INTERNATIONAL JOURNAL OF
INNOVATIVE RESEARCH AND KNOWLEDGE
ISSN-2213-1356 www.ijirk.com

Climate Change Connections in Oceans, How Warming Waters affect Coral Reefs and Marine Biodiversity

Assoc. Prof. Ezekiel N. Okemwa
School of Applied & Health Sciences,
Department of Environment & Health Sciences, Marine Sciences Section,
Technical University of Mombasa, Kenya

ABSTRACT

The world's oceans cover approximately 70 percent of the Earth's surface, indicating their importance to the global environment. In addition to having a large influence on global heat transport and precipitation, the oceans are comprised of diverse habitats that support a wealth of marine wildlife. They also provide humans with a wide variety of goods and services including foods, recreational opportunities, and transportation corridors. Based upon current scientific evidence, emissions of greenhouse gases from human activities are projected to cause significant global climate change during the 21st century. Such climate change will create novel challenges for coastal and marine ecosystems that are already stressed from human development, land-use change, environmental pollution, and over-fishing. In this paper details on the impacts of climate change of the following are given: the basics of climate change and the ocean; the effects of warming waters; the effects of climate change on coral reefs; marine biodiversity loss due to climate change; coastal and ocean species; migration due to the effects of climate change and hypoxia (dead zones). Changes in precipitation and sea-level rise will have important consequences for the water balance of coastal ecosystems. Increases or decreases in precipitation and runoff may respectively increase the risk of coastal flooding or drought. Meanwhile, sea-level rise will gradually inundate coastal lands. Coastal wetlands may migrate inland with rising sea levels, but only if they are not obstructed by human development. Climate change is likely to alter patterns of wind and water circulation in the ocean environment. Such changes may influence the vertical movement of ocean waters (i.e., upwelling and down welling), increasing or decreasing *the availability of essential nutrients and oxygen to marine organisms. Changes in ocean circulation patterns can also cause substantial changes in regional ocean and land temperatures and the geographic distributions of marine species. Critical coastal ecosystems such as wetlands, estuaries, and coral reefs are particularly vulnerable to climate change. Such ecosystems are among the most biologically productive environments in the world. Their existence at the interface between the terrestrial and marine environment exposes them to a wide variety of human and natural stressors. The added burden of climate change may further degrade these valuable ecosystems, threatening their ecological sustainability and the flow of goods and services they provide to human populations.*

Keywords: *Climate Change, Oceans, Warming Waters, Coral Reefs, Marine Biodiversity, Coastal, Ocean Species, Migration, Hypoxia*

1. Introduction

Oceans cover more than two-thirds of our planet and give us food, energy and other resources. They provide many services to human communities from mitigating weather extremes to generating the oxygen we breathe, from producing the food we eat to storing the excess carbon dioxide we generate. But worldwide, this fantastic underwater world is in danger. Is there still time to prevent the worst? However, the effects of increasing greenhouse gas emissions threaten coastal and marine ecosystems through changes in ocean temperature and melting of ice, which in turn affect ocean currents, weather patterns, and sea level. And, because the carbon sink capacity of the ocean has been exceeded, we are also seeing the ocean's chemistry change because of our carbon emissions. In fact, mankind has increased the acidity of our ocean by 30% over the past two centuries.

The ocean and climate are inextricably linked. The ocean plays a fundamental role in mitigating climate change by serving as a major heat and carbon sink. The ocean also bears the brunt of climate change, as evidenced by changes in temperature, currents and sea level rise, all of which affect the health of marine species, near shore and deep ocean ecosystems. As concerns about climate change increase, the interrelationship between the ocean and climate change must be recognized, understood, and incorporated into governmental policies. Surfing, boating, long walks on the beach - yes, we love our oceans. And yet, we treat them horribly, even though we need them to survive. Since the Industrial Revolution, the amount of carbon dioxide in our atmosphere has increased by over 35%, primarily from the burning of fossil fuels. Ocean waters, ocean animals, and ocean habitats all help the ocean absorb a significant portion of the carbon dioxide emissions from human activities.

The global ocean is already experiencing the significant impact of climate change and its accompanying effects. They include air and water temperature warming, seasonal shifts in species, coral bleaching, sea level rise, coastal inundation, coastal erosion, harmful algal blooms, hypoxic (or dead) zones, new marine diseases, loss of marine mammals, changes in levels of precipitation, and fishery declines. In addition, we can expect more extreme weather events (droughts, floods, storms), which affect habitats and species alike. To protect our valuable marine ecosystems, we must act.

The overall solution to climate change is to significantly reduce the emission of greenhouse gases. The most recent international agreement to address climate change, the Paris Agreement, entered into force in 2016. Meeting the targets of the Paris Agreement will require action at international, national, local and community levels around the world. Additionally, blue carbon may provide a method for the long-term sequestration and storage of carbon. "Blue Carbon" is the carbon dioxide captured by the world's ocean and coastal ecosystems. This carbon is stored in the form of biomass and sediments from mangroves, tidal marshes, and seagrass meadows.

Simultaneously, it is important to the health of the ocean—and us—that additional threats are avoided, and that our marine ecosystems are managed thoughtfully. It is also clear that by reducing the immediate stresses from excess human activities, we can increase the resilience of ocean species and ecosystems. In this way, we can invest in ocean health and its “immune system” by eliminating or reducing the myriad of smaller ills from which it suffers. Restoring abundance of ocean species—of mangroves, of seagrass meadows, of corals, of kelp forests, of fisheries, of all ocean life—will help the ocean continue to provide the services on which all life depends.

The oceans not only store CO2 - they also store heat. In fact, they absorb more than 93 percent of the heat generated by man-made CO2 emissions, warming the water.

Between 1900 and 2008, seawater surface temperature rose by 0.62 Celsius (1.12 Fahrenheit) on average. In some areas in the Western Pacific Ocean, that increase was as much as 2.1 Celsius. Warming is major problem for many underwater organisms, and in particular corals.

