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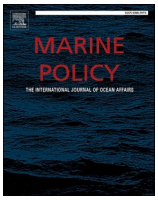

Coral reef restoration in Indonesia: A review of policies and projects

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ABSTRACT

Indonesia's coral reefs have been severely damaged by global and local stressors, and a range of active restoration techniques are now being used in attempts to rebuild degraded reefs. However, it is difficult to summarise Indonesia's restoration efforts as a whole due to a lack of consistent reporting. Here, we first discuss Indonesia's legal policy framework concerning reef restoration; this is included in the agenda of two government ministries (Marine Affairs and Fisheries, and Environment and Forestry), and comprises national laws and governmental, presidential and ministerial regulations. We then provide an extensive review of reef restoration projects in Indonesia, documenting 533 records across the country between 1990 and 2020. Most (73%) of these records come from the past ten years, and many (42%) are reported in online news articles rather than scientific reports or papers. This review identified 120,483 units of artificial reef installed across Indonesia, along with 53,640 units of coral transplantation (including both coral nurseries and direct out-planting onto reefs); in total, 965,992 fragments of hard coral have been planted across Indonesia. The most favoured restoration materials are concrete (46%) and steel structures (24%). Projects are organised by a diverse range of governmental, NGO, private and community-led organisations. This review demonstrates that Indonesia's policy has encouraged a diverse range of practitioners to implement reef restoration, but projects are often not coordinated with wider networks of restoration practitioners or scientists, and only 16% of the identified projects included a post-installation monitoring framework. Incorporating clear objectives and long-term monitoring programmes in project planning stages, while prioritising knowledge exchange and engagement with international scientific community, will substantially improve restoration outcomes in Indonesia. This will allow the country to fulfil its considerable potential as a global leader in rebuilding damaged coral reefs.

1. Introduction

Indonesia's 39,538 square kilometres of coral reefs account for 16% of the global total reef area and are recognised as being amongst the most diverse ecosystems in the world [1]. Unfortunately, Indonesia's reefs have also been severely damaged by anthropogenic causes, including local stressors such as pollution, eutrophication, overfishing and destructive fishing practices, as well as mass bleaching linked to climate change [2,3]. Nearly a quarter of Indonesia's 270 million population live on the coast within 30 km of a coral reef, which is the largest reef-associated human population of any country in the world. Due to this high concentration of people near the coasts, over 95% of Indonesian reefs are considered under threat, mainly due to overfishing and destructive fishing [1].

Despite dynamite fishing being illegal since 1985 [4], this practice remains a major and widespread threat to Indonesia's reefs. In many of Indonesia's damaged reef areas, natural ecosystem recovery is precluded by the creation of unconsolidated rubble fields [5]. Rubble fields are hostile environments for coral recovery, because the highly unstable substrate causes young coral colonies to be easily overturned, abraded,

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or buried [6,7]. As such, even if rubble field sites have a good supply of coral larvae and favourable water quality, they often show no signs of natural recovery. Whilst rubble fields are created by a range of degradation processes around the world, this problem is particularly acute in Indonesia due to the prevalence of blast fishing (sometimes referred to as bomb or dynamite fishing). Many rubble fields that were created by historic blast fishing have not recovered even decades later [8].

A range of active reef restoration techniques are increasingly being implemented around the world, in attempts to rebuild reefs where natural recovery processes are slow or non-existent [9,10]. Ideally, these efforts are implemented alongside efforts to mitigate local threats to reefs, and targeted at bypassing barriers to natural recovery (such as rubble or reduced recruitment), until the system reaches a point where the coral reef can recover naturally. In Indonesia, the installation of artificial structures and coral transplantation have become popular restoration techniques and have been carried out for over four decades. The first documented installation of artificial reefs was by the Indonesian Navy in July 1979, aiming to rehabilitate the coral reef around Seribu Islands, north of Jakarta, by submerging old cars, rickshaws and tires. It was hoped that this would provide topographic complexity, stable substrate for coral and other invertebrate settlement, and habitat to attract fish [11].

In recent decades, a wide range of restoration projects using a diverse suite of methods have been established in Indonesia's coastal waters. The methods and materials used for restoration projects vary significantly, including deployments of repurposed waste material, piles of volcanic rocks, custom-designed concrete structures, branching ceramic modules, electrolytic deposits on shaped wire mesh templates, hexagonal steel structures, and direct fixing of coral fragments onto the seabed. Projects have been initiated by a range of government initiatives, local and international NGOs, private sector companies and coastal communities. However, many of these projects have not been officially reported, and reviews of reef restoration projects across Indonesia are outdated and not published in the peer reviewed literature [8]. Further, the deployment of artificial reefs or other restoration methods falls under multiple government policy frameworks, and it is difficult to assess permit requirements and regulations pertaining to reef restoration activities.

In this paper, we present a summary of the policy framework supporting reef restoration in Indonesia, and a comprehensive review of restoration projects across the country from 1990 to 2020. First, in order to understand the legislative and legal structure that governs and supports restoration in Indonesia, we describe statutes and guidelines taken from government, presidential and ministerial regulations and decrees. Second, we review Indonesian restoration projects described in both the academic and grey literature, including both traditional and social media, written in both English and Bahasa Indonesia. To our knowledge, this study represents the first publicly available database of reef restoration projects in Indonesia. The database and its accompanying interactive visualisation is available at bit.ly/Indonesian_restoration.

