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Big events, little change: Extreme climatic events have no region-wide effect on Great Barrier Reef governance

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1. Introduction

Extreme climatic events present a growing global challenge for the governance of social-ecological systems (Hitz and Smith, 2004, Carpenter et al., 2012, Hughes et al., 2017, Bellwood et al., 2019). These events occur when an unusual climatic period causes persistent shifts in the structure of natural systems and the services they provide (Smith, 2011), potentially undermining efforts to sustain social-ecological systems and exacerbating inequitable outcomes for people (Chaffin et al., 2016b, Blythe et al., 2018). Although crises like extreme climate events often have negative impacts, there is some evidence that they may also provide windows of opportunity to transition towards more adaptive and inclusive governance of social-ecological systems, which may improve outcomes for people and ecosystems in the long run (Birkland, 1998, Olsson et al., 2006, Brunner and Lynch, 2013, Chaffin and Gunderson, 2016, McHugh et al., 2021). These studies suggest that the lasting impact of crises on social-ecological systems may depend in part on whether these events trigger action by governance actors, including managers, policy-makers, resource users, and others who influence decision-making (Olsson et al., 2006, Chaffin and Gunderson, 2016). However, research to date in environmental governance, political science, and natural hazards has generated conflicting findings regarding the question of whether or not crises lead to change (Birkland, 1998, Olsson et al., 2006, Nohrstedt et al., 2021, Morrison et al., 2020b). Exploring new methods for empirical investigation of governance actors' activities during and after crises can contribute to answering this unsettled question.

This study leverages the power of social network analysis to detect potential changes in governance actors' activities in a large social-ecological system—the Great Barrier Reef—before, during, and after an extreme climatic event. We build on existing work (e.g. Berardo et al., 2015, Berardo and Lubell, 2019) by demonstrating how network analysis of actors' attendance at decision-making forums can be used to evaluate whether shifts in the interests, participation, and influence of governance actors occur after extreme climatic events. *Forums* include venues where diverse governance actors exchange information or make decisions, such as meetings, conferences, partnerships, or advisory panels (Berardo et al., 2015, Berardo and Lubell, 2019). This study aims to detect potential changes in governance actors activities after an extreme climate event through the following research objectives: 1) determine whether or not governance actors convene new forums, 2) detect whether there are changes in the management issues that garner governance actors' interest by examining the topics of forums, and 3) examine whether there are any changes in two aspects of governance actor engagement: (A) actor participation in forums; and (B) the relative influence of actors attending forums. This study is exploratory in nature and therefore rather than focusing on hypotheses, we organize our literature review in the next section around the gap in understanding how governance actors' activities shift (or not) across geographically extensive social-ecological systems after crisis, and the contribution of a network analysis of forums to addressing this gap. Our method section describes the relevance of the Great Barrier Reef social-ecological system as a case study, and the details of our social network analysis. Our analysis reveals general consistency and only minor shifts in the priorities and relative influence of hundreds of actors responsible for governing a large social-ecological system. We reflect on what these findings imply about the challenges of navigating extreme climatic events and provide insight into the benefits and limitations of this method for investigating governance of social-ecological systems after such events.

1.1 Theoretical framework

1.1.1 Adaptive governance and crises

Governance involves interactions between organizations, individuals, and institutions through which people make decisions and distribute power, including, but not limited to, laws, norms, language, market forces, regulations, and civic protests (Lebel et al., 2006, Bevir, 2012). Adaptive governance research focuses on supporting approaches that allow actors to realize democratic ideals (e.g. inclusive participation), address problems at multiple levels (local to global), and experiment and adjust approaches as needed to navigate ongoing change and deliver equitable outcomes (Dietz et al. 2003, Folke et al., 2005, Armitage, 2008, Chaffin et al., 2014, Blythe et al., 2018, Morrison et al., 2019). Extreme climatic events may trigger the emergence of adaptive governance as governance actors self-organize to address the impacts of the crisis and prepare for future change (Olsson et al., 2006, Chaffin and Gunderson, 2016, De Leo et al., 2021). For example, extreme events (e.g. fires) can shift who influences the political agenda, what topics receive attention, and who benefits or loses as a result (Birkland, 1998, Albright, 2011, Liu et al., 2011, Berardo et al., 2015, DeLeo et al., 2021). However, some researchers suggest that crises may entrench existing inequities (Blythe et al., 2018) or fail to trigger actors to make adjustments needed to effectively govern social-ecological systems (Morrison et al., 2020a, Norhstedt et al., 2021). These scholars suggest instead that governance change is slow, and that crises may sometimes, but not often, result in change (Boin and Hardt, 2003, Nohrstedt et al., 2021). While realizing the aims of adaptive governance implies that governance *should* change after an extreme climatic event if needed to continue pursuing desired outcomes, this may not occur in reality. As extreme climatic events become more frequent (Carpenter et al., 2012, Bellwood et al., 2019), it is critical to fill this gap in understanding whether or not these events are triggering changes in the governance of social-ecological systems.

While much previous research to detect change after crisis focuses primarily on policy agendas or change in specific organizations (e.g. Birkland, 1998, Bellwood et al., 2019, Nohrstedt et al., 2021), examining governance actors' activities beyond policy development, such as engagement in meetings and other informal aspects of governance, can broaden our understanding of whether or not crises catalyze a response in social-ecological system governance. By examining these activities in this study we can detect shifts in the relative influence of different governance actors, or in the topics that draw actors' attention, which is relevant for understanding how actors may or may not realize adaptive governance of social-ecological systems in the wake of extreme climatic events (Berardo and Lubell, 2016, Chaffin et al., 2016b). First, examining the topics that governance actors engage with after crises can shed light on whether or not the adaptive governance aim of addressing problems at multiple levels is being met. Second, assessing shifts in *who* engages in governance and how influential they are can reveal winners and losers as a result of governance (Angst et al., 2021, Olivier and Berardo, 2021), which relates to the adaptive governance aims of inclusive participation and equitable outcomes (Chaffin et al., 2014, Blythe et al., 2018, Morrison et al., 2019). However, detecting shifts in these two areas is challenging because it is difficult to procure longitudinal data on entire landscapes of governance actors, particularly in large social-ecological systems (Chaffin et al., 2016a, Berardo et al., 2015). Here, we demonstrate how social network analysis can be utilized to undertake such a large-scale analysis.

1.1.2 Network analysis of forum attendance

Social network science is increasingly utilized by environmental governance scholars to uncover the relationships between actors (in our case, organizations) in formal and informal social networks, and to investigate the implications of these patterns of relationships for social and ecological outcomes (Bodin and Crona, 2009, Bodin and Prell, 2011, Barnes et al., 2016). Taking a network approach allows us to quantify and analyze the "big picture" of interactions between organizational actors, which is particularly useful in geographically extensive and institutionally complex social-ecological

systems, where a plethora of governance organizations interact simultaneously (Morrison, 2017). Recent research on organizations' attendance at forums (e.g. Berardo and Lubell, 2016) offers an approach that can be utilized to broaden analyses of governance regimes after crises.