2. The Basics of Climate Change and the Ocean

The effects of stronger storms and rising seas are intangible and will become impossible to ignore, Peterson, J. (2019, November). Damage, property loss, and infrastructure failures due to coastal storms and rising seas are unavoidable. However, science has progressed significantly in recent years and more can be done if the United States’ government takes prompt and thoughtful adaptation actions. The coast is changing but by increasing capacity, implementing shrewd policies, and financing long-term programs the risks can be managed and disasters may be prevented. Hoegh-Guldberg, O., Caldeira, K., Chopin, T., Gaines, S., Haugan, P., Hemer, M. & Tyedmers, P. (2019).

Ocean-based climate action can play a major role in reducing the world’s carbon footprint delivering up to 21% of the annual greenhouse gas emission cuts as pledged by the Paris Agreement. Published by the High-Level Panel for a Sustainable Ocean Economy, a group of 14 heads of states and governments at the U.N. Secretary-General’s Climate Action Summit this in-depth report highlights the relationship between the ocean and climate. The report presents five areas of opportunities including ocean-based renewable energy; ocean-based transportation; coastal and marine ecosystems; fisheries, aquaculture, and shifting diets; and carbon storage in the seabed. Kennedy, K. M. (2019).

It is necessary to put a price on carbon in order to reduce carbon emissions to the levels set by the Paris Agreement. Carbon price is a charge applied to entities that produce greenhouse gas emissions to shift the cost of climate change from society to entities responsible for emissions while also providing an incentive to reduce emissions. Additional policies and programs to spur innovation and make local-carbon alternatives more economically attractive are also necessary to achieve long-term results. Macreadie, P., Anton, A., Raven, J., Beaumont, N., Connolly, R., Friess, D. & Duarte, C. (2019’)

2.1. The role of Blue Carbon

The role of Blue Carbon, the idea that coastal vegetated ecosystems contribute disproportionately large amounts of global carbon sequestration, plays a major role in international climate change mitigation and adaptation. Blue Carbon science continues to grow in support and is highly likely to broaden in scope through additional high-quality and scalable observations and experiments and increased multidisciplinary scientists from a variety of nations. Heneghan, R., Hatton, I., & Galbraith, E. (2019)

Climate change is a very complex issue that is driving countless shifts across the world; particularly it has caused serious alterations in the structure and function of marine ecosystems, Rush, E. (2018).

The International Union for Conservation of Nature presents a detailed fact-based report on the state of the ocean. The report finds that sea surface temperature, ocean heat continent, sea-level rise, melting of glaciers and ice sheets, CO2 emissions and atmospheric concentrations are increasing at an accelerating rate with significant consequences for humanity and the marine species and ecosystems of the ocean. The report recommends recognition of the severity of the issue, concerted joint policy action for comprehensive ocean protection, updated risk assessments, addressing gaps in science and capability needs, acting quickly, and achieving substantial cuts in greenhouse gases. The issue of a warming ocean is a complex issue that will have wide-ranging effects, some may be beneficial, but the vast majority of effects will be negative in ways that are not yet fully understood. Poloczanska, E., Burrows, M., Brown, C., Molinos, J., Halpern, B., Hoegh-Guldberg, O. & Sydeman, W. (2016).

Marine species are responding to the effects of greenhouse gas emissions and climate change in expected ways. Some responses include poleward and deeper distributional shifts, declines in calcification, increased abundance of warm-water species, and loss of entire ecosystems (e.g. coral reefs). The variability of marine life response to shifts in calcification, demography, abundance, distribution, phenology is likely to lead to ecosystem reshuffling and changes in function that necessitate further study. Gattuso, J.P., Magnan, A., Billé, R., Cheung, W.W., Howes, E.L., Joos, F. & Turley, C. (2015).

In order to adapt to anthropogenic climate change, the ocean has had to profoundly alter its physics, chemistry, ecology, and services. The current emissions projections would rapidly and significantly alter ecosystems that humans heavily depend upon. The management options to address the changing ocean due to climate change narrows as the ocean continues to warm and acidify. The article successfully synthesizes recent and future changes to the ocean and its ecosystems, as well as to the goods and services those ecosystems provide to humans. The Institute for Sustainable Development and International Relations. (2015)

Providing an overview of policy, this brief outlines the intertwined nature of the ocean and climate change, calling for immediate CO2 emission reductions. The paper explains the significance of these climate-related changes in the ocean and argues for ambitious emissions reductions at the international level, as increases in carbon dioxide will only become harder to tackle. Stocker, T. (2015).

The ocean provides crucial services to the earth and to humans that are of global significance, all of which come with an increasing price caused by human activities and increased carbon emissions. It is emphasizing that the need for humans to consider the impacts of climate change on the ocean when considering adaptation to and mitigation of anthropogenic climate change, especially by intergovernmental organizations. Levin, L. & Le Bris, N. (2015).
The deep ocean, despite its critical ecosystem services, is often overlooked in the realm of climate change and mitigation. At depths of 200 meters and below, the ocean absorbs vast amounts of carbon dioxide and needs specific attention and increased research to protect its integrity and value. McGill University. (2013)

Humans are changing the amount of nitrogen available to fish in the ocean by increasing the amount of CO2 in our atmosphere. Findings show it will take centuries for the ocean to balance the nitrogen cycle. This raises concerns about the current rate of CO2 entering our atmosphere and it shows how the ocean may be changing chemically in ways we wouldn't expect. Fagan, B. (2013)

Since the last Ice Age sea levels have risen 122 meters and will continue to rise. Fagan takes readers around the world from prehistoric Doggerland in what is now the North Sea, to ancient Mesopotamia and Egypt, colonial Portugal, China, and modern-day United States, Bangladesh, and Japan. Hunter-gatherer societies were more mobile and could fairly easily move settlements to higher ground, yet they faced growing disruption as populations became more condensed. Today millions of people around the world are likely to face relocation in the next fifty years as sea levels continue to rise. Doney, S., Ruckelshaus, M., Duffy, E., Barry, J., Chan, F., English, C. & Talley, L. (2012).

In marine ecosystems, climate change is associated with concurrent shifts in temperature, circulation, stratification, nutrient input, oxygen content, and ocean acidification. There are also strong linkages between climate and species distributions, phenology, and demography. These could eventually affect the overall ecosystem functioning and services upon which the world depends. Vallis, G. K. (2012).

