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RESEARCH ARTICLE

Social adaptation can reduce the strength of social–ecological feedbacks from ecosystem degradation

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Abstract

1. Feedbacks between people and ecosystems are central to the study of social–ecological systems (SES) but remain poorly understood. It is commonly assumed that changes in ecosystems leading to a reduction in ecosystem services will trigger human responses that seek to restore service provision. Other responses are possible, however, but remain less studied.
2. We evaluated the effect of environmental change, specifically the degradation of coral reefs, on the supply of and demand for a cultural ecosystem service (CES); that is, recreation. We found that declines in coral cover reduced demand for recreational ecosystem services but had no apparent effect on the benefits received from recreation.
3. While this finding seems counter-intuitive given previous experimental data that suggest ecosystem quality affects people's satisfaction, our analysis suggests that social adaptation could have mediated the anticipated negative impact of environmental change on CES benefits. We propose four mechanisms that may explain this effect and that require further research: spatial diversification; (service) substitution; shifting baselines; and time-delayed effects.
4. Our findings emphasize the importance of human culture and perception as influences on human responses to environmental change, and the relevance of the more subjective elements of social systems for understanding social–ecological feedbacks.

KEYWORDS
adaptation, climate change, coral reefs, cultural ecosystem services, social–ecological systems, sustainability, tourism

1 | INTRODUCTION

Human responses to changes in ecosystems are the basis for a wide range of complex feedbacks within social–ecological systems. Understanding these cycles of causality, and particularly the ways in which adaptation by people mitigates the impacts of ecological change on human well-being, is becoming increasingly important as the scale and intensity of human impacts increases (Hughes, Barnes, et al., 2017). For example, the responses of fish communities to coral bleaching events, the knock-on effects on harvesting by humans, and consequent impacts on food security remain largely unknown (Eriksson et al., 2017). Globally, over the last century, ecosystems have declined while human well-being has increased (Raudsepp-Hearne et al., 2010); but it remains unclear how long this pattern can persist (Cumming et al., 2014). Presumably, global human well-being will decline rapidly due to famine and disease if a threshold is crossed in the production of provisioning and regulating services (Rockström et al., 2009). An extreme outcome such as the end of human civilization seems unlikely (Cumming & Peterson, 2017), but smaller, less obvious declines in human quality of life that result from ecological degradation occur frequently and can provide informative insights into social–ecological feedbacks and how they can be managed (Chapin et al., 2010; Maciejewski et al., 2015). Our research addresses an existing gap in knowledge of social–ecological feedbacks by exploring the human side of the nexus between people and ecosystems using the concept of Cultural Ecosystem Services (CES) (Chan, Guerry, et al., 2012).

CES refer to the interactions between people and nature that deliver non-material benefits that directly contribute to changes in human well-being (Fish et al., 2016). CES are inherently subjective, and the ways in which people value and experience CES are influenced by individual perceptions, preferences and socialization (Chan, Satterfield, & Goldstein, 2012; Fischer & Eastwood, 2016; Kenter et al., 2015; Zoeller et al., 2021). Depending on the magnitude of ecological change, ecosystem condition may be only a secondary driver of CES benefits; individual experiences of an ecosystem service may exert a stronger influence on CES benefits unless ecological degradation is extreme. Understanding the relationships between an ecosystem's condition, the services it produces, and its perceived effects on human well-being is vital in understanding human responses to ecosystem change and setting conservation priorities for degrading systems (Plieninger et al., 2013).

Recreation is an important CES. It is often enabled through the socioeconomic services offered by tourism operators. For example, in ecosystems like the Florida Everglades and the Australian Great Barrier Reef (GBR), it can be difficult for people without local knowledge and experience to recreate safely, affordably and comfortably without a third-party intermediary. By providing access to ecosystems in accordance with consumer preferences, tourism operators enable people to experience the ecosystem in different ways. The services delivered by tourism operators are in themselves not an ecosystem service (Pueyo-Ros, 2018), but the demand for tourism activities can be used as a tangible proxy for the intangible value of recreational ecosystem services and people's conservation priorities (i.e. 'willingness to pay') (van Berkel & Verburg, 2014). Indeed, the tourism sector often adds substantial value to the economy (Spalding et al., 2017), of which direct expenditures by tourists (to participate in tours) make up a large proportion. Linking CES benefits derived from recreation to monetary value can thus provide a useful metric to better understand how people perceive and value ecosystems, and how CES benefits might change in response to changes in ecological condition.

In this paper we empirically tested the impact of climate-induced ecosystem change on the demand for and satisfaction with recreation on coral reefs in the GBR region of Australia. The GBR is the world's largest coral reef ecosystem, covering 344,400 km^2 along the east coast of Queensland in Australia (Great Barrier Reef Marine Park Authority, 2021). It contributed $6.4 billion annually in economic value and 64,000 jobs to the Australian economy in the years 2015–2016 (Deloitte Access Economics, 2017). Due to increasing sea temperatures, marine heatwaves linked to El Niño conditions have exceeded the thermal limits of corals and their zooxanthellae (Hoegh-Guldberg, 1999). As a result, the GBR has been severely affected by coral bleaching. Bleaching events in 2016 and 2017 have had a severe impact on the integrity of the GBR ecosystem (Dietzel et al., 2020; Hughes et al., 2018), although there have been indications of reef recovery in recent years (Australian Institute of Marine Science, 2021).

