Coral reef restoration in Indonesia: lessons learnt from the world's largest coral restoration nation

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Abstract

Indonesia is the global coral reef restoration leader by number of projects, yet these remain diverse and disparate. This study reviews the status of Indonesian coral reef restoration and current best practice (CBP) through the lens of international CBP as defined by the National Oceanic and Atmospheric Administration manager's guide for reef restoration planning and design, providing suggestions for a formal network of reef restoration practitioner network to develop and implement a national restoration roadmap. Surveyed projects were identified from existing reef restoration networks and databases and using online search engines. Responses were obtained from 45 projects with whom interviews were conducted to determine alignment with international CBP. There is particular scope to increase quantitative data collection, reinforce community involvement, and improve ecological data collection. While 84% of projects reported quantifiable goals, 64% didn't quantify goals during planning and 61% didn't incorporate climate smart design features. Quantitative reef monitoring surveys were absent in 22% of projects. Important ecological metrics including coral community composition/diversity (96%), coral health/bleaching (89%), benthic community (62%), and coral survival (62%) weren't quantified by long-term monitoring in the majority of projects. Indonesia has the capacity, regulations, and networks to position itself as reef restoration driver in the Coral Triangle region, but this will require countrywide coordination, alignment, and quantification of restoration. A structured, collaborative and iterative national network of government authorities, decision-makers, and reef restoration managers, practitioners, and researchers, could facilitate the development of a national restoration roadmap, including a tiered system to standardise project planning, monitoring, and reporting, and greater focus on climate change adaptation goals.

Introduction

The economic and ecological importance of coral reefs in the Coral Triangle (CT) region is well-established and the area is recognised as the world centre for marine biodiversity and one of the planet's primary biodiversity storehouses (Burke et al. 2012; Williams et al. 2017). Indonesia harbours more than 39,500 km^2 of coral reef area (16% of the global total), including the world's most biologically rich coral reefs in eastern Indonesia at the heart of the CT, with approximately 590 of the region's 605 recorded hard coral species and 2,200 reef fish species (Burke et al. 2012). Indonesia has the world's largest reef-associated population: around 60 million people (26% of the population) live within 30 km of a reef (Burke et al. 2012) and it is among the top five global reef product exporters, while more than one million fishers depend on reef fisheries for their livelihood. Tourism revenue is closely linked to reefs, and the annual net economic benefits of the shoreline protection they provide are estimated at US$387 million (Burke et al. 2012).

While efforts have been made to increase marine conservation awareness, Indonesia is rated in the highest category of vulnerability to coral reef degradation and loss globally and over 90% of its coral reefs have been impacted by various local activities (Burke et al. 2012). A recent report on the status of Indonesian coral reefs surveyed 1,153 sites across the country, revealing that only 6.4% were in an excellent state (> 75% healthy hard coral), while the majority (71.2%) were classified as being in poor or fair condition (< 50% healthy hard coral) (Hadi et al. 2020). Ongoing overfishing (Larsen et al. 2018) and blast fishing (Saragih and Trencher 2020; Veloria et al. 2021) remain two of the most immediate localised threats to Indonesian reefs. Destructive fishing is widespread (e.g. Simmons and Fielding 2019; Shafira and Anwar 2021), partly due to difficulties in the effective enforcement of legislation banning illegal practices (Gorris 2016) and mild penalties for those prosecuted (Renggong et al. 2021).

Coral reef restoration has a long history in Indonesia, with the original artificial structures being deployed in 1979 (Sukarno 1988). Artificial reef structures and coral transplantation are popular techniques, but restoration projects incorporate a diverse range of materials and methods including piles of volcanic rocks, custom-designed concrete structures, branching ceramic modules, electrolytic deposits on shaped wire mesh templates, hexagonal steel structures, and direct attachment of coral fragments to consolidated ocean substrate (Razak et al. 2022).

Many different sectors are involved in coral reef restoration in the country, including national and local government, local and international NGOs, the private sector, and coastal communities. However, the majority of projects are not officially reported, while project reviews are neither up to date, nor published in peer reviewed literature (Fox et al. 2019). In addition, various restoration methods fall under multiple government policy frameworks, and it is difficult to assess permit requirements and regulations relating to reef restoration (Razak et al. 2022).

A renewed emphasis on permit requirements may be in response to the upsurge in new projects in recent years. Of 533 reef restoration project records identified between 1990 and 2020, 388 (73%) were established since 2010, and 294 (55%) since 2015. Despite the Covid-19 pandemic, 2020 featured more new project records than any other year under review (Razak et al. 2022), mainly due to the Coordinating Ministry for Maritime and Investment Affairs-driven Indonesia Coral Reef Garden (ICRG) project – part of a wider pandemic-related coastal community economic recovery strategy.

Indonesia's coral reef restoration regulations promote wide community participation, and local governments are encouraged to share ownership and responsibility with local communities living near and benefiting from reefs. Razak et al. (2022) identify 17 Indonesian reef restoration policies and regulations: four national laws, three government regulations, two presidential regulations, and eight ministerial regulations. Examples include Presidential Regulation No. 121/2012 ('*Rehabilitation can be conducted through cooperation between government, regional government, person or community*' [Article 12.1] and '*Community or persons can participate in the implementation and maintenance of rehabilitation voluntarily*' [Article 15.1]).

The regional governance of permit issuance in Indonesia reflects a more community-driven approach than the centrally governed administration of other countries with a large restoration footprint, like Australia and the US (Razak et al. 2022). However, the many local government and national park authorities involved and the myriad small-scale restoration projects and initiatives driven by NGOs, tourism operators, local communities, and the private sector complicate attempts to standardise planning, assessments, and reporting.

The Coral Triangle Initiative on Coral Reefs, Fisheries, and Food (CTI-CFF) has, on the other hand, been a significant regional mechanism for collaborative international marine resource management and conserving key ecological and economic components (Veron et al. 2009). A precursor to the CTI-CFF was Indonesia's Coral Reef Rehabilitation and Management: Coral Triangle Initiative Project (COREMAP–CTI), aimed at sustainably managing coral reef resources, associated ecosystems, and biodiversity to increase coastal community incomes.

The CTI-CFF and COREMAP have achieved some major conservation successes. West Papua's Raja Ampat MPA network, for example, has significantly reduced destructive and illegal fishing and improved live coral cover and fish biomass in the area. Communities now catch more fish, traditional practices are being revitalised, and new livelihood opportunities are appearing in the growing tourism sector (Fischborn and Levitina 2018).

Donor funding has supported some private sector successes but is usually short-term and often relies on monetary incentives for community buy-in (Depondt and Green 2006; Wilkinson et al. 2006). There are, however, various mechanisms and tools available for securing the long-term coral reef restoration sustainability. Socio-economic approaches being used include diversified participation and local leadership (e.g., integrating local fisher groups into project management); supply chain management and business and industry involvement; centralised training hubs; and strategic project placement (Lamont et al. 2022). Improvements to coral reef restoration social-ecological system resilience will, therefore, necessarily rely on diversified community-based management governance, better coordination and planning between fisheries and MPAs, fostering sustainable tourism, and planning for future conditions (Tranter et al. 2022). Even long-term funding has inherent dangers linked to its continued availability (Browne et al. 2022), and in the majority of cases, cross-sector cooperation is key (Bottema and Bush 2012).

A failure to include communities and other stakeholders in decision-making processes usually leads to a lack of support for conservation (Ferse et al. 2010). Local community involvement, buy-in, and support are some of the most effective ways to ensure the long-term sustainability of reef restoration projects and other forms of ecosystem-based adaptation (EbA). Definitions of community buy-in encompass a spectrum of interactions and participation levels. Direct buy-in can be linked to a sense of project ownership (Westoby et al. 2020) and can be monitored by gauging community satisfaction with the project (Hein et al. 2017). This is in turn tied to the community's degree of involvement, sense of ownership, and perceptions of success (Westoby et al. 2020).

The involvement of local communities should therefore be central to efforts to improve the success and effectiveness of Indonesian coral reef restoration projects. Stakeholders may include divergent viewpoints from various sectors, all of which need to be considered when planning restoration projects (Langston et al. 2020). Organisations and authorities can achieve a greater positive impact through strategic engagement with a broad range of actors to find a common purpose and an effective use for investments and potential infrastructure.

The sheer number of projects and the diversity of organisations involved provide opportunities to view restoration at a national scale, with a standardised and coordinated effort to collect meaningful data in order to drive functional restoration. Despite this, projects are often not coordinated with wider networks of restoration practitioners or scientists. Mismatches between programme objectives and the metrics used to assess their effectiveness hamper restoration efforts (Hein et al. 2020) and there remains a widespread lack of effective ecological monitoring and consistent reporting: only 16% of projects have historically incorporated a post-installation monitoring programme to gauge ecological responses to restoration (Razak et al. 2022).

Restoration efforts should follow a holistic, rights-based approach that integrates ecological, economic, social, and political considerations (Bender 2018) without promoting certain considerations to the detriment of others (e.g. conservation over food security). It is nevertheless critical to promote a standardised scientific approach focused through a lens of international current best practice (CBP) to maximise the impact of the disparate restoration efforts across Indonesia.

This study will review the planning stages of coral reef restoration projects in Indonesia and identify how project planning corresponds with international CBP to examine the relevance, suitability, and application of international guidelines within an Indonesian context. It provides recommendations on how Indonesia can adopt and adapt international CBP to avoid the risk of inappropriate, unbalanced, and/or ineffective interventions and frame restoration efforts within a national and regional context. It further suggests creating a national network of reef restoration managers, policymakers, and researchers to develop a roadmap for Indonesia's reef restoration efforts. This can tap into Indonesia's massive potential, cementing the country's leading role in global coral reef conservation and restoration efforts and informing reef restoration in the CT.