2. Materials and methods

2.1. Legal and policy documents

An extensive review of national and ministerial policy documents was carried out to identify those that pertain to coral reef or coastal ecosystem restoration or rehabilitation. The review analysed the content of each regulation to summarise its core aspects, incentivisation for coral reef restoration and guidelines for best practice.

Most policy documents were available online in Bahasa Indonesia. Online platforms such as peraturan.go.id (an online platform to disseminate all the laws and regulations managed by the Directorate General of Legislation of the Indonesian Ministry of Law and Human Rights) and jdih.kkp.go.id (a legal documentation and information network of the Indonesian Ministry of Marine Affairs and Fisheries (MMAF)) were used to access policy documents. A two-category string approach was used to search for policy documents, by combining pairs of words from each of two categories: one that described a legal framework; and one that described an aspect of coral reef restoration (Table 1).

2.2. Review of reef restoration records

An extensive review was carried out of the academic and 'grey' literature describing coral reef restoration projects in Indonesia over the past three decades (1990–2020). This multiple-source approach was critical to gain an accurate understanding of the true extent of reef restoration activities in Indonesia, given that the majority of projects have been reported outside of the scientific literature. Searches were carried out in both Bahasa Indonesia and English, using combinations of the keywords '*karang*' (coral), '*terumbu karang*' (coral reef), '*terumbu karang buatan*' (artificial coral reef), '*terumbu buatan*' (artificial reef), '*transplantasi*' (transplantation), '*rehabilitasi*' (rehabilitation), '*restorasi*' (restoration), '*pemulihan*' (recovery) and '*laju pertumbuhan karang*' (coral growth rate). Records from these searches were compared with English-language records of Indonesian reef restoration summarised in a recent global review of coral reef restoration [9]. Following this comparison, all records from both reviews were combined into the database associated with this study.

When entering the data, it was necessary to distinguish between *projects* and *records*, as some projects from a single source reported multiple locations and/or methods and were split over multiple rows in the database. Therefore, there are a greater number of records than projects in the database. Further, not all entries are complete, as sources did not always report information about every aspect recorded in the database. Percentages belonging to a specific group or category (i.e. restoration method, materials used etc.) were therefore calculated as $k = \frac{y}{x}$, where y = the total number of records in the category, and x = total numbers of records that contained information about that category. Thus the denominator can be $<$ the total number of individual projects in the database when information is missing from that source, but also $>$ the total number of individual projects in the database when a project contains multiple records.

2.3. Terminology

Readers should note that the terminology describing restoration methods in Indonesia, and therefore in this study, differs slightly from that generally adopted to describe coral reef restoration methods elsewhere (i.e. compared to [9,12]). The term 'transplantation' is used here to describe any method that involves coral fragments, whether these are directly transplanted onto a substrate (elsewhere: 'direct transplantation'), or via an intermediate coral nursery (elsewhere: 'coral gardening', or 'asexual propagation'). The term 'transplantation rack' refers here to a specific type of coral nursery that is used commonly in Indonesia (elsewhere: 'table nursery'). Finally, reef restoration is generally referred to as 'reef rehabilitation' in the majority of Indonesian

Table 1
The two-category string approach used to search for policy documents. Multiple non-systematic searches were carried out, with each one combining at least one term describing a legal framework (left-hand column) and one term describing an aspect of coral reef restoration (right-hand column).

Legal framework search term	Coral reef restoration search term
Undang-undang (Law)	*Terumbu karang* (coral reef)
Peraturan Pemerintah (Government Regulation)	*Pesisir* (coastal)
Peraturan Presiden (Presidential Regulation)	*Pulau-pulau kecil* (small islands)
Peraturan Menteri (Ministerial Regulation)	*Rehabilitasi* (rehabilitation)
Keputusan Menteri (Ministerial Decree)	*Restorasi* (restoration)
	Pemulihan (recovery)
	Transplantasi (transplantation)

legal documents and references; this term was included alongside restoration for all aspects of this review.

3. Results and discussion

3.1. Indonesian laws and regulations on coral reef restoration

Seventeen policies and regulations were identified that pertain to coral reef restoration in Indonesia (Table 2). These regulations comprise four national laws, three government regulations, two presidential regulations and eight ministerial regulations.

All of Indonesia's regulations concerning coral reef restoration encourage wide community participation, with ownership and responsibility shared between government (both central and local) and local communities who live near and benefit from reefs. For example, Law No. 27/2007 (amended by Law No. 1/2014) stipulates that restoration practices can be conducted by '*Government and/or Regional Government and/or each person which directly or not directly obtains the benefit from coastal areas and small islands*' [Article 33.1]. This sentiment of community-driven management of restoration is echoed in Presidential Regulation No. 121/2012 ('*Rehabilitation can be conducted through cooperation between government, regional government, person or community*' [Article 12.1] and '*Community or persons can participate in the implementation and maintenance of rehabilitation voluntarily*' [Article 15.1]), and also in the recent MMAF Ministerial Regulation No. 26/2021 ('*Each person can participate in the rehabilitation of fisheries resources and their environment*' [Article 67.1]).

