Coral Reefs
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EDITORIAL

The Fourth Global Coral Bleaching Event: Where do we go from here?

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The Fourth Global Coral Bleaching Event was officially confirmed by the National Oceanic and Atmospheric Administration (NOAA) and International Coral Reef Initiative (ICRI) on April 15, 2024, with press releases and a coordinated call to arms to address the impacts of climate change (https://icriforum.org/4gbe/). As the International Coral Reef Society (ICRS), the principal association of coral reef scientists, we would be remiss not to comment on this unfortunate milestone. Given our central role in the study of coral reefs, we are compelled to join the increasing call for action against this pressing environmental challenge.

The Fourth Global Coral Bleaching Event started in the Caribbean in the Northern Hemisphere (boreal) summer of 2023 (Fig. 1e), followed by the Southern Hemisphere in the (austral) summer of 2023–24 (Fig. 1f). Although the first two global bleaching events (1998 and 2010) were associated with peaks of very strong El Niños, the latest two global coral bleaching events (2014–2017 and 2023) began prior to El Niños. Thus, the earlier onset and greater

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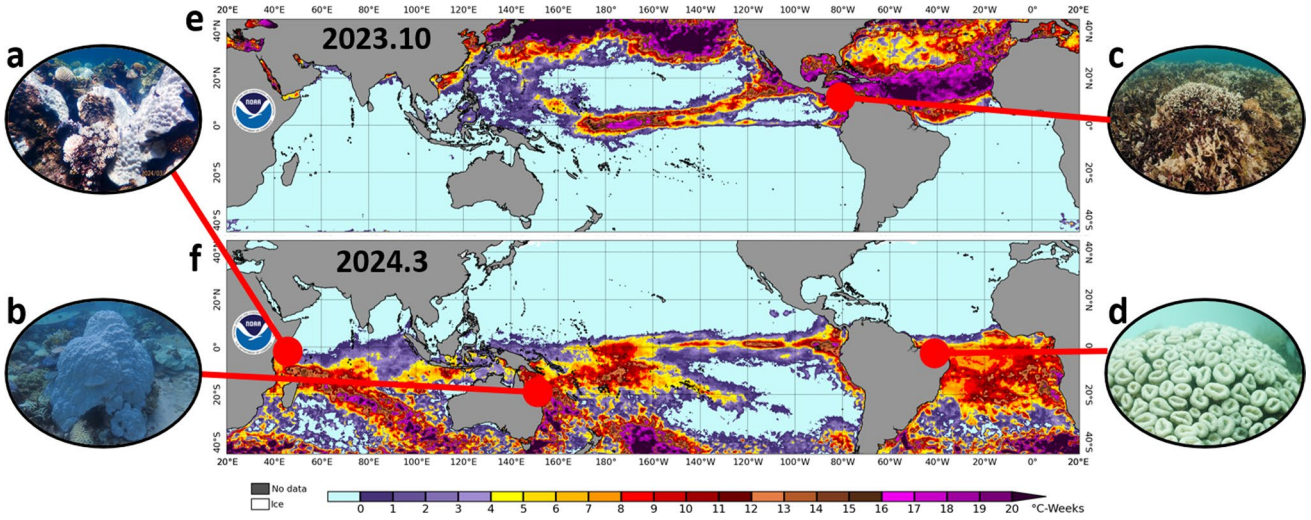

Fig. 1 Images of bleaching from the Fourth Global Coral Bleaching Event: **a** Watamu, Kenya, in March 2024 (image: A. Mayfield), **b** Capricorn Bunkers in the southern Great Barrier Reef, Australia, in March 2024 (image: M. S. Pratchett), **c** Bocas del Toro, Panama, in October 2023 (image: Kelly Wong Johnson), **d** Costa dos Corais, Alagoas, Brazil, in April 2024 (image: Pedro Pereira), **e** NOAA Coral Reef Watch 5 km Degree Heating Week for monthly maximum for October 2023 for the Caribbean Sea, and **e** DHW monthly maximum for March 2024 (v3.1; NOAA/CRW 2024)

