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RESEARCH ARTICLE

Imagining outcomes of coral restoration and adaptation intervention in the Great Barrier Reef

Stewart Lockie[1,2,3], Gillian Paxton[1], Henry A. Bartelet[1,4,5], Linde Draaisma[1], John L. Brooksbank[1]

Restoration initiatives are expanding globally to address climate and biodiversity threats and to help ecosystems adapt to environmental change. Research in Australia's Great Barrier Reef (GBR) is exploring novel intervention options to scale up restoration, protect corals from climate extremes, and accelerate their adaptation to heat stress. This manuscript explores the potential outcomes of such interventions as imagined by members of the GBR community. Drawing on semi-structured interviews with 140 Reef Traditional Owners, stakeholders, and members of the public, it identifies six key themes—Indigenous Partnerships, Distributional Equity, Reef Outcomes, Community Engagement, Program Sustainability, and Unintended Consequences—through which participants envisaged a diversity of potential outcomes. The most frequently mentioned adverse outcomes were potential failure to achieve desired ecological outcomes and to secure ongoing funding for restoration and adaptation research and implementation. The most frequently mentioned positive outcome, meanwhile, was engaging the community in restoration and adaptation efforts, consequently increasing public support and pressure on governments to take meaningful action. The value of key themes identified in this study lies not in predicting the potential success or failure of restoration and adaptation projects but in guiding their design, implementation, and evaluation.

Key words: climate adaptation, coral reef, ecosystem adaptation, ecosystem resilience, ecosystem restoration, Great Barrier Reef, imagined futures, risk perception

Implications for Practice

- Participants believed the ecological success of restoration and adaptation interventions is dependent on clear goals, effective community engagement, and sustained political commitment. Participants also believed that involving community members in meaningful, collaborative restoration and adaptation initiatives has the potential to increase commitment to climate action at local, regional, and global scales.
- While poorly designed projects risk undermining the rights and wellbeing of Indigenous peoples, genuine partnerships and openness to traditional knowledge create opportunities for social and ecological co-benefits.
- The themes identified in this research (Indigenous Partnerships, Distributional Equity, Reef Outcomes, Community Engagement, Program Sustainability, and Unintended Consequences) should be considered when defining project goals and success criteria and when identifying potential issues for risk assessment and management.

Introduction

Declaration of the 2020s as the United Nations' Decade on Ecosystem Restoration reflects the importance of not only stopping but reversing ecosystem degradation in order to stabilize the Earth's climate and limit species extinctions (Strassburg et al. 2020; Ladouceur et al. 2022). Restoration initiatives have proliferated worldwide along with calls for the massive upscaling of projects to reflect the scale of threats to climate and biodiversity and to help people and other species adapt to environmental change (Levinthal & Weller 2023). The need to adapt is further reflected in research into new options to build ecosystem resilience in the face of climate change by accelerating the evolution of target species and ecosystems using techniques such as genetic screening for heat tolerance, selective breeding, and assisted species migration (Vella et al. 2021; Twardek et al. 2023; Lockie et al. 2024a).

It is well-understood that positive perceptions of restoration among local communities improve the likelihood of project success and that effective communication and opportunities for participation help build trust and support (Höhl et al. 2020; Castillo et al. 2021; Ortega-Álvarez et al. 2022). Research highlights the risk of community members perceiving little value in the ecosystem services provided by restoration

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[1]The Cairns Institute, James Cook University, PO Box 6811, Cairns, Queensland 4870, Australia
[2]School of Sociology, The Australian National University, Canberra, Australian Capital Territory 2601, Australia
[3]Address correspondence to S. Lockie, email stewart.lockie@jcu.edu.au
[4]School of Project Management, Faculty of Engineering, The University of Sydney, 21 Ross Street, Forest Lodge, Sydney, New South Wales 2037, Australia
[5]John Gokongwei School of Management, Ateneo de Manila University, Katipunan Avenue, Quezon City 1108, Metro Manila, Philippines

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(Su & Gasparatos 2023) or, alternatively, perceiving restoration as a barrier to accessing those services (Bax et al. 2023). For many community members, social outcomes are valued as highly as ecological outcomes as measures of restoration success (Galbraith et al. 2021). Restoration thus attracts criticism for prioritizing the biological, ecological, and technical dimensions of ecosystem repair over the perspectives and wellbeing of people who live in and around those ecosystems (Fischer et al. 2021) and several authors argue that understanding of the social dimensions of ecosystem restoration remains limited (Martin 2017; Puspitaloka et al. 2020; Löfqvist et al. 2023).

It is perhaps not surprising that literature on public perceptions of novel interventions to accelerate ecosystem adaptation is dominated by studies of social acceptability. Novel interventions such as assisted species migration and genetic modification are consistently found to be broadly acceptable among members of the public (Zander et al. 2021; Hobman et al. 2022; Lockie et al. 2024a). While people often express a preference, when forced to choose, for practices they perceive as more natural and familiar, the effectiveness of novel interventions relative to other conservation methods may ultimately be more important in driving acceptance (Mankad et al. 2021). Indeed, Hein et al. (2019) report that participants in coral restoration projects believe the scale of existing projects, relative to threats, is their main limitation (meaning social outcomes are perceived to outweigh the ecological benefits of those projects). Ng et al.'s (2023) study of how Singaporean residents perceive coral restoration found both support for doing more restoration and a preference for the prioritization of coral resilience over the provision of habitat for other species or the relative abundance of various coral taxa.

The objectives of this manuscript are to: (1) map public perceptions of the potential outcomes of reef restoration and adaptation interventions with potential to assist the Great Barrier Reef (GBR, the Reef) recover and adapt to climate change; and (2) explore the implications of these perceptions for program design and risk assessment in the GBR and elsewhere.