There is a strong interconnected relationship between the climate and the ocean demonstrated through plain language and diagrams of scientific concepts including systems of wind and currents within the ocean. Created as an illustrated primer, *Climate and the Ocean* serves as an introduction into the ocean role as a moderator of the Earth's climate system. The book allows readers to make their own judgments, but with the knowledge to understand generally the science behind the climate. Spalding, M. J. (2011).

Carbon dioxide is being absorbed by the ocean and affecting the pH of the water in a process called ocean acidification. International laws and domestic laws in the United States, at the time of writing, have the potential to incorporate ocean acidification polices, including the U.N. Framework Convention on Climate Change, the U.N. Convention on the Laws of the Sea, the London Convention and Protocol, and the U.S. Federal Ocean Acidification Research and Monitoring (FOARAM) Act. The cost of inaction will by far exceed the economic cost of acting, and present-day actions are needed. Spalding, M. J. (2011).

Underwater cultural heritage sites are being threatened by ocean acidification and climate change. Climate change is increasingly altering the ocean's chemistry, rising sea levels, warming ocean temperatures, shifting currents and increasing weather volatility; all of which affect the preservation of submerged historical sites. Irreparable harm is likely, however, restoring coastal ecosystems, reducing land-based pollution, reducing CO2 emissions, reducing marine stressors, increasing historic site monitoring and developing legal strategies can reduce the devastation of underwater cultural heritage sites. Hoegh-Guldberg, O., & Bruno, J. (2010).

Rapidly rising greenhouse gas emissions are driving the ocean toward conditions that haven't been seen for millions of years and is causing catastrophic effects. So far, anthropogenic climate change has caused decreased ocean productivity, altered food web dynamics, and reduced abundance of habitat-forming species, shifting species distribution, and greater incidences of disease. Spalding, M. J., & de Fontaubert, C. (2007).

There is a careful balance between local consequences and global benefits particularly when considering the detrimental effects from wind and wave energy projects. There is a need for the application of conflict resolution practices to be applied to coastal and marine projects that are potentially damaging to the local environment but are necessary to reduce reliance on fossil fuel. Climate change must be addressed and some of the solutions will take place in marine and coastal ecosystems, to mitigate conflict conversations must involve policymakers, local entities, civil society, and at the international level to ensure the best available actions will be taken. Spalding, M. J. (2004). The ocean provides many benefits in terms of resources, climate moderation, and aesthetic beauty. However, greenhouse gas emissions from human activities are projected to alter coastal and marine ecosystems and exacerbate traditional marine problems (over-fishing and habitat destruction). Yet, there is opportunity for change through philanthropic support to integrate the ocean and climate to enhance the resilience of the ecosystems most at risk from climate change. Bigg, G.R., Jickells, T.D., Liss, P.S., & Osborn, T.J. (2003).

2.2. The ocean is a vital component of the climate system

It is important in the global exchanges and redistribution of heat, water, gases, particles, and momentum. The freshwater budget of the ocean is decreasing and is a key factor for the degree and longevity of climate change. Dore, J.E., Lukas, R., Sadler, D.W., & Karl, D.M. (2003).

Carbon dioxide uptake by ocean waters can be strongly influenced by changes in regional precipitation and evaporation patterns brought on by climate variability. Since 1990, there has been a significant decrease in the strength of the CO_2 sink, which is due to the increase of partial pressure of ocean surface CO_2 caused by evaporation and the accompanying concentration of solutes in the water. Revelle, R., & Suess, H. (1957).

The amount of CO_2 in the atmosphere, on the rates and mechanisms of CO_2 exchange between the sea and the air, and the fluctuations in marine organic carbon have been studied since shortly after the beginning of the Industrial Revolution. Industrial fuel combustion since the start of the Industrial Revolution, more than 150 years ago, has caused an increase of the average ocean temperature, a decrease in the carbon content of soils, and a change in the amount of organic matter in the ocean. This document served as a key milestone in the study of climate change and has greatly influenced scientific studies in the half century since its publication.

3. The Effects of Warming Waters

Fish are the predominant source of human exposure to methylmercury, which can lead to long-term neurocognitive deficits in children that persist into adulthood. Since the 1970s there has been an estimated 56% increase in tissue methylmercury in Atlantic bluefin tuna due to increases in seawater temperatures. Smale, D., Wernberg, T., Oliver, E., Thomsen, M., Harvey, B., Straub, S. & Moore, P. (2019).

3.1. The ocean has warmed considerably over the past century

Marine heat waves, periods of regional extreme warming, have particularly affected critical foundation species such as corals and sea grasses. As anthropogenic climate change intensifies, the marine warming and heat waves have the capability to restructure ecosystems and disrupt the provision of ecological goods and services. Sanford, E., Sones, J., Garcia-Reyes, M., Goddard, J., & Largier, J. (2019).

In response to prolonged marine heat waves, increased pole ward dispersal of species and extreme changes in sea surface temperature may be seen in the future. The severe marine heat waves have caused mass mortalities, harmful algal blooms, declines in kelp beds, and substantial changes in the geographic distribution of species. Pinsky, M., Eikeset, A., McCauley, D., Payne, J., & Sunday, J. (2019).

It is important to understand which species and ecosystems will be most affected by warming due to climate change in order to ensure effective management. Higher sensitivity rates to warming and faster rates of colonization in marine ecosystems suggest that extirpations will be more frequent and species turnover faster in the ocean. Morley, J., Selden, R., Latour, R., Frolicher, T., Seagraves, R., & Pinsky, M. (2018).

Due to changing ocean temperatures, species are beginning to change their geographic distribution towards the poles. Projections were made for 686 marine species that are likely to be affected by changing ocean temperatures. Future geographic shift projections were generally pole ward and followed coastlines and helped identify which species are particularly vulnerable to climate change. Hughes, T., Kerry, J., Baird, A., Connolly, S., Dietzel, A., Eakin, M., Heron, S. & Torda, G. (2018).

In 2016, the Great Barrier Reef experienced a record-breaking marine heat wave. The study hopes to bridge the gap between the theory and practice of examining the risks of ecosystem collapse to predict how future-warming events might affect coral reef communities. They define different stages, identify the major driver, and establish quantitative collapse thresholds. Gramling, C. (2015).