As venues where multiple actors come together to exchange information and make decisions, forums present opportunities for organizational representatives to connect with one another, further their agendas, defend their positions, and gather information about other organizations' intentions (Berardo et al., 2015, Berardo and Lubell, 2016). Forums are thus venues for organization representatives to influence one another as they negotiate governance strategies and decisions. Past research has investigated actor attendance at forums to identify fragmentation and gaps in governance systems coping with climate change (Lubell, 2017). Previous research investigates how actors' characteristics and patterns of participation in forums drive the structure of institutionally complex governance regimes (Berardo et al., 2015, Berardo and Lubell, 2016). Other research has demonstrated that the structure of governance networks they create can evolve over time to meet the ongoing threat of climate change (Lubell & Robbins, 2021). Additional research demonstrated that new forums can arise and become more popular than old forums after a crisis (e.g. widespread fires) in situations where the old forums were ill-equipped to deal with new problems that arose from the event (Berardo et al., 2015). Much of this research has focused on how network structure affects actor collaboration (Berardo et al., 2015, Berardo and Lubell, 2016), or why actors chose to engage in forms or not (Angst et al., 2021, Olivier and Berardo, 2021). There has been little longitudinal research over consecutive years on the effect of extreme climatic events on what forum topics gain attention (Berardo et al., 2015, Berardo and Lubell, 2016), or how participation in forums changes over time. This gap is in part be due to the challenge of collecting annual data by survey (Chaffin et al., 2016a, Berardo et al., 2015). Here we follow Berardo et al.'s (2015) approach of analyzing forums and adopt a document-based method of data collection (Chaffin et al., 2016a, Schoon et al., 2017) to examine the topics of forums and characteristics of participants before, during, and after an extreme climatic event in a large social-ecological system.

1.1.3 Research questions: applying network analysis to understand social-ecological systems governance after an extreme climatic event

Here we demonstrate how a network analysis of forums can be used to examine three questions about the governance of a geographically extensive social-ecological system after extreme climatic events. We apply these questions to the case of the Great Barrier Reef after mass coral bleaching. Mass coral bleaching events are extreme climatic events during which marine heat waves cause coral animals to reject the algae that gives them their color, which can cause corals to die (Hughes et al., 2017, Bellwood et al., 2019). Dying corals lead to changes in the composition of coral reefs (Bellwood et al., 2019) and can negatively affect reef-dependent industries like tourism (Bartelet et al., 2022). We describe our three research questions below and provide additional information about the Great Barrier Reef case in Section 3.

Research Question (RQ) 1: Do extreme climatic events catalyze governance actors to convene new forums detectable across a large social-ecological system?

If actors are utilizing extreme climatic events as windows of opportunity as posited above, we expect that new forums emerge in reaction to the events (henceforth "event-related forums"), and participation in these new forums is higher than in forums not related to the events (Berardo, et al. 2015).

RQ 2: Do extreme climatic events affect which topics receive attention from governance actors?

Given that extreme climatic events have global level drivers (e.g. emissions) (Hughes et al., 2017, Bellwood et al., 2019), we expect that topics related to global drivers, as well as impacts at lower levels (e.g. state) will be reflected in the topics of forums in the governance regime. Specifically, governance actor responses to extreme climatic events may include an increasing proportion of forums on topics related to climate mitigation (e.g. emissions reduction), climate adaptation (e.g. restoration), or building resilience through ecosystem-based management (e.g. water quality improvements) (Morrison et al., 2020a, Kleypas et al., 2021). If an extreme climatic event does not trigger change, topics will remain the same as prior to the events, or shift for reasons other than the event. In this situation, actors may be struggling to address the multi-level problem presented by climate change.

RQ 3: Are there shifts in the relative representation or influence of governance actors after extreme climatic events?

We are concerned with whether the proportion or influence of actors representing particular types (e.g. government, NGO), focuses (e.g. water quality, fisheries), or levels (e.g. local, national) remains stable, increases, or decreases after extreme climatic events. Previous research posits that including diverse actors in management and decision-making supports adaptive and equitable outcomes (Folke et al., 2005, Huitema et al., 2009, Bennett and Satterfield, 2018). Stability or an increase in the diversity of actors participating in governance may indicate that a system is attaining the same or improved inclusivity after an extreme climate event. A decrease in overall representation or overall influence of particular actor groups may indicate their exclusion from participation and/or benefits from governance outcomes. We demonstrate how network analysis of forums can identify potential shifts that would then warrant further qualitative investigation.

If extreme climatic events catalyze actors to pursue adaptive governance aims, we would expect to see changes in at least one of the three aspects described above. Previous research investigated the impacts of bleaching on GBR governance actors' priorities at the organizational level (Barnes et al., 2022, Bellwood et al., 2019, Lubell and Morrison, 2021), but no empirical research has examined possible effects of bleaching events on what topics attract attention or which actors engage in governing across the entire social-ecological system. We demonstrate how network analysis of actor attendance at forums helps to measure whether individual actors' actions are detectable at the regional scale. We discuss how unveiling this big picture is useful to augment detailed qualitative analyses of participation, equity, and multi-level problems in adaptive governance. It is essential to explore these methods for detecting such dynamics at a time when climate change is triggering extreme events globally with the potential to disrupt governance actors' pursuit of desirable ecological states and equitable social outcomes (Chaffin et al., 2016b, Blythe et al., 2018, Bellwood et al., 2019, Morrison et al., 2020a).

2. Methods

2.1 Case study: Governance of the Great Barrier Reef in an era of recurrent mass coral bleaching

This study investigates the effects of mass coral bleaching events on governance of the GBR. At 344,000 km^2 (the size of Italy), the GBR is the largest reef system in the world and contributes $6.4 billion to the Australian economy each year (GBRMPA, 2019). The GBR is governed through a bilateral agreement between the Queensland Government (state level) and the Australian

Commonwealth (federal level), and is also listed as a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site. The Great Barrier Reef Marine Park Authority (GBRMPA) is the central agency responsible for the reef, and regularly engages with research institutions, reef-dependent industries (e.g. fisheries, dive tourism), industries relevant to the GBR watershed (e.g. agriculture, mining), and Traditional Owners. These organizations convene at forums focused on a broad range of issues related to the GBR (e.g. water quality, fisheries, reef-wide planning) (Morrison, 2017, Bellwood et al., 2019). We henceforth refer to these interacting actors as the "GBR governance network," and use this term interchangeably with "GBR governance regime."

The GBR has been recognized by Olsson et al. (2008) as a rare example of adaptive, ecosystem-based governance after the radical re-zoning of reef uses to better protect the biodiversity of the reef (GBRMPA, 2021a). Today, GBR governance actors still pursue adaptive governance aims (Day et al., 2019, Barnes et al., 2022), such as the engagement of diverse actors [i.e., inclusive participation (Wyborn et al., 2015)] and ability to address problems at local and regional levels [i.e., bioregional fit (Olsson et al., 2008, Huitema et al., 2009, Day et al., 2019)]. However, some have questioned the ability of the system to cope with all relevant stressors, especially climate change, which threatens the environmental and economic value of the reef (Hughes et al., 2017, Morrison, 2017, Bellwood et al., 2019, Hughes et al., 2019). Four mass coral bleaching events occurred in the last decade due to marine heat waves driven by global emissions, including back-to-back events in 2016 and 2017, and additional events in 2020 and 2022 (Hughes et al., 2021, Australian Institute of Marine Science, 2021, GBRMPA, 2022). These events fit the definition of extreme climatic events (Smith, 2011) as they can result in significant shifts in the species composition and overall function of coral reefs (Hughes et al., 2017, Bellwood et al., 2019, Hughes et al., 2021). We study the coral bleaching events on the GBR in 2016 and 2017, as these are the first back-to-back events in the region and garnered significant attention from media and key organizations (e.g. Great Barrier Reef Marine Park Authority (GBRMPA)).

