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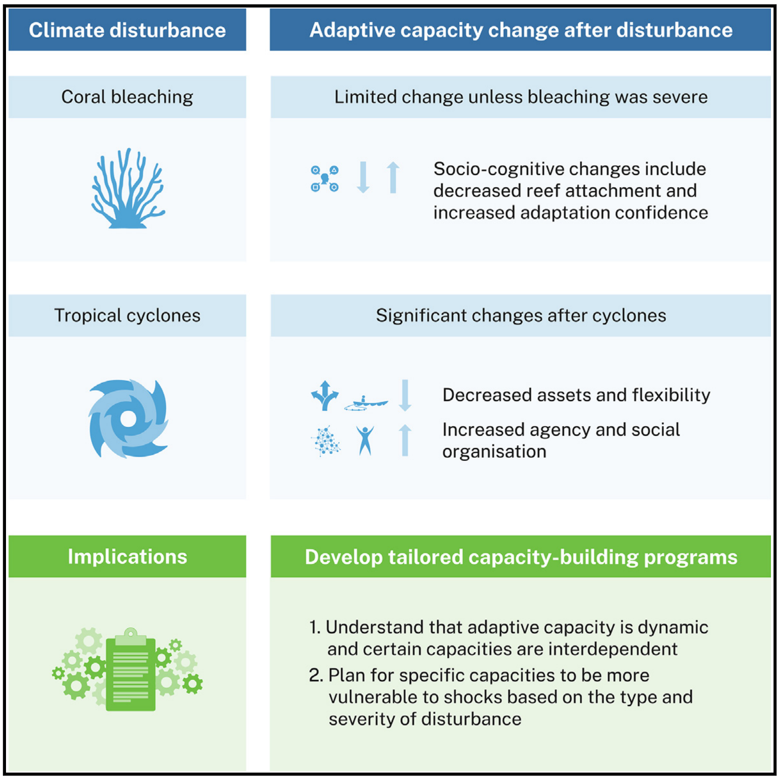
Changes in reef tourism's adaptive capacity after severe climate disturbances

Graphical abstract



Highlights

- Adaptive capacity can change rapidly after climate disturbances
- The type and severity of impacts mediate changes in adaptive capacity
- After cyclones, assets and flexibility decreased; agency and organization increased
- Bleaching impacts were followed by less frequent change in adaptive capacity

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In brief

Adaptive capacity (AC) building programs are developed globally to help people adapt to climate change. However, our limited understanding of how AC changes after disturbance might limit program effectiveness. Our study shows that specific components of AC, such as assets and flexibility, can decline rapidly, especially after severe disturbances.

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Changes in reef tourism's adaptive capacity after severe climate disturbances

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SCIENCE FOR SOCIETY Understanding adaptive capacity is important to assess whether and how people will be able to deal with climate (and other) disturbances. Most studies on adaptive capacity have not, however, considered how it might change over time, especially after severe shocks. Here, we show that the adaptive capacity of individuals can change rapidly after they are affected by a severe disturbance. Reef tourism operators affected by tropical cyclones experienced reductions in their assets and flexibility (boats, savings, and accessible reef sites), while their levels of agency (management participation) and social organization (ties to research institutions) increased. We found less frequent changes in adaptive capacity following impacts from coral bleaching. Our study informs efforts to build adaptive capacity by providing insights into which components of adaptive capacity may be most vulnerable to disturbance, as well as by demonstrating how bolstering one component may impact others.

SUMMARY

Knowledge about adaptive capacity and its determinants has increased significantly over the last decade. However, most research on adaptive capacity has been static, not considering how adaptive capacity might change over time, particularly after severe disturbances. We studied the adaptive capacity dynamics of Asian-Pacific reef tourism operators affected by coral bleaching and tropical cyclones compared with a control group with non-affected operators. We found that impacts from tropical cyclones were associated with frequent changes in adaptive capacity. Notably, we found a reduction in tangible attributes (assets and flexibility) of adaptive capacity, whereas intangible attributes (agency and social organization) increased. Our findings provide evidence that adaptive capacity is not necessarily a slowly changing variable; rather, adaptive capacity can change rapidly and in complex ways following severe climate impacts. Understanding adaptive capacity dynamics can support adaptation programs by showing where changes in capacity are most likely to occur after severe climate impacts.

INTRODUCTION

Adaptation has long been recognized as a key element of maintaining an appropriate degree of fit between an individual and its environment.[1] Building on its original scientific formulation in evolutionary biology, research on adaptation has developed and generalized the concept of *adaptive capacity*: the idea that particular attributes or "capacities" of individuals (or of complex systems composed of multiple interacting individuals) determine their ability to respond successfully to change.[2] For example, in ecology, successful adaptations to environmental change (i.e., those that ensure long-term viability) are more likely to arise in populations with faster turnover rates and large populations with variable genomes because these properties increase the chance that a favorable mutation will arise and spread through a population.[3,4] In human societies, successful adaptation tends to be associated with reductions in social vulnerability (i.e., the susceptibility of communities and people to be harmed by social and environmental change[5,6]). Social vulnerability differs between communities depending on their exposure, sensitivity, and adaptive capacity to change.[7] The mechanisms underlying adaptive capacity relate closely to societal properties such as trust, information, and wealth.[8,9]