A Greenland glacier is shedding kilometers of ice into the sea each year as warm ocean waters undermine it. What is going on under the ice raises the most concern, as warm ocean waters have eroded the glacier far enough to detach it from the sill. This will cause the glacier to retreat even faster and creates huge alarm about the potential sea-level rise. Precht, W., Gintert, B., Robbart, M., Fur, R., & van Woesik, R. (2016).

3.2. Effects of high water temperatures

Coral bleaching, coral disease, and coral mortality events are increasing due to high water temperatures attributed to climate change. Looking at the unusually high levels of contagious coral disease in southeastern Florida throughout 2014, the paper links the high level of coral mortality to thermally stressed coral colonies. Friedland, K., Kane, J., Hare, J., Lough, G., Fratantoni, P., Fogarty, M., & Nye, J. (2013).

Within the ecosystem of the US Northeast Continental Shelf there are different thermal habitats, and the increasing water temperatures are impacting the quantity of these habitats. The amounts of warmer, surface habitats have increased whereas the cooler water habitats have decreased. This has the potential to significantly lower quantities of Atlantic Cod as their food zooplankton is affected by the shifts in temperature.

4. The Effects of Climate Change on Coral Reefs

Coral reefs and algae are essential to ocean ecosystems and they are in competition with one another due to limited resources. Due to warming water and acidification as a result of climate change, this competition is being altered. To offset the combined effects of ocean warming and acidification, tests were conducted, but even enhanced photosynthesis was not enough to offset the effects and both corals and algae have reduced survivorship, calcification, and photosynthetic ability. Bruno, J., Côté, I., & Toth, L. (2019).

Reef-building corals are being devastated by climate change. To combat this, marine protected areas were established, and the protection of herbivorous fish followed. The others posit that these strategies have had little effect on the overall coral resilience because their main stressor is the rising ocean temperature. To save reef-building corals, efforts need to go past the local level. Anthropogenic climate change needs to be tackled head-on as it is the root cause of global coral decline. Cheal, A., MacNeil, A., Emslie, M., & Sweatman, H. (2017)

Climate change boosts the energy of cyclones that cause coral destruction. While cyclone frequency is not likely to increase, cyclone intensity will as a result of climate warming. The increase in cyclone intensity will accelerate coral reef destruction and slow post-cyclone recovery due to the cyclone's obliteration of biodiversity. Hughes, T., Barnes, M., Bellwood, D., Cinner, J., Cumming, G., Jackson, J., & Scheffer, M. (2017).

Reefs are degrading rapidly in response to a series of anthropogenic drivers. Because of this, returning reefs to their past configuration is not an option. To combat reef degradation, this paper calls for radical changes in science and management to steer reefs through this era while maintaining their biological function. Hoegh-Guldberg, O., Poloczanska, E., Skirving, W., & Dove, S. (2017).

Studies have begun to predict the elimination of most warm-water coral reefs by 2040-2050 (although cold-water corals are at lower risk). They assert that unless rapid advances are made in emission reduction, communities that depend on coral reefs to survive are likely to face poverty, social disruption, and regional insecurity. Hughes, T., Kerry, J., & Wilson, S. (2017).

Recent recurrent mass coral bleaching events have varied significantly in severity. Using surveys of Australian reefs and sea surface temperatures, the paper explains that water quality and fishing pressure had minimal effects on bleaching in 2016, suggesting that local conditions provide little protection against extreme temperatures. Torda, G., Donelson, J., Aranda, M., Barshis, D., Bay, L., Berumen, M., …, & Munday, P. (2017).

A coral reefs' ability to adapt to climate change will be crucial to projecting a reef's fate. This paper dives into the trans generational plasticity among corals and the role of epigenetics and coral-associated microbes in the process. Anthony, K. (2016).

Considering the rapid degradation of coral reefs due to climate change and ocean acidification, this paper suggests realistic goals for regional and local-scale management programs that could improve sustainability measures. Hoey, A., Howells, E., Johansen, J., Hobbs, J.P., Messmer, V., McCowan, D.W., & Pratchett, M. (2016).

Evidence suggests coral reefs may have some capacity to respond to warming, but it's unclear if these adaptations can match the increasingly rapid pace of climate change. However, the effects of climate change are being compounded by a variety of other anthropogenic disturbances making it harder for corals to respond. Ainsworth, T., Heron, S., Ortiz, J.C., Mumby, P., Grech, A., Ogawa, D., Eakin, M., & Leggat, W. (2016).

The current character of temperature warming, which precludes acclimation, has resulted in increased bleaching and death of coral organisms. These effects were most extreme in the wake of the 2016 El Nino year. Graham, N., Jennings, S., MacNeil, A., Mouillot, D., & Wilson, S. (2015).

Coral bleaching due to climate change is one of the major threats facing coral reefs. This paper considers long-term reef responses to major climate-induced coral bleaching of Indo-Pacific corals and identifies reef characteristics that favor rebound. It is projected to use their findings to inform future best management practices. Spalding, M. D., & B. Brown. (2015).

Coral reefs support huge marine life systems as well as providing critical ecosystem services for millions of people. However, known threats such as overfishing and pollution are being compounded by climate change, notably warming and ocean acidification to increase the damage to coral reefs. This paper provides a succinct overview of the effects of climate change on coral reefs. Hoegh-Guldberg, O., Eakin, C.M., Hodgson, G., Sale, P.F., & Veron, J.E.N. (2015).

Coral reefs provide goods and services worth at least US$30 billion per year and support at least 500 million people worldwide. Due to climate change, reefs are under serious threat if actions to curb carbon emissions globally are not taken immediately. This statement was released in parallel with the Paris Climate Change Conference in December 2015.

5. Marine Biodiversity Loss due to Climate Change

Climate change is causing ecosystems to rapidly change states, which renders a lot of conservation strategies based on historical patterns ineffective. With deep-water temperatures warming at rates twice as high as surface water rates, species like Calanus finmarchicus, a critical food supply for North Atlantic right whales, have changed their migration patterns. North Atlantic right whales are following their prey out of their historical migration route, changing the pattern, and thus putting them at risk to ship strikes or gear entanglements in areas conservation strategies do not protect them. Bryndum-Buchholz, A., Tittensor, D., Blanchard, J., Cheung, W., Coll, M., Galbraith, E. & Lotze, H. (2018).

