the more acceptable

and contemporary method has been to force food production rates to rise to the same level of human population growth. This leads us to Robbins et al.'s concept of induced intensification, the idea that while a population rises, "demands for food lead to technological innovations resulting in the increased food production on the same amount of available land" (Robbins et al. 23).

One notable example of induced intensification is golden rice. Golden rice is one of many products of the Green Revolution (also referred to as the Third Agricultural Revolution) that was developed by the International Rice Research Institute (IRRI), alongside partners, to complement already existing interventions meant to address vitamin A deficiency (VAD). This is a problem known to impact millions of people globally, especially women and children whose main sustenance is rice ("Golden Rice").

There is no denial of golden rice's importance in terms of feeding millions of people, especially in areas with known dietary deficiencies of vitamin A, an essential vitamin. These claims are supported by research from Tang et al., who found that 200 grams of golden rice contain more β -carotene (a provitamin that converts into vitamin A) than a mixture of golden rice and white rice. This is a clear benefit of induced intensification, as more people can now get what is an essential vitamin. Unfortunately, the cultivation of golden rice gives rise to issues like reductions in biodiversity and genetic pollution. Besides the adoption of golden rice, we have seen that nations such as India increased wheat production triple fold from 1965-1980, and in "Indonesia ... rice production increased by 37% ... [while the] Philippines ... increased ... 40%." We can therefore see that, from the "period of [the] middle 1960's to the present ... more food has been produced than consumed" (Robbins, et al. 23).

While this seems good on the surface, as it means more people will have more access to food, there are also downsides that we must consider.

While some of the food produced in those nations may be consumed by those within the borders, much of it is exported to other nations, like the US, which according to the U.S. Food and Drug Administration (FDA) wastes about 30-40% of its current food supply, or roughly 133 billion pounds of food annually ("Food Loss and Waste"). What is the point of increased food production (at the cost of natural land) if the increased population does not appreciate it and throws it into the bin? Despite this mass increase in production, which initially seems like a positive thing, "a number of other environmental issues [come] with...expansion of food production" (Robbins et al. 24) Golden rice, for instance, was only one of many products that came from induced intensification and the Green Revolution. The problem is that where induced intensification is practiced, we see "a massive input of fertilizers and pesticides," with the result being a "loss of unbroken soils across the prairies and rainforests of Earth and ... concomitant loss in biodiversity" (Robbins, et al. 23-24).

Moving from the dangers of not caring for soil health and focusing primarily on the utilization of petrol-based fertilizers and pesticides on various crops, we encounter an obvious downside of induced intensification. The more these techniques are used, the more GHGs we will see emitted into our atmosphere via petrol-based pesticides and fertilizers, which our oceans must also absorb, as well as decreased ecosystem services. "Ecosystem services" are the benefits to humans from a functioning ecosystem. Robbins et al. provide an example of increased soybean production in Brazil to show these decreased ecosystem services. This increased soybean production requires new lands, which are home to a diverse range of flora, to be converted into a monoculture plot. While Robbins et al. do not

explicitly say it, the forest that is sacrificed is probably the Amazon rainforest, the world's largest rainforest that provides a plethora of ecosystem services.

While this may seem better than turning the land into something like a slab of concrete, there are still drastic, negative impacts to the local area that will have global consequences. First, with less biodiversity within an area, we will see reduced effectiveness of ecosystem services for example, the clean air and water that biodiverse flora can provide. Ecosystem services from places like the Amazon Rainforest are critical because they serve as a carbon sink (a natural carbon reservoir that absorbs more carbon than it emits) or as natural sites for the sequestration of billions of tons of carbon. Yet the Amazon is being deforested for the purpose of things like soybean plantations, all for human consumption.

Couple destroying the Amazon (and other forests globally) with the increased production of non-organic fertilizers and pesticides to facilitate the growth of crops for human consumption, and it is not much of a surprise that GHG emissions will rise, in turn increasing atmospheric temperatures. The removal of the Amazon for monoculture crops leads to less ability for carbon sequestration, combined with fossil fuel consumption (in this case, of fertilizers and pesticides). All these things are the result of increased populations, yet we also know the answer cannot be to commit to mass reductions in human population. As a result, we remain on a path towards the acidification of our oceans.