Building and supporting adaptive capacity in both human societies and ecosystems has become vital in a world that is increasingly affected by severe ecological and social disturbances. Adaptive capacity in human societies has been specifically defined as the attributes of society that enable it to prepare, modify, and improve itself in response to a changing environment.[7,10,11] The scientific literature on adaptive capacity has increased exponentially since 2009,[12–14] but most empirical work characterizes adaptive capacity at one point in time, although the determinants of adaptive capacity and vulnerability are argued to be dynamic.[7,15]

Understanding whether and how adaptive capacity changes (and can be changed) over time would provide important insights for policymakers trying to address adaptation barriers and social vulnerabilities.[16–18] Yet only a limited number of studies have examined empirically whether and how adaptive capacity changes over time. Two of these studies have done so qualitatively[19,20] and four quantitatively.[18,21–23] These studies found that attributes related to financial assets, social networks, and attachment to place experienced changes over time in some cases.

Generally, it would be expected that adaptive capacity, as a slow-moving variable (system state), would only change gradually over longer time periods.[24] Empirical evidence supports this hypothesis. Cinner et al.[21] found that two indicators (out of a total of nine) of adaptive capacity (credit availability and infrastructure) increased slightly and significantly over a 4-year period in a coastal community in Kenya that did not experience any major disturbance. Adaptive capacity also increased slightly for French Polynesian households despite several drivers of change (e.g., cyclones, coral bleaching, and socioeconomic crisis).[18] Although existing empirical evidence aligns with the hypothesis that adaptive capacity is a slowly changing variable (5-to-10-year time scales or longer) due to the social and economic processes underlying its rate of change (e.g., slow shifts in awareness, education, or levels of investment in different priorities), this hypothesis has not yet been robustly tested against alternatives.[25]

Here we address this gap in the existing literature by contrasting the hypothesis that adaptive capacity changes slowly with an alternative hypothesis that rapid post-disturbance responses (1–2 years) may occur in adaptive capacity, based on faster-changing socioeconomic responses and flexibility. We tested whether changes in adaptive capacity 1 year after a climate disturbance differed between actors based on their experienced severity of a (climate) disturbance. We used a period of 1 year after a disturbance because we wanted to test the hypothesis that short-term shifts in adaptive capacity are possible. We also tested the direction in which different domains of adaptive capacity moved after severe disturbance.

We studied the dynamics of adaptive capacity in a coral reef tourism context. Coral reefs have already come under severe threat from elevated water temperatures and changes in disturbance regimes due to climate change.[26,27] Both the frequency and severity of coral bleaching (occurring when the thermal tolerance of corals and their symbiotic algae is exceeded)[28,29] and tropical cyclones[30] are driven by increasing sea temperatures and can lead to significant loss of coral reefs. The degradation of coral reefs can affect the tourism industry in a direct and immediate way. For example, an increasing trend in visitor numbers to the Great Barrier Reef (GBR) in Australia leveled off after the severe mass bleaching event in 2016, with visitor numbers beginning a slow decline thereafter.[31] The impacts of coral bleaching in particular, especially the mass bleaching event of 2016, which affected reefs across the globe,[32] offer a useful case study because they were geographically extensive while still being sufficiently homogenous for comparative purposes.[27] We used a comparative sample with cyclone-affected operators because cyclones have different ecological and social impacts. Cyclone-related damage to coral reefs is typically less extensive than bleaching-related coral mortality but more severe in the short term because it affects not only the coral polyps but also the reef substrate. Additionally, cyclone impacts affect people's adaptive capacity directly because the impacts are not just in the water but also on and above ground (e.g., direct damage to tourism infrastructure and assets).

We conducted 213 surveys with representatives (e.g., owners or managers) of reef tourism companies (operators) across the Asia-Pacific to obtain information about their adaptive capacity before and after a severe climate disturbance. A third (32%) of the total sample consisted of operators in Indonesia, followed by 27% from Australia, 11% from Japan, 8% each from Fiji and the Mariana Islands, and 7% each from the Hawaiian Islands and French Polynesia. Our sample includes a less-affected control group to explore whether increasingly severe climate change impacts led to significant changes in people's adaptive capacity. The sampling strategy and sample details have been described in the experimental procedures. We built on the adaptive capacity framework proposed by Cinner and colleagues[11,33] by capturing factors within six interrelated domains of adaptive capacity. The domains that are argued to represent adaptive capacity are assets (e.g., access to financial resources), flexibility (e.g., to switch between adaptation strategies), learning (e.g., capacity to generate, absorb, and process information about climate change), (social) organization (e.g., social networks, social capital), agency (e.g., the power and freedom to change), and socio-cognitive constructs. The domain of socio-cognitive constructs reflects so-called "second generation" theories on adaptive capacity, which have focused on the psycho-social factors such as adaptation confidence that enable the mobilization of assets and other determinants (such as flexibility) to successfully adapt to climate change.[34,35]

