Advancing Coral Reef Governance into the Anthropocene

Tiffany H. Morrison,[1,*] Neil Adger,[2] Jon Barnett,[3] Katrina Brown,[2] Hugh Possingham,[4] and Terry Hughes[1]
[1]Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia
[2]College of Life and Environmental Sciences, University of Exeter, Exeter, UK
[3]School of Geography, University of Melbourne, Melbourne, VIC, Australia
[4]The Nature Conservancy, Arlington, VA, USA
*Correspondence: tiffany.morrison@jcu.edu.au
https://doi.org/10.1016/j.oneear.2019.12.014

The unprecedented global heatwave of 2014–2017 was a defining event for many ecosystems. Widespread degradation caused by coral bleaching, for example, highlighted the vulnerability of hundreds of millions of people dependent on reefs for their livelihoods, well-being, and food security. Scientists and policy makers are now reassessing long-held assumptions about coping with anthropogenic climate change, particularly the assumption that strong local institutions can maintain ecological and social resilience through ecosystem-based management, adaptation, and restoration. Governance is struggling to address the new normal as ecosystem assemblages transform to novel configurations. A central challenge for policy makers in the Anthropocene is navigating environmental crises and coping with societal insecurity and change. Ecosystem governance needs a new paradigm to embrace rapid change and shape future trajectories. In this Perspective, we focus on coral reefs as vanguards for governance transformation. We explain the spatial, temporal, and political dynamics of reefs as they respond to climate change and outline a new governance paradigm applicable to all ecosystems.

Introduction

The unfolding crisis in coral reefs will have profound environmental, economic, social, and cultural consequences for reef-dependent societies.[1] Reefs provide critical ecosystem services, such as fisheries, tourism, and shoreline protection, that are essential to the social and cultural fabric of maritime tropical communities.[2–4] The 2018 Intergovernmental Panel on Climate Change (IPCC) Special Report warns that many coral reefs will struggle to cope with future global average temperatures of 1.5°C–2°C above pre-industrial levels. With 1°C of global average warming so far, 94% of coral reefs have already experienced one or more episodes of severe coral bleaching since 1980 due to record-breaking temperature extremes.[5] The urgent need to sustain coral reefs has prompted a range of interventions, including not just global agreements to reduce greenhouse gas emissions but also additional marine protected areas, extra water pollution control, and coral gardening programs.[6–8] Central to these efforts is an improved understanding of the governance that enables appropriate interventions to succeed.

In this Perspective, we argue that a new governance paradigm is required to sustain coral reefs under climate change. First, we examine the new challenges for governing reefs in the Anthropocene. Second, we consider whether the current governance paradigm is enabling successful intervention. We caution that some interventions, despite good intentions, have the potential to form a governance trap for coral reefs because they fail to address the contemporary root causes or the political dynamics of coral reef degradation. Third, we examine the conventional framing and scaling of reef governance. We argue that a narrow focus on local and biophysical interventions can distract from the multiscale political dynamics (including political legitimacy and societal conflict) that must be overcome in order to save reefs at a meaningful scale. Fourth, we develop a conceptual framework to advance understanding of interactions among multiple interventions and their effects on reef trajectories. Last, we explore a series of emerging solutions that offer a forward trajectory for reef ecosystems and reef peoples. We emphasize that, for reefs to survive the Anthropocene, coral reef governance can and must move beyond the conventional framings and scales of local conservation.

Contemporary Governance Is Failing

Until very recently, reef governance, and ecosystem governance in general, has operated according to an established paradigm—that strong local management can maintain ecological and social resilience by reducing proximate stressors (e.g., overharvesting and pollution) and by restoration. Under this paradigm, ecosystem governance has focused on the goal of maintaining biodiversity or restoring social and ecological systems to recent historical baselines.[9,10] The primary targets of intervention have been local ecosystem-dependent people operating within relatively defined ecosystem boundaries.[11] However, the escalating impacts of climate change demonstrate that this paradigm is no longer tenable for coral reefs and many other ecosystems.[12,13]

Regional and pan-tropical coral bleaching events are occurring more frequently, challenging the capacity of reefs to recover between temperature extremes.[5] A dynamic new normal is emerging as reef species respond to altered disturbance regimes that now include episodic climate extremes. The biodiversity, species abundances, physiology, and genetic composition of corals and associated species is shifting in response to selective mortality. Furthermore, stock-recruitment relationships and larval dispersal are changing, altering networks of connectivity among reefs.[14] Many individual species are expanding into subtropical seas.[15] As coral populations acclimate, evolve, and disperse, reefs in the Anthropocene are increasingly dominated by tougher, thermally tolerant survivors or by weedy, fast-growing species that are quick to recolonize.[5,16]

Interacting pressures from climate change, overfishing, and pollution are escalating (Box 1). These proximate drivers of degradation of coral reefs are themselves driven by distal changes in national and transnational markets, consumption, and regulation. The combined impacts of these stressors are already affecting reef-dependent communities, especially in small and poor island states (e.g., the Solomon Islands, Micronesia, and Fiji). Coral reef degradation combined with sea level rise and increased climate-related disasters is leading to depletion of fish stocks, salinization of aquifers, and loss of prime coastal land. In the Pacific, vulnerable Small Island Developing States (SIDS) are experiencing accelerated saltwater intrusion of their freshwater supplies and inundation of agricultural land and human settlements due to rising sea levels. These changes pose significant risks to land, food, and water security.[17–19] In many places, increased conflict over basic land, food, and water resources[20,21] and migration triggered by climate change[22] have the potential to aggravate existing social problems of poverty, urban crowding, and poor public health.[23,24]

Helping reefs and reef peoples to navigate these trends is a major governance challenge. Governance is broader than government and incorporates the overarching structures and processes for creating knowledge about coral reef degradation, prioritizing issues, formulating policy, delegating responsibility, and for making decisions about how to intervene. The creation of the Great Barrier Reef Marine Park Management Authority (GBRMPA) in 1975, for example, was a major governance innovation.[9] However, the recent multi-year global marine heatwave of 2014–2017 has now revealed the limitations of conventional ecosystem governance. New studies are exposing governance delays and mismatches, power asymmetries in governance, and ultimately governance failure. The United Nations Educational, Scientific and Cultural Organization (UNESCO) and State Party reporting on climate change impacts on the 29 World Heritage-listed coral reefs, for example, has lagged the observed impacts by close to a decade.[25] Similarly, analysis of 40 years of GBRMPA Annual Reports highlights a continuous pattern of mismatches between threats identified by the Authority and subsequent management goals, as well as mismatches between management goals and subsequent management interventions.[13] Analysis of governmental responses to the recent back-to-back bleaching of the Great Barrier Reef demonstrate that the preferences of the fossil fuel industry continue to outweigh those of the reef tourism industry, local communities, and marine scientists.[28] Even the best-managed, most remote, and untouched reefs, including World Heritage-listed reefs,[27,29] are vulnerable to global heating (Figure 1). The challenge now is to develop an alternative governance paradigm, one that is up to the task of sustaining reefs into the Anthropocene.

Understanding Ecosystem Governance

Reducing greenhouse gas emissions is critical for arresting the degradation of all ecosystems across the globe.[1] However, in the case of tropical reefs, scientists and policy makers have begun to experiment with, and advocate for, a wildly expanding suite of interventions, including ecosystem-based interventions, land-sea planning, bioengineering, and even geoengineering interventions. Contemporary governance that is focused on local conservation is often incapable of overseeing many of these new and proposed interventions. Typically, contemporary governance places the burden of restoration or maintenance onto local reef managers and users, rather than on other parts of society responsible for broad-scale drivers of reef degradation. Furthermore, many contemporary reef governance actors are powerless to oversee the complicated socioeconomic decisions that need to be taken at much higher national and global scales in order to ultimately arrest reef degradation. Such broader responsibility and accountability are crucially important because without them, reef outcomes will be determined by uneven politics and power dynamics[30] rather than by critical analysis and fair and democratic processes.