Addressing these objectives builds on the research findings summarized above in three important ways. First, with climate change raising questions about whether restoration can be undertaken in a way that builds ecosystem resilience to future climate states, we explore the perceived implications of novel interventions intended to expand the restoration toolkit and promote reef resilience by accelerating coral adaptation to climate change. Second, with broad public and political support needed to upscale ecosystem restoration and adaptation efforts, we explore these perceptions not only among participants in restoration projects but also among members of the wider community. Third, we synthesize perceptions shared with us as participants considered the potential outcomes of upscaled restoration and assisted adaptation into six major themes and discuss the relevance of these themes for restoration and adaptation intervention and project design which, we argue, can be used to inform the design of more inclusive and sustainable restoration and adaptation interventions and the assessment of risks associated with their implementation.

Research Context

Comprising over 2500 individual reefs and stretching 2300 km along the coast of northeast Australia, the GBR is the world's largest reef system. World Heritage listing recognizes the GBR's outstanding universal value as a site of extraordinary beauty, biodiversity, evolutionary significance, and scale. As a biocultural landscape, it is home to over 70 Aboriginal and Torres Strait Islander peoples with Traditional Ownership rights and responsibilities (Jarvis et al. 2019). The economic, social, and iconic asset value of the GBR has been estimated at AUS $56 billion, with 64,000 jobs in industries such as fishing and tourism, and an annual contribution to the Australian economy of AUS$6.4 billion (Deloitte Access Economics 2017). These values are at serious threat, however, without strong and effective action at global, regional, and local scales to mitigate climate impacts and build reef resilience (GBRMPA 2024).

Australia's Reef Restoration and Adaptation Program (RRAP), which provides the context for this research, is a multi-institutional initiative aiming to help corals within the GBR adapt to the effects of climate change by providing reef managers with an innovative suite of safe, acceptable, and cost-effective interventions. Following a preliminary assessment of 160 possible interventions (Bay et al. 2019), RRAP commenced detailed research in 2020 on: (1) solar radiation management (SRM) interventions intended to reduce the impact of extreme heat events at both local and reef-wide scales through seawater fogging and marine cloud brightening, respectively; (2) enhanced reef restoration interventions intended to facilitate recovery from disturbance by increasing the recruitment of juvenile corals to degraded reefs, increasing the efficiency of coral aquaculture and outplanting, and stabilizing disturbed reef substrates; and (3) coral adaptation interventions intended to increase heat tolerance through the identification of corals with suitable genetic traits, selective breeding, preconditioning juvenile corals, and the introduction of heat-evolved coral symbionts (McLeod et al. 2022). Parallel research was also initiated on fundamental ecosystem and evolutionary processes, decision support, and social and regulatory dimensions of restoration and adaptation (McLeod et al. 2022; Lockie et al. 2024b).

Utilization of restoration and adaptation interventions subject to research and development through RRAP and other programs within the GBR World Heritage Area will require assessment of risks to the Reef's outstanding universal value and evidence of consultation with Reef Traditional Owners, stakeholders, and communities (Lockie et al. 2024b). Regulatory requirements for consultation notwithstanding, understanding how people perceive restoration and adaptation projects will be critical for mobilizing support, harnessing local knowledge and resources, and identifying potential outcomes. We elaborate on the theoretical rationale for considering community perceptions of potential intervention outcomes below.

Theoretical Framework: Imagined Futures and Risk Perceptions

Research design was informed by the literatures on imagined futures and risk perception, both of which focus on the ways in which perceptions of the future shape individual and

collective behaviors in the present. Imagined futures can be defined as perceptions and representations of a future yet to come (Suckert 2022). They are as inclusive of what people foresee, or think *might* happen, as they are of what people predict, or expect *will* happen, and of expectations communicated to others (Lockie 2014). Imagined futures are social, in the sense people draw on forecasting tools, knowledge, and expertise provided by external agencies, in addition to their own formal and vernacular knowledge, as they anticipate and respond to complex and uncertain possibilities (Lockie 2014; Suckert 2022). It follows that the capacity to communicate, influence, or challenge imaginings of the future is an important source of authority, helping shape people's agency and the ways in which they orient their behavior toward perceived risks and opportunities.

Risk perception—the subjective appraisal of risk by individuals and groups (Renn & Benighaus 2013; Lockie et al. 2024b)—may be understood as a particular kind of imagined future. The risk perception literature adds usefully to our understanding of imagined futures, however, by highlighting the influence of values, trust in information sources, emotional and affective responses to change, communication channels, and other aspects of individual and collective subjectivity, in addition to traditional, local, and practical knowledge (Renn & Benighaus 2013; Lockie et al. 2024b). A crucial feature of risk perceptions is their potential to change the material likelihood and consequences of prospective outcomes through their influence on behaviors, decisions, investments, etc. (Kasperson et al. 2022).

While some risks are characterized by well-understood causal pathways, others are characterized by complexity, uncertainty, and moral ambiguity (Renn et al. 2011). Openness to the potentially myriad futures imagined by relevant communities and institutions is important to avoid untested assumptions about how they will act in relation to such risks—including the potential for resistance to specific policies, programs, and practices—and to open possibilities for knowledge sharing and dialog (Lockie et al. 2024b). This is of particular relevance to restoration and adaptation given the involvement of multiple stakeholders and governance actors with potentially competing interests, aspirations, and values (Sovacool et al. 2023) and the nascent state of knowledge regarding options for large-scale restoration and assisted adaptation in marine environments (McLeod et al. 2022).

