Biodiversity and Conservation
https://doi.org/10.1007/s10531-024-02897-8

REVIEW PAPER

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

Rowan Watt-Pringle[1] · Tries B. Razak[2,3] · Jamaluddin Jompa[1,4] · Rohani Ambo-Rappe[1] · Alyssa N. Kostaman[5] · David J. Smith[6,7]

Received: 14 December 2023 / Revised: 18 May 2024 / Accepted: 20 June 2024

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 within a framework of international common best practice (CBP) that incorporates internationally-recognised Standards for Ecological Restoration (SER). This framework is used to formulate recommendations for a formal network of reef restoration practitioners with the purview to develop and implement a national restoration roadmap. Forty-five projects were surveyed to determine how projects have been planned and implemented. This was compared with recommendations from CBP. There is particular scope to increase quantitative data collection, reinforce community involvement, improve ecological data collection, and standardise monitoring protocols. While 84% of projects reported quantifiable goals, 64% did not quantify goals during planning and 61% did not incorporate climate-smart design features. Quantitative reef monitoring surveys were absent in 22% of projects. The majority of projects did not quantify important ecological metrics like coral community composition/diversity (96%), coral health/bleaching (89%), benthic community (62%), and coral survival (62%). Indonesia has the capacity, regulations, and networks to position itself as a reef restoration driver in the Coral Triangle region; this will require increased coordination, alignment, and quantification of restoration. A structured, collaborative, and iterative national network of various stakeholders would facilitate the development of a national restoration roadmap based on adaptive management strategies. This would aid in standardising project planning, monitoring, and reporting. Efforts should include an increased focus on climate change adaptation goals.

Keywords Coral rehabilitation · Reef restoration · Project planning · Coral Triangle · Coral reef conservation · Reef management

Communicated by Matthew Godfrey.

Extended author information available on the last page of the article

Published online: 28 June 2024

Introduction

The economic and ecological importance of coral reefs in the Coral Triangle (CT) is well-established; the region 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, these reefs are home to approximately 590 of the region's 605 recorded hard coral species and 2,200 reef fish species (Burke et al. 2012). Indonesia also 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). The nation is among the top five global reef product exporters; 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 reefs provide are estimated at US$387 million (Burke et al. 2012). The country's reefs are, however, under severe pressure.

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. 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. Only 6.4% of reefs were in an excellent state (>75% healthy hard coral); 71.2% had less than 50% healthy hard coral (Hadi et al. 2020). Widespread Marine Protected Area (MPA) implementation and restrictions on reef ecosystem utilisation have not been enough to halt ongoing reef degradation in the face of persistent threats. 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. Destructive fishing is widespread (e.g. Simmons and Fielding 2019; Shafira and Anwar 2021); this is partly due to ineffective enforcement of legislation banning illegal practices (Gorris 2016) and mild penalties for those prosecuted (Renggong et al. 2021). The combination of high biodiversity and high prevalence of localised threats means that effective coral reef restoration is widely perceived as valuable and important. Ongoing attempts to support, improve, and scale up active coral reef restoration efforts are therefore imperative (Lamont et al. 2022). The assertion that Indonesia is one of the most important countries for coral reef conservation and restoration is supported by the "50 Reefs Initiative". This identified an optimum portfolio of 50 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 are located in Indonesia (Beyer et al. 2018).

Indonesian coral reef restoration has a long history: the first artificial reefs (ARs) were deployed in 1979 (Sukarno 1988). ARs and coral transplantation are popular techniques, although restoration projects incorporate diverse materials and methods. These include 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; prominent stakeholders include national and local government, local and international non-governmental and non-profit organisations (NGOs and NPOs), the private sector, and coastal communities. Indonesia's coral reef restoration regulations promote wide community participation; local governments are encouraged to share ownership and responsibility with local communities living near and benefiting from reefs. There are 17 Indonesian reef restoration policies and regulations: four national laws, three government regulations, two presidential regulations, and eight ministerial regulations (Razak et al. 2022). There have also been various long-term regional and national initiatives focused on coral reef health and other marine conservation priorities.

The Coral Triangle Initiative on Coral Reefs, Fisheries, and Food (CTI-CFF) has been a significant regional mechanism for collaborative marine resource management and conserving key ecological and economic components (Veron et al. 2009). This was preceded by the Coral Reef Rehabilitation and Management: Coral Triangle Initiative Project (COREMAP–CTI), aimed at sustainably managing coral reef resources, biodiversity, and associated ecosystems to increase coastal community incomes. The CTI-CFF and COREMAP have achieved some major conservation successes. Southwest Papua's Raja Ampat MPA network, for example, has significantly reduced destructive and illegal fishing and improved live coral cover and fish biomass. Communities catch more fish, traditional practices are being revitalised, and new livelihood opportunities are appearing in the growing tourism sector (Fischborn and Levitina 2018). Despite individual success stories, however, there remains a need to bolster passive conservation efforts with active ecological restoration (ER) interventions.

Effective and sustainable ER should not only focus on protecting biodiversity, but also on addressing socioeconomic concerns and supporting climate change mitigation, resilience, and adaptation (Gann et al. 2019). Restoration is a complex undertaking requiring substantial time, resources, and expertise; despite the best intentions, restoration projects regularly underperform (Gann et al. 2019). International standards for ecological restoration (SER) provide a foundation on which to build well-designed, planned, and implemented restoration projects. These standards recognise the need for appropriate knowledge and resources, an understanding of different contexts and risks, ongoing stakeholder involvement, and monitoring programmes that allow for adaptive management. Applying clear and carefully considered SER principles can therefore lead to improved outcomes from well-implemented monitoring and assessments (Gann et al. 2019).

The sheer number of projects and diversity of organisations involved in Indonesian coral reef restoration presents various challenges for standardisation. Current efforts are hampered by mismatches between programme objectives and assessment metrics used (Hein et al. 2020b); selecting appropriate metrics enables more rigorous assessments of performance and the employment of adaptive strategies to improve efficacy. There remains a widespread lack of effective ecological monitoring and consistent reporting: only 16% of projects since 1990 have incorporated a post-installation monitoring programme to gauge ecological responses to restoration (Razak et al. 2022). Standardised approaches to and monitoring of restoration activities would greatly benefit Indonesia's efforts to protect its valuable coral reef resources. Meaningful comparisons between sites across the country and evaluations informing the direction of conservation and restoration efforts would enable Indonesia to maximise its substantial coral restoration footprint.

This study reviews the planning stages of coral reef restoration projects in Indonesia. It identifies how project planning corresponds with international CBP (Goergen et al. 2020; Shaver et al. 2020) and restoration projects (e.g. Boström-Einarsson et al. 2020; Ferse et al. 2021), and the SER underpinning coral reef restoration CBP (McDonald et al. 2016; Gann et al. 2019). These principles inform recommendations on how Indonesia can further adopt and adapt international CBP based on SER to minimise inappropriate, unbalanced, and/or ineffective interventions and scale up coral restoration nationwide.

Sharing practical and scientific knowledge is key to implementing restoration efficiently and effectively, and to achieving restoration at scale. The creation of a national network of reef restoration managers, policymakers, and researchers is recommended; this aligns with recommendations to develop and promote bilateral and multilateral cooperation among and within countries (Gann et al. 2019). Primary goals include to coordinate more projects with wider, integrated networks of diverse stakeholders and to develop a roadmap for Indonesia's reef restoration efforts. This can help to realise Indonesia's substantial potential, cement its leading role in global coral reef conservation and restoration efforts, and inform reef restoration in the CT.

Methods

CBP for coral restoration is underpinned by eight general principles for ecological restoration: ER (1) engages stakeholders; (2) draws on many types of knowledge; (3) is informed by native reference ecosystems, while considering environmental change; (4) supports ecosystem recovery processes; (5) is assessed against clear goals and objectives, using measurable indicators; (6) seeks the highest level of recovery attainable; (7) gains cumulative value when applied at large scales; and (8) is part of a continuum of restorative activities (Gann et al. 2019). With these principles in mind, Shaver et al. (2020) propose a six-step iterative planning cycle for coral reef restoration projects, including multiple entry points to which managers can refer. Responses relevant to the planning cycle, restoration principles underpinning its various stages, and other considerations are detailed in the results. The first four stages focus purely on planning; the final two stages encompass implementing and evaluating active restoration:

1. *Set goal and geographic focus*.
2. *Identify, prioritise, and select sites*: Create a framework for prioritising sites and involving stakeholders in the planning and selection process.
3. *Identify, design, and select interventions*: Identify diverse intervention options, apply climate-smart design considerations, and engage stakeholders to design and select applicable approaches.
4. *Develop Restoration Action Plan (RAP)*: Define SMART (Specific, Measurable, Achievable, Relevant, Timebound) objectives (Table 1); develop a restoration timeline and strategic plan.
5. *Implement restoration*: Ensure long-term project sustainability; identify control sites against which to evaluate restoration and measure successes and shortcomings.
6. *Monitor and evaluate progress alongside restoration implementation*: Analysing monitoring data enables progress evaluations. Over time, short-term assessments of restoration interventions should switch to examining reef-scale effects over longer timeframes.

Monitoring and evaluation benefit from incorporating universal and goal-based performance (GBP) metrics that quantify change to address goals identified during planning (Goergen et

Table 1 Attributes and examples of 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; local and 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 (goals usually 10–20 years; objectives 1–10 years)	Identifies deadlines considering biological and ecological parameters

al. 2020). Universal metrics are assessed at reef-scale, population, and colony levels. They provide a basic, standardised description of restoration size, composition, and status that is accessible to practitioners – regardless of expertise or resources. This facilitates meaningful comparisons between sites: what and how much was restored, and the progress of restored sites over time (Goergen et al. 2020). GBP metrics should focus particularly on diverse ER categories. These should encompass coral population enhancement; community and habitat enhancement, including invertebrate and reef fish communities; reef structure and complexity; and habitat quality. Other categories for GBP include various ecological, socio-economic, event-driven, climate change adaptation, and research metrics.

Using Google, Google Scholar, Ecosia, and YouTube search engines, extensive Boolean searches were conducted to identify active coral restoration projects in Indonesia. The terms "reef rehabilitation" and "reef restoration" were treated as interchangeable. 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", "NPO", "university", "government", and "dive centre OR center". When compiling the final list of projects reviewed, those identified in online searches who were contactable were added to projects sourced from extant networks of coral reef restoration practitioners within Indonesia, including the School of Coral Reef Restoration (SCORES), the national Indonesia Coral Reef Garden (ICRG) project, and the International Coral Reef Initiative (ICRI) online restoration database.

A survey template (supplementary material 1) was developed based on the planning cycle recommended in international CBP (Shaver et al. 2020). Social desirability bias (SDB) was considered as a potential skewing factor on 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); however, evidence suggests it plays a relatively minor role in environmental psychology research (Vesely and Klöckner 2020). As this study is not concerned directly with environmental psychology, SDB was not deemed a significant confounding factor. Nevertheless, measures were taken to minimise SDB. Data was sourced through various channels: documented information and formal presentations were supported by face-to-face online interviews where possible to allow questioning and clarifications (Mooney et al. 2018). An introductory discussion established rapport; assured response anonymity; and explained the study's focus, purpose, and use of data. This reassured respondents that accurate responses would not cast them in a negative light (Bergen and Labonté 2020) and removed significant motivations for SDB, such as potential social sanctioning (Vesely and Klöckner 2020).

Data were 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 were extracted from 19 videos (25:20 h) on 29 projects from the SCORES coral reef restoration knowledge-sharing platform's webinar series hosted by IPB University and supported by the World Wide Fund for Nature (WWF) CT Programme. This included 20:25 h in Bahasa Indonesia and 4:55 h 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 h (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 the webinars, and eight as the sole form of data provided. One project that delivered a webinar declined to provide further data to inform the study. All data collected related to different aspects of project planning and implementation, as summarised in the data sheet template (supplementary material 2).

