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Title: Navigating climate crises in the Great Barrier Reef

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Navigating climate crises in the Great Barrier Reef

Abstract

A dramatic escalation of extreme climate events is challenging the capacity of environmental governance regimes to sustain and improve ecosystem outcomes. It has been argued that actors within adaptive governance regimes can help to steer environmental systems toward sustainability in times of crisis. Yet there is little empirical evidence of how acute climate crises are navigated by actors operating within adaptive governance regimes, and the factors that influence their responses. Here, we qualitatively assessed the actions key governance actors took in response to back-to-back mass coral bleaching – an extreme climate event – of the Great Barrier Reef in 2016 and 2017, and explored their perceptions of barriers and catalysts to these responses. This research was, in part, a product of collaboration and knowledge co-production with Great Barrier Reef governance actors aimed at improving responses to climate crises in the region. We found five major categories of activity that actors engaged with in the wake of recurrent mass coral bleaching: assessing the scale and extent of bleaching, sharing information, communicating bleaching to the public, building local resilience, and addressing global threats. These actions were both catalyzed and hindered by a range of factors that fall within different domains of adaptive capacity; such as assets, social organization, and agency. We discuss the implications of our findings as they relate to existing research on adaptive capacity and adaptive governance. We conclude by coalescing insights from our interviews and a participant engagement process to highlight four key ways in which the ability of governance actors, and the Great Barrier Reef governance regime more broadly, can be better prepared for, and more effectively respond to extreme climate events. Our research provides empirical insight into how crises are experienced by governance actors in a large-scale environmental system, potentially providing lessons for similar systems across the globe.

Keywords: environmental governance, adaptive capacity, climate change, coral bleaching, stakeholder engagement

Introduction

Ecosystems across the globe are facing rapidly changing social, political, and ecological pressures exacerbated by extreme climate events. Under such conditions, sustainably managing large-scale ecosystems; e.g. those that extend across multiple jurisdictions and include a diversity of stakeholders, often with conflicting interests; is increasingly challenging (Wyborn and Bixler 2013). Many argue that actors within adaptive governance regimes, which bring stakeholders together and emphasize learning, can help to steer environmental systems toward sustainability (Armitage et al. 2008, Bodin 2017), particularly in times of crisis (Folke et al. 2005). Yet most of the scholarly focus to date has been on the emergence and principles of adaptive governance (Chaffin et al. 2014), with scant empirical evidence of how acute climate crises are navigated by actors operating within existing adaptive governance regimes, and the factors that influence their responses.

An adaptive governance regime is defined as a system that brings diverse stakeholders together, incorporates multiple types of knowledge, devolves and decentralizes decision-making, and facilitates adaptive, ecosystem-based management that addresses problems at nested scales (i.e. through polycentricity) (Folke et al. 2005, Chaffin et al. 2014, Morrison et al. 2017). The Great Barrier Reef (GBR); a UNESCO World Heritage Site located off the north-eastern coast of the state of Queensland, Australia; has long been considered a prime example of a large-scale environmental system managed under a robust, adaptive governance regime (Olsson et al. 2008). Yet its' ability to sustain the reef and improve ecosystem outcomes is currently being challenged by a dramatic escalation of extreme climate events (Hughes et al. 2017b, Morrison 2017). In 2016 and 2017, the reef experienced unprecedented back-to-back mass coral bleaching triggered by rising global temperatures. In 2016 the bleaching event affected 91% of the GBR and killed an estimated 67% of shallow corals in a large region of the northern section where bleaching was most severe (Hughes et al. 2017b). In 2017 severe coral bleaching affected the central third of the GBR, compounding the 2016 damage and other environmental (e.g. severe tropical cyclones and crown-of-thorns starfish outbreaks) and human pressures (Authority 2019). These cumulative impacts have stimulated increased concern over the state of the reef and led to intense public and scientific debate about the threat that climate change poses to the GBR, as well as other World Heritage listed coral reefs. As of 2020, amidst the backdrop of yet another round of coral bleaching, the GBR's conservation status had declined from "significant concern" to "critical" according to the International Union for Conservation of Nature's (IUCN) World Heritage Outlook report (Osipova et al. 2020).

In this paper we provide an empirical, qualitative assessment of the actions key GBR governance actors took in response to mass coral bleaching on the GBR in 2016 and 2017, and explored their perceptions of barriers and catalysts to these responses. Governance is broader than government, and includes the structures and processes for creating knowledge, prioritizing issues, formulating policy, delegating responsibility, and making decisions about how to intervene (Morrison et al. 2020). Governance actors therefore include both state and non-state actors (i.e., organizations and stakeholder groups) involved in and/or influencing these processes, including industry and civil society organizations in addition to formal government agencies. Critically, governance actors are argued to play a key role in steering social-ecological systems toward sustainability through times of crisis (Folke et al. 2005, Olsson et al. 2008). Our research provides empirical insight into how crises are experienced by such governance actors. We additionally investigate the barriers and catalysts that arise as these actors respond to crisis, filling an important need for empirical evidence of the strengths and weaknesses in the adaptive capacity of actors within adaptive governance regimes (Armitage and Plummer 2010, Dressel et al. 2020). Importantly, this research is, in part, a product of collaboration and knowledge co-production (Lemos et al. 2018) with governance actors aimed at improving governance responses to extreme climate events in the GBR region (Schmidt et al. 2020), and potentially other regions around the world. We describe this collaboration in the Methods section following a discussion of the theoretical foundation for our overall research approach.

Theoretical foundation

Extreme climate events and other rapid change in social-ecological systems require quick and creative responses from governance actors (Folke et al. 2005, Plummer and Armitage 2010). In order to take such responses, it is now widely acknowledged that governance actors require governance institutions (e.g. laws, policies, social norms, decision-making processes) that allow for self-organization, learning, knowledge integration, and the ability to address problems at all relevant levels (e.g. local to national) (Dietz et al. 2003, Folke et al. 2005, Chaffin et al. 2014). These institutions are often collectively referred to as "adaptive governance" (Folke et al. 2005), and significant research has focused on how such arrangements emerge in a social-ecological system (Olsson et al. 2008, Chaffin and Gunderson 2016) and bolster the adaptive capacity of the overall system (Plummer and Armitage 2010). From this perspective, adaptive capacity – often referred to as the capability of a social-ecological system to be robust to disturbance and to adapt to actual or anticipated changes (Cinner et al. 2018) – has most often been assessed by examining the characteristics of institutions, policies, and specific governance arrangements that are argued to enable adaptive governance approaches (Pahl-Wostl 2009, Gupta et al. 2010, Brockhaus et al. 2012). These high-level efforts have been critical in furthering our understanding of the factors that facilitate the emergence of adaptive governance. However, there has been scant research regarding the capacity of governance actors themselves to effectively navigate crises within a system where these adaptive governance institutions have become established in formal management and policy arrangements. Yet understanding how governance actors respond to crises, and the barriers they face in doing so, is crucial for identifying areas where additional support may be needed to improve how governance regimes function in practice (Dressel et al. 2020), and can provide critical insight into the trajectory of the system as a whole. As the climate crisis unfolds, it is thus becoming increasingly critical that we gain a better understanding of the factors that enable (or constrain) how governance actors respond to crises.