2.2 Scope of the network analysis

We analyze a two-mode social network created from archival online data based on organizations engaged in forums related to the management and governance of the GBR and the catchment area adjacent to the reef. The network includes two types of nodes (i.e. entities)—organizations and forums (Borgatti & Everett, 1997). We included forums that serve as venues where members from multiple organizations come together to share information, provide advice, and make decisions on issues related to the GBR. Specifically, forums included projects, meetings, programs, and other venues where organization members: 1) make decisions about reef policies or management strategies for the entire, or at least majority of, the reef social-ecological system (e.g. Reef 2050 plan development); 2) provide advice to decision-makers (e.g. Reef 2050 Plan Independent Expert Panel); 3) engage in partnerships to implement policies and management strategies (e.g. Eye on the Reef monitoring program); or 4) share research, monitoring, or management project findings to inform management decisions (e.g. 2017 Reef Summit) (See Appendix A for more information). The topics of these forums are considered to represent priority areas for action by governance actors, allowing for assessment of actors' attention to problems at nested spatial levels (e.g. water quality is a regional problem, whereas restoration is site-specific).

We included forums that focused on multiple reef management issues or single issues relevant to the entire region (e.g. coral restoration, invasive species), referred to here as "reef topics". Localized, site-specific reef management projects and individual research or decision tool development projects not intended to have a bearing on the rest of the reef system were not included. International and national forums inclusive of the GBR, but not primarily focused on the GBR, were

also excluded (for example, national marine forums like the Australian Marine Debris Initiative were excluded).

2.3 Data collection

The dataset includes network data on organization members' (*n*= 451) attendance at forums (*n*= 145) related to coral reefs in the GBR region each year from 2012 to 2019. This period includes three years prior to the first bleaching event in 2016, and three years after this event, including the second event in 2017. This allows for a comparison of the composition of the GBR governance network before (2012-2015), during (2016-2017), and after the bleaching events (2018-2019).

Following Berardo et al. (2015), we created a two-mode network by defining network ties based on organizational members' attendance at forums. Data on forums was collected from publicly available documents and organizations' websites (Chaffin et al., 2016a). Specifically, we collected data on forums present in the network between 2012 and 2019 from documents and websites published between 2012 and 2020. Documents included reef management reports, strategies, reef program brochures, meeting minutes, and other forum documentation that included information about the forum topics and lists of participants. Documents and websites were iteratively reviewed until saturation was reached. Additional detail on data collection and limitations is provided in Appendix A.

We classified each forum according to type (e.g. advisory panel) and topic (e.g. water quality). In addition, we classified forums into a binary category of "event-related" or "other," where "event-related" forums were those explicitly formed in response to bleaching events (e.g. GBRMPA 2016 Bleaching Event Impact Assessment and Incident Response), or were motivated broadly by climate change impacts and cited bleaching as a major impact (e.g. Reef Restoration and Adaptation Program). Some event-related forums focused on topics beyond bleaching, such as restoration, but documented that they were motivated by the bleaching events. A complete list of types and topics of forums is provided in Appendix B.

Organizations present in the network were categorized into type (e.g. government, NGO), focus (e.g. fisheries, infrastructure), and level (e.g., local, national). For example, SCUBA tour operators were classified as industry organizations, with a focus on tourism, operating at the local level. Note that references to "NGO" category throughout this article includes NGOs, intergovernmental organizations, not-for-profit organizations, foundations, and environmental lobby groups. A complete list of the types, focuses, and levels of organizations is included in Appendix B.

2.4 Data analysis

A summary of our empirical strategy is provided in Table 1. A detailed description of each stage of our analysis is provided in the sections below (2.4.1-2.4.3).

Table 1. Summary of our empirical strategy in relation to our three research questions

	Objectives	Data	Analysis
RQ 1: Do extreme climatic events catalyze governance actors to create new forums?	A. Detect whether new event-related forums emerge.	Two-mode network data[a]	Presence or absence of event-related forums; number of event-related forums if present.

	B. Determine whether any detected event-related forums attract higher participation than other forums.	Two-mode network data; only years 2015-2019.	Independent t-test for difference of means between in-degree centrality of event-related forums and other (non-event-related) forums. In-degree centrality represents attendance (Freeman 1978, Borgatti 2018).
RQ 2: Do extreme climatic events affect which topics receive attention from governance actors?	A. Assess the topics of event-related forums.	Two-mode network data	Proportion of event-related forums focused on different reef topics.
	B. Assess the topics of all forums.	Two-mode network data	Proportion of all forums focused on different reef topics in each year. General linear model testing the impact of forum topic and type on the in-degree centrality of forums (Freeman 1978, Borgatti 2018).
RQ 3: Are there shifts in the representation or influence of governance actors after extreme climatic events?	A. Assess participation in event-related forums.	Two-mode network data	Proportion of organizations participating in event-related forums.
	B. Assess participation in all forums.	One-mode network data[b]	Proportion of organizations co-attending all forums collectively, classified by organization type, focus, and level.
	C. Analyze participant influence across all forums.	One-mode network data	General linear model testing the impact of actor type, focus, and level on the beta centrality of governance actors co-attending forums. Beta centrality of governance actors represents their potential social influence.

[a] Two-mode network data of organization members (mode one) attending forums (mode two) held in the GBR region related to management of the reef ('reef related forums') between 2012 and 2019 (pre and post-bleaching). Forums were categorized by topic (i.e. issue discussed, e.g. water quality) and type (e.g. advisory committee, partnership). Forums with documentation citing the bleaching events as the primary reason they were established or continued were classified as "event-related."

[b] One-mode network representing co-attendance of different organization members (i.e., governance actors) at reef-related forums between 2012-2019 (pre and post-bleaching). Governance actors were categorized according to their type (e.g. government), focus (e.g. environment), and level (e.g. state).

2.4.1 RQ 1: Analyzing bleaching event-related forums

We identified event-related forums and calculated the average in-degree centrality (normalized to account for differences in network size across years) for event-related forums and for all other forums in the network in each year from 2015 to 2019, which includes the years following the initial bleaching event in 2016. In degree centrality is the number of organizations attending a forum (Freeman, 1978, Friedkin, 1991, Borgatti et al., 2018). We included forums in 2015 because one

forum was formed in anticipation of the bleaching events (see 4.2 Results). Difference of means tests were conducted to detect any significant differences in in-degree centrality between event-related forums and other forums in the network for the years 2016 to 2019, excluding 2015 as a test is not possible with only one forum.

2.4.2 RQ 2: Analyzing priorities via forum topics

We used the two-mode network data to assess attention to topics addressed by all forums in each year (2012-2019). We examined: 1) the proportion of *event-related* forums that focused on each reef topic (e.g. water quality, fisheries) in each year, 2) the proportion of *all* forums focused on each topic in each year, and 3) attendance at *all* forums focused on different topics (i.e. forum activity). To understand whether the topics of forums were associated with how active they were (i.e. how many participants attended), we ran a series of General Linear Models (GLMs). We modelled each year individually and tested for the main effects of forum type and forum topic on normalized in-degree centrality. We describe this procedure in detail at the end of the methods section and in Appendix A.

