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A systematic review of mangrove restoration studies in Southeast Asia: Challenges and opportunities for the United Nation's Decade on Ecosystem Restoration

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Mangroves provide valuable ecological and socio-economic services. The importance of mangroves is particularly evident in Southeast (SE) Asia where the most extensive and diverse forests are found. To recover degraded mangroves, several SE Asian countries have implemented restoration programs. However, to date, there has been no systematic and quantitative synthesis on mangrove restoration studies in the region. Here, we provide a bibliometric-based analysis of mangrove restoration to provide understanding on trends and future directions needed to meet biodiversity and restoration targets in the region. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, we analyzed 335 articles (249 articles with ecological attributes; 86 articles with social attributes) published until February 2022 from Scopus and Web of Science databases. Mangrove restoration studies with ecological and social attributes started around the early 1990s mostly from Indonesia, Thailand, Malaysia, Vietnam, and the Philippines. Majority of SE Asian countries have stronger collaboration to western countries rather than within the region. Reasons for restoration vary per country, but mostly were intended to rehabilitate damaged mangroves. Direct planting was the most common restoration method used while hydrological rehabilitation was less practiced. Research on ecological attributes were dominated by biodiversity-related studies focused on flora and fauna, and less on other ecosystem services (e.g., coastal protection, fisheries production, etc.). Studies with social attributes only accounted for <30% of the publications, mostly on topics related to ecological economics. Although mangrove restoration studies are apparent, some thematic restoration foci are needed. We propose priority research topics to help achieve the biodiversity and restoration targets by 2030.

KEYWORDS

mangroves, Southeast Asia (SE Asia), ASEAN network, restoration, ecology, social, policy and governance, bibliometric analysis

Introduction

Mangroves provide a range of ecosystem services including coastline protection (Hochard et al., 2019), carbon storage and sequestration (Donato et al., 2011), and provision of habitat for wildlife and commercially important species (Friess et al., 2020). Mangroves also provide socio-economic benefits like support to livelihood (e.g., ecotourism; Spalding and Parrett, 2019), aqua-silviculture, and forest products (Orchard et al., 2016). Despite these services, reports on mangrove losses at global (Romañach et al., 2018) and regional scales (Richards and Friess, 2016) are apparent.

Southeast Asia (SE Asia) accounts for the world's largest (32.2%; 43,767 km^2) and most diverse mangrove forests (>50 species; Spalding et al., 2010), but unfortunately also has the most extensive mangrove loss (Spalding and Leal, 2021; Bhowmik et al., 2022). Mangrove loss varies regionally, but in many countries the main drivers are the rapid expansion of aquaculture ponds (for fish and shrimp in Vietnam, Indonesia, Thailand, and Myanmar; Luo et al., 2022; for fish in the Philippines; Primavera, 1995), rice production (in Myanmar), and oil palm expansion (in Malaysia and Indonesia; Richards and Friess, 2016). At country-level, Myanmar is the primary mangrove loss hotspot (with 27.6% loss between 2000 and 2014; Estoque et al., 2018) followed by the Philippines (10.5% loss from 1990–2010; Long et al., 2014).

Mangrove losses result in biodiversity lost as well as reduction of ecosystem services (Sannigrahi et al., 2020). Mangroves are regarded as a high-priority ecosystem in a number of international conservation initiatives like the Global Mangrove Alliance (GMA; Bunting et al., 2022). Several international commitments and targets have been set to bolster biodiversity conservation and ecosystem restoration (da Rosa and Marques, 2022), for example, the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement, and the Convention on Biological Diversity (CBD) Aichi Targets. The Association of Southeast Asian Nations (ASEAN) member states are signatories to these international commitments (ACB, 2017). While these programs may indicate positive mangrove conservation and restoration strategies, restoration success on the ground is not evenly distributed (Friess et al., 2020) nor systematically reported.

SE Asian countries have been doing mangrove restoration and management for decades. For example, the Matang Mangrove Forest in Peninsular Malaysia was gazetted in 1906 as a permanent forest reserve (Hamdan et al., 2014). In the Philippines, mangrove planting dates back to the 1930s for the supply of construction posts for fish weirs and fuel (Walters, 2003). In Indonesia, mangrove rehabilitation started in the 1930s for timber production (Ilman et al., 2011). In Vietnam, direct planting of fastly-growing *Rhizophora apiculata* was practiced in 1978 on areas affected by the herbicide Agent Orange during the war (Hong, 2001). Clearly, early mangrove rehabilitation practices were focused on establishing mangrove cover for short-term economic gains (i.e., fuel, timber; Suman, 2019). While these practices contributed to the recovery of forest cover, it may no longer be sufficient to address current and future needs (e.g., biodiversity loss, climate-related disturbances, etc.; Andradi-Brown et al., 2013).

Mangrove restoration is a nature-based solution (NbS) advocated to conserve/protect biodiversity and in climate change adaptation and mitigation (CCAM) programs (Zari et al., 2019). However, most restoration programs rarely integrate ecological components (Lewis, 2000) and its social aspects are often neglected (Egan et al., 2011). Despite the proliferation of massive mangrove restoration efforts across SE Asia, a systematic assessment and documentation of its outcomes are still lacking. With different restoration objectives and techniques employed, the general effectiveness of restoration on ecological attributes is not clear (Andradi-Brown et al., 2013) nor whether management efforts are successful or not (Salmo, 2021).

Ecological restoration should aim for substantial ecosystem recovery relative to an appropriate reference model including species composition, community structure, and physical conditions (Gann et al., 2019). For restoration science and practice to advance, it is necessary to learn from previous restoration programs such that failures are minimized, and success is achieved. The experiences in mangrove restoration in SE Asia provide an opportunity to advance mangrove restoration in the region. Hence, in this study, we aim to collate, analyze, and synthesize learnings from mangrove restoration research and identify themes needed to meet the biodiversity and restoration targets in SE Asia.

Methods

We systematically searched on mangrove restoration studies in SE Asia. The term "rehabilitation" is often used interchangeably with "restoration" (Andradi-Brown et al., 2013; Guan et al., 2019). In this context, we used "restoration" as an umbrella term covering a range of intervention activities applied on mangrove forests, including plantation, protection allowing natural regeneration, and habitat restoration (Andradi-Brown et al., 2013). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was used for study selection and inclusion (Moher et al., 2009). All analyses were performed after characterization of suitable studies and mapped guidance following the PRISMA 2009 checklist (Supplementary Table 1).

Publications on mangrove restoration studies in SE Asia were identified from Elsevier's Scopus and Clarivate Analytics' Web of Science (WOS) Core Collection databases through two iterative searches. The first search was conducted on October 16, 2021, using the query words "mangrove* AND (restoration OR rehabilitat* OR plantation) AND ("southeast asia" OR Philippine* OR Indonesia OR Malaysia OR Thailand OR Vietnam OR Singapore OR Cambodia OR Myanmar OR Brunei). The detailed query is reported in Supplementary Table 2. Member countries of the Association of Southeast Asian Nations (ASEAN) were specifically added in the query terms to gather researches per individual country. We later updated our datasets and conducted a second search on February 28, 2022, without date restriction to include all relevant publications (Figure 1). The collections from the two databases were merged following Caputo and Kargina (2021). In total, 1,578 publications were retrieved (Scopus: 806; WOS: 772) but only 668 records were retained after duplication removal.

A screening process was conducted based on the selection criteria below:

Criterion 1: We focused on research articles about mangrove restoration with ecological attributes in SE Asia, in general. These included studies from individual ASEAN member countries as well as those involved in more than one country as study sites.

Criterion 2: Articles that described the study sites and how mangrove restoration was done (i.e., direct planting, protection allowing natural regeneration, hydrological rehabilitation, or incorporation of coastal engineering methods). Restoration studies that showed comparison between restored and natural/intact stands as reference sites were also considered.

Criterion 3: Articles classified with social attributes. These included topics on valuation studies, ecotourism potential, ecological economics, environmental education, community engagement, and perception studies.

Criterion 4: Quantitative studies that reflect empirical data on ecological functions. Studies that include assessment metrics related to ecological functions (i.e., biodiversity of flora and fauna, above and below ground biomasses, carbon storage and sequestration, among others) were included. Studies conducted in microcosms, greenhouses, and experimental tanks were excluded.

The first screening involved titles and abstracts for inclusion, resulting to 461 documents considered for full-text screening. In total, 335 articles were included for synthesis (Supplementary Table 3). We further categorized the articles based on the primary objectives for restoration, the restoration approaches used, the ecological attributes assessed, and the social-related attributes reported (Supplementary Table 4). Review articles, editorial materials, conference proceedings, and non-English documents were excluded. Conference proceedings refer to documents with available abstracts only while conference papers are publications with full text articles. Both authors worked independently in the screening and selection of documents for inclusion or exclusion. The extracted data were then validated to check accuracy.

We utilized the Bibliometrix package (Aria and Cuccurullo, 2017) in R studio for bibliographic analysis. Quantitative indices related to scientific productivity, topical trends, and collaboration networks among countries, institutions, and authors were analyzed (Supplementary Table 5). We used the

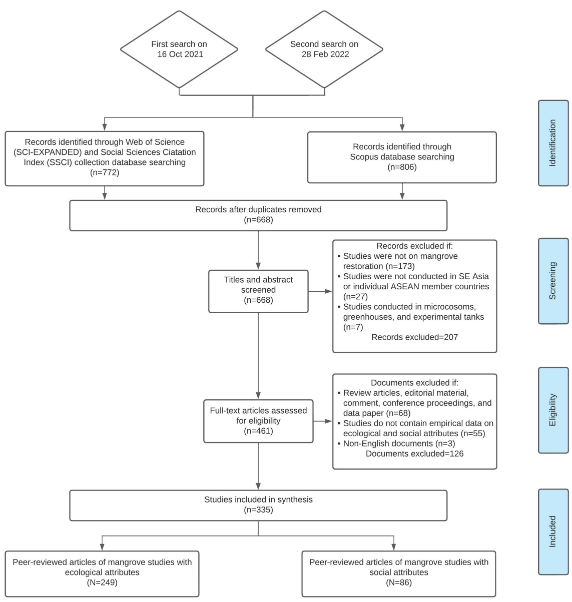

FIGURE 1
PRISMA (Preferred Reporting Items for Systematic Reviews) flow diagram of bibliographic analysis in the systematic review.

web-interface Biblioshiny and data visualization packages from RStudio for the graphical layouts.

Results and discussion

Publication performance and characteristics

Out of 335 total articles compiled, 249 articles (74%) have ecological attributes, and 86 articles (26%) have social attributes. Records on mangrove restoration-related articles in SE Asia started around the 1970s. However, research with ecological and social attributes only appeared in the 1990s (Figure 2). From 1972-2010, restoration records were published at an average of six records per year and greatly increased to 47 per year starting 2011. In 2021, 87 records were published, the highest number of publications per year recorded so far, with topics related to biodiversity (24%), monitoring of land cover changes using remote sensing (17%), and carbon storage and sequestration (14%).

The 249 articles with ecological attributes had an average of 14.2 citation per article and 1.6 citation per article per year. The dataset was composed of articles (212, 85% of the total) and conference papers (37; 15%). Articles with ecological attributes only commenced in 1990 with the work of Martin et al. (1990) being the first and only article recorded in that year. The study investigated the recolonization of *Avicennia* in an oil-polluted mangrove in the east coast of Borneo Is., Indonesia. Parallel analysis on studies with social attributes started in 1993 with the works of Bennett and Reynolds (1993) and Rittibhonbhun et al. (1993). Bennett and Reynolds (1993) investigated the economic and employment values of mangrove forests in Sarawak Mangroves Forest Reserve, Malaysia while the work of Rittibhonbhun et al. (1993) presented the progression of community-based mangrove management and rehabilitation in Trang, Thailand.

The field of ecological restoration (also synonymously with "Restoration Ecology") was developed during the 1980s (Guan et al., 2019). In SE Asia however, articles related to mangrove restoration were only reflected in the early 1990s, at least from the databases accessed in this study. Some articles may have used different terms other than "restoration" or "rehabilitation" that may underestimate the number of publications reported in this study. The number of articles gradually increased from 1990-2009, then increased to 17 per year since 2010 (Figure 2). Starting 2015, mangrove publications increased at 29% annually with topics related to management approaches (22%), carbon storage (19%), coastal protection (12%), and erosion control and sediment stabilization (9%; Table 1). Topics on greenhouse gas fluxes, species interaction networks, and remote sensing applications emerged in 2017 (Table 1; Figure 7).

A total of 119 different journals published mangrove restoration studies with ecological attributes in SE Asia. The top 20 most relevant journals were dominated by international journals which accounted for 39% of the total, i.e., *IOP Conf. Ser. Earth Environ. Sci.* (7.4%), *Forest Ecology and Management* (3.5%), *Biodiversitas* (3.3%), *Ocean and Coastal Management* (3.3%), and *Estuarine, Coastal, and Shelf Science* (2.9%). Among the 20 most relevant journals, the *Malaysian Forester* (Malaysia) and *Biodiversitas* (Indonesia) were the only country-based journals within SE Asia (Figure 3). Based on Total Citations (TC), *Estuarine, Coastal, and Shelf Science* was the most cited

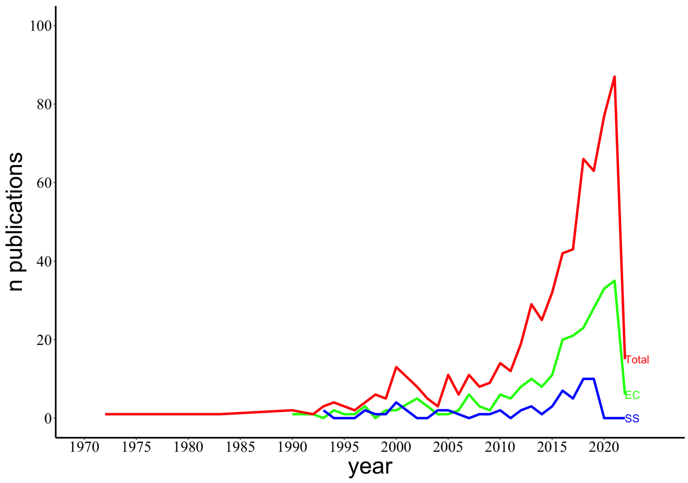

FIGURE 2
Number of documents published annually related to mangrove restoration in SE Asia. Total - all document types; EC, peer-reviewed articles with ecological attributes; SS, peer-reviewed articles with social attributes.

TABLE 1 Most frequent words used in titles, abstracts, and keywords on mangrove studies with ecological attributes in SE Asia.