2 | THEORETICAL FOUNDATIONS AND HYPOTHESES

We tested two sets of hypotheses that could explain the relationship between ecosystem conditions and recreation, as shown in Table 1.

We evaluated the effect of climate-induced ecosystem impacts on the tangible value of recreation by analysing the effects on the demand for tourism (H1). We posit two competing hypotheses here: first, that climate-induced impacts on the ecological quality of a nature-based tourism destination would negatively impact visitor numbers (H1a) (Pickering, 2011; Rosselló et al., 2020). Second, lower than expected quality of the ecosystem due to climate impacts may increase visitor numbers ('last-chance tourism', H1b). There are a number of empirical studies which led us to posit the first hypothesis. For example, a survey of 194 Canadian and 109 Australian scuba

TABLE 1 Overview of hypotheses and methods

Effect	Hypotheses
Hypothesis Set 1: Explaining demand	H10—no effect of coral bleaching on visitor numbers H1a—coral bleaching decreases visitor numbers ('reputation effect') H1b—coral bleaching increases visitor numbers ('last-chance tourism')
Hypothesis Set 2: Explaining satisfaction	H20—no effect of coral bleaching on visitor satisfaction H2a—coral bleaching decreases visitor satisfaction due to reduction in service received

divers revealed that the majority would change their behaviour in response to marginal reef conditions (Verkoeyen & Nepal, 2019). The most likely response was change of location, followed by decreasing dive frequency. Similarly, Uyarra et al. (2005) found that 80% of the 654 surveyed tourists on Bonaire and Barbados would not return to the island for the same price if coral bleaching occurred. However, a recent study suggested the opposite effect, that is, the impacts of climate change increased visitor numbers in a rush for taking advantage of the 'last chance' for people to visit the ecosystem (Piggott-McKellar & McNamara, 2017). Finally, we introduced a null hypothesis through which no change in visitor numbers would occur as a result of climate change impacts. The null hypothesis could be the result of a limited elasticity of tourism demand to changes in ecosystem quality (Mourey et al., 2020).

We evaluated the effect of climate change impacts on the intangible value of recreation by analysing satisfaction levels of tourists visiting the ecosystem (H2). Here, we hypothesized that climate change impacting the ecological quality of a nature-based tourism destination would negatively impact tourist satisfaction (H2b). Indeed, a number of studies have shown that visitors to coral reefs (and specifically divers) put a higher value on reefs with higher coral cover and biodiversity (Grafeld et al., 2016; Peng & Oleson, 2017; Pert et al., 2020; Schuhmann et al., 2013). However, tourist operators' ability to compensate for lower ecosystem quality by improving other parts of their offering could potentially offset any negative impacts on tourist satisfaction (Atzori et al., 2018). We thus included a null hypothesis (H20) that posited that tourist satisfaction would not be affected by coral bleaching. In the absence of compensation effects, the null hypothesis could also be explained by tourist satisfaction being insensitive to changes in ecosystem quality.

3 | METHODOLOGY

We used TripAdvisor (TA) data to extract the number of customer reviews as a proxy for visitor numbers (Ma & Kirilenko, 2021; Teles da Mota & Pickering, 2020). Although TA data have been found to be a good predictor of tourist flows (Ma & Kirilenko, 2021), we cross-verified our results with actual visitor data on the GBR (Great Barrier Reef Marine Park Authority, 2020). TA data were also used to extract customer satisfaction ratings, which have previously been used as a measure of recreation-based CES benefits (Cong et al., 2014).

We focused our research on tourism operators in the central and northern sections of the GBR because these areas were most severely affected by the coral bleaching events in 2016 and 2017 (Australian Institute of Marine Science, 2017; Great Barrier Reef Marine Park Authority, 2017; Hughes et al., 2018; Hughes, Kerry, et al., 2017). Our sample thus addresses reef tourism operators between Townsville and Cape Tribulation. Although it is possible that not all operators in these areas were directly affected by the bleaching events, they do operate in the areas that had the highest chance of being affected. We sampled the full population of in-water reef tourism operators that offer recreation-based activities like diving and snorkelling that are directly linked to coral reefs. These operators were identified through an online search (i.e. Google search engine, Google Maps and TripAdvisor) with the search terms 'coral tours' and 'coral reefs tours', and 'great barrier reef tours'. We excluded dive resorts because TA reviews will likely be biased towards rating the sleeping arrangements rather than reef-based tourism activities. Scenic flight operators and fishing charters were excluded because we judged their visitors to be less closely interacting with coral reefs during their tours as compared to in-water activities. Private charter boats were excluded because of the limited availability of TA data. Finally, we limited our analysis to TA reviews written in the English language to facilitate review content analysis. Our final dataset included a total of 41 coral reef tourism operators and some 48,000 customer reviews from the years 2008–2021. The choice for the time period of 12 years helped us to extract longer term trends in visitor numbers and tourist satisfaction.