2.4.3 RQ 3: Analyzing representation and relative influence of governance actors

To analyze the representation and potential influence of organizations, we used the two-mode network data to first assess the proportions of governance actors of each organization type, focus, and level that participated specifically in *event-related* forums (e.g. percentage of government versus NGOs). Next, to assess trends in participation across *all* forums collectively, we transformed the two-mode networks into one-mode networks of organizations (Figure 1) (Borgatti and Everett, 1997, Borgatti and Halgin, 2011), which reflect co-attendance by organization members at reef-related forums. These networks are referred to as “co-affiliation” networks, which indicate shared interest in the forum topic and the potential for interaction (Borgatti and Halgin, 2011). Our co-affiliation networks have valued ties, with values representing the number of forums two actors co-attended in a given year. We generated eight separate networks, one for each year (2012-2019). See Appendix A for additional information on co-affiliation network concepts and methods.

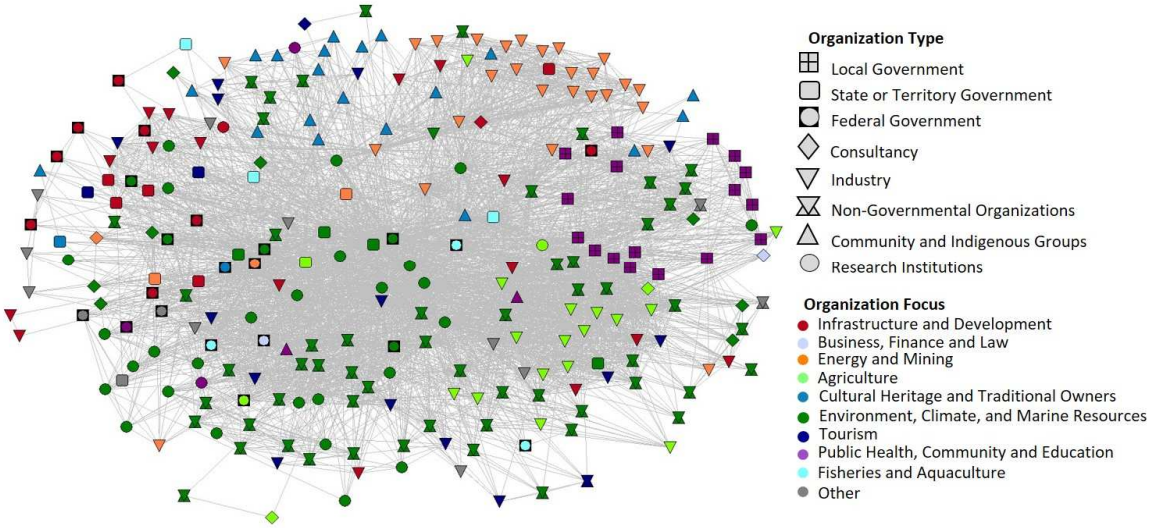


Figure 1. Example of the co-affiliation GBR governance network representing co-attendance of different organizations at reef-related governance forums in 2017.

To evaluate governance actors' potential influence over governance priorities, we first assessed their representation in the co-affiliation network by examining the proportions of governance actors represented across *all* forums in terms of organization type, focus, and level (e.g. state). Next, to measure the potential influence of governance actors, we calculated the beta centrality score for each actor in each year (Bonacich, 1987, Hanneman and Riddle, 2005). Beta centrality measures the extent to which an actor is connected to well-connected actors (i.e. actors with many ties to others)—the higher the centrality, the more potential influence the actor has (Bonacich, 1987). To understand whether certain attributes of governance actors are related to their beta centrality, we ran a series of GLMs, modelling each year individually (2012-2019). Specifically, we tested for the main effects of all organization attributes (i.e. type, focus, and level) on beta centrality.

In all our GLMs, we performed a logarithmic transformation on the centrality data and reported exponentiated results. We used 1,000 bootstrap samples (with replacement) due to the non-independent nature of our data and evaluated statistically meaningful relationships based on 95% confidence intervals (see Appendix A for detailed methods). All network transformations and calculations of centrality measures were performed in UCINET 6.716 (Borgatti et al., 2002). All statistical analyses were performed in R (R Core Team, 2021).

3. Results

3.1 New forums in the wake of mass coral bleaching events

Fifty new forums emerged in the period after the first and second bleaching event occurred (2016 to 2019). Of these, 15 (30%) were event-related forums that were initiated and/or continued in response to the bleaching events and associated impacts. One additional forum (National Coral Bleaching Taskforce) formed in 2015 in anticipation of the bleaching event based on projected summer temperatures for 2016.

Event-related forums were not meaningfully more or less central than other forums in any year (Table C3, Appendix C). A qualitative assessment of our 2-mode network data and forum documents indicates this may be because governance actors largely chose to engage with existing, long-standing forums to grapple with the aftermath of mass coral bleaching events. For example, two cornerstone advisory panels for implementation of the Reef 2050 plan (the Reef Advisory Committee and the Independent Expert Panel) held special workshops with members of their existing forums to generate advice on how to respond to coral bleaching events. Both above-mentioned advisory panels specifically noted in forum documents that the Reef 2050 plan and associated pre-existing forums are the appropriate venue(s) for addressing coral bleaching.

3.2 Topics attracting attention in the GBR governance regime

3.2.1 Topics of event-related forums

All but one of the 15 event-related forums focused on the topic of restoration and adaptive interventions (Figure 2). Five forums focused explicitly on climate and bleaching; two arose to assess and share information about the bleaching events; two were advisory panels providing recommendations to the GBR Ministerial Forum (responsible for implementing a region-wide "Reef 2050" plan); and the fifth was the launch of a "Super Coral Expedition" to find bleaching-resistant corals. The majority of the remaining event-related forums focused on general reef health (e.g., implementation of the "Blueprint for Resilience," which addressed multiple reef issues). The last

event-related forum was a multi-issue strategy—the expedited review of a region-wide strategy for GBR management ("Reef 2050" plan).

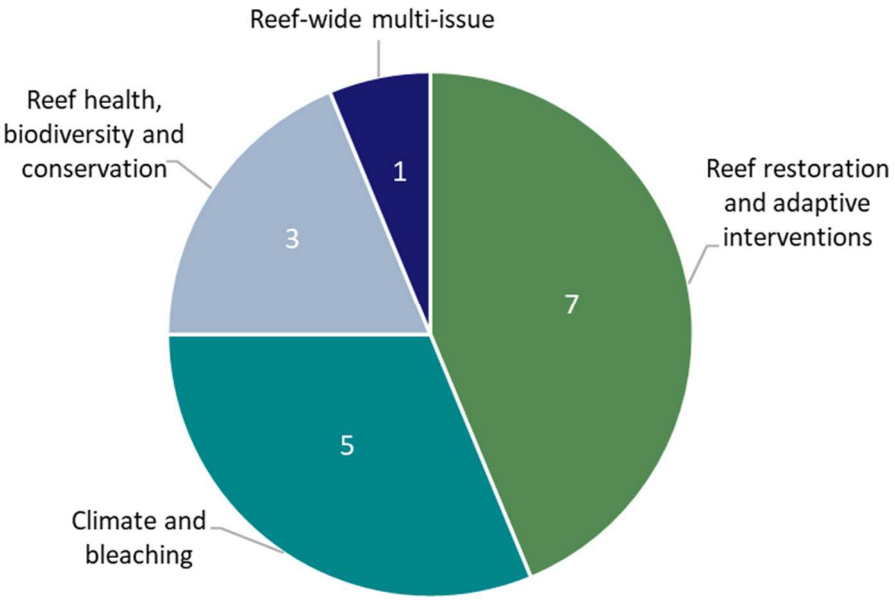


Figure 2. Topics of event-related forums. Event-related forums are those created primarily to respond to bleaching events and or the aftermath of these events.