Methods

The National Oceanic and Atmospheric Administration's (NOAA's) manager's guide for reef restoration planning and design (Shaver et al. 2020) is taken as a lens for international current best practice (CBP), through which to review Indonesian coral reef restoration project planning and implementation. A six-step iterative planning cycle informs international CBP, including multiple entry points to which managers can refer. The first four stages represent purely planning phases, while the final two stages encompass implementing active restoration. Responses relevant to specific stages are detailed in the results section.

1. **Set goal & geographic focus**, including identifying and prioritising focused goals, and selecting a goal and geographic focus for restoration planning and design.
2. **Identify, prioritise & select sites**, including a framework for prioritising sites and involving stakeholders in the planning and selection process.

3. **Identify, design & select interventions**, including identifying diverse intervention options, applying climate-smart design considerations, and engaging stakeholders to design and select applicable approaches.
4. **Develop restoration action plan**, including defining SMART (Specific, Measurable, Achievable, Relevant, Timebound) objectives (Table 1), developing activities and a restoration timeline, and building a Restoration Action Plan.
5. **Implement restoration**, including ensuring long-term project sustainability and identifying control sites against which to measure restoration and measure restoration successes and shortcomings.
6. **Monitor & evaluate progress** alongside restoration implementation. Over time, short-term assessments of restoration interventions should switch to examining reef-scale effects over longer timeframes. Monitoring data analysis enables progress evaluations.

Table 1
Attributes and examples of the SMART Goals and Objectives to be considered by coral reef restoration projects

[Adapted from Shaver et al. (2020) and CMP (2020)].

Attribute	**Description (adapted from CMP 2020)**	**Examples (adapted from Shaver et al. 2020)**
Specific	Clearly defined so all involved share an understanding of what the objective means	Identifies restoration site, species, or techniques for restoration
Measurable	Can be defined relative to a standard scale (e.g. numeric or all/nothing states)	Identifies size of area for restoration / number of outplants / survival rate compared to a baseline
Achievable	Practical and appropriate in light of project site, political, social, and financial context	Considers feasible numbers of corals / measurable outcomes within project scope, and local/climatic threats to restoration activities
Relevant	Ensures the significance of the outcome within regional or local management context	Coral species selected for specific resilience, ecological importance, or conservation status
Timebound	Achievable within a specific period of time (generally 10–20 years for goals and 1–10 years for objectives)	Identifies deadlines considering biological/ecological parameters

This study is concerned with efforts to improve reef conditions, so the terms “reef rehabilitation” and “reef restoration” are used interchangeably. When analysing projects’ restoration techniques, a distinction was made between substrate stabilisation methods and ARs. While the former often include artificial structures similar to ARs, they focus specifically on stabilising loose, shifting coral rubble in addition to increasing habitat complexity.

The Google, Google Scholar, Ecosia, and YouTube search engines were used to conduct extensive Boolean searches to increase precision and speed when looking for online records of active coral restoration projects in Indonesia. Keywords and phrases acted as operators to narrow down or broaden search results, such as “active AND/OR coral AND/OR reef restoration”, “coral nursery/ies”, “coral conservation” and “coral transplantation”, in conjunction with “Indonesia”, and/or “Coral Triangle”, “Indo-Pacific”, “NGO” (non-governmental organisation), “NPO” (non-profit organisation), “university”, “government”, and “dive centre OR center”.

When compiling the final list of projects reviewed, those identified in online searches were added to contacts made through networks of coral reef restoration practitioners within Indonesia, including the School of Coral Reef Restoration (SCORES), the national ICRG project, and the International Coral Reef Initiative (ICRI) online restoration database.

A survey template (supplementary material 1) was developed based on international CBP (Shaver et al 2020). Data was recorded using publicly available information, webinars, follow-up interviews, and/or email correspondence. Interviews were conducted in English, or in Bahasa Indonesia and translated into English. Data was extracted from 19 videos (25:20 hours) on 29 projects from the SCORES webinar series between July 2022 and February 2023, including 20:25 hours in Bahasa Indonesia and 4:55 hours in English.

Twenty-six respondents were interviewed directly in September and October 2022 (22 in English and four in Bahasa Indonesian) for a total of 15:45 hours (13:00 in English and 02:45 in Bahasa Indonesia) and 13 of these projects also provided further information by email. Between September 2022 and January 2023, 17 projects returned completed survey forms to provide responses, nine of which were in addition to data extracted from SCORES webinars, and eight as the sole form of data provided. One project that gave a SCORES webinar declined to provide further information. All data collected related to different aspects of project planning and implementation, as summarised in the data sheet template (supplementary material 2).

Results

Data was separated into six broad categories to analyse the extent to which Indonesian projects met international CBP criteria.

1. Set goal & geographic focus

Project leaders selected a primary goal that best described project aims in line with eight primary restoration goals established for global projects (Boström-Einarsson et al. 2020). Almost one-third of 45 respondents (31%) selected “Re-establish a self-sustaining, functioning reef ecosystem”, followed by “Promote coral reef conservation stewardship” (22%), and “Accelerate reef recovery post-disturbance” (16%) (Fig. 1).

Of the 45 projects surveyed, 84% reported medium- to long-term quantifiable and relevant objectives they aimed to achieve on a timescale of up to 10 years as defined by Shaver et al. (2020). These diverse objectives included increasing biodiversity, attracting fish to support local fisheries and reduce fishing pressure on other reef areas, mitigating beach erosion, developing tourism, promoting coral reef conservation, and protecting shores from wave damage.

During the planning phase 36% of the projects quantified at least one specific goal relevant to their overall objectives. These included identifying the size of reef area to rehabilitate, delivering a set number of coral restoration scholarships within a specified timeframe, setting timeframes within which to monitor and analyse success, and allocating 10% of farmed corals to restoration.

Setting a geographic focus area involves identifying a broad area where conducting restoration interventions would be most appropriate or relevant to achieving the project's goal. Appointing a technical advisory team is recommended (Shaver et al 2020). Eighty-nine percent of projects used a technical advisory team, and all bar one (which provided no response) set a geographic focus area related to their project goal within which final site selection took place.

Quantified climate change adaptation goals metrics used to aid geographical focus included coral thermal tolerance/growth and restoration success at different temperatures and depths (14%); monitoring bleaching occurrence, changes, and/or resistance (9%); water temperature (7%); and disturbance response (2%).

2. Identify, prioritise & select sites

A documented site selection process that considered the potential to improve restoration site condition was described by 89% of the 45 projects, 78% of which incorporated ecological/social surveys. Criteria followed for identifying, prioritising, and selecting sites within geographical focus areas were grouped into six broad categories. Ecological considerations were the most cited criteria (91%), followed by a site's tourism value (64%); pragmatic considerations such as logistics, finances, and accessibility (58%); climate-smart design considerations including potential temperature changes, storm intensity, and interactions with local stressors (38%); improving local fish stocks or sustaining fisheries (27%); and compliance with legislation requiring restoration of areas degraded by mining activities (7%).

Of 44 projects, 84% incorporated local expert knowledge into site selection, while 61% ranked site importance to prioritise where to start restoration and 68% discussed potential sites with local stakeholders before finalising site selection. Two projects (4.5%) did not involve communities in planning.

3. Identify, design & select interventions

Eighty-nine percent of 44 projects used an evaluation process for determining the type of restoration used, while 84% of 43 projects considered different restoration techniques during planning. Restoration techniques varied, with 80% of 45 projects incorporating multiple approaches. Coral fragment transplantation was the most commonly cited approach (84%), followed by diverse AR structures (58%). Seven projects (16%) relied solely on natural larval recruitment on ARs, while the bioacoustics project did not involve growing corals.

One international coral restoration project review (including projects in Indonesia) reports a lower percentage of AR structures (21%) (Boström-Einarsson et al. 2020), while another reports the transplantation of corals onto artificial structures in 48% of projects (Ferse et al. 2021).

For the 37 projects actively sourcing corals, already-broken fragments, or Corals of Opportunity (CoPs), were the main source for fragments. CoPs were used in 73% of these projects and were the sole fragment source in 41%. Nursery or commercially grown fragments augmented or replaced CoPs in 41% of 37 projects, while 11% exclusively used commercially farmed corals. Twenty-seven percent of the projects fragmented wild colonies alongside other fragment sources, while 8% relied exclusively on wild donor colonies. This resembles international findings that COPs are the most frequent source of coral fragments (58% of projects), with 46% of projects also sourcing fragments from wild colonies (Ferse et al. 2021).

For the types of corals used, 38% of the projects utilised a natural mix of local coral species, while 46% chose local corals based on specific factors, chiefly: fast-growing corals, especially branching and mainly *Acropora* (24%); variety of ecological function (11%); and thermal resilience (8%). For comparison, international reviews variously report one-third of projects incorporating *Acropora* and more than three-quarters of projects using branching corals (Boström-Einarsson et al. 2020), and the use of fast-growing, branching corals in 96% of projects (Ferse et al. 2021). There was no mention in international reviews of the number of projects investigating or incorporating coral thermal resilience into restoration efforts.

4. Develop restoration action plan

Project responses were used to categorise the SMART features of their goals and objectives (Fig. 2). Timebound goals were the most lacking, with 49% of 45 projects not specifically outlining objectives within a contextualised timeframe (Fig. 2a). Fifty-one percent met the criteria for all SMART features and 80% met at least four of five criteria (Fig. 2b).

Projects listed all restoration objectives measured, with a total of 18 different measurable objectives reported across five broad categories (Fig. 3). Ecology/restoration success was the most common type of objective, accounting for 54% of 127 responses, followed by alternative livelihoods/tourism (18%), and local stewardship (12%). The most common metric, quantitative reef monitoring, was listed by 78% of projects, while semi-quantitative and qualitative reef monitoring surveys were used by 9% and 11% respectively. Post-impact change was not measured by 62% of projects, while 69% did not quantify local stewardship/community buy-in. The extent of alternative livelihoods provided was not quantified by 73% of projects and 84% conducted no socio-economic or reef user satisfaction surveys.