We developed 15 key actor-specific indicators (Figure 1) to capture the six broad domains of adaptive capacity.[36] The adaptive capacity indicators were based on an empirical review of determinants of adaptation by microeconomic actors,[37] a review of disaster risk reduction and behavioral science literature on adaptive capacity,[35] and on tourism industry expert consultation (M. Curnock, 2019, personal communication). The indicators we

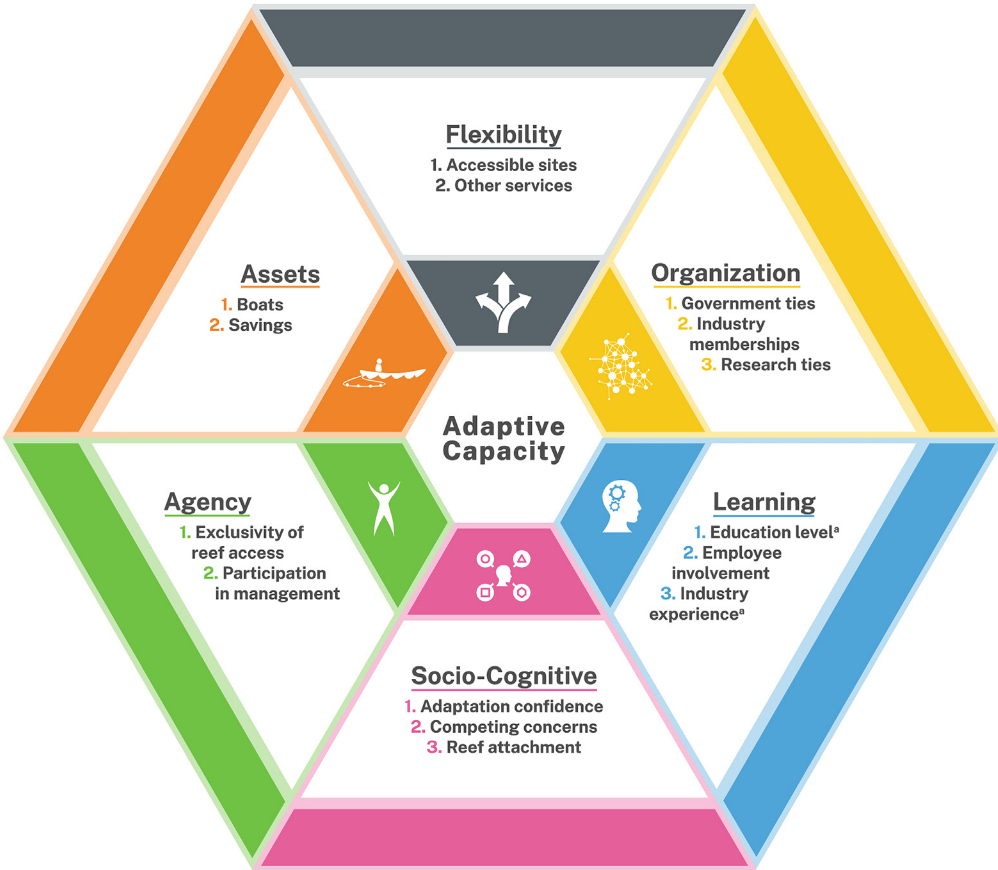

Figure 1. Indicators of adaptive capacity based on adaptive capacity domains by Cinner and Barnes

Indicators were measured using recall data in two time periods: 1 month before and 1 year after a climate disturbance occurred. All variables were measured as ordinal variables using multiple-choice categories. For participation in management (agency), we used separate questions for participation in coral and tourism management. Boats (assets) were measured in passenger seats; exclusivity of reef access (agency) was measured as being either open, limited, or exclusive; and reef attachment (socio-cognitive constructs) was measured as the stated importance of the reef sites the operator was using for the identity of the company.
[a] Education level and industry experience are associated with the manager of the reef tourism operator.

used are justified in detail in Bartelet et al.,[36] and the ordinal levels we used in this study are described in Table S2.

To overcome the challenges associated with longitudinal analyses,[38,39] we adopted a pragmatic approach using recall data from participants about different attributes of adaptive capacity before and after a severe disturbance. We limited our study to bleaching and cyclone events that occurred in the last 5 years (2014–2019) due to the need for accurate recall data from respondents.[40] Recall bias was minimized by designing our surveys with multiple-choice categories with less-detailed answer alternatives,[41] also helping to provide a consistent and directly comparable level of detail in the answers. We asked each respondent first about their answer for each adaptive capacity indicator, as they judged it to be one month before a specific climate disturbance. We then asked whether the indicator was different 1 year after a specific climate disturbance, and if so, we again asked how they judged the indicator to be 1 year after the climate disturbance. For operators that were affected by two consecutive climate disturbances (e.g., GBR in Australia), we used 1 year after the latest disturbance as the reference period. In two out of our 213 surveys, respondents answered that an indicator was different 1 year after a specific climate change but consequently selected the same multiple-choice category as an answer, which would reflect either no change or a change that was within the same answer category. We followed up with the operators to identify whether it was a positive or negative change and included their answer in our subsequent analysis. In our dataset,[42] we captured this response by decreasing the indicator category by 0.5 instead of by one or more levels. Because not all operators might have answered that an indicator changed after a disturbance if it was within the same multiple-choice level, our survey might have missed more subtle changes in adaptive capacity. Our results should thus be interpreted as being focused on more substantial changes in adaptive capacity.