In our experimental design, we included a counterfactual from a different and less impacted Australian ecosystem. Specifically, we paired reef locations and dates with tourist locations in the rainforest areas of Northern Queensland where the tourism operators included in our sample are also based. We made this decision because many people who visit the GBR also visit the nearby rainforest (Reef & Rainforest Research Centre, 2007). Through this counterfactual we therefore expected to include many of the same people in both datasets. Because of the linkage between coral reef and rainforest visitors, we acknowledge that the counterfactual might not be fully valid for H1 which related to demand for coral reef activities. In H1, we therefore hypothesized that a reduction in visitors to the reef would also lead to a reduction in visitors to the rainforest. However, for H2, related to tourist satisfaction, the counterfactual helped us to control for any potential exogenous changes in the underlying sample of tourists. For example, a demographic shift (e.g. age or nationality) might have caused a change in the rating bias of tours. For the counterfactual, we included a full sample of rainforest operators in the North Queensland region based on an online search (i.e. Google search engine, Google Maps and TripAdvisor) with the search terms 'rainforest tours' and 'Daintree tours'. Our dataset included a total of 18 rainforest tourism operators and some 17,000 customer reviews over the study period (2008–2021).

We extracted TA reviews using the web scraping package 'RVEST' (Wickham, 2019) in R modelling software (R Core Team, 2013). After extracting the TA data, the number of reviews and customer satisfaction ratings were averaged on a monthly basis. We then filtered out the seasonality in the data using the 'BFAST' package in R (Verbesselt et al., 2010). The 'BFAST' package iteratively filters out the trend, seasonal effects and noise components from time-series data using methods to detect breakpoints. Breakpoints are points in the time series when the trend switches from one direction to another. We analysed whether any breakpoints occurred in the number of TA reviews, and whether these breakpoints coincided in time with the occurrence of the coral bleaching events in 2016 and 2017. To better understand any existing trends in satisfaction ratings, we used an exploratory post-hoc analysis of the written reviews. To do so, we used R to assess how often specific words in TA reviews were used per year. We then extracted the words that had seen the largest relative increase and decrease over our sample period. We cleaned the data, as detailed in the supporting information, to remove any company names and/or words that could not be meaningfully interpreted.

3.1 | Research ethics

No ethical approval was required for this research.

4 | RESULTS

We identified two breakpoints in the monthly number of TA reviews for GBR tourism (Figure 1a). Over the period 2008 to 2016, the number of monthly reviews increased from 0 to 400. This increasing trend was likely the result of both increasing visitor numbers to the GBR, and increasing popularity of TA as a review medium. In the year 2016, a breakpoint was observed, with the number of monthly reviews decreasing from 600 back to 400 in 2020. The third breakpoint began in 2020, and was associated with the COVID-19 pandemic. Figure 1b shows the results for doing the same analysis on a nearby and less-impacted Australian ecosystem, the rainforest. We found two