5. Implement restoration & 6. Monitor & evaluate progress

Shaver et al. (2020) propose five detailed planning components for the Restoration Strategic Plan developed in Stage 4. A formal action plan was not implemented by 34% of 44 projects. An annual work plan was absent from 48%, an operational plan was absent from 39%, and a monitoring plan and timeline for restoration were both absent from 30% of projects (Fig. 4a).

While 36% of projects implemented all five components, 36% implemented two or fewer and 16% had not implemented any (Fig. 4b).

Projects involved varying degrees of cross-sector cooperation at different scales (Fig. 5). Formal partnerships with local communities were present in 72% of the 43 projects not driven by the communities themselves. NGO/NPO-driven (86%) and government-driven (82%) projects in particular secured partnerships with local communities, while the private sector (17%) generally worked alongside, but did not partner with, communities.

Ecological data for monitoring and evaluating progress was collected by 84% of the 45 projects, comparing favourably to 80% of international projects reviewed (Ferse et al. 2021). Less than half the projects collected event-driven (49%), economic (44%), or socio-cultural (42%) data, while 33% collected climate change adaptation data (Fig. 6).

Quantitative reef monitoring surveys were the main type of ecological data collected (76%). Nine percent of projects only collected semi-quantitative reef monitoring data and 11% relied solely on qualitative visual observations (Fig. 7a). Coral cover/growth was the most commonly collected ecological metric, but was not collected by 36% of projects. Fish community data was absent from 49% of projects and 62% did not collect benthic community/associated biota or coral survival data. Coral community composition/diversity data was absent from 96% of projects, quantitative coral health/bleaching data was absent from 89%, data on recruits/juveniles was absent from 80%, and data on water quality/temperature was absent from 82% (Fig. 7b).

Discussion

Indonesia has the most coral reef restoration projects of any nation (Razak et al. 2022). Located in the heart of the CT, its status as home to the world’s most biologically diverse coral reefs makes Indonesia one of the most important countries for coral reef conservation and restoration. This is supported by the “50 Reefs Initiative”, which identified an optimum portfolio of 50 bioclimatic units (BCUs) – areas within which reefs have a higher potential to survive climate change impacts and the ability to repopulate neighbouring reefs over time. Almost one quarter of these BCUs are located in Indonesia (Beyer et al. 2018).

Many Indonesian reefs have suffered severe, long-term declines in diversity, habitat structure, and key species abundance, with 71.2% classified as having less than 50% healthy hard coral (Hadi et al. 2020). The widespread implementation of MPAs and restrictions on reef ecosystem utilisation has not been enough to halt ongoing reef degradation in the face of persistent threats; the combination of high biodiversity and high prevalence of localised threats means that effective coral reef restoration is widely perceived as valuable and important (Lamont et al. 2022). As such, ongoing attempts to support, improve, and scale up active coral reef restoration efforts are imperative, with a particular focus on identifying reefs with a higher potential for resilience and survival.

Restoration efforts in Indonesia encompass various methods across a wide range of geographies, organisation types, and project sizes (Razak et al. 2022). A focus on re-establishing a self-sustaining, functioning reef ecosystem implies an understanding that restoration must take a holistic approach encompassing the reef community, while the promotion of conservation stewardship and provision of alternative livelihoods acknowledge the importance of involving local communities and fostering a sense of ownership over restoration projects. The need to accelerate reef recovery post-disturbance and reduce degradation reflects the impacts of local and global stressors, while scientific research is an important aspect of refining reef restoration techniques and outcomes.

Lamont et al. (2022) offer insights learnt from Indonesian case studies to inform reef restoration management and policy interventions, recommending multi-dimensional approaches that include ecological, social, and economic processes. The study highlights success stories, including the incorporation of threat reduction involving local communities into restoration initiatives in Raja Ampat by two NGOs, strategic project placement in Bali to aid job creation in tourist areas heavily affected by the Covid-19 pandemic, and site selection guided by a mix of ecological and social factors, allowing efficient scale-up of restoration efforts in areas of the Spermonde Archipelago where future success was most likely. Projects in north Bali led by former cyanide and dynamite fishermen have been exemplars of engaging diverse local community participants; the youth-driven nature of initiatives have made them particularly impactful in achieving societal change. Restoration at Gili Trawangan island involves a collaboration of foreign businesses, academics, NGOs, and local government; local leadership is maintained through the institutionalisation of traditional customary laws for regulating marine activities, which all stakeholders work together to uphold and implement. The success of this venture highlights prioritising within-community leadership as a key enabling principle of scalable restoration success.

Indonesia is an attractive location for international funding, NGOs, eco-tourism, and scientific study. The government has established a commendable framework for coral reef restoration, with legislation specifically requiring, for example, that local communities and stakeholders be directly involved in both the planning and implementation of restoration activities (Razak et al. 2022). The legislature contains a prevailing sentiment of community-driven restoration management and the management of fisheries resources. Razak et al. (2022) highlight Presidential Regulation No. 121/2012 Article 12.1 ("Rehabilitation can be conducted through cooperation between government, regional government, person or community") and Article 15.1 ("Community or persons can participate in the implementation and maintenance of rehabilitation voluntarily"), as well as MMAF Ministerial Regulation No. 26/2021, Article 67.1 ("Each person can participate in the rehabilitation of fisheries resources and their environment"). While the legislative frameworks are in place and there is an abundance of restoration activity, there is now a needs to bring these efforts together and focus coral reef restoration across the country through a lens of CBP to deliver meaningful restoration at scale. The shortcomings in nationwide reef restoration efforts that require attention also provide opportunities to learn, consolidate, and create a lasting legacy of sustainable reef restoration projects on a national scale. Greater efficacy in meeting target-driven outcomes, consistency in ecological monitoring, and intentionality in global knowledge exchange can help to reposition Indonesia's restoration projects as a transformative resource for the region and an example for the world to follow (Razak et al. 2022).

Limitations

Social desirability bias (SDB) was considered as a potential skewing factor on survey responses. This is the tendency to present oneself and one's social context in a way perceived to be socially acceptable, but not wholly reflective of one's reality (Bergen and Labonté 2020). In some situations, people may tend to portray themselves in a more favourable light (Podsakoff et al. 2003). While measuring potential discrepancies is outside the scope of this study, measures were taken to minimise SDB, including conducting interviews face-to-face (online) whenever possible to allow additional questioning and clarifications (Mooney et al. 2018). An introductory discussion helped to establish rapport with participants, put them at ease, and display appropriate respect (Bergen and Labonté 2020) for the high standing of certain academics and government officials. It also allowed the interviewers to contextualise their own involvement in marine research in Indonesia and explain the study's focus, purpose and how data would be used (Bergen and Labonté 2020).

This study encompasses roughly 8% of all documented Indonesian coral reef restoration projects from the last three decades. An opportunity exists to engage with a higher proportion of ongoing active projects to develop sound, agreed frameworks within which projects should focus their efforts.

Recommendations and Opportunities

There is significant potential to standardise the setting of quantifiable, iterative goals that are integral to the restoration process (Hobbs and Harris 2001), as well as to consolidate the overarching objectives of Indonesian reef restoration and how these objectives are achieved, to deliver more efficient and effective collective reef restoration actions that provide balanced benefits to reefs and communities.

- More projects should set quantifiable goals during the planning phases, incorporating assessments of how relevant and realistic these goals are and considering the specific context and characteristics of each individual case. Nevertheless, a set of simple standards could be applied for determining desired aspects, including the size of the area to be rehabilitated, increases in coral cover and biodiversity, and socio-economic project functions.
- Long-term objectives can be consolidated by increasing the focus on the most pressing needs, including conducting restoration resilient to future climate change; reducing or eliminating the most harmful local stressors, including destructive fishing; better integrating socio-economic and cultural concerns into restoration objectives; and producing quantified outcomes to inform and evolve best practice. Strengthening ties between reef restoration projects and regulatory agencies may also increase the implementation of management measures to address ongoing stressors to restoration areas (c.f., Ferse et al. 2021) and deliver large-scale coral reef restoration.

- A national database of reef restoration projects, where reports can be submitted and stored in a repository, could be a potential vehicle for improved project outcome reporting. This will, however, need to be linked to a wide coalition or network of projects willing and able to ascribe to a set of project management, scientific monitoring, and outcome reporting best practice requirements. It must also allow for the inclusion of already-established projects, factoring in diverse goals and approaches, as well as disparate levels of financial and logistical support.
- The SCORES online community of scientists and reef restoration practitioners, although still in its infancy, is an excellent example of the potential of centralised training hubs to substantially accelerate the establishment and scaling up of successful projects through knowledge sharing (Lamont et al. 2022). While the creation of a national framework for coral reef restoration would add a significant administrative burden for projects, it would provide significant value, so long as projects can realistically meet logistical, financial, administrative, scientific, and reporting standards.
- There remain opportunities to improve how restoration sites are selected. Ecological considerations were by far the main driver of site selection in the current study, while tourism value was another predictably important factor.
- The utilisation of local knowledge in initial site selection could be better extended through the planning phases to include further discussions with local stakeholders prior to final site selection, a step lacking in one-third of projects. One in ten projects did not consider the potential to improve site condition during planning, while just under a quarter of projects did not employ ecological or social surveys to aid site selection. This largely reflected logistical and/or budgetary priorities or constraints (cited by over half the projects surveyed), limitations in scientific training, and a reliance on local knowledge about reef areas and conditions prior to disturbance, and the location of degraded areas of reef.
- Logistical, financial, and site accessibility considerations will remain critical, including minimising maintenance and long-term monitoring costs. It is worth considering the development and implementation of a national training element encompassing not only how to select areas for restoration, but also other elements of project design and implementation. A standardised and more structured approach to assessing and prioritising sites, as per international CBP, can help to bolster holistic restoration that includes ecological, operational, and societal aspects.