Indonesia's system for gaining official permission to conduct reef restoration is also reflective of this community-driven approach. While many other countries with a large restoration footprint (like Australia and the USA) rely on centrally-governed permits that are administered at a national level (e.g. Australia: https://www.gbrmpa.gov.au/access-and-use/permits), Indonesia's regulations are governed regionally. For example, Presidential Regulation No. 121/2012 states that proposals for restoration must be '*consulted with the Regional Working Unit in charge of the marine and fisheries affairs at the rehabilitation location*' [Article 9.2], rather than going through a nationally centralised governing unit. MMAF Ministerial Regulation No. 26/2021 also reflects this regional governance structure, dictating that plans for restoration '*must be delivered and consulted with Government, Governor or Regent/Major at the rehabilitation location*' [Article 48.4]. The requirement to obtain permits for marine activities is not new in Indonesia - Law No. 32/2014 states that '*Each person undertaking marine spatial use permanently in the waters and jurisdiction areas are obliged to own a location permit.*' [Article 47.1]. However, the most recent ministerial regulations released in 2021 have emphasised the need for permits - MMAF Ministerial Regulation No. 28/2021 repeats this sentiment that '*Each person conducting marine spatial use activity on the coastal waters, waters area, and/or jurisdiction area permanently on some parts of marine space is obliged to have KKPRL [permit].*' [Article 113.1]. This renewed emphasis on permit requirements may be in response to a rapidly growing number of new restoration projects around the country in recent years (see Sections 3.2 and 3.3).

In addition to having a regionally structured permitting system, Indonesia's legislation specifically requires that local communities and stakeholders should be directly involved in both the planning and implementation of restoration activities. MMAF Ministerial Regulation No. 26/2021 states that restoration plans '*must be consulted with related stakeholders around the rehabilitation location in order to receive inputs and responses*' [Article 48.3], in a system that echoes the broader rules laid out by the Ministry of Forestry (MoF) for all categories of ecosystem restoration ('*Implementation of ecosystem recovery is conducted by the management unit and/or can be conducted by permit holder after obtaining a permit from the Minister by involving the local community.*', MoF Ministerial Regulation No. 48/2014, Article 15.1). As such, Indonesia's legislation around restoration decentralises the governing responsibility to regional authorities rather than a national centre, and encourages the participation of a diverse range of local communities and stakeholders.

Indonesia's regulatory structure also creates space for a diverse range of methods and approaches to reef restoration. It is specified at a broad level that all projects should aim to protect and enrich natural ecosystems and resources. For example, Law No. 27/2007 (amended by Law No. 1/2014) states that restoration should be carried out in ways that '*pay attention to the balance of the ecosystem and/or local biodiversity*' [Article 32.1] and are '*environmentally sound*' [Article 32.2d]. However, within this framework, the regulations do not specifically regulate restoration methods or specify measurable target outcomes. A recent MMAF Ministerial Decree (General Director of Marine Spatial Management Decree No. 10/2021) provides guidelines for a range of restoration activities, but there are no permits or legal approval that are conditional on these guidelines. As such, Indonesia's regulatory framework is likely to lead to a high degree and diversity of participation in restoration, but a lack of a synchronized approach or common methods. Further, an emphasis on deployment without a requirement for clearly specified objectives and measurable targets increases the risk of ill-advised restoration projects that are likely to fail to deliver genuine conservation benefits.

3.2. Summary of reef restoration projects in Indonesian waters (1990–2020)

We documented 533 restoration projects spanning 29 of Indonesia's 34 provinces (Fig. 1). These projects were recorded as 600 separate records in the database (Table S1, Supplementary Material). The primary source of records was online news sites (222, 42%), followed by official organisation websites (106, 20%), peer reviewed literature i.e. local and international journals (71, 13%) and reports (54, 10%, Fig. 2a). This wide range of sources illustrates the complexity of summarising restoration activities across the country, and is driven in large part by the diversity of participation in restoration.

A range of public and private organisations have established Indonesia's reef restoration projects (Fig. 2b). One third of records in the database were organised by the Indonesian government (205, 38%), with the next most common organisers being in the private sector (79, 15%), university (75, 14%) and NGOs (68, 13%). This diversity in practitioners mirrors the policy landscape in Indonesia; national laws and regulations promote inclusivity and heterogeneity in participation (Section 3.1; Table 2), and so it is unsurprising that a wide range of practitioners are actively involved in establishing a high number of restoration programmes. Intersectional collaboration is also a common feature of Indonesia's restoration landscape; many of the projects were led by one organisation, but included involvement of partner organisations in different sectors. Collaborative approaches of this nature have the potential to overcome the limitations of any single organisational structure and lead to better restoration practice [13].

3.3. Temporal trends in reef restoration practice within Indonesia

The number of coral reef restoration projects in Indonesia has increased dramatically in recent years (Fig. 3). Over two thirds of restoration projects in this database were established in the past ten years (388 projects established since 2010, 73%), with over half established in the past five years (294 records since 2015). Strikingly, this recent increase has continued even despite the COVID-19 global pandemic, with the year 2020 featuring more new records of restoration projects than any previous year (Fig. 3). These new projects in 2020 were largely attributed to the 'Indonesia Coral Reef Garden' programme, organised by the Coordinating Ministry for Maritime and Investment Affairs as part of an economic recovery strategy for coastal communities impacted by unemployment due to COVID-19 (https://maritim.go.id/mewujudkan-indonesia-coral-reef-garden/). In total, this programme is estimated to have employed 10,000 people in planting nearly 96,000

units of artificial reefs and transplantation racks/coral nurseries covering 74.3 Ha in five areas in Bali between October 2020 and January 2021 [14]. This large programme is one example of a general trend demonstrating that the operational scale of restoration activities across Indonesia has increased dramatically in recent years. Before 2010, only two projects had outplanted more than 10,000 coral fragments; by contrast, in the subsequent decade (2010–2020) this milestone was achieved by nine further projects (Fig. 3c). While these numbers are impressive, it is important to remember that a high number of outplanted fragments does not necessarily indicate a successful project. Rather, the ultimate goal of restoration projects should be the long-term survival and proliferation of outplanted corals into a self-sustaining functioning ecosystem (see Section 3.4 for more details on monitoring).