Title			Abstract			Keywords		
Words	Occurrences	%	Words	Occurrences	%	Words	Occurrences	%
carbon	34	2.0	species	387	1.5	restoration	32	3.5
restoration	31	1.8	carbon	205	0.8	rehabilitation	24	2.6
coastal	29	1.7	coastal	203	0.8	biodiversity	14	1.5
rehabilitation	29	1.7	natural	201	0.8	forest	11	1.2
diversity	20	1.2	soil	177	0.7	plantation	11	1.2
structure	18	1.1	restoration	168	0.6	biomass	8	0.9
Rhizophora	17	1.0	rehabilitation	164	0.6	blue carbon	8	0.9
ecosystem	16	0.9	ecosystem	149	0.6	climate change	8	0.9
plantation	15	0.9	biomass	132	0.5	diversity	8	0.9
restored	15	0.9	*Rhizophora*	120	0.5	coastal erosion	7	0.8
soil	15	0.9	vegetation	112	0.4	deforestation	7	0.8
community	13	0.8	seedlings	105	0.4	aquaculture	6	0.7
species	13	0.8	diversity	98	0.4	conservation	5	0.5
abandoned	12	0.7	stands	96	0.4	erosion	5	0.5
biomass	12	0.7	planted	95	0.4	remote sensing	5	0.5
coast	12	0.7	structure	94	0.4	sediment	5	0.5
dynamics	12	0.7	density	93	0.4	stand structure	5	0.5
vegetation	11	0.6	plantations	86	0.3	coastal protection	4	0.4
composition	9	0.5	erosion	85	0.3	*Rhizophora*	4	0.4
erosion	9	0.5	management	81	0.3	carbon sequestration	3	0.3

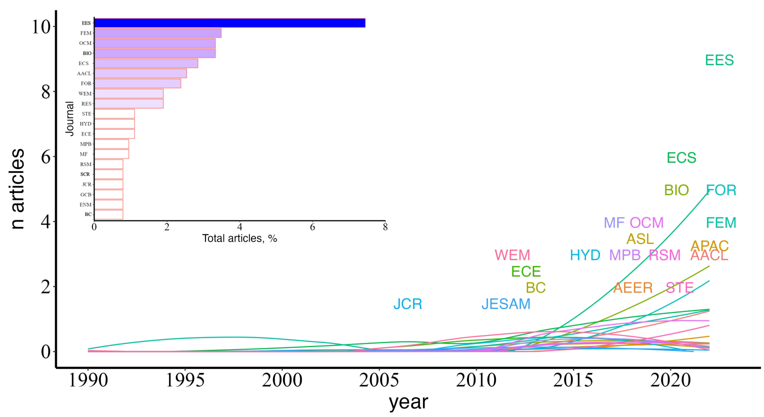

FIGURE 3
Most relevant sources that published mangrove restoration studies with ecological attributes from 1990-2022 (Inset: Most cited sources based on Total Citations). The names of the sources (journals) are placed in years when the highest number of manuscripts was published. Early restoration studies were limited to only five journals but steadily increased after 2015 (> 10 journals). Complete names of sources' letter codes are available in Supplementary Table 6.

journal (>500 citations) followed by *Forest and Ecology Management* (259 citations) and *Journal of Biogeography* (201 citations; Table 2).

The top 20 most relevant documents were dominated by SE Asian-based authors (55%). This indicates a growing number of experts on mangrove restoration in the region. The most relevant document was published in *Ocean and Coastal Management* with 15 citations per year (Lai et al., 2015; Table 2). This work focused on the potential of coastal engineering to mitigate the impact of coastal transformations in Singapore. The study of Giri et al. (2008) published in *Journal of Biogeography* ranked second with 14 citations annually,

TABLE 2 Most frequently cited articles on mangrove studies with ecological attributes in SE Asia and the top cited document per country.

Paper	Author/s and Publication Year	Journal	Citation per year	Total Citation	Country-specific cited documents
The effects of urbanisation on coastal habitats and the potential for ecological engineering: A Singapore case study	Lai et al., 2015	Ocean and Coastal Management	15	121	–
Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia	Giri et al., 2008	Journal of Biogeography	14	203	IDN, THA, MYS
Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami	Tanaka et al., 2007	Landscape and Ecological Engineering	12	196	THA
Coastal erosion and mangrove progradation of Southern Thailand	Thampanya et al., 2006	Estuarine, Coastal and Shelf Science	10	175	THA
Is Matang Mangrove Forest in Malaysia sustainably rejuvenating after more than a century of conservation and harvesting management?	Goessens et al., 2014	PLoS One	8	75	MYS
Carbon stocks in artificially and naturally regenerated mangrove ecosystems in the Mekong Delta	Nam et al., 2016	Wetlands Ecology and Management	8	57	VNM
Mangrove blue carbon stocks and dynamics are controlled by hydrogeomorphic settings and land-use change	Sasmito et al., 2020	Global Change Biology	8	23	IND
Mangrove rehabilitation and intertidal biodiversity: A study in the Ranong Mangrove Ecosystem, Thailand	Macintosh et al., 2002	Estuarine, Coastal and Shelf Science	8	158	THA
Rehabilitating mangrove ecosystem services: A case study on the relative benefits of abandoned pond reversion from Panay Island, Philippines	Duncan et al., 2016	Marine Pollution Bulletin	7	47	PHL
Defining eco-morphodynamic requirements for rehabilitating eroding mangrove-mud coasts	Winterwerp et al., 2013	Wetlands	7	65	IDN, THA, PHL
Mangrove restoration without planting	Kamali and Hashim, 2011	Ecological Engineering	6	76	MYS
The impacts of degradation, deforestation and restoration on mangrove ecosystem carbon stocks across Cambodia	Sharma et al., 2020	Science of The Total Environment	6	19	–
Vegetation and soil characteristics as indicators of restoration trajectories in restored mangroves	Salmo et al., 2013	Hydrobiologia	6	61	PHL
Vegetation regeneration in a sustainably harvested mangrove forest in West Papua, Indonesia	Sillanpää et al., 2017	Forest Ecology and Management	5	35	IDN
Loss and recovery of carbon and nitrogen after mangrove clearing	Adame et al., 2018	Ocean and Coastal Management	6	28	MYS
An integrated approach to coastal rehabilitation: Mangrove restoration in Sungai Haji Dorani, Malaysia	Hashim et al., 2010	Estuarine, Coastal and Shelf Science	6	72	MYS
Community structure dynamics and carbon stock change of rehabilitated mangrove forests in Sulawesi, Indonesia	Cameron et al., 2019a	Ecological Applications	6	22	IDN
Hydroperiod, soil moisture and bioturbation are critical drivers of greenhouse gas fluxes and vary as a function of landuse change in mangroves of Sulawesi, Indonesia	Cameron et al., 2019b	Science of The Total Environment	5	21	IDN
Mangrove forests store high densities of carbon across the tropical urban landscape of Singapore	Friess et al., 2016	Urban Ecosystems	5	34	–
Site-specific and integrated adaptation to climate change in the coastal mangrove zone of Soc Trang Province, Viet Nam	Schmitt et al., 2013	Journal of Coastal Conservation	5	47	–
Carbon sequestration and fluxes of restored mangroves in abandoned aquaculture ponds	Sidik et al., 2019	Journal of the Indian Ocean Region	4	17	IDN

*IDN, Indonesia; VNM, Vietnam; MYS, Malaysia; THA, Thailand; PHL, Philippines.

followed by the work of Tanaka et al. (2007) with 12 citations per year. There were also variations on the most cited documents on a per country basis. For example, the work of Giri et al. (2008) was included in the top 10 most relevant documents for Indonesia, Thailand, and Malaysia. On the other hand, only the work of Nam et al. (2016) appeared for Vietnam. For the Philippines, the most cited sources were the articles of Salmo et al. (2013); Winterwerp et al. (2013), and Duncan et al. (2016). The variations in citation patterns is likely due to the different needs of the country, ecological conditions of the restored sites, or accessibility of the paper. Open access (OA) publications can maximize the benefits of scientific findings for researchers, practitioners, and policy-makers (Iyandemye and Thomas, 2019) resulting in a minimized research-implementation gap in restoration research (Zhang et al., 2018). While positive growth on OA publications have been reported over time, institutional license or publisher's fee is still required for more than 50% of newly-published research (Piwowar et al., 2018). These fees can impede researchers and individuals from low-income countries (Matheka et al., 2014) such as most SE Asian countries to access and publish OA manuscripts.

More than 200 institutions contributed to mangrove restoration studies with ecological attributes. The University of Malaya (UOM) was the most relevant institution in terms of article count (n= 40; Figure 4A). This institution accounted for 16% of the articles, which is approximately double that of the second-ranked institution. The National University of Singapore (NUS), Kasetsart University (KU), the University of Queensland (UQ), and Ateneo de Manila University (ADMU) were the top institutions with 20, 18, 15, and 14 articles, respectively. Among the top 20 most relevant institutions, eight institutions are based outside SE Asia, including Australian and Japanese institutions like UQ, Charles Darwin University (CDU), James Cook University (JCU), and Ehime University. These institutions are regarded as the most productive institutions in terms of mangrove research (Ho and Mukul, 2021).

Over 2,000 authors contributed to mangrove publications in SE Asia. The top five most relevant authors (based on fractionalized article count) were Friess (NUS-Singapore, 8.4), Primavera (ZSL-Philippines, 6.7), Basyuni (USU-Indonesia, 5.6), Salmo (UQ/ADMU/UP-Philippines, 4.0), and Duke (JCU-Australia, 2.7; Figure 4B). Most of the authors included in the list were from SE Asia (65%) and were affiliated with the top 20 most relevant institutions (Figure 4A). Six articles in the top 20 most cited documents (Table 2) were authored by SE Asian authors (Figure 4B) indicating a growing number of experts on mangrove restoration with high scholarly impact.

Based on the country affiliations of corresponding authors, articles were categorized as either single country publications (SCP; reflecting intra-country publication) or multiple country publications (MCP; Figures 5A, B). Malaysia has the highest SCP (62%) while Indonesia, Thailand, Vietnam, and the Philippines have 27 to 44% (Figure 5A). Countries with the highest MCPs were Japan (81%), Australia (93%), Singapore (80%), Philippines (73%), and Vietnam (69%). Thailand and Indonesia have 60% and 56% MCPs, respectively. Among SE Asian countries, Malaysia has the lowest MCP (38%; Figure 5B). The MCPs may indicate the extensive collaboration among countries through research and scholarship grants which provide funding for research, training, and restoration initiatives.

Thematic evolution, topic trends, and collaboration dynamics

The mangrove restoration studies with ecological attributes were dominated by Indonesia (34%), Thailand (16%), Vietnam (16%), Malaysia (15%), and Philippines (13%). Similar pattern was observed in articles with social attributes although the sequence among countries varied: Indonesia (43%), Philippines (20%), Vietnam (15%), Thailand (14%), and Malaysia (4%).

Globally, SE Asia contributes to almost a third of the world's mangrove extent (Spalding and Leal, 2021), with vast covers in Indonesia (2,801,795 ha) and Malaysia (515,743 ha; Bunting et al., 2022). Indonesia is the most productive country in terms of article count (Figures 6A-C). Notably, Myanmar, the third country with highest mangrove cover (496,686 ha; Bunting et al., 2022), has fewer publications (1.6%) over countries with smaller mangrove cover (i.e., Philippines - 260,993 ha, 13%; Thailand - 223,137 ha, 16%; Vietnam - 157,028 ha, 16%; Bunting et al., 2022). The number of published documents per country reflects its importance in a given research field (Guan et al., 2019).

The keyword *plantation* was one of the earliest topics of interest from 2006 until 2019, followed by *deforestation,*

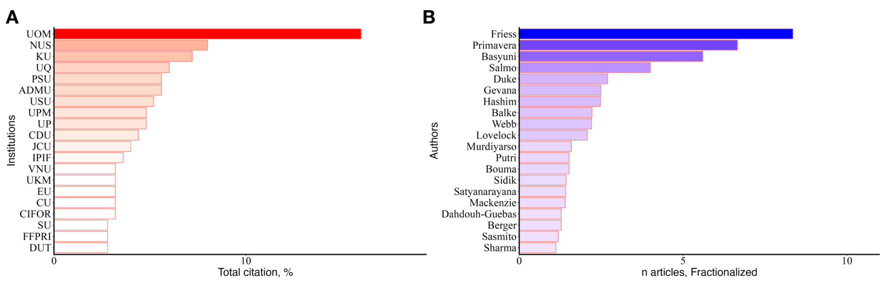

FIGURE 4
Most relevant **(A)** institutions and **(B)** authors in restoration manuscripts in SE Asian mangroves. Most relevant authors were based on fractional authorship which quantifies the individual author's contributions to a published set of papers. Complete names of most relevant institutions are available in Supplementary Table 7.

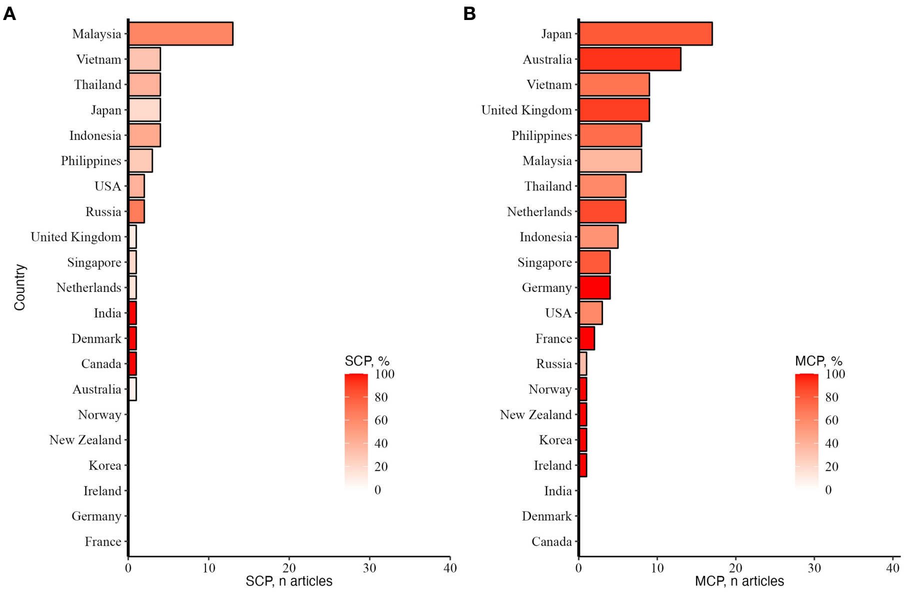

FIGURE 5
Top countries involved in mangrove restoration studies in SE Asia as **(A)** single-country publications (SCP) and **(B)** multiple-country publications (MCP).

rehabilitation, and restoration (Figure 7). Starting 2014, *disturbance*-related topics on erosion and climate change became more frequent. In recent years, more studies used the keywords *blue carbon* and *remote sensing*. Parallel analysis on the most frequent terms associated with titles revealed the words *carbon, restoration, coastal, rehabilitation*, and *diversity* as the most used words (Table 1). This reflects interest in mangrove ecosystem services like coastal protection and carbon storage. With the extreme climatic events (primarily tsunami and typhoons) that affected many countries in SE Asia, protection of mangroves and other coastal vegetation were highlighted (Kathiresan and Rajendran, 2005; Primavera et al., 2016) resulting in the integration of mangrove restoration in coastal rehabilitation plans (Albers and Schmitt, 2015).

