New interventions are needed to save coral reefs

We anticipate that conventional management approaches will be insufficient to protect coral reefs, even if global warming is limited to 1.5 °C. Emerging technologies are needed to stem the decline of these natural assets.

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Since 2014, coral reefs worldwide have been subjected to the most extensive, prolonged and damaging heatwave in recorded history[1]. Large sections of Australia's Great Barrier Reef (GBR) bleached in response to heat stress in 2016 and 2017 — the first back-to-back events on record. Such severe coral bleaching results in widespread loss of reef habitat and biodiversity. Globally, we are facing catastrophic decline of these ecosystems, which sustain services valued at around $US10 trillion per year[2], are home to over a million species[3], and feed and support the livelihoods of hundreds of millions of people[4].

Model predictions indicate that mass coral bleaching could become the new norm by 2050 (ref. [5]). Critically, even if global warming can be kept within 1.5 °C above pre-industrial levels, shallow tropical seas would warm at least 0.4 °C in the coming decades, triggering frequent bleaching of the most sensitive habitat-forming coral species[6]. This outlook poses a time-critical decision challenge for management and conservation. Existing conservation approaches, despite innovative governance arrangements[7], could simply become insufficient to protect coral reefs under any expected climate future. Thus, for coral reefs to remain resilient and their services sustained, we argue that new and potentially riskier interventions must be implemented alongside conventional management efforts and strong action to curb global warming. We build the case for this strategy below.

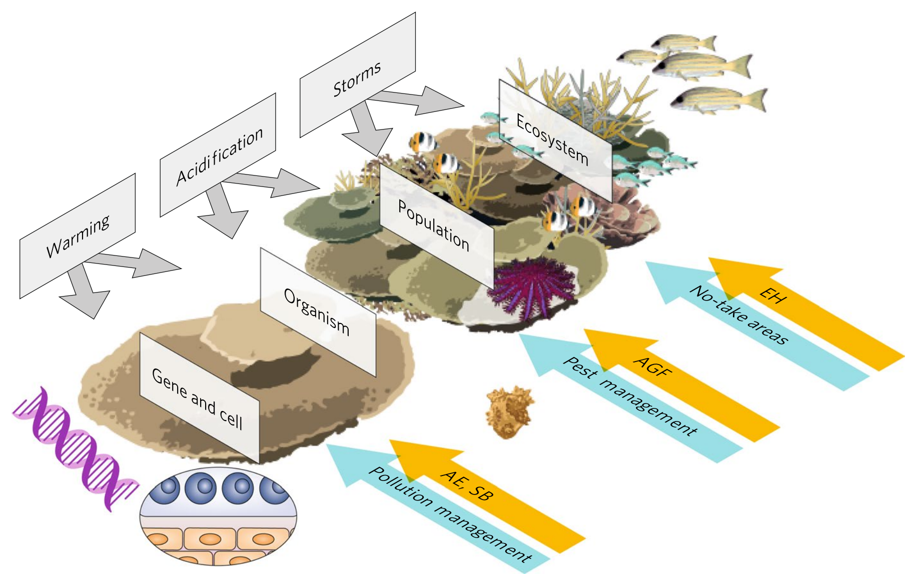

Fig. 1 | An integrated approach to reef resilience. Climate change brings ocean warming, ocean acidification and potentially stronger storms, which affect biological and ecological processes in reef corals. Initial impacts of warming at the genetic and cellular level flow on to organismal levels and ultimately reduce ecosystem resilience. Conversely, the effects of storms at the ecosystem level are felt at population and organismal levels, for example, by impacting species that provide habitats or by disrupting source–sink relationships. We propose that emerging interventions such as assisted gene flow (AGF), assisted evolution (AE), synthetic biology (SB) and habitat engineering (EH), operating at the appropriate organismal or ecosystem levels, are essential to build reef resilience, and should be integrated with existing management strategies such as pest and pollution control and no-take areas. Illustrations by Andreas Wagner.

Emerging alternatives

A long-standing principle of coral reef management has been that impacts of climate change can be at least partially offset by intensified local and regional scale management[8]. However, model predictions of bleaching under future warming[5] and experimental analyses of the impacts of ocean acidification[9] indicate that physical and chemical climate change compromise the very processes that underpin reef resilience.

Coral bleaching initially operates at the cellular level, through the breakdown of the symbiotic relationship between the coral host and its endosymbiotic microalgae; if sustained, these effects flow on to alter the entire ecosystem (Fig. 1). This process is exacerbated by ocean acidification, which impairs reef calcification and the recovery potential of coral and fish species — two cornerstones of reef resilience[6]. Sustaining coral reefs in the face of physical and chemical climate change will therefore require a multi-pronged strategy that combines intensified conventional management approaches to support ecological resilience with interventions designed to boost biological resilience (Fig. 1). We propose that such a strategy

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should proactively integrate emerging technologies in an adaptive process of research and development, learning, consultation, risk management and staged implementation.