From an actor-level perspective, adaptive capacity has been described as the suite of assets or resources (technical, financial, social, institutional, political) available to enable responses to change, and the social processes and structures through which they are employed and mediated (Plummer and Armitage 2010). Here, we follow recent work which organized the suite of resources, processes, and structures argued to be important for adaptive capacity into six broad domains; these include: (1) the *assets* that actors can draw upon, (2) the *flexibility* to change strategies, (3) the ability to organize and act collectively (i.e. *social organization*), (4) *learning* to recognize and respond to change, (5) the *socio-cognitive* constructs that enable or constrain human behavior (such as risk attitudes), and (6) the *agency* or power to determine whether to change or not (Cinner et al. 2018, Cinner and Barnes 2019). Though initially focused on the community-level (Cinner et al. 2018), this framework was developed through a review of research on adaptive capacity in the context of environmental change across multiple social science disciplines that spanned different scales and levels of analysis, with the aim of bringing together disparate conceptualizations of adaptive capacity. The framework is thus widely applicable. Indeed, many of the adaptive capacity domains in the framework incorporate concepts that are commonly regarded as important for adaptive capacity at the system-level. For example, Plummer and Armitage (2010) identify *capacity and capacity building*, *social capital and social networks,* and *learning* as critical components of adaptive capacity for environmental governance, which are related to the *assets, social organization, and learning* domains, respectively. Critically however, the framework goes a step further by incorporating aspects of adaptive capacity which have received less attention in the governance literature focused on adaptive capacity, yet can be important for determining how governance actors respond to change (Mortreux and Barnett 2017), such as how risk is perceived and managed [*socio-cognitive constructs;* (Truelove et al. 2015)], and whether actors have the power and freedom to mobilize their capacities and shape future trajectories [*agency*; (Avelino and Rotmans 2009, Brown and Westaway 2011)]. In recognition of its broad applicability, this framework has now been adapted to conceptualize and measure adaptive capacity and the related concept of resilience among individual actors (Barnes et al. 2020), governance arrangements (Rubio et al. 2021), as well as entire social-ecological systems [including community, governance, and ecological-levels (Mason et al. 2021)]. Here, we draw on this framework to enable a clearer interpretation of the catalysts and barriers governance actors face in navigating a critical climate crisis.

As one of the original (and rare) examples of adaptive governance (Olsson et al. 2008), the GBR governance regime is a useful case for exploring how the adaptive capacity of governance actors influences responses to climate crises (Flyvbjerg 2006). Spanning 348,000km2, the GBR is recognised as the largest living structure in the world by UNESCO. Today, the reef is valued at an estimated $56 billion as an Australian economic, social, and iconic asset (DAE 2017). 52% of this value is from tourism (DAE 2017), and the GBR also holds significant value to a range of other key stakeholders, such as fishers, scientists, and the general public – both locally and globally (Gurney et al. 2017, Marshall et al. 2018). The GBR governance regime is characterized by multi-actor, collaborative arrangements involving knowledge sharing, formal and informal partnerships, joint projects, and joint rules that have evolved since 1975 through public participation, cooperative state and national law, international oversight, and a variety of other collaborative relationships (Morrison

2017). In 1998, the GBR Marine Park Authority (GBRMPA) initiated a major rezoning process that enabled the adoption of an ecosystem-based management approach and earned the GBR scholarly recognition as a best-practice example of adaptive governance (Olsson et al. 2008, Day 2017). Although the GBR governance regime is now challenged by climate change and mass bleaching events (Hughes et al. 2017a, Morrison et al. 2017), it retains its role as global leader in reef management. The GBR case is therefore of theoretical and practical importance because it provides a unique opportunity to investigate the strengths and weaknesses of actors' adaptive capacity in a rare and iconic example of an established adaptive governance regime.

Methods

We conducted confidential, semi-structured interviews with 31 participants who were asked to represent their organization and/or group which, following the definition in the above section, can be classified as 'GBR governance actors'. The GBR is both a national and global icon which is governed through a multilevel structure that includes the UNESCO World Heritage Committee. Official regulatory authority of the GBR region falls under the Australian commonwealth (e.g. Australian Federal Government) and state jurisdiction (e.g. Queensland Government). Other influential actors playing a role in the GBR governance (through direct or indirect involvement or advocacy) range from local to global and include a large number of both state and non-state actors, including industry and civil society organizations. We bounded our study by focusing on governance actors' (i.e., organizations/groups) whose livelihoods, well-being, or professional objectives depended on the GBR. With the guidance of key informants who collectively had extensive experience working with different sectors and groups in the GBR region, interviews were stratified to ensure that key actors from the following groups were represented (see Table 1 for a list of acronyms): UNESCO (n = 1); Policy-makers (i.e., Ministers/Members of Parliament; n = 1); Federal and State Government Agencies (n = 8; e.g. GBRMPA; the then Department of Environment & Energy; Office of the GBR; Queensland Department of Agriculture & Fisheries); Local, National, and International NGOs (n = 8; e.g. GBR Foundation; WWF); Research Institutions (n = 5; e.g. Australian Institute for Marine Science; CSIRO); the Tourism Industry (n = 4; e.g. Queensland Tourism Industry Council; Association of Marine Park Tourism Operators); the Fishing & Aquaculture Industry (n = 3; e.g. Cairns Recreational Fishing Industry Stakeholders; Provision Reef); and Traditional Owner Representatives (n = 1). Note that only one policy-maker agreed to participate despite repeated requests for interviews to several relevant Ministers and Members of Parliament. Similarly, though we reached out to several traditional owner representatives, only one participated. All other actor categories were well-represented.

Table 1. List of acronyms.