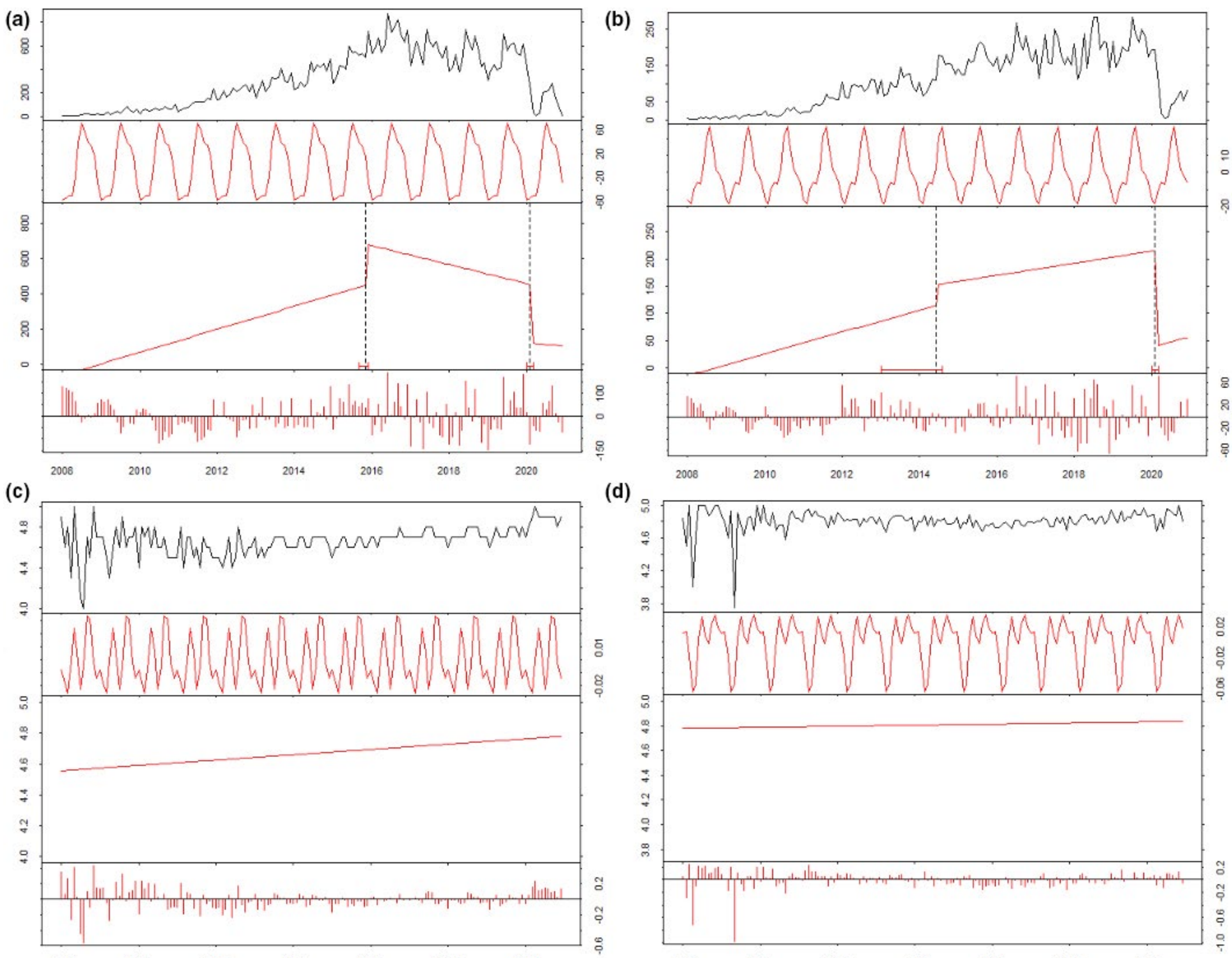

FIGURE 1 Trend analysis of reef and rainforest tourist operators. Top figures show number of TripAdvisor reviews for reef (a) and rainforest (b) tourism operators in Tropical North Queensland. Bottom figures show TripAdvisor customer satisfaction ratings (i.e. between 1 and 5) for same reef (c) and rainforest (d) operators. Reef operators' data based on 47,735 reviews of 41 reef tourism operators on the Great Barrier Reef between 2008 and 2021, specifically those that operate in the areas most affected by the 2016 and 2017 coral bleaching events (i.e. located between Townsville and Cape Tribulation). Rainforest operators' data based on 16,930 reviews of 18 rainforest tourism operators nearby the Great Barrier Reef between 2008 and 2021, specifically those visiting the Daintree Rainforest (i.e. operators between Cairns and Cape Tribulation). Datasets were aggregated and averaged on a monthly basis. Seasonality was filtered out using 'BFAST' package in R. The top frame in each figure displays monthly data, while the second panel depicts seasonal variation detected in the number of reviews over time. This seasonal variation was then removed and the resulting trend is displayed in panel three. The fourth panel depicts residual variation which cannot be accounted for in the seasonal variation or trend

breakpoints in the monthly number of TA reviews, a proxy for rainforest trips in the Cairns region of Tropical North Queensland. Over the period 2008 to mid-2014, the monthly number of reviews increased from about 0 to about 100. From mid-2014, the number of reviews increased from some 150 to some 200 in 2020.

The actual number of reef trips from our sample of operators, that is, Townsville (Tsv) to Cape Tribulation (CT), as well as for the GBR as a whole, levelled off around 2016 and started a slow decline (Figure 2).

Comparing TA review data to actual visitor data to the GBR, we found that the fraction of visitors that wrote a TA review ranged between 0.17% (2011) and 0.85% (2016). Assuming an average group size of four people, this meant that about 3% of groups visiting the GBR wrote a TA review. Although our TA sample thus includes only a small selection of visitors, we did find a similar breakpoint around the year 2016 in our cross-verification dataset (Figure 2). We noted that the same trend applies to the GBR as a whole, not just to those areas that were most severely affected by coral bleaching in 2016 and 2017.

No breakpoints were found in the customer satisfaction ratings for our sample of reef operators (Figure 1c). The average monthly customer rating increased from about 4.6 in 2008 to about 4.8 in 2020. This result showed no visible effect from the coral bleaching events in 2016 and 2017 on recreation-based CES benefits from the GBR in terms of tour-based satisfaction. Our analysis showed that average monthly customer ratings for rainforest tourism operators remained approximately constant at about 4.9 between 2008 and 2020 (Figure 1d). Thus, our results suggest that recreation-based CES benefits for the GBR have been increasing relative to benefits from rainforests in terms of tour-based satisfaction.