Involving the local community in planning does not necessarily lead to support for conservation interventions. One survey response noted that local community participation and buy-in remained low despite frequent campaigns and events attempting to address marine degradation caused by terrestrial farming practices and pesticide use. In another response, one of three villages refused to support restoration activities after focus group discussions, due to previous destructive mining activity that had degraded the surrounding environment. Neither was long-term support garnered from the other two villages: while the coral restoration programme started with 10 volunteers, only two remained by the end of the programme. A third response highlighted ongoing destructive fishing practices and a gap in understanding about the sustainable use of coral reefs, despite discussions and attempts to educate the local community on the benefits of eradicating these practices.

There is an opportunity to increase the focus on local community involvement and attempts to gauge the success of these efforts. This is illustrated by the low incidence of reporting and quantification of alternative livelihoods and local stewardship as project objectives comparative to ecological and/or restoration success. Involving local communities from early in the project planning stages should be seen as imperative. Focus group discussions and agreements with local community leaders are important in laying the groundwork, as is ongoing community participation, but it is essential that communities recognise the benefits of this participation. One project trained members of village community groups in Locally Managed Marine Areas (LMMAs) to become future project managers, while another reported building long-term relationships and deepening engagement and support over a three-year pilot phase to demonstrate the feasibility of community-based reef restoration, which then continued with the participation of community members. One NGO-run project has a member of the local fishing community as a co-founder and worked with community leaders and fishers to agree on the best project method; it continues to work in close collaboration with fishers and restoration is run in conjunction with various other environmental and social projects.

Another vehicle for community involvement with potential for wider implementation is the creation of community surveillance groups ("pokmaswas"). As part of the CTI, the MPA authorities of Nusa Penida and the Gili Islands consulted with stakeholders and drafted seven standard operating procedures to promulgate these groups, with resounding success, and community members are reportedly benefitting from employment, education, stewardship, recreation, satisfaction, and other social and cultural benefits (ADB 2022).

Establishing and maintaining trust is a complex issue requiring more than simply "providing" alternative livelihoods. For example, an increased focus on the potential for improving local fish stocks and sustaining local fisheries can be a significant driver for community support, but restoration practitioners must be sure to respect, integrate, and actively encourage local customs such as traditional rules on access to certain fishing grounds (Bottema and Bush 2012).

Overall, there remains a need to better quantify local communities' support for and involvement in coral reef restoration across Indonesia, and this could potentially be achieved via the creation and adoption of standardised socio-economic and reef user satisfaction surveys to inform interactions with community leaders and others.

Quantitative measurements of bleaching, coral health, coral thermal tolerance and/or changes in restoration success relating to temperature and depth were underrepresented in the projects surveyed. There is therefore a decisive opportunity to better integrate and increase the focus on climate smart design considerations and climate change adaptation goals to increase the meaningful and impactful outcomes of Indonesian coral reef restoration efforts in the long-term. This is likely to require updates to legislation, increased funding for scientific studies, and standardised planning structures that incorporate a more detailed approach to climate-based goals. This includes more widespread adoption of innovative climate-smart reef restoration efforts nationwide in the near future (Camp et al. 2018a, 2018b; van Oppen et al. 2017), particularly if significant local threats persist.

Building on work already done by the 50 Reefs Initiative (Beyer et al. 2018), Indonesia can concentrate large-scale restoration efforts on reefs with the greatest potential to survive climate change impacts and repopulate neighbouring reefs, identifying refugia for coral diversity, including thermally resistant corals that have survived numerous mass bleaching events.

As mass bleaching events become increasingly common and severe, a better understanding of which corals will survive best in particular areas and conditions will be vital to restoration success, as will the prioritisation of environmentally buffered core refugia zones. This can be achieved by more stringent scientific selection of viable sites and by adopting innovative management approaches that incorporate restoration in lower light conditions, focus on more resilient corals, and/or experiment with assisted evolution, hybridisation, and other potential solutions (Camp et al. 2018b; Chan et al. 2018; van Oppen et al. 2015, 2017), as well as the proactive integration of emerging technologies in an adaptive process of research and development, learning, consultation, risk management, and staged implementation (Anthony et al. 2017) should be fostered and encouraged. This will likely require financial backing and scientific training from national and/or international partners.

A more structured evaluation of restoration techniques and approaches being used in Indonesia could be beneficial to identify and prioritise a list of broadly standardised interventions. There is scope to increase the use of coral nurseries to produce additional coral biomass for transplantation and reduce reliance on CoPs and parent colonies on the reef. The use of a closed cycle of nursery-reared fragments following an initial collection phase is one approach that has potential for wider implementation, with these corals supplemented or replaced in certain areas by corals sourced from commercial farms.

The use of ARs relying solely on natural recruitment would benefit greatly from standardised site assessment protocols that include scientific analyses of natural larval supply and recruitment levels. The selection of groups of corals with varying ecological functions can align projects more closely with international CBP for re-establishing a fully functioning reef community.

Ongoing monitoring of restoration efforts was varied, with quantitative data collected ranging from changes in coral growth and cover to a count of the number of artificial structures installed. Data collection on the wider reef ecosystem is currently under-represented, with roughly half the projects collecting fish community data and just over one-third monitoring the benthic community and/or associated biota.

The variable quality of monitoring programmes is one of the multi-faceted challenges facing attempts to characterise the effectiveness of restoration programmes and quantify efforts on regional and national scales. Clearly defined indicators linked to specific objectives and the properties of the entire reef community, as well as appropriate timeframes, are needed (Hein et al. 2017), and monitoring programmes should abide by basic scientific principles and accurately follow standardised procedures.

Large scale, long-term restoration efforts while improve understanding of restoration effectiveness in light of environmental trends and/or ecosystem-wide effects (Jokiel et al. 2004, Hein et al. 2017). Ongoing funding will be particularly important to carry out long-term ecological monitoring programmes due to the complexity and expense of systematic monitoring.

There are clear opportunities to position Indonesia at the forefront of international CBP when it comes to identifying reef degradation causes and using environmental assessments to inform reef restoration efforts. As a comparison, in their survey of restoration projects from mostly the Caribbean and Indo-Pacific regions using coral transplantation, Ferse et al. (2021) found that most projects did not conduct environmental assessments prior to transplantation, with no project reporting an assessment of coral recruitment and two-thirds of projects failing to assess the initial causes of reef degradation. The researchers further noted that a lack of monitoring standards and guidelines has impeded the measurement of social and ecological success in coral reef restoration projects.

The creation of standardised national frameworks or guidelines for a) assessing the causes of reef degradation and whether environmental conditions are conducive to restoration, b) levels of natural coral recruitment, c) climate change adaptation metrics to identify high priority restoration areas, and d) long-term reef monitoring protocols would therefore help Indonesia to position itself as a driver of reef restoration initiatives in the CT. Pooling data in a centralised database would facilitate more accurate nationwide assessments of reef restoration and help researchers and decision-makers to more effectively evolve restoration approaches and policies over time. Ferse et al. (2021) posit that consistent minimum standards of accountability and monitoring for reef restoration projects would be highly beneficial; if Indonesia can bolster existing regulations seeking to open restoration up to local communities with complementary mechanisms for improving the overall quality of the projects being created – and the potential to collate their data – it would help to achieve this aim.

Creating a national reef restoration network

The vast scale required of global reef restoration efforts will necessitate collaboration, a variety of approaches, increased capacity, and engaging new actors to assist in restoration efforts and the development of innovative technologies and approaches. In Indonesia, the establishment of a core coral reef restoration network comprising diverse restoration practitioners and decision-makers will help to facilitate knowledge-sharing and accelerate and improve the conservation and rehabilitation of degraded reefs (Fig. 8).

The initial success of the SCORES network, the strengthening of connections forged via the ICRG project, and other initiatives provide a foundation on which to base a standardised, coordinated framework for multi-dimensional, scalable reef restoration efforts. Knowledge and skills sharing, as well as a centralised training hub, can promote a concerted restoration drive based on scientific assessment and monitoring, where successes and failures can be quantified to support approaches that can be adapted in line with CBP and rapidly changing environmental conditions. The mechanisms of such a training hub would need to be worked out, but could include the creation of regional hubs delivering physical workshops, and/or the development of online materials, courses, and workshops, and knowledge-sharing sessions.

If existing networks like SCORES and the ICRG can be brought into the fold along with leading academics from Indonesian institutions and national and regional policymakers, it will lend credibility to the concept and assist with gaining buy-in from others to expand the network. Along with bringing onboard local and national government authorities, as well as companies and NGOs with a long-standing presence in the country, this would be a highly complex undertaking. If done well, however, it can increase the effectiveness, accountability, and longevity of restoration projects and facilitate increased funding opportunities for projects by creating links between restoration practitioners and the corporate sector, international and Indonesian NGOs, government agencies, and regional programmes like the CTI-CFF. This would help to ensure funding is channelled into efforts that support the restoration and protection of prioritised reefs on a national scale to maintain Indonesia's status as a hotspot for global marine biodiversity.

There are certainly hurdles to overcome, not least of which will be the need to align potential competing interests to come to a consensus on a wide range of issues. These may include the best restoration techniques to adopt in different areas, which areas to prioritise for restoration incorporating climate change adaptation goals, the allocation of any funding secured, and what constitutes an acceptable level of scientific and administrative reporting.

A strong emphasis will need to be placed on the value of building stronger partnerships and sharing knowledge, which may at times necessitate compromises from diverse parties. The network should also provide an upliftment and training aspect: by becoming part of the network, restoration projects should be able to gain access to a pool of experts who can provide consultation, feedback, and guidance on various processes, including project administration, monitoring, reporting and community engagement.

Developing a roadmap for Indonesian coral reef restoration

Indonesian reef restoration and the legislation that supports it cover the whole spectrum of expertise levels. International coral reef restoration CBP provides a solid framework on which projects can base their project planning and design, and which can potentially be evolved to suit the specific needs of the wider and highly diverse Indonesian restoration community.