The words *natural* and *plantation* were also frequently used in abstracts and keywords (Table 1). Based on the standards of the Society for Ecological Restoration (SER), the use of reference systems (usually referred to as natural mangrove stands;

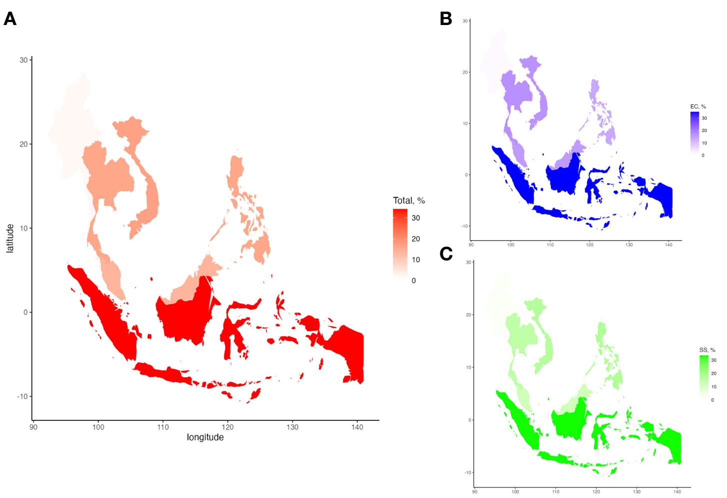

FIGURE 6
Geographical distribution of publications related to mangrove restoration in SE Asia. **(A)** Total - all document types; **(B)**. EC, peer-reviewed articles with ecological attributes; **(C)**. SS, peer-reviewed articles with social attributes

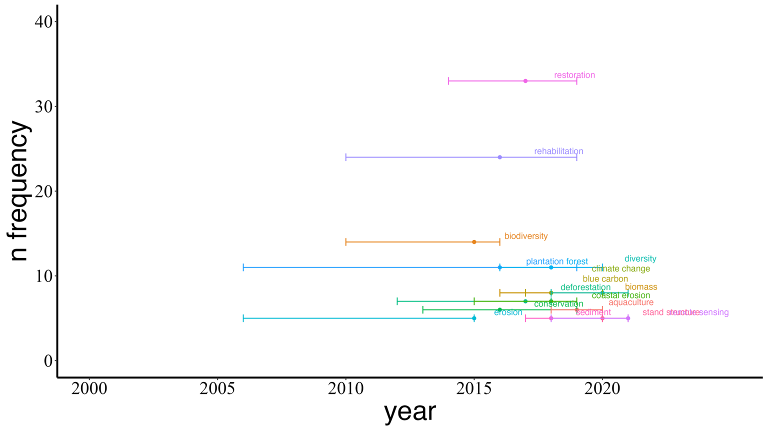

FIGURE 7
Topic trends using author's keywords over the years.

Salmo et al., 2013) in restoration studies, is vital in framing ecological restoration plans and in assessing the success or failure of restoration efforts (Gann et al., 2019). Similarly, analysis on thematic change and evolution using abstracts and titles revealed that topics related to *Rhizophora*, ponds, restoration and seedlings were the foci for the period 1990-2000 (Figure 8). Based on abstract evolution trends, *restoration* studies (1990-2000) evolved to include natural stands (2002-2010) as reference systems. In title evolution trends, the words *rehabilitation* and *plantation* diversified to themes like *diversity, structure*, and *carbon*. Various institutions and government agencies organized mangrove replanting and rehabilitation activities as natural barriers to natural disasters (Barbier, 2007; Baird and Kerr, 2008). Mangroves and other coastal wetlands (i.e., seagrass meadows and tidal salt marshes) are regarded as "blue carbon ecosystems" because of their ability to sequester and store large amounts of carbon (Howard et al., 2017). Salmo and Gianan (2019) reported that disturbances (e.g., catastrophic typhoons) contribute to massive changes in stocks and rates of carbon sequestration. Hydrological alteration in abandoned fishponds was also reported to increase carbon recovery (Matsui et al., 2010).

Research collaboration enables countries with limited experts, experience, and resources to produce impactful studies with other countries (Zhang et al., 2018). Country collaboration networks showed variations of connections between and among SE Asian countries. Among the SE Asian countries, Indonesia (IDN), Malaysia (MYS), Singapore (SGP), Philippines (PHL), Thailand (THA), and Vietnam (VNM) have established networks with the USA, Australia, Netherlands, and to some extent with China. Generally, there are stronger collaborations between SE Asian countries and western countries than among SE Asian countries (Figures 9A-C). In terms of authors' network, SE Asian prolific authors like Friess, Basyuni, Murdiryaso, Primavera, Salmo, and Sasmito have established collaborative networks with other authors (Figure 4B). Similarly, SE Asian research universities (NUS, UP, VNU, Kasetsart, and UOM), non-government organizations (Center for International

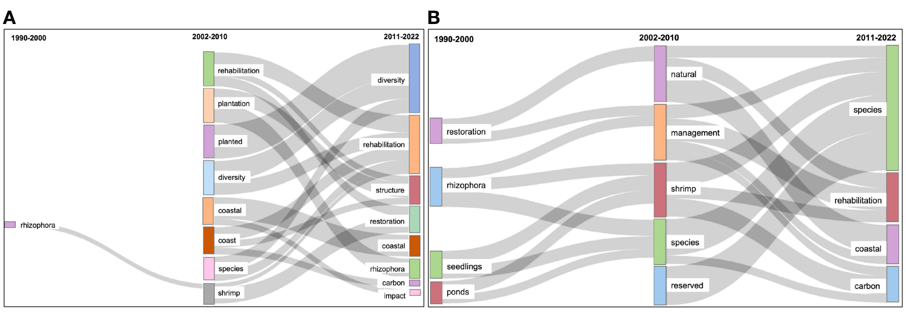

FIGURE 8
Thematic evolution using **(A)** titles and **(B)** abstracts.

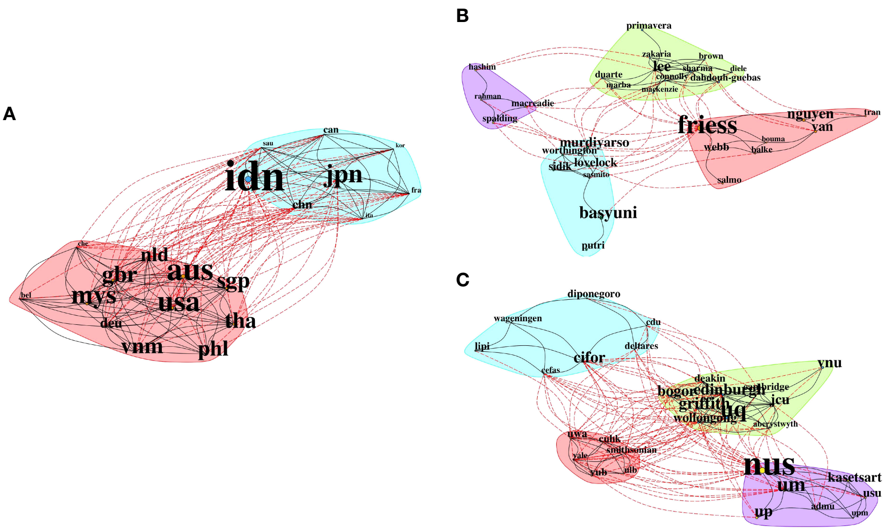

FIGURE 9
Collaboration network by **(A)** countries, **(B)** authors, and **(C)** institutions on mangrove restoration studies with ecological attributes in SE Asia. Country ISO and institutional codes are available in Supplementary Table 8.

Forestry Research [CIFOR], Centre for Environment, Fisheries and Aquaculture (CEFAS), and research institutions like Deltares showed different clusters of networks with western institutions.

Recovery of mangrove areas as drivers for mangrove restoration studies

Threats to mangrove loss (Richards and Friess, 2016) resulting in fragmentation (Bryan-Brown et al., 2020) vary in different SE Asian countries. Coastal lands are high-valued areas for aquaculture, agriculture, settlement, and infrastructure projects for harbors and industries in SE Asia (Slamet et al., 2020). Mangroves, mostly located in coastal fringes, are relatively accessible and always subjected to coastal development pressures (Thakur et al., 2021). Most restoration and rehabilitation programs were implemented to recover mangrove cover. Overall, most of the restoration studies in the region were in response to problems associated with mangrove conversion to aquaculture (58%), coastal erosion (31%), and natural disaster (10%; Table 3). In Indonesia, large-scale conversion of mangroves to aquaculture ponds has been responsible for the destruction of nearly one million ha of mangroves since 1800 (Ilman et al., 2016). Likewise, approximately half of the 279,000 ha of mangroves lost from 1951 to 1988 were converted to aquaculture ponds in the Philippines (Primavera, 2000). The ecological effects of such conversion results in the patchiness of forests affecting biodiversity (Bryan-Brown et al., 2020), carbon storage capacity (Sasmito et al., 2020), and physico-chemical properties of the soil (Matsui et al., 2008), among others. Mangrove forests are highly affected by sediment dynamics. Coastal reclamations for infrastructure, mining, and dam constructions accelerated coastal erosion negatively affecting mangrove ecosystems. Although the issue of natural disasters like tsunami and typhoons have seldom been investigated before the year 2000, such issues are recently getting more studied (10%). The extreme climatic events, such as the Indian Ocean tsunami (in 2004) and Typhoon Haiyan (in 2013), highlighted the importance of restoring coastal vegetation (primarily mangroves) for coastal protection.

Restoration studies in response to mangrove conversion to aquaculture, either for fishpond or shrimp pond production are widespread, with most studies from Indonesia (39%), Philippines (13%), and Thailand (13%). These countries have considerably lost their mangrove cover to aquaculture (Richards and Friess, 2016). Meanwhile, restoration studies in Vietnam were highly focused on coastal erosion reflecting one of the country's main problems. For example, Nguyen et al. (2013) investigated sediment accretion and erosion dynamics through soil particle size fractions in mangrove forests. Notably, only Thailand and Vietnam reported studies on mangrove restoration as a possible solution to pollution (e.g., mining, runoff, etc.). These varying foci of restoration efforts reflect the individual country's local problems and priorities.

Restoration techniques practiced

Three mangrove restoration techniques were commonly reported: direct planting (either monogeneric or multi-species

TABLE 3 Summary of general problems addressed by mangrove restoration from each country and in Southeast Asia.

General problems	Description	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM	SE Asia (Total)
Damage to mangrove habitat	Conversion to aquaculture (fish/shrimp ponds, rice production, oil palm expansion, and herbicide damage)	–	1	64	–	22	4	21	2	28	22	164
Coastal erosion	Eroded floodplain due to rapid reclamation for human settlements and industrial development, etc.	–	2	30	–	15	–	7	2	3	2	61
Natural disaster	Tsunami, typhoons	–	–	11	–	6	1	7	–	5	–	30
Pollution	Poor water and sediment quality due to mining, runoff, etc.	–	-	-	–	–	-	–	–	3	2	5

BRN, Brunei; KHM, Cambodia; IDN, Indonesia, LAO, Laos; MYS, Malaysia; MMR, Myanmar; PHL, Philippines; SGP, Singapore; THA, Thailand; VNM, Vietnam. - no reported article based on the data inclusion criteria in this study.

planting), integration of coastal engineering methods, and hydrological rehabilitation (Table 4). Direct planting, primarily using species from the *Rhizophora* genus, was used as the main restoration technique in all SE Asian countries (74%; Table 4). Monogeneric planting has been widely practiced dating back to the 1930s (Walters, 2003; Ilman et al., 2011) but became more massive and frequent starting in the late 1980s (Primavera and Esteban, 2008; Lee et al., 2019; Arifanti, 2020). Despite the call to follow science-based protocols (i.e., correct site/species matching; Primavera et al., 2016) in mangrove restoration, widespread use of monogeneric *Rhizophora* planting is still reported. In fact, massive restoration programs funded by the national government or in partnership with local government have planted *Rhizophora* in non-mangrove zones (National Greening Program of the Philippines, Primavera et al., 2019) and that post-planting management strategy was based on available funds (Damastuti et al., 2022). Species from the *Rhizophora* genus are widely used planting material due to convenience, easy to collect and plant, and higher survival rate upon initial monitoring (Wodehouse and Rayment, 2019). Hence, the increase of mangrove cover as reported by many countries during the 2nd ASEAN Mangrove Congress in 2017 could be attributed to massive *Rhizophora* planting (Lee et al., 2019). However, the effectiveness of monogeneric planting have been doubted at least in terms of habitat functionality (Barnuevo et al., 2017) and coastal protection (Villamayor et al., 2016) nor in enhancing faunal biodiversity (Salmo et al., 2017; Salmo et al., 2018). Moreover, empirical studies to support its long-term benefits are lacking.

Vietnam along with Indonesia and Malaysia lead in studies on coastal engineering methods, while Indonesia lead in the hydrological rehabilitation methods (Table 4). Hydrological rehabilitation (9%) was advocated prior to planting or to encourage natural regeneration, and some have integrated coastal engineering measures (18%). Studies from Vietnam and Indonesia showed incorporation of engineering measures with various designs to support restoration activities (Albers and Schmitt, 2015; Nguyen, 2018). Different structures and

TABLE 4 Mangrove restoration techniques from each country and in SE Asia.

Restoration techniques	Description	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM	SE Asia (Total)
Direct planting	Monogeneric planting - widely-used species were *Rhizophora apiculata* and *R. stylosa;* Multi-species planting	–	1	63	–	23	4	28	1	31	29	180
Integration of coastal engineering methods	Deployed hard (various types of breakwaters and sea dykes) and soft-engineering methods (T-groins/ fences made up of bamboo, Melaleuca entrapping microsites prior to planting or to encourage natural recruitment)	–	–	9	–	9	–		1	4	11	34
Hydrological rehabilitation	Physical changes made to restore hydrological conditions of the site (considered surface elevation, tidal inundation, etc.) before planting or to encourage natural regeneration	–	–	12	–	1	–		1	2	1	17

BRN, Brunei; KHM, Cambodia; IDN, Indonesia, LAO, Laos; MYS, Malaysia; MMR,Myanmar; PHL, Philippines; SGP, Singapore; THA, Thailand; VNM, Vietnam. - no reported article based on the data inclusion criteria in this study.

construction materials have been tested, including perforated/permeable breakwaters made of bamboo and branches of trees, T-fence, rubble-mound, among others (Akbar et al., 2017; Suripin et al., 2017). In recent years, hydraulic parameters and physical model tests have been incorporated in pre-implementation plans in reducing wave transmission to enhance seedling growth and survival (Le Xuan et al., 2022). A range of hard and soft breakwater structures have been tested to reduce coastal erosion and restore mangrove forests (Thieu Quang and Mai Trong, 2020; Winterwerp et al., 2020; Sartimbul et al., 2021). Successful implementation of breakwaters in Indonesia and Vietnam led to wave energy dissipation (Le Xuan et al., 2022), reduced coastal erosion, sediment build up, and increased colonization rate of mangroves (Akbar et al., 2017; Suripin et al., 2017).

