Back to Blue

An initiative of
Economist Impact and The Nippon Foundation

OCEAN ACIDIFICATION AND BIODIVERSITY LOSS

Connecting the dots with data

ECONOMIST IMPACT

THE NIPPON FOUNDATION

Contents

About the report

Ocean acidification and biodiversity loss: Connecting the dots with data is a report written by Economist Impact for Back to Blue, an initiative of Economist Impact and The Nippon Foundation. The purpose of this report is to highlight the need for ocean scientists to prove causal links between ocean acidification (OA) and damage to marine species, and the challenges involved in doing so.

To inform this report, we conducted a series of in-depth interviews with oceanographers and other experts in this field. Our thanks are due to the following people (listed alphabetically by primary institution) for their time and insights:

- Karen Evans, principal research scientist, **CSIRO**; co-chair, Biology and Ecosystems Panel, **Global Ocean Observing System (GOOS)**
- David Obura, chair, **IPBES**; founding director, **CORDIO East Africa**
- Steve Widdicombe, director of science, **Plymouth Marine Laboratory**; co-chair, **Global Ocean Acidification Observing Network (GOA-ON)**; co-lead, UN Ocean Decade's **Ocean Acidification Research for Sustainability (OARS) Programme**
- Kirsten Isensee, programme specialist for ocean carbon, Intergovernmental Oceanographic Commission (IOC), **(UNESCO)**; co-lead, UN Ocean Decade's **Ocean Acidification Research for Sustainability (OARS) Programme**
- Sebastian Hennige, reader, School of Geosciences, **University of Edinburgh**
- Sam Dupont, senior lecturer, Department of Biological and Environmental Sciences, **University of Gothenburg**; design consultant, Ocean Acidification International Coordination Centre, **International Atomic Energy Agency**
- Masahiko Fujii, professor, Atmosphere and Ocean Research Institute, **University of Tokyo**
- Pepe Clarke, oceans practice leader, **WWF International**

This report was written by Denis McCauley and edited by Naka Kondo.

Key takeaways

- Earlier Back to Blue reports highlighted the existential dangers that OA pose to marine life and ecosystems as well as actions that some governments are taking to combat it. This report discusses OA in the context of biodiversity loss and highlights the need for more integrated research to better document OA's role in it.

- Well-intentioned initiatives to combat OA often flounder at national, regional and local levels due to competing priorities. Documenting causality between OA and species decline will generate additional urgency among policymakers to act.

- Within individual marine environments, isolating OA's influence on change to biological processes will also help reduce the chance of actions being taken that cause unintended damage. In some environments, other stressors may be the primary cause of harm to organisms.

- Research to determine OA's impact on marine organisms must move beyond laboratories to incorporate much wider data gathering in the field. That should involve closer co-ordination between chemical and biological monitoring efforts.

- A group of scientists are championing a new approach to integrating chemical and biological monitoring that would involve, among other steps, adopting of common indicators. This approach would facilitate work to definitively link OA to changes in biological processes.

Summary

The world is living through a biodiversity crisis. The rapid pace at which animal and plant species have declined in recent decades has led some experts to declare that another mass extinction is under way.[1] What distinguishes this from previous periods of accelerated biodiversity loss are its causes. Whereas naturally occurring events—some sudden and cataclysmic, others more gradual—were the triggers in pre-historic times, human actions are the root cause of species decline today. They include over-hunting, over-fishing and over-farming, but potentially the most devastating in the long term is climate change brought about by our unrelenting carbon dioxide (CO_2) emissions..

The impacts of emissions-induced climate change are readily evident in the world's oceans, perhaps most vividly in the decline of warm water coral reefs caused by warming. Excess CO_2 emissions—more than the oceans can safely absorb—are putting many other marine species under direct threat, such as several forms of plankton and shellfish. Those excess emissions also cause ocean acidification (OA), which changes seawater chemistry in ways that make it difficult for many organisms to survive or thrive.

Scientists understand the malign connection between OA and changes to ocean chemistry and biological processes. Many have highlighted the biodiversity loss that will result from OA, and the follow-on harm it will cause to marine ecosystems and the communities that rely on them for food and livelihoods. Policymakers and international organisations are generally aware of the threat that OA poses. The UN Convention on Biological Diversity (CBD) has mandated member countries to actively combat it, and many are putting action plans in place for that purpose. At national, regional and local levels, however, where action is most vital, competing priorities too often deprive those plans of resources and impetus.

Ocean experts advocating for action against OA worry that their efforts are not creating sufficient urgency among policymakers. OA's effects are not easy to see, unlike other manifestations of climate change. Therefore, scientists are seeking to provide incontrovertible evidence by demonstrating causality between OA and species decline. Doing so will perform another service: making it easier to determine whether OA is or is not the major stressor on marine life in specific environments, reducing the chances that remedial actions are misdirected and cause unintended harm.