Acronym	Definition
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
IUCN	International Union for Conservation of Nature
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WWF	World Wildlife Fund
NGO	Non-governmental organization
CSIRO	Commonwealth Scientific and Industrial Research Organization
COTS	Crown-of-thorns starfish
AIMS	Australian Institute for Marine Science
RRRC	Reef and Rainforest Research Center
GBRF	Great Barrier Reef Foundation
AMCS	Australian Marine Conservation Society

Interviews were conducted in March and April of 2019 either in person or via telephone. The first half of our interviews were conducted jointly by the first and second author to establish consistency in the interview process. The remaining were conducted by either the first or second author following the same format and approach. Interviews lasted 45 minutes to one hour and covered the following topic areas in relation to the 2016 and 2017 bleaching events: 1) impacts of coral bleaching events on participants' professional work, 2) how participants and/or their organization/stakeholder group responded to coral bleaching, 3) enabling conditions and barriers for their responses to coral bleaching, and 4) any responses participants expected of other actors. All interviews were transcribed verbatim using a transcription service (rev.com). The first and second author jointly developed the coding framework, and the second author coded all interviews using QSR International's NVIVO 12 qualitative data analysis software. Interviews were coded inductively to generate key themes within each of the four topic areas included in our interviews (listed above). Five broad categories of 'responses' to bleaching were uncovered through this analysis, which we discuss in the following section. Note that although our focal scale of analysis is the organization/group level, occasionally interviewees mentioned individual actions they had taken in response to bleaching that extended beyond their formal capacity within their organization or group. We included these activities where they were relevant to understanding key actions taken in the region. Key themes within the 'enabling conditions and barriers' topic area were coded deductively according to the six domains of adaptive capacity described in the above section [assets, flexibility, social organization, learning, socio-cognitive constructs, and agency (Cinner and Barnes (2019)]. Though our primary focus here is on responses to bleaching and their enabling conditions and barriers, we draw on data from topic area #1 in our interviews ('impacts') to first briefly summarize the various impacts the bleaching events had on different actor groups in the region.

Once we completed the analysis described above, we engaged directly with a core set of key stakeholders from diverse backgrounds who were also research participants to (1) improve the practical relevance of our research, and (2) stimulate processes of social learning to develop a better understanding of how actors in the GBR region might collectively address future crises in a way that accounts for diverse perspectives and interests (Schmidt et al. 2020). This part of the research involved iterative conversations regarding our results with six representatives from the tourism industry, research institutions, the NGO sector, and GBRMPA (the federal management agency responsible for management of the GBR). Each of these participants contributed feedback on our results; helped to interpret our results in the context of their unique knowledge base; and contributed insight and recommendations for how to overcome the barriers identified in our research. One of the final sections of our manuscript, 'Looking to the future', draws on the key themes derived from the fourth topic area included in our interviews ('responses expected of others') and was co-produced with this core set of key stakeholders through this engagement process. As a result, these six individuals were invited to be co-authors on this manuscript, and three accepted (X.X, X.X., X.X). This manuscript is thus in part a product of collaboration and knowledge co-production with practitioners aimed at improving governance responses to extreme climate events in the GBR region, and potentially other similar regions around the world (Lemos et al. 2018, Schmidt et al. 2020, Bojovic et al. 2021).

Impacts of bleaching on the Great Barrier Reef

Participants across sectors reported significant but varied impacts of bleaching. Most participants noted that the extent of the bleaching event took many by surprise, and that it was found to be quite confronting. Many expressed a combination of fear, helplessness, sorrow, and even depression regarding the impacts to the reefs they manage, depend on for their livelihoods, or associate with their group's identity.

Multiple dive tour operators noted that the effects of the bleaching event were patchy, i.e. some locations were affected, while others were not. Still, they expressed that bleaching, and particularly the coverage of it in the news media, caused a severe drop in visitation, though changes in demand varied across markets in different parts of the world. Fishing industry professionals (including aquarium collectors) reported little impact from bleaching on their trade, but did mention concerns about the possible long-term effects of bleaching and rising temperatures on fish habitat and behavior.

In the nonprofit and government communities, bleaching led to a mix of questioning and reinforcing motivation for various conservation and management activities. For the research community, the bleaching events reinforced the findings of some, and generated a shared recognition that climate change impacts were happening here and now. Similar to those working in government and nonprofits, bleaching brought researchers grief, but also a resolve to press forward with finding solutions.

Responses to bleaching on the Great Barrier Reef

We found five major categories of activity that actors engaged with in the wake of recurrent mass coral bleaching: (1) assessing the scale and extent of bleaching ('assessing bleaching'), (2) sharing information, (3) communicating bleaching to the public (public communication), (4) building local resilience, and (5) addressing global threats, which we describe in turn.

Assessing bleaching

Assessing the extent and scale of bleaching was one of the most immediate responses to the bleaching events. Researchers from around Australia, and internationally, created a "Coral Bleaching Task Force" in the lead up to the 2016 event in order to coordinate the collection and analysis of data, not only within Australia, but around the world. At the onset of the bleaching event on the GBR, these researchers conducted aerial surveys supplemented by in-water surveys of the reef. GBRMPA and the Australian Institute of Marine Science (AIMS, the Federal Government's tropical marine research agency) coordinated in-water surveys using existing, and some new, long term transect lines on the reef. Dive operators and concerned citizens conducted site-specific surveys of bleaching as well. Many of these efforts were coordinated by organizations like the Reef and Rainforest Research Center (RRRC), Citizens of the GBR, and GBRMPA through its Eye on the Reef program. Some large dive companies also conducted their own assessments of their more popular dive sites.

Sharing information

In addition to collecting data and information, actors needed improved means for sharing data and information in the wake of the bleaching events. Several participants mentioned the formation of new partnerships or collaborations across organizations and sectors for this purpose. For example, GBRMPA established an "Incident Management Group" that enabled partners to share information and collaborate on bleaching assessment actions, and in 2017 convened a Reef Summit involving more than 70 experts from around the world in response to the events. GBRMPA also used its networks and website to provide information on bleaching. Meanwhile, the Coral Bleaching Task Force provided a venue for academics to share study design protocols and data. New collaborations focused on information sharing also began occurring at smaller scales. For example, AIMS began coordinating with tour operators to generate fine scale data on the extent of bleaching.

Public communication

Responses to coral bleaching were not only focused on information and actions on the ground, but also on how to communicate the bleaching events to the public. Nineteen participants described communications as a major part of their response to coral bleaching events; this included individuals from the government, NGO, research, and tourism sectors, as well as a Traditional Owner representative. Researchers and NGOs put out press releases and social media posts (e.g. Twitter, Facebook), often detailing the extent of bleaching damage. The World Wildlife Fund (WWF) helped to break the news of the bleaching event internationally. Traditional Owners spoke at events about the impacts of climate change on their sea country. GBRMPA used its existing web platform to share information about the events, and shifted the topic of its educational Reef Guardians program to climate change. GBRMPA also hosted information sharing events requested by Traditional Owners. The tourism industry struggled to get the attention of the press, particularly internationally, but posted videos and other bleaching information on their websites in order to communicate that not all of the reef was affected by the bleaching events.