The research reported in this manuscript will not negate the need for proponents of restoration and adaptation projects to undertake project-specific consultation and risk assessment. It may, however, help to ensure intervention development and subsequent project design is sensitive to public perceptions of potential outcomes, both adverse and beneficial, and are suitable for use by a diversity of actors. The emphasis in presentation of results on imagined intervention outcomes, rather than the perceived risks of specific interventions, in this manuscript is deliberate (see also Paxton et al. 2024). While in lay terms "risk" is used as an analog of "hazard" or "danger" it is important interventions are designed and deployed in ways that promote multiple ecological, social, and cultural values (Lockie et al. 2024b). Large-scale restoration and adaptation projects, moreover, will more than likely utilize a mix of intervention techniques (Anthony et al. 2020).

Methods

Between 2021 and 2023, 117 semi-structured interviews involving 140 GBR community members were conducted to explore participants' relations to and experiences of the GBR, their visions for its future, and their responses to the prospect of novel scientific approaches to help the Reef survive, recover from, and adapt to the impacts of climate change.

All interview participants lived in or worked closely with the GBR. Participants were recruited using a combination of snowball (referral) and purposive sampling and drawn from four broad community categories:

- Reef Traditional Owners (10 participants): Aboriginal and Torres Strait Islander peoples with ongoing traditional connections to and rights over Sea Country in the GBR.
- Livelihood users (30 participants): individuals who derive income, revenue, profit, or other financial benefits from Reef-related businesses and industries.
- Institutional stakeholders (28 participants): representatives from science and research organizations, government, and other community institutions.
- Civil society communities (49 participants): members of public interest groups active in the GBR, including reef management non-government organizations, wildlife advocates, conservationists, and recreational users.

Wherever possible, interviews were conducted face-to-face at a location convenient to the participant. Participants were located along the whole length of the GBR, from the Torres Strait to the southern GBR region. A little under half (44%) of the interviews included community members from the Far North Queensland Region (including Cairns and the region between Cairns and the Torres Strait Islands); one quarter (26%) were conducted with community members from the North Queensland Region (including Airlie Beach and the region between Airlie Beach and Cairns) and another quarter (26%) with community members from the Central Queensland Region (including the region south of Airlie Beach to the southern-most tip of the GBR). The remaining four interviews (3%) were with community members from outside the GBR or encompassing the whole GBR Region.

Open-ended questions and prompts were used to encourage participants to candidly discuss their views and raise issues important to them. This paper relates particularly to participants' responses to questions relating to novel interventions being researched through RRAP. As these interventions were in early stages of development, participants were not expected to be familiar with either the interventions or with RRAP. Our purpose in discussing these nascent technologies with participants was not to engage them in a comprehensive evaluation of the interventions, but to encourage them to articulate and express their initial thoughts, considerations, or concerns relating to the prospect of assisted adaptation in the GBR.

Interviews commenced by advising participants of ethical issues related to the research and sought their consent to continue the interview. Questions then explored participants' backgrounds, their hopes and expectations in relation to the future of the GBR, and their perceptions of Reef management, before moving on to questions about restoration and adaptation. Participants were asked to describe their familiarity with RRAP and, if necessary, interviewers provided a brief verbal description of the program and the strategies being explored. The description provided to participants was brief and typically included the words "*RRAP is a cross-institutional research program experimenting with broadscale methods to help the Great Barrier Reef resist, adapt to, and recover from the impacts of climate change*." Examples of the strategies given included coral breeding and aquaculture, coral seeding, rubble stabilization, and cooling and shading technologies. We then invited participants to articulate their views using the following questions:

(1) What are your initial thoughts on this project and how confident are you that the activities being explored by RRAP are a suitable step to take in managing the Reef's future?
(2) What are some positive outcomes you could see being created by RRAP activities (probe for personal and broader social and community outcomes if possible)?
(3) What are some negative outcomes you could see being created by RRAP activities (probe as above)?

Through the interviews, we gained rich and nuanced personal accounts regarding the prospect of assisted adaptation in the GBR. Interviews were audio-recorded and transcribed verbatim.

Our analysis of these transcripts was informed by constructivist grounded theory, an inductive approach to the identification of patterns in unstructured data through iterative cycles of data collection and coding (Bryant & Charmaz 2007). While the results of grounded theory analyses are not generalizable to the general population, the method is well-suited to exploration and mapping of the range of perceptions held by participants in a given social setting.

Facilitated with NVivo 20 software, we aimed to identify common themes in the way potential outcomes were articulated by participants as they discussed their responses to the prospect of reef restoration and adaptation. Our analysis commenced with an initial stage of open coding—conducted separately by two researchers—in which all interview material relating to the ways participants expressed thoughts and concerns relating to restoration and adaptation technologies and their outcomes were given individual codes. This included commentary on the potential outcomes of restoration and adaptation made in response to any questions, not only those questions focused directly on anticipated outcomes. A second stage—conducted collaboratively between the two coders—saw the creation of higher order themes or categories into which these open codes could be integrated and grouped. These themes reflect the primary concerns around which participants articulated the possibilities, both positive and negative, they imagined arising through assisted adaptation interventions.

Stakeholder categories were used to guide the recruitment of participants but had limited use as analytical categories. Participants were quickly observed to hold multiple and overlapping interests and experiences in relation to the reef. It was not unusual, for example, to find a livelihood user who participated in conservation activities and government advisory groups, a government employee who also engaged in recreational fishing, or a scientist who also volunteered in a local school or community group.