Our analytical design included *a priori* treatment and control groups of tourism operators based on whether their reef sites had been directly affected by a specific climate disturbance. For example, in Australia, we included tourism operators from the southern GBR that were less directly affected by coral bleaching in 2016 and 2017.[43] We included a question about

Table 1. Observed changes in adaptive capacity indicators by disturbance type and severity

Adaptive capacity indicator	Δ	Operators: control (0%) (n = 62)	Operators: bleaching (<50%): (n = 86)	Operators: bleaching (>50%): (n = 39)	Operators: cyclone (>25%) (n = 26)
Exclusivity of reef access	−, +	0%, 2%	0%, 0%	0%, 3%	0%, 0%
Coral mgmt	−, +	0%, 2%	0%, 6%	3%, 5%	0%*, 12%*
Tourism mgmt	−, +	0%, 3%	0%, 5%	3%, 8%	0%, 8%
Savings	−, +	4%, 7%	5%, 10%	9%, 9%	27%**, 0%**
Boats	−, +	0%, 3%	5%, 3%	5%, 5%	27%***, 0%***
Other services	−, +	0%, 10%	1%*, 1%*	0%, 3%	0%, 0%
Accessible sites	−, +	2%, 5%	3%, 2%	5%, 5%	42%***, 0%***
Education	−, +	0%, 2%	2%, 0%	0%, 3%	0%, 4%
Experience	−, +	5%, 3%	1%, 2%	3%, 3%	4%, 4%
Employee involvement	−, +	2%, 3%	7%, 1%	3%, 3%	4%, 4%
Govt. ties	−, +	0%, 2%	0%, 0%	0%, 0%	0%*, 15%*
Research ties	−, +	0%, 0%	3%, 1%	0%, 0%	0%***, 23%***
Industry member	−, +	0%, 5%	0%, 3%	3%, 0%	4%, 4%
Reef attachment	−, +	0%, 0%	3%, 0%	10%*, 3%*	12%**, 4%**
Comp. Concerns	−, +	0%, 2%	2%, 5%	3%, 8%	27%***, 15%***
Adaptation conf.	−, +	2%, 0%	2%, 6%	5%*, 8%*	15%**, 12%**

This table shows the percentages of sampled operators within each set of samples that experienced either a decrease (−) or an increase (+) in a particular indicator of adaptive capacity. From left to right, columns describe operators that had none of their reef sites severely affected by either coral bleaching or a tropical cyclone (control sample); operators that had 25% or 50% of their reef sites severely affected by coral bleaching; operators that had 75% or 100% of their reef sites severely affected by coral bleaching; and operators that had at least 25% of their reef sites affected by tropical cyclone impacts. Indicators that changed for a significant fraction of reef operators, compared with the control set, are shown with asterisk presenting significant results (p values), respectively, below 5% (*), below 1% (**), and below 0.1% (***). Significance test based on Pearson's[44] chi-square test of independence, with results available in our dataset.[42]

disturbance severity in our surveys to check whether the treatment/control divide was consistent with operators' personal experiences. We divided our total sample of 213 operator surveys into four sets based on their self-reported severity of climate change impacts. The four sets were, respectively, composed of control, bleached, severely bleached, and cyclone impacted samples. The control group consisted of all operators that had none of their reef sites (that they were using before the disturbance) severely affected by either coral bleaching or a tropical cyclone. The bleached set consisted of operators that had up to 50% of their reef sites severely affected by coral bleaching, while the severely bleached set included operators that had more than 50% of their reef sites severely affected by bleaching. Finally, the cyclone set consisted of operators that had at least some (25% or more) of their reef sites affected by tropical cyclone impacts. We used a different cut-off point for cyclones (25% instead of 50%) because the set was not large enough to distinguish between less and more severely affected operators.

For each set of samples, we calculated the fraction of samples that experienced a change (either a decrease or an increase) in each of the adaptive capacity indicators. Using non-affected operators as the control group, we used Pearson's[44] Chi-square test of independence with significance thresholds (p value) of 5% to test whether changes in adaptive capacity were significantly different in the three sets with operators that were affected by climate change impacts.

Finally, within each of the sets that experienced changes in multiple indicators that were significantly different from the control group, we tested whether changes in different adaptive capacity indicators clustered together. We used Spearman's rank-order correlation to test whether changes between different adaptive capacity indicators were significantly associated.

RESULTS

Observed changes in adaptive capacity by disturbance type and severity

The analysis indicated that most operators in our control set did not experience any change in their adaptive capacity 1 year after a climate disturbance that did not affect them directly (Table 1).

