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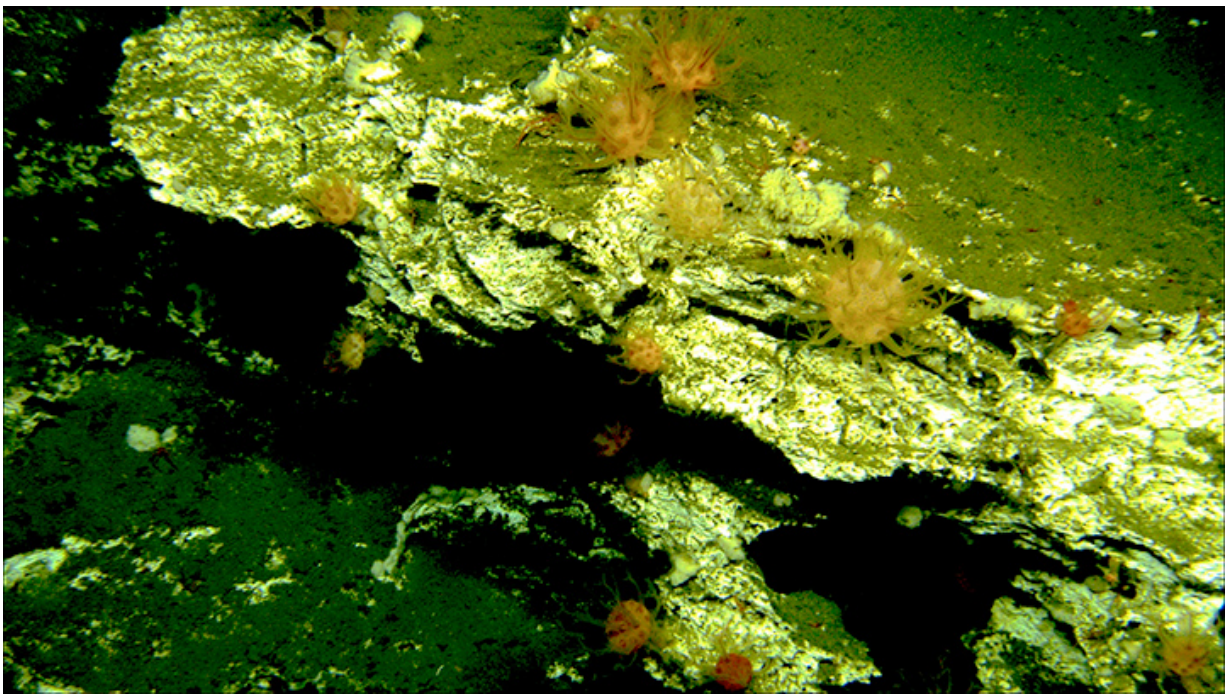
# World Ocean Systems Undermined by Climate Change by 2100

## Scientists warn against the high risk of degradation of marine ecosystems and associated human hardships



*Deep ocean coral such as this Anthomastus reef off Eel River, Calif., represent the type of organisms that can survive in low oxygen conditions and may become prevalent as ocean oxygen declines due to climate change.*

An ambitious new study that includes Lisa Levin of Scripps Institution of Oceanography at UC San Diego describes the full chain of events by which ocean biogeochemical changes triggered by manmade greenhouse gas emissions may cascade through marine habitats and organisms, penetrating to the deep ocean and eventually influencing humans.

Previous analyses have focused mainly on ocean warming and acidification, considerably underestimating the biological and social consequences of climate change. Factoring in predictable synergistic changes such as the depletion of dissolved oxygen in seawater and a

decline in productivity of ocean ecosystems, the new study shows that no corner of the world ocean will be untouched by climate change by 2100.

“When you look at the world ocean, there are few places that will be free of changes; most will suffer the simultaneous effects of warming, acidification, and reductions in oxygen and productivity,” said lead author Camilo Mora, a former Scripps postdoctoral researcher and now an assistant professor at the Department of Geography in the College of Social Sciences at the University of Hawai‘i at Mānoa (UH Mānoa). “The consequences of these co-occurring changes are massive—everything from species survival, to abundance, to range size, to body size, to species richness, to ecosystem functioning are affected by changes in ocean biogeochemistry.”