There are a diverse range of methods and materials used in Indonesian reef restoration projects (Fig. 3), which have also changed markedly through time. Across all time periods, the most favoured materials used to make restoration structures are concrete (173, 46%), and steel (91, 24%) (Fig. 3b). However, the diversity of materials used has increased in recent years; projects established in the 1990 s predominantly used concrete and tyres, compared to a far more diverse array of approaches used in recent years, that includes ceramic structures, steel frames, direct transplantation and biorock. Whilst concrete has remained the dominant material throughout all three of the decades studied, other materials have seen changes in their popularity. For example, the use of tyres was popular throughout the 1990 s, representing 50% of projects in that decade, including some years (1996–1997) where it was the only material used. However, the use of tyres has gradually declined such that no such projects have been recorded since 2009. The use of steel structures has dramatically increased in recent years, from four records in the 2000 s to 86 in the last decade. Many of these structures use a hexagonal shape, mimicking the success of the 'Mars Assisted Reef Restoration System (MARRS)' in southern Sulawesi [15]. These structures were first used by Mars in 2013 and they now represent 18% of project records over the last three years (33 projects between 2018 and 2020). As such, there are several lines of evidence that different methods and materials for restoration are spread throughout the country, with certain techniques becoming more and less popular over time. These changing trends may be a result of different projects inspiring and imitating each other, or may be due to fluctuations in the availability and affordability of certain materials above others.

3.4. Post-installation monitoring

Amongst reef restoration efforts worldwide, there remains a need to align and standardise metrics for ecological monitoring [16]. This is particularly important for evaluating the success of different approaches to restoration and to guide management decisions in different contexts. The diversity of restoration approaches in Indonesia means that ecological monitoring is of particular importance in this region; however, only 16% (85) of the reef restoration 533 projects incorporated a post-installation monitoring programme. These 85 projects were recorded as 101 separate records in the database (Table S2, Supplementary Material). All of the projects that mentioned ecological monitoring were published in the academic literature (i.e. journals, theses, proceedings and reports) or official project websites, with no online news reports (the dominant source of reef restoration records) mentioning ecological monitoring. There may be a reporting bias present in these calculations (i.e. news reports may be more likely to report on project establishment rather than project monitoring). However, it remains clear that ecological monitoring is far from ubiquitous in Indonesian reef restoration practice.

While 85 records indicated that they had conducted monitoring, the vast majority lacked sufficient detail to reliably extract information about focal taxa and/or to discuss outcomes of the restoration. As such, in this review we detail only the proportion of projects that conducted certain types of monitoring, rather than the results of that monitoring. Those projects that did include ecological monitoring featured monitoring schedules that varied in duration from one month to 16 years after the installation of artificial reefs/coral nursery. Most of these monitoring studies reported only a single visit to the restoration sites (47 of 85 projects, 55%), while remaining projects visited sites between 2 and 16 times over the study period. A majority of monitoring studies (80, 94%) had monitored some aspect of the coral community, with the primary focus being on the survival and/or skeletal extension rate of the coral transplants. A number of studies (39, 46%) reported monitoring the fish community on restoration sites, most often expressed as raw abundances or as density measures; while 26% (22) monitored both reef benthic and fish populations. Only one study examined in detail the physical condition of the artificial reefs [17], reporting that between one and five years post-installation the concrete structures in several restoration sites have been completely buried by rubble or destroyed due to poor setting or placement during the installation process.

This diversity of restoration approaches, combined with a lack of ecological monitoring, combines to limit the potential for evaluating success in Indonesia's reef restoration efforts. Whilst many different methods and materials are used, very few approaches seem to have implemented monitoring programmes to understand how coral, fish and invertebrate populations are responding to restoration interventions. Some projects do offer encouraging examples of successful monitoring; for example, there are well-documented increases in coral cover on rock piles in Komodo National Park [8] and on Reef Stars in South Sulawesi [15] - but these projects are the exception rather than the norm (Fig. 4). For future reef restoration initiatives to learn more effectively from each other and share knowledge of best practice, a common approach to monitoring and data sharing is required. To achieve this, reef restoration budgets need to include costs for ecosystem monitoring and data sharing protocols as essential items to evaluate project outcomes. These budgets must also be structured to provide for future monitoring events, in order to allow long-term evaluation of restoration success for the years following restoration interventions. This would facilitate understanding of which restoration practices were most effective for meeting different targets in different socioeconomic and ecological contexts - in turn allowing the formulation of more efficient restoration strategies across the country.