In the control set, the most notable change was that 10% of the sampled operators increased their flexibility by increasing the number of services they sold other than tourism activities. Examples of services to which operators in the control set diversified were first aid training, accommodation, equipment servicing, and transportation. Operators in the bleached set of samples (<50% of their reef sites severely bleached) did not experience significantly different changes in adaptive capacity compared with the control set and did not experience a similar increase in flexibility through increased service offerings. Operators in the severely bleached set (>50% of reef sites severely bleached) experienced significantly different changes in adaptive capacity compared with the control set in terms of their reef attachment (socio-cognitive constructs) and adaptation confidence (socio-cognitive constructs). Specifically, reef attachment decreased for 10% of the sampled operators, while adaptation confidence increased for almost a tenth (8%). Operators in the cyclone set experienced the most notable changes in adaptive capacity, with nine indicators that changed significantly compared with the control sample (Table 1). Although assets (savings and boats) and flexibility (accessible sites) decreased after severe cyclone impacts, agency (participation in coral management) and social organization (ties to government and research institutions) increased. Like the severely bleached set, reef attachment decreased. Other indicators associated with socio-cognitive constructs (competing concerns and adaptation confidence) experienced changes in both directions.

Correlations between changes in adaptive capacity

For impacts from tropical cyclones, operators that experienced reductions in boats (assets, measured in passenger seats) were significantly more likely to also experience reductions in savings (assets; rho = 0.41, p = 0.036) and accessible dive and snorkel sites (flexibility; rho = 0.53, p = 0.005) (Figure 2A). Operators that experienced a reduction in savings were significantly more likely to have also experienced a reduction in their adaptation confidence (socio-cognitive constructs; rho = 0.63, p = 0.001). Operators that had a lower reef attachment (socio-cognitive constructs) after a tropical cyclone were significantly more likely to have experienced an increase in adaptation confidence (socio-cognitive constructs; rho = −0.60, p = 0.001). Operators in countries with higher government effectiveness (contextual condition), in Australia compared with Fiji, were significantly more likely to have lower reef attachment after a tropical cyclone (socio-cognitive constructs; rho = −0.40, p = 0.043). Finally, operators that experienced an increase in government ties (social organization) were significantly more likely to also have experienced an increase in research ties (social organization; rho = 0.53, p = 0.006) and competing concerns (socio-cognitive constructs; rho = 0.40, p = 0.042).

Operators affected by coral bleaching experienced less frequent changes in adaptive capacity after this disturbance (Table 1), and we therefore found less common and weaker relationships between changes (Figure 2B). For impacts from coral bleaching (n = 125), operators that experienced reductions in boats (assets, measured in passenger seats) were significantly more likely to also experience reductions in accessible dive and snorkel sites (flexibility; rho = 0.21, p = 0.025). Changes in reef attachment (socio-cognitive constructs) were positively correlated with changes in employee involvement (learning; rho = 0.26, p = 0.006). Operators in countries with higher government effectiveness (contextual condition) were significantly less likely to experience an increase in participation in coral management after a bleaching event (agency; rho = −0.19, p = 0.047).

DISCUSSION

We explored the dynamics of adaptive capacity at an individual-actor level to test whether there is a relationship between the type (coral bleaching and tropical cyclones) and severity of disturbances and changes in adaptive capacity. In our control set with non-affected tourism operators, adaptive capacity remained relatively constant over time. We found a significant increase only in livelihood diversity (flexibility). This finding supports that of Cinner et al.,[21] who identified slight improvements in adaptive capacity over time for non-affected community members. In this study, for impacts from coral bleaching, most operators did not experience any change in their adaptive capacity attributes. However, the most-severely bleaching-affected operators were significantly more likely than operators in the control group to experience changes in two indicators within the adaptive capacity domain of socio-cognitive constructs: reef attachment and adaptation confidence. Impacts from tropical cyclones, on the other hand, were associated with significant reductions in assets and flexibility, increased agency and social organization, and changes in both directions for socio-cognitive constructs. Our findings differ from those of Thiault et al.,[18] who also focused on impacts from bleaching and cyclones in French Polynesia but found that the adaptive capacity of households overall increased slightly. The difference in results can be explained by two elements of their study design. First, Thiault et al.[18] evaluated changes over a 5-year period (while we used a 1-year period), and any negative impacts on adaptive capacity might have been compensated for in the longer period after some of the disturbances occurred. Second, the authors might not have specifically included the most-severely affected groups by the climate events that occurred in their sample period because this was not the aim of their study. Further research is required to understand how the detailed dynamics of adaptive change over different time periods and to understand how long it takes for adaptive capacity to bounce back to its pre-disturbance level.[48]

Severe impacts from coral bleaching and cyclones led a significant fraction of the operators we sampled to experience a reduction in their company's attachment to the reef sites that they were using. We do not know whether this was an active or passive process. We had measured reef attachment on an ordinal scale reflecting whether the reef sites an operator was using were not, somewhat, or of major importance for the company's identity. This could be interpreted as operators trying to decouple their business from an ecological environment that is increasingly under threat from climate change. This is an important finding because loss of people's ties to specific coral reefs could lead to a loss or change of cultural values,[49] impacting the social license for reef conservation. For tropical cyclone impacts, reductions in reef attachment were more common in Australia than Fiji, indicating that tourism operators in Australia might have less strong cultural ties to reefs and/or more other attractions to use in diversifying their business.