Results

The outcomes imagined by participants as they discussed the prospect of assisted adaptation with researchers can be categorized into six common themes summarized in Figure 1. While each theme is inclusive of both adverse and beneficial outcomes, there was little evidence of disagreement between participants over which themes or outcomes are most likely or important. Certainly, some outcomes were discussed more often than others. However, the majority of participants foresaw multiple possibilities in relation to each theme, including possibilities that might, in practice, be mutually exclusive.

Indigenous Partnerships

Effective partnerships with Indigenous peoples holding associations, rights, and interests in Sea Country within the GBR were considered fundamental to the success of restoration and assisted adaptation in the GBR by both Indigenous and non-Indigenous participants (see Fig. 2). Country, including Land and Sea Country, refers to the totality of social, cultural, ecological, and spiritual connections embedded within the territories of Aboriginal and Torres Strait Islander Australians—Country encompassing all living things along with cultural practices, knowledge, and responsibilities (Janke et al. 2021).

Positive accounts typically related to opportunities for Reef Traditional Owners to be meaningfully engaged in, and to lead and implement, restoration and adaptation projects. These opportunities were contingent on early engagement with Reef Traditional Owners, a commitment to genuine co-management, the establishment of and compliance with Traditional Use of Marine Resource Agreements (TUMRAs), and respectful relationships. Participants also imagined enriched management outcomes arising from effective partnerships with Reef Traditional Owners for established Reef management, noting the success of models like Indigenous Land and Sea Ranger groups, the disproportional pressures placed on the Reef since European appropriation and management of the Reef, and the empirical value to be gained through the meaningful inclusion of Traditional knowledge and science in marine management, research, and education.

Negative accounts under this theme often involved scenarios in which restoration or adaptation projects were imagined to erode or undermine opportunities for Reef Traditional Owner leadership and effective partnerships between Reef Traditional Owners, management institutions, and researchers. A common fear was the possibility that Reef Traditional Owners might be engaged tokenistically in assisted adaptation and restoration projects rather than in genuine codesign and delivery of those

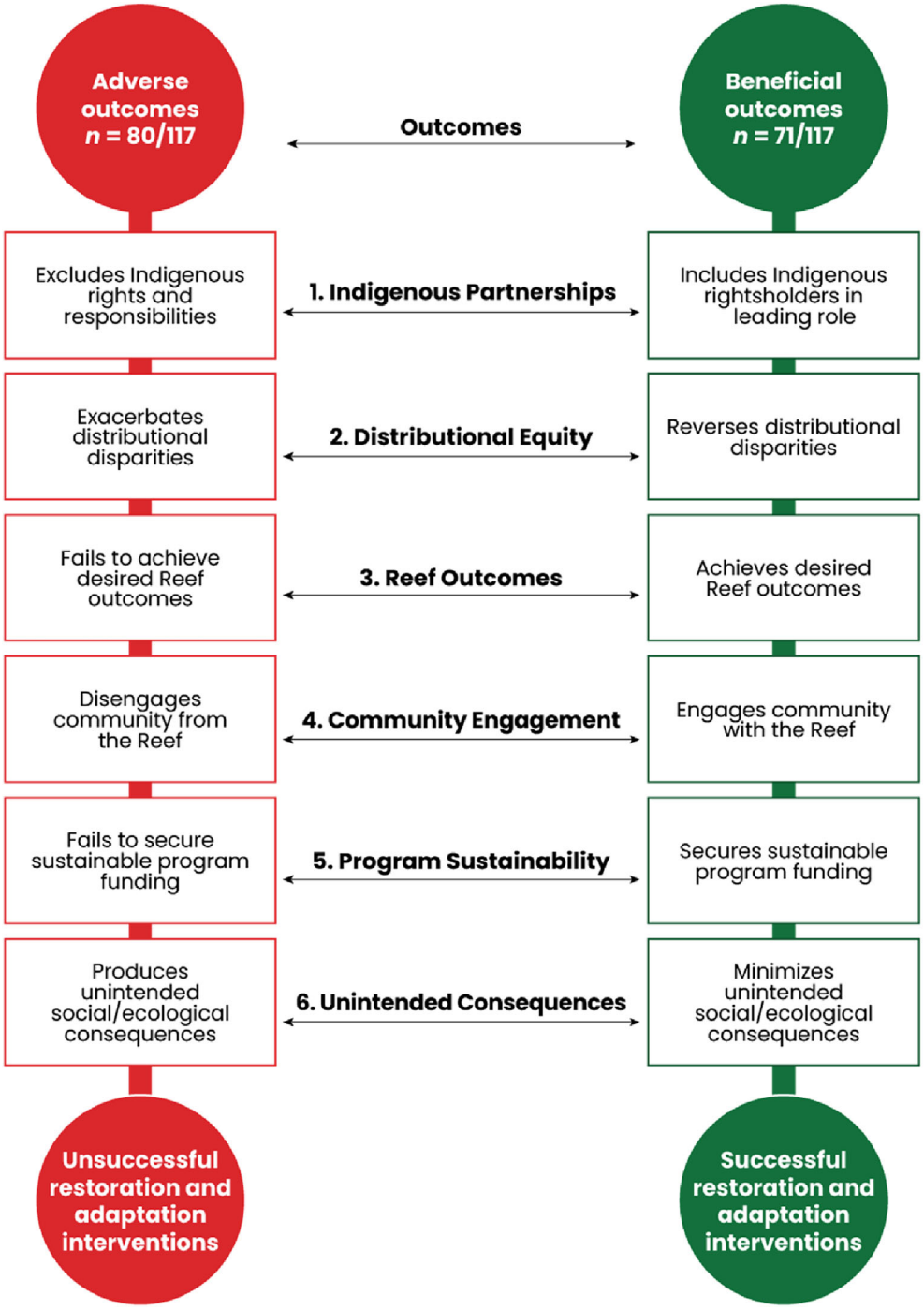

Figure 1. High-level conceptualization of potential intervention outcomes identified by Reef community members. n = number of interviews in which outcome was mentioned.