Results

Data from 45 respondents were analysed to examine the planning, implementation, and monitoring stages of coral reef restoration projects and make comparisons with coral restoration CBP and international recommendations for monitoring and assessing restoration.

Set goal and geographic focus

Survey respondents defined a primary goal (Fig. 1a) best describing their project's aims, in line with eight global primary restoration goals (Boström-Einarsson et al. 2020). Almost one-third of respondents (31%, $n=45$) selected "reestablish a self-sustaining, functioning reef ecosystem", followed by "promote coral reef conservation stewardship" (22%), and "accelerate reef recovery post-disturbance" (16%).

The eighth principle of ecological restoration advocates an holistic approach as part of a continuum of restorative activities. This encapsulates four major approaches: reducing societal impacts, rehabilitating degraded areas, ecological restoration, and (where applicable) remediating contaminated or polluted sites (Fig. 1b). Goals related to reducing societal impacts were the most widely and frequently reported (71 citations of six goals across

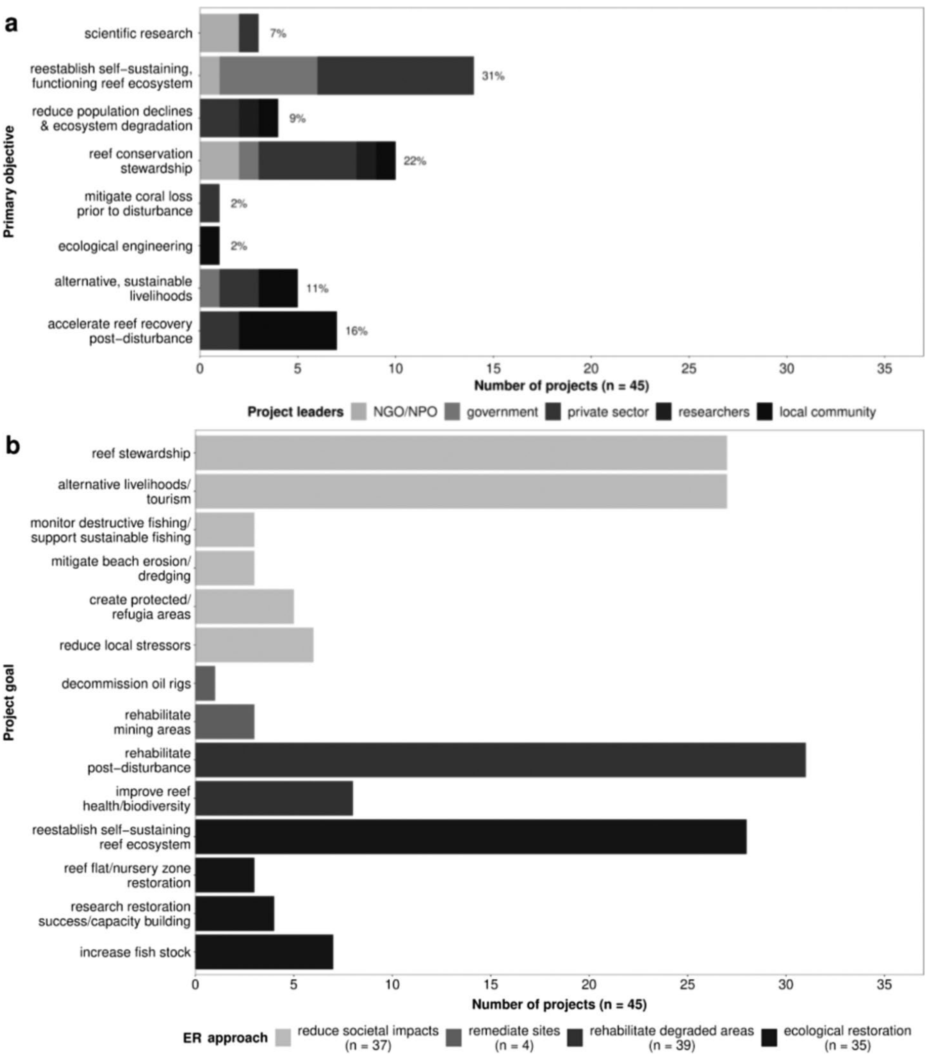

Fig. 1 (**a**) Ecological restoration (ER) was the most common primary objective identified by projects, followed by reef conservation stewardship. (**b**) Of the four major ER approaches applied in coral restoration, goals relating to societal impact reduction were the most frequently cited (71 mentions of six goals across 37 projects). Two goals focusing on degraded area rehabilitation were cited by 39 projects and four ER goals were cited across 35 projects. Rehabilitating degraded reef areas post-disturbance was the single most commonly cited goal, followed by reestablishing a self-sustaining, functioning reef ecosystem

82% of projects) followed by the rehabilitation of degraded areas (39 citations of two goals across 87% of projects).

Four ecological restoration goals were cited 42 times across 78% of projects. The most frequently reported goal encompassed rehabilitating degraded reef areas and/or accelerating recovery post-disturbance (69% of projects). This was followed by reestablishing a self-sustaining, functioning reef ecosystem (62%); promoting reef conservation stewardship (60%); and developing alternative livelihoods and/or tourism (60%). Due to its limited specificity, remediation was excluded when looking at the extent to which projects approached restoration holistically. Twenty-seven projects (60%) included goals relating to all three of the other major approaches; nine projects (20%) included goals for reducing societal impacts and degraded reef rehabilitation; five (11%) had goals for rehabilitation and ecological restoration; three (7%) had only restoration goals; and one (2%) had only rehabilitation goals.

In terms of measurable indicators, 84% of projects reported diverse medium- to long-term quantifiable and relevant objectives they aimed to achieve on a timescale of up to 10 years. These 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 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, within which final site selection takes place. All projects bar one (which provided no response) followed this step. Appointing a technical advisory team is recommended for the goal-setting stage, including any experts or scientists that may be needed to complete any of the steps (Shaver et al. 2020). This was done by 89% of projects.

Identify, prioritise, and select sites

A documented site selection process that considered the potential to improve restoration site condition was described by 89% of projects. Criteria followed for identifying, prioritising, and selecting sites within geographical focus areas were grouped into six broad categories (Fig. 2a). Ecological considerations were most common, cited by 91% of projects. Other considerations were a site's tourism value (64%); pragmatic considerations such as logistics, finances, and accessibility (58%); climate-smart design considerations including

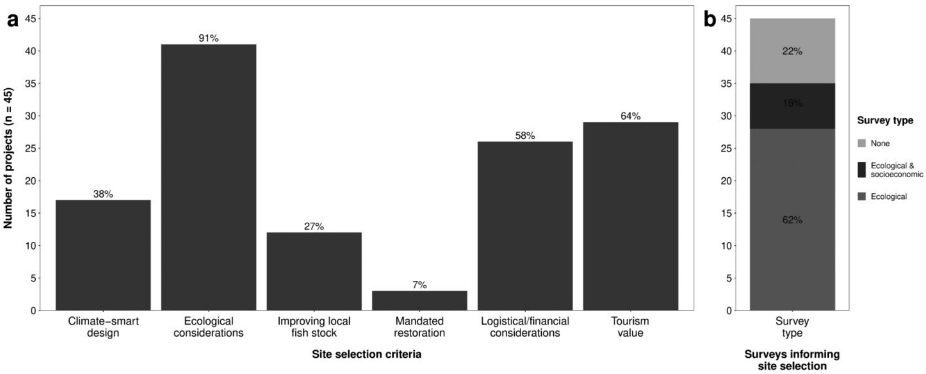

Fig. 2 (**a**) Criteria followed for identifying, prioritising, and selecting sites within geographical focus areas were grouped into six broad categories. Ecological considerations were the most commonly cited, followed by the site's tourism value. (**b**) Ecological and/or socioeconomic surveys were incorporated into site selection by 78% of projects

potential temperature changes, storm intensity, and interactions with local stressors (38%); improving local fish stocks or sustaining fisheries (27%); and compliance with legislation that mandated restoration of areas degraded by mining activities (7%).

Ecological surveys were incorporated into site selection by 78% of projects; 16% also conducted reef user satisfaction and other socioeconomic surveys. Socioeconomic data were absent from projects where no ecological data were collected (Fig. 2b). Local expert knowledge was incorporated into site selection by 84% of projects. Site importance was ranked to prioritise where to start restoration by 61% of projects; 68% discussed potential sites with local stakeholders before finalising selection. Two projects (4%) did not involve communities in planning.

Identify, design, and select interventions

Eighty-nine percent of projects implemented an evaluation process for determining the type of restoration intervention; 84% considered different restoration techniques during planning. Restoration techniques varied; 80% of projects incorporated multiple approaches. When analysing projects' restoration techniques, a distinction was made between substrate stabilisation methods and ARs. The former often include artificial structures similar to ARs but focus specifically on stabilising loose, shifting coral rubble in addition to increasing habitat complexity. Coral fragment transplantation was the most commonly cited approach (84%), followed by ARs (58%); 16% of projects relied solely on natural larval recruitment on ARs. One bioacoustics research study did not involve growing corals.

Already-broken fragments, or Corals of Opportunity (CoPs), were the main source for fragments for projects actively sourcing corals. CoPs were used in 73% ($n=37$) of projects and were the sole fragment source in 41%. Nursery or commercially grown fragments augmented or replaced CoPs in 41% of these projects; 11% exclusively used commercially farmed corals. Twenty-seven percent of these projects fragmented wild colonies alongside other fragment sources; 8% relied exclusively on wild donor colonies. This resembles international findings that CoPs are the most frequent source of fragments for transplantation projects (58%, $n=50$); although a higher proportion (46%) of global projects also sourced fragments from wild colonies (Ferse et al. 2021).

Thirty-eight percent of projects in the current study ($n=37$) utilised a natural mix of local coral species in restoration. Forty-six percent 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%). 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 transplantation projects (Ferse et al. 2021). There was no mention in international reviews of the investigation or incorporation of coral thermal resilience in coral selection.

Develop restoration action plan

Project responses were used to categorise the SMART (Specific, Measurable, Achievable, Relevant, and Timebound) features of their goals and objectives. Timebound goals were the most lacking, with 51% of projects specifically outlining objectives within a contextualised timeframe; 51% met the criteria for all SMART features and 80% met at least four of five criteria. Of the nine projects that met three or fewer SMART objectives, seven were small-scale or once-off projects driven by local communities, private resorts, or local NGOs. The other two projects were managed by local government authorities. Seven of these projects were not partnered with researchers; the other two were small-scale community projects driven by a local NGO and a city government authority respectively.

Projects listed all restoration objectives measured; metrics were separated into five broad categories (Fig. 3). Ecology/restoration success was the most common overarching objective category, accounting for 54% of responses ($n=127$), followed by alternative livelihoods/tourism (18%), and local stewardship (12%). The most common metric, quantitative reef monitoring, was listed by 78% of projects; semi-quantitative and qualitative reef monitoring surveys were used by 9% and 11% respectively. Post-impact change was measured by 38% of projects; 31% quantified local stewardship / community buy-in. The extent of alternative livelihoods provided was quantified by 27% of projects, while 16% conducted socio-economic or reef user satisfaction surveys.