There are several examples of monitoring schemes and tools which might help to achieve more holistic monitoring of reef restoration programmes in Indonesia. For example, the Global Coral Reef Monitoring Network (GCRMN) guides and mobilises monitoring of reef health and bleaching status around the region [18]; this model might be adapted to evaluate the health of reef restoration projects around Indonesia. Additionally, several organisations have published guidelines for designing and implementing monitoring protocols for restoration programmes; for example, the NOAA manager's guide for reef restoration includes guidelines and ideas for monitoring strategies specific to restoration projects [19]. The high number and diversity of Indonesia's restoration projects demonstrate that there is great capacity to carry out restoration work; now developing a similar capacity for monitoring will allow these interventions to be more evidence-led and effective.

3.5. International communication

The vast majority of records in this database were written in Bahasa Indonesia (450 of 533, 84%) and/or published in online Indonesian media outlets (222, 42%). These communication methods are excellent for reaching audiences within Indonesia - and much of the within-country knowledge exchange that has occurred over the past three decades is likely to have been influenced by these media reports. However, these sources of information are largely inaccessible to people and organisations outside of Indonesia's borders, reducing the potential for knowledge exchange with other countries. A recently compiled global

Table 2
Specific topics mentioned by laws and regulations that govern coral reef restoration in Indonesia. This table includes laws (items 1–4), government regulations (items 5–7), presidential regulations (items 8–9) and ministerial regulations from the Ministries of Environment (MoE), Forestry (MoF), and Marine Affairs and Fisheries (MMAF) (items 10–17). Ticks indicate that laws mention the topic denoted by each column. Shaded items (8, 11, 12, 15 and 17) are those that contain the most comprehensive rules and guidelines for coral reef restoration in Indonesia. * * denotes the guideline that describes transplantation (i.e. cutting a piece of live coral for planting/attaching it to an artificial substrate or natural coral rock; Article 26 verse 1d), where it is described as a method for breeding protected and non-protected fish species.

No.	Name of regulation	Reef management, conservation or protection	Reef destruction or damage	Reef rehabilitation or restoration	Organisational responsibility	Artificial reefs	Coral transplantation	Methods for coral restoration	Ecological monitoring
1	Law No. 31/2004 on fisheries (Amended by Law No. 45/2009)	✓	✓	✓	-	✓	-	-	-
2	Law No. 27/2007 on management of coastal area and small islands (Amended by Law No. 1/ 2014)	✓	✓	✓	✓	-	-	✓	-
3	Law No. 32/2009 on environmental protection and management	✓	✓	✓	✓	-	-	-	-
4	Law No. 32/2014 on marine affairs	✓	✓	✓	-	-	-	-	-
5	Government Regulation No. 19/1999 on marine pollution and/or destruction control	-	✓	-	✓	-	-	-	-
6	Government Regulation No. 60/2007 on conservation of fisheries resources	✓	-	✓	-	-	**	**	-
7	Government Regulation No. 27/2021 on effectuation of marine affairs and fisheries	✓	✓	✓	✓	✓	-	-	-
8	Presidential Regulation No. 121/2012 on rehabilitation of coastal area and small islands	✓	✓	✓	✓	✓	✓	-	✓
9	Presidential Regulation No. 63/2015 on Ministry of Marine Affairs and Fisheries	✓	-	✓	✓	-	-	-	✓
10	Ministry of Marine Affairs and Fisheries (MMAF) Ministerial Regulation No. PER 30/MEN/2010 on management and zonation planning for aquatic conservation area	✓	-	✓	-	-	-	-	-
11	Ministry of Forestry (MoF) Ministerial Regulation No. P.48/MenhutII/2014 on procedures for the implementation of ecosystem recovery in nature sanctuary and nature conservation areas	✓	✓	✓	✓	✓	✓	✓	✓
12	MMAF Ministerial Regulation No. 26/2021 on prevention to pollution, prevention to destruction, rehabilitation, and improvement of fisheries resources and the surrounding environments	✓	✓	✓	✓	✓	✓	✓	✓
13	MMAF Ministerial Regulation No. 17/PERMEN-KP/2020 on strategic planning of ministry of marine affairs and fisheries year 2020-2024 (Amended by Ministerial Regulation No. 57/PERMEN-KP/2020)	✓	✓	✓	✓	-	-	-	-
14	MMAF Ministerial Regulation No. 28/2021 on effectuation of marine spatial planning	✓	✓	✓	✓	-	-	-	-
15	Ministry of Environment (MoE) Ministerial Decree No. 4/2001 on coral reef destruction standard criteria	✓	✓	✓	✓	-	✓	✓	✓
16	MMAF Ministerial Decree No. KEP.38/MEN/2004 on general guidelines on coral reef management	✓	✓	✓	✓	-	-	-	-
17	General Director of Marine Spatial Management (MMAF) Decree No. 10/2021 on technical instruction on restocking and rehabilitation of habitat of protected fish species and/or fish species listed in the Convention on International Trade in Endangered Speciesof Wild Fauna and Flora (CITES) Appendices	-	-	✓	✓	✓	✓	✓	✓