projects, or that scientists and policy makers might fail to recognize the extent of and value of knowledge that Reef Traditional Owners can contribute to GBR management and adaptation. A significant concern related to Traditional Owner consent, with several participants imagining the possibility that protocols for gaining consent with assisted adaptation projects would be inadequate, particularly around the importance of unanimous (rather than majority based) consent prior to research activities and management on Sea Country. This failure was imagined to undermine Indigenous rights, authority, responsibilities, lore, and customs. Another fear was expressed about the sampling of material and coral from Sea Country by scientists without collaborative agreements and clear plans regarding the removal, treatment, and return of this material. A small number of

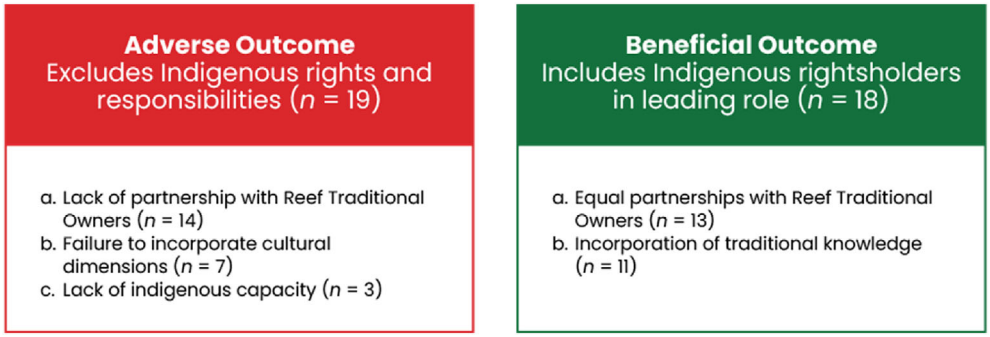

Figure 2. Potential outcomes of reef restoration and adaptation intervention outcomes identified by Reef community members in relation to Indigenous Partnerships.

participants also imagined obstacles to the capacity of Traditional Owner organizations to participate in reef restoration and adaptation projects. These obstacles included a lack of access to boats, infrastructure, baseline scientific information, and operational experience.

Distributional Equity

Equity and fairness, the second key theme, related to how the implementation and outcomes of restoration and adaptation might differentially affect various Reef communities and stakeholders (Fig. 3). In positive responses, participants imagined the creation of multiple opportunities for Reef Traditional Owners, Reef communities, and stakeholders to benefit from investments in restoration and assisted adaptation, and imagined how these might address existing social disparities in the GBR. They imagined possibilities for Traditional Owner groups to lead restoration and adaptation projects, build skills and capacity in GBR science and management, and contribute knowledge and expertise to assisted adaptation research, implementation, and governance. Options for doing so included Indigenous academic scholarships, project grants, and increased investment in Indigenous Land and Sea Ranger programs. Possibilities to diversify economic and vocational participation in the GBR were also envisaged, with assisted adaptation imagined to create—alongside tourism—an alternative pathway to capacity building and employment in the GBR. As people welcomed the possibility of expanded social and economic participation in the GBR, they foresaw positive effects on the Reef's social values and greater Reef Traditional Owner, community, and stakeholder influence in GBR management and decision-making.

Negative accounts centered on the possibility restoration and adaptation might exacerbate social disparities and create obstacles to, rather than opportunities for, equitable participation in the GBR. Some participants highlighted the potential for restoration and adaptation projects to reinforce existing geographic disparities in the distribution of social and economic opportunities across GBR communities—particularly among those remote from major population centers and characterized by significant social and economic disadvantage. Pointing to what they saw as a historical prioritization of management on high visitation and economically valuable "tourist reefs," participants expressed concern about the concentration of benefits from restoration and adaptation in particular regions at the expense of others, and the possibility of leadership and employment opportunities accumulating within urban centers such as Brisbane (outside the Reef catchment) rather than across regional Queensland. Disparities in funding and opportunities between Traditional Owner groups and in regions like the Torres Strait (which lies outside the GBR Marine Park) were also a concern. Similarly, participants imagined disparities in the distribution of benefits from assisted adaptation across sectors. Some speculated that established industries such as tourism—which had

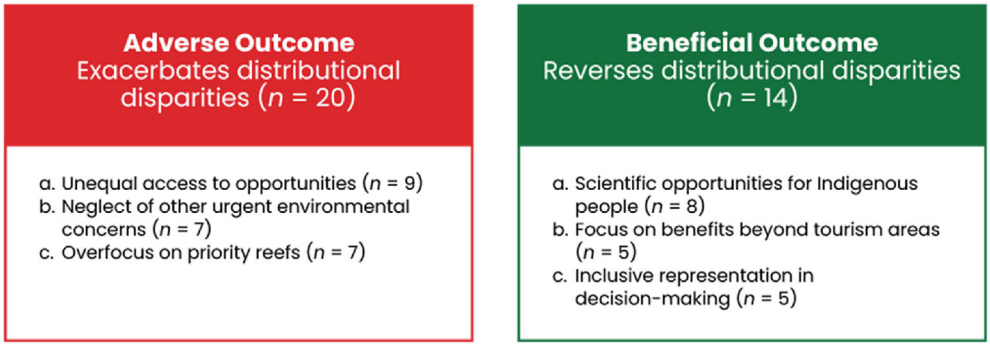

Figure 3. Potential outcomes of reef restoration and adaptation intervention outcomes identified by Reef community members in relation to Distributional Equity.

already developed much of the significant capital (such as a readily available workforce, existing infrastructure, and regulatory permissions) needed to participate in restoration project implementation—would reap greater rewards than less developed industries. This would compound the likelihood of benefits from restoration and adaptation concentrating in economically valuable sites within the GBR at the expense of those less-frequented but of equal ecological and cultural importance.