Governance as More Than the Sum of the Parts

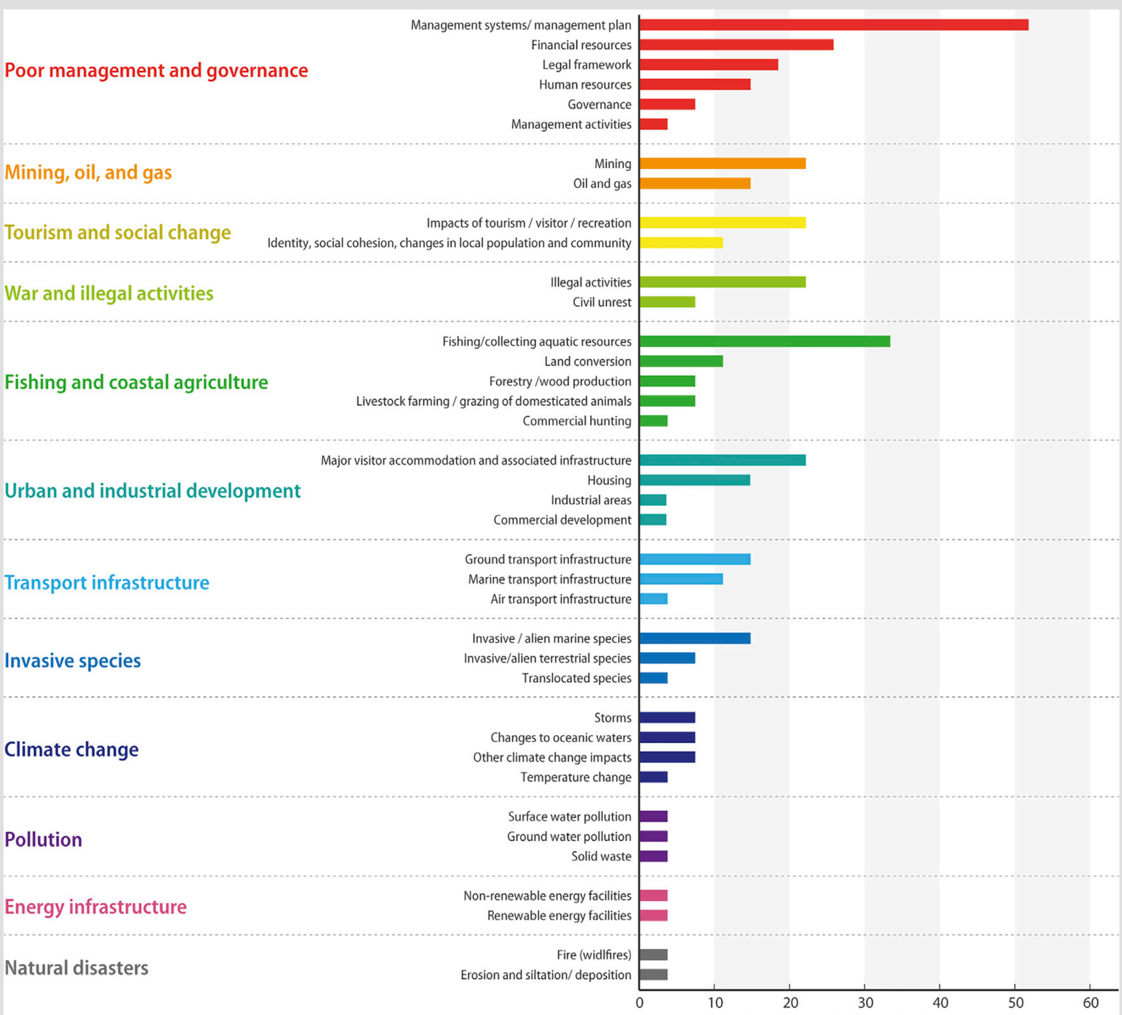
A new governance paradigm for ecosystem intervention entails thinking very critically about feasible trajectories for ecosystems[31] and the kinds of interventions necessary to achieve those trajectories (Figure 2). Clearly, no intervention—that is, business as usual—will lead to a degraded ecosystem state. Medium-intensity intervention, comprising conservative and incremental adjustments, could slow down but not prevent future decline. High-intensity intervention, by contrast, entailing transformative change, is needed to sustain ecosystems into the future. Interventions must address the root causes of environmental degradation at the scale at which they arise, and the overall advantages and challenges of the mix of interventions also need to be assessed holistically.[32] In considering the intervention mix, both primary (e.g., local reef sustainability) and secondary (e.g., higher scientific and political outcomes) outcomes must be considered. Building on this understanding, we propose that a more effective governance paradigm has three features: (1) it analyzes the range of proposed interventions for coral reefs according to their intensity and scale of cause and effect, (2) it interrogates how interventions work together as a group and in sequence, and (3) it assesses the broader scientific and political implications of a particular intervention and groups of interventions. To demonstrate, we now develop a first-cut typology of the interventions currently implemented and proposed (Table 1) and briefly assess them in turn.

In many reef nations, business as usual remains a popular short-term response despite scientific projections of global heating. However, business-as-usual emissions of greenhouse gases will destroy most coral reefs by mid-century, even if local stressors are curtailed.[1] By contrast, global agreements, specifically the 2015 Paris agreement, recognize that for coral reefs to have any viable future, global society must mobilize to meet the climate mitigation challenge. The pathway to zero net emissions means reducing global carbon emissions by 45% below 2010 levels by 2030.[1] Notwithstanding genuine leadership by some governments, nongovernmental organizations (NGOs), community groups, and individuals, global mitigation ambitions have been hampered by many challenges and road blocks, including divergent capacities for change, short-term economic interests, carbon lock-in, and sustained public misinformation campaigns funded by fossil fuel industries.[28,33]

Box 1. Threats Outpacing Governance of 29 World Heritage-Listed Coral Reefs

As the threats to ecosystems grow in scale and frequency, they are outpacing conventional institutions, laws, and governance. Twenty-nine coral reefs are listed under the 1972 UNESCO World Heritage Convention, including reefs in the Galapagos, Australia, and Hawaii. The first World Heritage-listed coral reef bleached in 1979, before inscription, but climate reporting did not commence until 1991. Since then, the number and frequency of bleaching events has increased over time.[5] Today, 23 of the 29 coral reef sites are reported as affected by climate change, although 27 have bleached severely at least once. UNESCO reporting on climate change has also steadily increased—mainly as a result of a series of environmental NGO petitions—but still maintains a significant time lag.[25]

UNESCO has traditionally shied away from seeking to influence nonlocal threats, effectively delegating responsibility to other conventions (e.g., the UN Framework Convention on Climate Change). Understanding and reporting of the cumulative effect of different threats also remains poor.[26] Recent trends and events (such as glaciers melting in ecosystems in North America and Europe, and coral reefs bleaching in Australia and across the tropics) are now motivating UNESCO to reconsider the challenge of maintaining Outstanding Universal Value under climate change.[27] UNESCO recognized in 2017 that local-level action is not enough to tackle the critical threat of climate change and is currently preparing a new policy for climate change and World Heritage. One solution, opposed by some state parties, is that national policies for climate change are taken into account in World Heritage decision making, which could form part of the revised climate policy to be presented at the 44th World Heritage Committee meeting in Fuzhou, China, in 2020. Such unconventional and inherently political solutions could prove critical to sustaining coral reefs through the coming centuries.