Implement restoration

Shaver et al. (2020) propose five components for the Restoration Action Plan (RAP) developed in Stage 4. Of these, a formal Action Plan was implemented by 55% of projects ($n=44$); an Annual Work Plan was present in 41%; an Operational Plan was present in 50%; and a Monitoring Plan and Restoration Timeline were both present in 68%. While 36% of

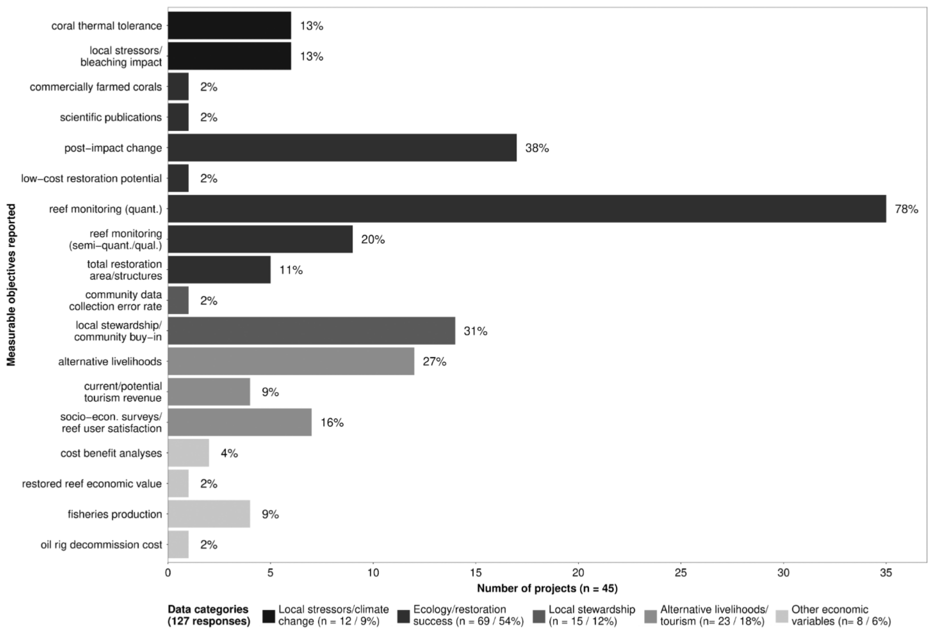

Fig. 3 Measurable objectives reported by projects showed that most data were gathered on ecological/restoration success (54% of 127 total responses), followed by data on alternative livelihoods and/or tourism (18%). Reef monitoring programmes were conducted by 78% of projects. They represented the most common form of data collection, followed by post-impact change (38%)

all projects implemented all five components, 36% implemented two or fewer, and 16% implemented none. The bioacoustics study was excluded due to the absence of long-term planning requirements.

Sixty-seven percent of projects with no action plan ($n=15$) were run on a local scale (only one site location) by NGOs, local communities, private sector players, or (in one case) a single researcher conducting a once-off intervention at a small resort. Localised projects also accounted for 47% of projects that lacked an operational plan ($n=17$), 54% ($n=13$) that lacked a rehabilitation timeline, 57% that lacked an annual work plan ($n=21$), and 46% that lacked a monitoring programme ($n=13$). Of the 13 projects with no monitoring plan, five (38%) gauged success by visual observation and one (8%) by counting the number of artificial structures installed without measuring coral cover or growth. The remaining seven projects (54%) ran reef monitoring surveys but without a formal monitoring plan. At two projects, surveys were conducted by outside or affiliated researchers who may not have shared monitoring plans with project partners.

Forty-two percent of projects were at a local scale; 40% were regional, with more than one location in the same area; and 18% were multi-regional or national programmes with multiple locations and/or projects (Fig. 4a). Projects involved varying degrees of cross-sector cooperation at different scales (Fig. 4b). Formal partnerships with local communities were present in 72% of projects not driven by the communities themselves ($n=43$). 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.

Monitor and evaluate progress

Ecological data for monitoring and evaluating progress were collected by 84% of projects, comparing favourably to 80% of international coral transplantation projects (Ferse et al. 2021). Less than half the projects collected event-driven (49%), economic (44%), or socio-cultural (42%) data; 36% collected climate change adaptation data (Fig. 5a). In terms of specific climate change adaptation goal (CCAG) metrics, 16% of projects measured coral

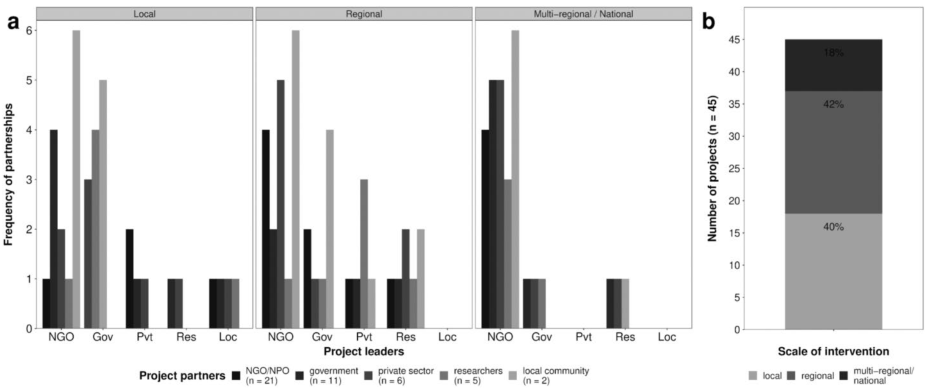

Fig. 4 Scale of restoration interventions and degrees of cross-sector cooperation at different scales. (**a**) Local and regional projects were more common than larger scale multi-regional and national programmes. (**b**) NGOs/NPOs frequently cooperated with other sectors (particularly local communities) at all scales. Government projects frequently cooperated with communities at local and regional scales

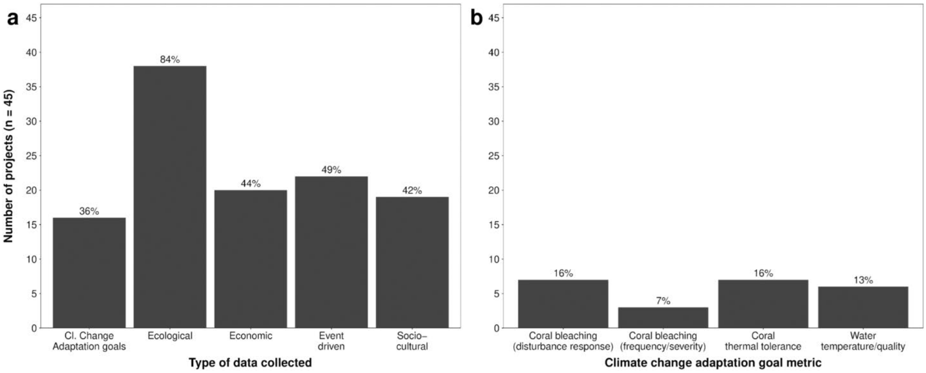

Fig. 5 (**a**) Ecological data were the most commonly represented metric, followed by event-driven data. Data on climate change adaptation goals (CCAGs) were the most lacking. (**b**) Of the 16 projects that reported specific CCAG metrics, thermal tolerance of restored corals and their response following bleaching disturbances were the most common metrics collected

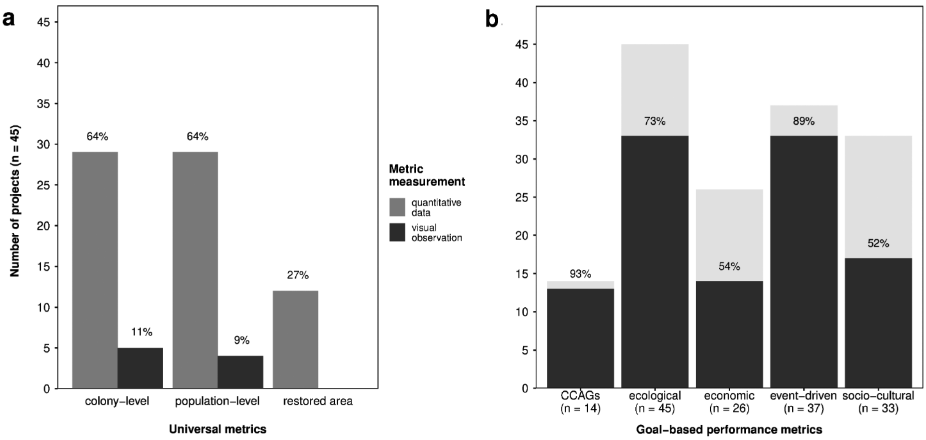

Fig. 6 Projects incorporating (**a**) universal and (**b**) goal-based performance metrics from international monitoring CBP. (**a**) Colony-level and population-level metrics were each quantified by 64% of projects; 11% and 9% monitored these respective metrics via visual observation. Restored area was quantified by 27% of projects. (**b**) The majority of projects that specified CCAGs collected goal-related metrics (93%). The same was true for event-driven goals (89%) and ecological goals (73%). Roughly half the projects that specified economic (54%) and sociocultural (52%) goals collected goal-related metrics

thermal tolerance, including growth and restoration success at different temperatures and depths; 16% monitored coral recovery post-bleaching (disturbance response); 7% monitored bleaching frequency and severity; and 13% monitored water temperature and/or quality (Fig. 5b).

Not all universal metrics recommended by international monitoring CBP (Goergen et al. 2020) were ascertained. Where possible, however, specific metrics were examined (Fig. 6a). Reef-level restored area was quantified by 27% of projects. Colony-level and population-level metrics were each quantified by 64% of projects; a further 11% and 9% respectively used visual observation to estimate these metrics. Only two projects (4%) specifically mentioned collecting water temperature measurements (the universal environmental metric); the extent to which genetic and genotypic diversity were monitored was not ascertained. The prevalence of GBP metrics from international CBP was assessed by looking at whether metrics collected related to the types of goals specified by projects (Fig. 6b). The majority of projects that specified CCAGs (93%, $n=14$); event-driven goals (89%, $n=37$); and ecological goals (73%, $n=45$) collected metrics related to those goals. Roughly half the projects that specified economic (54%, $n=26$) and sociocultural (52%, $n=33$) goals collected goal-related metrics.

Quantitative reef monitoring surveys were the main tool used to collect ecological data (76%); 9% of projects collected semi-quantitative reef monitoring data and 11% relied on qualitative visual observations (Fig. 7a). Coral cover/growth was the most commonly collected ecological metric and was measured in 64% of projects. Fish community data were collected by 51% of projects and 38% collected benthic community/associated biota or coral survival data. Coral community composition/diversity data were only collected by 4% of projects, quantitative coral health/bleaching data by 11%, data on water quality/temperature by 18%, and data on recruits/juveniles by 20% (Fig. 7b).

Discussion

The findings of the current study provide a snapshot of the planning and implementation of coral reef restoration across Indonesia. The study encompasses approximately 28% of documented active Indonesian coral reef restoration projects ($n=159$). This was estimated by excluding 374 projects from a database of 533 historical projects up to 2020 (Razak et al. 2022). These comprised concluded projects, once-off installations, defunct methods (tyre reefs), localised projects within the purview of wider-ranging projects/programmes in the current study, and time-specific academic projects, studies, and theses. Results highlight a number of important considerations, which are unpacked as they relate specifically to the six-step planning cycle. Other general considerations are also examined, such as the early and continued engagement of all stakeholders, with a particular focus on local communities.

Set goal and geographic focus

The fifth principle of ecological restoration states that it should be assessed against clear goals and objectives, using measurable indicators (Gann et al. 2019). International monitoring protocols for coral restoration support this; the first step in developing a restoration monitoring plan is to clearly define goals and objectives aligned to the project's capacity and restoration abilities (Goergen et al. 2020). This underpins the first phase in the six-step planning cycle.

