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Save reefs to rescue all ecosystems

All the coral reefs in the world could be gone by 2070 if global warming continues on its current trajectory[1]. Since 1998, heatwaves have bleached or killed corals in more than 90% of World Heritage-listed reefs worldwide (including in the Galapagos Islands, Hawaii and Australia)[2]. In the Great Barrier Reef, the world's largest reef system, half of the corals died in 2016 and 2017 alone[3].

Coral reefs cover only 0.5% of the ocean floor, but they support almost 30% of the world's marine fish species. They also protect coastal communities from the impacts of waves, storms and floods. Their loss has huge implications for biodiversity and for the around 400 million people who depend on them for their livelihoods, food security and coastal protection, in more than 100 countries across Australasia, Southeast Asia, the Indo-Pacific, the Middle East, the Caribbean and Tropical Americas.

We think a change in approach is urgently needed from the slew of groups striving to safeguard reefs: ecologists, conservationists, non-governmental organizations, national and regional policymakers, and philanthropists. Such groups must address the causes of reef ecosystem decline -- not just focus on biodiversity, or on trying to restore a particular reef or region to some idealized 'prior state', for instance by establishing marine parks.

Policymakers in Australia, say, should try to change land use in the 424,000-km^2 catchment area of the Great Barrier Reef. (Currently, they funnel some US $20 million each year into local-scale approaches such as coral gardening to restore damaged reefs.) Instead, they should replace coal-fired power with renewable energy sources, develop land-based aquaculture (which avoids the release of animal waste and antibiotics into the sea), and restore or rehabilitate terrestrial vegetation, wetlands, mangroves and seagrass. All these actions would simultaneously reduce emissions, capture carbon, curb agricultural runoff onto coastal reefs, and enhance people's livelihoods and food security. What's more, the benefits would extend far beyond coral reefs.

There is enormous interest in coral reefs worldwide, and growing concern about the pace of their decline. Done right, efforts to safeguard reefs could protect other ecosystems from climate change and other pressures. We could do this through direct implementation, but also indirectly by providing a model for other scaled-up approaches. Indeed, the plight of coral reefs could finally help push nations past a societal and political tipping point, where the protection of ecosystems, with their multiple services and functions, becomes socially and politically essential.

Heat stress

Raised sea temperatures during heatwaves can kill sensitive corals, or prompt them to expel the beneficial microscopic algae (*Symbiodinium* and related genera) living in their tissues, resulting in mass bleaching. Over one or two decades, most coral populations depleted by

bleaching can recover. But the gap between consecutive bleachings has shrunk dramatically -- from an average of 25 years in the 1980s to just six years since 2010[3].

Already, people in the 22 small island nations of the South-West Pacific have increased their reliance on imported foods, including canned meats and packaged products, in part because of depleted fish stocks. Food imports to countries such as Samoa and Tonga now exceed total exports[4]. What's more, deaths in the Pacific from preventable diseases, such as diabetes, cardiovascular disease and cancer, have risen in part due to the dietary and lifestyle changes that have accompanied people's increased reliance on imports. (Five years ago, these diseases caused 80% of all deaths; today they cause 86%)[5].

The decline of reefs -- especially in the past five years has prompted scientists, policymakers, non-governmental organizations and philanthropists to undertake increasingly desperate attempts to save or restore targeted coral species. (The most recent 2014 to 2017 global bleaching was the longest ever recorded and caused at least 70% of the world's reefs to bleach once or more in consecutive record-breaking hot years[6].)

In Australia, engineers are using a robot to disperse coral larvae to degraded sites, and experimenting with underwater fans to create cooling, artificial upwellings. In Florida, surviving corals are being transferred from degraded reefs to aquaria to rescue them from disease. In many countries, artificial reefs are being built to promote biodiversity, or corals are being reared in the lab or in underwater 'nurseries' and later transferred to reefs to bolster existing colonies. Coral sperm are even being frozen in the hope that populations could be re-established in the future[7].