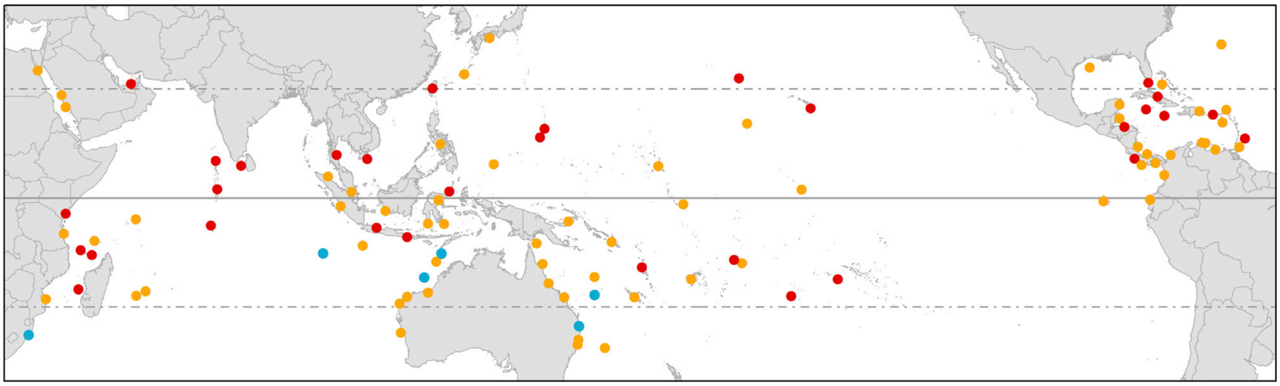


Figure 1. Extent and Frequency of Coral Bleaching since 1980
One hundred reef locations were assessed for severe bleaching events each year from 1980 to 2017,[5] affecting >30% of coral colonies. Blue, orange, and red reef locations have already bleached severely 0, 1–3, and 4 or more times, respectively.

At a more local scale, ecosystem-based interventions are designed to address local reef stressors through marine protected areas, management of fisheries, and water quality management.[34] Ecosystem-based interventions remain popular because overfished and/or polluted reefs may be less likely to recover quickly between episodic bouts of mass bleaching caused by rising temperatures.[35] However, these interventions do not prevent global heating or ocean acidification. Nor do they address the root causes of overfishing or pollution, for example, poverty, market demands, or migration. Furthermore, the selection of sites for marine protected areas and fisheries management is not always based on ecological values, and once implemented, their effectiveness is highly dependent on local support and compliance.[36–38]

Bold land-sea interventions seek to extend ecosystem-based interventions by integrating marine approaches with terrestrial-based investment in renewable energy, fossil fuel divestment, land-based aquaculture, and restoration of carbon sinks. Land-sea programs draw on a long history of comprehensive land-use planning, such as the Tennessee Valley Authority established in the 1930s in the United States.[39] Today, land-sea interventions are being promoted by transnational partnerships, international aid agencies, and major social movements across the world, including the Coral Triangle Initiative, the Global Environment Facility, and the Green New Deal movement.[25] However, local opposition, vested interests, and lack of public investment can hamper these efforts.[40–42] Ambitious land-sea planning will be difficult to implement without a clear vision, leadership, and social acceptance of the radical changes needed to avoid dangerous levels of climate change by mid-century.

Bioengineering interventions include small-scale coral gardening, assisted migration, and *in vitro* breeding of climate-resistant corals. These interventions are controversial because they are challenging to scale up beyond reseeding one or two species in small plots.[43] To date, few restoration attempts have adequately monitored the medium-term (>5 years) outcomes of planting juvenile corals or branch fragments. Unless the underlying causes of coral decline are addressed, the local history of episodic and chronic mortality is likely to repeat itself and continue. Typically, restoration attempts lack a control (adjacent reef areas that are monitored for natural recovery), hindering a rigorous assessment of the cost-effectiveness of restoration efforts. Laboratory breeding and genetic engineering of new coral strains, so-called super corals, will bring new ethical challenges and risks of unexpected outcomes.[44] Furthermore, it is unclear whether the release of new genotypes could change the gene pool of much larger wild populations that are already under intense natural selection from major bleaching events.

At the more extreme end of the intervention spectrum are geoengineering proposals, which range vastly in scale from local attempts to protect corals from spikes in temperature (by cooling or shading), to radical action that could alter the Earth's climate system at a regional or global scale.[45] Proposals such as solar radiation management remain mostly hypothetical and will be dogged by significant governance challenges, including the lack of a multilateral geoengineering agreement, the potential for unilateral action by individual states, and a lack of frameworks for risk assessment and management.[46] Experience with coastal geoengineering on small islands, for example, demonstrates significant trade-offs and feedbacks between human needs (such as flood defense) and ecological needs (such as structure and function of coral reefs).[47] Many geoengineering proposals also convey a false promise: that it is possible to address ecosystem decline by curbing the symptoms of rising temperatures without dealing with the underlying drivers of rising greenhouse gas emissions.

Governance Traps and Placebo Policies

Each of the interventions summarized above varies in its effectiveness in addressing the root causes of coral reef degradation. Each intervention also differs in the extent of its future orientation, evidence base, and political acceptability. However, when some interventions are promoted together as a group, they risk forming a governance trap (Figure 2). A governance trap occurs when the ability to address the problem becomes constrained by a misdiagnosis of the nature of the problem and a miscalculation of the social actors responsible for its solution. In the case of reefs, the degradation problem has typically been diagnosed as the symptom (local biodiversity decline from recent baselines) rather than the cause (climate change and other anthropogenic drivers). The actors targeted to solve the problem are often the recipients of the problem (local reef managers and users) rather

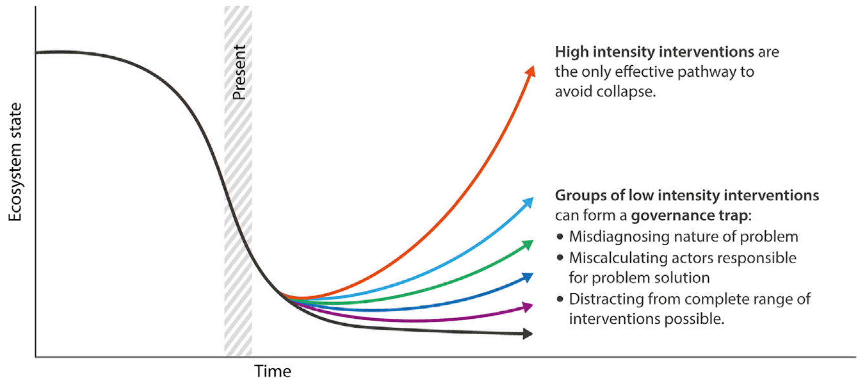


Figure 2. Future Coral Reef Ecosystem Trajectories

than other parts of society who are responsible for broad-scale drivers.

Governance actors typically escape such traps through two alternatives: either treatment policies (high political risk and high political cost) or placebo policies (low political risk and low political cost). In the case of the Great Barrier Reef, for example, the Australian government has recently funded a US$65 million restoration research program to restore corals in the aftermath of mass mortality caused by record-breaking temperatures in 2016 and 2017,[48] while also subsidizing further expansion of fossil fuels. The reef restoration program is essentially a placebo policy,[49] which allows the Australian government to be seen to "do something" (escaping the trap through reef restoration research) rather than dealing with the much tougher task of addressing the deeper causal drivers of the problem (action on climate mitigation). Placebo interventions are problematic because when they are promoted alongside other low-intensity solutions (such as ecosystem-based management), they reinforce the idea that it is possible to address ecosystem degradation without addressing the long-term and often distant drivers of reef decline.

Governance traps and placebo policies also have broader societal implications because not only do they hide inaction by diverting attention elsewhere, but they also mask the complete range of interventions that are possible (Figure 2). For example, the significant investment in restoration research could lead to a slippery slope of science-policy lock-in that precludes a broader scientific agenda into alternative interventions, thereby affecting ecosystem outcomes in a more profound way into the future.[50] There is therefore a very important role for science to play in escaping the governance trap—both through better diagnosis of the coral reef problem and through better identification of the range of possible solutions.

Escaping the Governance Trap

How do concerned scientists and policy makers escape the governance trap? We believe that this challenge can be achieved by (1) improving how all actors frame and scale the coral reef problem and (2) harnessing broader governance experiments across social, ecological, economic, and policy science and practice.

To liberate future coral reefs from today's governance trap, scientists and policy makers must first begin to radically reframe and rescale the coral reef crisis. Framing is the way scientists and policy makers explain and understand ecosystem decline. For coral reefs, the dominant frame today is loss of reef biodiversity. Scaling is the way we explain the geographic coverage and time span of the solution. For coral reefs, the dominant spatial scale is still at the local-ecosystem level, as understood over a medium-term, decadal timescale.