Climate change affects marine ecosystems in relation to primary production, ocean temperature, species distributions, and abundance at local and global scales. These changes significantly alter marine ecosystem structure and function. This study analyzes the responses of marine animal biomass in response to these climate change stressors. Niiler, E. (2018).

Male blacktip sharks historically have migrated south during the coldest months of the year to mate with females off the coast of Florida. These sharks are vital to Florida's coastal ecosystem: By eating weak and sick fish, they help balance the pressure on coral reefs and sea grasses. Recently, the male sharks have stayed farther north as the northern waters become warmer. Without southward migration, the males will not mate or protect Florida's coastal ecosystem. Worm, B., & Lotze, H. (2016).

5.1. Climate-driven changes in species assemblages

Long-term fish and plankton monitoring data has provided the most compelling evidence for climate-driven changes in species assemblages. The paper concludes that conserving marine biodiversity may provide the best buffer against rapid climate change. McCauley, D., Pinsky, M., Palumbi, S., Estes, J., Joyce, F., & Warner, R. (2015).

Humans have profoundly affected marine wildlife and the function and structure of the ocean. Marine defaunation, or human-caused animal loss in the ocean, emerged only hundreds of years ago. Climate change threatens to accelerate marine defaunation over the next century. One of the main drivers of marine wildlife loss is habitat degradation due to climate change, which is avoidable with proactive intervention and restoration. Deutsch, C., Ferrel, A., Seibel, B., Portner, H., & Huey, R. (2015).

Both the warming of the ocean and the loss of dissolved oxygen will drastically alter marine ecosystems. In this century, the metabolic index of the upper ocean is predicted to reduce by 20% globally and 50% in northern high-latitude regions. This forces pole ward and vertical contraction of metabolically viable habitats and species ranges. The metabolic theory of ecology indicates that body size and temperature influence organisms' metabolic rates, which may explain shifts in animal biodiversity when the temperature changes by providing more favorable conditions to certain organisms. Marcogilese, D.J. (2008).

The distribution of parasites and pathogens will be directly and indirectly affected by global warming, which may cascade through food webs with consequences for entire ecosystems. Transmission rates of parasites and pathogens are directly correlated to temperature, the increasing temperature is increasing transmission rates. Some evidence also suggests that virulence is directly correlated as well. Barry, J.P., Baxter, C.H., Sagarin, R.D., & Gilman, S.E. (1995)

The invertebrate fauna in a California rocky intertidal community has shifted northward when comparing two study periods, one from 1931-1933 and the other from 1993-1994. This shift northward is consistent with predictions of change associated with climate warming. When comparing the temperatures from the two study periods, the mean summer maximum temperatures during the period 1983-1993 were 2.2˚C warmer than the mean summer maximum temperatures from 1921-1931.

6. Coastal and Ocean Species Migration due to the Effects of Climate Change

Every year, black tip sharks migrate north in the summer seeking cooler waters. In the past, the sharks would spend their summers off the coast of the Carolinas, but due to the warming waters of the ocean, they must travel further north to Long Island to find cool enough waters. At the time of publication, whether the sharks are migrating farther north on their own or following their prey farther north is unknown. Fears, D. (2019, July 31).

Blue crabs are thriving in the warming waters of the Chesapeake Bay. With the current trends of warming waters, soon blue crabs will no longer need to burrow in the winter to survive, which will cause the population to soar. The population boom may lure some predators to new waters. Furby, K. (2018).

Vital fish species such as salmon and mackerel are migrating to new territories necessitating increased international cooperation to ensure abundance. The article reflects on the conflict that can arise when species cross national boundaries from the perspective of a combination of law, policy, economics, oceanography, and ecology. National Oceanic and Atmospheric Administration. (2013).

Marine life throughout all parts of the food chain is shifting towards the poles to stay cool as things heat up and these changes can have significant economic consequences. Species shifting in space and time are not all happening at the same pace, therefore disrupting the food web and the delicate patterns of life. Now more than ever is it important to prevent overfishing and continue to support long-term monitoring programs. Poloczanska, E., Brown, C., Sydeman, W., Kiessling, W., Schoeman, D., Moore, P., …, & Richardson, A. (2013)

Over the last decade, there have been widespread systemic shifts in phenology, demography, and distribution of species in marine ecosystems. This study synthesized all available studies of marine ecological observations with expectations under climate change; they found 1,735 marine biological responses which either local or global climate change was the source.

7. Hypoxia (Dead Zones)

Hypoxia is low or depleted levels of oxygen in water. It is often associated with the overgrowth of algae that leads to oxygen depletion when the algae die, sink to the bottom, and decompose. Hypoxia is also exacerbated by high levels of nutrients, warmer water, and other ecosystem disruption due to climate change. National Oceanic and Atmospheric Administration. (2019).

A dead zone is the common term for hypoxia and refers to a reduced level of oxygen in the water leading to biological deserts. These zones are naturally occurring, but are enlarged and enhanced by human activity through warmer water temperatures caused by climate change. Excess nutrients that run-off the land and into waterways is the primary cause of the increase of dead zones. Environmental Protection Agency. (2019).

Nutrient pollution fuels the growth of harmful algal blooms (HABs), which have negative impacts on aquatic ecosystems. HABs sometimes can create toxins that are consumed by small fish and work their way up the food chain and become detrimental to marine life. Even when they do not create toxins, they block sunlight, clog fish gills, and create dead zones. Dead zones are areas in water with little or no oxygen that are formed when algal blooms consume oxygen as they die causing marine life to leave the affected area. Breitburg, D., Levin, L., Oschiles, A., Grégoire, M., Chavez, F., Conley, D., …, & Zhang, J. (2018).

Largely due to human activities that have increased the overall global temperature and the amount of nutrients that are discharged into coastal waters, the oxygen content of the overall ocean is and has been declining for at least the last fifty years. The declining level of oxygen in the ocean has both biological and ecological consequences on both regional and global scales. Breitburg, D., Grégoire, M., & Isensee, K. (2018).