- The prominence of restoring the reef ecosystem as a primary goal reported by surveyed projects aligned with the sixth principle of ER: to seek the highest level of recovery attainable. Ecosystem restoration was also the primary consideration identified by reef restoration practitioners interviewed during the development of international guidelines for GBP metrics (Goergen et al. 2020). Reestablishing the reef ecosystem; accelerating recovery post-disturbance; reducing population declines and ecosystem degradation;

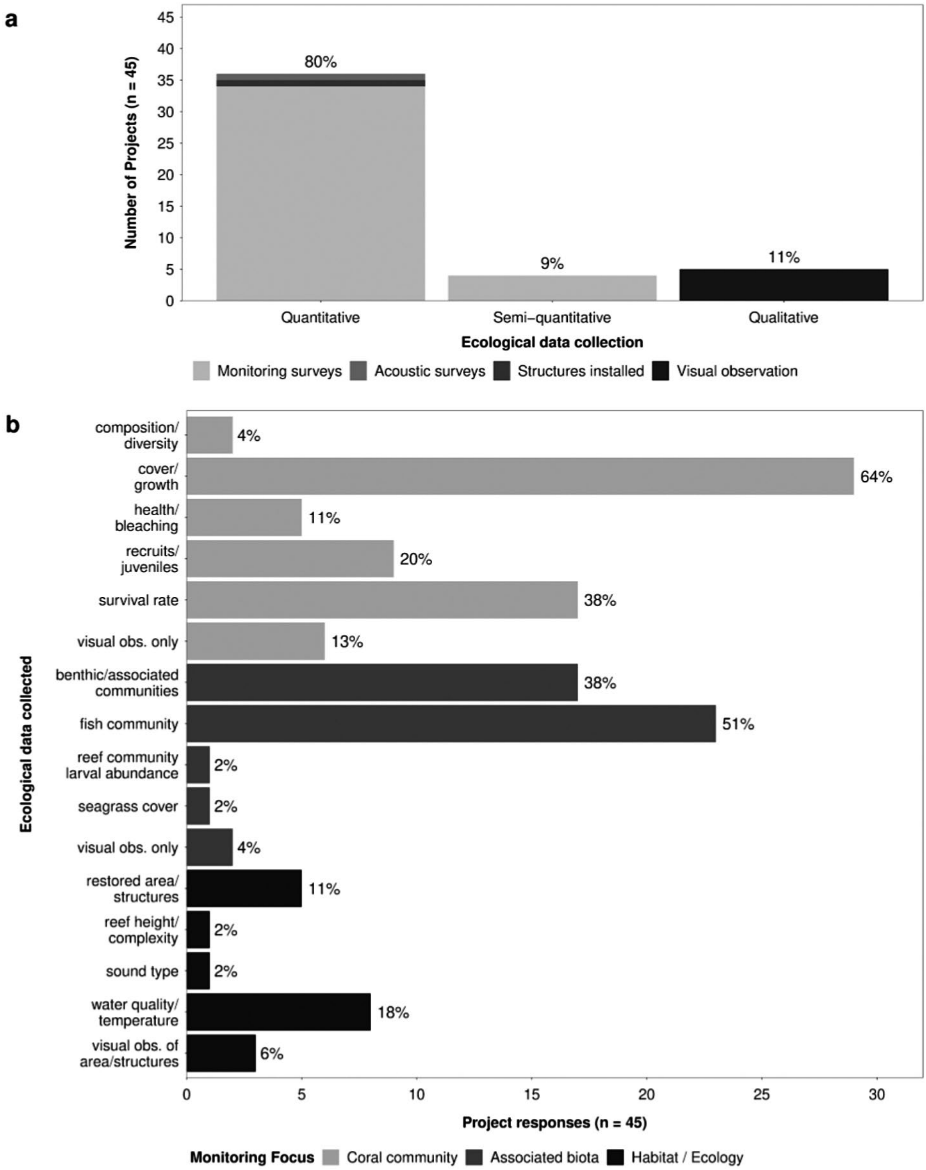

Fig. 7 (**a**) Eighty percent of projects collected quantitative ecological data, mostly in the form of monitoring surveys. (**b**) Coral cover/growth was the most commonly monitored ecological restoration metric; more effort was put into monitoring the coral community than associated biota, habitats, or other ecological factors

and ecological engineering accounted for the primary aim of a combined 58% of projects. This aligned with the fourth ER principle: that it supports ecosystem recovery processes (Gann et al. 2019).

- A focus on reef ecosystem restoration implies an understanding that restoration must take a holistic approach that encompasses the reef community as well as external fac-

tors. Goals relating to reducing societal impacts (82% of projects), rehabilitating degraded areas (85%), and ecological restoration (78%) were defined by the majority of projects. Sixty percent of projects defined goals from all three of these aspects of a holistic approach.
- The number of projects identifying goals related to alternative livelihoods and reef stewardship (each present in 60% of projects) compared well with other parts of the world; a review of 12 restoration projects in Latin America reported 15% and 13% of projects with goals relating to alternative livelihoods and reef stewardship respectively (Bayraktarov et al. 2020). Australia reports the involvement of local communities and traditional owners in all 19 restoration efforts on the Great Barrier Reef (McLeod et al. 2022). The quantification of socioeconomic goals is still lacking; this will be discussed further regarding RAP development.
- Indonesian projects should do more to set quantifiable goals during initial planning phases; these were totally absent from 64% of projects. A set of simple standards could be applied for determining desired aspects, including the size of area to be rehabilitated, coral cover and biodiversity increases, and socio-economic project functions. This could be informed by universal and GBP metrics (Goergen et al. 2020).
- Technical advisory groups were present in most projects. Although the exact composition of these groups was not always verifiable, projects should follow the ecological principles within international CBP in utilising available scientific, practical, traditional, and local knowledge. This may include stakeholders from various sectors: local leaders and other community members, scientists, engineers, the private sector, and national and local governments (Shaver et al. 2020). In Pemuteran, Bali, for example, the pivotal role played by community leaders in bridging the gap between global science and local awareness has previously been highlighted (Trialfhianty and Suadi 2017).

Identify, prioritise, and select sites

Improper site selection is one of the most commonly cited failures of coral reef restoration projects. Areas should be selected where stressors can be minimised; long-term survival of reefs can be achieved; and stakeholders, policies, and legislation support restoration (Hein et al. 2020a). Site identification and selection should also be done to meet goals specified within an agreed prioritisation framework. This should emphasise the site's relevance to goals; restoration's potential to improve site condition; and short- and long-term coral survivorship, encompassing vulnerability to climate change and other stressors. Selection should also be informed by the collection of various quantitative or semi-quantitative data depending on specified goals (Shaver et al. 2020). The first principle of ER stresses the genuine and active engagement of local communities and other stakeholders at the conceptual phase or prior to project initiation (Gann et al. 2019). Prioritising restoration sites can be significantly aided by local knowledge.

- 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. This step was lacking in one-third of projects.
- One in ten projects did not consider the potential to improve site condition during plan-

ning. Just under a quarter of projects did not employ ecological or social surveys to aid site selection. The absence of quantitative data collection largely reflected logistical and/or budgetary priorities or constraints (cited by over half the projects); limitations in scientific training; and a reliance on local knowledge of the reefs, degraded areas, and pre-disturbance conditions.

- There is a pressing need for greater emphasis on the future vulnerability of reefs: 62% of projects did not incorporate climate-smart design considerations into site selection. Prioritising restoration sites by considering their potential to withstand future climate change is increasingly crucial, yet 39% of current projects did not rank sites by order of importance in any way. This is, however, understandable when one considers everyday practicalities: 58% of projects cited logistical, financial, and accessibility considerations as important criteria for site selection.
- While ecological considerations were by far the main driver of site selection, scientific standardisation of primary ecological data for site selection would help to improve success at a national scale. This should be informed by international CBP and universal monitoring metrics, potentially including metrics such as water circulation, natural recruitment levels, health of associated habitats, and the prevalence of local environmental stressors.
- The absence in 22% of projects of any form of ecological surveys informing site selection – along with the ad-hoc nature of many smaller projects – suggests that a substantial number of projects are not comparing restoration efforts with baseline controls or reference sites.

There are further opportunities to refine restoration site selection. Logistical, financial, and site accessibility considerations will remain critical; this includes 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. Other important aspects of site selection that can be improved via standardised protocols include more widespread evaluation of socio-economic benefits related to restoring a particular site, the incorporation of marine spatial planning principles (Viehman et al. 2023), and measurable assessments of the potential for local community buy-in and long-term ownership. ER standards adopted in international CBP stress the importance of reference sites representing approximate reef conditions in the absence of degradation (Gann et al. 2019). They highlight six key elements for selecting a reference site: absence of threats, physical conditions, species composition, structural diversity, ecosystem function, and external biotic and abiotic exchanges. The inclusion of reference sites would be greatly improved by standardised planning within a science-based framework.

Identify, design, and select interventions

Lamont et al. (2022) offer insights from Indonesian case studies to inform reef restoration management and policy interventions. They recommend multi-dimensional approaches that include ecological, social, and economic processes. This aligns with CBP recommendations for a holistic approach to restoration.

- The majority of projects were aligned with CBP recommendations to select a limited combination of priority interventions following an evaluation of potential choices (Shaver et al. 2020). However, climate-smart design considerations require more attention for a truly holistic approach; only 38% of projects included these in intervention design.
- The use of ARs was almost three times higher than in international coral restoration projects (Boström-Einarsson et al. 2020). This may partly reflect the widespread structural degradation on Indonesian reefs (Burke et al. 2012; Razak et al. 2022).
- Coral transplantation was the most common restoration approach. This was substantially more common than international restoration projects involving coral fragmentation or transplantation (84% versus 68%) (Boström-Einarsson et al. 2020). Twenty-four percent of Indonesian projects focused primarily on fast-growing branching species, compared with 59% of international projects (Boström-Einarsson et al. 2020) and 96% of transplantation projects (Ferse et al. 2021).
- Indonesian projects have done well in reducing pressure on natural reefs when sourcing coral fragments. Only 8% of projects relied exclusively on wild donor colonies; 27% fragmented wild colonies alongside other fragment sources, compared to 46% of international coral transplantation projects (Ferse et al. 2021). CoPs were replaced or augmented by nursery-reared and/or commercially farmed corals in 41% of projects.
- Just 16% of Indonesian projects focused on a single coral species, compared to 28% of international projects (Boström-Einarsson et al. 2020). This aligns with holistic approaches and universal metrics for achieving reef-scale restoration.
- When selecting coral species, more projects should factor in thermal resilience and other climate-smart considerations like resistance to bleaching (Rinkevich 2019).

The use of a nursery phase to grow corals for transplantation ('coral gardening') has been gaining in popularity across Indonesia for a number of years. Coral gardening principles have been developed and tested in a wide variety of studies over more than two decades (e.g. Epstein et al. 2001; Rinkevich 2006; Shaish et al. 2008; dela Cruz et al. 2015). Today, it is one of the most popular approaches in Indonesia as well as in international coral restoration interventions (Rinkevich 2019).

A more structured evaluation of restoration techniques and approaches 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 (Boström-Einarsson et al. 2020). 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 selection of groups of corals with varying ecological functions can better align restoration projects with international CBP for reestablishing a fully functioning reef community; this should incorporate climate-smart design considerations. The use of ARs relying solely on natural recruitment, meanwhile, would benefit from standardised site assessment protocols including scientific analyses of natural larval supply and recruitment levels.

Develop restoration action plan

SMART objectives provide a framework within which to assess progress and apply adaptive management principles to improve interventions. Project design should facilitate decision-making with a number of diverse stakeholders and be transparent about decisions made on restoration interventions (Shaver et al. 2020).