3.2.2 Topics of all forums in the network

Across all forums (event-related or not), we found that the proportion of forums focused on different topics did not dramatically shift after the coral bleaching events in 2016 and 2017 (Figure 3). However, there were some slight changes. Specifically, the proportion of forums focused on reef restoration and adaptive interventions increased from one forum before 2016, to eight by 2019. These forums are primarily venues to experiment with active interventions to restore coral reefs after bleaching events (e.g., dispersing coral larvae), or shelter reefs during heat waves in the future (e.g., microfilm screens to block sunlight). The proportion of forums focused on climate or coral bleaching was relatively small across all years (<1%), but increased from three in 2013 to seven by 2017, before decreasing to just two in 2018 and 2019. This decrease was due to the planned end of several long-term climate programs, in addition to the culmination of forums reporting on the extent of bleaching events. The proportion of forums focused on fisheries increased from one or two forums before 2016, to seven to eight forums from 2017 to 2019; forum documentation (e.g. forum reports, meeting minutes, and program websites) indicated this was due to the development and implementation of the Queensland Sustainable Fisheries Strategy (2017-2027) and associated new fisheries advisory groups (i.e., not directly associated with the bleaching events). Last, the proportion of forums focused on water quality was greater in 2016 at 29%, compared to 25% or less in other years. Documentation of new water quality forums arising in 2016 indicates these were related to pre-existing management goals in the region and were not explicitly linked to the bleaching events. Documentation of forums focused on 'climate and bleaching' and 'restoration and adaptive interventions' indicated most *were* related to the bleaching events, as described earlier (Section 3.2.1).

Our GLM model on forums indicated that there are few meaningful relationships between the in-degree centrality of forums and the topic and type of forum in most years (see Table C1, Appendix C). The GLM model indicates that although the number of forums on the topics of restoration and adaptation and fisheries increased (Figure 3), these forums did not attract greater participation than other forums in the network overall (Table C1).

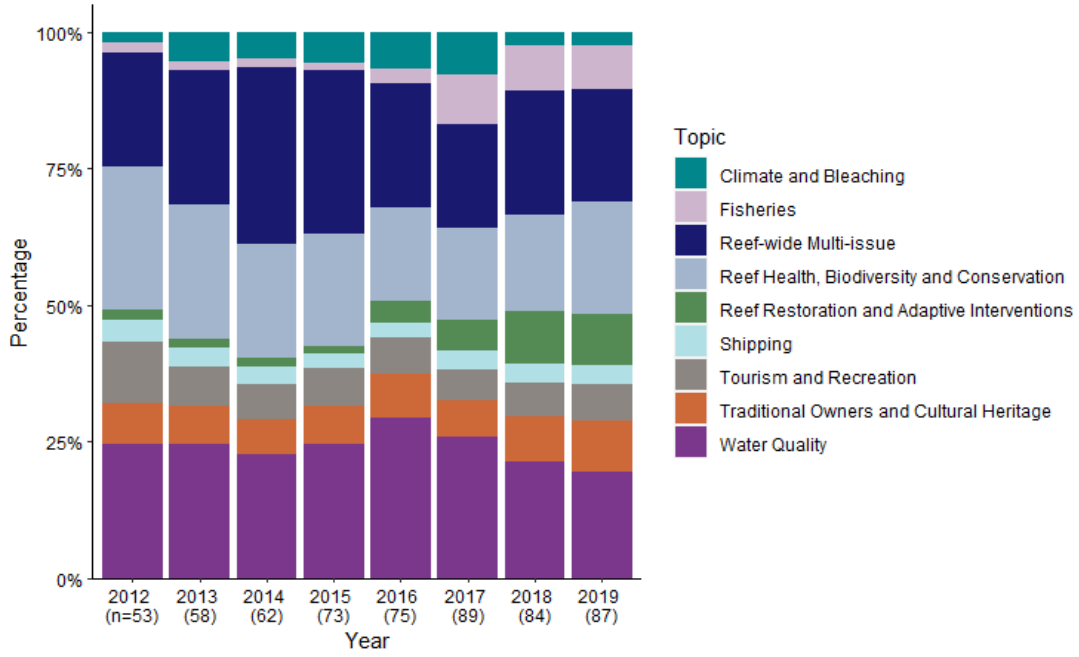


Figure 3. Regional attention to different reef issues: Proportions of forums focused on different reef issues from 2012 to 2019 (n=number of forums per year). Note that the 'reef health, biodiversity and conservation' category refers to forums focused on the overall status of the reef and its maintenance, whereas 'reef restoration and adaptive interventions' refers more specifically to more direct interventions to restore damaged reefs, including experimentation with new approaches and technologies.

3.3 Engagement of governance actors

3.3.1 Engagement in event-related forums

We found that the type of organizations participating in event-related forums somewhat differed depending on the topic of the forum (Figure 4). Forums that focused on climate and coral bleaching were attended primarily by research institutions and NGOs; whereas participation in restoration and adaptive intervention forums was more varied, including a larger representation of industry and participation from some community and indigenous groups (Figure 4). Forums focused on the topic of reef health, biodiversity, and conservation were attended by a mix of NGOs, industry, and research institutions. The one reef-wide multi-issue forum, a review of the Reef 2050 plan in 2018, had participation only from research institutions and government.

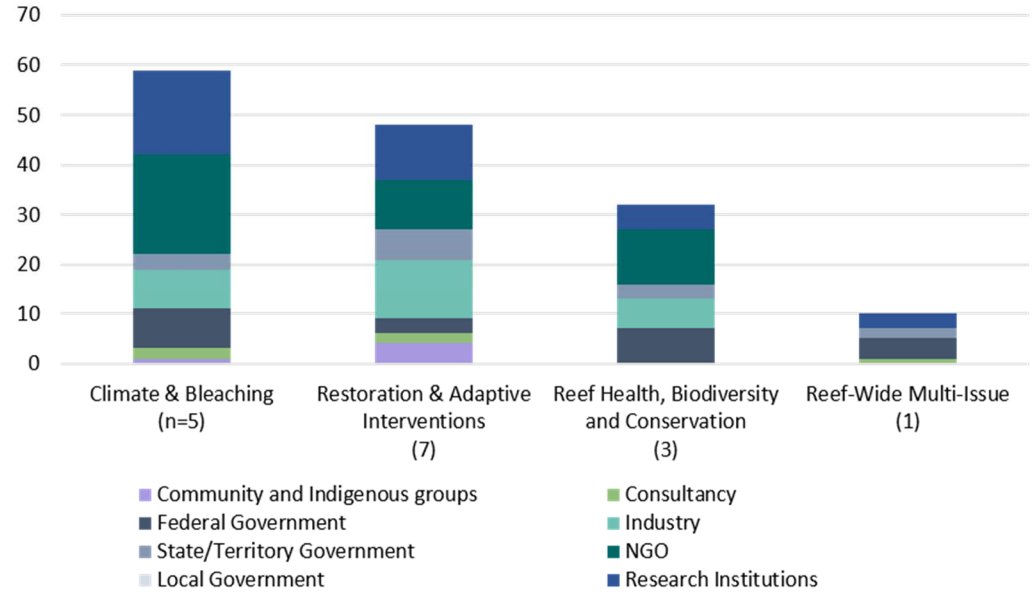
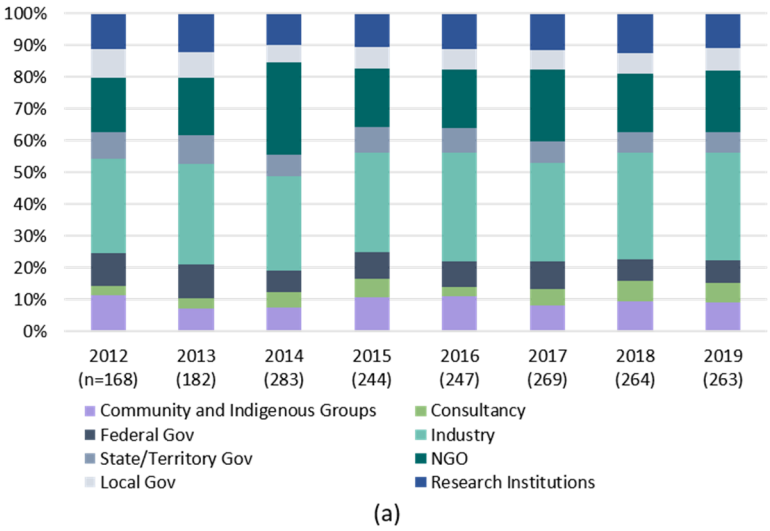