Such interventions are expensive and require a huge workforce. Re-planting coral fragments grown in a nursery costs US $1-4 million per hectare. Thus, even without factoring in ongoing maintenance, restoring 10 km^2 of reef would cost in the region of one billion dollars[8]. None of these approaches will restore the ecological functions of reefs at a meaningful scale. (Indeed, given the current levels of human influence on the environment, restorations to past ecological conditions and past levels of biodiversity are no longer possible[9].) What's more, small-scale attempts at coral gardening, aquarium-breeding and cryo-preservation can convey a misleading message: that the decline of coral reefs is solvable without rapid, coordinated action on anthropogenic climate change.

We think that the new approach to the governance of coral reefs should be inspired by ecological and political theory on synergistic effects.

Make change on land and sea

Over the past decade, ecologists have found that the response of reefs to any one pressure, such as overfishing or pollution, is typically non-linear. Numerous feedbacks and multiple drivers reinforcing each other can lead to novel stable states[10]. For example, agricultural runoff may promote the growth of algae that compete with corals for space – a problem that is exacerbated by the overfishing of herbivores. Under many pressures, the capacity of corals to reassemble after disturbances may be so reduced that a new stable ecosystem results, often consisting mainly of mats of algae or cyanobacteria.

The sustained protection of coral reefs similarly requires making many changes at once: reducing greenhouse gas emissions, rebuilding fish stocks and improving water quality. This

requires policymakers to work with a far broader range of social actors, including commercial and recreational fishers, farmers, the tourism industry, mining companies, energy providers, developers, and individual citizens**.**

The importance of such broader-scale, synergistic policy interventions to protect ecosystems is starting to be recognized in multi-lateral policy agreements; by major environmental non-governmental organizations and international aid agencies; even by some countries.

As one example, the Ramsar Convention on Wetlands of International Importance now highlights how the conservation of wetlands can help achieve multiple goals: a sink for carbon, a provider of ecosystem services, protection against flooding. (In 1971, when the Ramsar Convention was first established, it focused far more on the conservation of wetlands species than on their broader social and environmental benefits.)

Likewise, non-governmental organizations are beginning to combine ecological, economic and social interventions to help sustain ecosystems. For instance, the Nature Conservancy is considering funding the installation of sewage-treatment plants and other infrastructure that would improve public health, but also prevent sewage from reaching coral reefs[11]. In May this year, the Hawaiian government announced such a plan for Puako Island, designed specifically to minimise risks to marine life and human health. And agricultural research and development agencies, such as the Consultative Group on International Agricultural Research, are supporting integrated national policies for agriculture and the environment in Pacific island nations, to address the declining supply of reef fish and the altered movement of pelagic stocks due to climate change. (Historically, agricultural and environmental ministries in most countries have operated in silos, or even in opposition)[12].

Meanwhile, the Philippines, along with Indonesia, Malaysia, Papua New Guinea, the Solomon Islands and Timor-Leste have formed the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security. Established formally in 2014, this trans-national partnership initially focused on the conservation of marine biodiversity, megafauna and coastal resources. Since August 2017**,** the six governments have also begun to address the management of mangroves, seagrass meadows and tidal marshes to help sequester carbon. A similar initiative called the Global Environmental Fund Pacific Ridge to Reef Program, is seeking to promote sustainable energy and food production, while reducing global greenhouse gas emissions and pollutant runoff into coastal waters in 14 Pacific Island nations[13].

So on many fronts the approach we endorse is gaining traction. The major challenge now is establishing the governance, organizations, mechanisms and funding to realise broad, synergistic goals at scale.

Conventional governance -- for instance, of fisheries or agriculture -- is typically uncoordinated, competitive and short-sighted[14]. We think that catchment-based agencies could better integrate environmental, social and economic planning. A good example is the 86-year-old Tennessee Valley Authority in the United States. The agency led innovations in education, agriculture and energy use in the 1930s to help lift the region out of depression.