The length and complexity of the NOAA guidelines may be off-putting for some projects, especially in countries where English is not the first language. Indonesia would benefit more from a specific national roadmap for coral reef restoration, incorporating a tiered system for structuring protocols or guidelines for restoration, to make standardisation accessible to a wider range of projects within a formal network of reef restoration practitioners. This could involve using various guidelines and document templates from Shaver et al. (2020) as a starting point to develop standardised documentation and protocols at different expertise levels (e.g., “Standard”, “Expert”, and “Multi-Dimensional”). Putting checks in place to monitor the extent to which guidelines are being followed may help to improve accountability. This should include the formation and implementation of reporting requirements, the provision of feedback from a central board or other restoration network members, and the creation of procedures and channels for submitting project documentation to a central repository. This would also allow the network to identify projects in need of additional training and/or administrative assistance periodically and iteratively (Fig. 8).

Aspects of a potential reef restoration roadmap based on international CBP

1. Set goal & geographic focus: Incorporating SMART (Specific, Measurable, Achievable, Relevant, Timebound) goals and objectives, a standardised set of reef restoration goals can be created based on overarching national objectives (e.g., removing local stressors, restoring degraded reef ecosystems, increasing reef biodiversity, providing socio-economic benefits, and an increased focus on coral thermal resilience and natural refugia zones in areas least vulnerable to climate change).

In light of the low numbers of climate change adaptation goals quantified when setting the geographical focus of projects in Indonesia, this should an integral part of a national roadmap. It will also be important to focus on areas of ecological significance, including areas of high biodiversity, endemism, and ecological uniqueness. Priority geographical areas nationwide can be further refined based on the presence, scale, sustainability, and successes of existing restoration projects, particularly if practitioners involved are a part of the restoration network. This should be done in the context of international recommendations to consider the functionality and benefits of conducting restoration in a particular area, including identifying the greatest management challenges, the biophysical context within which these will need to be addressed, the likelihood they can be overcome, and any unique opportunities (Shaver et al. 2020).

The role of a technical advisory group recommended under international CBP could be fulfilled by the national reef restoration network for projects without access to this level of expertise. Alternatively, the network could provide additional technical support for local advisory groups to ensure that restoration standards are met.

2. Identify, prioritise & select sites: Protocols to assess restoration sites within prioritised geographical areas can follow international CBP, ensuring that site selection considers specific restoration goals, the potential to improve site condition, and short- and long-term coral survivorship (including external factors such as local stressors and resilience to climate change). Projects within the restoration network will benefit from a centralised framework for prioritising sites and an agreement on how this framework will be implemented. The use of semi-quantitative or quantitative data could be differentiated within a tiered system, depending on the level of project expertise available.

The site selection process should include identifying areas where restoration will *not* be conducted, within which natural recovery is possible due to the absence of local stressors and the presence of high larval supply, consolidated substrate for larval settlement, and other favourable conditions.

A template of guidelines for effective community engagement actions can be developed, along with strategies on how to best involve all project stakeholders in the early planning stages (c.f., Shaver et al. 2020). The restoration network can help projects to fulfil this brief via project reporting and expert feedback.

3. Identify, design & select interventions: Over a quarter of the projects surveyed fragmented wild colonies and almost one in 10 projects relied exclusively on wild donor colonies. Considering that under half of the projects incorporated a nursery phase to increase coral biomass production and/or sourced commercially farmed corals, these approaches can be further promoted in certain contexts to provide more broodstock for transplantation, reducing the number of corals required from healthy reef areas.

Because the science of restoration is evolving rapidly (Shaver et al 2020), knowledge and skills sharing potentially supported by a consultation process with restoration experts can help to avoid duplication of effort and reliance on trial and error selections. Overall national objectives defined by the roadmap can be considered within individual contexts to select the intervention(s) that will best marry local and national goals, while access to expert advice will increase the number of projects able to incorporate climate-smart design considerations put forward in international CBP.

4. Develop restoration action plan: Nationwide standardisation and guidance can have a major positive influence in ensuring that restoration practitioners are pulling in the same direction when developing a restoration action plan. The inclusion of a pilot phase to assess the viability of proposed interventions should be standard practice, while detailed documentation of the action plan can greatly aid projects to meet goals and potentially scale up in the future, as this plan serves as a basis for securing funding, communicating with stakeholders, building out a broader strategic plan, and putting theory into practice (Shaver et al. 2020).

Indonesia- or Indo-Pacific-centric versions of document templates proposed by Shaver et al. (2020) could be developed in line with the proposed tiered system for project planning and development to make documentation more widely accessible, whilst maintaining formal administrative standards to assist with effective project management.

There is a need for improved quantification of alternative livelihoods and local stewardship/community buy-in, while less than half of projects set goals within a contextualised timeframe. The restoration action plan will also need to ensure transparency of all decision-making processes, offering all stakeholders the opportunity to provide input and feedback for consideration when implementing restoration.

5. Implement restoration: The implementation of a formal Restoration Action Plan will be critical to standardising and scaling up reef restoration efforts. Currently, more than one in three projects have formally implemented two or fewer of the five action plan elements, while 16% have no formal action plan elements in place. As a minimum, projects should be measuring restoration efforts and defining successes and shortcomings compared to control sites, and outlining an achievable plan for ongoing community involvement to better achieve larger restoration scales, create interest in the project, and promote shared ownership. Survey responses suggest that private sector participants, in particular, should be encouraged to formalise their interactions with local communities to create partnerships in areas where they are conducting restoration. Within a tiered system, projects can iteratively increase their efficacy over the course of several years of implementation through training, support, knowledge sharing, and shared experiences (Fig. 8).

6. Monitor and evaluate progress: The evaluation of restoration progress should switch over time from short-term assessments of restoration interventions to examining reef-scale effects over longer timeframes (Shaver et al. 2020). Using the proposed tiered system of project design, local community members can potentially take part in reef monitoring programmes, while regular meetings help to keep all stakeholders abreast of progress. Within the scope of a national restoration network and roadmap, regular progress meetings should be held with those appointed to represent network members, to assist projects in meeting specific goals and objectives in line with the roadmap.

Just under one quarter of surveyed projects did not conduct quantitative reef monitoring surveys. Over one-third of projects did not quantify coral cover/growth, while almost half the projects did not collect fish community data and just under two-thirds did not collect benthic community/associated biota or coral survival data. Even more strikingly, only 4% of projects quantified coral community composition/diversity data and 11% quantified coral health/bleaching.

Differentiated assessment and monitoring protocols can be developed for projects with varying levels of expertise. At a basic level this should include standard measures of common metrics like coral cover, natural recruitment, mortality rates, bleaching incidence, fish counts, and environmental conditions like water temperature, although assessing ecological functions will also be crucial. Moving towards a multi-dimensional approach could include testing and/or monitoring of coral thermal resilience and other climate change adaptation metrics.

Feedback, recommendations and training from restoration network representatives would increase the potential for project managers to scale up their monitoring programmes over time, including how best to train and involve local community members in monitoring efforts and how to collect useful socio-economic data.

Conclusion

Coral reef ecosystems and associated habitats are extremely complex biomes, while reef conditions and the use of marine resources by local communities across Indonesia are extremely varied. While no single management objective will be sufficient for coral reef ecological restoration (Williams et al. 2019), certain policies, actions, and approaches can be identified to transfer and strengthen nationwide efforts, reducing the need for projects to “reinvent the restoration wheel”.

Simple, standardised scientific methodologies can help Indonesia to play a leading role as a natural laboratory in which to make further advances in coral reef restoration methods and techniques. A well-developed network of knowledge sharing would allow scientific institutions to iteratively feed positive research outcomes into best practice to include climate change adaptation and other advances, such as the use of midwater nurseries to take advantage of enhanced reef function metrics including higher flow, light, and dissolved oxygen, higher survival of translocated corals, and reduced sedimentation and microbialisation relative to the seafloor (Baer et al. 2023).

The use of various structures to stabilise shifting areas of dead coral rubble has widespread applicability throughout Indonesia and the CT due to the historical prevalence of destructive fishing techniques (Fox 2004) and the presence of vast rubble beds throughout the region (White et al. 2014). Construction of these structures and (where financial backing is available) the employment of community members in various capacities can provide sustainable alternative livelihoods (e.g., Williams et al. 2019), while future-proofing techniques can be integrated where scientific input is available by selecting more resilient species and/or sites with potential as climate refugia.

Coral reef restoration projects regularly commence with little by way of planning or framework. As noted by one NGO, "Project planning is evolving. With each site, the process is formalised more." The adaptation of international CBP approaches within an iterative, tiered roadmap designed specifically for the Indonesian context should be a priority for the country's authorities and restoration practitioners to ensure effective, efficient, and successful restoration efforts with the potential for replication, adaptation, and scaling up.

This roadmap can position Indonesia as a regional leader in coral restoration best practice and serve as a framework for the whole CT by taking country-specific factors into consideration, rather than trying to directly adopt international CBP approaches that do not necessarily take regional challenges into account. Nevertheless, until an Indonesian reef restoration roadmap is developed, international CBP provides a useful blueprint for projects to use at any stage to formalise their activities, notwithstanding logistical, administrative, and financial constraints.

Declarations

The authors have no relevant financial or non-financial interests or any other competing interests to disclose, and declare that no funds, grants, or other support were received during the preparation of this manuscript.

Author Contribution

RWP, JJ, RAR, and DJS conceived and initiated the study, and TBR assisted with formulating and conceptualising the incorporation of projects from the IPB SCORES webinar series. RWP (English) and AN (Bahasa Indonesia) conducted data collection. AN translated data in Bahasa Indonesia into English. RWP analysed the data, prepared the figures, and wrote the manuscript. DJS, TBR, RAR, JJ, and RWP reviewed the manuscript.