Consistently framing coral degradation as a biological rather than a socioeconomic challenge is problematic because this framing emphasizes biological and technological interventions (such as reef fans or a robot that disperses coral larvae on a few hectares of the Great Barrier Reef) and ignores higher-scale social and economic interventions. Likewise, scaling coral degradation as a local and immediate problem reinforces the idea that nonlocal and long-term drivers are exogenous and therefore ungovernable.[51] In Pacific atoll countries, international assistance continues to promote ad hoc and local marine conservation and human migration initiatives rather than the long-term and multiscale adaptation planning required to sustain coastal socioecological systems into the future.[52]

Framing and scaling can also work in ways that are more subtle. For example, as more and more ecosystems have been degraded due to climate extremes, some governments, such as the United States government, have worked to deny, suppress, or downplay information about the role of climatic change in ecosystem degradation, thereby hindering political support for reduction of emissions.[53] A growing body of evidence shows that the terminology and the images that define climate change shape the way it is understood and acted upon.[54–56] A number of large influential organizations (such as the Science Media Centre, *The Guardian*, and the BBC) are therefore beginning to rethink their communication of climate-impacted communities and ecosystems, including terminology and visual imagery.

How we choose to frame and scale environmental change and resilience sends a powerful message about how we should respond to reef degradation and about who is accountable and responsible. For example, scientists have highlighted the need to shift intervention away from the management of harvested fish stocks and coral cover toward maintenance of the more abstract ecosystem functions that sustain reefs and the services we require from them.[13] Clearly, identifying these functions and ecosystem services is only part of the task; managing them in a way that resonates with communities and policy

Table 1. Types and Selected Examples of Intervention Options for Coral Reefs

Business as usual	climate denialism combined with unchecked greenhouse gas emissions and increasing local stressors
Greenhouse gas mitigation	mostly focused on reduction of global emissions through pricing carbon, emissions trading, carbon accounting, and renewable energy and clean technology targets
Marine ecosystem-based management	extension of marine protected areas, fisheries management, and regulation of water quality
Land-sea decarbonization and adaptation	integration of marine ecosystem-based management approaches (above) with terrestrial-based investment in renewable energy, fossil fuel divestment, land-based aquaculture, and restoration of carbon sinks
Marine bioengineering	coral gardening, assisted migration, and *in vitro* breeding of climate-resistant corals
Geoengineering	structural fortification, underwater fans, shading of corals, and solar-radiation management

makers requires careful framing. Further, as ecosystem functions change in the Anthropocene, scientists need to be careful to appropriately scale the cause of the problem (climate change and other anthropogenic drivers) rather than the symptom (e.g., changing compositions of species, pests, and disease).[57]

A New Ecosystem Governance Paradigm

Improving how we frame and scale the coral reef crisis is not just a biological or social problem; it is also a governance problem.[58–60] Rapid and uncertain transnational threats, and globally uneven power relations and development patterns, have exposed the political limitations of conventional ecosystem governance. Governance of the Great Barrier Reef, for example, has evolved over the last decade from a local assemblage of social actors (dominated historically by fishing and tourism stakeholders, local conservation groups, and traditional owners) to a more complex polycentric regime, including mining lobbyists, UNESCO, and large international environmental NGOs.[9] Similarly, governance of the Pacific islands now involves international banks, coastal engineers, and property lawyers, among others. Governance for local conservation and traditional livelihoods is no longer enough; it must evolve to reflect current and future interests.

Synergistic Intervention

One important new way of thinking about ecosystem futures is to consider the interactions between multiple interventions. Ecological and political science theories on intervention interactions hold much promise for a more effective approach to ecosystem intervention.[61–63] Interventions are antagonistic if they weaken or block one another, so that the combined effect is less than the sum of the individual effects. For example, Australia has multiple policies for protecting the Great Barrier Reef but also seeks to expand fossil fuels, coal and gas ports, and shipping. Additive effects occur when actions simply coexist without affecting each other's outcomes for better or worse, and therefore the combined effects are equal to the sum of the individual effects. An example of an additive effect is where a government adopts an environmental regulation that an industry has already voluntarily adopted and even exceeded (e.g., regulation of ecotourism). Synergistic outcomes occur when one policy, law, or management intervention has a reinforcing effect on another, so that the combined outcomes exceed the individual effects.[64,65] Combining economic (e.g., debt alleviation) and social (e.g., public health) interventions with ecological interventions (e.g., to reduce pollution), for example, can synergistically build both social and ecological resilience.[66]

Synergistic interventions are part of the paradigmatic shift that is required to move from a sole focus on collective action at either the ecosystem level or the global level to a much more multiscale and interactive approach. However, synergistic interventions also include substantial reorganization of the local and global economy if they are to "go to scale."[67] For example, land-sea interventions (such as the Green New Deal) require industry and government at multiple levels to embrace a decarbonization agenda that integrates investment in renewable energy with fossil fuel divestment, land-based aquaculture, and restoration of carbon sinks. Such synergistic interventions therefore not only require scientific evidence and modeling but also require a strong moral case, political legitimacy, and economic incentive.

Changing the Political Economy

In recent years, theoretical and empirical studies have provided a robust framework for understanding multiscale responses to climate change. For example, it is now widely recognized that effective multiscale governance entails multiple governing authorities at different scales that are engaged in self-organization and mutual adjustment. Multiscale governance is more than just networks of actors; it also includes nonstructural functions such as cooperation, learning, and equitable resource distribution. However, considerable gaps in our knowledge remain—in particular how to harness untapped power dynamics within multiscale structures in order to sustain coral reefs.[30] Overcoming this gap is critical because the climate challenge is not just a biological or social problem but also a political task.

Emerging research is showing how coral reefs are central to conceptions of identity and community, and how loss of reef leads to measurable loss of well-being.[68,69] Emotional and social impacts are felt not only by individuals intimately connected with reefs on a day-to-day basis but also by populations far away from reef locations.[70] For example, charismatic and stunningly beautiful coral reefs continue to feature as the totem of many climate protests worldwide. Scientists and policy makers are beginning to focus on how such social movements are formed and how views of coral reef dynamics are framed, maintained, and changed through such movements.[71] Other scientists are paying closer attention to multiple distant drivers of change (e.g., reef supply chains to distant markets).[72,73] Some of those scientists are working with so-called keystone actors (e.g., powerful companies, financial institutions, nation states, and/or regional governments) to modify their interactions to mitigate against climate change and reduce proximate stressors through diplomacy, trade, and/or exchange of information and technology.[74,75] Such activity has an expanding effect by increasing the moral pressure and economic incentive of less powerful actors to support sustainability initiatives.[33] However, there are also risks associated with such endeavors, such as when keystone actors redefine the problem and solution framing to better serve their own agenda and thereby reinforce the governance trap.[76] Identifying and targeting this broader political economy offers fresh opportunities to underscore the moral dimension of the climate crisis while also opening debate and deliberation to a much broader set of societal actors.[77]

Decarbonization as the Defining Challenge

To sustain ecosystems and people into the next century and beyond, we need a better governance frame, one that is fit for the Anthropocene. Building on emerging understanding of discourse, framing, and metaphor,[56,78,79] we propose that decarbonization rather than conservation or restoration needs to be more clearly understood as the defining challenge for coral reefs.[80] So far, reef conservation has been heavily influenced by commons and collective action theory, which still emphasizes reefs and reef-dependent peoples as the single arena for action. Changing perspective to consider the challenge of decarbonization opens up a much wider variety of multiscale strategies for governing coral reefs, including political, economic, technological, and cultural strategies.[81] Consider, for example, the self-funding system of renewable energy in Fiji, which has been recently installed by the Fijian Government in partnership with the Leonardo DiCaprio Foundation, the Fiji Locally Managed Marine Area Network, and private energy companies. This potentially transformative intervention is improving livelihoods, reducing emissions, and increasing climate resilience for Fijian coastal communities.[82] Changing perspective to consider the reef challenge as a decarbonization rather than a conservation or restoration challenge opens new avenues for research on some of the biggest practical questions in reef governance, such as how we reconcile environment and development globally and how we develop novel solutions to fit the scale of the problem. For example, rather than pitting sustainable ecosystems against energy security, we ask about the relationship between them. Similarly, rather than focusing solely on local sectors such as fisheries and tourism, we question the transformative role of sectors operating at higher scales, such as health, energy, and transport.