More generally, our findings contribute to understanding adaptive capacity by providing real-world evidence that adaptive capacity can change rapidly and in multiple ways following severe disturbance. Although adaptive capacity is often considered a slow-moving[24] and path-dependent[1,2] variable, our findings, at least for severe impacts from tropical cyclones, suggest that other pathways are possible. It is particularly interesting that changes in adaptive capacity occurred in different directions depending on which domain of adaptive capacity was considered. An interesting question is whether the observation that different adaptive capacity domains changed in different ways indicates that some adaptive capacity domains are being degraded due to impacts from climate change or whether it reflects people

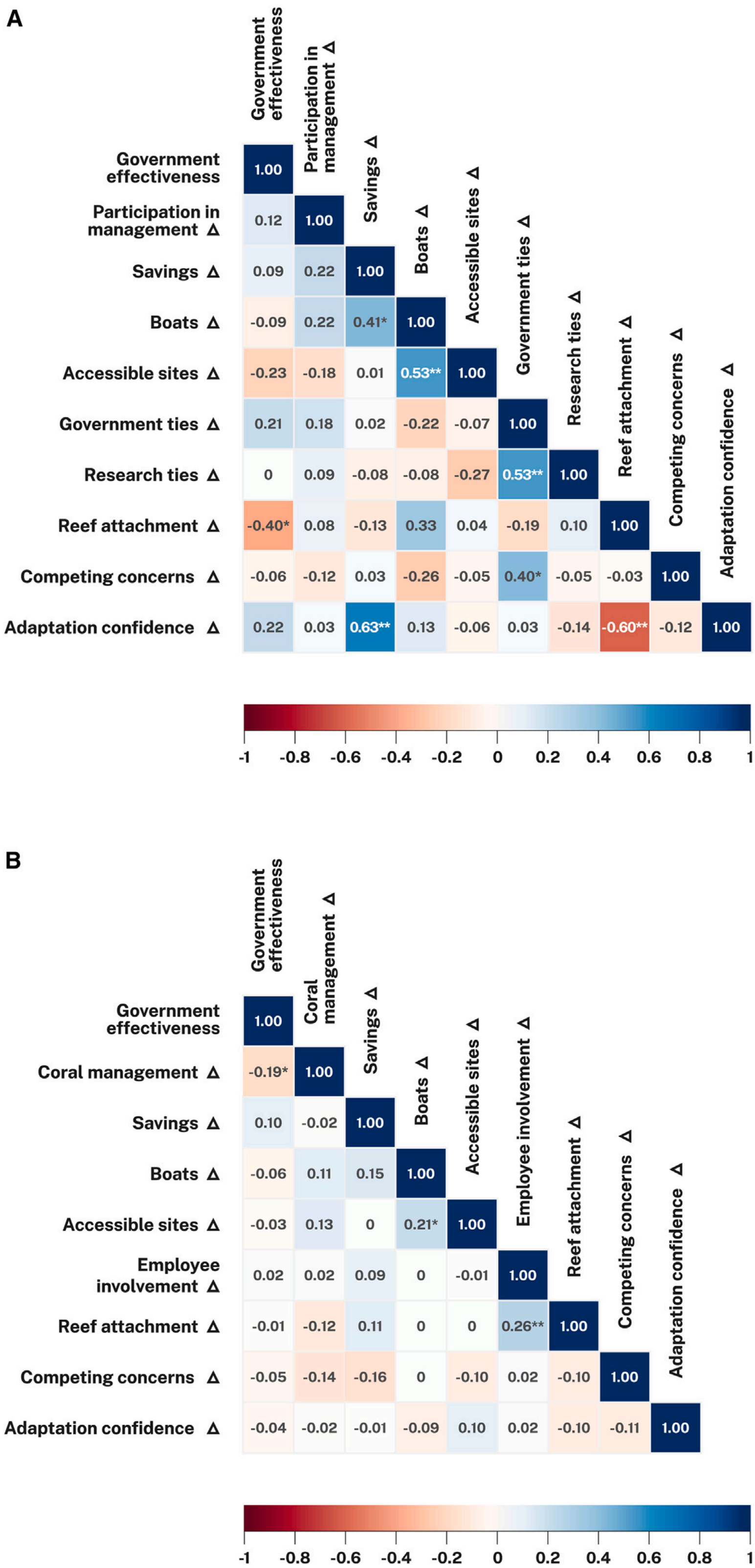

Figure 2. Cross-correlations between changes in adaptive capacity

Graph describes the Spearman rank's correlation coefficients, respectively, for operators within the tropical cyclone subsample (A, n = 26) and the coral bleaching subsamples (B, n = 125). Government effectiveness[45,46] is a binary indicator that shows whether the operator is based in a country with higher government effectiveness versus lower government effectiveness. Participation in management refers to coral reef management (Table 1). We visualized correlations between changes in adaptive capacity indicators using the *corrplot* package in R. We cross-verified the correlations using Kendall rank-order correlation, which is usually more stringent for smaller sample sizes[47] and found no differences that changed the significant results we found. Asterisk reflects significance with * indicating p value less than 5%, ** indicating p value less than 1%, and *** indicating p value less than 0.1%.