We identified several causal factors that could have been responsible for the increase in customer satisfaction ratings for GBR operators, despite the impacts from coral bleaching (Figure 3). We noted that most of the trends in word usage in the written reviews preceded the coral bleaching events by a number of years. We found, as shown in Figure 3a, that several words linked to the organization of the tours and the quality of staff have seen an increase in the written TA reviews, for example, 'team', 'knowledgeable' and 'informative'. Food and beverages might also have improved as the word 'delicious' has grown. On the other hand, as shown in Figure 3c, words related to the costs of the tours have decreased, for example, 'expensive', 'price' and 'pay'. Words related to the ecosystem featured prominently in the written reviews, for example, the words 'reef', 'coral' and 'fish' are used in respectively 61%, 16% and 23% of written reviews in the year 2019. However, we did not find strong trends in wording that are linked to the ecosystem, except for 'deep' that has decreased and 'clams' that has increased.

Our analysis showed that for rainforest operators, the relative growth in words seemed less steep compared to the reef operators. We also noted that the word 'knowledgeable' that saw strong growth with reef operators (14% of reviews in 2019) was already more frequently used for rainforest operators (35% in 2019).

Through our analysis and findings we were not able to reject two of the hypotheses that we posited at the start of our research (Table 2).

5 | DISCUSSION

We found support for our hypothesis (H1a) that climate change impacts on ecosystems led to a reduction in visitor numbers due to a societal response to ecological degradation. Specifically, our results show that the ecosystem impacts from coral bleaching could have contributed to a reduction in the demand for recreation on the GBR, as shown by the decreasing trend in visitor numbers around the time of the first bleaching event in 2016 (Figure 1a). Climate change impacts might have affected visitor numbers through marketing and reputational effects (Evans et al., 2016; Gössling et al., 2012). Previous research had shown that it was international visitor numbers to Tropical

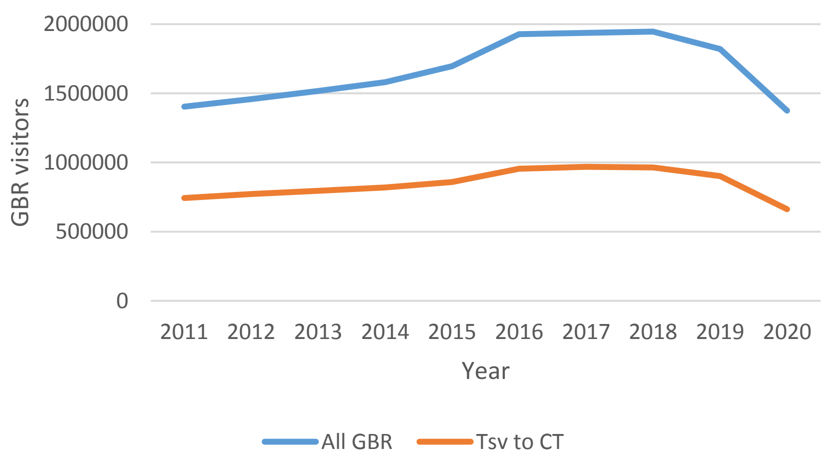

FIGURE 2 Great Barrier Reef (GBR) tourist numbers, derived from Environmental Management Charge receipts from commercial tourist operations (Great Barrier Reef Marine Park Authority, 2020). Townsville (Tsv) to Cape Tribulation (CT) includes Cairns/Cooktown Management Area, Townsville/Whitsunday Management Area (minus Whitsunday Plan of Mgmt). Includes only 'Full Day' and 'Part Day' visitations, but excludes 'Total Exempt's. The years reflect the financial year, thus the latest data point reflects mid-2020 and so the steep decline in the last year can be attributed to the impact of the COVID-19 pandemic