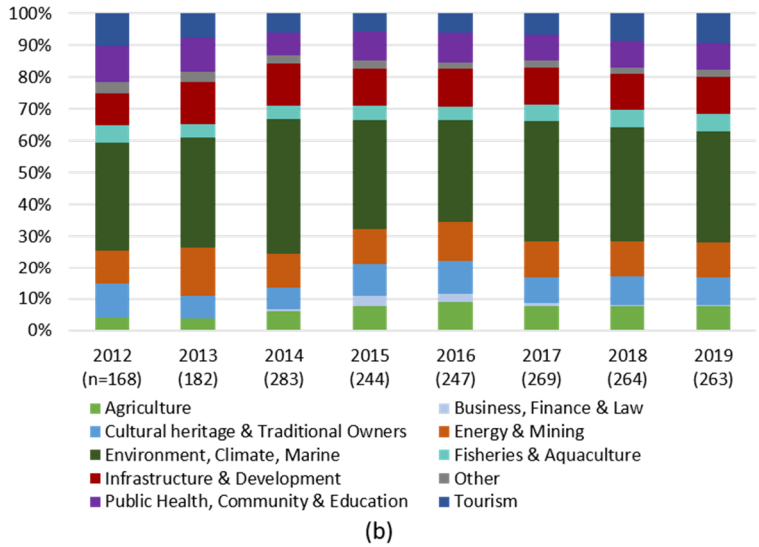
Figure 4. Proportions of different organization types participating in coral bleaching event-related forums. The number of forums for each topic is indicated parentheses.

3.3.2 Engagement in all forums in the network

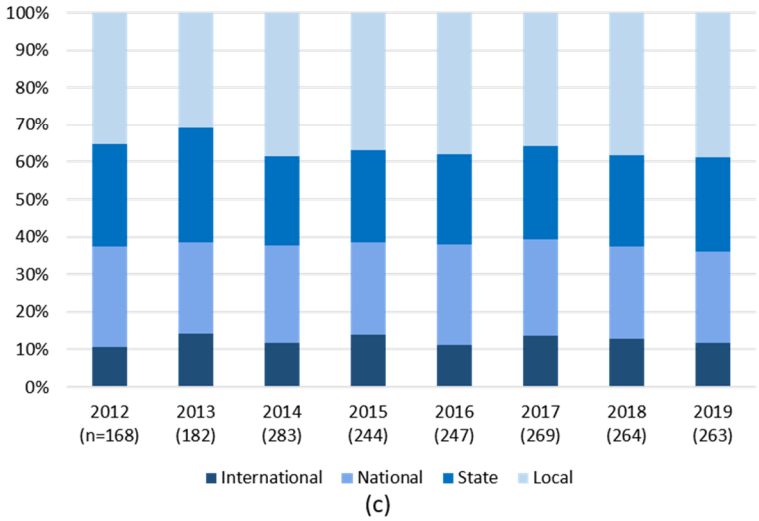
The proportions of organizations indicate representation in the network (Figure 5), while the GLM model predicting beta centrality indicates the influence of organizations (Table 3); we consider these two sets of results together to understand changes in both the representation and influence of organizations. The proportion of different types of organizations engaged in GBR governance remained consistent from 2012 and 2019, as did the proportions of organizations operating at different levels; industry continued as the most represented group, followed by NGOs (Figure 5). The proportions of organizations with different foci showed slight variation in some categories during and after the bleaching events, though organizations with a focus on environment, energy and mining, and infrastructure and development continued to have the highest representation (Figure 5). Our GLM model indicated that organization level was a reliable predictor of beta centrality in only some years, whereas organization type was a reliable predictor in all but 2012 and 2015, and focus was a reliable predictor of beta centrality in all but 2012 (Table 3). Overall, there were some changes in the potential influence of different actors after bleaching events, but none that spanned more than one or two years with the exception of a decrease in the centrality of NGOs (Table 3). A few minor changes in organization representation and influence are elaborated in Appendix C.



(a)



(b)



(c)

Figure 5. Organizations attending forums in each year (2012-2019). Proportions of organizations attending forums are shown by organization type (a), focus (b), and level (c).

Table 3. GLM parameter estimates from modelled beta centrality of organizations using 1,000

bootstrap samples.