Negative accounts also noted potential disparities created by scale. Many expressed concern that large and ambitious programs like RRAP, which involve multiple institutions and a broad range of expertise, might impact smaller community-led projects by distracting from their achievements, depleting their volunteer base, and competing for government, philanthropic, and commercial funding. Similarly, participants imagined similar impacts on terrestrial restoration and other environmental projects, mindful of the GBR's considerable economic and iconic value and its ability to elicit broad collective concern and action. Many imagined this privileging GBR management and assisted adaptation relative to other pressing environmental issues.

Reef Outcomes

The third key theme related to the outcomes imagined for reef ecologies and associated terrestrial and marine ecosystems (Fig. 4). When positive, responses to the prospect of assisted adaptation in the GBR articulated clear and observable benefits of restoration and adaptation programs to reef ecologies, including the possibility that pressures on reef systems might be reduced and the expected ecological decline of reefs slowed or even reversed. Participants also imagined demonstrable benefits for associated ecosystems such as rainforests, mangroves, and seagrass, and the possibility that investments in reef adaptation would lead to ideas, techniques, knowledge, and technologies that could be applied in other ecological contexts. Lastly, some participants imagined adaptation and restoration projects to create efficient, practical outcomes, countering the extent and rate of ecological decline in the GBR. This, it was reasoned, would enable time to implement the broader social, political, and practice changes required to address climate change.

In negative responses, a large number of participants worried restoration and adaptation would ultimately prove ineffective in the face of complex and systemic environmental issues, including accelerating rates of climate change—expressing concern that restoration and adaptation research would fail in its ambition to deliver feasible solutions and ecological benefits. Again, issues around scale and temporality were a significant part of this concern, with a number of participants doubtful that adaptation interventions could deliver solutions at the scale necessary, and within the time available, to prevent substantial and rapid ecological decline. Further, they imagined the possibility of attention to restoration and adaptation undermining political momentum to mitigate global fossil fuel emissions and/or local pressures on coral reefs such as sedimentation, eutrophication, and chemical residues from agriculture and mining.

Community Engagement

The fourth theme related to engagement with local and broader communities with connections to the GBR (Fig. 5). When positive, participants imagined reef adaptation research and implementation as a collaborative and collective process, building opportunities for community involvement and capacity building through citizen science, knowledge sharing hubs, ecotourism opportunities, reef restoration eco-credentials, and vocational qualifications. Beyond direct involvement in reef restoration and adaptation activities, participants imagined that reef restoration and adaptation could cultivate an ethic of custodianship over the Reef, a sense of self-efficacy in the face of growing environmental problems, and greater advocacy for meaningful climate action. To enhance possibilities for engaging communities, participants emphasized the importance of good relationships and transparent, inclusive communication. Participants suggested several mechanisms to enable this, including knowledge translation, collaborative hubs, the involvement of schools and local governments, and capacity-building networks.

Negative accounts imagined engagement efforts that were tokenistic, driven by institutional interests, and failed to meaningfully involve and empower communities. Without a commitment to meaningful engagement, participants foresaw the exclusion of communities from adaptation activities and greater

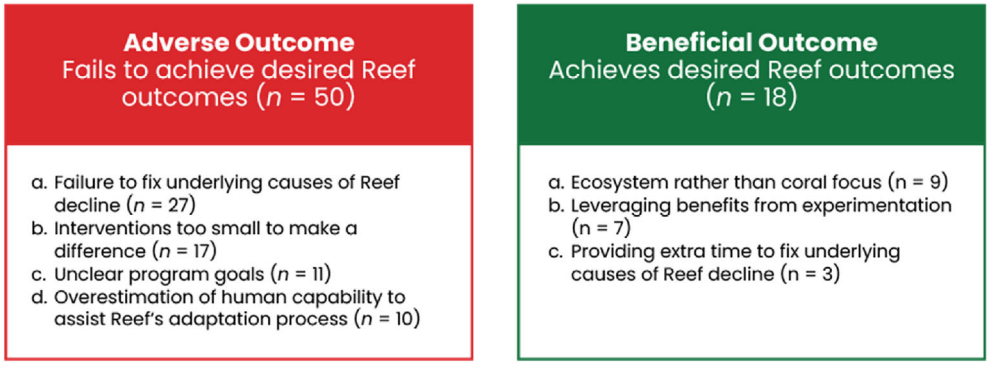

Figure 4. Potential outcomes of reef restoration and adaptation intervention outcomes identified by Reef community members in relation to Reef Outcomes.