Oxygen is declining in the ocean and humans are the major cause. This occurs when more oxygen is consumed than replenished where warming and nutrient increases cause high levels of microbial consumption of oxygen. Deoxygenation can be worsened by dense aquaculture, leading to reduced growth, behavioral changes, increased diseases particularly for finfish and crustaceans. Deoxygenation is predicted to become exacerbated in coming years, but steps can be taken to combat this threat including reducing greenhouse gas emissions, as well as black carbon and nutrient discharges. Bryant, L. (2015).

Historically, sea floors have taken millennia to recover from past eras of low oxygen, also known as dead zones. Due to human activity and rising temperatures dead zones currently constitute 10% and rising of the world's ocean surface area. Agrochemical use and other human activities lead to rising levels of phosphorus and nitrogen in the water feeding the dead zones.

REFERENCES

Ainsworth, T., Heron, S., Ortiz, J.C., Mumby, P., Grech, A., Ogawa, D., Eakin, M., & Leggat, W. (2016, April 15). Climate change disables coral bleaching protection on the Great Barrier Reef. *Science*, *352*(6283), 338-342. Retrieved from: science.sciencemag.org/content/352/6283/338

Anthony, K. (2016, November). Coral Reefs Under Climate Change and Ocean Acidification: Challenges and Opportunities for Management and Policy. *Annual Review of Environment and Resources.* Retrieved from: annualreviews.org/doi/abs/10.1146/annurev-environ-110615-085610

Bigg, G.R., Jickells, T.D., Liss, P.S., & Osborn, T.J. (2003, August 1). The Role of The Oceans in Climate. *International Journal of Climatology, 23*, 1127-1159. Retrieved from: doi.org/10.1002/joc.926

Barry, J.P., Baxter, C.H., Sagarin, R.D., & Gilman, S.E. (1995, February 3). Climate-related, long-term faunal changes in a California rocky intertidal community. *Science, 267*(5198), 672-675. Retrieved from: doi.org/10.1126/science.267.5198.672

Breitburg, D., Levin, L., Oschiles, A., Grégoire, M., Chavez, F., Conley, D., …, & Zhang, J. (2018, January 5). Declining oxygen in the global ocean and coastal waters. *Science, 359*(6371). Retrieved from: doi.org/10.1126/science.aam7240

Breitburg, D., Grégoire, M., & Isensee, K. (2018). The ocean is losing its breath: Declining oxygen in the world's ocean and coastal waters. *IOC-UNESCO, IOC Technical Series, 137.* Retrieved from: https://orbi.uliege.be/bitstream/2268/232562/1/Technical%20Brief_Go2NE.pdf

Brown, K., Bender-Champ, D., Kenyon, T., Rémond, C., Hoegh-Guldberg, O., & Dove, S. (2019, February 20). Temporal effects of ocean warming and acidification on coral-algal competition. *Coral Reefs, 38*(2), 297-309. Retrieved from: link.springer.com/article/10.1007/s00338-019-01775-y

Bruno, J., Côté, I., & Toth, L. (2019, January). Climate Change, Coral Loss, and the Curious Case of the Parrotfish Paradigm: Why Don't Marine Protected Areas Improve Reef Resilience? *Annual Review of Marine Science, 11*, 307-334. Retrieved from: annualreviews.org/doi/abs/10.1146/annurev-marine-010318-095300

Bryndum-Buchholz, A., Tittensor, D., Blanchard, J., Cheung, W., Coll, M., Galbraith, E., …, & Lotze, H. (2018, November 8). Twenty-first-century climate change impacts on marine animal biomass and ecosystem structure across ocean basins. *Global Change Biology, 25*(2), 459-472. Retrieved from: https://doi.org/10.1111/gcb.14512

Bryant, L. (2015, April 9). Ocean ‘dead zones’ a growing disaster for fish. *Phys.org.* Retrieved from: https://phys.org/news/2015-04-ocean-dead-zones-disaster-fish.html

Cheal, A., MacNeil, A., Emslie, M., & Sweatman, H. (2017, January 31). The threat to coral reefs from more intense cyclones under climate change. *Global Change Biology.* Retrieved from: onlinelibrary.wiley.com/doi/abs/10.1111/gcb.13593

Deutsch, C., Ferrel, A., Seibel, B., Portner, H., & Huey, R. (2015, June 05). Climate change tightens a metabolic constraint on marine habitats. *Science, 348*(6239), 1132-1135. Retrieved from: science.sciencemag.org/content/348/6239/1132

Doney, S., Ruckelshaus, M., Duffy, E., Barry, J., Chan, F., English, C., …, & Talley, L. (2012, January). Climate Change Impacts on Marine Ecosystems. *Annual Review of Marine Science, 4,* 11-37. Retrieved from: https://www.annualreviews.org/doi/full/10.1146/annurev-marine-041911-111611

Dore, J.E., Lukas, R., Sadler, D.W., & Karl, D.M. (2003, August 14). Climate-driven changes to the atmospheric CO2 sink in the subtropical North Pacific Ocean. *Nature, 424*(6950), 754-757. Retrieved from: doi.org/10.1038/nature01885

Environmental Protection Agency. (2019, April 15). Nutrient Pollution, The Effects: Environment. *The United States Environmental Protection Agency.* Retrieved from: https://www.epa.gov/nutrientpollution/effects-environment

Fagan, B. (2013) *The Attacking Ocean: The Past, Present, and Suture of Rising Sea Levels.* Bloomsbury Press, New York.