severity of bleaching in recent years are driven by the relentless march of climate change, upon which El Niños are superimposed. Whether the event spills over into the Northern Hemisphere's summer of 2024 remains to be seen, as a shift away from El Niño to La Niña is now expected (NOAA/NWS/CPC 2024). Regardless of what happens in the coming summer, the Fourth Global Bleaching Event has already been devastating for coral reefs. From the NOAA's Degree Heating Week (DHW) homepage (NOAA/CRW 2024), year-to-date maxima have exceeded 20 °C heating weeks in several locations in the Indo-Pacific (Fig. 1), and record DHWs have been reported from different corners of the globe in 2023–2024 (e.g., Red Sea, Caribbean, Brazil; Hoegh-Guldberg et al. 2023; Fig. 1a–d). NOAA's Bleaching Alert year-to-date maxima for 2024 also show grim numbers with a band stretching across the Atlantic, Indian, and Pacific Oceans from approximately the equator to 30°S at Alert Level 1 or higher (Fig. 1f), signifying the risk for broad spatial bleaching (NOAA/CRW 2024). The unprecedented nature of the Fourth Global Coral Bleaching Event is also exemplified by the fact that NOAA had to extend their Bleaching Alert scale to Alert Level 5 to indicate near-complete mortality (NOAA/CRW 2024). As the true toll of the Fourth Global Coral Bleaching Event is assessed by researchers at 'ground zero,' many reports documenting the damage will be published, some of them undoubtedly in the pages of this journal. All of this is occurring while a complete understanding of the Third Global Coral Bleaching Event of 2014–2017 is still being documented (Eakin et al. 2022).

Combined with the latest estimates from the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (2023), reporting very high risks for near-term losses in coral reef biodiversity and 99% loss of coral reefs with 2 °C warming, it is a challenging time to be on the frontlines in coral reef science. ICRS's official guidelines are clear and emphatic; the only way to save coral reefs is to recognize and work toward three equally important pillars of action: (1) mitigate global greenhouse gas emissions; (2) mitigate local stressors; and (3) conduct active restoration to retain corals, i.e., buy time, while the desired pillars 1 and 2 are achieved (Knowlton et al. 2021). Thus, there are many things that we, as an academic society, as teams of researchers, and as individuals, can and must do to help protect our beloved coral reef ecosystems into the future (Knowlton et al. 2021).

First, coral reef scientists need more and better (experimental, environmental, and observational) data collected in a standardized and easily accessible manner (Grottoli et al. 2021), particularly from areas that have yet to be studied in detail. This will help to generate better predictive models,

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understand a broader diversity of coral reefs, and emphasize wider trends to ultimately refine ocean basin or global hypotheses; for example with regard to the identification of naturally highly resilient corals, the environmental conditions that shape them, and how such knowledge can be used to inform conservation/restoration action. While many developed countries have enviable datasets and prediction tools to help keep both scientists and the general public informed of the condition of their coral reefs (e.g., Australia, USA, etc.; Souter et al. 2021), many of the world's coral reefs will bleach and suffer tremendous damage without their fates being recorded. As many coral reefs are in low- to middle-income nations, generally with limited access to funding opportunities and with structural and technological challenges, stronger collaborative efforts are needed across all nations to better document reef conditions more inclusively. Rapid efforts to adapt tools implemented on the Great Barrier Reef and in the Caribbean, for example, and applying them to reefs in other regions, would yield valuable data that would inform coral reef science worldwide. To fill scientific gaps, we need to conduct standardized surveys, embrace automated and cost-efficient technologies, expand the application of prediction tools to remote areas, and better include the voices and contributions of traditional and indigenous communities. A large workforce is necessary to co-design a reliable, inclusive, and robust open data system that incorporates both scientific and indigenous knowledge, ensuring that science remains relevant and integrated into culture and policy processes.

Second, the need to protect these ecosystems surpasses geographical and political barriers. Despite a trend of generally rising nationalism with increasing amounts of red tape and rules stymying international collaboration, only international collaboration can effectively coordinate actions to address these global bleaching events that span borders and politics. We should all make an effort to use science-driven frameworks, risk assessment tools, and follow recommendations (Knowlton et al. 2021) and ask local, regional, and national authorities to make collaboration easier and more just, also taking into consideration the high toll of inaction (Peixoto et al. 2022; Peixoto and Voolstra 2023). Simplifying bureaucratic processes can critically improve our effectiveness in performing our functional role in society (Fernandez 2011). Raising our voices to communicate what is happening underwater and making it easier for future generations to conduct research is one of our foundational duties. Governments worldwide need to better protect the ecosystems both within and outside of their jurisdiction, as ecosystems do not function in isolation. We cannot sit and wait for government agencies to recognize the urgency of mass coral bleaching. ICRS can play a critical role; we need to act now, while also advocating for stakeholder support. As the most diverse and widespread global coral reef scientific society, we should strive, in collaboration with regional coral reef-focused organizations, to create networks to collect data, conduct experiments, and strategize on ways forward. While this is already occurring at various scales, we strongly encourage each and every coral reef scientist to reconsider this challenge and how we can each best contribute to global efforts to help better protect reefs, one coral reef at a time. Actively pursuing joint funding projects with collaborators in heavily affected regions, especially those lacking governmental support and coordinated monitoring and restoration efforts, conducting online workshops and seminars for interested parties including local scientists, managers, and policy-makers, creating online videos on mitigation efforts, encouraging and facilitating data sharing, all can make a compounding difference. Using ICRS contacts and networks to achieve these goals brings real value and importance to our shared connections.