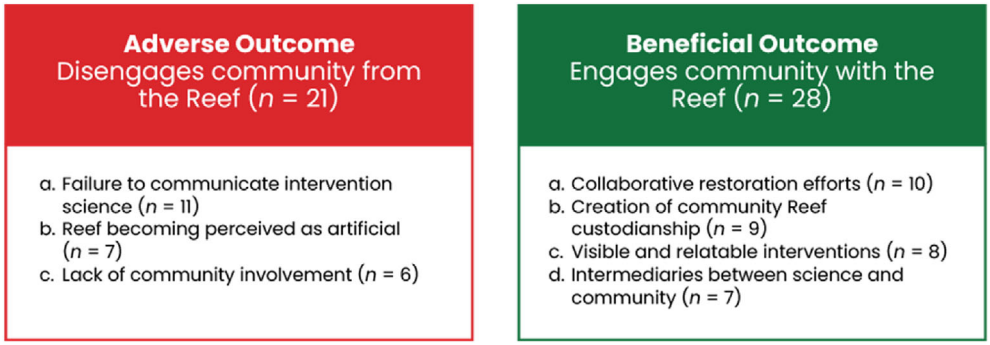

Figure 5. Potential outcomes of reef restoration and adaptation intervention outcomes identified by Reef community members in relation to Community Engagement.

privilege and authority afforded to scientists and scientific institutions. They also imagined greater legitimacy bestowed on scientific and technical knowledge and discourse, with the considerable stocks of vernacular knowledge and experience held by local communities devalued and undermined. Fears were also expressed regarding the spatial and material impacts of assisted adaptation on the Reef; namely that, as the reef became an increasingly altered and technocratically controlled landscape, it would alienate the connections that communities practiced and present obstacles to existing and future access to the reef.

Program Sustainability

The fifth theme centered on the perceived sustainability of reef adaptation and restoration programs (Fig. 6). When positive, participants imagined tangible and long-term benefits arising from research and investment in reef adaptation and restoration. They imagined the enhancement of existing industries (especially tourism) and the development of economically and politically viable Reef industries around activities like coral aquaculture and enhanced business, employment, and vocational opportunities. They also imagined possibilities to secure sustainable funding for reef restoration and adaptation efforts through commercial, philanthropic, and government avenues and for the continued development of business opportunities for Reef Traditional Owners in project design and delivery. A small number of participants saw potential funding sources in mining and fossil fuel companies.

Negative accounts highlighted the potential precarity of restoration and adaptation programs dependent on funding arrangements, public support, regulatory approvals, and political commitment. Reasoning that these factors would be highly contingent on the ability to demonstrate tangible benefits arising from assisted adaptation strategies in the GBR, participants worried this might not happen within time frames consistent with political cycles and the shifting expectations of governments, regulatory bodies, and the Australian public. The impacts of discourse around ecological loss on Reef tourism were also a common concern, with fears expressed that communication around reef restoration and adaptation might compound uncertainty around the health of the Reef and loss of tourism revenue. Uncertainty over long-term investment in intervention science and deployment was considered a potential deterrent to the private-sector investment, industry partnerships, and regulatory certainty considered necessary to sustaining large-scale intervention efforts.

Unintended Consequences

The final theme relates to unintended or unexpected social and ecological consequences imagined as a result of assisted adaptation and coral restoration in the GBR (Fig. 7). When positive, accounts highlighted the indirect benefits that might arise as a consequence of restoration and adaptation activities. The most

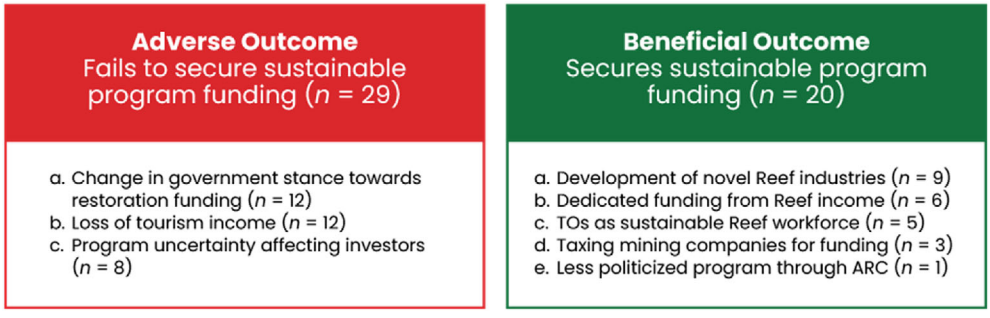

Figure 6. Potential outcomes of reef restoration and adaptation intervention outcomes identified by Reef community members in relation to Program Sustainability.

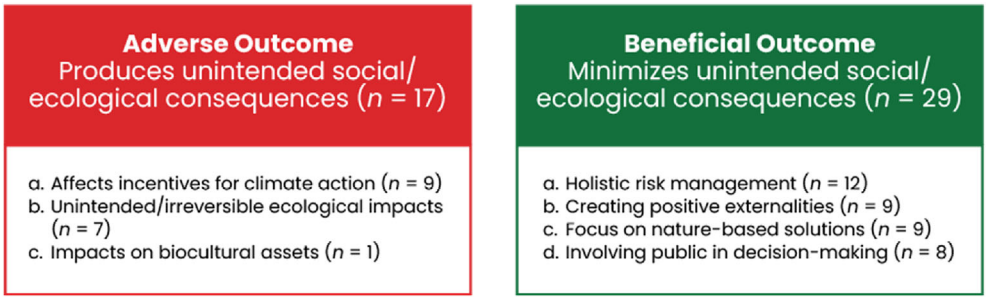

Figure 7. Potential outcomes of reef restoration and adaptation intervention outcomes identified by Reef community members in relation to Unintended Consequences.

notable of these was the possibility that adaptation in the GBR might help galvanize public concern for the Reef and commitment to action on climate change, build people's capacity, knowledge, and sense of efficacy to change practices, and encourage them to consider their voting behavior or engage in activism. Other possibilities imagined included the development of specialized coral restoration expertise, skills, and techniques that could be transferred and applied to coral restoration and adaptation programs internationally (e.g. in Indonesia or Papua New Guinea) and assisted adaptation in other ecological contexts. Similarly, participants imagined an enhanced understanding of coral reef systems and their capacity to recover and adapt resulting, in turn, in more nuanced, respectful, and effective human stewardship practices.