Analysis of Robbins et al.'s Perspective

Japan, an island nation with over 120 million people, "depends heavily on imports for its food supply" (Munesue & Masui Abstract). It is therefore a good example for considering food consumption rates in places with relatively high populations in relation to the GHG emissions that lead to ocean acidification. Despite

many of Japan's edible items being shipped in, in 2012, it produced around 6.42 million tons of food waste. Munesue and Masui tell us that such figures "indicate ... wasted natural resources and excessive greenhouse gas emissions both in Japan and in countries that export to Japan" (Munesue & Masui Abstract). Because it is an island nation, domestic resource shortages in Japan can produce global consequences. Some of those global consequences sparked via Japanese food waste equated to about 1.23 million hectares of land converted into monocultures and 413 million cubic meters of wasted water resources. Japanese food waste at the time also unnecessarily emitted about 3.51 million tons of CO₂e and 0.49 million tons of CO₂e in the transportation of foods. This unnecessary waste was not only a contributor to GHG emissions globally but can be used as an argument against utilizing induced intensification. Despite all this food wasted by one nation, Munesue and Masui tell us there were "821 million undernourished people in the world" (Munesue & Masui 1196). Thus, what could have been sustenance and nutrition for nearly 1 billion people was instead allowed to be wasted and contribute to already high GHG emissions.

Yet this is not just a regional issue. The United Nations Food and Agriculture Organization (FAO) tells us that one third of world food production is wasted or lost along our complex food supply chain, creating even more unconscious consumption that in turn forces us to spew increasingly more GHGs. To make Japan look like models of conscious consumption, Munesue and Matsui explain that "the United States loses around 70 million tonnes of edible food between farm and fork annually [whereas, in] Switzerland, 48% of calories ... are lost" (Munesue & Masui 1196). If such waste is deemed high in Japan, it is astronomical in places like the US or certain European nations. With this amount of global food waste, which in turn

creates increased GHGs and contributes to ocean acidification, a good amount of CO₂ remains in the atmosphere. In the words of Johnson and White, "as much as 25 percent is absorbed by the world's oceans, according to ... NOAA" and "the pH level of the world's oceans has dropped by 0.1 unit," meaning "a 30-percent increase in acidity" (Johnson & White, 71) since the beginning of the Industrial Revolution.

The International Panel on Climate Change (IPCC) was established in 1988 by the World Metrological Organization (WMO) and serves as the international governing body that assesses the interdisciplinary science behind climate change. The IPCC "provide[s] a scientific basis for governments at all levels to develop climate related policies, which underlie negotiations at the UN Climate Conference—the United Nations Framework Convention on Climate Change" ("IPCC FACTSHEET" 1) The IPCC suggests that, if we keep consuming at the rates we do, by 2099 we could see another 0.5 decrease in pH of oceans (Johnson and White 71). This is a 150 percent increase in acidity compared to today. While this may not seem incredibly significant to some people, even minor changes in ocean acidity can dramatically affect marine life that has evolved to be comfortable within specific parameters. Our irresponsible consumption habits partly contribute towards ocean acidification and will have a significant impact on life within our oceans.

Despite this, we do not have to wait till 2099 to see the impacts of change. As Johnson and White show us, the pteropod, a pea-sized calcareous marine snail popularly known as the "butterfly snail," acts as an indicator species. This is a species within an ecosystem whose presence signals the health or standing of that ecosystem. For example, lichens act as indicators of air quality and levels of pollution. In turn butterfly snails, when present in high numbers, indicate that there is an abundant amount of CaCO₃ (used to form their protective shells) and thus a

stable pH level. Johnson and White point out the snail's importance for the marine ecosystem and human consumption, noting it serves "as a major food source for commercial fishes such as pink salmon." Yet despite their importance to commercially important fish, they are a resource "on the wane, as increasing levels of acid in the ocean threaten to dissolve its aragonite shell ... [and] impair its normal development" (71). As with the butterfly snail, various "corals, clams, scallops, oysters, and other shellfish" will all suffer as oceans acidify (Johnson & White 73).

Further, according to Johnson and White, we see that fish show various forms of impaired development. Some examples are via decreased olfactory ability and altering body compositions (73). One example of fish impacted by rising GHG levels is the Pacific cod, a commercially important fish found in the Gulf of Alaska. According to Slesinger et al., the "Pacific Cod support the second largest ground fishery in Alaska with \$400 M (wholesale value 2009-2019)" (121). Data such as this warn us that if fish are increasingly suffering from the impacts of ocean acidification, the result will be lower profits and less food production, which is what we are trying to avoid.