Building local resilience

Local management responses by government and NGOs were described by participants in terms of 'building resilience', and included activities at a range of scales. Participants from GBRMPA discussed how the Great Barrier Reef Blueprint for Resilience (hereafter, 'Reef Blueprint') the primary outcome of the Reef Summit, identified building local resilience as one of the key priorities for future management of the GBR (GBRMPA 2017). The blueprint detailed four on-the-ground actions to support this, including enhancing compliance, ramping up COTS control, protecting key species for reef recovery, and active localized restoration. The scaling up of COTS removal was specifically mentioned as a priority by participants in government and at the GBR Foundation (GBRF) – a registered Environmental Organization which in 2018 received a controversial Australian Government grant of AUD $443 million for projects on the GBR. Others in the Queensland government and at NGOs like Terrain Natural Resource Management discussed a renewed focus on reducing agricultural runoff from watersheds across the GBR region, e.g., through policies and outreach regarding best management practices.

Participants from the Office of the GBR (an office of the Queensland government), AIMS, and the GBRF also mentioned supporting experiments with novel restoration approaches and new technical innovations for protecting the reef from bleaching events; such as transplanting or breeding corals that withstood the stress of bleaching events, dispersing coral spawn, and even experimenting with technologies to shade or cool the reefs during periods of extreme heat (e.g., cloud brightening, fogging, and surface films). In 2018, the Australian Federal Government allocated AUD $6millon for the development of the Reef Restoration and Adaptation Program, a partnership between scientists and government tasked with creating and trialing a suite of these types of interventions to help the GBR resist, adapt to, and recover from climate change impacts. The Queensland government hosted a competition for novel restoration approaches, promising to fund the winner, while Queensland Parks and Wildlife provided logistical support for coral larvae dispersal experimentation. AIMS and GBRMPA also conducted feasibility analyses for large-scale implementation of new restoration techniques. These activities were described as a major paradigm shift towards an interventionist approach and away from the more preservationist, "hands off" approach to reef management popular in the past. Participants from GBRMPA and the GBRF noted that the creation of the Reef Blueprint represented a fundamental pivot towards this more interventionist approach, and a move away from simply documenting bleaching extent and subsequent coral mortality.

Addressing global threats

It was well-recognized amongst GBR governance actors that a reduction in greenhouse gas emissions – the root cause of coral bleaching – is urgently needed to halt degradation of the reef. Yet major policy change to combat global warming has not occurred within Australia, despite repeated exposure to mass coral bleaching events and other significant climate crises, such as wildfires (Yu et al. 2020); echoing similar trends around the world (Nohrstedt et al. 2021). In response to back-to-back bleaching on the GBR, a few individuals and organizations pivoted their efforts in an attempt to address this policy gap and push for climate action. For example, the Australian Marine Conservation Society (AMCS) began supporting campaigns (such as 'Stop Adani') to advocate against coal export, and especially against mining in the GBR watershed. In 2019, two years following the coral bleaching events, GBRMPA published a position statement identifying climate change as the greatest threat to the GBR, which called for a swift reduction in greenhouse gas emissions. Some organizations' activities in response to coral bleaching on the GBR also influenced changes in their activities at a global scale. For example, as WWF Australia shifted to having a stronger focus on emissions, WWF International was inspired to pivot towards a greater global-scale focus on coral reef ecosystems. Similarly, a participant from UNESCO indicated that their experiences with actors and bleaching events in the GBR region inspired a deeper look at how climate change is affecting reefs and other ecosystems within World Heritage areas.

Some participants also mentioned changes in their personal professional choices. For example, a few researchers previously focused on the biophysical aspects of climate change became inspired to focus on communicating their findings to the public, while others became engaged directly in policy advocacy. Advocacy activities included increasing climate science messaging on social media platforms, speaking in Parliament House, and engaging in climate-related lawsuits. One university researcher also mentioned novel collaborations with insurance companies to explore the option of insuring reefs to buffer against climate change impacts, which would allow payments to be disbursed to restore reefs in the wake of bleaching or storm events.

Catalysts and barriers to bleaching responses

Actions that governance actors took in response to the coral bleaching events in 2016 and 2017 on the GBR were both catalyzed and hindered by a range of factors that fall within different domains of adaptive capacity (Fig 1). Notably, some domains of adaptive capacity, such as agency and social organization, were described as both a catalyst and a barrier to responses by different actors. Moreover, participants often emphasized important interrelationships between adaptive capacity domains (Cinner et al. 2018), e.g. some described assets as a catalyst underpinning their response, but noted that having flexibility in the allocation of these assets was critical. We discuss these relationships and interactions in further detail organized by domain below.

Assets

The ability to access financial, technical, and service-related resources (Yohe and Tol 2002) was a frequently mentioned factor affecting actors' capacity to respond (or not) to the bleaching events. In particular, access to funding, information, and infrastructure for information sharing and in-water reef surveys affected actors' ability to share information with the public, conduct surveys ('assessing bleaching'), make changes to existing management/business practices, and/or implement new interventions to build reef resilience (e.g. water quality improvements). For example, some university research labs (e.g. James Cook University) had immediate access to funds that allowed them to conduct aerial and in-water surveys in real-time during the events. Some government entities, such as GBRMPA and AIMS, were able to reallocate some funds for in-water surveys. GBRMPA was also able to draw on existing staff and website infrastructure to support communications about the bleaching events. Other government organizations, such as the Queensland Government Office of the GBR, built upon existing funding and staff capacity to boost reef resilience through improving water quality. In more specific localities, tourism companies with diverse operations and range of permits found that they were able to adjust to visit less bleached sites as necessary. These were primarily larger businesses (e.g. Quicksilver, Inc.), who also possessed trained staff and materials necessary to conduct their own site-specific surveys.

A lack of assets prevented some organizations and actor groups from responding to the events in the way they hoped to. For example, insufficient funds prevented some government institutions from performing surveys as extensively as they might have otherwise. Participants from government research and management institutions also mentioned chronic funding problems that affected their responses, such as a lack of sustained funding for long term monitoring, and the absence of a flexible contingency fund for post-bleaching surveys and other unexpected needs. Traditional Owner groups were interested in contributing to surveys and building reef resilience in the wake of bleaching, but were unable to access the reef in their traditional territories because they did not possess the boats, training, and other resources necessary.