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Figures

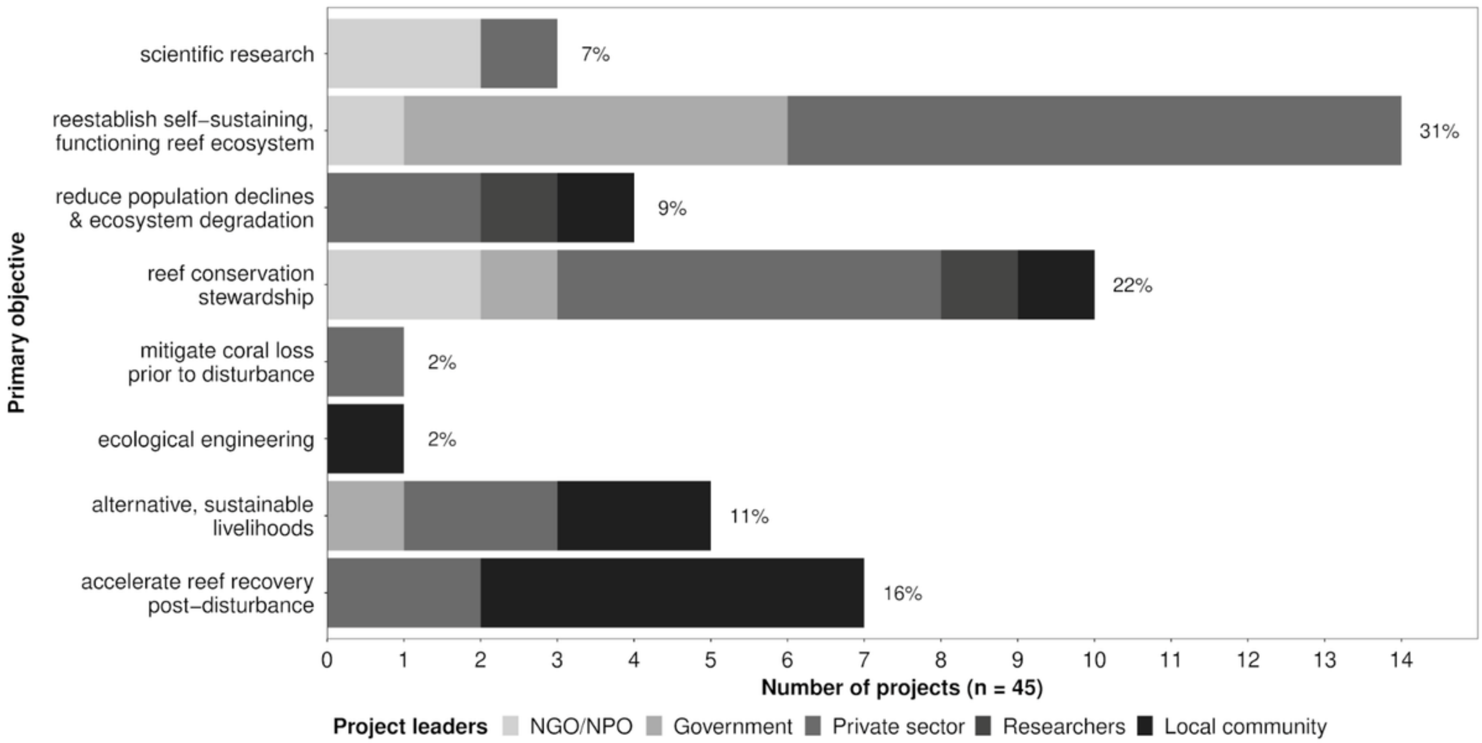

Figure 1

Primary objectives identified by coral reef restoration projects across Indonesia.

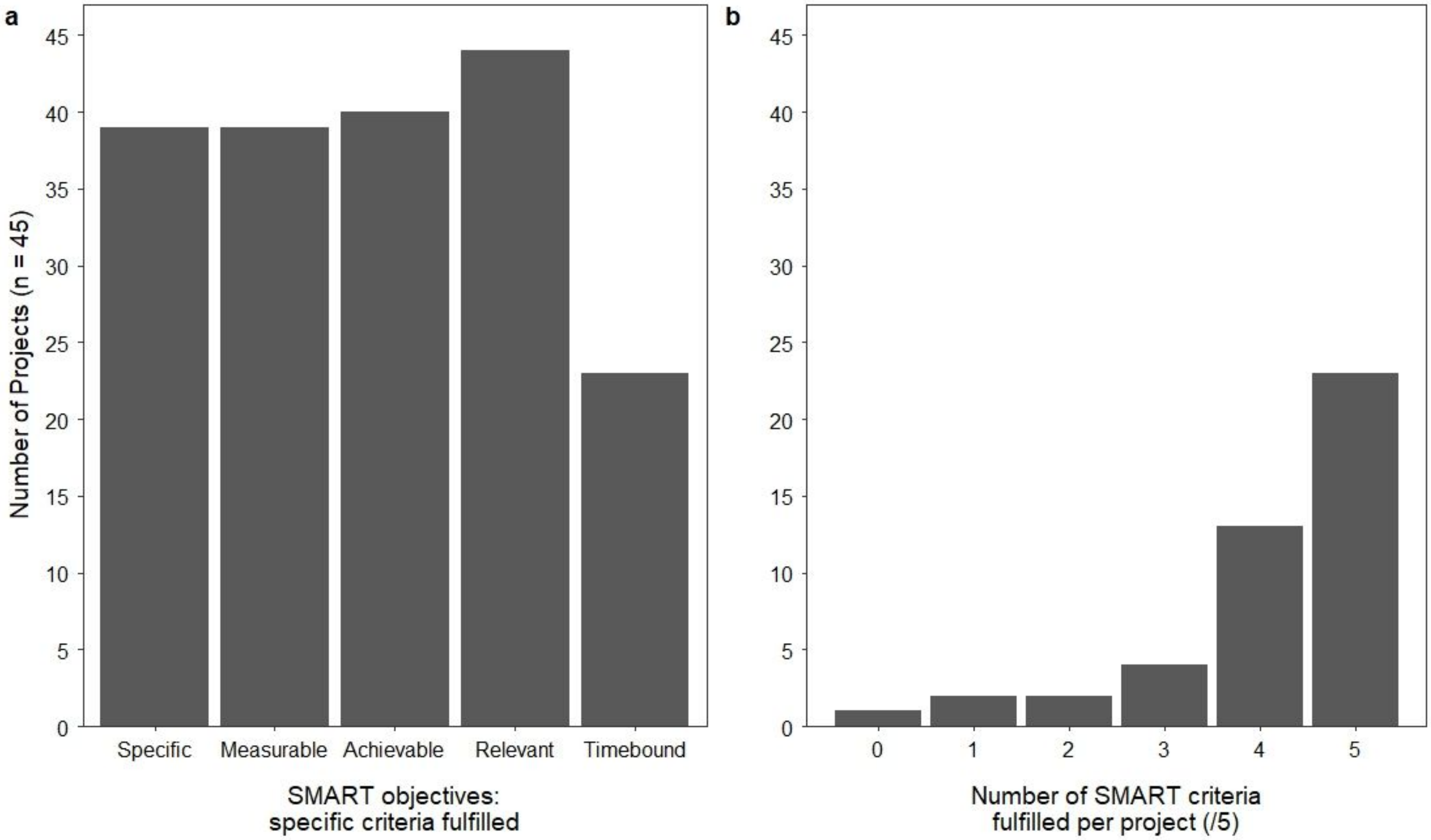

Figure 2

(a) The number of projects meeting SMART objectives for coral reef restoration planning. The biggest deficiency in project planning was the lack of timebound objectives in 49% of projects. (b) The number of the five SMART criteria fulfilled by each project. At least four of five criteria were met by 80% of projects.