	2012	2013	2014	2015	2016	2017	2018	2019
Type								
Federal Government	1.62[a] (0.52)	1.73 (0.47)	1.3 (0.44)	1.58 (0.42)	1.51 (0.39)	2.14 (0.41)	1.81 (0.44)	1.62 (0.48)
State or Territory Government	1.84 (0.47)	2.17* (0.37)	1.76 (0.35)	1.28 (0.37)	1.36 (0.36)	1.8 (0.36)	1.46 (0.39)	1.86 (0.4)
Local Government	0.87 (0.43)	0.75 (0.47)	1.36 (0.56)	1.42 (0.56)	1.61 (0.44)	0.94 (0.46)	1.33 (0.34)	1.59 (0.5)
Industry	1.05 (0.44)	1.17 (0.36)	1.91* (0.32)	0.75 (0.35)	0.8 (0.32)	1.06 (0.35)	0.95 (0.35)	0.88 (0.32)
NGO	0.99 (0.27)	0.74 (0.28)	1.34 (0.24)	0.56 (0.28)	0.49* (0.28)	0.57* (0.27)	0.49* (0.27)	0.36* (0.3)
Community & Indigenous Groups	1.07 (0.43)	1.44 (0.57)	1.31 (0.64)	1.09 (0.76)	1.42 (0.69)	2.24 (0.58)	2.78* (0.44)	2.93 (0.59)
Consultancy	0.72 (0.43)	1.06 (0.5)	0.62 (0.28)	0.61 (0.38)	0.67 (0.84)	0.52 (0.37)	0.54 (0.33)	0.49 (0.36)
Research Institution	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Focus								
Agriculture	1.83 (0.34)	2.13* (0.3)	0.41 (0.53)	1.41 (0.35)	2.05* (0.33)	1.67 (0.31)	1.66 (0.31)	0.8 (0.3)
Business, Finance & Law	-	-	1.31 (0.3)	0.18 (0.53)	0.25* (0.67)	1.82 (0.49)	1.09 (0.36)	0.84 (0.37)
Cultural heritage & Traditional Owners	1.13 (0.46)	1.03 (0.54)	1.25 (0.7)	0.91 (0.76)	0.59 (0.67)	0.47 (0.59)	0.4 (0.52)	0.45 (0.65)
Energy & Mining	1.06 (0.3)	1.33 (0.24)	0.92 (0.3)	1.35 (0.31)	1.33 (0.29)	1.06 (0.27)	1.22 (0.23)	1.13 (0.23)
Environment, Climate, Marine	1.86 (0.44)	2.51* (0.39)	2.1* (0.35)	2.48* (0.37)	2.97* (0.37)	2.76* (0.29)	2.55* (0.3)	2.07* (0.29)
Infrastructure & Development	0.75 (0.31)	0.97 (0.24)	1.45 (0.29)	1.26 (0.3)	0.96 (0.3)	0.75 (0.27)	0.84 (0.22)	0.78 (0.25)
Other	1.68 (0.67)	2.23 (0.69)	2.66 (0.68)	2.51 (0.76)	2.81 (0.87)	1.84 (0.74)	2.26 (0.8)	0.73 (1.02)
Public Health, Community & Education	0.82 (0.49)	1.02 (0.52)	0.88 (0.63)	0.57 (0.62)	0.61 (0.5)	1.12 (0.43)	0.75 (0.43)	0.63 (0.53)
Tourism	1.29 (0.32)	1.06 (0.26)	0.95 (0.35)	0.94 (0.35)	0.96 (0.35)	0.97 (0.3)	0.89 (0.24)	0.94 (0.25)
Fisheries and Aquaculture	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Level								
Local	1.24 (0.19)	1.19 (0.16)	0.87 (0.18)	1.32 (0.2)	1.59* (0.2)	1.22 (0.18)	1.39* (0.17)	1.13 (0.23)
State	1.91* (0.24)	1.37 (0.19)	1.46 (0.21)	1.99* (0.21)	1.82* (0.23)	1.45 (0.21)	1.57* (0.19)	1.59 (0.24)
National	1.41 (0.2)	1.21 (0.22)	1.27 (0.19)	1.16 (0.25)	1.3 (0.23)	1.11 (0.22)	1.14 (0.22)	1.29 (0.29)
International	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]

[a] Cells contain exponentiated estimates (i.e. multipliers) and bootstrapped standard errors in parentheses. For example, in 2012 the multiplier for organization type 'federal government' was 1.62, indicating a 62% increase in beta centrality relative to research institutions (the reference category).

[b] This category served as the reference category.

* Parameter is statistically meaningful based on a 95% confidence interval.

412

413 4. Discussion

414 The impact of extreme climatic events on governance actors' activities is underexplored, in part due
415 to the challenge of collecting longitudinal data for large and complex social-ecological systems
416 (Chaffin and Gunderson, 2016, Herrfahrdt-Pähle et al., 2020, Levin et al., 2021). Using the GBR as an
417 example, we demonstrate how social network analysis can be used to analyze forum attendance to
418 investigate environmental governance regimes before and after extreme climatic events. We
419 uncovered governance changes in regard to only the first of the three research questions we
420 considered—new bleaching event-related forums did emerge, but were not more attended than
421 other forums (RQ 1). The overall lack of change in actors' topics of interests (RQ 2), and the relative
422 stability in the representation and relative influence of different actors (RQ 3), suggests coral
423 bleaching events catalyzed only mild change governance actors' activities. Here we discuss the
424 implications of the overall stability of this regime for adaptive governance in the era of climate
425 change. We then highlight the few slight changes in the GBR governance network we observed, and
426 what this may indicate about the future of the system. Last, we reflect on the benefits and
427 limitations of our network analysis approach, and discuss future directions for research and practice.

428 4.1 Stability and trajectory of the GBR regime

429 Three aspects of our results suggest that the GBR regime remained relatively stable after mass coral
430 bleaching events: (1) though new event-related forums emerged, they were not more attended than
431 other forums (RQ 1); (2) there was limited change in the proportion of forums focused on different
432 topics, and in which forum topics attracted attendance (RQ 2); and (3) there was limited change
433 from 2012 to 2019 in the representation or relative influence of actors (RQ 3). These findings
434 reinforce the idea that governance regimes may remain stable in the wake of extreme climatic
435 events (Nohrstedt et al., 2021), providing a contrast to Berardo et al.'s (2015) findings that new
436 event-related forums were more attended than older forums. These contradictory findings may be
437 explained by the differences in the composition and structure of governance actor communities in
438 each context (Birkland, 1998, Johnson et al., 2005, Berardo et al., 2015). For example, Berardo et al.
439 (2015) hypothesized that new forums would be more attended in the Paraná River delta in Argentina
440 because pre-existing forums would be ill-equipped to deal with new problems; but in our case,
441 governance actors appeared to identify pre-existing forums as appropriate venues for responding to
442 bleaching (e.g. forums related to the region-wide Reef 2050 strategy). Here, governance actors'
443 decisions about the value of existing governance institutions (e.g. Reef 2050) for solving new
444 problems may have impacted the extent to which an adaptive governance regime changes after
445 extreme climatic events. This demonstrates that understanding the factors that affect actors'
446 decisions to continue with existing forums over time versus creating new ones is critical for
447 understanding when extreme climatic events do or do not influence the structure and function of
448 governance (see Angst et al., 2021, Olivier and Berardo, 2021).

449 The persistent balance of attendance across forum topics before and after bleaching events sheds
450 light on the capacity of governance actors to address problems at nested levels. Addressing
451 problems at multiple nested levels first earned the GBR recognition as an example of adaptive
452 governance (Olsson et al., 2008). Our results indicate that governance actors continue to address
453 problems at multiple spatial levels after bleaching events, from climate adaptation (e.g. restoration
454 of specific reef sites) to ecosystem-based management (e.g. reducing runoff pollution from the GBR

catchment). However, though new forums focused on climate mitigation (e.g. emissions reduction or carbon sequestration) might also have been expected given that coral bleaching results from climate-driven warming of oceans (Hughes et al., 2017), no forums on these national and global level topics appeared in the GBR region after mass coral bleaching events. While national emissions reduction efforts beyond the boundaries of the GBR were outside the scope of this study, venues hosted by GBR governance actors seeking to connect GBR management to higher level efforts to mitigate emissions would have been detected. This result may be explained by previous research findings that many organizations in the GBR region consider mitigation to be beyond their jurisdiction or abilities, and most favor adaptation (e.g. Hoegh-Guldberg et al., 2018, Morrison et al., 2020a, Lubell and Morrison, 2021, Barnes et al., 2022). However, widespread support for climate action on organizations' websites and in forum documentation suggests that there is interest in such efforts, but that governance mechanisms that empower actors to connect regional impacts to national and global drivers of change are still needed to fully realize the adaptive governance aim of addressing multi-level problems.