The human ramifications of these changes are likely to be massive and disruptive. Food chains, fishing, and tourism could all be impacted. The study shows that some 470 to 870 million of the world’s poorest people rely on the ocean for food, jobs, and revenues, and live in countries where ocean goods and services could be compromised by multiple ocean biogeochemical changes.

“Because many deep-sea ecosystems are so stable, even small changes in temperature, oxygen, and pH may lower the resilience of deep-sea communities,” said co-author Levin, a professor at Scripps and director of the Center for Marine Biodiversity and Conservation at Scripps. “This is a growing concern as humans extract more resources and create more disturbances in the deep ocean.”

Mora and Craig Smith with UH Mānoa’s School of Ocean and Earth Science and Technology (SOEST) worked with a 28-person international collaboration of climate modelers, biogeochemists, oceanographers, and social scientists to develop the study, which is published in the scientific journal *PLOS Biology*.

The researchers used the most recent and robust models of projected climate change developed for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) to inform their analysis. They quantified the extent of co-occurrence of changes in temperature, pH, oxygen, and primary productivity based on two scenarios: a business-as-usual scenario wherein atmospheric $CO_2$ concentrations could reach 900 ppm by 2100, and an alternative scenario under which concentrations only reach 550 ppm by 2100 (representing a concerted, rapid $CO_2$ mitigation effort, beginning today).

They discovered that most of the world’s ocean surface will be simultaneously impacted by varying intensities of ocean warming, acidification, oxygen depletion, or shortfalls in productivity. Only a very small fraction of the oceans, mostly in polar regions, will face the

opposing effects of increases in oxygen or productivity, and nowhere will there be cooling or pH increase.

“Even the seemingly positive changes at high latitudes are not necessary beneficial. Invasive species have been immigrating to these areas due to changing ocean conditions and will threaten the local species and the humans who depend on them,” said co-author Chih-Lin Wei, a postdoctoral fellow at Ocean Science Centre, Memorial University of Newfoundland, Canada.

The researchers assembled global distribution maps of 32 marine habitats and biodiversity hotspots to assess their potential vulnerability to the changes. As a final step, they used available data on human dependency on ocean goods and services and social adaptability to estimate the vulnerability of coastal populations to the projected ocean biogeochemical changes.

“Other studies have looked at small-scale impacts, but this is the first time that we’ve been able to look the entire world ocean and how co-occurring stressors will differentially impact the earth’s diverse habitats and people,” said co-author Andrew Thurber, a Scripps alumnus and now a postdoctoral fellow at Oregon State University. “The real power is in the quantitative, predictive approach using IPCC climate models that allow us to see how much it will all change, and also how confident we can be in our estimates.”

By 2100, global averages for the upper layer of the ocean could experience a temperature increase of 1.2 to 2.6° C, a dissolved oxygen concentration reduction of ~2% to 4% of current values, a pH decline of 0.15 to 0.31, and diminished phytoplankton production by ~4% to 10% from current values. The seafloor was projected to experience smaller changes in temperature and pH, and similar reductions in dissolved oxygen.

Of the many marine habitats analyzed in the study, researchers found that coral reefs, seagrass beds, and shallow soft-bottom benthic habitats would experience the largest absolute changes in ocean biogeochemistry, while deep-sea habitats would experience the smallest changes.

“The deep-sea floor covers most of the Earth’s surface and provides a whole host of important ecosystem services including carbon sequestration in seafloor sediments, buffering of ocean acidity, and providing an enormous reservoir of biodiversity,” said Smith. “Nonetheless, very little attention has been paid to modeling the effects of climate change on these truly vast ecosystems. Perhaps not surprisingly, many deep seafloor ecosystems appear susceptible to the effects of climate warming over the next century.”

“The impacts of climate change will be felt from the ocean surface to the seafloor. It is truly scary to consider how vast these impacts will be,” said co-author Andrew K. Sweetman, who helped to convene the original team of investigators and now leads the deep-sea ecosystem research group at the International Research Institute of Stavanger, Norway. “This is one legacy that we as humans should not be allowed to ignore.”

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