- Projects failed to meet SMART objectives for multi-faceted reasons. Indonesian policy encourages diverse practitioners to implement reef restoration (Razak et al. 2022); ad-hoc projects undertaken in isolation could benefit from coordination with other restoration practitioners and scientists. A failure to set timeframes for specific quantifiable goals reflects varied approaches to project monitoring and evaluations. Historically, monitoring schedules have ranged anywhere from one month to 16 years (Razak et al. 2022). Respondents in the current study highlighted financial and logistical constraints as challenges for conducting regular monitoring activities. As reef restoration is increasingly placed on government agendas worldwide, there may be further avenues for sustainable funding to improve restoration efficacy (Ferse et al. 2021) which could be augmented by national, regional, and international networks.
- The preponderance of reef monitoring surveys – alongside the relative dearth of social, economic, climate change adaptation, and local stressor metrics – suggests more focus is needed on holistic approaches beyond basic measurements of coral cover, growth, and survival (Razak et al. 2022).
- There remains a need to better incorporate explicit objectives during planning (Razak et al. 2022). The varied objectives reported exemplify the diversity of projects. Further standardisation of ecological monitoring metrics would improve evaluation of successes and failures and guide management decisions in different contexts (Vardi et al. 2021; Razak et al. 2022).
- Long-term objectives can be consolidated by increasing the focus on the most pressing needs and aligning with ER goals identified in international CBP. Local stressors need to be reduced; restoration objectives should incorporate and evaluate socio-economic and cultural concerns; and restoration should be resilient to future climate change and produce quantified outcomes to inform and evolve best practice. Strengthening ties between reef restoration projects and regulators may help to address ongoing stressors (Ferse et al. 2021) and deliver large-scale restoration.

Implement restoration

A complete RAP includes descriptions of project scope, vision, and targets (restoration timeline); an analysis of project situation (work plan); and action, monitoring, and operational plans (Shaver et al. 2020). It is a highly effective way of planning, implementing, and assessing restoration progress. Many projects without a formal plan may informally adhere to aspects of a RAP; this minimises accountability and the ability to meaningfully assess progress. Furthermore, ER principles emphasise the full utilisation of available scientific, traditional, and local knowledge (Gann et al. 2019), including CBP frameworks like RAPs.

- The fact that over one third of projects used two or fewer RAP components may reflect the ad-hoc nature and small scale of many projects. Concerns were raised by smaller-scale projects regarding the added logistical workload of putting together and maintaining detailed documentation. Another point raised was the reliance on and uncertain availability of donor funding; in some instances, projects planned interventions as and when funds were received, rather than laying out a detailed annual work plan or operational plan.
- The absence of a monitoring plan can be linked to various factors. These include a lack of sustainable funding or technical expertise, and the use of visual observation or other qualitative monitoring. The absence of various RAP elements from project planning emphasises the importance of promoting a simplified framework for implementing restoration. This will help to make effective restoration accessible to as wide a range of projects as possible, while still utilising a standardised framework.
- Nearly three quarters of projects had formal partnerships in place with local communities. The private sector in particular, however, tended to work alongside local communities rather than with them as equal partners. Merely involving the community does not guarantee an effective collaboration; focus group discussions and agreements with local community leaders are important in laying groundwork, as is ongoing community participation. It is also essential that communities recognise and understand the potential benefits of participation.
- There is an opportunity to increase the focus on and assessment of local community involvement by standardising the quantification of sociocultural/socioeconomic metrics. This is illustrated by the low incidence of reporting and quantification of alternative livelihoods and local stewardship objectives compared to ecological and/or restoration success.

Consistent minimum standards of accountability and monitoring for reef restoration projects can be highly beneficial (Ferse et al. 2021). Existing regulations seek to open up restoration to local communities. Bolstering these regulations with complementary mechanisms based on international CBP would help to achieve this aim and improve overall project efficacy and sustainability. Standardisation would increase the potential to collate data from multiple projects and increase meaningful contributions from small-scale projects nationwide. Achieving meaningful community engagement and buy-in should be seen as imperative; this should ideally start prior to project commencement and seek to foster a sense of community ownership over restoration efforts.

Monitor and evaluate progress

Monitoring and evaluation of restoration are critical components of the adaptive management of restoration efforts (Gann et al. 2019). The variable quality of monitoring programmes worldwide is one multi-faceted challenge facing attempts to characterise restoration effectiveness and quantify efforts on regional and national scales. Clearly defined indicators linked to specific objectives and the properties of the entire reef community are needed, as are appropriate timeframes; it is also critical to integrate ecological indicators with sociocultural, economic, and governance considerations (Hein et al. 2017). International CBP for monitoring programme implementation emphasises the need for quantifiable universal metrics as a minimum requirement for any restoration project, regardless of goals and objectives. Monitoring should happen simultaneously with restoration implementation; it should shift over time from short-term effects of interventions to examining reef-scale effects over longer timeframes (Shaver et al. 2020). Measurable performance metrics should include SMART objectives identified in planning Stage 3 and consider socioeconomic elements; they should also encompass climate-smart design considerations and CCAGs (Shaver et al. 2020; Goergen et al. 2020).

- Ongoing monitoring of restoration efforts was varied. Twenty-four percent of projects did not conduct quantitative reef monitoring surveys and 36% of projects did not quantify coral cover or growth. Data collection on the wider reef ecosystem was underrepresented: 51% of projects collected fish community data, 38% monitored the benthic community and/or associated biota, and 4% quantified coral community composition/diversity. Qualitative visual observations were conducted by 13% of projects; with some expert input, the adoption of simplified monitoring metrics, and/or an effective monitoring plan, the majority of these projects could likely achieve quantifiable outputs with minimal difficulty.
- Quantitative measurements of bleaching, coral health, coral thermal tolerance and/or changes in restoration success relating to temperature and depth were also underrepresented. CCAG metrics are an imperative focus point, as fewer than 20% of projects quantified any of these metrics.
- There is a decisive opportunity to better integrate climate-smart design considerations and CCAGs to increase meaningful and impactful outcomes in the long-term. Legislative updates, increased funding for scientific studies, standardised planning structures, and the adoption of innovative climate-smart reef restoration efforts will likely be required (Camp et al. 2018a, b; van Oppen et al. 2017). This will be especially pertinent if significant local threats persist. Accurate reporting of restored area in particular was underrepresented and the extent to which projects consider genetic/genotypic diversity warrants further investigation. While the extent of water temperature monitoring was unsubstantiated, this should be a standard approach as an entry-point to climate-smart design and the integration of CCAGs.
- Indonesia can play a significant international role in identifying reef degradation causes and using environmental assessments to inform reef restoration efforts. For comparison, a survey of coral transplantation projects mostly from the Caribbean and Indo-Pacific found that most projects did not conduct environmental assessments prior to transplantation; no project reported an assessment of coral recruitment and two thirds of projects failing to assess initial causes of reef degradation. The researchers further noted that a lack of monitoring standards and guidelines has impeded measurements of social and ecological success (Ferse et al. 2021).
- The ongoing use of standardised socio-economic and reef user satisfaction surveys can help to inform interactions with community leaders and other stakeholders and help to improve relations in an adaptive approach.

There are readily available ER tools developed for international CBP. The CRC Restoration Evaluation Tool, for example, has developed standardised guidelines for reporting progress in projects with varying expertise levels and goals (Goergen et al. 2020). The Five-Star

System and Ecological Recovery Wheel (McDonald et al. 2016) have been increasingly adapted and utilised by practitioners and scientists in a wide variety of ecosystems globally, including coral reefs (Gann et al. 2019). Both tools offer potential standardised approaches for evaluating restoration effectiveness and applying adaptive management principles, which could add significant value to restoration efforts in Indonesia.

Major challenges faced by Indonesian reef restoration practitioners

Engaging stakeholders

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). Definitions of community buy-in encompass a spectrum of interactions and participation levels. Direct buy-in 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). Some responses received in the study reflect community integration challenges. Minimal community buy-in at one project likely reflected a disconnect between terrestrial farmers and marine environmental issues, as well as productivity and efficiency concerns regarding the removal of pesticide use (c.f. Coggan et al. 2021). Another mandated mining remediation project failed to establish long-term community support because of negative reactions to the mining company's previous destructive activities. Ongoing destructive fishing practices at another project reflected a gap in understanding about the sustainable use of coral reefs, despite attempts to educate the community.

Amongst the challenges faced when dealing with local communities is to accommodate cultural norms to enrich collaboration. Failure to do this can cause divergent experiences of participation, a mismatch between efforts to involve the community and the true integration and representation of its needs, and gaps in understanding between communities and conservation authorities (Tam 2015). Establishing and maintaining trust is also a complex issue requiring more than simply "providing" alternative livelihoods. An increased focus on the potential for improving local fish stocks and sustaining local fisheries, for example, can be a significant driver for community support; however, restoration practitioners must respect, integrate, and actively encourage local customs such as traditional rules on access to certain fishing grounds (Bottema and Bush 2012). Sociopolitical factors also present challenges in a country as culturally and ethnically diverse as Indonesia. Marginalised ethnic groups such as the Bajau have commonly been associated with destructive fishing practices and over-exploitation of resources (Pet-Soede and Erdmann 1998; Exton et al. 2019). In Southeast Sulawesi, value and belief systems of this traditionally nomadic ethnic group contrast with conservation aims; the sedentarisation of Bajau communities has led to intensified fishing effort, accelerating the impacts of their fishing practices (Crabbe and Smith 2005). Destructive fishing is often prevalent in more remote areas where alternative employment opportunities are low. In South Sulawesi, complex societal issues perpetuate the problem. Fishers are economically dependent on patrons embedded in a complex governance network. These patrons supply fishing technologies like boats, bombs, and cyanide, to reinforce their positions of power over socially marginalised and excluded individuals (Grydehøj and Nurdin 2016).

One vehicle for community involvement with potential for wider implementation is the creation of community surveillance groups ("pokmaswas"). As part of the CTI, MPA authorities in Nusa Penida and the Gili Islands consulted with stakeholders and drafted seven standard operating procedures to promulgate these groups, with resounding success. Community members reportedly benefit from employment, education, stewardship, recreation, satisfaction, and other social and cultural benefits (ADB 2022); the report does not quantify successes or cover challenges faced by the surveillance groups. In a government-led programme in Gorontalo province, pokmaswas members were positive about the effectiveness of decision-making structures, chain of command, and available human resources. Some members, however, raised concerns about physical and psychological wellbeing, and a lack of support and facilities. The study noted that the group lacked written plans and could benefit from better organisational structures (Rohyani et al. 2023). In Banten province, the main obstacles to a formal pokmaswas programme included conflicting interests across different provincial sectors; a lack of understanding of the reasons to create the programme; the enforcement of pokmaswas authority; and the need to improve understanding and perception of environmentally friendly fishing gear (Wicaksono et al. 2019).

Lamont et al. (2022) highlight several community engagement success stories across Indonesia. 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.

Funding

A lack of sustainable funding is an ongoing challenge for coral reef restoration practitioners. Internationally, 60% of projects reported that funding received was associated with specific monitoring requirements (Hein and Staub 2021). Funding is essential for effective long-term monitoring programmes, yet funding timelines are predominantly between one and three years; this is inadequate for long-term planning, monitoring, and management (Hein and Staub 2021).

Not only is donor funding usually short-term, but it often relies on monetary incentives for community buy-in (Depondt and Green 2006; Wilkinson et al. 2006); long-term funding also has inherent dangers linked to its continued availability (Browne et al. 2022). Cross-sector cooperation is usually key (Bottema and Bush 2012). Practitioners' concerns include the linking of funding to specific outplanting requirements, rather than long-term goals associated with restoration success; and a disconnect between funders' expectations of coral reef restoration and practical project realities (Hein and Staub 2021). Detailed work plans and budgets are essential to gauge what is realistically possible and achievable under budgetary and capacity constraints.