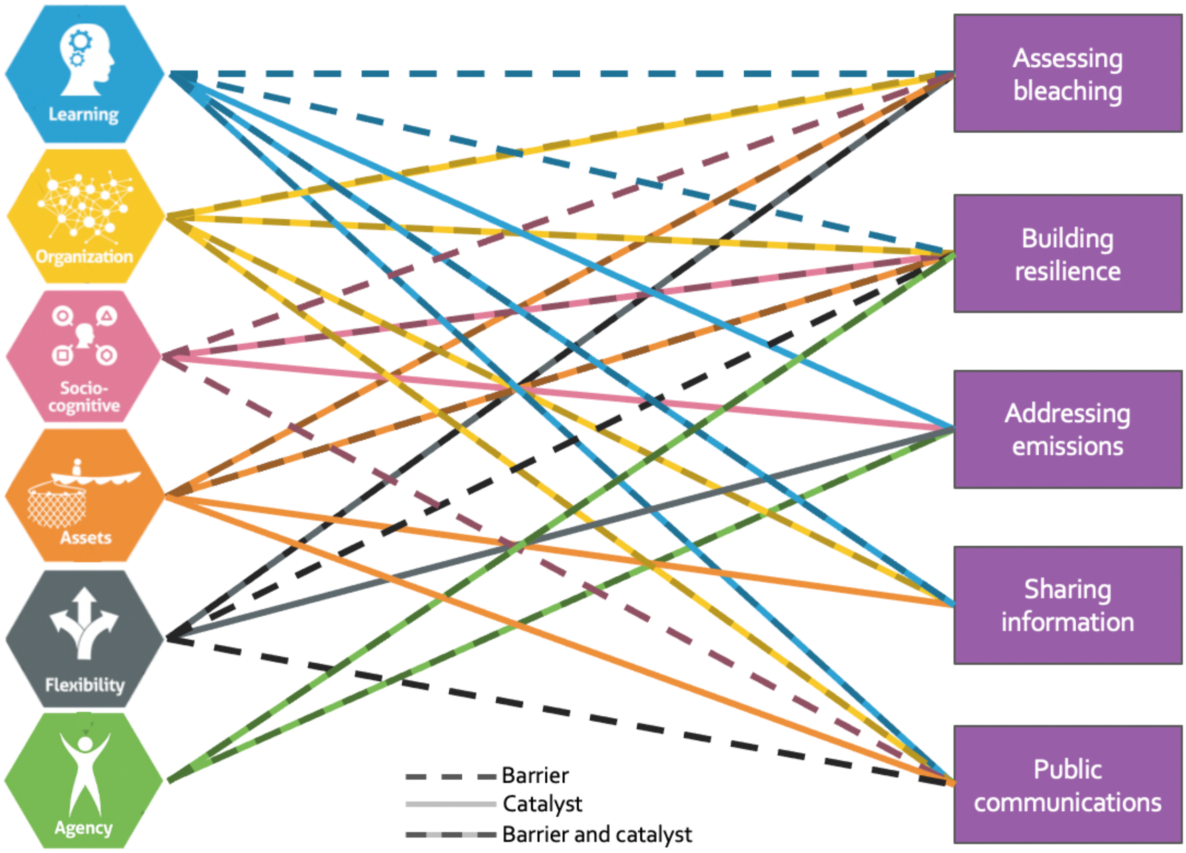

Fig. 1. The five types of activities governance actors undertook in response to bleaching (right column) were underpinned by different domains of adaptive capacity (left column). Solid lines represent catalysing influences of a domain on an activity; dashed lines indicate barriers of a given domain (i.e. those that hindered an activity). In many cases, domains were discussed as both a catalyst and a barrier (represented by solid lines overlaid by darker dashed lines). Lines match the colour of their respective domain. Domains and activities appear in ascending order by the number of linkages they have across columns (aspects of learning were discussed as catalysts and/or barriers in relation to all five different response activities; as such, learning appears at the top of the left column). Adaptive capacity domains (left) adapted from Cinner and Barnes (2019) and Cinner et al. (2018).

Flexibility

Flexibility, or the ability to quickly switch to new strategies and activities (Mortreux and Barnett 2017), was critical for both short term and long-term responses to bleaching. We found that the flexibility of organizations was closely interconnected with other dimensions of adaptive capacity, such as assets and social organization. For example, university institutions were able to conduct timely surveys during the peak of the bleaching events not only because they had sufficient funding, but because they had the administrative flexibility necessary to immediately access it. Existing relationships within the research sector also played a big part in coordinating surveys through the Coral Bleaching Task Force. One researcher described this flexibility:

> It was an informal network designed to be nimble, to be mobile and to do research. So it wasn't bureaucratic in any way. There was no bureaucracy. (Participant 2)

In contrast, government organizations like AIMS had funding, but faced challenges in redirecting it away from previously approved uses towards responses like large scale surveys directly preceding the events. Over a longer time scale, the GBRF, another organization responsible for using public funds, also found that close scrutiny on the allocation of the money awarded to them following the events made it difficult to change how it was used. Bureaucratic processes also slowed public messaging and permitting for experimentation with new approaches to build local resilience.

The flexibility of both government bodies (e.g. CSIRO, AIMS) and NGOs (e.g. WWF Australia, AMCS) was also frequently limited by obligations to focus on existing programs and contracts before shifting to efforts to respond to bleaching events. In the longer term, NGOs like WWF and AMCS eventually had the flexibility to move towards a greater focus on addressing emissions issues related to the Australian coal export industry.

Social organization

The role of social relationships between individuals and between organizations, in addition to social organization more broadly (Adger 2003), was frequently mentioned as either a barrier or a catalyst for actors' responses. For example, a researcher involved with the Coral Bleaching Task Force emphasized the importance of individual (rather than institutional) relationships in forming this group at several points in the interview and suggested that this enabled a quicker response than what they observed in government institutions. Similarly, one participant from the Queensland Government found that having pre-existing relationships with colleagues in the government and research sector sped up their response and also enabled them to receive the information they needed in a timely fashion. This participant stated:

> I think one thing about the GBR, it's an area of…long and established partnerships. So, I think we can take advantage of that, that we're able to really leverage off that work and I think that's why we've been able to step up so rapidly, particularly for government. Government, well we move slowly. And we really have moved really quite quickly in this and I think that's the strength of those partnerships. (Participant 22)

Participants in the NGO sector also expressed that they tended to have diverse partnerships that enabled their response. One participant from the GBRF noted that as a NGO, the organization has an "innovative ability to leverage benefits across [sectors]" (Participant 8). This participant went on to express that although controversial, GBRF's partnerships with corporations and a myriad of researchers enables it to innovate and experiment with new ideas for building reef resilience.