Innovative Forms of Adaptation

Innovative forms of adaptation planning could also provide opportunities to induce necessary disruption and transformation of failing governance. Despite growing acknowledgment of climate impacts and the need to manage reefs for ecosystem function and resilience, adaptation planning is still lagging for most reef systems.[13] Where it does occur, it is typically restricted to adaptive management (such as permitting systems that reflect fish stock changes) and generally does not consider broader adaptive capacity[83] or emerging social, technological, political, or economic trends. A variety of novel theories (e.g., behavioral priming) and social engagement tools (e.g., participative scenario building, foresighting, and future prototyping) can enable scientists and policy makers to explore how different conditions, drivers, and decisions shape pathways toward alternate visions of the future.[84–86] Adaptation planning is therefore essential to navigate emerging conflicts[20,21] and avoid potentially maladaptive interventions.[87] Understanding decarbonization and adaptation planning as part of the political economy and intervention mix will be integral to addressing the escalating problems that confront coral reefs (Figure 3).

Hope in the Anthropocene

Arresting coral reef degradation is a monumental global challenge. Previous social and environmental challenges have been overcome in the past through a variety of means, including social sanctioning (smoking in public places), changing community norms (fertility control), and global agreement (chlorofluorocarbon control).[88,89] These interventions have steered the trajectories of lung cancer, overpopulation, and ozone depletion toward more sustainable outcomes. A series of similar interventions are now emerging to offer hope for reef ecosystems and reef peoples. Taken together, these interventions indicate the potential for scientists, local communities, transgovernmental organizations, and NGOs to mobilize a new coalition for climate action[90] linked to coral reef sustainability. Such mobilization is essential to the development of a countervailing force against the dominating political influence of the fossil fuel lobby.

The Alliance of Small Island States, for example, is a collation of 44 low-lying and small island states that share common concerns about oceans and islands. This broad coalition has opened new policy windows, influenced government action, and mobilized additional resources to address the impacts of climate change on reefs and reef peoples.[91] Through their collective action in the United Nations system, they have increased international pressure to set the ambitious 1.5°C Paris target.[92]

Other authorities are also helping to create collective action across the world to mitigate emissions, facilitate adaptation, and propose policies and measures addressing coral reef degradation. The UNESCO World Heritage Centre, for example, has improved reporting on the vulnerability of individual World Heritage-listed reefs to climate change[27] (Box 1). Established in 1972, the World Heritage Convention is widely regarded as one of the world's most powerful global environmental regimes, ratified by 192 countries. Whereas some countries (including Australia) have resisted moves by UNESCO to consider climate change within the World Heritage framework, other countries (including the United Kingdom) have responded to the World Heritage Convention's powerful messaging and begun to systematically assess the vulnerability of World Heritage-listed properties to climate change. Those countries are now developing proactive mitigation and adaptation plans.[93]

The Nature Conservancy, along with many other environmental NGOs, is beginning to adopt synergistic interventions that aim to benefit both people and nature. For example, major conservation interventions are now evaluated (and therefore reframed) using multiple metrics, including the number of people benefiting from ecosystem services,[94] metric tons of CO_2 equivalents/year sequestered,[95] increased equity, number of fisheries with improved management, increased food production and security, and area of land or sea protected.[96] Other partnerships between governments, development institutions, and philanthropic foundations (e.g., through the Consultative Group for International Agricultural Research) are also beginning to champion cross-sectoral interventions to climate mitigation and adaptation, especially focused on food security in the Pacific.[97]

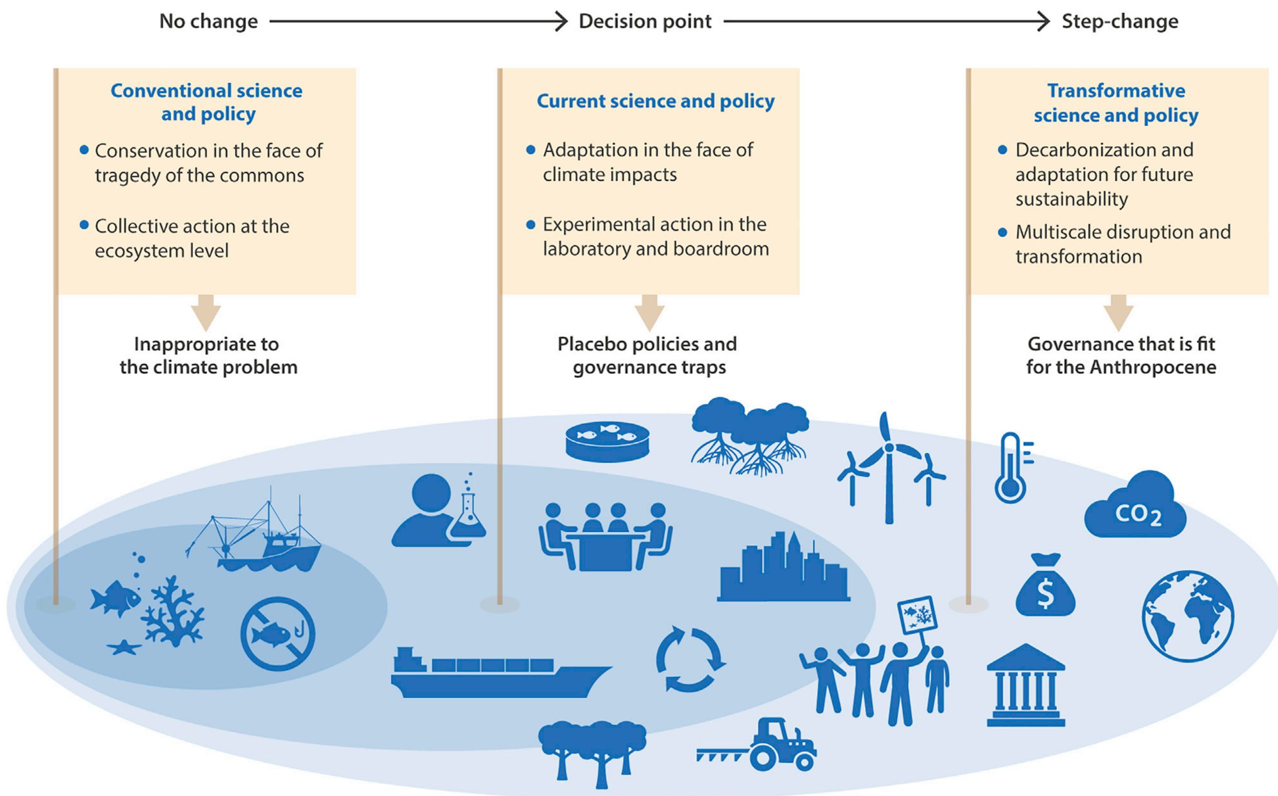


Figure 3. Conventional, Current, and Transformative Governance of the Broader Coral Reef System under Climate Change

Similarly, the Global Environment Facility—an international partnership of 183 countries, international institutions, civil society organizations, and the private sector—has set up a Pacific Ridge to Reef program to simultaneously reduce global emissions and pollutant runoff and promote sustainable energy and food production in 14 Pacific Island nations.[98]

NGOs are also experimenting with different funding schemes to increase the scale of interventions (including crowd funding, debt conversions, reef insurance, and other payments for ecosystem services).[99,100] New public-private green economic stimuli also hold much promise for reinforcing multiple outcomes.