Proving causality cannot be done through laboratory research alone. It requires extensive data gathering in the field, where OA's impact on organisms can be observed in real (not simulated) environments. It also demands much closer co-ordination between researchers monitoring ocean chemistry and those monitoring biological processes—activities that thus far have been unconnected. Although decades of data gathering may be needed before some correlations are proven, the ocean experts pressing for a new approach to research believe many correlations will become manifest in the next few years.

This report discusses how current ocean research approaches can be adapted to yield such correlations. And while decades may be required for some findings to be confirmed, the report also highlights opportunities to demonstrate causality today—environments where the impacts on biodiversity can be viewed in isolation from other stressors. When it comes to prodding policymakers into action, such results could bear fruit sooner rather than later.

1. The marine biodiversity crisis

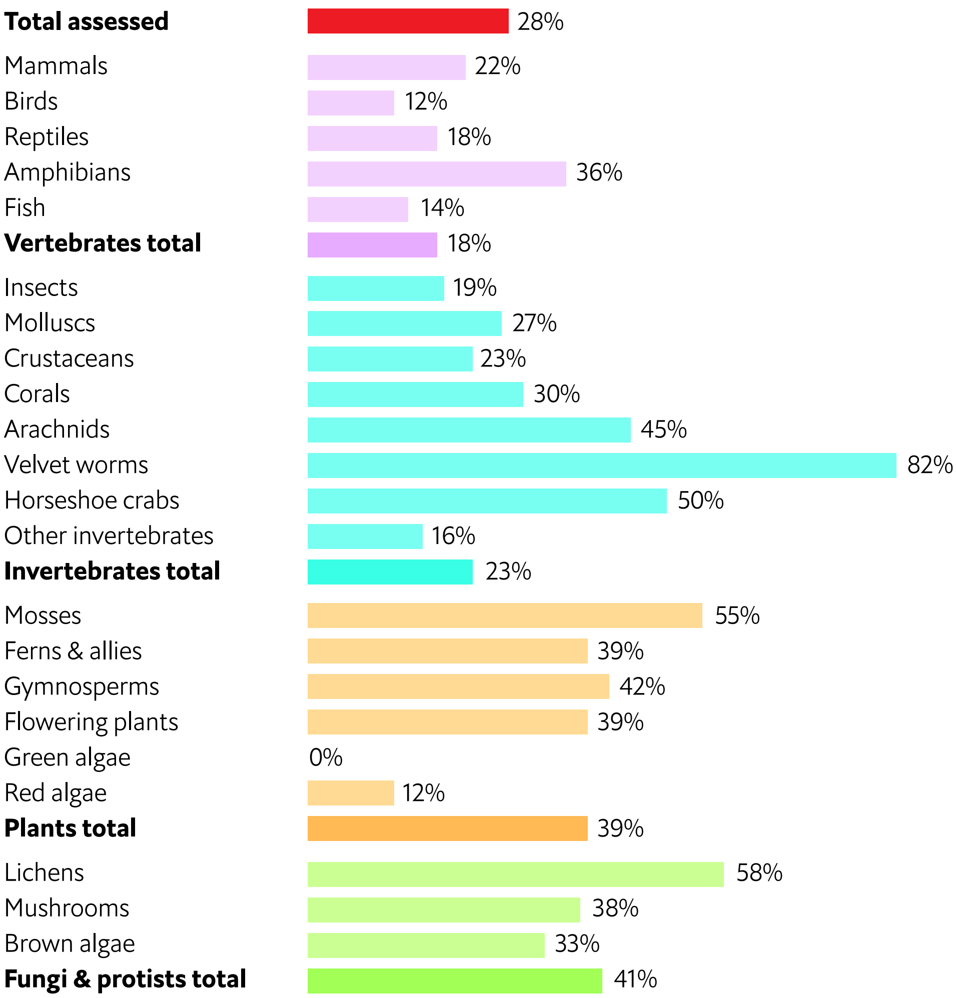
Global biodiversity is in an accelerated state of decline. An estimated 28% of the world's animal and plant species are currently under threat of extinction, according to the International Union for Conservation of Nature (IUCN).[2] This figure has increased steadily each year since the mid-1990s as the IUCN has increased its assessment efforts.

The ecological crisis resulting from the decline of species is even more dire, according to David Obura, chair of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services and founding director of CORDIO East Africa, an oceans research organisation. "It is species' interactions that define how ecosystems function," he says. "When species become too rare, or decline below a certain point, the functions they perform may cease to exist, and long before they become extinct." This, says Mr Obura, puts under threat those ecosystems' contributions to people.