Not all participants felt that their ability to respond was catalyzed by existing networks, and the overwhelming majority of participants emphasized that a lack of coordination and leadership more broadly acted as a significant barrier to responses. For example, participants described incompatible survey data formats between institutions, slow information sharing, and disagreements over the utility of citizen science survey data. In several cases, participants from the private sector and NGOs voiced a need for increased leadership to coordinate these activities. One NGO participant declared:

> If I could summarize in one sentence, it would be there was an absolute lack of leadership to respond. Lack of leadership at a political level. Lack of leadership at a bureaucratic level. And to be honest, a little bit of a lack of leadership at the scientific level. (Participant 10)

Participants also noted that an initial lack of leadership also left the tourism industry and individual researchers to individually spearhead communication about the events. This ultimately led to conflicting messages, exacerbating cross-sector conflict between tour operators and scientists over public communications about climate change. One government professional with experience working with communities in the region described conflicts between tour operators, the RRRC, AIMS, and GBRMPA as a "maelstrom of conflicting views that were going on at every level."

Some participants also suggested cross-sector tensions and interpersonal conflicts, in addition to inter-organizational coordination issues, impacted responses to bleaching across the region. For example, the bleaching events appeared to exacerbate cross-sector tensions between government and agricultural interests over efforts to build resilience by improving water quality. Several participants also mentioned that conflicts at the personal level fed into cross-sector tensions, and tensions amongst sectors engaged in the same activities, such as reef surveys.

Learning

Learning reflects the capacity to recognize change, attribute this change to causal factors, and assess potential response strategies (Lebel et al. 2010, Cinner et al. 2018). Governance actors' ability to draw on aspects of learning in their response was impacted by their past experiences and access (or not) to relevant data, information, and human capital assets. Although a few actors had experienced bleaching events in the past, a majority of participants noted that the 2016 and 2017 bleaching events were unprecedented in terms of scale and severity. However, a few actors were able to learn from past experiences with relevant conservation actions (rather than with bleaching itself) in their response. For example, AMCS was able to pivot to addressing global threats, specifically climate change, within a few years of the bleaching events. This was because key staff possessed past experience and knowledge on how to advocate for climate change solutions.

Several reef managers and decision-makers raised the issue of information availability and legitimacy. The extensive surveys of bleaching events at both the regional level and in specific localities (e.g. dive sites) provided a wealth of information that actors' could learn from in order to coordinate their response. However, differing methods for assessing bleaching led to challenges with collating bleaching assessments and rapidly distributing this data. This presented a barrier to decision-makers and others seeking to learn about the impacts of the event. For example, one decision-maker responsible for fisheries voiced a need for more readily available and finer scale data that could inform decisions about which specific areas to close to the harvest of species like beche-de-mer. In addition, researchers, government professionals, NGO professionals, and tour operators expressed differing opinions on what sources of knowledge regarding the extent of bleaching were considered legitimate. For example, tour operators and some NGOs tended to support the use of citizen science and surveys conducted by dive operators, whereas other NGOs and most researchers considered these sources of data less relevant to decision-making, while government professionals expressed a range of views.

Agency

Aspects of agency, described here as the power to influence change or make free choices regarding whether to change or not (Avelino and Rotmans 2009, Brown and Westaway 2011), were frequently mentioned as barriers to bleaching responses in our interviews. Many of our participants expressed feelings of helplessness or disempowerment given the scale of bleaching and a sense that its causes were global, inevitable, and beyond the control of any one individual, organization, or nation. For example, several professionals working in government and NGOs questioned the potential for their strategies and projects to have positive outcomes for the reef given the overwhelming impacts of bleaching, leading to a sense of disempowerment and uncertainty regarding how to respond. Most other participants similarly felt little sense of agency to undertake activities to address global threats. Moreover, any gains in addressing climate change were perceived as intangible, in that the benefits will not be experienced in the short term.

A number of participants suggested that organizations had the greatest agency when they undertook activities to build reef resilience, as this fit firmly within their respective jurisdictions:

> I've got no control over the climate change policy for Australia. It's not in my jurisdiction…it's not in my department's jurisdiction. So in the absence of being able to do anything there, you've got to be able to work within your remit and the outlets and tools that you have at your disposal to try and do something. So that's what you're seeing playing out. (Participant 15)

Participants in the NGO, government, and tourism sector frequently voiced that activities to build local resilience by addressing systemic issues (e.g. water quality and COTS outbreaks) or experimenting with new technology (e.g. coral breeding or reef shading) were most tangible and relevant to the work of organizations and government agencies across the region – rather than a focus on global threats. Traditional owner groups however felt little sense of agency to undertake even locally based projects to build resilience, in part because of their lack of assets such as boats.

Many participants also shared dissatisfaction and a general sense of disempowerment regarding initial public messaging about the bleaching events. Individuals in the tourism sector felt that their message about the events was either unheard, or not heard loudly enough. For example, one participant from the tourism sector expressed frustration that the initial news coverage of the events incorrectly indicated that the entire GBR was dead while excluding other perspectives. This participant explained:

> We had all these [videos of the reef] but the only place we could use that was in social media. The main media wouldn't run it. They're not interested in the good story…the media will always try and balance it…but the one that gives the negative message is the one that'll get the main bloody thrust of the story. (Participant 19)

There were some cases where participants were able to exert agency in order to respond to the bleaching events in unique ways. For example, one of the researchers we interviewed stepped out of the traditional box of 'research' and found purpose in political activities to address global causes of climate change.

Socio-cognitive factors

Actors' perceptions of impacts and risk are a key dimension of the socio-cognitive domain of adaptive capacity (Mortreux and Barnett 2017, Cinner and Barnes 2019). Governance actors expressed a range of different views on the severity of the coral bleaching events and what risk the events pose to the future of the reef, which underpinned their responses. For example, researchers tended to emphasize that bleaching was severe and widespread, while representatives from the tourism industry pointed out that bleaching was patchy, with some sites only slightly affected. This disagreement around how the events were framed ultimately posed a barrier to clear public communications.

Varying perceptions of impacts and risk also led to differences of opinion across sectors regarding what management and policy actions were most important to focus on in the wake of the events, further exacerbating conflicts over messaging that were already playing out across the region. Specifically, government decision-makers, NGO professionals, and university researchers expressed conflicting opinions regarding how to balance management funds and activities between efforts to (1) build local resilience (e.g. breeding high heat tolerance corals), (2) address system-wide issues (e.g. water quality), and (3) address global causes (e.g. lobby for emissions reduction). Participants in research or NGO positions argued that back-to-back mass coral bleaching events challenged the idea that building the resilience of reefs at the local scale could help to reduce the impacts of climate change. NGO and government participants frequently mentioned that the bleaching events indicated the need for a myriad of responses across the spectrum of local, short-term actions (e.g. COTS removal) to more globally oriented long-term actions (e.g. emissions reduction). Yet even where there was agreement on this type of broader approach, participants diverged from one another on how much attention and resources should be dedicated to activities at different ends of the spectrum. These differences appeared to arise not only from perceptions of risk, but also from varying perceptions of the scope of the capabilities and responsibilities of participants' organizations (which relates to agency, discussed above), as well as different perceptions about the types of actions that organizations receiving funding for reef management should or should not be responsible for. One NGO participant argued that mixed messages regarding bleaching severity and what responses should be prioritized resulted in confusion amongst politicians responsible for funding GBR management at the federal level, ultimately leading to less funding for the reef overall.