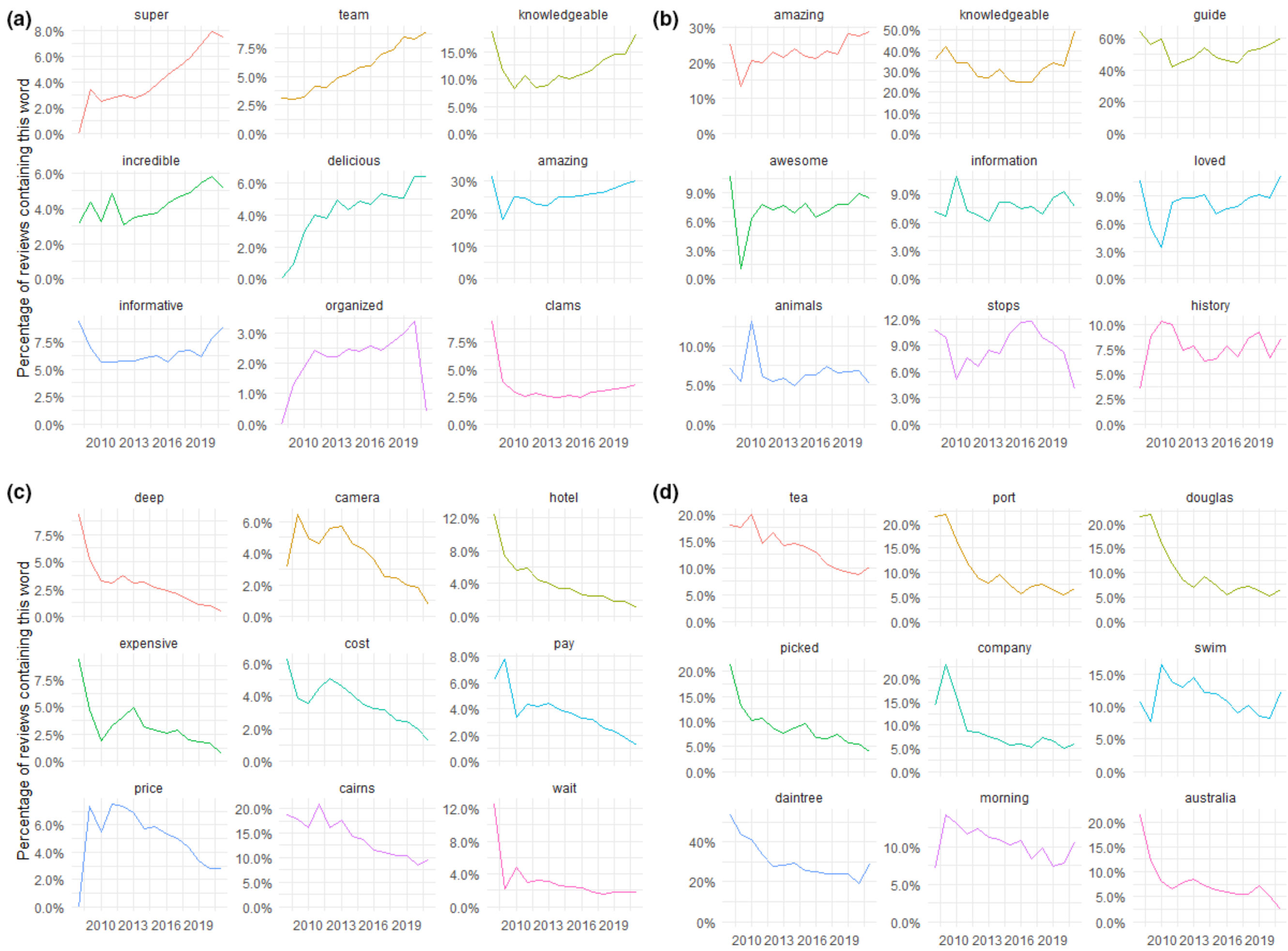

FIGURE 3 TripAdvisor review content. Top figures show words in review text that have seen the largest relative increase between 2008 and 2021 for reef operators (a) and rainforest operators (b) respectively. Bottom figures show words in review text that have seen the largest relative decrease between 2008 and 2021 for reef operators (c) and rainforest operators (d) respectively

TABLE 2 Summary of hypotheses and results. Bold hypotheses are those that our results were not able to reject

Effect	Hypotheses	Result
Hypotheses 1: Demand effect	H10—no effect of coral bleaching on visitor numbers **H1a—coral bleaching decreases visitor numbers ('reputation effect')** H1b—coral bleaching increases visitor numbers ('last-chance tourism')	A breakpoint in the trend of visitors occurred in the year of the bleaching event in 2016. Thus, we could not reject H1a
Hypotheses 2: Satisfaction effect	**H20—no effect of coral bleaching on visitor satisfaction** H2a—coral bleaching decreases visitor satisfaction due to reduction in service received	Visitor satisfaction kept its increasing trend despite bleaching. Thus, we could not reject H20

North Queensland, where the GBR is located, that peaked in 2016 and started a slow decline, while domestic visitations saw a strong increase post-2016 (Queensland Government, 2020). Thus, marketing and reputational effects might have mostly affected international visitors. There may also be other, non-climate related explanations for the trend changes in international and domestic visitor numbers however. For example, competition from other industries, like mining and construction, could have affected the opportunity cost for capital and the public and private priority of infrastructure expansion for the tourism industry (Jarvis et al., 2016). Thus, the reduction in visitor numbers could be explained by a supply (reduction in tourist capacity) rather than a demand effect. Our findings reject the 'last-chance' tourism hypothesis (Piggott-McKellar & McNamara, 2017) and the null hypothesis of a limited elasticity of tourism demand to changes in ecosystem quality (Mourey et al., 2020). We found that visitor numbers to rainforests in the same region as the GBR did not see a similar breakpoint, but kept their increasing trend (Figure 1b). This is surprising because previous research found that people tend to visit both forest and coral ecosystems on their trip to Tropical North Queensland (Reef & Rainforest Research Centre, 2007).