Interventions to increase climate resilience at the biological level include tools such as assisted gene flow (AGF), assisted evolution and synthetic biology[1]. AGF, in the form of assisted larval dispersal or assisted adult migration, might facilitate the spread of genotypes with heritable traits — for example, heat tolerance — from warmer to cooler locations[10] or habitats[11]. For example, the northern GBR is approximately 2 °C warmer than its southern region and contains genetically heat-adapted corals[10]; thus, northern coral stocks provide the potential to enhance bleaching resistance on southern reefs. An opportunity to climate-harden the northern GBR using AGF could come from warmer seas such as the Persian Gulf. Here, thermal bleaching thresholds of corals are 3–4 °C higher than the most bleaching-tolerant assemblages in the Indo-Pacific or the Caribbean[12]. However, the potential to increase bleaching resistance through assisted migration would come with risks of also importing pathogens[13], the probability of outbreeding depression and maladaptation to other (non-climate-related) environmental conditions[14].

Complementing the idea of translocating existing coral genotypes is the concept of generating new capacities for climate resilience through assisted evolution and synthetic biology. Assisted evolution builds on the principle of selection using existing genetic material[15], whereas synthetic biology could involve genome editing using natural or synthetic genes, for example using CRISPR-associated 9 (Cas9) technology. These techniques, paired with natural or synthetic gene drives[16], could enable rapid spread of climate-adapted genotypes of species that serve key ecosystem functions, and that would succumb to climate change without such interventions.

We believe that assisted evolution and synthetic biology could offer more opportunities than risks for climate-hardening coral reefs, as long as such technologies are developed and deployed under a stringent and adaptive framework that includes extensive societal consultation[16,17]. For example, the risk of a new engineered coral genotype dominating a reef ecosystem becomes a benefit if native coral genotypes are predicted to decline under climate change. However, a downside of these or any other laboratory-based or resource-intensive technique is that only a subset of the million species on coral reefs could feasibly be made climate tolerant. Prioritization of key species groups is unavoidable, but this carries risks of altered ecosystem dynamics and unintended consequences for the processes that underpin ecological resilience. Enhancing our understanding of species roles is thus an essential element of such strategy development.

Under severe climate change, tropical sea surface warming may eventually exceed the physiological tolerance limits of most reef-building species beyond the remediation potential even of these emerging genetic-based technologies. Since habitat-forming corals are among the most vulnerable to ocean warming, acidification and storms, the development of engineered reef habitats could become necessary to protect key reef-dependent species, including fish and invertebrates. The challenges for such engineering solutions include society's acceptance of artificial structures as replacements for natural habitats that underpin the richest biodiversity in the oceans, and careful spatial triage for what would be a costly intervention. Although engineered habitats would not protect the underlying integrity and diversity of coral reef systems, they could become essential to maintain some reef-related ecosystem goods and services.

Implications for coral reef futures

The decision to adopt or dismiss new interventions pits two fundamental values against each other: the wish to conserve the natural biodiversity on coral reefs and the desire to maintain ecosystem functions, goods and services in the face of external threats. Some interventions carry a risk of unintended ecosystem disruptions[15] and might transform coral reefs into new or hybrid systems. However, reefs are already in transition, driven by differential species responses to environmental change[18]. The challenge is to steer that transition towards ecosystem states that can maintain key functions and values. This will involve difficult trade-offs — which species and ecosystem functions are most important to conserve given limited resources? Although an interventionist pathway may be at odds with the tenets of traditional conservation and its emphasis on minimalist human intervention, it has already become the necessary trajectory for both natural[19] and cultured[20] ecosystems. For example, artificial selection and gene modification for drought and disease resistance in crops has been driven by necessity.

On the GBR, the bleaching events of 2016 and 2017 send that same signal loud and clear: current management toolsets are insufficient to afford protection. We acknowledge that systems like the GBR, which represent high biodiversity and natural World Heritage values, may be perceived to be compromised by interventions like large-scale AGF, assisted evolution, synthetic biology or habitat engineering. However, the opportunities these interventions offer to sustain functioning, albeit altered, coral reefs worldwide must be weighed against the alternative of continual decline and increasingly insufficient and costly management.

And time is of the essence. The pipeline from the initiation of research and development of emerging technologies to their safe deployment with social and political licence to operate takes years[17]. And as species are lost to rapid climate change, so are opportunities to protect them. Therefore, a seemingly risk-averse decision to delay the adoption of emerging technologies from a standpoint of precaution could become the greatest risk by limiting our options in the future. ❐

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Competing interests

The authors declare no competing financial interests.

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