Ecological functions assessed

We identified and categorized nine ecological functions commonly reported in mangrove restoration studies in the region. Floral diversity (34%), carbon sequestration (16%), erosion control and sediment stabilization (14%) were the most commonly reported ecological functions. Other ecological functions related to nutrient cycling (6%), coastal protection (5%), fisheries (5%), and microbial diversity (5%) were relatively less studied (Table 5). The ecological functions reported were probably attempts to link the effectiveness of restored mangroves in delivering ecosystem services (Salmo et al., 2018; Castillo et al., 2022; Comer-Warner et al., 2022). However, documentation and attribution of ecosystem services in restored mangroves are difficult especially if these services are interrelated and there are no baseline datasets to compare with (Salmo, 2021).

Oftentimes, mangrove plant diversity is used as a proxy indicator in the recovery of ecosystem services (Andradi-Brown et al., 2013). The assessment of floral diversity is relatively easier to do (in comparison with other ecosystem services) which could explain why practically all SE Asian countries are reporting it. Flora and fauna diversity, and carbon sequestration characterized most of the studies from Indonesia, while erosion and sediment stabilization, primary productivity, and coastal protection were the primary foci in Vietnam. Despite the relatively fewer studies from Myanmar, they have publications related to carbon sequestration and sediment stabilization. Meanwhile, Malaysia led in microbial diversity assessment (Table 5). The high focus on flora diversity studies can be attributed to the timber value of mangroves. Across SE Asian countries, mangroves are used for posts, and for charcoal and tannin production (Gevaña et al., 2018). Surprisingly however, studies linking restored mangroves with fisheries were seldomly assessed despite the need for food and livelihood of the coastal communities. Among fishery-related topics, nekton communities (e.g., crabs, shrimps, fishes) were the most studied organisms (Salmo et al., 2018; Ridlo et al., 2020; Then et al., 2021) as it is the closest indicative of the food provisioning service of the mangrove ecosystem.

TABLE 5 Ecological functions assessed on mangrove restoration studies from each country and in SE Asia.

Ecological functions	Example of assessment metrics	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM	SE Asia (Total)
Flora diversity	Stand structural characteristics, diversity, distribution, survival and growth patterns	–	1	41	–	12	4	15	2	26	14	115
Carbon sequestration	Above and belowground biomasses, sediment carbon content	–	1	16	–	2	1	7	1	7	6	41
Erosion control and sediment stabilization	Shoreline differences, longshore sediment transport (LST), sedimentation rate, elevation changes	–	–	11	–	9	1	2	–	6	9	38
Fauna diversity	Species composition, richness, diversity and evenness	–	–	20	–	12	–	6	2	5	6	51
Primary productivity	Litter production and accumulation	–	–	6	–	8	–	5	–	3	7	29
Nutrient cycling	Litter decomposition, nutrient load (total nitrogen, available phosphorus)	–	–	3	–	7	–	3	1	4	1	19
Coastal protection	Tide and wave dynamics, wave spectral transformation, wave transmission	–	–	2	–	3	–	1	1	2	5	14
Fisheries and other economically important species	Forest structural characteristics (mangrove stem density, stem diameter, tree height), faunal assemblage patterns, density, abundance	–	–	6	–	2	–	3	–	2	1	14
Microbial diversity	Microbial community composition, distribution	–	–	–	–	3	–	–	1	–	1	5

BRN, Brunei; KHM, Cambodia; IDN, Indonesia, LAO, Laos; MYS, Malaysia; MMR,Myanmar; PHL, Philippines; SGP, Singapore; THA, Thailand; VNM, Vietnam. - no reported article based on the data inclusion criteria in this study.

Recent recognition of the importance of mangroves as a nature-based solution (NbS) have led to various restoration efforts (Cadiz et al., 2020; Basyuni and Simanjutak, 2021; Kusumaningtyas et al., 2022). For example, an increased awareness of the role of mangroves in carbon storage is reflected in our findings (Table 5; see also Tables 1, 2). The inclusion of microbial diversity and other fauna may reflect the recognition of the need to include other important biodiversity components in restoration.

Social attributes assessed

Studies that linked mangrove restoration to social attributes were at least three times lower compared to those that assessed ecological attributes (Figure 2). We identified and classified six categories of social attributes associated with mangrove restoration in Southeast Asia (Table 6). Most of the studies were focused on ecological economics which estimated the economic value of mangroves and its ecosystem services (24%). Topics related to collaboration among different sectors (23%), policies and governance (20%), and community-based restoration (15%) were also explored. Eco-cultural practices (14%) and environmental education (5%) were relatively less studied. Despite the wide range of ecosystem services that the mangroves provide, estimating its non-market ecosystem services results in undervalued estimates of its benefits (Salem and Mercer, 2012). Proper accounting of the multiple services of mangroves is vital for efficient decision-making between conservation and conversion (Song et al., 2021). Collaboration among different sectors (public and private institutions, and community) in implementing restoration projects have been studied for more effective and coordinated conservation efforts (Zhang et al., 2018). For example, local people's participation (Valenzuela et al., 2020) in mangrove restoration with active collaboration of the government and research institutions was an effective strategy towards sustainable and effective mangrove restoration programs (Camacho et al., 2020).

Summary and recommendations for the improvement of mangrove restoration studies in SE Asia

Our study presented a bibliometric-based analysis of mangrove restoration publications in SE Asia to date, providing current knowledge structure, and identifying opportunities for research and collaboration for improved mangrove restoration. We acknowledge that there are a variety of reports and studies (i.e., project technical reports, research studies published in journals not indexed by the databases used) that may not have been covered. However, we argue that the peer-reviewed literature synthesized in this study reflects in general what is available to the wider scientific community. Similar to other bibliometric-studies, data availability and accessibility remains as one of the limitations that may impact the quantification of records and limits the datasets (Mohd Razali et al., 2021). In fact, the research-implementation gap is well documented and criticized in the field of conservation since information from researchers are often not integrated into practice and vice versa (Zhang et al., 2018; Eger et al., 2022). Hence, it is important to make unpublished works be communicated and be subjected to peer-review process in

TABLE 6 Commonly examined social dimensions in mangrove restoration studies from each country and in Southeast Asia.

Social dimensions	Description	BRN	KHM	IDN	LAO	MYS	MMR	PHL	SGP	THA	VNM	SE Asia (Total)
Collaboration among government, NGOs and stakeholders	Explore the role of the different sectors in mangrove restoration and management	–		15	–	–	–	5	–	3	2	25
Ecological economics	Provide estimate of economic value of mangrove ecosystems and their services	–		8	–	3	1	4	–	4	7	27
Community-based restoration	Report of successes and challenges of community-based mangrove restoration	–		10	–	–	–	4	–	2	1	17
Environmental education	Report on the use of mangrove ecosystem as a means to raise awareness of the environment and conservation	–		2	–	2	–	1	–	1	–	6
Ecocultural and practices	Describe local knowledge, practices, and use of mangrove forests	–		8	–	–	–	3	–	2	2	15
Policy and politics	Describe institutional arrangements, issues, policy challenges, and approaches for mangrove conservation	–		11	–	–	–	4	–	2	4	21

BRN, Brunei; KHM, Cambodia; IDN, Indonesia, LAO, Laos; MYS, Malaysia; MMR,Myanmar; PHL, Philippines; SGP, Singapore; THA, Thailand; VNM, Vietnam. - no reported article based on the data inclusion criteria in this study.

order for the wider community to advance restoration practice in the region.

The compiled studies for SE Asia are comparable with the number and rate of publications with other regions (e.g., Asia, Africa) but probably are relatively lower than Australia and the Americas (Ho and Mukul, 2021). There is an increasing trend on mangrove restoration studies with high citations. The commonly cited articles reflect the shared interests among SE Asian countries (particularly on mangrove mapping). Some articles that were authored by researchers from the same country were heavily cited indicating either limited access to international journals or preference to cite locally-published articles. For example, the presence of country-based journals (*Malaysian Forester* for Malaysia and *Biodiversitas* for Indonesia, and to some extent some local journals in the Philippines) could explain high citations in these countries but could also imply limited readership outside the country/region.

The variations of scientific productivity among SE Asian countries is likely due to the differences of resource allocation and the research thrust of the government. Each country may have different investment and strategy in science, fewer research universities and institutions, and less funding opportunities. Mangrove restoration studies are predominantly contributed by Indonesia, Thailand, Malaysia, Vietnam, and the Philippines. These countries have long been doing mangrove research and management and were beneficiaries of several international-funded programs (Salmo, 2019; Hai et al., 2020; Nawari et al., 2021). However, countries like Brunei, Cambodia, Laos, and Myanmar have lower publications despite having considerable mangrove cover and biodiversity (Bunting et al., 2022). The rich history of mangrove research and management in Indonesia (Basyuni et al., 2022), Thailand (Thompson, 2018), Malaysia (Gopalakrishnan et al., 2021), Vietnam (Hai et al., 2020), and Philippines (Garcia et al., 2014) may have contributed to the transition and continuous development of "local experts" in these countries. Clearly, the region benefited from the collaboration networks with authors and institutions outside SE Asia. Almost 50% of the most relevant authors and documents were from outside SE Asia. The region is always at the forefront for international biodiversity conservation and ecosystem restoration programs; hence, it always attracts foreign authors and institutions. For example, the study of Donato et al. (2011) on the contribution of mangroves in abating impacts of climate change revolutionized the "blue carbon" research initially in Indonesia then eventually within and beyond the region. In addition, the long presence of international/regional NGOs and research institutions (e.g., USAID, CIFOR, SEAFDEC, CI, TNC, WWF, etc.) contribute to providing funds to do mangrove research and restoration programs (see for example Figures 4A, 5A, B, 9).

The primary motivation to restore mangroves is to recover mangrove cover (Table 3), mainly through direct planting (Table 4). Although not systematically documented and reported, common indicators for success are usually survival rate and area planted (Kodikara et al., 2017; Wodehouse and Rayment, 2019; Gatt et al., 2022). The reasons for doing mangrove restoration studies are naturally linked to the objectives and practice of restoration. Hence, early topics pursued were on vegetation structure, ecosystem dynamics, composition, biomass and density, deforestation, aquaculture, and management, and recently on "blue carbon", and climate change (Table 1; Figures 7, 8). There are of course common topics among SE Asian countries such as mangrove mapping and coastal dynamics. But there are also topics that are reflective of country-specific needs. For instance, coastal protection is the interest in Vietnam while carbon sequestration along with flora and fauna diversity were the topics pursued in Indonesia. These topics are probably either mandated by the advocacies of the collaborating countries/institutions or a response to international commitments, or both. For example, "blue carbon" is a popular topic probably because it is directly linked to climate change adaptation and mitigation (CCAM) programs with economic and financing opportunities (Chou et al., 2022; da Rosa and Marques, 2022; Macreadie et al., 2022). Interestingly, "biodiversity" which is also a global priority (CBD, 2010; Díaz et al., 2020) is not as comprehensively-studied as "blue carbon", and in fact highly-focused only on measures of vegetation structure related to plant species diversity.

Biodiversity is one of the ecosystem services expected to be recovered in restored mangroves (da Rosa and Marques, 2022). Aside from plant species diversity, other taxa are not assessed/reported probably because of the inherent difficulties associated with biodiversity studies (e.g., lack of baseline, need to establish gene flow and connectivity, expensive instruments, etc.; Gatt et al., 2022). Aside from biodiversity, other ecosystem functions that are expected to improve following restoration are also not systematically assessed yet (Table 5), probably because there are few biodiversity experts and ecologists that integrate these studies on restored mangroves in the region (but see Basyuni et al., 2021; Then et al., 2021). Outcomes or progress from mangrove restoration programs are needed to document and assess the actual results based on the set objectives. These outcomes are analyzed to show the restoration trajectories over time using sets of restoration indicators (Cadier et al., 2020; Gatt et al., 2022).

Aside from the measured biophysical variables, restoration outcomes should also be assessed on how it contributes to the well-being of the society that are using mangroves and the policy makers that govern mangroves (Bayraktarov et al., 2020; Arifanti et al., 2022b). These outcomes are then integrated to improve mangrove conservation and restoration policies (Lee et al., 2019; Friess et al., 2022; Gatt et al., 2022). The rubrics we adapted in classifying ecological and social attributes are relatively less complete relative to the integrative rubrics or "recovery wheel" proposed by the Society for Ecological Restoration (Gann et al., 2019). However, most (if not all) publications we reviewed here have extremely variable ecological and social variables assessed and therefore limited our ability in evaluating the progress or success of mangrove restoration programs in the region.

Based on the identified gaps and needs, and in line with the international policies/programs, we proposed five priority topics that will enhance the impacts of mangrove restoration studies for SE Asia. We acknowledged that these topics are biased for "biodiversity" and "ecosystem services" simply because these are the pressing needs which we think will highlight the contribution of the region in realizing the targets for the UN's Decade on Ecosystem Restoration in 2030. Although some of these topics may be considered an independent topic on its own, these are complementary to each other. It is also possible that there are topics that are equally important that we may have unintentionally excluded.

Restoration areas and methods

The region already has lessons and experiences (some of it are even painful) on mangrove restoration programs (Primavera et al., 2011; Gevaña et al., 2018; Lee et al., 2019). The massive "planting" programs implemented in the 1990s provided learnings on what system will work as opposed to programs that are bound to fail (Barnuevo et al., 2017; Wodehouse and Rayment, 2019). In general, restoration programs that are implemented at smaller/local-scales and in mid to upper intertidal areas have a higher chance to succeed as opposed to massive planting in lower intertidal coastal fringes. Although restoration at a smaller scale has a higher chance to succeed, it has to be balanced with the urgency of the need to recover mangrove areas. A set of criteria has to be defined to delineate and prioritize restoration areas. There are already existing rubrics in site selection and prioritization, for example former mangrove areas, proximity to existing intact/healthy mangroves, tidal range, and projected vulnerability to sea-level rise, among others (Primavera et al., 2012; Lewis et al., 2019; Teutli-Hernández et al., 2020). We proposed to add mangrove plant diversity based on historical species composition/distribution to integrate data on genetic connectivity for transboundary biodiversity conservation (as posited by Wee et al., 2019). Suitable mangrove species at specific sites can be then determined similar to the proposition of Su et al. (2022). Worthington and Spalding (2018) estimated ca. 3,000 km^2 potential restorable areas in SE Asia. This estimate needs to be further calibrated at country-specific (or even local/site-specific) levels following set rubrics to come up with a reasonable target area. Hopefully, the estimated target areas could match the projected needs of increasing mangrove cover by at least 20% in 2030 (GMA; https://mangrovealliance.org/). A significant restorable area would be the abandoned aquaculture fish/shrimp ponds which account for ca. 23,000 km^2 in the region (Luo et al., 2022). We acknowledge that delineating or even prioritizing areas for restoration will be challenging as these are the same areas where the government institutions are also considering as human settlement and reclamation areas for coastal development (Powell, 2021; Tinh et al., 2022). We argue however that addressing this challenge will be more beneficial in the long run as it will come up with a more realistic plan.