The main causes of biodiversity loss today are linked to human actions. On land, the drivers include agricultural expansion, deforestation, over-hunting and the introduction of invasive species. In coastal waters and the open ocean, over-fishing is a major cause, as are, close to shores, agricultural run-off and chemical pollution. A common driver both on land and in water is climate change caused by the unrelenting growth of CO_2 emissions since the dawn of the Industrial Age.

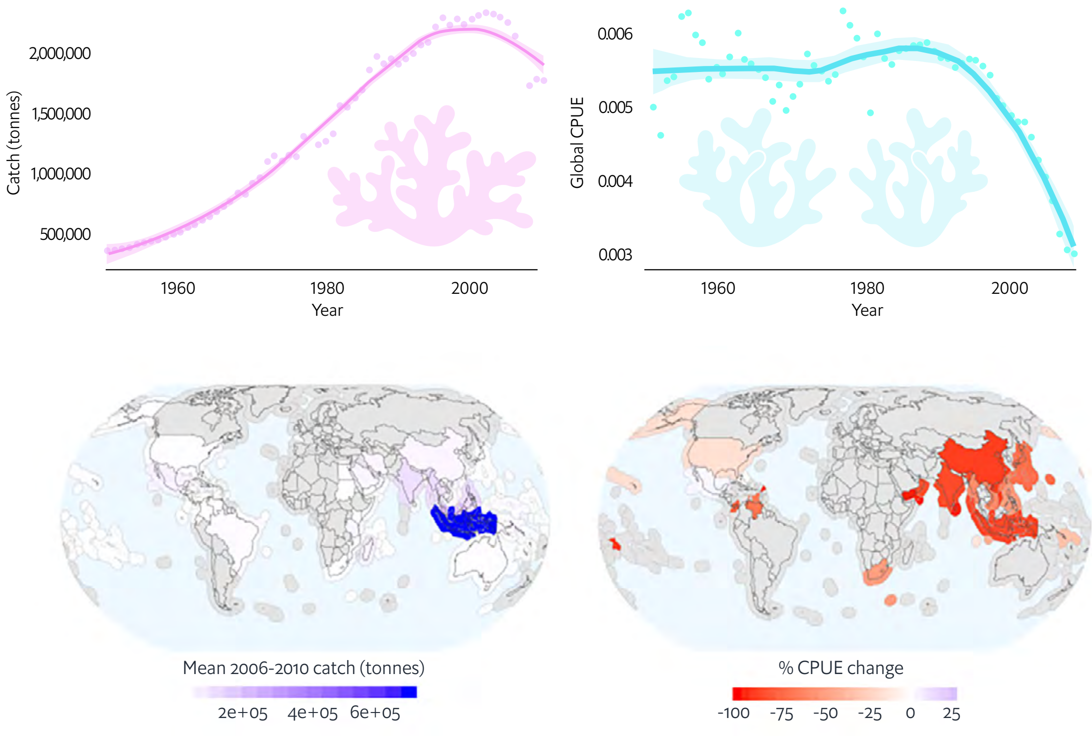
Climate-related biodiversity loss in the oceans is already catastrophic. "Coral reef systems, for example, are collapsing around the world," says Pepe Clarke, oceans practice leader at WWF International. It is a well-documented calamity. There was a roughly 50% decline in the world's coral reef cover between 1957 and 2007.[3] A consequence of that loss has been a reduced abundance of coral reef fish. Global catches of such fish peaked in volume in 2001 at around 2.3 million tonnes, after which they began to decline. And catch per unit of effort (CPUE, an "effort" being the weight of fish taken per hour of trawling, the number of fish taken per thousand hooks or another similar measure) has declined steadily since 1971.[4] This manifestation of marine biodiversity loss particularly affects less developed countries, especially small island developing states where coral reef fish are a major source of nutrition for inhabitants and income for fishing communities. "Biodiversity loss always hits poor countries and communities the hardest," says Mr Obura. "Their natural ecosystems are declining, and they lack the wealth to help them cope and adapt."