Fears, D. (2019, July 31). Climate change will spark a baby boom of crabs. Then predators will relocate from the south and eat them. *The Washington Post.* Retrieved from: https://www.washingtonpost.com/climate-environment/2019/07/31/climate-change-will-spark-blue-crab-baby-boom-then-predators-will-relocate-south-eat-them/?utm_term=.3d30f1a92d2e

Friedland, K., Kane, J., Hare, J., Lough, G., Fratantoni, P., Fogarty, M., & Nye, J. (2013, September). Thermal habitat constraints on zooplankton species associated with Atlantic cod (Gadus morhua) on the US Northeast Continental Shelf. *Progress in Oceanography, 116*, 1-13. Retrieved from: https://doi.org/10.1016/j.pocean.2013.05.011

Furby, K. (2018, June 14). Climate change is moving fish around faster than laws can handle, study says. *The Washington Post.* Retrieved from: washingtonpost.com/news/speaking-of-science/wp/2018/06/14/climate-change-is-moving-fish-around-faster-than-laws-can-handle-study-says

Gattuso, J.P., Magnan, A., Billé, R., Cheung, W.W., Howes, E.L., Joos, F., & Turley, C. (2015, July 3). Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios. *Science, 349*(6243). Retrieved from: doi.org/10.1126/science.aac4722

Gramling, C. (2015, November 13). How Warming Oceans Unleashed an Ice Stream. *Science, 350*(6262), 728. Retrieved from: DOI: 10.1126/science.350.6262.728

Goodell, J. (2017). *The Water Will Come: Rising Seas, Sinking Cities, and the Remaking of the Civilized World.* New York, New York: Little, Brown, and Company.

Graham, N., Jennings, S., MacNeil, A., Mouillot, D., & Wilson, S. (2015, February 05). Predicting climate-driven regime shifts versus rebound potential in coral reefs. *Nature*, *518*, 94-97. Retrieved from: nature.com/articles/nature14140

Heneghan, R., Hatton, I., & Galbraith, E. (2019, May 3). Climate change impacts on marine ecosystems through the lens of the size spectrum. *Emerging Topics in Life Sciences*, *3*(2), 233-243. Retrieved from: http://www.emergtoplifesci.org/content/3/2/233.abstract

Hoegh-Guldberg, O., & Bruno, J. (2010, June 18). The Impact of Climate Change on the World's Marine Ecosystems. *Science, 328*(5985), 1523-1528. Retrieved from: https://science.sciencemag.org/content/328/5985/1523

Hoegh-Guldberg, O., Eakin, C.M., Hodgson, G., Sale, P.F., & Veron, J.E.N. (2015, December). Climate Change Threatens the Survival of Coral Reefs. *ISRS Consensus Statement on Coral Bleaching & Climate Change.* Retrieved from: https://www.icriforum.org/sites/default/files/2018%20ISRS%20Consensus%20Statement%20on%20Coral%20Bleaching%20%20Climate%20Change%20final_0.pdf

Hoey, A., Howells, E., Johansen, J., Hobbs, J.P., Messmer, V., McCowan, D.W., & Pratchett, M. (2016, May 18). Recent Advances in Understanding the Effects of Climate Change on Coral Reefs. *Diversity.* Retrieved from: mdpi.com/1424-2818/8/2/12

Hoegh-Guldberg, O., Poloczanska, E., Skirving, W., & Dove, S. (2017, May 29). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers in Marine Science.* Retrieved from: frontiersin.org/articles/10.3389/fmars.2017.00158/full

Hoegh-Guldberg, O., Caldeira, K., Chopin, T., Gaines, S., Haugan, P., Hemer, M., …, & Tyedmers, P. (2019, September 23) The Ocean as a Solution to Climate Change: Five Opportunities for Action. *High Level Panel for a Sustainable Ocean Economy.* Retrieved from:https://devoceanpanel.pantheonsite.io/sites/default/files/2019-09/19_HLP_Report_Ocean_Solution_Climate_Change_final.pdf

Hughes, T., Kerry, J., & Wilson, S. (2017, March 16). Global warming and recurrent mass bleaching of corals. *Nature, 543*, 373-377. Retrieved from: nature.com/articles/nature21707?dom=icopyright&src=syn

Hughes, T., Barnes, M., Bellwood, D., Cinner, J., Cumming, G., Jackson, J., & Scheffer, M. (2017, May 31). Coral reefs in the Anthropocene. *Nature, 546*, 82-90. Retrieved from: nature.com/articles/nature22901

Hughes, T., Kerry, J., Baird, A., Connolly, S., Dietzel, A., Eakin, M., Heron, S., …, & Torda, G. (2018, April 18). Global warming transforms coral reef assemblages. *Nature, 556,* 492-496. Retrieved from: nature.com/articles/s41586-018-0041-2?dom=scribd&src=syn

Kennedy, K. M. (2019, September). Putting a Price on Carbon: Evaluating a Carbon Price and Complementary Policies for a 1.5 degree Celsius World. *World Resources Institute.* Retrieved from: https://www.wri.org/publication/evaluating-carbon-price

Laffoley, D., & Baxter, J. M. (2016, September). *Explaining Ocean Warming: Causes, Scale, Effects, and Consequences. Full Report.* Gland, Switzerland: International Union for Conservation of Nature.

Levin, L. & Le Bris, N. (2015, November 13). The deep ocean under climate change. *Science*, *350(6262),* 766-768. Retrieved from: https://science.sciencemag.org/content/350/6262/766

Macreadie, P., Anton, A., Raven, J., Beaumont, N., Connolly, R., Friess, D., …, & Duarte, C. (2019, September 05) The Future of Blue Carbon Science. *Nature Communications, 10*(3998). Retrieved from: https://www.nature.com/articles/s41467-019-11693-w

Marcogilese, D.J. (2008). The impact of climate change on the parasites and infectious diseases of aquatic animals. *Scientific and Technical Review of the Office International des Epizooties (Paris), 27*(2), 467-484. Retrieved from: https://pdfs.semanticscholar.org/219d/8e86f333f2780174277b5e8c65d1c2aca36c.pdf

McCauley, D., Pinsky, M., Palumbi, S., Estes, J., Joyce, F., & Warner, R. (2015, January 16). Marine defaunation: Animal loss in the global ocean. *Science, 347*(6219). Retrieved from: https://science.sciencemag.org/content/347/6219/1255641

McGill University. (2013, June 14) Study of Oceans' Past Raises Worry About Their Future. *ScienceDaily.* Retrieved from: sciencedaily.com/releases/2013/06/130614111606.html

Morley, J., Selden, R., Latour, R., Frolicher, T., Seagraves, R., & Pinsky, M. (2018, May 16). Projecting shifts in thermal habitat for 686 species on the North American continental shelf. *PLOS ONE.* Retrieved from: doi.org/10.1371/journal.pone.0196127

National Oceanic and Atmospheric Administration. (2013, September). Two Takes on Climate Change in the Ocean? *National Ocean Service: The United States Department of Commerce.* Retrieved from: http://web.archive.org/web/20161211043243/http://www.nmfs.noaa.gov/stories/2013/09/9_30_13two_takes_on_climate_change_in_ocean.html

National Oceanic and Atmospheric Administration. (2019, May 24). What is a Dead Zone? *National Ocean Service: The United States Department of Commerce.* Retrieved from: oceanservice.noaa.gov/facts/deadzone.html

Niiler, E. (2018, March 8). More Sharks Ditching Annual Migration as Ocean Warms. *National Geographic.* Retrieved from: nationalgeographic.com/news/2018/03/animals-sharks-oceans-global-warming/

Peterson, J. (2019, November). *A New Coast: Strategies for Responding to Devastating Storms and Rising Seas*. Island Press.