Given inevitable delays in reducing emissions and stabilizing climatic conditions, researchers can simultaneously contribute to reducing local stressors on coral reefs (e.g., Donovan et al. 2021; Good and Bahr 2021). Thinking globally while acting locally can have many positive repercussions, including motivating local action from others, all while providing your local coral reefs—and the communities they support—a fighting chance of a better outcome against future events. Establishing or expanding marine protected areas, addressing other localized causes of coral mortality, and reducing pollution and marine debris at a local level, all serve to benefit local reefs and communities more broadly. Organizing and conducting research and activities on a local level is much easier than global efforts. Still, ensuring local efforts are available openly, whether in published form, preprints, or online via the Coral List, social media, or a homepage, can help spread data and lessons learned far and wide. ICRS is poised to support such endeavors.

Finally, there are many more direct interventions that may increase hope in the face of coral reefs facing hard adaptation limits and resultant degradation. For example, coral restoration can enhance ecological recovery (Suggett et al. 2024) and, under certain conditions, restore important ecosystem functions in just under 5 years (Lange et al. 2024), thus providing economic support to local communities. These efforts are crucial to maximize the abundance and diversity of corals until effective mitigation (reduction of global and local stressors) is achieved, while demonstrating that even heavily degraded reefs can be restored to sustain marine life and local communities. In many cases, however, climate resilience cannot be achieved via restoring with the same corals that were heavily affected by bleaching in the past—a bitter but important lesson from 2023 in the Caribbean. Restoration can be enhanced by selection of source corals from naturally heat-tolerant populations or through thermal pre-screening (Evensen et al. 2023), enhancing

genetic diversity through sexual reproduction and assisted gene flow (Banaszak et al. 2023), in situ probiotic provisioning (Santoro et al. 2021; Peixoto et al. 2022), or assisted migration (Mertz and McDonald 2022). In line with the above, such efforts are improved through global collaboration, standardization, and coordination (Voolstra et al. 2021). Arguably, it remains to be determined at what scale, how, and where such active interventions are useful, justified, and poised to make a difference (Voolstra et al. 2021). Protection of remaining reefs also needs prioritization, minimizing any future need for restoration efforts. Similar to European forests, where only 3% are represented by primary and old-growth forests (Barredo et al. 2021), one may argue that we need to adopt a perspective that coral 'reforestation' is possible, sensible, and necessary to provide a fighting chance for coral reef survival (Peixoto and Voolstra 2023).

Is this editorial naïve in parts and unrealistic in others? Certainly; the fact is that the ongoing Fourth Global Coral Bleaching Event has been devastatingly lethal for many Caribbean and Southern Hemisphere corals. These events and their effects are cumulative and increasing in frequency (Hughes et al. 2017). Long-term solutions require massive and urgent global efforts and funding. Our ability to limit damage from excessive emissions still exists. We know most of the solutions and implementation is urgent. However, the impacts of mitigation efforts will not be fully realized if coral reefs are functionally extinct by the time we reach carbon neutrality. We argue that our ability as humans and as an academic society to learn from such tragic events is poised to be higher than ever, and we should strive our utmost to apply our knowledge and skills in lessening the damage from current and future bleaching events in any and all ways possible (Voolstra et al. 2023), while raising our voices that more help is urgently needed. We will need much help and support from global governments and funding agencies, but with the very existence of coral reef ecosystems at stake, we cannot do any less. The realization that 'doing nothing changes nothing' can serve as inspiration to find optimism, hope, and motivation to keep fighting for a future of coral reefs.

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Declarations

Conflict of interest Morgan S. Pratchett is the Editor-in-Chief of Coral Reefs, and Verena Schoepf and James Davis Reimer are on the Editorial Board of the same journal. All authors are members of or involved in the International Coral Reef Society.

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