Figure 1: Share of threatened species within major groups of organisms (2023)



Source: IUCN Red List (2023). See https://www.iucnredlist.org/resources/summary-statistics

Figure 2: The declining abundance of coral reef fish



Source: Courtesy of TD Eddy, VWY Lam et al, "Global decline in capacity of coral reefs to provide ecosystem services", One Earth (17 September 2021). See: https://www.sciencedirect.com/science/article/pii/S2590332221004747

Less familiar and less documented are declines in marine species that are critical links in ocean food chains. An example is coccolithophores, a type of phytoplankton at the base of food chains that is a key producer of carbonate, a chemical that higher-level species use to build shells and skeletons. One study of coccolithophore populations in the Mediterranean Sea found progressive depletion in 27 of their species in terms of cell concentration and diversity.[5]

OA: a likely suspect

Almost certainly a contributor to this and other examples of marine biodiversity loss is OA. OA is a direct result of CO_2 emissions from burning fossil fuels for heating, power generation, transport and other human activities. The ocean absorbs between 20% and 30% of the carbon released into the atmosphere each year.[6] Carbon forms a natural part of many marine biological processes, and many species use it to aid their development. Its absorption from the atmosphere, and its sequestering in these processes over long timescales, also helps to mitigate global warming. But as more carbon is released into the atmosphere, the oceans can't sequester it quickly enough. When oceans have excess carbon, this usually leads to a lower pH and higher acidity.[7]

The malign effects of OA are easiest to see in shellfish and other calcifying organisms in weakening shells and skeletons. "The problem is much bigger than this, however," says Sam Dupont, a senior lecturer in the Department of Biological and Environmental Sciences at the University of Gothenburg. "If organisms are exposed to conditions they've never experienced before, which is what OA does, there is a cost in the energy the organisms must expend in order to cope." Many will not have access to this energy, which is when the damage becomes evident. According to Mr Dupont: "First they grow slower, the amount of eggs they produce declines, and ultimately when the cost is really too high, they start dying."

A prime example of the damage OA can cause emerged in the US North-west in 2007-08, when oyster hatcheries in Oregon and Washington experienced large-scale losses of oyster larvae. Scientists found the cause to be a rise in the acidity of the hatchery waters.[8] Another victim of OA harm is the shelled pteropod, a species of zooplankton that is a source of food for larger organisms, including salmon and whales. Pteropods' shell dissolution has been observed to be rapid in waters with high concentrations of CO_2 and low concentrations of aragonite (a mineral needed for shell and skeleton production)—together a sure indicator of OA.[9]

High-level recognition, insufficient action

The international community appears to recognise the gravity of OA's threat to biodiversity. COP 15 of the CBD, held in December 2022, set 23 targets to be achieved by 2030 to help stem biodiversity loss and restore natural ecosystems. Target 8 calls for actions to "minimise the impact of climate change and ocean acidification on biodiversity and increase its resilience through mitigation, adaptation and disaster risk reduction".[10]

By enshrining this target in an international treaty, the UN has formally acknowledged a connection between OA and biodiversity loss and obligated member countries to take actions to combat OA. To meet Target 8, countries will need to inject OA considerations into their biodiversity legislation, mandate national action to reduce OA's impacts, set specific targets for achieving the latter and monitor progress for achieving them.

Although limited in number, national and regional governments are beginning to take the above measures. At the time of writing, 13 government-level OA action plans are in existence, according to the OA Alliance (formally known as the International Alliance to Combat Ocean Acidification).[11]

Why aren't there more? As we explained in an earlier report,[12] one reason is a lack of funding and other resources needed just to draft an action plan, much less to implement and monitor one. Even for governments that can muster the resources, the need to address other pressing marine challenges, such as over-fishing and chemical pollution, often pushes OA lower down the priority list. "We know what needs to be done, but it's hard convincing policymakers to do it," says Mr Dupont. "It's difficult to generate urgency by showing them that some species are likely to disappear in 20 years."

Convincing policymakers should be easier when ocean scientists can prove beyond the shadow of a doubt that OA is a direct cause of the demise of species.

2. Documenting the OA impact

With a large body of scientific research on OA having been conducted in the past 20 years, documenting its link with biodiversity loss seems like it should be straightforward. It is anything but. The cases of clear causality cited above are few and far between.

This is not to say that scientists lack a clear understanding of how OA changes ocean chemistry and affects marine life. By and large, however, the evidence they've gained comes from laboratory work, not field research. Lab experiments can simulate real marine environments, but they are limited in scope. "We can study the response of a single species to OA by rearing it in a tank of seawater with artificially increased CO_2," says Masahiko Fujii, a professor at the University of Tokyo's Atmosphere and Ocean Research Institute. "But it's impossible in a lab to study OA's effects on complex interactions among marine organisms, particularly food chain relationships." In Japan, he says, policymakers and other government stakeholders want to see real-world proof of causality before committing resources to take action.

"From the body of research conducted to date, we can say with certainty that OA is starting to have a negative impact on marine species and ecosystems, and that these will suffer if acidity levels increase," says Karen Evans, who is principal research scientist at CSIRO, Australia's national agency for scientific research. "But we don't really understand how different stressors interact, and we don't understand the adaptive capacity of individual species."

