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Marine heatwaves and coral bleaching: what are the opportunities and challenges for research and public policy?

Since the beginning of the industrial era, climate change has warmed the ocean's surface worldwide and caused intense episodes of high ocean temperatures known as marine heatwaves. These intermittent events, which are becoming more and more frequent and intense, cause coral bleaching and degradation of coral ecosystems on a massive scale. Last April, the American National Oceanic and Atmospheric Administration (NOAA) and the International Coral Reef Initiative (ICRI) confirmed the fourth global coral bleaching event, the second in a decade, which had begun in February 2023.

These phenomena present serious ecological and socioeconomic challenges. This article examines the impact of marine heatwaves on corals and explores the opportunities and challenges in order to suggest ways forward for research and public policy.

Increasingly frequent and intense marine heatwaves

Since the pre-industrial period, greenhouse gas emissions caused by human activity have risen dramatically, resulting in an increase in the average atmospheric temperature of 1.1°C (IPCC, 2021). This global warming has led to a significant increase in sea surface temperatures in recent decades in most parts of the world. In this context, recent studies agree that marine heatwaves are becoming increasingly intense and frequent as the climate changes (Oliver *et al.*, 2018). A marine heatwave is defined as a prolonged

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period, lasting from several days to several weeks, of abnormally high sea temperatures (generally between 1°C and 5°C higher than a baseline value), over an area that may extend over several square kilometers. Although their causes are not yet properly understood, marine heatwaves are thought to be more likely when oceanic mixed layers are shallow and stratified, there is unusually little wind (i.e., a reduction in heat loss from the ocean), and atmospheric temperatures have recently peaked (Sen Gupta *et al.*, 2020). Other regional or global climate events, such as El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multidecadal Oscillation (AMO), can also trigger marine heatwaves (Oliver *et al.*, 2018).

By compiling temperature datasets taken both directly from the ocean and *via* satellite, researchers have shown that the average frequency and duration of marine heatwaves increased by 34 % and 17 % respectively between 1925 and 2016 (Oliver *et al.*, 2018). This has meant a 54 % increase in the number of days of marine heatwaves *per* year worldwide over the same period, with a marked acceleration since the 1980s. In other words, these observations show that the increase in frequency and duration of this phenomenon is equivalent to an average of 30 additional days *per* year of marine heatwaves in 35 years.

These episodes of intense heat have harmful consequences for marine ecosystems: a reduction in ocean productivity, disappearance of kelp forests, death of marine invertebrates, migration of certain species, and changes in the composition of reef communities. These consequences have inevitable ecological, social, and economic repercussions (e.g., the modification of fishing quotas) and sometimes result in economic or geopolitical tensions between nations (Oliver *et al.*, 2018). The main reason for these trends is the worldwide increase in sea surface temperatures, and therefore these extreme ocean events seem likely to intensify in the coming decades.

Natural cycles in action: Understanding ocean and climate dynamics

Many different natural phenomena influence weather patterns and variations in climate at both the regional and global level. Among them, the El Niño Southern Oscillation (ENSO) refers to periodic variations in sea surface temperatures in the equatorial Pacific Ocean, alternating between phases of warming (El Niño) and cooling (La Niña). These cycles, which last between 2 and 7 years, affect global temperatures, rainfall, and cyclonic activity. Pacific Decadal Oscillation (PDO) is the name given to a longer-term oscillation between warmer and colder periods in the North Pacific Ocean, with cycles that last 20 to 30 years, mainly influencing the North American climate and the fishing industry. In the North Atlantic Ocean, the Atlantic Multidecadal Oscillation (AMO), which occurs over 40-to-80-year cycles, affects temperatures in Europe, as well as droughts and hurricanes in Africa. These cycles affect global climatic variations on different timescales and, in certain cases, exacerbate the impacts of climate change.