There were several areas where participants felt that public perceptions and public support had important impacts on responses to bleaching. Participants cited public climate change skepticism, hopelessness, a perception of the reef as 'too big to fail,' and a hesitance to embrace interventionist approaches to building reef resilience as barriers to effective bleaching responses. Several participants in government and NGOs argued that citizens in the GBR region are accustomed to the norm of a "hands-off" approach to reef management, and expressed an interest in convincing the public about the need for more direct interventions. For instance, one participant noted, "they're putting a nano layer of something on top of the water that will actually reflect some of the sunlight…but we need to get the community on our side" (Participant 27). Socio-cognitive factors in this case were closely related to the flexibility and learning of organizations seeking to trial novel management approaches.

Discussion

When faced with back-to-back mass coral bleaching caused by extreme global temperatures in 2016 and 2017, state and non-state actors involved in and/or influencing governance processes in the GBR overcame uncertainty and hopelessness in order to document the unfolding crisis, reinforce previous efforts to build resilience, design new interventions, and focused on communicating these efforts amongst themselves and with the public. A few actors pivoted their efforts to addressing the root causes of climate change. Others struggled with fundamental questions regarding their professional capabilities and responsibilities in light of a global threat seen as largely beyond their control.

We explored barriers and catalysts to these actions in reference to domains of adaptive capacity (Cinner et al. 2018, Cinner and Barnes 2019). We found that unequal underlying capacities among actors within specific domains led to responses being facilitated for some, yet impeded for others – this was particularly true when it came to *assets* and *social organization*. Though adaptive governance approaches emphasize capacity building, power sharing, and collaboration; these findings raise important questions regarding how these principles play out in practice in crisis situations, and who benefits (and who loses) in the process (Cleaver and Whaley 2018). Future research that interrogates how adaptive governance can be adjusted in practice to ensure that all relevant actors; including industry, civil society, and traditional owners/indigenous peoples; have the capacity to flexibly navigate change when needed will be critical as the climate crisis unfolds (Schlosberg 2012, Karpouzoglou et al. 2016).

We also found that interrelationships between adaptive capacity domains (e.g., between *assets* and *flexibility*) had a critical impact on how adaptive capacity was translated into action (or not). Though important interrelationships in adaptive capacity domains have previously been theorized (Cinner et al. 2018), to our knowledge this study represents the first to illustrate them empirically. Our research focused on the organization/group level (with a specific focus on those whose livelihoods, wellbeing, and professional objectives depended on the GBR) and the ability of these governance actors to navigate a climate crisis. Yet adaptive capacity is critical across all levels of governance (Armitage and Plummer 2010, Dressel et al. 2020). Thus, future research that rigorously builds a more nuanced understanding of how different domains of adaptive capacity interact not only within levels (i.e., governance-actor level), but also across levels will likely be increasingly critical for navigating the novel and complex challenge of climate change not only within the GBR, but in other systems as well (Dressel et al. 2020).

A major barrier to climate crisis responses in our case was conflicting views among governance actors on pathways forward to ensure a sustainable future for the reef (*socio-cognitive* domain). Most actors agreed that a suite of actions aimed at both mitigation and adaptation are required to address the critical crisis of coral bleaching caused by climate change, but how funds and effort should be balanced between them was a key area of divergence between actors. Other major barriers included challenges associated with collaboration (*social organization* domain), and difficulty dealing with uncertainty and feelings of disempowerment associated with the scale of the problem (*socio-cognitive* and *agency* domains). These latter results largely echo similar findings in an analysis of barriers to climate change adaptation in coastal British Columbia, where several principles of adaptive governance are also in place (Whitney and Ban 2019); which suggests that aspects of social organization, socio-cognitive constructs, and agency may be more broadly relevant for determining how governance actors respond to change in other contexts as well. Taken together, our findings emphasize the utility of the adaptive capacity framework adopted here (Cinner et al. 2018, Cinner and Barnes 2019), which enabled a sharper picture of how these less studied factors may work to enable and constrain the actions governance actors can take as they navigate unprecedented change.

Looking to the future

Participants across sectors suggested several ideas for improving the ability of governance actors and the GBR governance regime more broadly to be prepared for, and respond to climate crises such as coral bleaching. Here we highlight four key ideas put forth in interviews and further elaborated through our participant engagement process, with the aim of inspiring future practical endeavours to improve the management and governance of the GBR, and perhaps other regional social-ecological systems. Our participants emphasized that, while challenging, fostering hope amongst coral reef professionals is critical in the wake of coral bleaching events and other climate crises. We aim to inspire such hope by offering these tangible ways forward through the uncertainty wrought by climate change.

Venues for sharing information, coordinating actions, and building empathy

Despite the high level of collaborative processes embedded in current governance of the GBR, there was a strong desire among diverse GBR governance actors for greater coordination and collaboration in both preparing for, and responding to coral bleaching. This ranged from calls for a) improved planning for collaborative data collection and dissemination; b) coordinating networks for public communication; and c) providing targeted opportunities for stakeholders to interact directly (as opposed to via media or social media) to rebuild social relations, inspire empathy regarding one another's needs, and provide opportunities to locate untapped capacity for reef management through collaboration or sharing of resources. The importance of bringing networks of diverse actors together to draw on social memory (i.e. the accumulation of a diversity of experiences, in this case concerning the reef and its management), enhance learning and information flow, and create new interactions in order to navigate social-ecological crises has long been emphasized (Folke et al. 2005, Bodin 2017) and is a central argument in the inclusion of social organization as a key domain of adaptive capacity (Adger 2003, Cinner et al. 2018, Cinner and Barnes 2019). Yet the collaborative activities necessary to effectively respond to crises often include a diversity of actors and need to navigate a collision of different worldviews, interests, values systems, power asymmetries, and discrepancies in conceptualizations; which can sometimes lead to or exacerbate significant conflicts (Morrison et al. 2019, Bodin et al. 2020). Leadership from trusted organizations or professional facilitation can play a key role in navigating this collision to catalyze opinion shifts, establish consensus, or at the very least, identify opportunities for compromise (Folke et al. 2005, Ernst 2019). In our case, participants from NGOs and the private sector were often specific in nominating GBRMPA as the organization they felt best suited to lead coordination of bleaching responses. Among a broader range of interviewees particular emphasis was also placed on the role of GBRMPA in coordinating public communications, suggesting that the organization remains widely trusted and is viewed as a natural leader in this space.