Isolating the main culprit

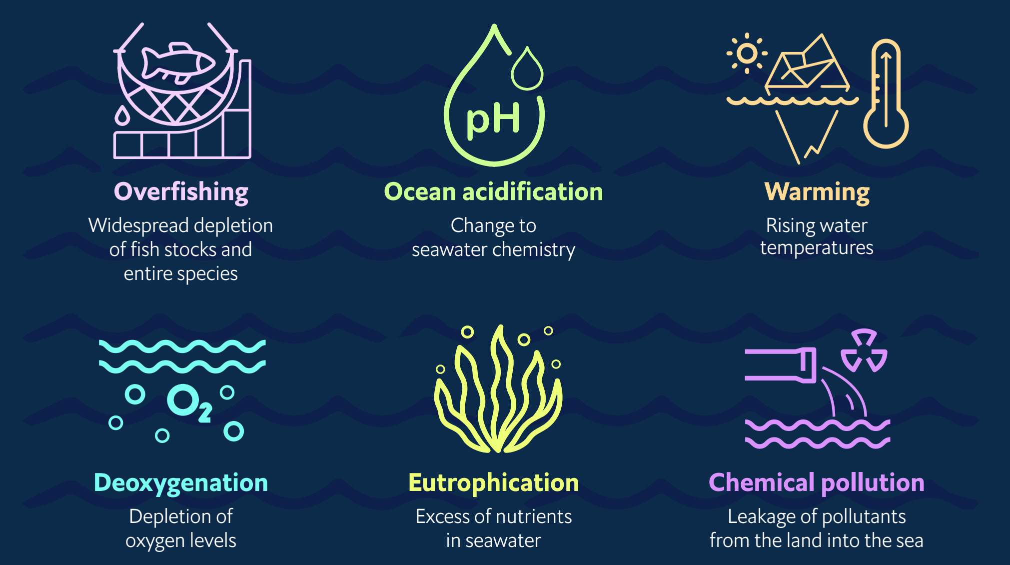
The different stressors on marine organisms that Ms Evans mentions are potentially numerous, particularly in coastal waters, and they will typically vary from one marine environment to the next. Aside from OA, the principal ones are:

Warming: ocean waters are heating up as a consequence of rising temperatures in the atmosphere. Higher temperatures can have profound physiological affects on marine organisms. Warming can change their metabolism and need for oxygen, sometimes leading them to move to less stressful waters, thus altering established food chains.

Deoxygenation: in coastal environments, warming and increases in nutrient inputs from river run-off can combine to deplete oxygen content, which impairs organisms' physiological and biological processes. To complicate matters further, oxygen is also depleted in deeper waters, and these often rise closer to the surface in a process known as upwelling.

Eutrophication: when nutrients accumulate near river estuaries—usually the result of run-off from agricultural land—algae and other plant life become overabundant. The decomposition of this organic matter produces large amounts of CO_2, which leads to lower pH and higher acidity levels.

Major sources of stress to marine species



The interaction of these and other stressors in coastal waters is one of scientists' key unknowns about how OA affects marine life. "We understand well how excess CO2 is changing ocean waters," says Steve Widdicombe, director of science at Plymouth Marine Laboratory in the UK and co-chair of the Global Ocean Acidification Observing Network (GOA-ON). "But it gets more complicated when we get to the coastal zone, due to these other processes that can create great variability in the carbonate chemistry parameters."

Isolating these stressors and correctly determining their impact on organisms is important because remedial actions can have unintended consequences. One example comes from restoring natural habitats, a measure widely considered to be effective in helping organisms to survive and adapt. "Restoration requires more science," says Mr Dupont. "If you do it wrong, it will do more harm than good." He recently found that to be the case with a seagrass restoration initiative. "It's an important initiative for many reasons, but we've found that the presence of seagrasses is actually amplifying the negative effects of OA."

Establishing causality requires identifying statistical correlations between increases in OA and changes in biological processes. At the micro level, that of individual ecosystems and local environments, identifying such correlations increases the chances that the right measures will be taken to reduce acidity levels in those waters. At national and wider levels, proving the existence of similar correlations across multiple environments will help convince policymakers and other key stakeholders that the OA threat to biodiversity is real, not just assumed.

A window to the ocean's future—part one: volcanic seeps

For ocean scientists, natural environments offering unmistakeable evidence of the impact of ocean acidification (OA) marine species are worth their weight in gold. Lab experiments can simulate such environments, but they cannot replicate the richness of interactions between different organisms. That is why Masahiko Fujii, professor, Atmosphere and Ocean Research Institute, University of Tokyo and other scientists are currently focusing their field research on volcanic ocean seeps—natural environments with relatively high CO_2 concentrations and low pH levels, which together are clear indicators of OA.