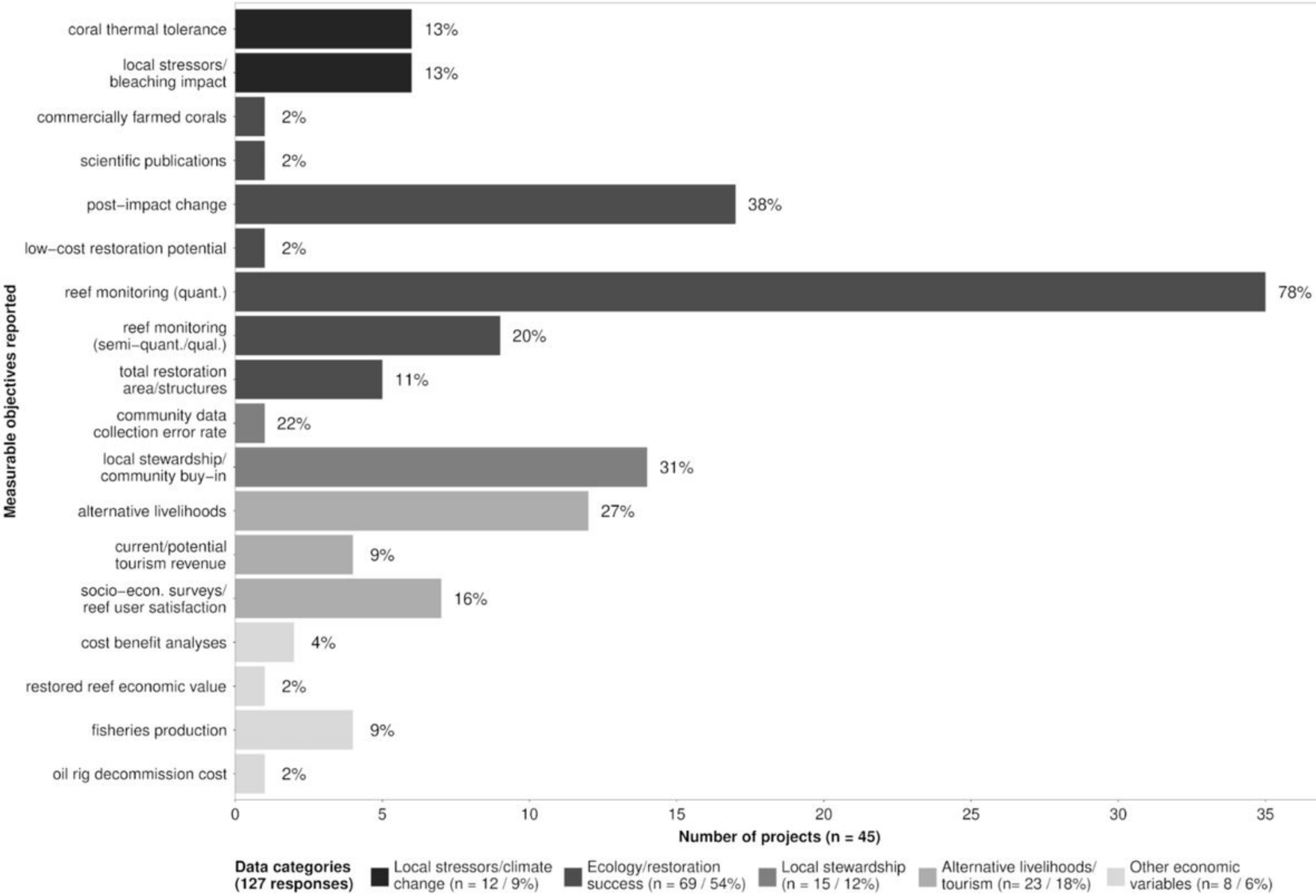

Figure 3

Measurable objectives reported by projects showed that most data was gathered on ecological/restoration success (54%, of 127 total responses), followed by data on alternative livelihoods and/or tourism (18%). Reef monitoring programmes were conducted by 78% of projects and represented the most common form of data collection, followed by post-impact change (38%).

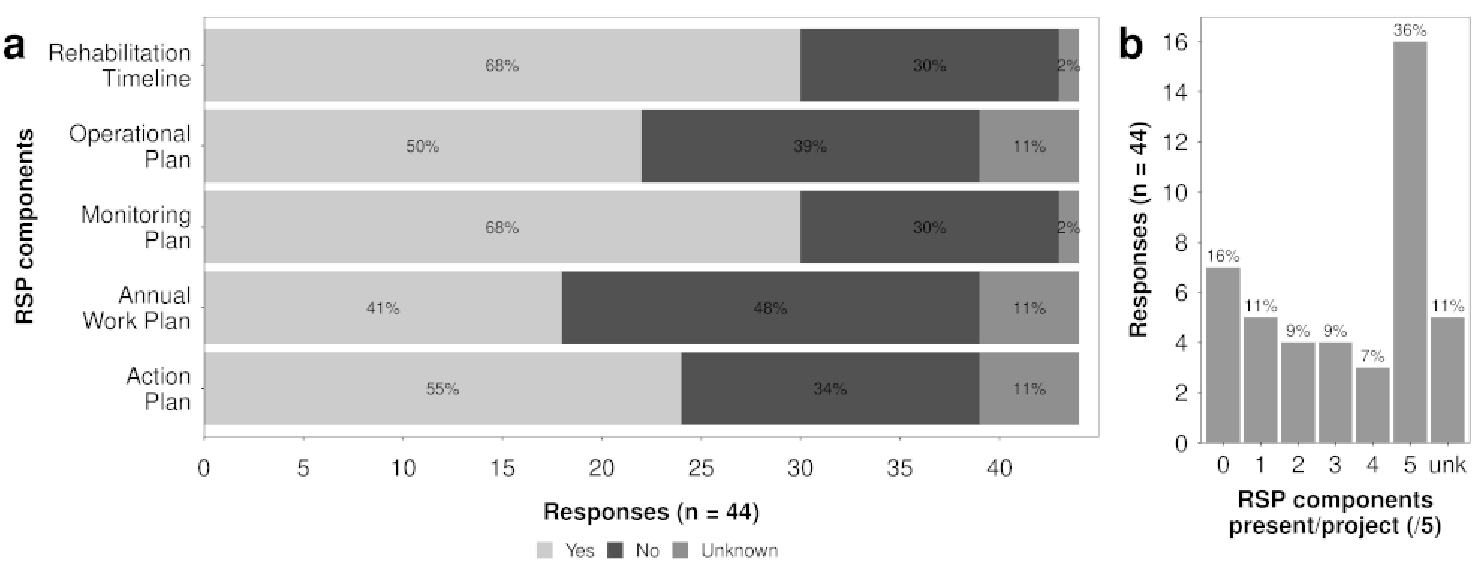

Figure 4

(a) The number of projects to implement each of the five elements of a Restoration Strategic Plan (RSP), and (b) the number of RSP components implemented per project.

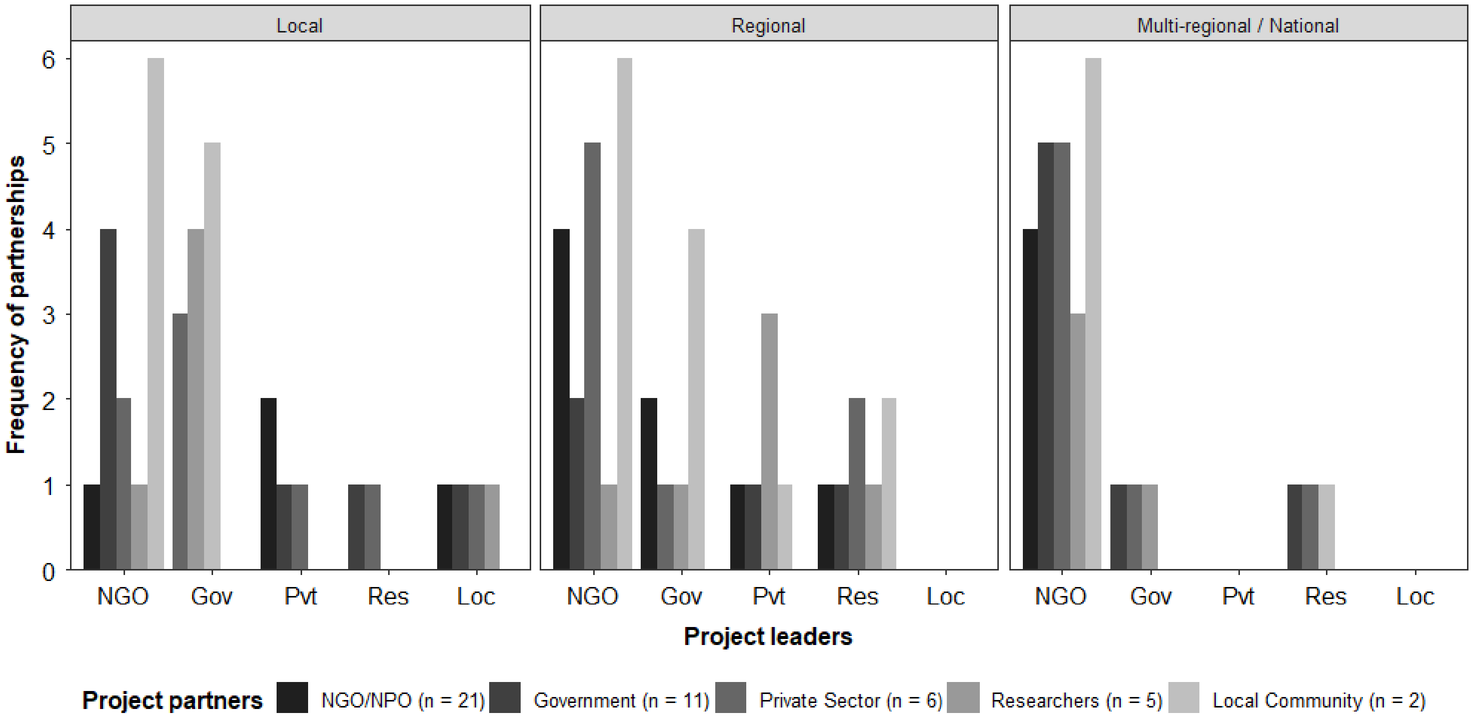

Figure 5

Degrees of cross-sector cooperation at different scales. NGOs/NPOs tended to have higher cooperation with other sectors (particularly local communities) at all scales. Government projects also had higher cooperation with local communities at local and regional scales.