When negative, accounts highlighted the potential for undesirable side effects arising from reef restoration and adaptation efforts. A clear risk articulated in these accounts stemmed from a perceived tension between the pragmatic imperative to explore effective and feasible technological strategies to help the GBR and the urgent need for broader societal change to address the causes of anthropogenic climate change (Paxton et al. 2024). In this context, participants worried that the demonstrable benefits of reef adaptation and restoration could perversely promote complacency and inaction on greenhouse gas mitigation. Unforeseen alteration and damage to reef ecologies—through, for example, the introduction of pest species, biotic homogenization, and biocultural impacts—were also raised as potential impacts. Participants counseled holistic measures to understand and manage the potential for negative consequences, including the need to balance these consequences against the potential risks of not intervening or helping the Reef, building sound and extensive scientific evidence to support decision-making and risk management, and exercising caution when transitioning to large-scale implementation. Meaningful engagement and deliberation with the public were considered an important step in managing the risk of Unintended Consequences and grappling with important ethical considerations (e.g. around assisted adaptation interventions).

Discussion

When articulating responses to the prospect of novel technological strategies to help the GBR survive, recover, and adapt to the impacts of climate change, members of the GBR community imagined a range of potential outcomes focused on six common themes—Indigenous Partnerships, Distributional Equity, Reef Outcomes, Community Engagement, Program Sustainability, and Unintended Consequences. These themes reflect the range of outcomes participants *foresaw* as opposed to those they necessarily *expected* or indeed preferred. Uncertainty over the timing of climate impacts and other dimensions of global environmental change, the relatively early stage of intervention research and development, and the importance of policy, regulation, decision-making, etc. in program design necessarily complicate the task of predicting what will be achieved through novel restoration and adaptation interventions. While the outcomes people thus expect to arise from these interventions will change over time and in relation to specific projects, the range of potential outcomes they foresee is likely to prove more enduring. In addition, the range of potential outcomes Reef communities foresee provides a baseline understanding of possibilities that should inform risk assessment in relation to restoration and adaptation programs—the point here being not simply to predict or imagine outcomes but to manage them. Openness to the knowledge and values of Reef communities will improve risk characterization and decision-making, in the first instance, while contributing, over time, to community engagement with restoration and adaptation in ways that improve ecological and social outcomes.

Given the non-representative nature of our sample, it is important not to overinterpret the frequency with which any particular outcome was mentioned. Nonetheless, it is notable that the adverse outcomes mentioned in the highest number of interviews were failure to achieve desired Reef Outcomes and failure to secure Program Sustainability. Failure to achieve desired Reef Outcomes could, of course, undermine the case for investment to secure Program Sustainability, while inconsistent or inadequate investment would, in turn, undermine the potential to deliver intended outcomes and potentially increase the risk of Unintended Consequences. Similarly, failure to secure investment and deliver outcomes would present a challenge to meaningful Indigenous Partnerships and Community Engagement, while poor quality partnerships and engagement would challenge the case for investment and place regulatory approval of intervention deployment at risk.

Participants held strong views on the dependency of prospective Reef Outcomes from restoration and adaptation interventions on complementary action at both global and

local scales. The risks of doing both too little to address global drivers of climate change and too little to build reef resilience locally and regionally weighed heavily (see also Sovacool et al. 2023). That a number of participants thought replicating natural processes, where possible, could minimize risks of Unintended Consequences helps explain why other studies consistently report broad acceptance among members of the public for novel interventions despite a preference for those they perceive as "natural" (Ng et al. 2023; Bartelet et al. 2025; Lockie et al. 2024a). Focusing on the wider ecosystem in which coral reefs are embedded (including mangroves, seagrass, and rainforests) suggests further opportunities to both manage risk and increase climate resilience.

The most frequently mentioned positive outcome was engaging the community in the Reef. Participants discussed the potential social, political, and economic impacts of restoration and adaptation projects and the importance of effective public and political engagement in driving commitment to climate action and Program Sustainability—both critical to Reef Outcomes—for restoration and adaptation. This is consistent with research demonstrating that exposure to restoration projects among visitors to the GBR improves trip satisfaction and the perceived beauty of the Reef (Curnock et al. 2024).

Participants also linked the health of marine ecosystems on the GBR to the wellbeing of people in Reef communities and were particularly concerned about opportunities for Reef Traditional Owners. Echoing the *Strong Peoples—Strong Country* framework developed by Reef Traditional Owners to stress the interconnectedness of social and environmental health (Jarvis et al. 2019), participants spoke about the potential of restoration and adaptation projects to improve the social, cultural, and emotional wellbeing of Traditional Owners by establishing equal partnerships and providing space for Indigenous knowledge, custom, and authority.

The value of documenting the concerns and prospective visions of Reef communities in advance of large-scale deployment lies not in predicting the outcomes of restoration and adaptation projects but in guiding their development, design, implementation, and evaluation. This includes the design of Reef Traditional Owner, stakeholder, and community engagement strategies necessary for compliance with regulatory processes for intervention in the GBR World Heritage Area (Lockie et al. 2024b). The themes outlined here can provide a starting point to help define project goals and success criteria in ways that resonate with existing knowledge of Traditional Owner, stakeholder, and community values and aspirations, and to identify potential issues for risk assessment and management. The themes outlined here may also help environmental managers develop a portfolio of restoration and adaptation projects that address different outcomes—some, for example, focusing heavily on Community Engagement, others on Reef Outcomes, and so on.

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