As the term used to describe them suggests, such environments can be found near active coastal or island volcanoes. Clusters of vents in the ocean floor emit CO_2-rich gases that bubble up through the seawater columns above. In some seeps, such as a well-researched one off the coast of Vulcano Island, Sicily, pH levels can be below 6.[13] (Globally, the mean surface ocean pH level is currently around 8.[14]) Scientists have identified about 70 shallow volcanic seeps around the world, with most of them in the Mediterranean Sea.[15] There are several off the coasts of Japan as well. Mr Fujii is part of a research team exploring seeps there, near the islands of Himeshima and Shōwa Iōjima, to study the biodiversity effects of OA.

More OA, less complexity

Mr Fujii has yet to publish data from the team's research, but thus far he has observed substantially reduced biodiversity in the CO_2 seeps (no corals or reef fish, for example) compared with that in neighbouring waters where the pH is higher.

Fellow scientists studying other seeps have found that, in the areas of highest CO_2 concentration, some organisms adapt but biodiversity overall is reduced. A team of scientists that analysed data from the Vulcano Island seep found just that. For example, their analysis showed that most species of algae were resilient to OA even at the highest emissions levels that could result by the end of this century.[16] Many other species in that environment, however, such as coccolithophores, gastropods, bryozoans and serpulid worms—all vital food chain components—were less abundant than in nearby waters with higher pH levels.[17] Their conclusion is that prolonged exposure to OA will, more often than not, bring about reduced ecosystem complexity—in other words, a loss of marine biodiversity.

It is critical to develop an understanding of why some species thrive under elevated OA conditions while others deteriorate. Conducting biological experiments at volcanic CO_2 seeps can provide some answers now, says Mr Fujii. "They are considered a natural analogue to OA for a reason: they anticipate tomorrow's ocean environment if we continue to emit greenhouse gases at the pace we are doing today."

3. The integration imperative

At present, the challenge of establishing causality between OA and biodiversity loss is mainly one of conducting more integrated monitoring, data collection and analysis. In particular, it requires the closely co-ordinated analysis of chemical and biological observations.

The scientific observation of coastal and open ocean waters has been ongoing for decades. There are hundreds of coastal monitoring stations around the world regularly observing and studying marine organisms and their environments. Expeditions, research cruises and fixed moorings do the same in the open ocean. Still, only around 7% of the ocean's waters are regularly observed, according to a panel of experts convened by the Global Ocean Observing System (GOOS), a body administered by UNESCO and its International Oceanographic Commission (IOC).[18]

"We need much more data [to establish causality], not just on how pH is changing, but also the associated biological information," says Ms Evans, who serves as co-chair of the aforementioned GOOS panel. "We're currently only observing a tiny fraction of that biology, and we're not connecting the observations to changes taking place in ocean chemistry."

The problem is that OA monitoring and biological process monitoring are two distinct—and, to date, mostly unconnected—types of field research. By and large, neither have taken account of the other in any systematic way.

Creating common terms of reference

A group of ocean scientists aims to change that. They are members of the Biology Working Group of GOA-ON. As a first step, recognising that chemical scientists and marine biologists do not always speak the same language, they have developed a set of indicators for measuring and comparing the biological impacts of ocean acidification (OA) across different regions and time scales.[19]

The indicators fall into five traits that apply to organisms across all marine ecosystems. According to Steve Widdicombe, co-chair of GOA-ON, all the traits have been shown by previous research to be sensitive to OA. They are:

Calcification

OA's effects on calcium carbonate structures (shells and skeletons) are the best studied of all its impacts. Charting the changes to biomass, abundance and rates of calcification over time for calcifying and non-calcifying organisms can help isolate the OA impact from other stressors.

Primary production

Plants and algae are the foundation of all marine food webs. Changes in their growth and energy consumption can be compared with changes in carbonate chemistry in the same waters.

Growth

The ability of higher-level marine organisms to increase biomass and maintain reproduction levels may change when those organisms need to expend added energy to adapt to OA-induced changes in carbonate chemistry.

Biodiversity

Changes in the aforementioned traits and processes may ultimately lead to changes to biodiversity and community structure. OA may contribute to species loss either directly, as with weakened calcification and reduced ability to grow or reproduce, or indirectly, such as by changing grazing habits or increasing susceptibility to diseases.

Genetic adaptation

Species will respond to increased acidity in different ways, and OA is known to be a driver of genetic change. Existing technologies can identify and measure the specific OA signature at the molecular level, thus enabling projections to be made of OA adaptation across populations and species.