Mangrove restoration in climate change adaptation and mitigation programs

For a long time, the primary driver for doing mangrove restoration in the region is to recover mangrove forest (Tables 3, 4). Hence, the choice of species and planting sites were deliberately set for fast-growing species and/or in areas that can be easily restored. However, SE Asia (and as part of Asia-Pacific region) is considered as the most vulnerable region (Noor and Abdul Maulud, 2022) against climate change-related disasters (e.g., typhoons, tsunamis, rising sea-level, etc.). Conventional restoration objectives and designs particularly monogeneric planting in coastal fringes will no longer be sufficient to meet the challenges and complexities needed to adapt (and/or mitigate) the impacts of climate change. Mangroves are commonly advocated as a NbS (Jordan and Fröhle, 2022) indicating mangroves can naturally recover and could even expand in inland areas through natural re/colonization (Winterwerp et al., 2020). The natural recolonization, although relatively "free", is estimated to take a minimum of 10 to 25 years (Salmo et al., 2013) to come up with a developed forest, a period that is too long to wait to be adaptive to climate change impacts. The objectives and designs of restoration programs will have to be modified to be more strategic to adapt to the impacts of climate change. Recent integration of innovative (e.g., bamboo, *Melaleuca* entrapping microsites, rubble-mounds) and technological designs (e.g., coastal engineering) needs to be expounded (Table 4) in more areas. We acknowledge that technological innovations (permeable dams, dykes, and T-groins/fences) will entail substantial cost, a proposition that may be financially difficult for most SE Asian countries. We argue however that technological innovation is not just an option but in fact is a necessity to ensure faster and sustained mangrove forest recovery. For instance, an optimized dyke design considering hydrodynamic loads, including water levels successfully facilitated restoration of mangrove areas in Vietnam (Albers and Schmitt, 2015). Similarly, permeable dams constructed at various locations in Indonesia helped rehabilitate mangrove areas through re-establishment of sediments (following the Build with Nature approach; Winterwerp et al., 2020). A hybrid of mangrove protection, natural recolonization and technological-innovation can also be adapted in anticipation for the increased urgency for mangroves to adapt to uncertain climate change-induced conditions (e.g., less precipitation, rising sea levels, and extreme weather events; Friess et al., 2022). If properly done, the region will be poised to demonstrate the effectiveness of mangrove restoration programs in adapting and mitigating the impacts of climate change particularly on sequestering carbon, reducing GHG emission, and increasing surface elevation.

Monitoring recoveries of biodiversity and ecosystem services

The lack of monitoring data in most mangrove restoration projects has been a perennial problem in the region. Monitoring reports, if available, are confined to short-term monitoring that can potentially misinterpret the success or failure of a restoration project. Biodiversity-related studies on restored mangroves are already notable in the region, although limited to floral measures. Conversely, faunal species and ecological functions and services are rarely reported (Table 5) nor its relationship with the restored mangrove vegetation. Faunal studies have been more focused on molluscs (gastropods, bivalves, and crustaceans) probably as it provides direct food for the nearby coastal communities (Table 5). When mangroves mature, its vegetation structures (e.g., density, biomass, canopy, etc.) and structural complexity are expected to show progression over time following chronosequence (Salmo et al., 2013; Salmo et al., 2017; Salmo et al., 2018). At each forest development stage, the changes in vegetation will improve sediment properties which are then expected to attract different faunal cohorts, and probably also with different trophic levels. The shifts in species composition and dominant species at different forest developmental stages are important to assess linkages between restored mangroves and faunal composition/biodiversity. Similarly, such linkages can be used to establish restoration indicators and eventually be used to infer progress/success (Salmo et al., 2017; Barbanera et al., 2022). Beyond mangrove ecosystems, there is a need to expand and consider connectivity studies and include equally important but less studied taxa (i.e., microorganisms, wildlife fauna). Migration patterns of species (i.e., migratory shorebirds) and interconnectivity of adjacent habitats (coral reef, seagrass, and mangroves) are rarely studied. For example, the health of adjacent ecosystems may also play a role in the health of restored mangroves (see for example Sharma et al., 2017). Likewise, knowledge on mangrove biodiversity should be properly documented and systematically organized. Effective use of biodiversity data requires integration of disconnected datasets (Heberling et al., 2021) for strategic prioritization. We suggest the use of a database as a repository of biodiversity-related information. In this manner, information will be collated (at country-level) and integrated at a regional-level to provide timely and relevant information to researchers and policy makers.

There is a general consensus on accelerated global biodiversity loss in most ecosystems but could be higher in mangroves (Polidoro et al., 2010; Hughes, 2017). Southeast Asia is known as a biodiversity hotspot (Hughes, 2017), although evidence on patterns and rates of biodiversity losses in mangroves are lacking (Sodhi et al., 2010; Tan et al., 2022). One of the primary drivers for restoration is to complement biodiversity conservation (da Rosa and Marques, 2022). To meet agendas for biodiversity conservation and mitigation of climate change, we proposed that vegetation metrics be correlated/related to ecosystem services and functions. We acknowledge that vegetation metrics are relatively easier to measure and reflect the traits that recover faster (Cadier et al., 2020; Gatt et al., 2022). However, relating these metrics to ecological functioning (e.g., habitat provisioning for biodiversity) will be more strategic to quantify the effectiveness (or ineffectiveness) of restoration (Ulfa et al., 2018; Barbanera et al., 2022). Aside from vegetation metrics, we also recommend the comparative assessment on biodiversity and ecosystem services among intact, disturbed, and restored mangroves to provide information on restoration trajectory patterns, including species that are effectively restored. Aquaculture is considered as one of the main drivers of mangrove loss in the region (Richards and Friess, 2016; Gandhi and Jones, 2019), which has expanded about 2.5 times for the last 25 years (Luo et al., 2022). With changing policy discourse surrounding the utilization and value of mangroves, the massive clearing of mangroves for aquaculture from 1950s to 1980s (Primavera, 2000; Valiela et al., 2001) have transformed to mangrove reforestation since 2011 (Song et al., 2021; Arifanti et al., 2022b). However, a substantial area of abandoned, undeveloped and underutilized (AUU) ponds are still to be restored (Primavera et al., 2011; delos Santos et al., 2022). The existence of AUU ponds in the region provides a rare opportunity to assess biodiversity/ecosystem services and its recovery patterns from a damaged mangroves to a supposedly "healthy" mangroves.

We acknowledge that conventional biodiversity monitoring methods (e.g., transect, plot, capture-based samplings, etc.) are still important in providing empirical datasets. However, these methods are time-consuming and expensive (Taddeo and Dronova, 2018). The urgency to document and assess biodiversity calls for revolutionary monitoring methods such as the use of environmental DNA (eDNA) which can supplement conventional biodiversity monitoring methods (see for example Oka et al., 2021; Polanco Fernández et al., 2021). This technological advancement provides a new avenue on monitoring biota which is a non-destructive and rapid method. Another tool that has been progressively integrated in monitoring changes in mangroves and vegetation dynamics is remote sensing. Free access to satellite imagery can potentially support consistent assessment and monitoring of spatio-temporal changes of mangrove forests at a lower cost (Alexandris et al., 2013), yet provide reliable tracking on restoration progress (Reddy, 2021). This is particularly useful in challenging field conditions and difficult-to-access areas like mangrove ecosystems. However, monitoring might be challenging for small-scale restorations with low resolution imagery.

Policies, governance, and community engagement

Policies that are related to mangrove restoration already exist in the region, mostly adapting global policies that aims to conserve biodiversity (e.g., CBD Aichi Targets), to recover ecosystem services (e.g., SDG), and to reduce GHG emission (e.g., UNFCCC Paris Agreement), among others. The scope and context varied widely among SE Asian countries. The need to upscale and accelerate mangrove restoration will need realignment of the existing policies and synergies across institutions (Mursyid et al., 2021) to include financing, investments, and clear objectives through an overarching organization (e.g., UNFCCC; Waltham et al., 2020; Bhowmik et al., 2022). More importantly, the policies should consider mangrove restoration as part of the national development agenda (Mursyid et al., 2021; Arifanti et al., 2022a) that is integrated in the local coastal management plans (Quevedo et al., 2021a). If all AUU ponds are restored, there is a huge potential to contribute to each country's nationally determined contribution (NDC) targets. To date, Indonesia (Mursyid et al., 2021) and the Philippines (Salmo et al., 2021) have drafted mangrove roadmaps. The realigned policies will need to be "ambitious" following science-based and evidence-based protocols (*sensu* Friess et al., 2022). Fortunately, the ASEAN is already available which could be tapped to facilitate the development of common mangrove policies across countries (Palis et al., 2014; Arifanti et al., 2022b).

One of the priority policy needs is to ensure that the remaining mangroves will be effectively conserved (Lee et al., 2019) and to prevent activities that will damage the mangroves (see also example of coastal reclamation project in Jakarta Bay; Slamet et al., 2020). At the least, coastal development plans should integrate protection of mangroves rather than subjecting it to land reclamation activities. Moreover, a policy on science-based green-gray coastal engineering is critical to adapt to changing climatic conditions (Bruins et al., 2019). Complementary to mangrove protection is an enabling policy that will institutionalize upscaled and accelerated mangrove restoration programs in priority areas. These programs will need funding which could be beyond the capacity of most countries (Buchner et al., 2019; Ong, 2021). Some ASEAN countries are already beneficiaries of donor-assisted mangrove management programs (see for example Quevedo et al., 2021b). However, the realigned policies will need to provide supplemental funding and attract investments through public-private partnership or through the corporate social responsibility (CSR) program (Asaeda et al., 2013; Amin et al., 2021). The benefits derived from restored mangroves should be recognized distinct from the conserved mangroves (Ellison et al., 2020). Some coastal communities demonstrated their effectiveness in managing the restored mangroves (see for example Panay Island, Cogtong Bay, and Quezon in the Philippines; Katon and Pomeroy, 2000; Thompson et al., 2017; Gevaña et al., 2018; and in Indonesia, Basyuni et al., 2022). Their contribution to restoration should be recognized and incentivized either through monetary rewards or tenurial instruments (Lovelock and Brown, 2019) to encourage community engagement (Quevedo et al., 2020).

Mangrove conservation and restoration both contribute to climate change adaptation, hence restoration offers opportunities to develop market-based mechanisms in offsetting carbon emissions (Macreadie et al., 2022). For instance, carbon credits generated from planting 18 million trees by the communities in Indonesia is being used to repay project costs (Herr et al., 2019). These monetary-based mechanisms can potentially pay restoration project costs and support local communities through livelihood projects. The communities, as beneficiaries, will then serve as stewards in managing the restoration projects. However, despite the potential contribution of carbon credits to improve local livelihoods, many challenges remain. For one, the perceived social benefits (e.g., increased food and income) from restored mangroves, in general, and from carbon credits, in particular, may take time before the communities can realize it. While waiting for the tangible benefits, the communities have the tendency to resort to illegal activities (e.g., mangrove cutting) in pursuit of immediate and short-term economic gains (see for example Ken et al., 2020). Long-term growth and recovery of mangrove forests should be given more emphasis rather than the hype on carbon offsets (Wernick and Kauppi, 2022). Ensuring an enabling policy environment, including institutionalized funding mechanisms that will incentivize communities (Ken et al., 2020), is critical in achieving long-term restoration goals. Price-based instruments (e.g., tax credits, carbon credits; Lee et al., 2019) should be incorporated in the policy to incentivize coastal stakeholders managing the restored mangroves (Song et al., 2021; Macreadie et al., 2022) but should de-incentivize activities that damage mangroves (e.g., taxes on deforestation; Lee et al., 2019; Lin et al., 2022).

Policies supporting research and systematic monitoring of restoration programs are needed (Maina et al., 2021). The lack of monitoring data in most mangrove restoration projects has been a perennial problem in the region. Empirical studies using standardized restoration tracking tools (see for example Gatt et al., 2022) that document and assess both successes and failures of restoration programs are needed to provide timely inputs to mangrove managers (Friess et al., 2022). Restoration outcomes should be properly stored in a mutually agreed knowledge repository site similar to the biodiversity monitoring platform of the ASEAN Center for Biodiversity (ACB).

Strengthening of ASEAN network

Our study has shown considerable networks among authors, institutions, and countries among SE Asian nations although collaborations with the more developed western countries are more apparent (Figure 9). Establishment of relationships between individuals, institutions, and countries can facilitate the formation of common goals and concerted restoration efforts. Collaboration can offer a range of benefits through knowledge and resource sharing, and cooperative problem solving. The network might also be tapped to enhance mangrove research and management in other SE Asian countries currently with limited research. While external collaborations are helpful, we argue that enhancing collaboration among SE Asian countries will strengthen the network and could probably be more sustainable. The ASEAN can be tapped as a general platform to enhance the network, particularly on sharing best practices, in developing common mangrove management guidelines, in developing collaborative research, and in sharing the state of the environment report (ACB, 2017). To minimize the research-implementation gap, it is necessary that research be communicated in a wider platform. Equally important step is the peer-review process to publish high-quality research articles that can meaningfully contribute to restoration practice. To realize this, we proposed an ASEAN journal focused on mangrove restoration, conservation, and management with a multinational scientific editorial board who are experts in mangrove studies. This can potentially increase the readership of ASEAN-based mangrove studies beyond the region.

For mangroves in particular, to date, there were two scientific fora on ASEAN Mangrove Congress (held in 2012 and 2017 in the Philippines; Palis et al., 2014; Lee et al., 2019). The congress aimed to strengthen mangrove research and development in the ASEAN region through the enhancement of inter-agency and inter-sectoral coordination at the national and regional levels. Priority research areas and policy gaps were identified which were later on adopted through a resolution. Some of these resolutions include the establishment of a common database (e.g., mangrove information center), conduct of conservation and restoration programs, and institutionalization of a mechanism linking mangrove science, policy, and action. The ASEAN Mangrove Congress was initially planned to be held every three years where hosting will be on a rotational basis (Palis et al., 2014), however the 2nd Congress was made possible after five years (Lee et al., 2019). We recognize the inherent challenges that each individual country and the entire ASEAN might encounter (primarily on funding and administration) not to mention the sustainability of such an initiative. However, if only ASEAN members commit and recognize the importance of ASEAN cooperation in addressing regional mangrove research and management initiatives, then an ASEAN Mangrove Congress can be pursued on a bi-annual basis, parallel with the ASEAN Summit.