These developments are not exhaustive, and many of them require a fundamentally different mindset from the current paradigm. The potentials and limitations of these developments as a means of improving the outlook for coral reefs are also not yet fully understood. In particular, there is a need to further explore the role of the financial sector in escaping the governance trap and inspiring transformative change, for example, through controlling the pecuniary underpinning of large corporations. Other potential points of leverage, such as blue bonds, covenant loans (specific conditions associated with credit lending), and shareholder activism are also beginning to be explored.[101] Key additional opportunities include the role of new technologies, such as geovisualization and new media, new youth coalitions, and human emotion, as an untapped force for political change.[102] Active communication and collaboration among the biophysical sciences, the social sciences, and the humanities will be critical to this endeavor. The unifying characteristic of all of these and other similar initiatives is that they demonstrate the creativity and hope that is essential for transformative governance of reefs in the Anthropocene.

Reef Futures

Coral reef ecologists have comprehensively demonstrated how a combination of anthropogenic thermal stress, pollution, and overfishing collectively degrades reefs. Biological and climate scientists have also documented that most drivers of ecological change are increasing at a regional and global scale. Environmental social scientists have demonstrated that people, institutions, and politics are critical to effective governance. A developing research and policy agenda is beginning to extend these perspectives to incorporate recent political, cultural, and social innovations. Consequently, a new reef governance paradigm is emerging, which is expanding understanding and—potentially—accountability.

To liberate future coral reefs from today's governance trap, scientists and policy makers must continue to radically reframe and rescale. This paradigm shift is necessary to establish and test the political legitimacy and effectiveness of proposed interventions, to measure political feasibility and modify interventions accordingly, and to guide the development of completely new interventions that are often overtly political. Indeed, securing a future for coral reefs under climate change is a political challenge as much as an ecological or social one. Understanding how to manipulate ecological, social, and political dynamics at a variety of spatial and temporal scales is now integral to addressing the escalating problems that confront coral reefs. Although the scientific hurdles (interdisciplinarity, complexity, and urgency) of the new paradigm are challenging, the benefits are potentially gargantuan.

ACKNOWLEDGMENTS

The authors thank Cindy Huchery, Jerker Lokrantz, and Chia Miin Chua for assisting with illustrations and Pip Cohen, Marcus Lane, and two anonymous referees for their helpful comments and suggestions. This work was supported by the Australian Research Council.

REFERENCES

1. International Panel on Climate Change. (2018). Global Warming of 1.5 °C. https://www.ipcc.ch/sr15/.
2. Teh, L.S.L., Teh, L.C.L., and Sumaila, U.R. (2013). A global estimate of the number of coral reef Fishers. PLoS One *8*, e65397.
3. Donner, S.D., and Potere, D. (2007). The inequity of the global threat to coral reefs. BioScience *57*, 214–215.
4. Moberg, F., and Folke, C. (1999). Ecological goods and services of coral reef ecosystems. Ecol. Econ. *29*, 215–233.
5. Hughes, T.P., Anderson, K.D., Connolly, S.R., Heron, S.F., Kerry, J.T., Lough, J.M., Baird, A.H., Baum, J.K., Berumen, M.L., Bridge, T.C., et al. (2018). Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. Science *359*, 80–83.
6. Darling, E.S., and Côté, I.M. (2018). Seeking resilience in marine ecosystems. Science *359*, 986–987.
7. National Academies of Sciences Engineering and Medicine (2019). A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs (The National Academies Press), p. 258.
8. van Hooidonk, R., Maynard, J., Tamelander, J., Gove, J., Ahmadia, G., Raymundo, L., Williams, G., Heron, S.F., and Planes, S. (2016). Local-scale projections of coral reef futures and implications of the Paris Agreement. Sci. Rep. *6*, 1–8.
9. Morrison, T.H. (2017). Evolving polycentric governance of the Great Barrier reef. Proc. Natl. Acad. Sci. USA *114*, E3013–E3021.
10. Foley, M.M., Mease, L.A., Martone, R.G., Prahler, E.E., Morrison, T.H., Murray, C.C., and Wojcik, D. (2017). The challenges and opportunities in cumulative effects assessment. Environ. Impact Assess. Rev. *62*, 122–134.
11. Ostrom, E. (1990). Governing the Commons: The Evolution of Institutions for Collective Action (Cambridge University Press).
12. Hughes, T.P., Barnes, M.L., Bellwood, D.R., Cinner, J.E., Cumming, G.S., Jackson, J.B.C., Kleypas, J., van de Leemput, I.A., Lough, J.M., Morrison, T.H., et al. (2017). Coral reefs in the Anthropocene. Nature *546*, 82–90.
13. Bellwood, D.R., Pratchett, M.S., Morrison, T.H., Gurney, G.G., Hughes, T.P., Álvarez-Romero, J.G., Day, J.C., Grantham, R., Grech, A., Hoey, A.S., et al. (2019). Coral reef conservation in the Anthropocene: confronting spatial mismatches and prioritizing functions. Biol. Conserv. *236*, 604–615.
14. Hughes, T.P., Kerry, J.T., Connolly, S.R., Baird, A.H., Eakin, C.M., Heron, S.F., Hoey, A.S., Hogeboom, M.O., Jacobson, M., Liu, G., et al. (2019). Ecological memory modifies the cumulative impact of recurrent climate extremes. Nat. Clim. Change *9*, 40–43.
15. Vergés, A., McCosker, E., Mayer-Pinto, M., Coleman, M.A., Wernberg, T., Ainsworth, T., and Steinberg, P.D. (2019). Tropicalisation of temperate reefs: implications for ecosystem functions and management actions. Funct. Ecol. *33*, 1000–1013.
16. Edmunds, P.J., Adjeroud, M., Baskett, M.L., Baums, I.B., Budd, A.F., Carpenter, R.C., Fabina, N.S., Fan, T.-Y., Franklin, E.C., Gross, K., et al. (2014). Persistence and change in community composition of reef corals through present, past, and future climates. PLoS One *9*, e107525.
17. Willett, W., Rockström, J., Loken, B., Spring Mann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., et al. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet *393*, 447–492.
18. Mechler, R., and Schinko, T. (2016). Identifying the policy space for climate loss and damage. Science *354*, 290–292.
19. Belmar, Y.N., McNamara, K.E., and Morrison, T.H. (2016). Water security in small island developing states: the limited utility of evolving governance paradigms: water security in small island developing states. Wiley Interdiscip. Rev. Water *3*, 181–193.
20. Song, A.M., Hoang, V.T., Cohen, P.J., Aqorau, T., and Morrison, T.H. (2019). 'Blue boats' and 'reef robbers': a new maritime security threat for the Asia Pacific? Asia Pac Viewpoint *60*, 310–324.
21. Spijkers, J., Morrison, T.H., Blasiak, R., Cumming, G.S., Osborne, M., Watson, J., and Österblom, H. (2018). Marine fisheries and future ocean conflict. Fish Fish. *19*, 798–806.
22. Challinor, A.J., Adger, W.N., Benton, T.G., Conway, D., Joshi, M., and Frame, D. (2018). Transmission of climate risks across sectors and borders. Philos. Trans. A Math. Phys. Eng. Sci. *376*, 20170301.
23. Savage, A., McIver, L., and Schubert, L. (2019). Review: the nexus of climate change, food and nutrition security and diet-related non-communicable diseases in Pacific Island Countries and Territories. Clim. Dev. https://doi.org/10.1080/17565529.2019.1605284.
24. World Health Organization. (2018). Progress on the Prevention and Control of Noncommunicable Diseases in the Western Pacific Region: Country Capacity Survey 2017.
25. Morrison, T.H., Hughes, T.P., Adger, W.N., Brown, K., Barnett, J., and Lemos, M.C. (2019). Save reefs to rescue all ecosystems. Nature *573*, 333–336.
26. United Nations Educational, Scientific and Cultural Organization (2016). World Heritage and Tourism in a Changing Climate.
27. Heron, S., van Hooidonk, R., Maynard, J., Anderson, K., Day, J.C., Geiger, E., Hoegh-Guldberg, O., Hughes, T.P., Marshall, P., Obura, D., et al. (2018). Impacts of Climate Change on World Heritage Coral Reefs: Update to the First Global Scientific Assessment (United Nations Educational Scientific and Cultural Organization).
28. Nyberg, D., and Wright, C. (2019). Making climate change fit for capitalism: the corporate translation of climate adaptation. Acad. Manag. Proc. *2019*, 12618.
29. Eakin, C.M., Sweatman, H.P.A., and Brainard, R.E. (2019). The 2014–2017 global-scale coral bleaching event: insights and impacts. Coral Reefs *38*, 539–545.
30. Morrison, T.H., Adger, W.N., Brown, K., Lemos, M.C., Huitema, D., Phelps, J., Evans, L., Cohen, P., Song, A.M., Turner, R., et al. (2019). The black box of power in polycentric environmental governance. Glob. Environ. Change *57*, 101934.
31. Steffen, W., Rockström, J., Richardson, K., Lenton, T.M., Folke, C., Liverman, D., Summerhayes, C.P., Barnosky, A.D., Cornell, S.E., Crucifix, M., et al. (2018). Trajectories of the Earth system in the Anthropocene. Proc. Natl. Acad. Sci. USA *115*, 8252–8259.
32. Howlett, M., Mukherjee, I., and Woo, J.J. (2015). From tools to toolkits in policy design studies: the new design orientation towards policy formulation research. Policy Polit. *43*, 291–311.
33. Creutzig, F. (2019). The mitigation trinity: coordinating policies to escalate climate mitigation. One Earth *1*, 76–85.
34. Roberts, C.M., O'Leary, B.C., McCauley, D.J., Cury, P.M., Duarte, C.M., Lubchenco, J., Pauly, D., Sáenz-Arroyo, A., Sumaila, U.R., Wilson, R.W., et al. (2017). Marine reserves can mitigate and promote adaptation to climate change. Proc. Natl. Acad. Sci. USA *114*, 6167–6175.
35. Mellin, C., Aaron MacNeil, M., Cheal, A.J., Emslie, M.J., and Julian Caley, M. (2016). Marine protected areas increase resilience among coral reef communities. Ecol. Lett. *19*, 629–637.
36. Kuempel, C.D., Jones, K.R., Watson, J.E.M., and Possingham, H.P. (2019). Quantifying biases in marine-protected-area placement relative to abatable threats. Conserv. Biol. *33*, 1350–1359.
37. Stevenson, S.L., Woolley, S.N.C., Barnett, J., and Dunstan, P. (2019). Testing the presence of marine protected areas against their ability to reduce pressures on biodiversity. Conserv. Biol. https://doi.org/10.1111/cobi.13429.
38. Turner, R.A., Addison, J., Arias, A., Bergseth, B.J., Marshall, N.A., Morrison, T.H., and Tobin, R.C. (2016). Trust, confidence, and equity affect the legitimacy of natural resource governance. Ecol. Soc. *21*, art18.
39. Morrison, T.H., Lane, M.B., and Hibbard, M. (2015). Planning, governance and rural futures in Australia and the USA: revisiting the case for rural regional planning. J. Environ. Plann. Manag. *58*, 1601–1616.
40. Bell, J., and Morrison, T. (2015). A comparative analysis of the transformation of governance systems: land-use planning for flood risk. J. Environ. Policy Plann. *17*, 516–534.
41. Kolstad, I., and Søreide, T. (2009). Corruption in natural resource management: implications for policy makers. Resour. Policy *34*, 214–226.
42. Karasik, R., Pickle, A., Roady, S.A., Vegh, T., and Virdin, J. (2019). Analysis of Policies Related to the Protection of Coral Reefs - Analysis of Global and Regional Policy Instruments and Governance Mechanisms