Source: S Widdicombe, K Isensee, Y Artioli, JD Gaitan-Espitia, C Hauri, JA Newton, M Wells, S Dupont, "Unifying biological field observations to detect and compare ocean acidification impacts across marine species and ecosystems: What to monitor and why", Ocean Science (25 January 2023). See: https://egusphere.copernicus.org/preprints/2022/egusphere-2022-907/

According to Kirsten Isensee, who is programme specialist for ocean carbon at the IOC and also co-chair of the Biology Working Group, defining broad rather than prescriptive traits and indicators will enable monitoring and research teams in all regions to contribute and will enhance the comparability of their findings. "We've also shifted the basis of comparison to focus on rates of change rather than species-specific parameters," she says. "OA specialists and biologists alike should be able to measure these."

This approach to unifying biological and chemical observations is designed to guide future research. But it can also be applied to the analysis of already existing data, says Mr Widdicombe. "In some regions, we've got 10 or 15 years of biological and carbonate chemistry monitoring data that could be compared now. It may just require re-analysing the data in a different way using the method we've put forward," he says. "That will enable us to make connections no one's seen before."

A window to the ocean's future—part two: cold water coral

The tragic loss of tropical coral reefs is a story well known to the general public. Unbeknownst to all but marine scientists, however, is the simultaneous loss of cold water coral in the deep sea.

Reef loss has different primary causes in the different environments: rising temperatures and mass bleaching in the case of shallow tropical reefs and, scientists believe, ocean acidification (OA) in cold water systems. Due to their unique conditions, the study of those deep sea environments, such as one situated off the coast of southern California, offers clear evidence of OA's role in the loss of habitat in and around cold water coral reefs. "By looking at such ecosystems," says Sebastian Hennige, reader in the University of Edinburgh's School of Geosciences, "we can see how cold water coral will look in future acidification conditions—what we expect most deep sea reefs will be in by the end of this century."

Cold water coral reefs are calcium carbonate structures in the deep ocean that can extend several kilometres in breadth and form mounds up to 300 metres in height. The reefs atop the mounds are mostly dead coral skeletons that support live coral above and an enormous amount of biodiversity. "They are beautiful and complex 3D structures," says Mr Hennige. Organisms such as anemones, sea urchins, clams, starfish and shrimp live within the structure made by the dead coral skeletons, providing food for larger organisms like fish, crabs and lobsters. The reefs are also spawning grounds for large creatures such as rays and sharks.

Coralporosis

The problem is that elevated acidity in some deep sea waters is reducing the saturation of aragonite, a carbon mineral that skeletons (as well as the protective shells of many organisms) are built from. This leads to "coralporosis", a term Mr Hennige and his colleagues coined to describe the weakening and disintegration of those structures in a manner similar to osteoporosis in humans.[20] "Increasing porosity, which we've observed to be rapid, weakens the dead reef structure to the extent that it will crumble and collapse," he explains. "Live corals may survive, but the remaining habitats are much less complex." Given the size of such reef systems, says Mr Hennige, "this process could eventually lead to ecosystem-scale habitat loss in the near future."

Unlike in shallow coastal waters where OA is just one of many stressors impacting ecosystems and species, in the deep sea, scientists are almost certain that it's the primary cause of cold water coral habitat degradation. One of the reasons is that the part of the coral structure that OA is impacting is dead. "When we look at live organisms, it's sometimes difficult to tease apart the impacts of OA from those of deoxygenation or increases in water temperature, the latter of which is currently a far more important stressor in tropical reefs," says Mr Hennige. "But dead coral skeleton is not impacted by either of those stressors. We can very clearly say that porosis in the dead coral skeleton results from OA."

The applicability of these findings to other types of organisms in different environments is unclear. However, this is the type of causality between OA and ecosystem changes that many other marine scientists are seeking to prove.

4. From concept to action

The Biology Working Group's next step is to develop a proof of concept (POC) that demonstrates that their approach to integrating data collection and analysis will yield correlations. According to Ms Isensee, this two-year effort will focus on existing chemical and biological data sets from past monitoring efforts. "I'm convinced we will very quickly see correlations emerge from this analysis," she says.

After publication of the POC results comes outreach to biological researchers as well as to officialdom. "Essentially this will be a dissemination and marketing activity," says Mr Widdicombe. "We'll educate the monitoring community on our approach and encourage them to be part of the effort. We'll also make the commissioners of monitoring, such as governments, aware of the approach; this will hopefully generate top-down pressure on monitoring programmes to adopt it."

Capacity will then need to follow, in order to train biological monitoring teams, develop tools for analysis, and create standards for data and measurement. International organisations can help with this, an example being the Ocean Acidification International Coordination Centre, where Mr Dupont serves as a consultant. Part of the International Atomic Energy Agency, its mission is facilitating international collaboration on OA, including through data dissemination and training. The IOC will also disseminate training materials that are created as part of the POC.