Leading up to, and following the bleaching events GBRMPA coordinated several collaborative planning meetings, such as the Reef Summit in 2017. In the four years since, GBRMPA has invested in a platform to facilitate information and data sharing as a part of the Reef 2050 Plan; and in partnership with Tourism Events Queensland, GBRMPA has formed a task force to coordinate public messaging. Our research indicates that coordinated public messaging will need to strike a balance between capturing the severity of the challenges facing the GBR, while emphasizing the value of continuing efforts to navigate change. This is particularly important for NGOs and governments, who depend on the support of donors and/or politicians responsible for allocating funds. It is also important for tour operators seeking to inspire continued visits to the reef by tourists. We suggest that professionally facilitated meetings aimed at building trust and empathy, sharing knowledge and resources, and ultimately guiding future responses to climate and other crises could add value to these current efforts (Turner et al. 2016). Creating space for reef professionals to share experiences, hardships, and hopes can also help to alleviate the grief that follows crisis events (Marshall et al. 2019), such as mass coral bleaching and the more recent COVID-19 crisis that is having a severe impact on the GBR tourism industry.

Contingency funds

Results from our interviews coupled with further iterative discussions with stakeholders illustrated that having assets, particularly funds, does not necessarily improve responses unless processes are in place to facilitate the flexibility to redirect them as necessary – emphasizing key interactions between adaptive capacity domains that play a critical role in how capacity is translated into action. To address this, some actors recommended creating a pool of contingency funds that could be spent on emergency situations like bleaching as they arose. Contingency funds form a critical component of risk management and disaster response strategies (de Guzman and Unit 2003), and have been identified as a form of social protection that can contribute to the adaptive capacity of vulnerable populations (Ulrichs et al. 2019, Tenzing 2020). Governance responses to extreme weather events can similarly be improved with pools of contingency funds by providing governance actors with the assets and flexibility to navigate these events (Hjerpe and Storbjörk 2016). In the case of the GBR, contingency funds set aside could be used to repair sites after cyclones or conduct surveys after bleaching or major flooding events. While bureaucratic processes facilitate the transparency and accountability needed to secure public legitimacy in democratic systems, especially in the use of public funds, finding ways to improve the flexibility of these processes will be critical moving into the future given the expected increases in frequency and intensity of extreme climate events (Cosens 2013).

Adapting policies and perceptions to pave the way for intervention

The need to create or adapt policies as well as change public perceptions to accommodate a more interventionist approach to reef management was often expressed throughout our research process, particularly among actors in government. To date, reef governance in the GBR and around the globe has primarily focused on local management efforts to reduce proximate stressors (such as overfishing and pollution), and on local restoration projects. Given the escalating scale of impacts caused by climate change, it has become clear that this approach is no longer tenable, and that some type of direct (as well as indirect) intervention is necessary to sustain reefs into the future (Morrison et al. 2020). As we discussed in the 'Building local resilience' section, the Reef Blueprint outlined key interventions that need to be undertaken to support the resilience and adaptation of the GBR to the mounting pressures associated with climate change, including novel COTS control options and active restoration (GBRMPA 2017). GBR governance actors have also begun to experiment with, and advocate for a range of other interventions, including enhanced marine bioengineering (e.g. coral seeding) and even geoengineering (e.g. cooling and shading reefs) (Morrison et al. 2020). Yet immediately following the coral bleaching events, the regulatory environment – which was initially designed in a very different context – was largely inadequate for dealing with the novel risks and impacts associated with many of these unconventional interventions and the research needed to test them (McDonald et al. 2019, Taylor et al. 2019). Targeted policies to effectively govern and permit such interventions were urgently needed, and have only just started to emerge (GBRMPA 2020). Efforts are also needed to manage public perceptions regarding a more interventionist approach, which remains highly controversial amongst reef stakeholders (including many of our interview participants); though recent research suggests that the public appears to be more accepting of the idea (Taylor et al. 2019).

Expanding traditional owner engagement and capacity

Aboriginal and Torres Strait Islander people are the Traditional Owners of the GBR region and have an overwhelming desire to participate in, and influence GBR governance and research (Dale et al. 2016, Dale et al. 2018, Lyons et al. 2020). Many of the organizations represented in our research have active partnerships and programs to support Traditional Owner engagement (Evans-Illidge et al. 2020) and management of the reef (e.g. Traditional Use of Marine Resources Agreements). Notwithstanding, results from our work coupled with existing research (Dale et al. 2018) suggest that expanding these activities and ensuring Traditional Owners have the training, tools, and infrastructure (e.g. boats) to allow them to meaningfully engage in reef governance could play a significant role in improving responses to coral bleaching and other climate crises in the GBR region. Traditional Owners across Australia have valuable context specific knowledge and resources (Brugnach et al. 2017) and are already trialing and implementing a range of adaptation practices that have been forged over millennia (Nursey-Bray et al. 2019). These Traditional modes of adaptation have been argued to form the foundation for addressing the "new" challenge of climate change, whereby tailored, place-based responses can be co-designed with Traditional Owners (Nursey-Bray et al. 2019). Though the Reef Restoration and Adaptation Program is engaging with Traditional Owners as it seeks to establish interventions and other measures to protect the GBR, it has been argued that deeper engagement in this space is needed; such as researching Traditional Owner reef values, adopting best practices for participatory Indigenous research, and formally engaging Traditional Owners as leaders rather than 'stakeholders' in the co-design of the program from the outset (Taylor et al. 2019). Dale et al. (2018) provide further suggestions for improving Traditional Owner engagement in broader reef governance (e.g. in the Reef 2050 plan and beyond); such as creating a tripartite agreement between the Commonwealth, State government, and Traditional Owners that formally shares authority over reef management between the three entities.

Conclusion

Significant uncertainty remains over whether effective policies limiting greenhouse gas emissions will be enacted in Australia and across the world. Environmental governance regimes are thus likely to continue facing climate crises with increasing frequency, and will be faced with fundamental questions regarding how to navigate them to the best of their ability. Our research provides empirical insight into how climate crises are experienced by diverse governance actors in a governance regime that is largely considered to be adaptive, and the barriers and catalysts that arise in determining their responses. We also identified several ways in which some of these barriers might be overcome to improve responses to future crises, including creating and improving venues for collaboration, and adapting policies to pave the way for intervention. Our research contributes new knowledge answering longstanding calls to help build the evidence base needed to evaluate, and then improve upon the institutional arrangements of established adaptive governance regimes (Plummer and Armitage 2010). Though these pathways forward should help to improve responses among governance actors to future crises events, action depends on the willingness of diverse actors to negotiate a shared path forward, and ultimately on international and national commitments to address the root cause of climate change.

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