Poloczanska, E., Brown, C., Sydeman, W., Kiessling, W., Schoeman, D., Moore, P., …, & Richardson, A. (2013, August 4). Global imprint of climate change on marine life. *Nature Climate Change, 3,* 919-925. Retrieved from: https://www.nature.com/articles/nclimate1958

Poloczanska, E., Burrows, M., Brown, C., Molinos, J., Halpern, B., Hoegh-Guldberg, O., …, & Sydeman, W. (2016, May 4). Responses of Marine Organisms to Climate Change across Oceans. *Frontiers in Marine Science*. Retrieved from: doi.org/10.3389/fmars.2016.00062

Precht, W., Gintert, B., Robbart, M., Fur, R., & van Woesik, R. (2016). Unprecedented Disease-Related Coral Mortality in Southeastern Florida. *Scientific Reports, 6*(31375). Retrieved from: https://www.nature.com/articles/srep31374

Record, N., Runge, J., Pendleton, D., Balch, W., Davies, K., Pershing, A., …, & Thompson C. (2019, May 3). Rapid Climate-Driven Circulation Changes Threaten Conservation of Endangered North Atlantic Right Whales. *Oceanography, 32*(2), 162-169. Retrieved from: doi.org/10.5670/oceanog.2019.201

Revelle, R., & Suess, H. (1957). *Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase in Atmospheric CO2 during the Past Decades.* La Jolla, California: Scripps Institution of Oceanography, University of California.

Rush, E. (2018). Rising: *Dispatches from the New American Shore.* Canada: Milkweed Editions.

Sanford, E., Sones, J., Garcia-Reyes, M., Goddard, J., & Largier, J. (2019, March 12). Widespread shifts in the coastal biota of northern California during the 2014-2016 marine heatwaves. *Scientific Reports, 9*(4216). R Pinsky, M., Eikeset, A., McCauley, D., Payne, J., & Sunday, J. (2019, April 24). Greater vulnerability to warming of marine versus terrestrial ectotherms. *Nature, 569*, 108-111. Retrieved from: doi.org/10.1038/s41586-019-1132-4 etrieved from: doi.org/10.1038/s41598-019-40784-3

Schartup, A., Thackray, C., Quershi, A., Dassuncao, C., Gillespie, K., Hanke, A., & Sunderland, E. (2019, August 7). Climate change and overfishing increase neurotoxicant in marine predators. *Nature, 572*, 648-650. Retrieved from: doi.org/10.1038/s41586-019-1468-9

Smale, D., Wernberg, T., Oliver, E., Thomsen, M., Harvey, B., Straub, S., …, & Moore, P. (2019, March 4). Marine heatwaves threaten global biodiversity and the provision of ecosystem services. *Nature Climate Change, 9*, 306-312. Retrieved from: nature.com/articles/s41558-019-0412-1

Spalding, M. J. (2004, August). Climate Change and Oceans. *Consultative Group on Biological Diversity*. Retrieved from: http://markjspalding.com/download/publications/peer-reviewed-articles/ClimateandOceans.pdf

Spalding, M. J., & de Fontaubert, C. (2007). Conflict Resolution for Addressing Climate Change with Ocean-Altering Projects. *Environmental Law Review News and Analysis.* Retrieved from: https://cmsdata.iucn.org/downloads/ocean_climate_3.pdf

Spalding, M. J. (2011, May). Before the Sun Sets: Changing Ocean Chemistry, Global marine Resources, and the Limits of Our Legal Tools to Address Harm. *International Environmental Law Committee Newsletter, 13*(2). PDF.

Spalding, M. J. (2011). Perverse Sea Change: Underwater Cultural Heritage in the Ocean is Facing Chemical and Physical Changes. *Cultural Heritage and Arts Review, 2*(1). PDF.

Spalding, M. D., & B. Brown. (2015, November 13). Warm-water coral reefs and climate change. *Science, 350*(6262), 769-771. Retrieved from: https://science.sciencemag.org/content/350/6262/769

Stocker, T. (2015, November 13). The silent services of the world ocean. *Science, 350*(6262), 764-765. Retrieved from: https://science.sciencemag.org/content/350/6262/764.abstract

The Institute for Sustainable Development and International Relations. (2015, September). Intertwined Ocean and Climate: Implications for International Climate Negotiations. *Climate – Oceans and Coastal Zones: Policy Brief*. Retrieved from: https://www.iddri.org/en/publications-and-events/policy-brief/intertwined-ocean-and-climate-implications-international

Torda, G., Donelson, J., Aranda, M., Barshis, D., Bay, L., Berumen, M., …, & Munday, P. (2017). Rapid adaptive responses to climate change in corals. *Nature, 7,* 627-636. Retrieved from: nature.com/articles/nclimate3374

Whitcomb, I. (2019, August 12). Droves of Blacktip Sharks Are Summering in Long Island for the First Time. *LiveScience*. Retrieved from: livescience.com/sharks-vacation-in-hamptons.html

Worm, B., & Lotze, H. (2016). *Climate Change: Observed Impacts on Planet Earth, Chapter 13 – Marine Biodiversity and Climate Change*. Department of Biology, Dalhousie University, Halifax, NS, Canada. Retrieved from: sciencedirect.com/science/article/pii/B9780444635242000130

Vallis, G. K. (2012). *Climate and the Ocean*. Princeton, New Jersey: Princeton University Press.