Also, various nascent funding schemes could complement more traditional ones. These include green economic stimuli, such as public-private partnerships to facilitate the development of renewable energy systems[15]; and ‘debt-for-change’ schemes, whereby organizations such as the Nature Conservancy help pay off a country’s debt in exchange for

the nation reducing its environmental impact. More controversially, industrial and philanthropic payments for ecosystem services, and ecosystem insurance schemes, such as the coral reef insurance programme recently deployed in Mexico[16] could also help.

Already, key agencies are extending the responsibility for safeguarding coral reefs beyond local reef governments, managers and users. For example, in a major departure from the past, the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Centre is beginning to focus on the long-term and distant drivers of reef decline[2], not just on the symptoms of reef degradation. As is the US National Oceanic and Atmospheric Administration, and the Great Barrier Reef Marine Park Authority. In July, the latter called for immediate reductions in global greenhouse gas emissions, and acknowledged that local actions on water pollution and fishing pressure cannot reverse the ongoing decline of reefs. That same month, a new index for monitoring vulnerability to climate change was unveiled at the World Heritage Committee's annual meeting[17].

The Climate Vulnerability Index assesses the risk to individual World Heritage-listed sites (29 of which are coral reefs) of extreme climate events and changes in climate over the next 30 years[17]. Some observers are suggesting that this type of index could also be used to track accountability. Specifically, such tools could compare the vulnerability of a country's World Heritage Area with its national policy on carbon emissions, and progress on achieving commitments to the Paris Agreement on Climate Change. Conceivably, a World Heritage-listed site at high risk in a country reneging on its promises could be classified as 'In Danger'. Such a development would represent a radical expansion of UNESCO's oversight, and would highlight for the first time the responsibilities of individual nations for protecting World Heritage Areas from climate change.

The world is watching

Ultimately -- whatever else happens -- coral reefs will be lost unless global carbon emissions are slashed to 45% of 2010 levels by 2030[1]. Yet a bolder, scaled-up approach to the stewardship of land and sea – focused initially on coral reefs – could itself help society meet this goal.

International attempts to address climate change have repeatedly derailed[1]. At a national level, vested interests, entrenched priorities and social inertia are enormous barriers to change. Australia's lock-in to coal is a case in point[18]. But individual countries, such as Bhutan and Costa Rica, some states such as California and Tasmania, even certain cities such as Copenhagen and Canberra, are setting powerful examples for the rest of the world with mitigation and adaptation initiatives. California, the fifth largest economy in the world, has set a target date of 2045 for carbon neutrality. In August, the state brokered a deal with four leading carmakers to reduce air pollution, despite strong criticism from US President Donald Trump.

Effective efforts to protect coral reefs could similarly set an example for the world.

Reefs are revered worldwide. Their loss has even inspired 'last-chance tourism'[19] and what psychologists and others are labelling 'ecological grief'[20]. The plight of these charismatic and stunningly beautiful systems, and of the people who depend on them, is rapidly galvanising a broad spectrum of support -- from the United Nations, to movie stars, youth movements and industry barons.

In 2017, the Leonardo DiCaprio Foundation began to install a self-funding system of renewable energy to coral reef communities across Fiji, in partnership with the Fiji Locally Managed Marine Area Network, the Fijian Government, Sunergise (Fiji) Limited, and the Fiji Electricity Authority. In 2018, Bloomberg Philanthropies announced that it would provide $86 million to help build resilience of coral reef and fishing communities in ten countries, including Australia, Fiji, Indonesia, and the United States. And in May this year, when students from 1,664 cities across 125 countries walked out of school urging more climate action, coral reefs were the centrepiece of many of the protests.

We urge scientists, policymakers, non-governmental organizations and philanthropists to tap into this energy, and develop a bold strategy to protect reefs, other ecosystems and people in our warming world.