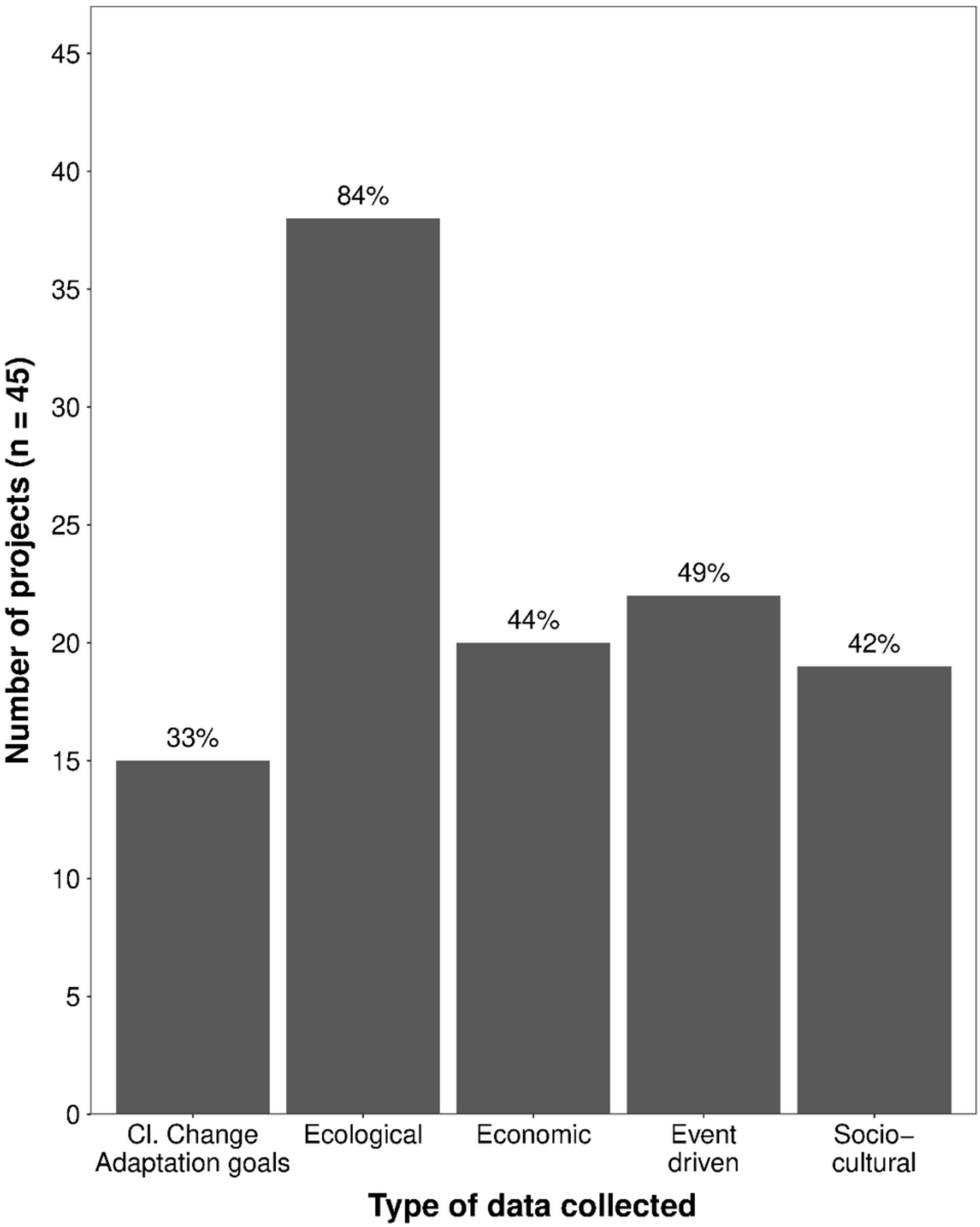

Figure 6

Ecological data was the most commonly represented metric, followed by event-driven data. Data on climate change adaptation goals was the most lacking.

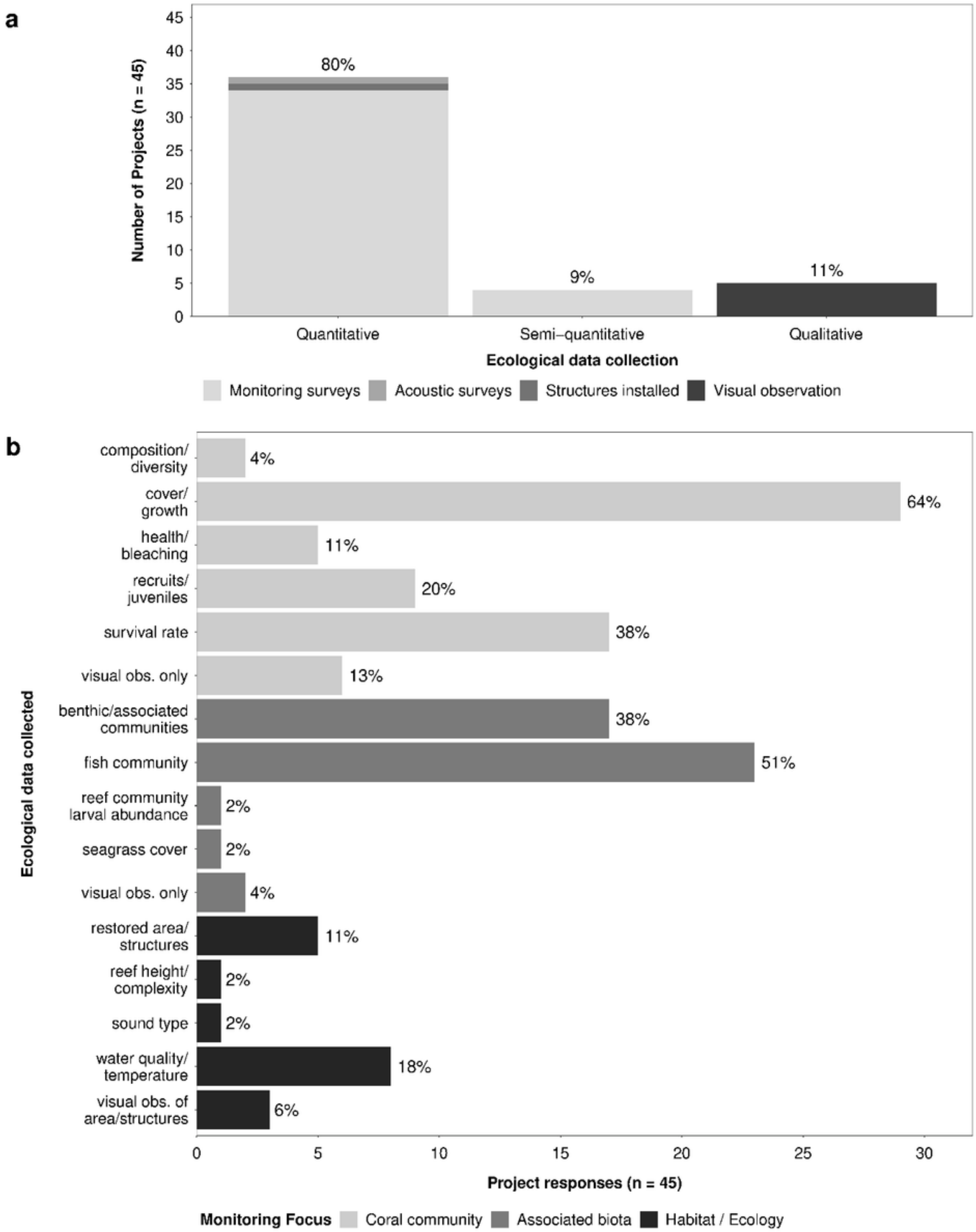

Figure 7

(a) Eighty percent of projects collected quantitative ecological data, mostly in the form of monitoring surveys. (b) Coral cover/growth was the most commonly monitored ecological restoration metric, with more effort put into monitoring the coral community than associated biota, habitats, or other ecological factors.

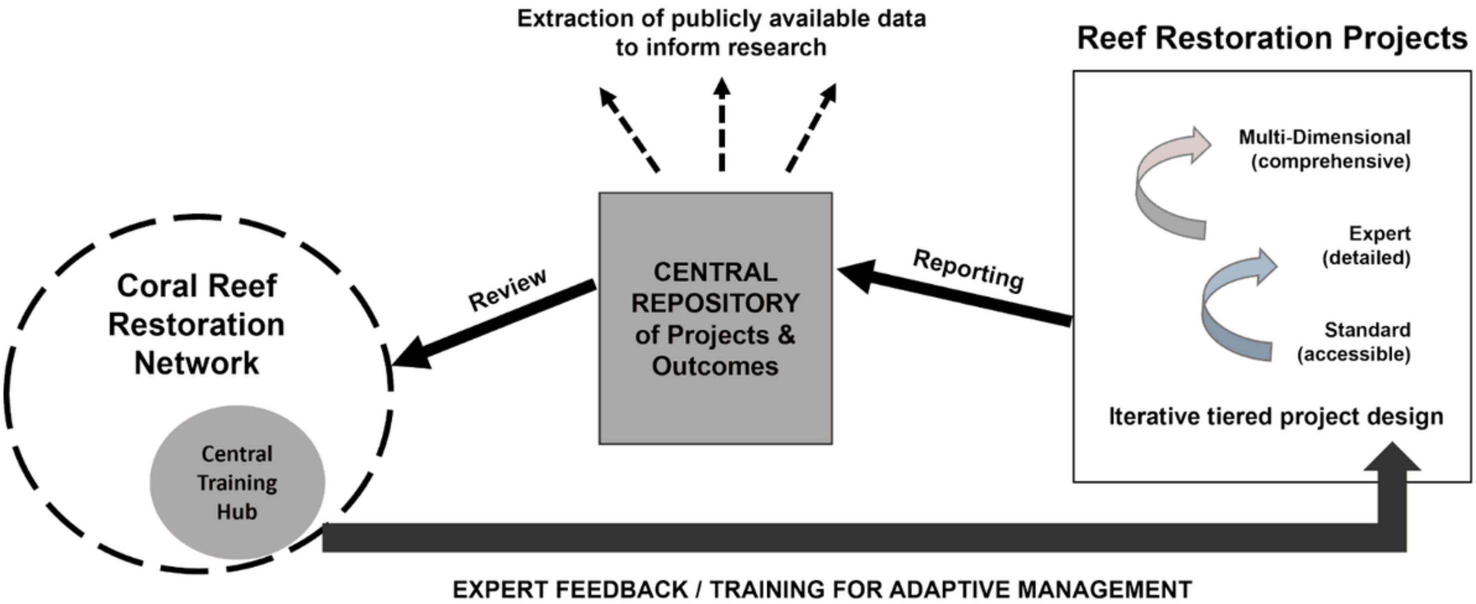

Figure 8

A formal network of coral reef restoration managers and decision-makers supported by centralised training hubs and data repositories can facilitate an iterative process of reef restoration project design and implementation. A tiered project design system can help to better implement a national reef restoration roadmap developed by this network, based on knowledge sharing and the alignment of overarching national goals and objectives for coral reef restoration.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial1Surveytemplate.docx
- SupplementaryMaterial2MasterDataSheet.xlsx