Indonesia is an attractive location for international funding, NGOs, eco-tourism, and scientific study. Projects should aim to be self-sustainable, but should also focus on creating detailed, goal-oriented planning documents and regular reports on quantitative monitoring data. This will greatly improve chances of securing and retaining meaningful external funds to supplement their activities. This is especially true as interest and support for coral reef restoration continues to grow in the UN Decade on Ecosystem Restoration (Hein and Staub 2021).

Ongoing reef degradation

Despite the widespread implementation of MPAs and restrictions on reef resource use, the degradation of Indonesia's reefs continues (Hadi et al. 2020) and many local stressors remain. Some of this is attributable to a lack of effective MPA and coral reef management. Less than 3% of existing MPAs worldwide are rated as effectively managed (Marine Protection Atlas 2022). Globally, 65% of MPAs have insufficient budget to cover management needs and over 90% lack staff capacity (Gill et al. 2017). A recent nationwide evaluation of Indonesian MPAs found an unequal distribution of staff, with provincial MPAs having fewer staff despite covering twice as large areas as national MPAs. Less than one third of 36 MPAs met minimum staffing requirements; the study emphasised the need for collaborations with local stakeholders and NGOs to bridge resource gaps (Capriati et al. 2024). Divergent interests and understanding of MPA goals among diverse stakeholders may also undermine MPA success (Fabinyi 2008).

Tourist pressure is another factor in reef degradation. The Indonesian government has focused on developing marine and coastal tourism to drive economic growth. Small islands in particular are vulnerable to tourism pressures; integrated small island management policies are essential (Kurniawan et al. 2016). On the other hand, tourism growth also increases opportunities for tourism-based restoration. This can create associated livelihoods, foster a sense of community stewardship, and aid economic security founded on reef health and restoration. ARs can help to ease diver pressure and reduce damage on natural reef areas, serving as tourist attractions in their own right (Piskurek 2001; Fadli et al. 2012).

The fundamental challenge facing widespread successful coral reef restoration and maintaining reef health in the future comes from global human-induced climate change. 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; van Oppen et al. 2017). 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 also be fostered and encouraged. This will likely require financial backing and scientific training from national and/or international partners.

Creating a consolidated coral reef restoration network

According to SER, sharing practical and scientific knowledge is key to implementing restoration efficiently and effectively, and to achieving restoration at scale. An important way to advance the science and practice of large-scale ecological restoration is hence to develop and promote forward-thinking cooperative networks.

Centralised training hubs can substantially accelerate the establishment and scaling up of successful projects through knowledge sharing (Lamont et al. 2022). A formal national network of practitioners, experts, and decision-makers would add significant value and create accountability. This should seek to consolidate and build on existing networks and knowledge sharing being forged by initiatives like SCORES, the Coordinating Ministry for Maritime Affairs and Investment's ICRG programme, the Coral Triangle Centre's Coral Reef Restoration Task Force (CTC-CRRTF), the National Park authority-aligned Mars Sustainable Solutions (MSS) training programme, and the CTI-CFF and COREMAP programmes. It will also be important to foster connections with those outside the field of coral restoration. The socioecological resilience of coral reef restoration, for example, can be improved by 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).

There is significant potential to standardise quantifiable, iterative goals (Hobbs and Harris 2001) integral to adaptive restoration management. 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). Efforts should be consolidated at a national scale to deliver more efficient and effective collective actions that provide balanced benefits to reefs and communities.

A potential vehicle for improved project outcome reporting within a consolidated reef restoration network is the creation of a national database of reef restoration projects or similar platform (Fig. 8). Reports and project-specific data could be submitted and stored in such a repository. This would facilitate the evaluation of reef restoration progress, successes, and failures at a national scale. Any such repository would require a wide coalition or network of projects willing and able to ascribe to a set of CBP requirements encompass-

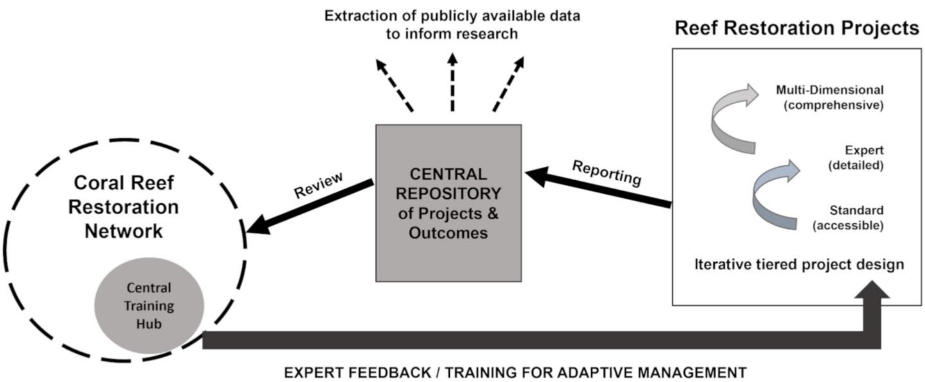

Fig. 8 A formal network of coral reef restoration managers and decision-makers supported by centralised training hubs and data repositories can facilitate an iterative process of reef restoration project design and implementation. In line with ER principles of adaptive management, a tiered project design system can help to better implement a national reef restoration roadmap developed by this network. This roadmap should be based on knowledge sharing and the alignment of overarching national goals and objectives for coral reef restoration

ing project management, scientific monitoring, and outcome reporting. Within such a framework, centralised skills and knowledge sharing from leading experts can help to decrease the gap in disparate levels of project funding and logistical resources. Pooling nationwide data would facilitate more accurate national assessments of reef restoration; this would aid researchers and decision-makers to evolve restoration approaches and policies over time, with data informing scientific research and adaptive management strategies. This network could help projects meet logistical, financial, administrative, scientific, and reporting standards via training, support, and skills transfer. Feedback from experts within the network would enable a tiered system of project design and implementation; in line with adaptive management strategies, projects could iteratively increase their efficacy over several years of implementation.

Various guidelines and document templates from Shaver et al. (2020) and other resources could be used 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 would improve accountability. This should include forming and implementing reporting requirements; providing feedback from restoration network members or a central board; and creating procedures and channels for submitting project documentation to a central repository. This would also facilitate periodic assessments and the identification of projects in need of additional training and/or administrative assistance to improve efficacy via adaptive management strategies.

The creation of a fully inclusive national network comprising all stakeholders 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 channel funding into supporting the restoration and protection of prioritised reefs on a national scale to maintain Indonesia's status as a hotspot for global marine biodiversity.

Developing a national roadmap for restoration

One of the primary objectives of a consolidated restoration network would be to cooperatively develop an iterative roadmap for coral reef restoration based on CBP principles (Table 2). The length and complexity of international CBP may be off-putting for projects, especially in countries where English is not the first language; there are distilled resources available, however (e.g. Hein et al. 2020a, c; Vardi et al. 2021). It is also recommended that authorities across the world aim to produce and disseminate resources in their countries' official language(s) to aid practitioners.

By becoming part of the network, new and extant projects with diverse goals and approaches would gain access to knowledge and skills transfer from a pool of experts. These experts could form part of project technical advisory groups to assist projects in implementing the key objectives of the national roadmap. In this capacity, leaders in the field of coral restoration could provide consultation, feedback, and guidance on various processes, including adaptive management, project administration, monitoring, reporting, and community engagement.

Table 2 Proposed Indonesian coral reef restoration roadmap elements. These include actions to be taken by a consolidated network of practitioners, scientists, regulatory authorities, and decision-makers; actions to be taken by individual projects within the network; and important considerations to inform these actions

	Network actions	Project actions	Considerations
1. Set goal and geographic focus	- Define overarching restoration goals. - Consolidate, homogenise, and expand participation in existing networks. - Emphasise climate-change adaptation goals (CCAGs). - Identify refugia for coral diversity, including thermally resistant coral survivors of mass bleaching events. - Refine priority geographical areas based on existing restoration successes, sustainability, and potential for futureproofing. - Ensure and assist technical advisory groups; develop availability of technical expertise. - Establish skills and knowledge transfer for stakeholders. - Assist projects to follow SER.	- Incorporate: • SMART characteristics; • standardised goals and objectives; • climate-smart design considerations; • specific social contexts/risks. - Focus on ecologically significant areas; identify priority areas linked to goals. - Utilise tiered project planning and development. - Maintain formal administrative standards. - Include any scientific, practical, traditional, and local knowledge available. - Promote community ownership and active, ongoing engagement in planning.	- Remove local stressors. - Ecosystem-level restoration. - Provide socio-economic benefits. - Accessible documentation for varying expertise levels. • Use distilled international CBP where necessary. • Develop resources in Bahasa Indonesia. - Establish functionality/benefits of restoration: • management challenges; • biophysical context; • likelihood of success; • unique opportunities of areas identified. - Build on 50 Reefs Initiative to identify refugia. - Increase focus on coral thermal resilience.
2. Identify, prioritise, and select sites	- Identify areas conducive to natural recovery; prioritise conservation areas within protected areas. - Develop standards, strategies, and evaluation protocols for site selection.	- Link site selection to specific restoration goals. - Follow a framework for prioritising sites for selection. - Base selections on standardised data collection. - Identify control/reference sites.	- Include CCAGs in site selection. - Evaluate areas conducive to natural recovery for favourable conditions (lack of local stressors; high larval supply; consolidated substrate for larval settlement). - Ensure effective community engagement actions and stakeholder integration in planning.
3. Identify, design, and select interventions	- Develop list of complementary potential interventions to promote on regional and national scales. - Facilitate project access to expert advice by strengthening networks for knowledge and skills sharing.	- Consider roadmap objectives within individual context to select applicable intervention(s) including: • sociocultural context • budgetary constraints	- Foster consultation with restoration experts to avoid duplication of effort / reliance on trial and error. - Promote coral biomass production in coral gardening projects to reduce pressure on wild donor colonies.

Table 2 (continued)

	Network actions	Project actions	Considerations
4. Develop Restoration Action Plan (RAP)	- Develop detailed and standardised RAP for projects based on international CBP. - Implement pilot phase assessments as standard practice. - Provide technical/scientific guidance through presence in technical advisory teams.	- Fully utilise all available knowledge and resources provided by the network. - Focus on primary goals; include SMART objectives. Use as a framework for funding applications/stakeholder interactions. - Establish contextualised timeframe for goals.	- Train community members in monitoring protocols. - Design plans to facilitate future upscaling. - Ensure transparency with stakeholders and the opportunity for input and feedback.
5. Implement restoration	- Encourage projects to utilise standardised RAP as a framework for restoration interventions. - Oversee minimum requirements for restoration projects, informed by international CBP. - Offer training, support, knowledge sharing, and skills transfer.	- Quantify successes and shortcomings compared to control sites. - Implement adaptive management strategies to improve efficacy over time. - Follow an achievable plan for ongoing community involvement.	- Maintain diligence in accounting procedures using the five aspects of a standardised RAP. - Ensure transparency, feedback, and standardisation between projects in the network to engender accountability. - Consider potential for project assessments/inspection by regional network representatives.
6. Monitor and evaluate progress	- Develop differentiated assessment and monitoring protocols. - Establish minimum monitoring requirements based on CBP universal monitoring metrics. - Integrate CBP principles and tools such as the CRC Restoration Evaluation Tool or the Five-Star System and Ecological Recovery Wheel. - Oversee monitoring of universal metrics to produce comparable results from projects.	- Clearly define metrics for success, linked to ecological, social, and economic outcomes. - Prioritise goal-based performance (GBP) metrics depending on available objectives, expertise, and resources.	- Timetable regular meetings to keep all stakeholders abreast of progress. - Quantify alternative livelihoods, local stewardship, and other socioeconomic objectives to enable adaptive management of community relations. - Organise regional and/or site specific training workshops to assist in elevating scientific monitoring standards across the board.
7. Scale up interventions	- Work towards a multidimensional and increasingly holistic approach in all projects.	- Incorporate monitoring of CCAG metrics and evaluate climate-smart design objectives. - Increase GBP metrics monitored based on available expertise.	- Develop evaluations to scale up over time from short-term assessments to long-term reef-scale effects. - Link with restoration in associated ecosystems.
8. Utilise adaptive management strategies	- Foster local, regional, national, and/or international reef restoration networks. - Promote reciprocal knowledge sharing, support, and adaptive management strategies for continual improvement and upscaling.	- Assess potential to scale up training and involvement of community members and other stakeholders. - Utilise expertise offered by knowledge sharing; supply data to the central repository.	- Conducting regular assessments and feedback will help to improve successful outputs. - Practitioners should remain open to adapting approaches that fall short of expectations.