Final remarks

As mangrove restoration initiatives grow owing to its recognition as a "blue carbon ecosystem", so will the need for mangrove restoration studies. While our findings represent the current status of mangrove restoration studies in SE Asia, we acknowledge that the field of "restoration ecology" is still developing. The inclusion of social attributes, in addition to the classical ecological attributes assessment in mangrove restoration can potentially enhance restoration outcomes. Integration of social dimensions in ecological restoration of mangroves can increase the socio-cultural value of mangroves and at the same time increase scientific output through community engagement (or through "citizen science", i.e., mapping mangroves with local community partners, local knowledge, practices, and use of mangrove forests). Future restoration strategies may benefit to focus on citizen science, and include social attributes, in addition to the usual focus of ecological attributes in mangrove restoration. Regional stakeholders' collaboration, including integration of science-based methods into practice, and improved communication across sectors, will significantly contribute to knowledge transfer. Research topics suggested in this study provide a path forward to improve mangrove restoration, and aid in the development of national and international restoration and conservation strategies, and eventually to contribute to the United Nation's Decade on Ecosystem Restoration.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MG-D: conceptualization, methodology, formal analysis, investigation, data curation, writing – original draft, review, and editing. SS: conceptualization, data visualization, writing – review and editing, supervision. All authors are responsible for and agreed to the publishing of the final version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.987737/full#supplementary-material

References

ACB (2017). *ASEAN centre for biodiversity (ACB) ASEAN biodiversity outlook 2* (Laguna, Philippines: ASEAN Centre for Biodiversity, Philippines). Available at: https://asean.chm-cbd.net/sites/acb/files/2020-03/ASEAN%20Biodiversity%20Outlook%202.pdf

Adame, M. F., Zakaria, R. M., Fry, B., Chong, V. C., Then, Y. H. A., Brown, C. J., et al. (2018). Loss and recovery of carbon and nitrogen after mangrove clearing. *Ocean Coast. Manag.* 161, 117–126. doi: 10.1016/j.ocecoaman.2018.04.019

Akbar, A. A., Sartohadi, J., Djohan, T. S., and Ritohardoyo, S. (2017). The role of breakwaters on the rehabilitation of coastal and mangrove forests in West kalimantan, Indonesia. *Ocean Coast. Manag.* 138, 50–59. doi: 10.1016/j.ocecoaman.2017.01.004

Albers, T., and Schmitt, K. (2015). Dyke design, floodplain restoration and mangrove co-management as parts of an area coastal protection strategy for the mud coasts of the Mekong delta, Vietnam. *Wetl. Ecol. Manage.* 23, 991–1004. doi: 10.1007/S11273-015-9441-3/FIGURES/6

Alexandris, N., Chatenoux, B., Harriman, L., Lopez Torres, L., and Peduzzi, P. (2013). Monitoring mangroves restoration from space. *Geneva: UNEP/GRID.* Available at: https://www.unep.org/resources/report/monitoring-restoration-mangrove-ecosystems-space-0

Amin, M. A., Mulyana, D., Damar, A., and Budiman, M. A. K. (2021). Effectiveness and impact studies of mangrove rehabilitation in the northern coast of West Java: A case study in karawang regency. *IOP Conf. Ser. Earth Environ. Sci.* 744, 12002. doi: 10.1088/1755-1315/744/1/012002

Andradi-Brown, D. A., Howe, C., Mace, G. M., and Knight, A. T. (2013). Do mangrove forest restoration or rehabilitation activities return biodiversity to pre-impact levels? *Environ. Evid.* 2, 1–8. doi: 10.1186/2047-2382-2-20/TABLES/2

Aria, M., and Cuccurullo, C. (2017). Bibliometrix: An r-tool for comprehensive science mapping analysis. *J. Informetr.* 11, 959–975. doi: 10.1016/J.JOI.2017.08.007

Arifanti, V. B. (2020). Mangrove management and climate change: A review in Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 487, 12022. doi: 10.1088/1755-1315/487/1/012022

Arifanti, V. B., Kauffman, J. B., Subarno, ., Ilman, M., Tosiani, A., and Novita, N. (2022a). Contributions of mangrove conservation and restoration to climate change mitigation in Indonesia. *Glob. Change Biol.* 28, 4523–4538. doi: 10.1111/gcb.16216

Arifanti, V. B., Sidik, F., Mulyanto, B., Susilowati, A., Wahyuni, T., Subarno, S., et al. (2022b). Challenges and strategies for sustainable mangrove management in Indonesia: A review. *Forests* 13, 695. doi: 10.3390/f13050695

Asaeda, T., Tsuneizumi, E., Kanehira, H., and Kanesaka, Y. (2013). "Streamlining corporate responsibility into effective mangrove rehabilitation and management scheme in the Philippines," in *Proceedings of regional symposium on mangrove ecosystem management in southeast Asia: Mainstreaming mangroves.* Eds. B. Santoso and T. Kusano (Surabaya, Indonesia: Indonesian Ministry of Forestry), 274–281.

Baird, A. H., and Kerr, A. M. (2008). Landscape analysis and tsunami damage in aceh: Comment on iverson and prasad, (2007). *Landsc. Ecol.* 23, 3–5. doi: 10.1007/S10980-007-9152-0

Barbanera, A., Markesteijn, L., Kairo, J., Juma, G. A., Karythis, S., and Skov, M. W. (2022). Functional responses of mangrove fauna to forest degradation. *Mar. Freshw. Res.* 73, 762–773. doi: 10.1071/MF21257

Barbier, E. B. (2007). In the wake of tsunami: Lessons learned from the household decision to replant mangroves in Thailand. *Resour. Energy Econ.* 30, 229–249. doi: 10.1016/j.reseneeco.2007.08.002

Barnuevo, A., Asaeda, T., Sanjaya, K., Kanesaka, Y., and Fortes, M. (2017). Drawbacks of mangrove rehabilitation schemes: Lessons learned from the large-scale mangrove plantations. *Estuar. Coast. Shelf Sci.* 198, 432–437. doi: 10.1016/j.ecss.2017.02.015

Basyuni, M., Sasmito, S. D., Analuddin, K., Ulqodry, T. Z., Saragi-Sasmito, M. F., Eddy, S., et al. (2022). "Mangrove biodiversity, conservation and roles for livelihoods in Indonesia," in *Mangroves: Biodiversity, livelihoods and conservation* (Singapore: Springer Nature Singapore), 397–445. doi: 10.1007/978-981-19-0519-3_16

Basyuni, M., and Simanjutak, E. O. (2021). Species composition and carbon stock estimation in pulau sembilan secondary mangrove forests, north Sumatra, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 713, 12014. doi: 10.1088/1755-1315/713/1/012014

Basyuni, M., Slamet, B., Sulistiyono, N., Munir, E., Vovides, A. G., and Bunting, P. (2021). Physicochemical characteristic, nutrient, and fish production in different types of mangrove forest in north Sumatra and aceh provinces of Indonesia. *Kuwait J. Sci.* 48, 1–14. doi: 10.48129/kjs.v48i3.9160

Bayraktarov, E., Brisbane, S., Hagger, V., Smith, C. S., Wilson, K. A., Lovelock, C. E., et al. (2020). Priorities and motivations of marine coastal restoration research. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.00484

Bennett, E. L., and Reynolds, C. J. (1993). The value of a mangrove area in Sarawak. *Biodivers. Conserv.* 2, 359–375. doi: 10.1007/BF00114040

Bhowmik, A. K., Padmanaban, R., Cabral, P., and Romeiras, M. M. (2022). Global mangrove deforestation and its interacting social-ecological drivers: A systematic review and synthesis. *Sustainability.* 14, 4433. doi: 10.3390/su14084433

Bruins, J., Corwin, E., Pangilinan, J., Pidgeon, E., Taylor, S., and Ng, K. (2019). "Building coastal resilience for disaster risk reduction and climate change adaptation through green-gray infrastructure," in *International conference on sustainable infrastructure 2019* (Reston, VA: American Society of Civil Engineers), 78–88. doi: 10.1061/9780784482650.009

Bryan-Brown, D. N., Connolly, R. M., Richards, D. R., Adame, F., Friess, D. A., and Brown, C. J. (2020). Global trends in mangrove forest fragmentation. *Sci. Rep.* 10, 1–8. doi: 10.1038/s41598-020-63880-1

Buchner, B., Clark, A., Falconer, A., Macquarie, R., Meattle, C., and Wetherbee, C. (2019) *Global landscape of climate finance 2019.* Available at: http://resp.llas.ac.cn/C666/handle/2XK7JSWQ/242591 (Accessed July 2, 2022).

Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., and Thomas, N. (2022). Global mangrove watch: Updated 2010 mangrove forest extent (v2.5). *Remote Sens.* 14, 1034. doi: 10.3390/rs14041034

Cadier, C., Bayraktarov, E., Piccolo, R., and Adame, M. F. (2020). Indicators of coastal wetlands restoration success: A systematic review. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.600220

Cadiz, P. L., Calumpong, H. P., Sinutok, S., and Chotikarn, P. (2020). Carbon storage potentials of natural and planted mangals in trang, Thailand. *Appl. Ecol. Environ. Res. h* 18, 4383–4403. doi: 10.15666/aeer/1803_43834403

Camacho, L. D., Gevaña, D. T., Sabino, L. L., Ruzol, C. D., Garcia, J. E., Camacho, A. C. D., et al. (2020). Sustainable mangrove rehabilitation: Lessons and insights from community-based management in the Philippines and Myanmar. *APN Sci. Bull.* 10, 18–25. doi: 10.30852/SB.2020.983

Cameron, C., Hutley, L. B., Friess, D. A., and Brown, B. (2019a). Community structure dynamics and carbon stock change of rehabilitated mangrove forests in sulawesi, Indonesia. *Ecol. Appl.* 29, 1–18. doi: 10.1002/eap.1810

Cameron, C., Hutley, L. B., Friess, D. A., and Munksgaard, N. C. (2019b). Hydroperiod, soil moisture and bioturbation are critical drivers of greenhouse gas fluxes and vary as a function of landuse change in mangroves of sulawesi, Indonesia. *Sci. Total Environ.* 654, 365–377. doi: 10.1016/j.scitotenv.2018.11.092

Caputo, A., and Kargina, M. (2021). A user-friendly method to merge scopus and web of science data during bibliometric analysis. *J. Mark. Anal.* 2021, 1–7. doi: 10.1057/S41270-021-00142-7

Castillo, J. A., MacKenzie, R., Manahan, J. R., and Castillo, J. (2022). Monitoring the sediment surface elevation change across a chronosequence of restored stands of tropical mangroves and their contemporary carbon sequestration in soil pool. *Forests*. 13, 241. doi: 10.3390/f13020241

CBD (Convention on Biological Diversity) (2010) *The strategic plan for biodiversity 2011-2020 and the aichi biodiversity targets COP 10 decision X/2.* Available at: https://www.cbd.int/decision/cop/?id=12268 (Accessed June 13, 2022).

Chou, M.-Q., Lin, W.-J., Lin, C.-W., Wu, H.-H., and Lin, H.-J. (2022). Allometric equations may underestimate the contribution of fine roots to mangrove carbon sequestration. *Sci. Total Environ.* 833, 155032. doi: 10.1016/j.scitotenv.2022.155032

Comer-Warner, S. A., Nguyen, A. T. Q., Nguyen, M. N., Wang, M., Turner, A., Le, H., et al. (2022). Restoration impacts on rates of denitrification and greenhouse gas fluxes from tropical coastal wetlands. *Sci. Total Environ.* 803, 149577. doi: 10.1016/j.scitotenv.2021.149577

Damastuti, E., de Groot, R., Debrot, A. O., and Silvius, M. J. (2022). Effectiveness of community-based mangrove management for biodiversity conservation: A case study from central Java, Indonesia. *Trees Forests People.* 7, 100202. doi: 10.1016/j.tfp.2022.100202

da Rosa, C. M., and Marques, M. C. M. (2022). How are biodiversity and carbon stock recovered during tropical forest restoration? Supporting the ecological paradigms and political context involved. *J. Nat. Conserv.* 65, 126115. doi: 10.1016/j.jnc.2021.126115

delos Santos, K. A., Avtar, R., Salmo, S., and Fujii, M. (2022). "Assessment of mangrove colonization of aquaculture ponds through satellite image analysis: Implications for mangrove management," in *Assessing, mapping and modelling mangrove ecosystem services in the Asia-pacific region*. Eds. R. Dasgupta (Singapore: Springer Nature). doi: 10.1007/978-981-19-2738-6_3

Díaz, S., Zafra-Calvo, N., Purvis, A., Verburg, P. H., Obura, D., Leadley, P., et al. (2020). Set ambitious goals for biodiversity and sustainability. *Sci. (1979)* 370, 411–413. doi: 10.1126/science.abe1530

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., and Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* 4, 293–297. doi: 10.1038/ngeo1123

Duncan, C., Primavera, J. H., Pettorelli, N., Thompson, J. R., Loma, R. J. A., and Koldewey, H. J. (2016). Rehabilitating mangrove ecosystem services: A case study on the relative benefits of abandoned pond reversion from panay island, Philippines. *Mar. pollut. Bull.* 109, 772–782. doi: 10.1016/j.marpolbul.2016.05.049

Egan, D., Hjerpe, E., and Abrams, J. (2011). *Human dimensions of ecological restoration: Integrating science, nature, and culture* (Washington D.C: Island Press).

Eger, A. M., Earp, H. S., Friedman, K., Gatt, Y., Hagger, V., Hancock, B., et al. (2022). The need, opportunities, and challenges for creating a standardized framework for marine restoration monitoring and reporting. *Biol. Conserv.* 266, 109429. doi: 10.1016/j.biocon.2021.109429

Ellison, A. M., Felson, A. J., and Friess, D. A. (2020). Mangrove rehabilitation and restoration as experimental adaptive management. *Front. Mar. Sci.* 7. doi: 10.3389/FMARS.2020.00327/BIBTEX

Estoque, R. C., Myint, S. W., Wang, C., Ishtiaque, A., Aung, T. T., Emerton, L., et al. (2018). Assessing environmental impacts and change in myanmar's mangrove ecosystem service value due to deforestation, (2000–2014). *Glob. Change Biol.* 24, 5391–5410. doi: 10.1111/gcb.14409

Friess, D. A., Gatt, Y. M., Ahmad, R., Brown, B. M., Sidik, F., and Wodehouse, D. (2022). Achieving ambitious mangrove restoration targets will need a transdisciplinary and evidence-informed approach. *One Earth* 5, 456–460. doi: 10.1016/j.oneear.2022.04.013

Friess, D. A., Richards, D. R., and Phang, V. X. H. (2016). Mangrove forests store high densities of carbon across the tropical urban landscape of Singapore. *Urban Ecosyst.* 19, 795–810. doi: 10.1007/s11252-015-0511-3

Friess, D. A., Yando, E. S., Alemu, J. B., Wong, L.-W., Soto, S. D., and Bhatia, N. (2020)Chapter 3 ecosystem services and disservices of mangrove forests and salt marshes. In: *Oceanography and marine biology* (Taylor & Francis). Available at: https://library.oapen.org/handle/20.500.12657/43146 (Accessed May 26, 2022).