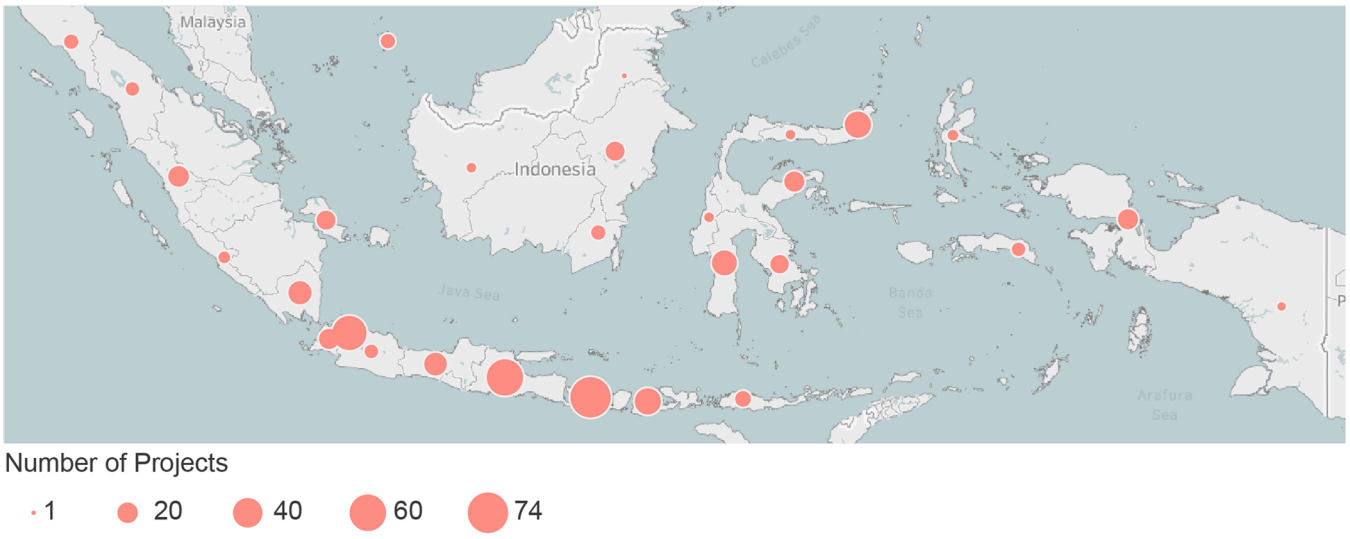

Fig. 1. Indonesia's coral reef restoration projects (1990–2020), aggregated by province. Circles are positioned at the geometric centre of each province; their size is proportional to the number of restoration projects in that province. There are a total of 533 projects in the database. To explore this database further, see the interactive visualisation here.

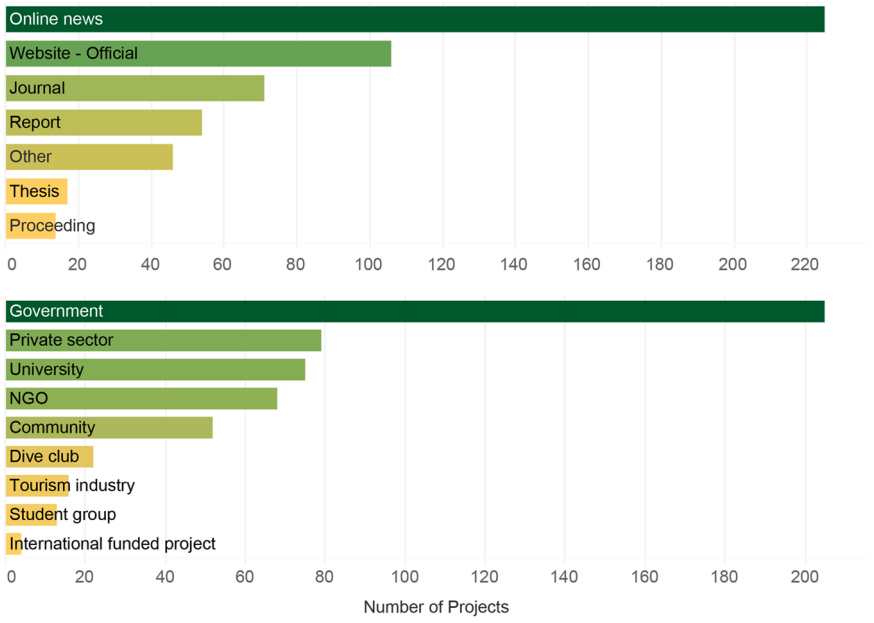

Fig. 2. The a) information source and b) main organiser of each of the 533 Indonesian coral reef restoration projects in the database.

database of restoration projects around the world [9] (www.icriforum.org/restoration/coral-restoration-database) captured only 5% of this study's Indonesian records (27 of 533), probably because it focused only on English-language sources. This highlights the extent to which lessons learned in Indonesian restoration projects are currently difficult to translate around the rest of the world. Indonesia is widely recognised as being the global epicentre of coral reef diversity [1], and the 533 restoration projects documented in this paper now also suggest that the country has the necessary experience to be a world leader in restoration capacity. If Indonesia's abundance of experience in a diverse array of restoration projects could be more effectively shared around the world, this might foster wider collaboration and capacity building, ultimately advancing global understanding and competence in reef restoration practice.

Recent initiatives within Indonesia have started to make encouraging progress in expanding knowledge exchange with international partners. For example, the Coral Triangle Center (CTC) have a training centre in Bali from which they can deliver training and capacity building for partners around South-East Asia (www.coraltrianglecenter.org), Department of Marine Science and Technology at IPB University have recently launched the School of Coral Reef Restoration (SCORES) a working group and knowledge-sharing platform for reef restoration practitioners in Indonesia and around the world (https://fpik.ipb.ac.id/), and Mars Sustainable Solutions provides restoration training to practitioners around the world based on successful methods developed within Indonesia (www.buildingcoral.com). Further progress on international collaborations such as these will ensure that the wealth of knowledge and experience accrued within Indonesia can be valuably disseminated amongst restoration practitioners around the world.