The national roadmap should include as a minimum requirement actions that: (a) assess the causes of reef degradation and whether environmental conditions are conducive to restoration; (b) quantify and evaluate ongoing community engagement; (c) integrate climate-smart design and CCAG metrics; (d) agree on high priority restoration areas, and standardise long-term reef monitoring protocols and project evaluation strategies; and (f) apply adaptive management principles.

Conclusion

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 strengthen nationwide efforts. This will reduce the need for projects to "reinvent the restoration wheel" when dealing with extremely complex reef ecosystems across a range of conditions and levels of resource utilisation.

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 CCAGs and other advances, such as the use of midwater nurseries to take advantage of enhanced reef function metrics (Baer et al. 2023).

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 adoption of international CBP approaches that incorporate SER, and adaptive management strategies within an iterative, tiered roadmap designed specifically for the Indonesian context should be a priority for the country's authorities and restoration practitioners. This will enable effective, efficient, and successful restoration efforts with the potential for replication, adaptation, and upscaling. This roadmap can position Indonesia as a regional leader in coral restoration best practice and serve as a framework for the CT by taking country-specific and regional challenges into account.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10531-024-02897-8.

Author contributions 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 ANK (Bahasa Indonesia) conducted data collection. ANK translated data in Bahasa Indonesia into English. RWP analysed the data and wrote the manuscript. DJS, TBR, RAR, JJ, and RWP edited the manuscript.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

References

ADB (2022) Indonesia: Coral Reef Rehabilitation and Management Program – Coral Triangle Initiative Project. Project Number 46421-001. Asian Development Bank. Retrieved from: https://www.adb.org//projects/46421-001/main

Anthony K, Bay LK, Costanza R, Firn J, Gunn J, Harrison P, Heyward A, Lundgren P, Mead D, Moore T, Mumby PJ (2017) New interventions are needed to save coral reefs. Nat Ecol Evol 1:1420–1422. https://doi.org/10.1038/s41559-017-0313-5

Baer JL, Carilli J, Chadwick B, Hatay M, van der Geer A, Scholten Y, Barnes W, Aquino J, Ballard A, Little M, Brzenski J (2023) Coral reef arks: an in situ mesocosm and Toolkit for assembling reef communities. J Vis Exp (JoVE) 191e64778. https://doi.org/10.3791/64778

Bayraktarov E, Banaszak AT, Montoya Maya P, Kleypas J, Arias-González JE, Blanco M et al (2020) Coral reef restoration efforts in latin American countries and territories. PLoS ONE 15(8):e0228477. https://doi.org/10.1371/journal.pone.0228477

Bergen N, Labonté R (2020) Everything is perfect, and we have no problems: detecting and limiting social desirability bias in qualitative research. Qual Health Res 30(5):783–792. https://doi.org/10.1177/1049732319889354

Beyer HL, Kennedy EV, Beger M, Chen CA, Cinner JE, Darling ES, Eakin CM, Gates RD, Heron SF, Knowlton N, Obura DO (2018) Risk-sensitive planning for conserving coral reefs under rapid climate change. Conserv Lett 11(6):e12587. https://doi.org/10.1111/conl.12587

Boström-Einarsson L, Babcock RC, Bayraktarov E, Ceccarelli D, Cook N, Ferse SCA, Hancock B, Harrison P, Hein M, Shaver E, Smith A, Suggett D, Stewart-Sinclair PJ, Vardi T, McLeod IM (2020) Coral restoration – A systematic review of current methods, successes, failures and future directions. PLoS ONE 15(1):e0226631. https://doi.org/10.1371/journal.pone.0226631

Bottema MJ, Bush SR (2012) The durability of private sector-led marine conservation: a case study of two entrepreneurial marine protected areas in Indonesia. Ocean Coast Manage 61:38–48. https://doi.org/10.1016/j.ocecoaman.2012.01.004

Browne K, Katz L, Agrawal A (2022) Futures of conservation funding: can Indonesia sustain financing of the Bird's Head Seascape? World Dev Perspect 26:100418. https://doi.org/10.1016/j.wdp.2022.100418

Burke L, Reytar K, Spalding M, Perry A (2012) Reefs at Risk Revisited in the Coral Triangle. WRI: World Resources Institute. USA. Retrieved from: https://policycommons.net/artifacts/1360491/reefs-at-risk-revisited-in-the-coral-triangle/1974017/

Camp EF, Schoepf V, Mumby PJ, Hardtke LA, Rodolfo-Metalpa R, Smith DJ, Suggett DJ (2018a) The future of Coral Reefs subject to Rapid Climate Change: lessons from Natural Extreme environments. Front Mar Sci 5:1–21. https://doi.org/10.3389/fmars.2018.00004

Camp EF, Schoepf V, Suggett DJ (2018b) How can Super corals facilitate global coral reef survival under rapid environmental and climatic change? Glob Chang Biol 24:2755–2757. https://doi.org/10.1111/gcb.14153

Capriati A, Widodo H, van de Leemput I, Hakim A, Timotius S et al (2024) Beyond numbers: assessing Staff Capacity and Competency to improve Marine protected areas (Mpas) Management in Indonesia. https://doi.org/10.2139/ssrn.4769600. preprint

Chan WY, Peplow LM, Menéndez P, Hoffmann AA, Van Oppen MJ (2018) Interspecific hybridization may provide Novel opportunities for Coral reef restoration. Front Mar Sci 5:160. https://doi.org/10.3389/fmars.2018.00160

CMP (2020) The Open Standards for the Practice of Conservation, v 4.0. Conservation Measures Partnership. Retrieved from: https://conservationstandards.org/wp-content/uploads/sites/3/2020/10/CMP-Open-Standards-for-the-Practice-of-Conservation-v4.0.pdf

Coggan A, Thorburn P, Fielke S, Hay R, Smart JC (2021) Motivators and barriers to adoption of Improved Land Management practices. A focus on practice change for water quality improvement in great barrier reef catchments. Mar Pollut Bull 170:112628. https://doi.org/10.1016/j.marpolbul.2021.112628

Crabbe MJC, Smith DJ (2005) Sediment impacts on growth rates of Acropora and Porites corals from fringing reefs of Sulawesi, Indonesia. Coral Reefs 24(3):437–441. https://doi.org/10.1007/s00338-005-0004-6

dela Cruz DW, Rinkevich B, Gomez ED, Yap HT (2015) Assessing an abridged nursery phase for slow growing corals used in coral restoration. Ecol Eng 84:408–415. https://doi.org/10.1016/j.ecoleng.2015.09.042

Depondt F, Green E (2006) Diving user fees and the financial sustainability of marine protected areas: opportunities and impediments. Ocean Coast Manage 49:188–202. https://doi.org/10.1016/j.ocecoaman.2006.02.003

Epstein N, Bak RP, Rinkevich B (2001) Strategies for gardening denuded coral reef areas: the applicability of using different types of coral material for reef restoration. Restor Ecol 9(4):432–442. https://doi.org/10.1046/j.1526-100X.2001.94012.x

Exton DA, Ahmadia GN, Cullen-Unsworth LC, Jompa J, May D, Rice J, Simonin PW, Unsworth RK, Smith DJ (2019) Artisanal fish fences pose broad and unexpected threats to the tropical coastal seascape. Nat Commun 10(1):1–9. https://doi.org/10.1038/s41467-019-10051-0

Fabinyi M (2008) Dive tourism, fishing and marine protected areas in the Calamianes Islands, Philippines. Mar Policy 32:898–904. https://doi.org/10.1016/j.marpol.2008.01.004

Fadli N, Campbell SJ, Ferguson K, Keyse J, Rudi E, Riedel A, Baird AH (2012) The role of habitat creation in coral reef conservation: a case study from Aceh, Indonesia. Oryx 46(4):501–507. https://doi.org/10.1017/S0030605312000142

Ferse SCA, Máñez Costa M, Mez KS, Adhuri DS, Glaser M (2010) Allies, not aliens: increasing the role of local communities in marine protected area implementation. Environ Conserv 37:23–34. https://doi.org/10.1017/S0376892910000172

Ferse SC, Hein MY, Rölfer L (2021) A survey of current trends and suggested future directions in coral transplantation for reef restoration. PLoS ONE 16(5):e0249966. https://doi.org/10.1371/journal.pone.0249966

Fischborn M, Levitina Z (eds) (2018) Solutions in focus: Community-led successes in marine conservation. International Union for Conservation of Nature (IUCN). Retrieved from: https://panorama.solutions/sites/default/files/mediathek/solutions_in_focus_community-led_successes_in_marine_conservation.pdf

Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J, Hallett JG et al (2019) International principles and standards for the practice of ecological restoration. Restor Ecol 27(1):1–46. https://doi.org/10.1111/rec.13035

Gill DA, Mascia MB, Ahmadia GN, Glew L et al (2017) Capacity shortfalls hinder the performance of marine protected areas globally. Nature 543(7647):665–669. https://doi.org/10.1038/nature21708

Goergen EA, Schopmeyer S, Moulding AL, Moura A, Kramer P, Viehman TS (2020) Coral reef restoration monitoring guide: methods to evaluate restoration success from local to ecosystem scales. NOAA Tech Memorandum NOS NCCOS 279:145. https://doi.org/10.25923/xndz-h538

Gorris P (2016) Deconstructing the reality of community-based management of marine resources in a small island context in Indonesia. Front Mar Sci 3:120. https://doi.org/10.3389/fmars.2016.00120

Grydehøj A, Nurdin N (2016) Politics of technology in the informal governance of destructive fishing in Spermonde. Indonesia Geoj 81(2):281–292. https://doi.org/10.1007/s10708-014-9570-x

Hadi TA, Abrar M, Giyanto, Prayudha B, Johan O, Budiyanto A, Dzumalek AR, Alifatri LO, Sulha S, Suharsono (2020) The status of Indonesian coral reefs 2019. Research Center for Oceanography – Indonesian Institute of Sciences, Jakarta 1–88. Retrieved from: https://www.researchgate.net/publication/342663285_The_Status_of_Indonesian_Coral_Reefs_2019

Hein MY, Staub F (2021) Mapping the global funding landscape for coral reef restoration. International Coral Reef Initiative. 23pp. Retrieved from: https://icriforum.org

Hein MY, Willis BL, Beeden R, Birtles A (2017) The need for broader ecological and socioeconomic tools to evaluate the effectiveness of coral restoration programs. Restor Ecol 25(6):873–883. https://doi.org/10.1111/rec.12580

Hein M, Mcleod E, Razak T, Fox H (2020a) Meeting 30 by 30: The role of coral reef restoration. International Coral Reefs Initiative (ICRI) Vibrant Oceans Initiative Whitepaper. pp 1–17. Retrieved from: https://icriforum.org/wp-content/uploads/2022/12/Hein-McLeod-et-al.-2022-Reef-Restoration-White-Paper.pdf