The overall persistent balance of participation amongst actors in the GBR regime suggests that extreme climatic events do little to shift pre-existing patterns in the relative influence of actor groups, implying that a status quo distribution of benefits was maintained. Well-represented groups such as industry actors may have benefited from this stability. Our results align with concerns that climate change may entrench existing inequities (Blythe et al., 2018, Morrison et al., 2019, McHugh et al., 2021) or at least do little to empower previously marginalized groups as found in other cases (Birkland 1998), even within adaptive governance regimes. Further qualitative investigation of impacts on specific GBR actor groups is needed to examine the influence of these organizations and consequences for how benefits are distributed after extreme climatic events.

Although we did not detect statistically meaningful changes in participation across the network up until 2019, the topics and participants at new event-related forums shed light on emerging priorities in the region and who may benefit from these priorities. Our findings demonstrate for the first time that responses to coral bleaching events previously documented at the level of individual organizations were also reflected at the level of the region-wide governance network—namely a focus on restoration, adaptation, and water quality; with less attention to climate mitigation (Bellwood et al., 2019, Morrison et al., 2020a, Lubell and Morrison, 2021, Barnes et al., 2022). The majority of event-related forums were focused on climate adaptation (e.g. the Reef Restoration and Adaptation Program), where dive tour operators, NGOs, and research institutions had strong representation. Partnerships between dive tour operators, researchers, and government organizations like GBRMPA are utilized for the implementation of trial restoration projects at tourism sites (GBRMPA, 2017). These mutually beneficial partnerships offer payments to tour operators and have recently been formalized under GBRMPA's "Tourism Industry Activation and Reef Protection Initiative" (GBRMPA, 2017, GBRMPA, 2021b). The development of restoration solutions may also benefit NGOs (includes not-for-profits, foundations) that may receive additional attention from donors, and research institutions that receive grants to test and later potentially sell their new technologies (e.g. Small Business Innovation Research program (Queensland Government, 2021)), though exact benefits are difficult to quantify at this stage. Lastly, the presence of four Indigenous and community organizations at restoration and adaptive intervention forums (see Figure 4) is notable because they tend to be poorly represented in the network overall. Their presence here contrasts with previous studies, which identify a lack of community engagement as a limitation on realizing the socio-ecological benefits of coral restoration (Hein et al., 2019). In the GBR region, the engagement of community and Indigenous groups in restoration and adaptation forums indicates potential benefits to these groups, and a potential increase in their influence. This suggests

the GBR region may join a limited number of examples of coral restoration leading to job creation and other benefits to communities (e.g. Kittinger et al., 2016).

4.2 Opportunities, limitations, and future directions for analysis of forums and extreme climatic events

The approach we adopted here revealed broad patterns in organizations' participation and influence in GBR governance, indicating its usefulness for longitudinal analyses of large social-ecological systems. The scope of our study captured action at the regional level, but may have missed action on climate change (e.g. emissions reduction, carbon sequestration) occurring at the local and/or national levels, and in the geography of the GBR reef catchments if such actions were not explicitly linked to the GBR. Without action on climate change, the above-mentioned benefits of restoration and adaptive interventions will be short-lived (Norström et al., 2016, Morrison et al., 2020a). Future research could use network analysis coupled with qualitative methods to expand this analysis to examine reef actors' involvement in forums to mitigate emissions or sequester carbon at the local, national or international levels, as well as any terrestrial efforts within the region.

Although our analysis indicates that by 2019 there was little attention given to the cross-level issue of climate mitigation, such efforts may yet emerge as a delayed response to mass coral bleaching events. More recently, at least a few efforts to transition from coal towards renewables in the GBR catchment (e.g. Renewables Nation), and at least one blue carbon sequestration effort (Blue Carbon Lab 2021) have emerged. There is thus a need for continued longitudinal research. Uncovering the mechanisms behind the growing engagement of reef actors with emissions reduction, carbon sequestration, and a transition to a low carbon economy could inform the evolution of the theory and practice of how actors in a given social-ecological system can address global challenges within adaptive governance regimes (Grech et al. 2015, Chaffin et al. 2016b, Morrison et al. 2020, Levin et al. 2021). Such an analysis might survey the broad suite of institutions, activities and norms under the umbrella of "governance" (Bevir, 2012, Lebel et al. 2006), ranging from re-framing reef problems (e.g., Morrison, et al. 2020) or public protests, to cross-level interactions in networks (e.g., Hamilton and Lubell, 2018) and changes in formal policy (e.g. Grech et al., 2015).

One limitation to our approach is that it does not allow us elaborate the nuances of the role of social influence in shaping whether or not actors collectively respond to crisis events. Future research might use qualitative network analysis, interviews, and/or participant observation to examine how governance actors influence one another's decisions regarding priority actions and what forums to attend (new or existing), as well as what role extreme climatic events versus other drivers played in these decisions. This approach may expose further nuances of the impact of bleaching as a catalyst for change (or not) by making it possible to decipher the extent to which bleaching events versus other ecological, social, or political factors catalyzed action on pre-existing priorities, particularly given that actors these actions may be taking place largely within pre-existing forums.

Last, network analysis and qualitative methods could together be used to compare the extent to which different types of extreme climatic events catalyze change within adaptive governance regimes. Political science research suggests that there may be substantial differences between events that directly harm people and ecosystems (e.g. cyclones, fires) versus those that directly harm ecosystems and indirectly harm people (e.g. coral bleaching) (Birkland, 1998). Understanding what factors cause an extreme climatic event to catalyze change or not can inform efforts to cope with ongoing climate change impacts across multiple social-ecological systems. Examining why some events are particularly good catalysts may also inform efforts to re-frame the climate change problem in order to make it a more salient concern in the public eye (Morrison et al., 2020a).

5. Conclusion

Extreme events place the daunting task of climate adaptation and mitigation on the doorstep of social-ecological governance actors. This study contributes a broad spatial and temporal perspective on the priorities and activities of hundreds of governance actors participating in over 150 forums in an adaptive governance regime over eight years. Our analysis goes beyond studies of individual organizations or forums by revealing the collective priorities and influential organizations that emerge from actual activity (i.e., forum participation) across an entire region. By bringing this focus to forum topics and the composition of participants, we expand the application of network analysis of forums in environmental governance research. Our results suggest that mass coral bleaching events can catalyze some action on restoration and adaptive interventions, but may primarily reinforce existing priorities and do not ultimately change the relative influence of actors across a social-ecological system. This implies that extreme climatic events may fail to unseat the entrenched the status quo influence of (and benefits to) governance actors. We also find that emerging priorities in this region indicate the ability of actors in an adaptive governance regime to address the drivers of global climate change is thus far limited, even as climate change causes damage within the bounds of the system. The problem of addressing global drivers from within a social-ecological system has long been recognized (Cash et al., 2006, Morrison et al., 2020a), but our findings indicate that extreme climatic events cannot be relied on to help governance actors overcome this challenge by catalyzing more inclusive participation or novel mechanisms for governance action across local to global levels. Future research must look broader and deeper to identify the causes of stagnating policies and practices, and uncover the seeds of change for governance transitions. Network research can broaden across different types of extreme climatic events, intersecting governance networks (e.g. climate and reef networks), and even longer time frames. Complementary qualitative research can more deeply investigate the drivers of governance actors' decisions to convene at new versus old forums, and explore how and why diverse actors interpret extreme climatic events.

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