(operators) shifting effort or resources between domains to bolster responses to specific types of impact. Although more tangible attributes of adaptive capacity (e.g., assets and flexibility) were reduced after severe impacts, less-tangible attributes such as agency and social organization tended to increase after disturbance. Changes in socio-cognitive constructs moved in both directions; further research is needed to determine whether these findings are consistent in other contexts. Our findings might be explained by the conservation of fragility hypothesis, which argues that all systems are fragile in some way and that no system is able to develop adaptive capacity to every threat.[50,51] From theoretical and practical perspectives, it seems unlikely that adaptive capacity would increase along all axes (or in all domains) at the same time; the more interesting question is whether trade-offs between adaptive capacity domains are predictable in some way, for example if some elements of adaptive capacity are naturally antagonistic to one another. There may, for example, be social-ecological parallels to the ecological trade-offs between the benefits of increasing body mass and the energetic costs of maintaining a higher body mass.[52]

Our findings also support calls to better understand how different indicators of adaptive capacity relate to one another.[13,53] We found that changes in adaptation confidence, our proxy for self-efficacy,[36] were significantly correlated with changes in both savings and reef attachment. Specifically, a loss of savings was frequently paired with loss of adaptation confidence, while reductions in reef attachment were frequently associated with increased adaptation confidence. These results are relevant to the growing literature that highlights the importance of self-efficacy for adaptation to climate change[34,54] because we provide potential explanations for changes in people's underlying levels of self-efficacy. For example, operators that had lowered attachment to their reef sites were more likely to experience an increase in adaptation confidence even if they were significantly affected by a cyclone. This could indicate that some of the operators might have diversified their operations away from coral reef attractions that may be perceived as at-risk from environmental change. The association between savings and adaptation confidence is interesting because the adaptation literature has proposed the idea that socio-cognitive factors may play a larger role in people's adaptation behavior than their physical and financial wealth.[35,55] However, our results indicate that whether people's self-efficacy remains high after climate change impacts might be intrinsically linked to whether or not they experience a decrease in financial assets.

We found other significant correlations between changes in adaptive capacity. A decrease in the accessible dive/snorkel sites (flexibility) was significantly correlated with a loss in boats (assets) for both cyclone and bleaching impacts, but we are unable to determine which change was the cause of the other. Operators that had their boats damaged by a cyclone might have been less able to reach their offshore dive/snorkel sites, whereas on the other hand, damage to dive/snorkel sites might have led some operators to reduce their boat capacity and focus on on-land attractions instead. For bleaching impacts, we found that operators that increased their employee involvement in decision-making after a disturbance were more likely to experience an increase in reef attachment. This finding could indicate that decentralization within the tourism industry could be associated with a strengthening of social-ecological ties.[56] Finally, for bleaching impacts, we found that operators in countries with higher government effectiveness were significantly less likely to have experienced an increase in their participation in coral management. Operators in countries with higher government effectiveness may assume that their governments will take control of adaptation, and they therefore do not need to take matters into their own hands.[8,35]

Our findings could provide some insights into the "weakest link" hypothesis,[53] indicating that adaptive capacity is only as good as the weakest link, i.e., there might be a specific component of adaptive capacity that is critical for all others to be effective. For example, we found that changes in assets (savings) might be affecting people's self-efficacy, measured as adaptation confidence (socio-cognitive constructs). At the same time, changes in flexibility (accessible reef sites) might be underlying changes in assets (boats). Without understanding such interlinkages in adaptive capacity, it could be argued that it is best for programs aimed at building adaptive capacity to focus on building general resilience (the capacity to adapt or transform to unforeseen, non-specific disturbances)[57,58] by spreading efforts across all adaptive capacity domains rather than focusing on only one or two. Focusing on general resilience can help to support effective adaptation to different types of disturbances and change, but it might be a less efficient strategy to provide resilience for specific disturbances.

Critiques and caveats

The main limitation of our study is that we used recall data to study changes in adaptive before and after climate disturbances. Although we have taken steps to reduce recall bias by using less-detailed questions, recall data will always be less accurate than direct observations in real time. Further research on this topic in related contexts is therefore needed to further validate our results, where possible, using before and after studies. Moreover, because we used less-detailed questions, our results have likely not picked up on more subtle changes in adaptive capacity, and the percentages of sampled operators that experienced a change in adaptive capacity (Table 1) are therefore likely to be underestimated and more representative of substantial changes in adaptive capacity. Another caveat is that our data collection occurred between October 2020 and December 2021, during the first one and a half years of the COVID-19 pandemic. Impacts from this pandemic could potentially have affected operators' perceptions of their adaptive capacity and how they were evaluating the past climate disturbances that we were interested in.