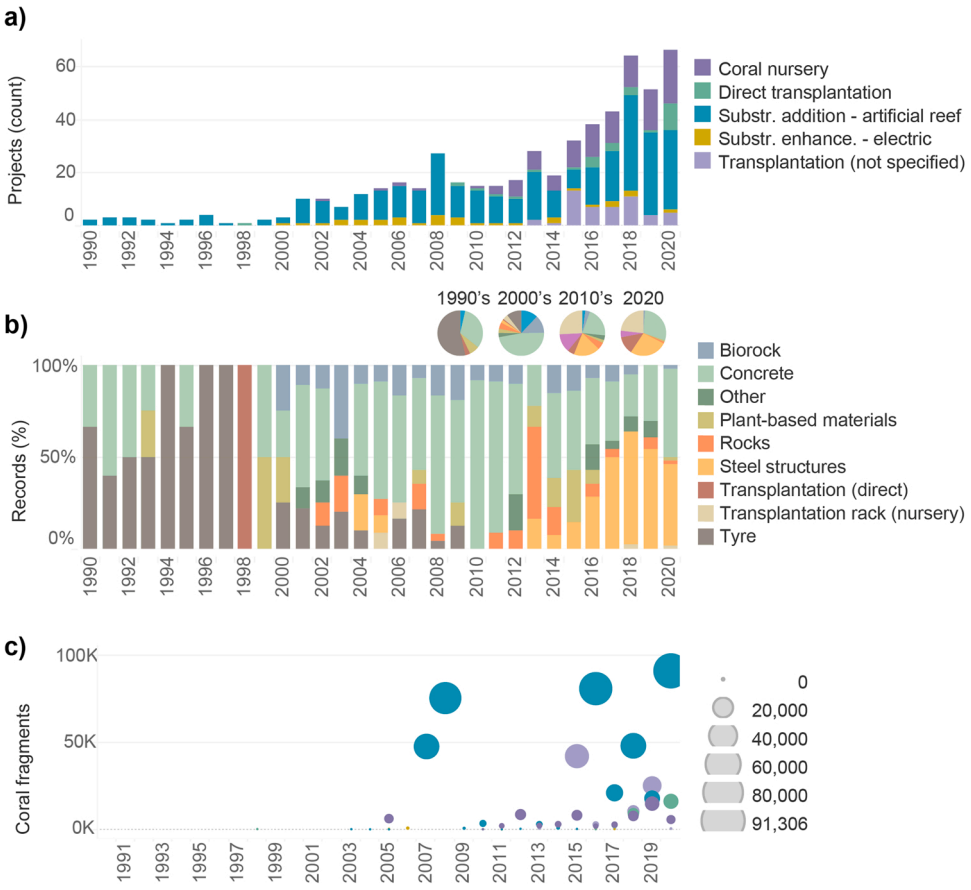

Fig. 3. Temporal trends in Indonesia's coral reef restoration projects. Shown are trends through time in the establishment of restoration projects, split by: a) method of restoration; b) materials used; and c) number of coral fragments installed. To explore the database further, see the interactive visualisation here.

3.6. Future directions

Over the past three decades, Indonesia has accumulated a wealth of practical knowledge regarding reef restoration. The sheer number of projects and outplanted coral fragments outnumber any other country covered in the global restoration review [9]. The extent and diversity of these projects clearly demonstrate Indonesia's potential as a global leader in coral reef restoration. However, Indonesian reef restoration shares many of the same growing pains that have been experienced by coral reef restoration globally, and coastal restoration in general [22].

A large proportion of projects are categorised as artificial reefs (397, 66%), but do not report that any coral fragments have been transplanted onto the reef, or that the reef is being maintained in any way. In the best-case scenario, these artificial reefs can act as fish-attracting devices by increasing structural complexity in the short-term [23], and act as settlement substrates for recruiting corals in the long-term [24]. However, when placed in sub-optimal locations (i.e. where no coral reef previously existed, or natural recruitment is low) these sites run the risk of being nothing more than underwater refuse heaps. Consistent monitoring and appraisal must be carried out to ensure that artificial reefs constructed in the name of coral restoration are functioning effectively, rather than as underwater structures that play no active role in regenerating coral populations.

Further, there appears to be an over-representation of records in the dataset that are categorised as coral nurseries (19% overall), while studies describing outplanting are much more scarce (5%) suggesting that these nursery racks are not an intermediate step towards outplanting corals, but rather a permanent structure. If Indonesia is to move towards a coral restoration programme that achieves measurable, ecologically meaningful outcomes on coral reefs at a nation-wide scale, it is imperative that objectives focus on holistic reef recovery rather than just numbers of corals grown in temporary or artificial nurseries. Ecological metrics must be incorporated into each step of the lifecycle of restoration projects. Several recent publications can serve as guides to help achieve these goals: for example, by outlining high-level steps to improve coral restoration in general [16]; guide managers through the steps of planning restoration projects [19]; providing suggestions for monitoring [25]; and highlighting the importance of including social metrics in the planning and evaluation of restoration success [13,26].