Coral bleaching: Potentially irreversible consequences

Among marine organisms, reef-building corals (Scleractinia) are particularly vulnerable to marine heatwaves as they live in shallow waters. These marine animals build themselves hard calcium carbonate skeletons and live in symbiosis with single-celled algae called zooxanthellae, which live within their tissues. This cohabitation between algae and coral benefits both parties: the coral (the host) provides the zooxanthellae (the symbionts) with a place to live, shelter, and protection, while the latter supply the coral with energy through photosynthesis. When sea temperatures become abnormally high, corals experience thermal stress and expel their symbionts. Without their symbiotic algae, coral tissues lose their usual color. Since this turns them white, this phenomenon is called coral bleaching.

Research has enabled the creation of a Global Coral-Bleaching Database (GCBD) made up of 34,846 measurements from 14,405 sites in 93 countries, providing essential information on the presence or absence of coral bleaching over the period 1980–2020 (van Woesik and Kratochwill, 2022). In recent decades, periods of thermal stress such as marine heatwaves have increased in frequency and intensity, leading to widespread coral bleaching around the world. In most cases, this phenomenon is reversible, and when coral colonies are no longer under stress, they can once again host new symbionts. According to some scientists, this process may represent a form of resilience for corals in the face of climate change, favoring long-term benefits (survival) rather than short-term ones (nutrition and protection). Others support the hypothesis of "adaptive bleaching," seeing these events as an opportunity for the corals to acquire new symbionts that are better adapted to current environmental conditions.

Numerous innovative conservation initiatives

The realization that almost all coral reefs may be lost by 2050 if the climate warms by 2°C (IPCC, 2021) has led to the implementation of numerous initiatives to counteract this trend and conserve reefs, both in France and worldwide.

In response to this urgent problem, France has committed to protecting all of its coral reefs by 2030. To this end, *France Relance* and the *Office français de la biodiversité* funded the Future Maore Reefs project in 2024, under the leadership of the *Institut de recherche pour le développement*, to test low-carbon, nature-based solutions for the sustainable restoration of coral reefs around Mayotte, Réunion, and Madagascar.

Similarly, the World Bank and its partners have established an innovative instrument that enables funds to be raised to support the Indonesian government to manage more than 5 million hectares of marine protected areas (MPAs) more effectively and thus preserve coral reefs. This concept, known as the Indonesia Coral Bond, is performance-based, linking funding to the achievement of relevant success indicators that focus on the environmental and social benefits of MPAs for reef conservation. One advantage of this approach is that it rewards performance, making it attractive for funders. In the same region, the Coral Triangle Initiative (CTI-CFF) promotes the sustainable management of coral reefs, fisheries, and food security, while strengthening regional cooperation on the protection of marine ecosystems and the resilience of coastal communities.

At the international level, The Coral Reef Breakthrough, a coalition launched during the ICRI 37th General Meeting in 2023, seeks to guarantee the future of more than 12.5 million hectares of tropical coral reefs in order to support the resilience of more than half a billion people worldwide by 2030.

In parallel, researchers need to develop innovative tools for studying ecology, in order not only to enable better data collection and access to data, but also to improve and accelerate the monitoring of reefs, so that ongoing conservation plans can be evaluated. This is, for example, the aim of the IA-Biodiv challenge, cofinanced by Meta, the *Agence nationale de la recherche*, and *Agence française de développement* since 2022, which seeks to use artificial intelligence to increase resources, make data more accessible, and contribute to technological advances in order to respond to the threats to marine biodiversity.

In the case of intense, prolonged marine heatwaves, this phenomenon can become irreversible, leading to coral mortality and resulting in the disappearance of coral reefs. In 2016, for example, the Australian Great Barrier Reef, the world's largest biomineral structure, extensive enough to be seen from space, experienced a severe El Niño event that caused the death of 30 % of its corals following bleaching. The loss of such ecosystems has considerable ecological and socioeconomic consequences. As coral reefs are home to 25 % of marine biodiversity, their disappearance leads to habitat loss for numerous marine species, potentially resulting in substantial local or regional biodiversity declines. Furthermore, corals provide essential ecosystem services (such as food provision, coastal protection, and tourism attraction) on which millions of people depend. Their decline can thus have serious repercussions, particularly in the fishing and tourism sectors. One example of this comes from an econometric study conducted in Southeast Asia that assessed the economic impact of the widespread coral bleaching event of 2010, particularly on the scuba diving sector (Doshi *et al.*, 2012). This study, carried out at 11 diving sites across Indonesia, Malaysia, and Thailand, estimated the loss of non-market economic value (in terms of consumer surplus) linked to this event at between 49 and 74 million dollars, due to the severity and duration of bleaching in the region. These losses, directly attributed to coral bleaching, are substantial for local communities.