Conclusions

We studied the dynamics of adaptive capacity within a coral reef tourism context. We found that impacts from coral bleaching, even when severe, did not strongly affect reef tourism operators' adaptive capacity, although there was a small but significant number of operators that experienced a reduction in reef attachment (agency) and an increase in adaptation confidence (socio-cognitive constructs). Impacts from tropical cyclones, on the other hand, led to frequent and significant changes in several indicators of adaptive capacity. More tangible attributes of adaptive capacity (i.e., assets and flexibility) were negatively impacted by tropical cyclones, whereas intangible attributes (agency and social organization) generally increased. Indicators within the adaptive capacity domain of socio-cognitive constructs changed in both directions. Our findings indicate that adaptive capacity is not necessarily a slow-moving variable and that context is important, in our case the type of disturbance and its experienced severity. Finally, we found that some of the changes in adaptive capacity were significantly related. For example, adaptation confidence increased for operators that reduced their reef attachment, whereas adaptation confidence decreased for operators that experienced reductions in their savings. Our findings suggest that the dynamics of adaptive capacity are complex and will require further in-depth investigation and empirical evidence to be fully understood.

EXPERIMENTAL PROCEDURES

Resource availability

Lead contact

Further information and requests for resources and reagents should be directed to and will be fulfilled by the lead contact, Henry Bartelet (henry.bartelet@jcu.edu.au).

Materials availability

This study did not generate new, unique reagents.

Data and code availability

The datasets generated during this study are available at James Cook University's Research Data Repository.[42]

We focused our sampling on the Asia-Pacific Region, which contains 80% of coral reefs globally.[59] We deliberately selected locations where high reef tourism density[60] coincided with high bleaching severity.[27] We selected study locations in countries spanning a range of human and institutional development so that we could interrogate the assumption that people in countries with lower living standards have lower capacity to adapt than their counterparts in more affluent countries.[61–63] We also implemented a separate survey for reef tourism operators from Fiji and Australia that had been subject to cyclone impacts (Cyclone Winston in 2016, Cyclones Yasi in 2011, and Debbie in 2017, respectively) to explore the influence of the type of climate disturbance on the relationship between adaptive responses and outcomes.

We sought to represent the full population of in-water reef tourism operators that offered recreation-based activities (e.g., diving and snorkeling) that are directly linked to coral reefs. Operators were identified through an online search (Google search engine, Google Maps, and TripAdvisor) with the search terms "coral tours," "coral reef tours," "reef diving," "reef snorkeling," and a term for the location. We identified a total of 650 reef tourism companies within our study locations that were in operation during the specific climate disturbances we studied, the majority (196) in Bali and Lombok, Indonesia. An Excel sheet with the reef tourism companies we identified is available in our data file.[42] All operators we identified were initially invited through e-mail and were later followed up with through either in-person visits or phone calls. For our sampling in Guam, Indonesia, Japan, Saipan, and the Hawaiian Islands, we employed local research assistants to contact potential participants. The lead author contacted operators in Australia. Surveys with company representatives were undertaken online with Kobotoolbox survey software. Surveys were administered in local languages (e.g., Indonesian, Japanese, and English). Surveys were undertaken between October 2020 and December 2021. Overall, 211 out of 650 operators that were active at the time of a specific climate disturbance at the locations we selected agreed to participate (response rate: 32%). The total sample consisted of 213 operator surveys because two operators participated in two surveys (they were affected by both a cyclone and bleaching in different years). Sample sizes and fractions for each of the eight countries and 28 study locations are reported in Table S1. We do not expect meaningful differences in responses based on the time between the disturbance and the survey. That is because by far the largest fraction (189 out of 213, or 89%) of the operator surveys was associated with disturbances condensed in the years 2016–2017. The small number of remaining surveys were mostly associated with disturbances in 2014–2015 (Hawaiian Islands, 15 out of 213, or 7%), with only a handful associated with disturbances in 2011 (Cyclone Yasi, Australia, 2 out of 231) and 2019 (Bleaching in Lord Howe Island, Australia, and French Polynesia, 7 out of 231).

A research permit for Indonesia was obtained from the Indonesian National Research and Innovation Agency, Deputy for Strengthening Research and Development (Badan Riset Dan Inovasi Nasional, Deputi Bidang Penguatan Riset dan Pengembangan) on August 23, 2021, under application identification number 41/TU.B5.4/SIP/VIII/2021. Research in Indonesia was undertaken under Memorandum of Agreement with its Indonesian counterpart, the University of Mataram, Faculty of Agriculture (Fakultas Pertanian, Universitas Mataram). Other locations were covered under a research permit that was obtained from James Cook University's Human Research Ethics Committee on July 20, 2020, under application identification number H8167.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.crsus.2024.100061.

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AUTHOR CONTRIBUTIONS

H.A.B. conceived the manuscript and developed the methodological approach with input from M.L.B. and G.S.C. H.A.B. collected data in Australia, the Hawaiian Islands, the Mariana Islands, Japan, Fiji, and French Polynesia; H.A.B. and L.A.A.B. collected data in Indonesia; H.A.B. ran the analyses and wrote the first draft. M.L.B., L.A.A.B., and G.S.C. helped write and revise the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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