Related to the Protection and Sustainable Management of Coral Reefs (United Nations Environment Programme).
43. Bayraktarov, E., Stewart-Sinclair, P.J., Brisbane, S., Boström-Einarsson, L., Saunders, M.I., Lovelock, C.E., Possingham, H.P., Mumby, P.J., and Wilson, K.A. (2019). Motivations, success, and cost of coral reef restoration. Restor. Ecol. *27*, 981–991.
44. Wolfenbarger, L.L., and Phifer, P.R. (2000). The ecological risks and benefits of genetically engineered plants. Science *290*, 2088–2093.
45. Flegal, J.A., Hubert, A.-M., Morrow, D.R., and Moreno-Cruz, J.B. (2019). Solar geoengineering: social science, legal, ethical, and economic frameworks. Annu. Rev. Environ. Resour. *44*, 399–423.
46. Pasztor, J., Scharf, C., and Schmidt, K.-U. (2017). How to govern geoengineering? Science *357*, 231.
47. Duvat, V.K.E., and Magnan, A.K. (2019). Rapid human-driven undermining of atoll island capacity to adjust to ocean climate-related pressures. Sci. Rep. *9*, 15129.
48. Australian Government and Queensland Government. (2018). Great Barrier Reef - Partnerships for the Future (Department of the Environment and Energy).
49. McConnell, A. (2019). The use of placebo policies to escape from policy traps. J. Eur. Public Policy. https://doi.org/10.1080/13501763.2019.1662827.
50. Bellamy, R., and Healey, P. (2018). 'Slippery slope' or 'uphill struggle'? Broadening out expert scenarios of climate engineering research and development. Environ. Sci. Policy *83*, 1–10.
51. Song, A.M., Johnsen, J.P., and Morrison, T.H. (2018). Reconstructing governability: how fisheries are made governable. Fish Fish. *19*, 377–389.
52. Barnett, J., and McMichael, C. (2018). The effects of climate change on the geography and timing of human mobility. Popul. Environ. *39*, 339–356.
53. Lubchenco, J. (2017). Environmental science in a post-truth world. Front. Ecol. Environ. *15*, 3.
54. Chapman, D.A., Corner, A., Webster, R., and Markowitz, E.M. (2016). Climate visuals: a mixed methods investigation of public perceptions of climate images in three countries. Glob. Environ. Change *41*, 172–182.
55. Wang, S., Corner, A., Chapman, D., and Markowitz, E. (2018). Public engagement with climate imagery in a changing digital landscape. Wiley Interdiscip. Rev. Clim. Change *9*, e509.
56. O'Neill, S. (2019). More than meets the eye: a longitudinal analysis of climate change imagery in the print media. Clim. Change. https://doi.org/10.1007/s10584-019-02504-8.
57. Williams, G.J., Graham, N.A.J., Jouffray, J.-B., Norström, A.V., Nyström, M., Gove, J.M., Heenan, A., and Wedding, L.M. (2019). Coral reef ecology in the Anthropocene. Funct. Ecol. *33*, 1014–1022.
58. Green, J.F., and Hale, T.N. (2017). Reversing the marginalization of global environmental politics in international relations: an opportunity for the discipline. PS Polit. Sci. Polit. *50*, 473–479.
59. Javeline, D. (2014). The most important topic political scientists are not studying: adapting to climate change. Perspect. Polit. *12*, 420–434.
60. Keohane, R.O. (2015). The global politics of climate change: challenge for political science. PS Polit. Sci. Polit. *48*, 19–26.
61. Rogge, K.S., and Reichardt, K. (2016). Policy mixes for sustainability transitions: an extended concept and framework for analysis. Res. Policy *45*, 1620–1635.
62. Schaffrin, A., Sewerin, S., and Seubert, S. (2015). Toward a comparative measure of climate policy output. Policy Stud. J. *43*, 257–282.
63. Brown, C.J., Saunders, M.I., Possingham, H.P., and Richardson, A.J. (2013). Managing for interactions between local and global stressors of ecosystems. PLoS One *8*, e65765.
64. Nilsson, M., Griggs, D., and Visbeck, M. (2016). Policy: map the interactions between sustainable development goals. Nature *534*, 320–322.
65. Morrison, T.H. (2014). Developing a regional governance index: the institutional potential of rural regions. J. Rural Stud. *35*, 101–111.
66. Wear, S.L. (2019). Battling a common enemy: joining forces in the fight against sewage pollution. BioScience *69*, 360–367.
67. Mills, M., Bode, M., Mascia, M.B., Weeks, R., Gelcich, S., Dudley, N., Govan, H., Archibald, C.L., Romero-de-Diego, C., Holden, M., et al. (2019). How conservation initiatives go to scale. Nat. Sustain. *2*, 935–940.
68. Marshall, N., Adger, W.N., Benham, C., Brown, K., Curnock, M.I., Gurney, G.G., Marshall, P., Pert, P.L., and Thiault, L. (2019). Reef Grief: investigating the relationship between place meanings and place change on the Great Barrier Reef, Australia. Sustain. Sci. *14*, 579–587.
69. Cunsolo, A., and Ellis, N.R. (2018). Ecological grief as a mental health response to climate change-related loss. Nat. Clim. Change *8*, 275–281.
70. Gurney, G.G., Blythe, J., Adams, H., Adger, W.N., Curnock, M., Faulkner, L., James, T., and Marshall, N.A. (2017). Redefining community based on place attachment in a connected world. Proc. Natl. Acad. Sci. USA *114*, 10077–10082.
71. Hayward, B., Salili, D.H., Tupuana'i, L.L., and Tualamali'i', J. (2020). It's not ''too late'': learning from Pacific Small Island Developing States in a warming world. Wiley Interdiscip. Rev. Clim. Change *11*, e612.
72. Fabinyi, M., Barclay, K., and Eriksson, H. (2017). Chinese trader perceptions on sourcing and consumption of endangered seafood. Front. Mar. Sci. *4*, 181.
73. Munroe, D.K., Batistella, M., Friis, C., Gasparri, N.I., Lambin, E.F., Liu, J., Meyfroidt, P., Moran, E., and Nielsen, J.Ø. (2019). Governing flows in telecoupled land systems. Curr. Opin. Environ. Sustain. *38*, 53–59.
74. Österblom, H., Jouffray, J.-B., Folke, C., and Rockström, J. (2017). Emergence of a global science–business initiative for ocean stewardship. Proc. Natl. Acad. Sci. USA *114*, 9038–9043.
75. Jouffray, J.-B., Crona, B., Wassénius, E., Bebbington, J., and Scholtens, B. (2019). Leverage points in the financial sector for seafood sustainability. Sci. Adv. *5*, eaax3324.
76. Folke, C., Österblom, H., Jouffray, J.-B., Lambin, E.F., Adger, W.N., Scheffer, M., Crona, B.I., Nyström, M., Levin, S.A., Carpenter, S.R., et al. (2019). Transnational corporations and the challenge of biosphere stewardship. Nat. Ecol. Evol. *3*, 1396–1403.
77. Schlosberg, D., Collins, L.B., and Niemeyer, S. (2017). Adaptation policy and community discourse: risk, vulnerability, and just transformation. Environ. Polit. *26*, 413–437.
78. Buschmann, P., and Oels, A. (2019). The overlooked role of discourse in breaking carbon lock-in: the case of the German energy transition. Wiley Interdiscip. Rev. Clim. Change *10*, e574.
79. Shaw, C., and Nerlich, B. (2015). Metaphor as a mechanism of global climate change governance: a study of international policies, 1992–2012. Ecol. Econ. *109*, 34–40.
80. Bernstein, S., and Hoffmann, M. (2019). Climate politics, metaphors and the fractal carbon trap. Nat. Clim. Change *9*, 919–925.
81. Green, F. (2018). Anti-fossil fuel norms. Clim. Change *150*, 103–116.
82. Republic of Fiji. (2018). COP23 Talanoa Dialogue Submission: 'Where Are We?' (United Nations Framework Convention on Climate Change).
83. Cinner, J.E., Adger, W.N., Allison, E.H., Barnes, M.L., Brown, K., Cohen, P.J., Gelcich, S., Hicks, C.C., Hughes, T.P., Lau, J., et al. (2018). Building adaptive capacity to climate change in tropical coastal communities. Nat. Clim. Change *8*, 117–123.
84. Curato, N., Dryzek, J.S., Ercan, S.A., Hendriks, C.M., and Niemeyer, S. (2017). Twelve key findings in deliberative democracy research. Daedalus *146*, 28–38.
85. Barnett, J., Graham, S., Mortreux, C., Fincher, R., Waters, E., and Hurlimann, A. (2014). A local coastal adaptation pathway. Nat. Clim. Change *4*, 1103–1108.
86. Berkhout, F., van den Hurk, B., Bessembinder, J., de Boer, J., Bregman, B., and van Drunen, M. (2013). Framing climate uncertainty: socio-economic and climate scenarios in vulnerability and adaptation assessments. Reg. Environ. Change *14*, 879–893.
87. Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N.J., Moore, M.-L., Morrison, T.H., and Brown, K. (2018). The dark side of transformation: latent risks in contemporary sustainability discourse. Antipode *50*, 1206–1223.
88. Haas, P.M. (2019). Robust ozone governance offers lessons for mitigating climate change. One Earth *1*, 43–45.
89. Nyborg, K., Anderies, J.M., Dannenberg, A., Lindahl, T., Schill, C., Schluter, M., Adger, W.N., Arrow, K.J., Barrett, S., Carpenter, S., et al. (2016). Social norms as solutions. Science *354*, 42–43.
90. Meckling, J., Kelsey, N., Biber, E., and Zysman, J. (2015). Winning coalitions for climate policy. Science *349*, 1170–1171.
91. United Nations General Assembly (2014). Resolution Adopted by the General Assembly on 14 November 2014: SIDS Accelerated Modalities of Action (SAMOA) Pathway. A/RES/69/15.
92. Benjamin, L., and Thomas, A. (2016). 1.5 to stay alive? AOSIS and the long term temperature goal in the Paris agreement. SSRN Electron. J. https://doi.org/10.2139/ssrn.3392503.
93. Day, J.C., Heron, S.F., Markham, A., Downes, J., Gibson, J., Hyslop, E., Jones, R.H., and Lyall, A. (2019). Climate Risk Assessment for Heart of Neolithic Orkney World Heritage Property: An Application of the Climate Vulnerability Index (Historic Environment Scotland).
94. Reguero, B.G., Beck, M.W., Agostini, V.N., Kramer, P., and Hancock, B. (2018). Coral reefs for coastal protection: a new methodological