The hypothesis (H2a) that climate change impacts on ecosystems would lead to a reduction in the delivery of recreation-based CES benefits, as measured by tourist satisfaction, was not supported. Our results show that tourist satisfaction continued to increase throughout our sample period, despite severe coral bleaching events in the years 2016 and 2017 (Figure 1c). Thus, we found support for our hypothesis (H20) that coral bleaching would not affect visitor satisfaction levels. We found evidence for tourism operators' ability to compensate for lower ecosystem quality by improving other parts of their offering (Atzori et al., 2018). However, these compensatory services mostly preceded the bleaching events, and have thus not been implemented solely because of the impacts from coral bleaching. Specifically, we found evidence of several aspects of tour offerings that could have contributed to the increasing trend in satisfaction levels: the organization of the tours, quality of staff, knowledge about the ecosystem, food and beverages, and the quality-price ratio. Despite ecosystem-related words featuring frequently in TA reviews, we found little evidence for trends in the written reviews that linked to either the quality of the ecosystem, or climate change impacts. We found that the delivery of recreation-based CES benefits in the GBR, measured via tourism satisfaction, increased relative to rainforest operators in the same region, who to our knowledge have not seen similar climate-related ecosystem impacts (Figure 1d). Our findings could be interpreted as evidence for the (partial) substitutability of natural capital by man-made capital (Chiesura & de Groot, 2003). Specifically, a reduction in natural capital (e.g. quality of coral reefs) might have been compensated for by an increase in man-made capital (e.g. quality of staff). Further research is required to evaluate whether indications of such substitutability are also observed for CES in other contexts and places, in particular in locations that are considered more vulnerable because of lower levels of wealth (Brooks et al., 2005).

Our findings regarding the demand and satisfaction effects (H1 and H2) lead to a counter-intuitive implication. Namely, our results suggest that climate change impacts could have contributed to a reduction in tourist visitations. Yet our results also suggest that tourists who decided not to visit the GBR due to climate impacts would likely have received substantial recreation-based CES benefits if they had instead chosen to visit. Indeed, customer satisfaction ratings associated with GBR tourism have been continuously increasing (Figure 1c). Additionally, official GBR visitor data (Figure 2) show that the demand effect also affected GBR visitor numbers to areas that were not, or were less directly affected by coral bleaching (i.e. areas south of Townsville). Both findings imply a potential mismatch between people's travel behaviour, and the actual impacts from climate change. Similarly, during and after the severe bushfires in Australia in 2019–2020, tourist sites thousands of kilometres away from the fire-affected area had to deal with cancellations. This effect was likely related to significant (social) media coverage as well as governments, including the United States and United Kingdom, warning their visitors about travelling to Australia. Both in the bleaching and wildfire cases, further information is required about the demographics of tourism market segments that decided not to visit and their motivations. Individual-specific factors such as expectations (Cumming & Maciejewski, 2017), the perceived contribution of the service to well-being (Plieninger et al., 2013) and specific socio-demographic characteristics such as age and education level (Jarvis et al., 2016) have previously been found to be key contributors to tourist satisfaction, and they might also affect people's decision to visit a particular location or ecosystem (Gössling et al., 2012).

Our finding that the CES benefits associated with recreation continued to increase despite the impacts from coral bleaching on the health of the GBR conflicts with conclusions from experimental studies showing that visitors put a higher value on reefs with higher ecological quality (Grafeld et al., 2016; Peng & Oleson, 2017; Pert et al., 2020; Schuhmann et al., 2013). We propose several mechanisms that may have contributed to this finding. First, it is possible that tourism operators were able to relocate their tours to areas that were not affected or were less affected by coral bleaching. Second, while coral reefs might have been affected by coral bleaching and mortality, the effect on the reef substrate takes a longer time to become visible. That is, the structural complexity of the reef would likely remain intact for quite some time even after the coral has died, allowing it to continue providing a suitable habitat for fish and other marine life, which may be what tourists are most interested in (Grafeld et al., 2016). The structural complexity of a reef tends to decrease about 4 to 5 years after severe coral loss (Pratchett et al., 2011). However, we did not find evidence for a time-lagged effect in at least the 5 years of data available on customer satisfaction after the first bleaching event in our sample area, which occurred in 2016. Furthermore, reefs in our study areas have seen rapid recovery in coral cover since 2019 (Australian Institute of Marine Science, 2021). Third, while tourists might have experienced coral reefs with reduced ecological quality, customer satisfaction might have been influenced by a myriad of factors of which ecosystem quality may not have been dominant (Cumming & Maciejewski, 2017; Roux et al., 2020). In other words, tourist satisfaction with the ecosystem might have decreased, but due to improvements in other parts of the tour service, we were not able to capture this effect. Finally, tourist satisfaction with the ecosystem might not have decreased due to 'shifting baselines' (Pauly, 1995; Soga & Gaston, 2018), that is, non-repeat visitors may lack a baseline of what a high-quality coral reef looks like. Indeed, existing research found that prior reef visitation on the GBR affected peoples' aesthetic ratings of reefs, specifically producing more extreme ratings (although not significantly more positive or negative; Pert et al., 2020). Further research is required to understand how tourism operators responded to the coral bleaching events, the spatial variation in climate change impacts within individual reefs, and the underlying processes linked to customer satisfaction (e.g. through visitor surveys with a rating system separating ecosystem satisfaction from other tour specifics).