While much of this research is still relatively new, Slesinger et al. determined the plethora of impacts on the ecologically and commercially important Pacific cod, especially in their developmental stages. At Kodiak Island in Alaska in April 2022, via a commercial fishing boat during the spawning season, they caught Pacific cod subjects to determine their sex and spawning status Slesinger et al. collected embryos from cod female, fertilized cod for the National Marine Fisheries Service (NMFS) laboratory in Newport, Oregon. To test outcomes of ocean acidification, they placed viable embryos in simulated environments of three different temperatures (3, 6 and 10 degrees Celsius) and at two different CO₂ concentrations. Slesinger et al.

recorded the differences in larval standard length, myotome height at the anus (mm), and yolk area (mm²), along with measuring the dry weight of larvae. Their results showed that as the ocean continues its warming, many life forms will experience increasingly adverse effects.

This poses a major problem for fisheries that act as both economic stimulators and sources of sustenance. Our acidification of the ocean not only compromises the physical development but also destroys the habitat of many of the life forms. As Johnson and White point out, "the first ecosystem[s] to be identified as vulnerable ... were the coral reefs"; it also does not help that "other reef-building species may be affected" (74). Recognizing that our unconscious consumption and waste are quite far reaching, from equatorial reefs to fish populations in the Gulf of Alaska, is crucial, even if the scale presents the reality of our impacts that is more than we would like to admit. Many researchers believe that by the middle of this century (2050) these corals and other reef-building species will be 10-50% less efficient at calcifying. This, in turn, "threatens the persistence of coral reef[s] and fish communities and ... the sustenance fishers who depend on them" (Johnson & White 74). Thus, it is not farfetched to conclude that, without significant alteration of our globalized conscious consumption, our extreme utilization of induced intensification will harm us more than help us in the longer term.

What Can We Do as a Collective? As Individuals?

While the continuing issue of ocean acidification comes with many worries, uncertainties, and both ecological and economic disaster, it is abundantly clear that "reducing atmospheric CO₂ levels is ultimately the best and most complete solution for ocean acidification," as this is a "global problem with local impacts" (Cooley et al. 1-2). Until this is achieved, it is ever more apparent that even small-scale action does

brings about meaningful change with net-benefits for all. There are many community, regional, and statewide actions that can be taken, and these “actions can be coupled, completed one at a time, or aligned with other environmental initiatives ... [which] can be tailored to [the] prevailing political or economic environment” (Cooley et al. as cited in Gattuso et al. 1).

If we zoom in to our little corner of Earth in Washington State, we see the state has created the Washington State Blue Ribbon Panel on Ocean Acidification (WSBRPOA), comprised of people from some private companies with stakes in natural resources: the Weyerhaeuser Company, various non-profit environmental groups, various County Commissions, research institutions, local partnerships, the University of Washington and Oregon State University, and finally Washington State senators and representatives, alongside their federal counterparts that represent Washington State (“Ocean Acidification”). Thus, there is an extensive body with a lot of knowledge around the issue of ocean acidification alongside policymakers at local, state, and federal levels who could enact the change that would combat this very issue.

This panel created a response playbook titled “Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response,” which mentions that the critical starting point to slow down ocean acidification rates is to begin “reducing the drivers of acidification in Washington's marine waters. These include carbon dioxide emissions and runoff of nutrients and organic carbon from local land-based sources” (“Ocean Acidification” 27). This response playbook goes into extreme detail on how the state can combat what is dubbed a “global problem with local impacts” (Cooley et al. 1-2) and start taking actions to reduce global, national, and local emissions of carbon dioxide (“Ocean Acidification” strategy 4.1). Some of these

actions would be to work with international, national, regional, and local partners to advocate for more robust strategies to reduce CO₂ emissions. This coordination would begin with reviewing data to further establish correlations between local human GHG emissions and increased acidity, which would further push change to reduce GHG emissions and slow down acidification.

Finally, we also see that "key leaders and policymakers [are needed] to act as ambassadors [that will advocate] for carbon dioxide emissions reductions and protection of Washington's marine resources from acidification" ("Ocean Acidification" 28). Alongside reductions in CO₂ emissions, it is critical that there is a notable reduction in local land-based activities which are known to contribute to ocean acidification ("Ocean Acidification" strategy 5.1). This may be one of the strategies where an individual will have a lot of power to enact a change they wish to see and "implement effective nutrient ... reduction programs in locations where these pollutants are causing or contributing to multiple water quality problems ("Ocean Acidification" 29). While this action should target the largest contributors to nutrient and pesticide/herbicide runoff, which are both frequently used in food production on commercial scales, there is no denial of the amounts of pesticides and excessive nutrients that individuals themselves use with minimal consideration of the impact.