approach and engineering case study in Grenada. J. Environ. Manage. *210*, 146–161.

95. Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P., et al. (2017). Natural climate solutions. Proc. Natl. Acad. Sci. USA *114*, 11645–11650.

96. Tallis, H.M., Hawthorne, P.L., Polasky, S., Reid, J., Beck, M.W., Brauman, K., Bielicki, J.M., Binder, S., Burgess, M.G., Cassidy, E., et al. (2018). An attainable global vision for conservation and human well-being. Front. Ecol. Environ. *16*, 563–570.

97. Rawe, T., Antonelli, M., Chatrchyan, A., Clayton, T., Fanzo, J., Gonsalves, J., Matthews, A., Nierenberg, D., and Zurek, M. (2019). Transforming Food Systems under Climate Change: Local to Global Policy as a Catalyst for Change (CGIAR Research Program on Climate Change, Agriculture and Food Security), CCAFS Working Paper no. 271. https://hdl.handle.net/10568/101601.

98. Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., and Clausen, T.J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. Water Policy *19*, 673–691.

99. Beck, M.W., Losada, I.J., Menéndez, P., Reguero, B.G., Díaz-Simal, P., and Fernández, F. (2018). The global flood protection savings provided by coral reefs. Nat. Commun. *9*, 2186.

100. Gallo-Cajiao, E., Archibald, C., Friedman, R., Steven, R., Fuller, R.A., Game, E.T., Morrison, T.H., and Ritchie, E.G. (2018). Crowdfunding biodiversity conservation: crowdfunding conservation. Conserv. Biol. *32*, 1426–1435.

101. Nyström, M., Jouffray, J.B., Norström, A.V., Crona, B., Søgaard Jørgensen, P., Carpenter, S.R., Bodin, Ö., Galaz, V., and Folke, C. (2019). Anatomy and resilience of the global production ecosystem. Nature *575*, 98–108.

102. Hulme, M. (2020). Is it too late (to stop dangerous climate change)? An editorial. WIREs Clim. Change *11*, e619.