Currently, many CES studies suffer from non-standardized measurement approaches. Since TA scores are ubiquitous across tourism-based CES, our approach offers a way to standardize value comparisons. TA data, or other publicly available social media data (Martinez-Harms et al., 2018), give researchers access to big datasets that do not suffer from hypothetical bias (Hausman, 2012). However, a limitation of this approach is that TA comments are likely more focused on informing other tourists about their experience with particular tours, and thus details about tour operators are weighted more heavily compared to a random survey of reef visitors. Other limitations can be identified and addressed in the study design, as we have done here. For example, there is the potential for TA samples to be biased. We addressed this by adding a comparison with another ecosystem that was correlated with our sample in both time and space. Another limitation is that TA review data might not coincide with actual visitor data, and thus provide inaccurate results for demand-based hypotheses (such as H1 here). We managed this limitation by cross-validating our findings with official visitor statistics (Figure 2). Other types of data could be used to extend our methods and hypotheses to non-cultural ecosystem services (e.g. provisioning services). Coastal communities that are dependent on fisheries might find it more difficult to adapt to ecosystem change than recreation providers, for example, because they have few other readily available sources of food or livelihood activities available. However, the adaptation mechanisms we identified for CES might also be applied to provisioning or other ecosystem services. First, there could be delayed ecosystem effects as well as shifting baselines. Second, fishermen might spatially diversify (Gonzalez-Mon et al., 2021) or substitute their dependence on natural capital by shifting towards human-made capital, for example, aquaculture. Thus our findings create a potential opportunity to synthesize responses across different kinds of ecosystem services (Grantham et al., 2020).

Our research has broader implications for recreation-focused CES research and for research on social–ecological feedbacks more generally. Our findings shed new insights into the role that ecosystem management authorities play in facilitating the delivery of recreation-based CES (Roux et al., 2020). Management authorities can play a role in the development of expertise in tourism operators' staff to ensure visitors have a more informed nature experience. For example, on the GBR, the Marine Park Authority's 'Master Reef Guides' program trains tourism operators' staff to become leading reef guides and ambassadors (Great Barrier Reef Marine Park Authority, 2019). Management authorities' role could focus on certification, that is, to make sure that tourists can identify the reef operators that are up to date on the latest scientific and cultural knowledge about the ecosystem. Management authorities could also play a more active role in providing reliable and scientific information about the spatial characteristics of ecosystem damage and travel safety. During the coral bleaching events in 2016–2017 (and the bushfires in 2019–2020), visitor areas that did not experience any direct ecological impacts were affected by reductions in visitor numbers. In the age of social media, information (true of false) can spread more rapidly than even the most severe bushfire.

6 | CONCLUSION

Our findings provide valuable insights into social–ecological feedbacks, most notably showing that social–ecological feedbacks can be complicated by compensatory and adaptation effects in human societies and individuals. In theory, we would expect first-hand experience of ecological degradation to provide an 'honest' signal that reliably informs each individual visitor to the reef of its current state and underlines the need for urgent action to reduce carbon dioxide emissions. We would also expect that an experience of a degraded ecosystem would be less pleasant and provide fewer well-being benefits than an experience of a pristine ecosystem. Our analysis raises the possibility that depending on their baselines and values, people may be vastly more accommodating of ecological degradation than conservation biologists and managers would expect; or conversely, that the threshold level of change (beyond which unease and a direct response to degradation are triggered) may be much higher than might be expected. This observation in turn suggests that where they are strongly modulated by social adaptation, feedbacks from ecosystems to the social system may be weaker than expected, and may be unreliable if they are expected to drive corrective action that seeks to conserve and restore ecosystems and ecosystem service provision. It thus seems essential for future research and management that models and scenarios that assume people will respond to ecological degradation start to take social adaptation into account, ideally based on a stronger understanding of its causes and context dependence.

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CONFLICT OF INTEREST

We have no conflicting interests.

AUTHORS' CONTRIBUTIONS

H.A.B. and M.L.B. conceived the manuscript; H.A.B. and G.S.C. developed methodological approach; H.A.B. ran the analyses and wrote first draft; M.L.B. and G.S.C. helped write and revise the manuscript; K.C.Z. provided expertise on cultural ecosystem services.

DATA AVAILABILITY STATEMENT

Our research used publicly accessible data from TripAdvisor (tripadvisor.com) and the Great Barrier Reef Marine Park Authority (2020).

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