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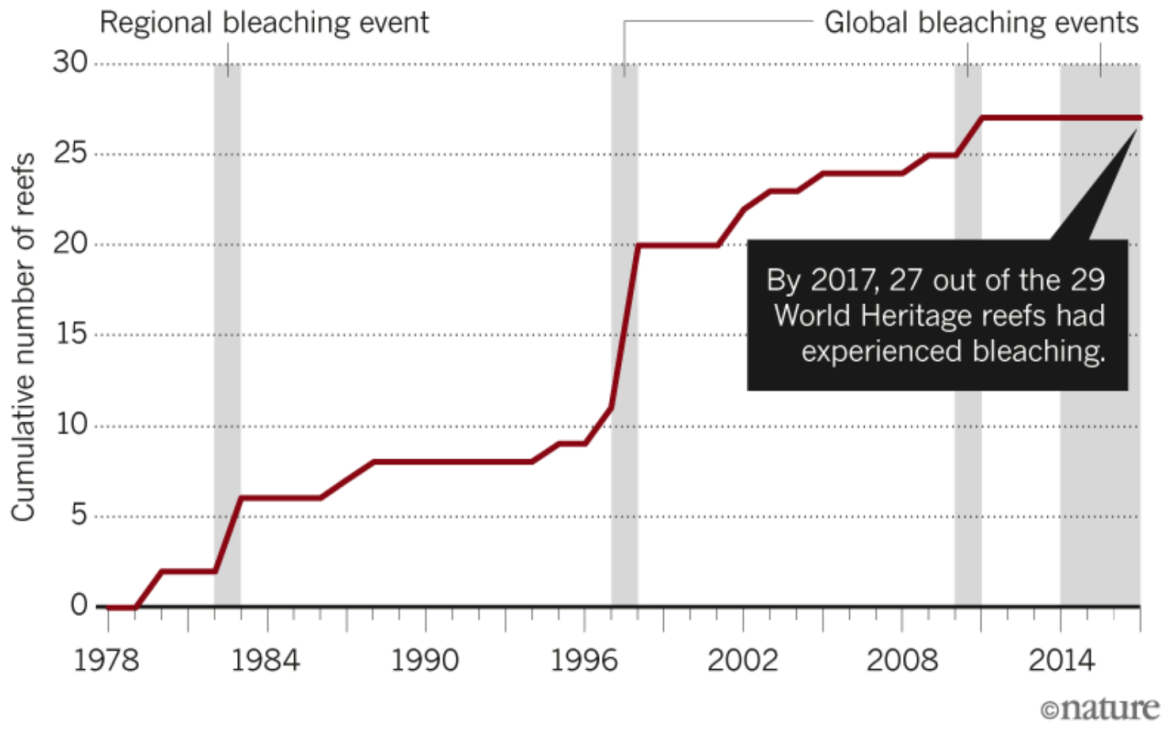
FIGURE 1 Under pressure: coral reefs listed as World Heritage Sites have been increasingly affected by regional and global bleaching since 1980.



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SUPPLEMENTARY MATERIALS

The cumulative number of UNESCO World Heritage-listed coral reefs affected by coral bleaching and subject to climate change reporting over time was assessed (Fig. 1). Bleaching frequency for the 29 reef-containing natural properties on the UNESCO World Heritage List since 1978 was determined from records drawn from published studies[1,2] and the ReefBase Bleaching Report[3]. UNESCO reporting on climate change was determined from World Heritage data on the State of Conservation for the same 29 properties[4]. UNESCO has a standard list of threats affecting the Outstanding Universal Value of World Heritage properties. The list was interrogated to determine all coral reef properties affected by "climate change and severe weather events" (including changes to oceanic waters, storms, temperature changes, and other climate change impacts). All 148 State of Conservation reports (1985-2017) for the 29 coral reefs were also interrogated for additional reporting on "ocean acidification", "bleaching" and "climate change".

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