More targeted international and local strategies and public policy

Climate change is already well underway and is likely to intensify over the coming decades, thus increasing the risk of global socioeconomic disruptions. As coral reefs face growing threats, an urgent response is needed: existing collective efforts must be rapidly scaled up, and effective, well-suited governance measures must be swiftly implemented. To enhance the effectiveness of public policy for coral reef protection, it is essential for science and politics to work together more closely, in order to better integrate scientific knowledge into decision-making. At the same time, an inclusive approach that ensures local actors (such as marine managers, local authorities, and civil society) are fully involved in public debate can enable the development of policies and strategies that are better suited to the ecological and social realities of each specific context. On a boarder scale, increased international cooperation, built on knowledge and resource sharing, can open up the possibility of collaborative, sustainable action to preserve coral reefs.

While addressing climate change and marine heatwaves remains complex at the local level, it is nonetheless possible to strengthen the resilience of coral reefs by mitigating other forms of pressure. Developing innovative and attractive financial tools is crucial for encouraging funders to invest in the conservation of reefs and the management of protected zones. Alongside classic forms of public financing, more innovative instruments, such as carbon credits for marine ecosystems ("blue carbon") and biodiversity non-sovereign bonds and credits (still in their early stages), aim to mobilize private investment. Other models, such as access fees or taxes on tourist activity, can directly increase the budgets of marine protected area managers. Successful case studies, such as the Bunaken National Park (Indonesia) and the Tubbataha Reefs World Heritage Site (Philippines), demonstrate the effectiveness of these approaches (Doshi *et al.*, 2012).

Finally, education and local involvement into coral reef conservation strategies are crucial to ensuring the sustainable protection of reefs. *Aires marines éducatives* (AMEs - Marine Education Zones) are an example of this, involving schoolchildren and communities in the management of their marine environment. By raising awareness among young people and involving them in concrete actions, they foster local ownership of conservation measures and efforts to improve ecosystem resilience. AMEs thus demonstrate the importance of policies that combine education and participatory governance in the effective preservation of reefs over the long term.

However, such conservation efforts for reef ecosystems are insufficient to prevent their decline, and that of the communities that depend on them. Without a drastic reduction in greenhouse gas emissions to achieve net zero, marine heatwaves will continue to intensify, threatening to irrevocably destroy all coral reefs by 2050.

Reference list

Intergovernmental Panel on Climate Change/IPCC (2021), *Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, https://doi.org/10.1017/9781009157896

Oliver E. C. J. *et al.* (2018), "Longer and more frequent marine heatwaves over the past century," *Nat Commun*, no. 9, 1324, https://doi.org/10.1038/s41467-018-03732-9

Sen Gupta A. *et al.* (2020), "Drivers and impacts of the most extreme marine heatwave events," *Sci Rep*, no. 10, 19359, https://doi.org/10.1038/s41598-020-75445-3

van Woesik R. *et al.* (2022), "Coral-bleaching responses to climate change across biological scales," *Global Change Biology*, vol. 28, no. 14, pp. 4229–4250, https://doi.org/10.1111/gcb.16192

Doshi A. *et al.* (2012), "Loss of economic value from coral bleaching in SE Asia," 12th International Coral Reef Symposium, Cairns, Australia, July 9–13, https://www.academia.edu/12494037/Loss_of_economic_value_from_coral_bleaching_in_SE_Asia

Fezzi C., Ford D. J. and Oleson K. L. L. (2023), "The economic value of coral reefs: Climate change impacts and spatial targeting of restoration measures," *Ecological Economics*, vol. 203, 107628, https://doi.org/10.1016/j.ecolecon.2022.107628

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