Nevertheless, Mr Widdicombe and his colleagues are under no illusion about the size of the effort needed to educate and train monitoring teams worldwide. It will require some funding, which is always a bigger challenge in developing countries than elsewhere. "This is why we sought to avoid developing an approach that requires expensive new kit and someone with many years of experience to record measurements and generate data," he says. "Monitoring teams in poorer countries are already gathering a lot of biological data today, so we're trying to make it easy for them to begin pairing it with OA data."

Another piece of the puzzle is making both categories of data easily accessible to researchers. There are portals where OA and biological researchers post their data separately, says Ms Isensee. "But what we really need is a sort of one-stop shop where experts looking to establish links between OA and biological processes can find all the data they need." She is confident that GOA-ON or another existing portal can perform that role, perhaps through automated tie-ups with national data repositories.

No time to waste

An uncomfortable feature of such monitoring and data collection initiatives is the time that may be needed—several years or even decades, depending on the species—before definitive calculations can be made. That is not a reason for delaying plans to combat OA now. “We must promote more science, but that cannot delay action,” says Mr Dupont. “Policymakers often want to wait to act until the evidence is overwhelming. But it’s a luxury we don't have.”

As we noted earlier (see “The marine biodiversity crisis”), a handful of jurisdictions are implementing dedicated and well-resourced OA action plans today. State governments in the US North-west, where OA’s deadly impacts on marine life first became clear, have led the way. Several other regional and national governments, in North America and elsewhere, are in the process of developing such plans. Even without dedicated plans in place, many agencies and authorities around the world are taking concerted actions to combat OA in their waters and mitigate its effects.[21]

Given the current dearth of proven correlations between OA and damage to species, there is a risk that some actions taken now will be misdirected. “Where the damage from these is potentially considerable, we must not proceed without better knowledge,” says Mr Widdicombe. “But in most cases, where the risks of negative consequences are relatively low, we must act sooner rather than later.”

Conclusion

This paper has argued the case for wider and more integrated research efforts that help to establish a clear causal link between OA and biodiversity loss. Aside from the benefits to science, such links will help to make OA real to policymakers and society more widely. Unlike the visible consequences of climate change, such as extreme weather events, people cannot see or feel lower pH or changes in carbonate chemistry in ocean waters. When science can show that OA is directly causing the demise of much-loved marine species, people are more likely to take notice and press for action to combat it.

To have a practical impact, however, the search for causality must extend further, to enable the accurate prediction of OA's impact on ecosystem services—the benefits that marine ecosystems provide to people.

One of the GOA-ON working group's key criterion in their identification of OA-sensitive traits is the latter's relevance to the provision of ecosystem services. The implication is that, once causal links are established between OA and species decline, more work will be needed to determine how those losses will affect fisheries and aquaculture, food supply, marine tourism, jobs, and local, regional and national economies.

This work cannot begin soon enough, says Mr Pepe Clarke of WWF. "We must link the foundational research to the follow-on effects for communities and businesses, because it helps to make the findings politically and socially relevant," he says. That work is critically important now for the communities, regions and countries that are currently struggling with the effects of biodiversity loss, he adds, including from the collapse of coral reef systems. "It can also provide practical utility to those communities or industries who ask, 'If things are going south for us over the next 15 or 20 years, what does that mean for us and how can we adapt?'"

End notes

1 See, for example, G Ceballos, P Ehrlich and R Dirzo, "Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines", PNAS (20 July 2017). See: https://www.pnas.org/doi/full/10.1073/pnas.1704949114

2 IUCN Red List (2023). See https://www.iucnredlist.org/resources/summary-statistics

3 TD Eddy, VWY Lam et al, "Global decline in capacity of coral reefs to provide ecosystem services", One Earth (17 September 2021). See: https://www.sciencedirect.com/science/article/pii/S2590332221004747

4 TD Eddy, VWY Lam et al

5 P Zivere, M Passaro et al, "Decline in Coccolithophore Diversity and Impact on Coccolith Morphogenesis Along a Natural CO2 Gradient", The Biological Bulletin (June 2014). See: https://www.journals.uchicago.edu/doi/10.1086/BBLv226n3p282

6 Economist Impact, "An ocean crisis in the making", Back to Blue (November 2022). See: https://backtoblueinitiative.com/ocean-acidification/

7 The pH scale runs from 0 to 14. Over the past century, the mean surface ocean pH level has fallen from 8.2 to below 8.1. About half of that decline has occurred in the past 40 years. Economist Impact, "An ocean crisis in the making"

8 A Barton, G Waldbusser, R Feely et al, "Impacts of Coastal Acidification on the Pacific Northwest Shellfish Industry and Adaptation Strategies Implemented in Response" (2015). See: https://ir.library.oregonstate.edu/downloads/5425kc600

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