The barriers to knowledge sharing and the lack of appropriate objectives and monitoring described in this review have the potential to prevent Indonesia from meeting its potential as a global leader in coral reef restoration. To address these issues, future projects should include: 1) explicit objectives, 2) long-term monitoring of ecological outcomes, and 3) improved knowledge exchange with the international scientific and restoration community.

4. Conclusions

Indonesia's coral reefs are amongst the most species-rich in the world, but also face exceedingly high levels of local anthropogenic pressure. When combined with threat mitigation (e.g. improved water quality, cessation of blast fishing, climate change mitigation), reef restoration is likely to play a valuable role in the management of these exceptionally diverse and threatened ecosystems. Indonesia's policy framework encourages an unusually high diversity of participation in restoration activities, with low levels of centralised regulation compared to other countries. This has led to diverse involvement in a high number of restoration projects across the country, organised by a multi-sector group of practitioners using a wide range of methods and materials.

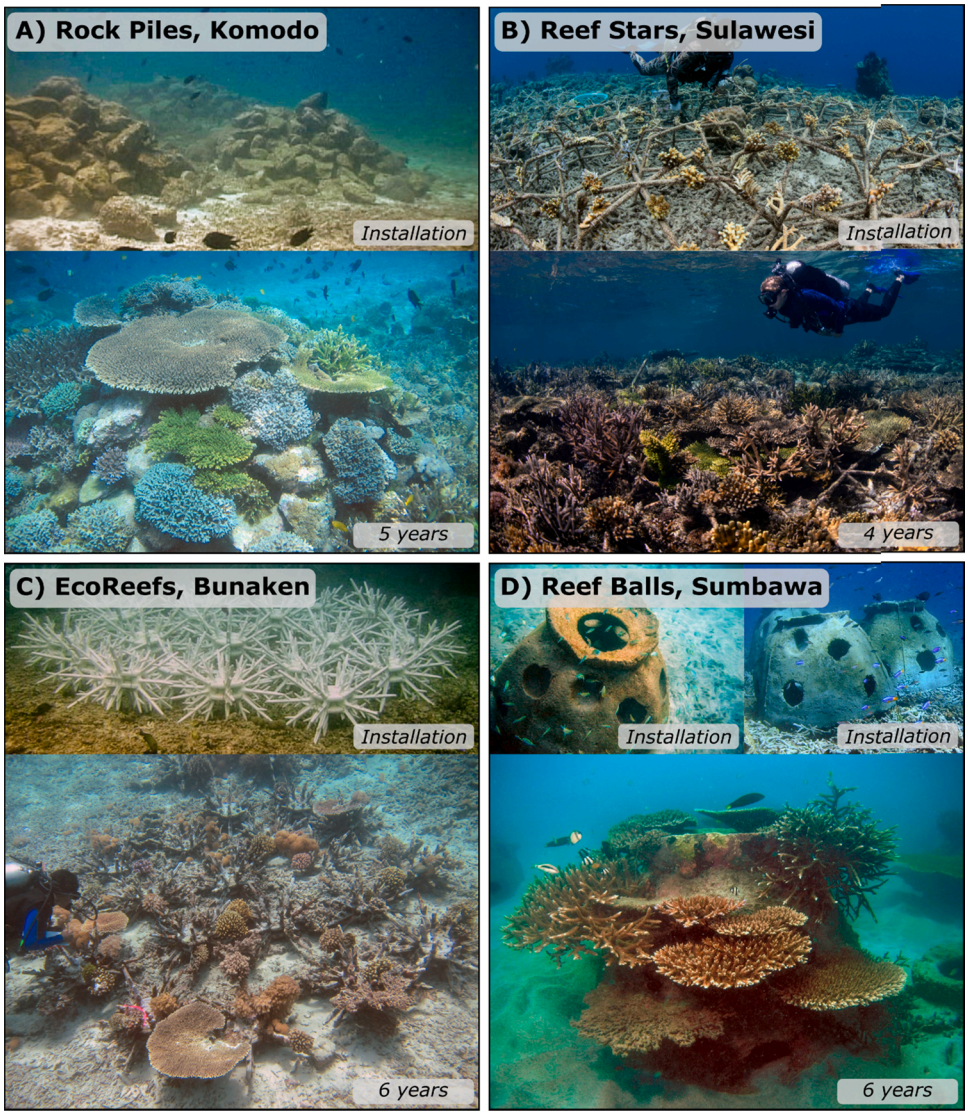

Fig. 4. Examples of coral reef restoration techniques used in Indonesia. Shown are A) Rock piles at Komodo National Park, East Nusa Tenggara [8], B) Mars Reef Stars at South Sulawesi [15], C) EcoReefs at Bunaken National Park, North Sulawesi [20] and D) Reef Balls at Sumbawa, West Nusa Tenggara [21]. Each technique is shown at the point of installation and after several years of successful coral growth. Note that these pictures represent 'best-case' outcomes, and the authors do not suggest that all projects using specific techniques have had the same success. Photo credits: Helen E. Fox (A), The Ocean Agency (B), Mark V. Erdmann and Tries B. Razak (C) and PT. Amman Mineral Nusa Tenggara (D).

However, significant challenges remain for Indonesia to meet its potential as a world leader in coral restoration. With greater efficacy in meeting target-driven outcomes, consistency in ecological monitoring, and intentionality in global knowledge exchange, Indonesia's restoration projects could become a transformative resource for the region and an example for the world to follow.

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CRediT authorship contribution statement

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Declaration of interest statement

All authors declare no conflicts of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104940.

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