Gandhi, S., and Jones, T. G. (2019). Identifying mangrove deforestation hotspots in south Asia, southeast Asia and Asia-pacific. *Remote Sens.* 11, 728. doi: 10.3390/RS11060728

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., et al. (2019). International principles and standards for the practice of ecological restoration. 2nd edition. *Restor. Ecol.* 27, S1–S46. doi: 10.1111/rec.13035

Garcia, K. B., Malabrigo, P. L., and Gevaña, D. T. (2014). "Philippines' mangrove ecosystem: status, threats and conservation," in *Mangrove ecosystems of Asia* (New York, NY: Springer New York), 81–94. doi: 10.1007/978-1-4614-8582-7_5

Gatt, Y. M., Andradi-Brown, D. A., Ahmadia, G. N., Martin, P. A., Sutherland, W. J., Spalding, M. D., et al. (2022). Quantifying the reporting, coverage and consistency of key indicators in mangrove restoration projects. *Front. For. Glob. Change* 5. doi: 10.3389/ffgc.2022.720394

Gevaña, D. T., Camacho, L. D., and Pulhin, J. M. (2018). Conserving mangroves for their blue carbon: Insights and prospects for community-based mangrove management in southeast Asia *Threats to Mangrove Forests, Coastal Research Library 25* C. Makowski and C. W. Frinkl (Cham, Switzerland: Springer Cham). 579–588. doi: 10.1007/978-3-319-73016-5_26

Giri, C., Zhu, Z., Tieszen, L. L., Singh, A., Gillette, S., and Kelmelis, J. A. (2008). Mangrove forest distributions and dynamics, (1975–2005) of the tsunami-affected region of Asia. *J. Biogeogr.* 35, 519–528. doi: 10.1111/j.1365-2699.2007.01806.x

Goessens, A., Satyanarayana, B., van der Stocken, T., Quispe Zuniga, M., Mohd-Lokman, H., Sulong, I., et al. (2014). Is matang mangrove forest in Malaysia sustainably rejuvenating after more than a century of conservation and harvesting management? *PloS One.* 9, e105069. doi: 10.1371/journal.pone.0105069

Gopalakrishnan, L., Satyanarayana, B., Chen, D., Wolswijk, G., Amir, A. A., Vandegehuchte, M., et al. (2021). Using historical archives and landsat imagery to explore changes in the mangrove cover of peninsular Malaysia between 1853 and 2018. *Remote Sens.* 13, 3403. doi: 10.3390/rs13173403

Guan, Y., Kang, R., and Liu, J. (2019). Evolution of the field of ecological restoration over the last three decades: A bibliometric analysis. *Restor. Ecol.* 27, 647–660. doi: 10.1111/REC.12899

Hai, N. T., Dell, B., Phuong, V. T., and Harper, R. J. (2020). Towards a more robust approach for the restoration of mangroves in Vietnam. *Ann. For. Sci.* 77, 1–18. doi: 10.1007/s13595-020-0921-0

Hamdan, O., Khali Aziz, H., and Mohd Hasmadi, I. (2014). L-band ALOS PALSAR for biomass estimation of matang mangroves, Malaysia. *Remote Sens. Enviro.* 155, 69–78. doi: 10.1016/j.rse.2014.04.029

Hashim, R., Kamali, B., Tamin, N. M., and Zakaria, R. (2010). An integrated approach to coastal rehabilitation: Mangrove restoration in sungai haji dorani, Malaysia. *Estuar. Coast. Shelf Sci.* 86, 118–124. doi: 10.1016/j.ecss.2009.10.021

Heberling, J. M., Miller, J. T., Noesgaard, D., Weingart, S. B., and Schigel, D. (2021). Data integration enables global biodiversity synthesis. *Proc. Natl. Acad. Sci.* 118, 1–7. doi: 10.1073/pnas.2018093118

Herr, D., Blum, J., Himes-Cornell, A., and Sutton-Grier, A. (2019). An analysis of the potential positive and negative livelihood impacts of coastal carbon offset projects. *J. Environ. Manage.* 235, 463–479. doi: 10.1016/j.jenvman.2019.01.067

Hochard, J. P., Hamilton, S., and Barbier, E. B. (2019). Mangroves shelter coastal economic activity from cyclones. *Proc. Natl. Acad. Sci. U.S.A.* 116, 12232–12237. doi: 10.1073/pnas.1820067116

Ho, Y. S., and Mukul, S. A. (2021). Publication performance and trends in mangrove forests: A bibliometric analysis. *Sustainability.* 13, 12532. doi: 10.3390/SU132212532

Hong, P. (2001). Reforestation of mangroves after severe impacts of herbicides during the Vietnam war: The case of can gio. *Unasylva.* 52 (207), 57–60. Available at: https://www.fao.org/3/y2795e/y2795e11.htm.

Howard, J., Sutton-Grier, A., Herr, D., Kleypas, J., Landis, E., Mcleod, E., et al. (2017). Clarifying the role of coastal and marine systems in climate mitigation. *Front. Ecol. Environ.* 15, 42–50. doi: 10.1002/fee.1451

Hughes, A. C. (2017). Understanding the drivers of southeast Asian biodiversity loss. *Ecosphere.* 8, e01624. doi: 10.1002/ecs2.1624

Ilman, M., Dargusch, P., and Dart, P. (2016). A historical analysis of the drivers of loss and degradation of indonesia's mangroves. *Land Use Policy.* 54, 448–459. doi: 10.1016/J.LANDUSEPOL.2016.03.010

Ilman, M., Wibisono, I. T. C., and Suryadiputra, I. N. N. (2011). *State of the art information on mangrove ecosystems in Indonesia* (Bogor, Indonesia: Wetlands International - Indonesia Programme). Available at: https://indonesia.wetlands.org/publications/state-of-the-art-information-on-mangrove-ecosystems-in-indonesia/

Iyandemye, J., and Thomas, M. P. (2019). Low income countries have the highest percentages of open access publication: A systematic computational analysis of the biomedical literature. *PloS One*. 14, e0220229. doi: 10.1371/journal.pone.0220229

Jordan, P., and Fröhle, P. (2022). Bridging the gap between coastal engineering and nature conservation? *J. Coast. Conserv*. 26, 4. doi: 10.1007/s11852-021-00848-x

Kamali, B., and Hashim, R. (2011). Mangrove restoration without planting. *Ecol. Eng.* 37, 387–391. doi: 10.1016/J.ECOLENG.2010.11.025

Kathiresan, K., and Rajendran, N. (2005). Coastal mangrove forests mitigated tsunami. *Estuar. Coast. Shelf Sci.* 65, 601–606. doi: 10.1016/j.ecss.2005.06.022

Katon, B. M., and Pomeroy, R. S. (2000). Rehabilitating the mangrove resources of cogtong bay, Philippines: A comanagement perspective. *Coast. Manage.* 28, 29–37. doi: 10.1080/089207500263620

Ken, S., Entani, T., Tsusaka, T. W., and Sasaki, N. (2020). Effect of REDD+ projects on local livelihood assets in keo seima and oddar meanchey, Cambodia. *Heliyon*. 6, e03802. doi: 10.1016/J.HELIYON.2020.E03802

Kodikara, K. A. S., Mukherjee, N., Jayatissa, L. P., Dahdouh-Guebas, F., and Koedam, N. (2017). Have mangrove restoration projects worked? An in-depth study in Sri Lanka. *Restor. Ecol.* 25, 705–716. doi: 10.1111/rec.12492

Kusumaningtyas, M. A., Kepel, T. L., Solihuddin, T., Lubis, A. A., Putra, A. D. P., Sugiharto, U., et al. (2022). Carbon sequestration potential in the rehabilitated mangroves in Indonesia. *Ecol. Res.* 37, 80–91. doi: 10.1111/1440-1703.12279

Lai, S., Loke, L. H. L., Hilton, M. J., Bouma, T. J., and Todd, P. A. (2015). The effects of urbanisation on coastal habitats and the potential for ecological engineering: A Singapore case study. *Ocean Coast. Manage.* 103, 78–85. doi: 10.1016/j.ocecoaman.2014.11.006

Lee, S. Y., Hamilton, S., Barbier, E. B., Primavera, J., and Lewis, R. R. (2019). Better restoration policies are needed to conserve mangrove ecosystems. *Nat. Ecol. Evol.* 3 (6), 870–872. doi: 10.1038/s41559-019-0861-y

Lewis, R. R. (2000). Ecologically based goal setting in mangrove forest and tidal marsh restoration. *Ecol. Eng.* 15, 191–198. doi: 10.1016/S0925-8574(00)00070-7

Lewis, R. R., Brown, B. M., and Flynn, L. L. (2019). "Methods and criteria for successful mangrove forest rehabilitation," in *Coastal wetlands* (Amsterdam, Netherlands: Elsevier), 863–887. doi: 10.1016/B978-0-444-63893-9.00024-1

Le Xuan, T., le Manh, H., Ba, H. T., Van, D., Duong Vu, H. T., Wright, D., et al. (2022). Wave energy dissipation through a hollow triangle breakwater on the coastal Mekong delta. *Ocean Eng.* 245, 110419. doi: 10.1016/j.oceaneng.2021.110419

Lin, R., Yu, S., and Hong, B. (2022). Socioeconomic patterns for global mangrove cover changes with multi-database analyses. *Wetlands* 42, 16. doi: 10.1007/s13157-022-01535-9

Long, J., Napton, D., Giri, C., and Graesser, J. (2014). A mapping and monitoring assessment of the philippines' mangrove forests from 1990 to 2010. *J. Coast. Res.* 30, 260–271. doi: 10.2112/JCOASTRES-D-13-00057.1

Lovelock, C. E., and Brown, B. M. (2019). Land tenure considerations are key to successful mangrove restoration. *Nat. Ecol. Evol.* 3, 1135. doi: 10.1038/s41559-019-0942-y

Luo, J., Sun, Z., Lu, L., Xiong, Z., Cui, L., and Mao, Z. (2022). Rapid expansion of coastal aquaculture ponds in southeast Asia: Patterns, drivers and impacts. *J. Environ. Manage.* 315, 115100. doi: 10.1016/j.jenvman.2022.115100

Macintosh, D. J., Ashton, E. C., and Havanon, S. (2002). Mangrove rehabilitation and intertidal biodiversity: a study in the ranong mangrove ecosystem, Thailand. *Estuar. Coast. Shelf Sci.* 55, 331–345. doi: 10.1006/ecss.2001.0896

Macreadie, P. I., Robertson, A. I., Spinks, B., Adams, M. P., Atchison, J. M., Bell-James, J., et al. (2022). Operationalizing marketable blue carbon. *One Earth*. 5, 485–492. doi: 10.1016/j.oneear.2022.04.005

Maina, J. M., Bosire, J. O., Kairo, J. G., Bandeira, S. O., Mangora, M. M., Macamo, C., et al. (2021). Identifying global and local drivers of change in mangrove cover and the implications for management. *Glob. Ecol. Biogeogr.* 30, 2057–2069. doi: 10.1111/geb.13368

Martin, F., Dutrieux, É., and Debry, A. (1990). Natural recolonization of a chronically oil-polluted mangrove soil after a de-pollution process. *Ocean Shoreline Manage.* 14, 173–190. doi: 10.1016/0951-8312(90)90033-E

Matheka, D., Nderitu, J., Mutonga, D., Otiti, M., Siegel, K., and Demaio, A. (2014). Open access: academic publishing and its implications for knowledge equity in Kenya. *Glob. Health*. 10, 26. doi: 10.1186/1744-8603-10-26

Matsui, N., Suekuni, J., Havanond, S., Nishimiya, A., Yanai, J., and Kosaki, T. (2008). Determination of soil-related factors controlling initial mangrove (*Rhizophora apiculata* BL.) growth in an abandoned shrimp pond. *Soil Sci. Plant Nutr.* 54, 301–309. doi: 10.1111/j.1747-0765.2007.00238.x

Matsui, N., Suekuni, J., Nogami, M., Havanond, S., and Salikul, P. (2010). Mangrove rehabilitation dynamics and soil organic carbon changes as a result of full hydraulic restoration and re-grading of a previously intensively managed shrimp pond. *Wetl. Ecol. Manage.* 18, 233–242. doi: 10.1007/s11273-009-9162-6

Mohd Razali, S., Radzi, M. A., Marin, A., and Samdin, Z. (2021). A bibliometric analysis of tropical mangrove forest land use change from 2010 to 2020. *Environ. Dev. Sustain*. doi: 10.1007/s10668-021-01935-7

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., and Group, T. P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PloS Med.* 6, e1000097. doi: 10.1371/JOURNAL.PMED.1000097

Mursyid, H., Daulay, M. H., Pratama, A. A., Laraswati, D., Novita, N., Malik, A., et al. (2021). Governance issues related to the management and conservation of mangrove ecosystems to support climate change mitigation actions in Indonesia. *For. Policy Econ.* 133, 1–6. doi: 10.1016/j.forpol.2021.102622

Nam, V. N., Sasmito, S. D., Murdiyarso, D., Purbopuspito, J., and MacKenzie, R. A. (2016). Carbon stocks in artificially and naturally regenerated mangrove ecosystems in the Mekong delta. *Wetl. Ecol. Manage.* 24, 231–244. doi: 10.1007/S11273-015-9479-2

Nawari, ., Syahza, A., and Siregar, Y. I. (2021). Community-based mangrove forest management as ecosystem services provider for reducing CO_2 emissions with carbon credit system in bengkalis district, riau, Indonesia. *J. Phys. Conf. Ser.* 2049, 12074. doi: 10.1088/1742-6596/2049/1/012074

Nguyen, T. P. (2018). Melaleuca entrapping microsites as a nature-based solution to coastal erosion: A pilot study in kien giang, Vietnam. *Ocean Coast. Manage.* 155, 98–103. doi: 10.1016/j.ocecoaman.2018.02.005

Nguyen, H. Y. T., Cao, D. M., and Schmitt, K. (2013). Soil particle-size composition and coastal erosion and accretion study in soc trang mangrove forests. *J. Coast. Conserv.* 17, 93–104. doi: 10.1007/s11852-012-0221-4

Noor, N. M., and Abdul Maulud, K. N. (2022). Coastal vulnerability: A brief review on integrated assessment in southeast Asia. *J. Mar. Sci. Eng.* 10, 595. doi: 10.3390/jmse10050595

Oka, S., Doi, H., Miyamoto, K., Hanahara, N., Sado, T., and Miya, M. (2021). Environmental DNA metabarcoding for biodiversity monitoring of a highly diverse tropical fish community in a coral reef lagoon: Estimation of species richness and detection of habitat segregation. *Environ. DNA*. 3, 55–69. doi: 10.1002/edn3.132

Ong, S. (2021). Southeast Asian countries join forces for scientific strength. *Nature*. 591, S30–S32. doi: 10.1038/d41586-021-00670-3

Orchard, S. E., Stringer, L. C., and Quinn, C. H. (2016). Mangrove system dynamics in southeast Asia: Linking livelihoods and ecosystem services in Vietnam. *Reg. Environ. Change*. 16, 865–879. doi: 10.1007/s10113-015-0802-5

Palis, H., Pasicolan, S., and Villamor, C. (2014). *Proceedings of the 1st ASEAN congress on mangrove research and development, 3-7 December 2012, Manila, Philippines*. Eds. H. G. Palis, S. A. Pasicolan and C. I. Villamor (Metro Manila, Philippines: Department of Environment and Natural Resources - Biodiversity Management Bureau and Conservation International Philippines). Available at: https://erdb.denr.gov.ph/wp-content/uploads/2015/06/asean_mangrove_proceedings.pdf