Hein MY, McLeod IM, Shaver EC, Vardi T, Pioch S, Boström-Einarsson L, Ahmed M, Grimsditch G (2020b) Coral Reef Restoration as a strategy to improve ecosystem services – A guide to coral restoration methods. United Nations Environment Program, Nairobi, Kenya. Retrieved from: https://wedocs.unep.org/20.500.11822/34810

Hein MY, McLeod IM, Shaver EC, Vardi T, Pioch S, Boström-Einarsson L, Ahmed M, Grimsditch G (2020c) Coral Reef Restoration as a strategy to improve ecosystem services – Policy Brief. United Nations Environment Program, Nairobi, Kenya. Retrieved from: https://wedocs.unep.org/bitstream/handle/20.500.11822/34811/CRRPB.pdf

Hobbs RJ, Harris JA (2001) Restoration ecology: repairing the earth's ecosystems in the new millennium. Restor Ecol 9(2):239–246. https://doi.org/10.1046/j.1526-100x.2001.009002239.x

Kurniawan F, Adrianto L, Bengen DG, Prasetyo LB (2016) Vulnerability assessment of small islands to tourism: the case of the Marine Tourism Park of the Gili Matra Islands, Indonesia. Glob Ecol Conserv 6:308–326. https://doi.org/10.1016/j.gecco.2016.04.001

Lamont TA, Razak TB, Djohani R, Janetski N, Rapi S, Mars F, Smith DJ (2022) Multi-dimensional approaches to scaling up coral reef restoration. Mar Policy 143:105199. https://doi.org/10.1016/j.marpol.2022.105199

Larsen SN, Leisher C, Mangubhai S, Muljadi A, Tapilatu RF (2018) Fisher perceptions of threats and fisheries decline in the heart of the Coral Triangle. Indo Pac J Ocean Life 2(2):41–46. https://doi.org/10.13057/oceanlife/o020201

Marine Protection Atlas, The (2022) Announcing the MPA Guide: a framework to achieve global goals for the ocean. Marine Conversation Institute, Seattle, Washington

McDonald T, Jonson J, Dixon KW (2016) National standards for the practice of ecological restoration in Australia. Rest, Ecol 2(24):S6–S32. https://doi.org/10.1111/rec.12359

McLeod IM, Hein MY, Babcock R, Bay L, Bourne DG, Cook N, Doropoulos C, Gibbs M, Harrison P, Lockie S, van Oppen MJ et al (2022) Coral restoration and adaptation in Australia: the first five years. PLoS ONE 17(11):e0273325. https://doi.org/10.1371/journal.pone.0273325

Mooney AC, Campbell CK, Ratlhagana MJ, Grignon JS, Mazibuko S, Agnew E, Gilmore H, Barnhart S, Puren A, Shade SB, Liegler T (2018) Beyond social desirability bias: investigating inconsistencies in self-reported HIV testing and treatment behaviors among HIV-positive adults in North West Province, South Africa. AIDS Behav 22(7):2368–2379. https://doi.org/10.1007/s10461-018-2155-9

Pet-Soede L, Erdmann MV (1998) Blast Fishing in Southwest Sulawesi, Indonesia. Naga, the ICLARM Quarterly 21(2):4–9. Retrieved from: https://aquadocs.org/handle/1834/26039

Piskurek N Dive tourism in coral reefs-impacts and conditions for sustainability: a case study from Desa Pemuteran (Bali/, Indonesia (2001) ACP-EU Fisheries Research Report 10:57–65. Retrieved from: https://aquadocs.org/bitstream/handle/1834/293/acp_10_proceedings_en.pdf

Razak TB, Boström-Einarsson L, Alisa CAG, Vida RT, Lamont TA (2022) Coral reef restoration in Indonesia: a review of policies and projects. Mar Policy 137:104940. https://doi.org/10.1016/j.marpol.2021.104940

Renggong R, Hamid AH, Yulia Y (2021) Investigating law enforcement for coral reef conservation of the Spermonde Archipelago, Indonesia. Retrieved from: https://repository.unibos.ac.id/xmlui/handle/123456789/861

Rinkevich B (2006) The coral gardening concept and the use of underwater nurseries: lessons learned from silvics and silviculture. Coral Reef Restor Handb 1:291–301

Rinkevich B (2019) The active reef restoration toolbox is a vehicle for coral resilience and adaptation in a changing world. J Mar Sci Eng 7(7):201. https://doi.org/10.3390/jmse7070201

Rohyani V, Baruadi AS, Husain R (2023) Institutional Effectiveness of Community Supervisory Group (Pokmaswas) in Supervision of Illegal Fishing and Destructive Fishing in Gorontalo Province. Central Asian J Soc Sci Hist 4(12):186–92. Retrieved from: https://cajssh.centralasianstudies.org/index.php/CAJSSH/article/view/1007

Saragih RF, Trencher G (2020) Blast fishing activity and coping strategies in Indonesia (South Nias and Pohuwato Regency). J Ilmiah Administrasi Publik 6(1):127–138. https://doi.org/10.21776/ub.jiap.2020.006.01.15

Shafira M, Anwar M (2021) Destructive Fishing Treatment Policy Based on Community Supervision in Lampung Province. In I-COFFEES 2019: Proceedings of the 2nd International Conference on Fundamental Rights, Bandar Lampung, Indonesia: p56. European Alliance for Innovation. https://doi.org/10.4108/eai.5-8-2019.2308671

Shaish L, Levy G, Gomez E, Rinkevich B (2008) Fixed and suspended coral nurseries in the Philippines: establishing the first step in the gardening concept of reef restoration. J Experimental Mar Biol Ecol 358(1):86–97. https://doi.org/10.1016/j.jembe.2008.01.024

Shaver E, Courtney C, West J, Maynard J, Hein M, Wagner C, Philibotte J, MacGowan P, McLeod I, Böstrom-Einarsson L, Bucchianeri K (2020) A manager's guide to Coral reef Restoration Planning and Design. NOAA Coral Reef Conservation Program. NOAA Tech Memorandum CRCP 36:120. https://doi.org/10.25923/vht9-tv39

Simmons EC, Fielding KS (2019) Psychological predictors of fishing and waste management intentions in Indonesian coastal communities. J Environ Psychol 65:101324. https://doi.org/10.1016/j.jenvp.2019.101324

Sukarno (1988) Terumbu karang buatan sebagai sarana untuk meningkatkan produktivitas perikanan di Perairan Jepara (Artificial coral reefs as a means to increase fisheries productivity in Jepara waters). J Perair Indones Biol Budidaya, Kualitas Lingkungan, Oseanografi 87–91

Tam CL (2015) Timing exclusion and communicating time: a spatial analysis of participation failure in an Indonesian MPA. Mar Policy 54:122–129. https://doi.org/10.1016/j.marpol.2015.01.001

Tranter SN, Ahmadia GN, Andradi-Brown DA, Muenzel D, Agung F, Ford AK, Habibi A, Handayani CN, Iqbal M, Krueck NC, Lazuardi ME (2022) The inclusion of fisheries and tourism in marine protected areas to support conservation in Indonesia. Mar Policy 146:105301. https://doi.org/10.1016/j.marpol.2022.105301

Trialfhianty TI, Suadi (2017) The role of the community in supporting coral reef restoration in Pemuteran, Bali, Indonesia. J Coast Conserv 21:873–882. https://doi.org/10.1007/s11852-017-0553-1 van Oppen MJ, Oliver JK, Putnam HM, Gates RD (2015) Building coral reef resilience through assisted evolution. PNAS 112(8):2307–2313. https://doi.org/10.1073/pnas.1422301112

van Oppen MJH, Gates RD, Blackall LL, Cantin N, Chakravarti LJ, Chan WY, Cormick C, Crean A, Damjanovic K, Epstein H, Harrison PL (2017) Shifting paradigms in restoration of the world's coral reefs. Glob Chang Biol 23:3437–3448. https://doi.org/10.1111/gcb.13647

Vardi T, Hoot WC, Levy J, Shaver E, Winters RS, Banaszak AT, Baums IB, Chamberland VF, Cook N, Gulko D, Hein MY (2021) Six priorities to advance the science and practice of coral reef restoration worldwide. Rest Ecol 29(8):e13498. https://doi.org/10.1111/rec.13498

Veloria AI, Hernandez DT, Tapang GA, Aragones LV (2021) Characterization of Open Water Explosions from Confiscated Explosives in the Philippines – Possible Implications to Local Marine Mammals. Sci Diliman 33(1). Retrieved from: https://www.researchgate.net/publication/352836610

Veron JE, Devantier LM, Turak E, Green AL, Kininmonth S, Stafford-Smith M, Peterson N (2009) Delineating the Coral Triangle. Galaxea. J Coral Reef Stud 11:91–100. https://doi.org/10.3755/galaxea.11.91

Vesely S, Klöckner CA (2020) Social desirability in environmental psychology research: three meta-analyses. Front Psych 24(11):545057. https://doi.org/10.3389/fpsyg.2020.01395

Viehman TS, Reguero BG, Lenihan HS, Rosman JH, Storlazzi CD, Goergen EA, Canals Silander MF et al (2023) Coral restoration for coastal resilience: integrating ecology, hydrodynamics, and engineering at multiple scales. Ecosphere 14(5):e4517. https://doi.org/10.1002/ecs2.4517

Westoby R, Becken S, Laria AP (2020) Perspectives on the human dimensions of coral restoration. Reg Envriron Chang 20:1–3. https://doi.org/10.1007/s10113-020-01694-7

Wicaksono AW, Abdul KM, Haerudin (2019) Empowerment strategy for Community Surveillance Groups (POKMASWAS) in marine and fisheries resource surveillance activities to prevent illegal and destructive fishing activities through Interpretive Structural Modeling (ISM). Int J Appl Environ Sci 14(4):307 – 24. Retrieved from: https://www.cabidigitallibrary.org/doi/full/https://doi.org/10.5555/20219919999

Wilkinson C, Caillaud A, DeVantier L, South R (2006) Strategies to reverse the decline in valuable and diverse coral reefs, mangroves and fisheries: the bottom of the J-Curve in Southeast Asia? Ocean Coast Manage 49(9–10):764–778. https://doi.org/10.1016/j.ocecoaman.2006.06.014

Williams SL, Ambo-Rappe R, Sur C, Abbott JM, Limbong SR (2017) Species richness accelerates marine ecosystem restoration in the Coral Triangle. Proc Natl Acad Sci 114(45):11986–11991. https://doi.org/10.1073/pnas.1707962114

Williams SL, Sur C, Janetski N, Hollarsmith JA, Rapi S, Barron L, Heatwole SJ, Yusuf AM, Yusuf S, Jompa J, Mars F (2019) Large-scale coral reef rehabilitation after blast fishing in Indonesia. Restor Ecol 27:447–456. https://doi.org/10.1111/rec.12866

Authors and Affiliations

Rowan Watt-Pringle[1] · Tries B. Razak[2,3] · Jamaluddin Jompa[1,4] · Rohani Ambo-Rappe[1] · Alyssa N. Kostaman[5] · David J. Smith[6,7]

✉ Rowan Watt-Pringle
rwp.unhas@gmail.com

1 Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, Indonesia

2 Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, IPB University, Bogor, Indonesia

3 School of Coral Reef Restoration (SCORES), Faculty of Fisheries and Marine Science, IPB University, Bogor, Indonesia

4 Graduate School, Hasanuddin University, Makassar, Indonesia

[5] Cakra Bhakti Samudra Diving, Jakarta, Indonesia

[6] Coral Reef Research Unit, School of Life Sciences, University of Essex, Colchester, UK

[7] Mars Inc, 4 Kingdom Street, Paddington, London, UK W2 6BD