Yet this is exactly where individual actions can bring about a collective positive change. Having individuals limit their excessive consumption of synthetic nutrients and petrol-based pesticides into their garden, for example, will naturally limit the amount found in runoff water that is ultimately discharged into larger bodies of water. This will help reduce the rate of acidification as there are fewer pollutants to contribute to acidification. If people use less petrol-based products like pesticides, we might even see GHG emissions decrease, as such products would lack sufficient

demand to keep supplies stocked, a net benefit for local environments, bodies of water, and humans overall. These synthetic fertilizers and pesticides could be replaced with organic or less environmentally detrimental variants, which are known to have significantly smaller impacts.

Without forcing residents to reduce their consumption of plant nutrients and pesticides via something like government intervention, it would seem best to combine the WSRPOA's action 5.1.1 with strategy 8.1, which is to "share information showing that ocean acidification is a real and recognized problem in Washington State." More specifically, action 8.1.2 states a goal to "increase understanding of ocean acidification among key stakeholders, targeted audiences and local communities" ("Ocean Acidification" 32). If we are able to educate communities on a large scale and put emphasis on the fact ocean acidification is a real, recognized issue that will have drastic impacts and consequences in not just our state but the entire globe, we may be able to see people begin to change some of their unconscious habits that contribute to acidification, or at minimum, begin to consider the consequences of their actions. After all, humans are social, habitual creatures that tend to want to fit into a greater collective.

Knowing that the key to addressing a problem like ocean acidification is a reduction in unconscious consumption, it would not be farfetched to say that more conscious consumption to mitigate ocean acidification requires societal behavior changes, from the individual and eventually adding up to the collective. The strategy posed by McKenzie-Mohr et al. called Community Based Social Marketing (CBSM) attempts to instill behavior changes via community-level initiatives with a focus on removing barriers to any activity while also enhancing its benefits. It would be wise to use CBSM to enact community (and even global) changes, as while "education and

advertising can be effective in creating awareness and in changing attitudes, numerous studies document that behavior change rarely occurs as a result of simply providing information,” meaning that “information alone cannot address the diversity of barriers that exist for most sustainable behaviors” (McKenzie-Mohr et al. 1).

There are five steps involved in CBSM. The first is "Selecting which behavior to target," followed by "Identify[ing] the barriers and benefits to selected behavior." Third is to "Develop a strategy that reduces barriers to the behavior to be promoted, while simultaneously increasing the behaviors perceived benefits. Fourth is to "Pilot the strategy," and, finally, "Evaluate[ing] broadscale implementation and ongoing evaluation once the strategy has been broadly implemented" (McKenzie-Mohr et al. 4). Combining CBSM can be fruitful to nudge people into making a more conscious change that will not only benefit them but their community, making this a double benefit as an individual is one part of the community that they are improving. Further combining CBSM with visible public commitments would be effective, such as a public commitment to reduce or eliminate any use of nutrients or petrol-based fertilizers and pesticides. Those nearby would follow suit, especially when benefits are both visible and reaped.

CBSM, alongside education, can also be utilized to address other aspects of the ocean acidification issue. For example, if we are to have people reconsider their diets and food consumption patterns with the end goal of reducing excessive consumption of all food categories for the sake of healthier communities, CBSM can be utilized initially as a solution on an individual level that will then accumulate into collective change. This is not done to deflect blame from those who are known to disproportionately emit more GHGs, produce more food with zero regard for the land they produce it on, or use more nutrients, fertilizers and pesticides with the same

lack of care. Rather, this approach is emphasizing that we all have steps to take for achieving a more holistic and conscious world that allows all life to thrive.

Conclusion

Ocean acidification presents an urgent environmental threat that is exacerbated by various human actions, though we emphasized the idea of induced intensification of foods to meet demands of an exponentially increasing population as a key culprit. We see that inventions like golden rice, while they may serve as an immediate solution to nutritional concerns, also have serious implications that are too-often ignored. Such downsides are habitat destruction, losses in biodiversity from monoculture crops, and increased GHG emissions that all contribute to the degradation of marine ecosystems. Consequences of this degradation span from declines of ecologically important and anthropogenically significant species of marine life, like the pteropod and Pacific cod, to the bleaching and death of marine habitats, like coral reefs. The disappearance of these vital species shows us how unsustainable anthropogenic processes undermine the very ecosystems that we fundamentally rely on for our economics and wellbeing. *It is evident that in our effort to feed growing populations, we are simultaneously poisoning the ecosystems that sustain us.* To mitigate the effects of ocean acidification, we as individuals in a greater collective must rethink our consumption habits and embrace more sustainable, conscious, and holistic approaches to both food production, resource use, and consumption. This can be done if, at first one by one, we commit as an entire community to making conscious changes in our consumption patterns, as shown through strategies like CBSM. Only then can we hope to preserve the delicate balance of life in our oceans and avoid the devastating environmental and economic consequences of inaction.

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