Piwowar, H., Priem, J., Larivière, V., Alperin, J. P., Matthias, L., Norlander, B., et al. (2018). The state of OA: A large-scale analysis of the prevalence and impact of open access articles. *PeerJ*. 6, e4375. doi: 10.7717/peerj.4375

Polanco Fernández, A., Marques, V., Fopp, F., Juhel, J., Borrero-Pérez, G. H., Cheutin, M., et al. (2021). Comparing environmental DNA metabarcoding and underwater visual census to monitor tropical reef fishes. *Environ. DNA*. 3, 142–156. doi: 10.1002/edn3.140

Polidoro, B. A., Carpenter, K. E., Collins, L., Duke, N. C., Ellison, A. M., Ellison, J. C., et al. (2010). The loss of species: Mangrove extinction risk and geographic areas of global concern. *PloS One*. 5, e10095. doi: 10.1371/JOURNAL.PONE.0010095

Powell, M. A. (2021). Singapore's lost coast: Land reclamation, national development and the erasure of human and ecological communities 1822-present. *Environ. Hist.* 27, 635–663. doi: 10.3197/096734019X15631846928710

Primavera, J. H. (1995). Mangroves and brackishwater pond culture in the Philippines. *Hydrobiologia*. 295, 303–309. doi: 10.1007/BF00029137

Primavera, J. H. (2000). Development and conservation of Philippine mangroves: institutional issues. *Ecol. Econ.* 35, 91–106. doi: 10.1016/S0921-8009(00)00170-1

Primavera, J. H., dela Cruz, M., Montilijao, C., Consunji, H., dela Paz, M., Rollon, R. N., et al. (2016). Preliminary assessment of post-haiyan mangrove damage and short-term recovery in Eastern samar, central Philippines. *Mar. pollut. Bull.* 109, 744–750. doi: 10.1016/J.MARPOLBUL.2016.05.050

Primavera, J. H., and Esteban, J. M. A. (2008). A review of mangrove rehabilitation in the Philippines: Successes, failures and future prospects. *Wetlands Ecol. Manage.* 16, 345–358. doi: 10.1007/s11273-008-9101-y

Primavera, J. H., Friess, D. A., van Lavieren, H., and Lee, S. Y. (2019). "The mangrove ecosystem," in *World seas: An environmental evaluation* (London, UK: Elsevier), 1–34. doi: 10.1016/B978-0-12-805052-1.00001-2

Primavera, J., Rollon, R., and Samson, M. (2011). "The pressing challenges of mangrove rehabilitation: pond reversion and coastal protection," in *Treatise on estuarine and coastal science*. Eds. E. Wolanski and D. McLusky (Waltham, MA, USA: Waltham: Academic Press), 217–244.

Primavera, J. H., Savaris, J. P., Bajoyo, B. E., Coching, J. D., Curnick, D. J., Golbeque, R. L., et al. (2012). *Manual on community-based mangrove rehabilitation*

– *mangrove manual series no. 1* (Iloilo, Philippines: Zoological Society of London-Philippines).

Quevedo, J. M. D., Uchiyama, Y., and Kohsaka, R. (2020). Perceptions of local communities on mangrove forests, their services and management: Implications for eco-DRR and blue carbon management for Eastern samar, Philippines. *J. For. Res.* 25, 1–11. doi: 10.1080/13416979.2019.1696441

Quevedo, J. M. D., Uchiyama, Y., and Kohsaka, R. (2021a). A blue carbon ecosystems qualitative assessment applying the DPSIR framework: Local perspective of global benefits and contributions. *Mar. Policy*. 128, 104462. doi: 10.1016/j.marpol.2021.104462

Quevedo, J. M. D., Uchiyama, Y., and Kohsaka, R. (2021b). Local perceptions of blue carbon ecosystem infrastructures in panay island, Philippines. *Coast. Eng.* 63, 227–247. doi: 10.1080/21664250.2021.1888558

Reddy, C. S. (2021). Remote sensing of biodiversity: What to measure and monitor from space to species? *Biodivers. Conserv.* 30, 2617–2631. doi: 10.1007/s10531-021-02216-5

Richards, D. R., and Friess, D. A. (2016). Rates and drivers of mangrove deforestation in southeast Asia 2000-2012. *Proc. Natl. Acad. Sci. U.S.A.* 113, 344–349. doi: 10.1073/PNAS.1510272113/-/DCSUPPLEMENTAL

Ridlo, I. A., Kurniawan, N., and Retnaningdyah, C. (2020). Communities structure of fish in some mangrove ecosystem as a result of the restoration in southern beach of malang, East Java Indonesia. *J. Phys. Conf. Ser.* 1665, 12020. doi: 10.1088/1742-6596/1665/1/012020

Rittibhonbhun, N., Chansanoh, P., Tongrak, S., and Suwannatchote, R. (1993). *Community-based mangrove rehabilitation and management: A case study in sikao district, trang province, southern Thailand* (Regional Development Dialogue) 14, 111–124.

Romañach, S. S., DeAngelis, D. L., Koh, H. L., Li, Y., Teh, S. Y., Raja Barizan, R. S., et al. (2018). Conservation and restoration of mangroves: Global status, perspectives, and prognosis. *Ocean Coast. Manage.* 154, 72–82. doi: 10.1016/j.ocecoaman.2018.01.009

Salem, M. E., and Mercer, D. E. (2012). The economic value of mangroves: a meta-analysis. *Sustainability*. 4, 359–383. doi: 10.3390/su4030359

Salmo, S. G. (2019) *Mangrove blue carbon in the Verde island passage. nature is 30 (Climate strategy)* (Conservation International Philippines). Available at: https://archium.ateneo.edu/es-faculty-pubs (Accessed February 7, 2022).

Salmo, S. G. (2021). "Assessment of typhoon impacts and post-typhoon recovery in Philippine mangroves: lessons and challenges for adaptive management," in *Dynamic sedimentary environments of mangrove coasts* (Amsterdam, Netherlands: Elsevier), 539–562. doi: 10.1016/B978-0-12-816437-2.00022-7

Salmo, S. G., Gevaña, G. D. T., Halun, S. Z. B., Castillo, J. A. A., Nuñez, E. A.Jr., Pangilinan, M. J. M., et al. (2021). *Revisiting learnings and envisioning Philippine mangroves in 2030: Proceedings of the 1st national state of the mangrove summit* (Metro Manila, Philippines: Department of Environment and Natural Resources - Biodiversity Management Bureau and Conservation International Philippines).

Salmo, S. G., and Gianan, E. L. D. (2019). Post-disturbance carbon stocks and rates of sequestration: Implications on "blue carbon" estimates in Philippine mangroves. *Philippine Sci. Lett.* 12, 122–132. Available at: https://www.philsciletters.net/2019/PSL%202019-vol12-no02-p122-132-Salmo%20and%20Gianan.pdf.

Salmo, S. G., Lovelock, C., and Duke, N. C. (2013). Vegetation and soil characteristics as indicators of restoration trajectories in restored mangroves. *Hydrobiologia*. 720, 1–18. doi: 10.1007/s10750-013-1617-3

Salmo, S. G., Tibbetts, I., and Duke, N. C. (2017). Colonization and shift of mollusc assemblages as a restoration indicator in planted mangroves in the Philippines. *Biodivers. Conserv.* 26, 865–881. doi: 10.1007/s10531-016-1276-6

Salmo, S. G., Tibbetts, I. R., and Duke, N. C. (2018). Nekton communities as indicators of habitat functionality in Philippine mangrove plantations. *Mar. Freshw. Res.* 69, 477–485. doi: 10.1071/MF17116

Sannigrahi, S., Zhang, Q., Pilla, F., Joshi, P. K., Basu, B., Keesstra, S., et al. (2020). Responses of ecosystem services to natural and anthropogenic forcings: A spatial regression based assessment in the world's largest mangrove ecosystem. *Sci. Total Environ.* 715, 137004. doi: 10.1016/j.scitotenv.2020.137004

Sartimbul, A., Ningtias, S. W., Dewi, C. S. U., Rahman, M. A. A., Yona, D., Sari, S. H. J., et al. (2021). Monitoring of sedimentation on geosynthetic bags installation area in banyuurip mangrove center, ujung pangkah, gresik, Indonesia. *ILMU KELAUTAN: Indonesian J. Mar. Sci.* 26, 173–181. doi: 10.14710/ik.ijms.26.3.173-181

Sasmito, S. D., Sillanpää, M., Hayes, M. A., Bachri, S., Saragi-Sasmito, M. F., Sidik, F., et al. (2020). Mangrove blue carbon stocks and dynamics are controlled by hydrogeomorphic settings and land-use change. *Glob. Change Biol.* 26, 3028–3039. doi: 10.1111/gcb.15056

Schmitt, K., Albers, T., Pham, T. T., and Dinh, S. C. (2013). Site-specific and integrated adaptation to climate change in the coastal mangrove zone of soc trang province, Viet nam. *J. Coast. Conserv.* 17, 545–558. doi: 10.1007/s11852-013-0253-4

Sharma, S., MacKenzie, R. A., Tieng, T., Soben, K., Tulyasuwan, N., Resanond, A., et al. (2020). The impacts of degradation, deforestation and restoration on mangrove ecosystem carbon stocks across Cambodia. *Sci. Total Environ.* 706, 135416. doi: 10.1016/j.scitotenv.2019.135416

Sharma, S., Nadaoka, K., Nakaoka, M., Uy, W. H., MacKenzie, R. A., Friess, D. A., et al. (2017). Growth performance and structure of a mangrove afforestation project on a former seagrass bed, Mindanao island, Philippines. *Hydrobiologia*. 803, 359–371. doi: 10.1007/s10750-017-3252-x

Sidik, F., Fernanda Adame, M., and Lovelock, C. E. (2019). Carbon sequestration and fluxes of restored mangroves in abandoned aquaculture ponds. *J. Indian Ocean Reg.* 15, 177–192. doi: 10.1080/19480881.2019.1605659

Sillanpää, M., Vantellingen, J., and Friess, D. A. (2017). Vegetation regeneration in a sustainably harvested mangrove forest in West Papua, Indonesia. *For. Ecol. Manage.* 390, 137–146. doi: 10.1016/j.foreco.2017.01.022

10.3389/fmars.2022.95147110.3389/fmars.2022.921542 w/CCSlamet, N. S., Dargusch, P., Aziz, A. A., and Wadley, D. (2020). Mangrove vulnerability and potential carbon stock loss from land reclamation in Jakarta bay, Indonesia. *Ocean Coast. Manage.* 195, 105283. doi: 10.1016/j.ocecoaman.2020.105283

Sodhi, N. S., Posa, M. R. C., Lee, T. M., Bickford, D., Koh, L. P., and Brook, B. W. (2010). The state and conservation of southeast Asian biodiversity. *Biodivers. Conserv.* 19, 317–328. doi: 10.1007/s10531-009-9607-5

Song, A. M., Dressler, W. H., Satizábal, P., and Fabinyi, M. (2021). From conversion to conservation to carbon: The changing policy discourse on mangrove governance and use in the Philippines. *J. Rural Stud.* 82, 184–195. doi: 10.1016/j.jrurstud.2021.01.008

Spalding, M., Kainuma, M., and Collins, L. (2010). *World atlas of mangroves* (London: Earthscan). doi: 10.4324/9781849776608

Spalding, M. D., and Leal, M. (2021) *The state of the world's mangroves* (Global Mangrove Alliance). Available at: https://www.mangrovealliance.org/mangrove-forests/ (Accessed November 8, 2021).

Spalding, M., and Parrett, C. L. (2019). Global patterns in mangrove recreation and tourism. *Mar. Policy*. 110, 103540. doi: 10.1016/j.marpol.2019.103540

Suman, D. O. (2019). "Mangrove management," in *Coastal wetlands* (Amsterdam, Netherlands: Elsevier), 1055–1079. doi: 10.1016/B978-0-444-63893-9.00031-9

Suripin, S., Sugianto, D., and Helmi, M. (2017). Coastal restoration with environmentally friendly permeable breakwater. *Advanced Sci. Lett.* 23, 2323–2325. doi: 10.1166/asl.2017.8733

Su, J., Yin, B., Chen, L., and Gasparatos, A. (2022). Priority areas for mixed-species mangrove restoration: the suitable species in the right sites. *Environ. Res. Lett.* 17, 065001. doi: 10.1088/1748-9326/ac6b48

Taddeo, S., and Dronova, I. (2018). Indicators of vegetation development in restored wetlands. *Ecol. Indic.* 94, 454–467. doi: 10.1016/j.ecolind.2018.07.010

Tanaka, N., Sasaki, Y., Mowjood, M. I. M., Jinadasa, K. B. S. N., and Homchuen, S. (2007). Coastal vegetation structures and their functions in tsunami protection: Experience of the recent Indian ocean tsunami. *Landsc. Ecol. Eng.* 3, 33–45. doi: 10.1007/s11355-006-0013-9

Tan, Y.-L., Chen, J.-E., Yiew, T.-H., and Habibullah, M. S. (2022). Habitat change and biodiversity loss in south and southeast Asian countries. *Environ. Sci. pollut. Res.* doi: 10.1007/s11356-022-20054-y

Teutli-Hernández, C., Herrera-Silveira, J. A., Cisneros-de la Cruz, D. J., and Román-Cuesta, R. (2020). *Mangrove ecological restoration guide: Lessons learned. mainstreaming wetlands into the climate agenda: A multilevel approach (SWAMP).* (Bogor, Indonesia: CIFOR/CINVESTAV-IPN/UNAM-Sisal/PMC)42p.

Thakur, S., Mondal, I., Bar, S., Nandi, S., Ghosh, P. B., Das, P., et al. (2021). Shoreline changes and its impact on the mangrove ecosystems of some islands of Indian sundarbans, north-East coast of India. *J. Clean. Prod.* 284, 124764. doi: 10.1016/j.jclepro.2020.124764

Thampanya, U., Vermaat, J. E., Sinsakul, S., and Panapitukkul, N. (2006). Coastal erosion and mangrove progradation of southern Thailand. *Estuar. Coast. Shelf Sci.* 68, 75–85. doi: 10.1016/j.ecss.2006.01.011

Then, A. Y.-H., Adame, M. F., Fry, B., Chong, V. C., Riekenberg, P. M., Mohammad Zakaria, R., et al. (2021). Stable isotopes clearly track mangrove inputs and food web changes along a reforestation gradient. *Ecosystems*. 24, 939–954. doi: 10.1007/s10021-020-00561-0

Thieu Quang, T., and Mai Trong, L. (2020). Monsoon wave transmission at bamboo fences protecting mangroves in the lower Mekong delta. *Appl. Ocean Res.* 101, 102259. doi: 10.1016/j.apor.2020.102259

Thompson, B. S. (2018). The political ecology of mangrove forest restoration in Thailand: Institutional arrangements and power dynamics. *Land Use Policy*. 78, 503–514. doi: 10.1016/j.landusepol.2018.07.016

Thompson, B. S., Primavera, J. H., and Friess, D. A. (2017). Governance and implementation challenges for mangrove forest payments for ecosystem services (PES): Empirical evidence from the Philippines. *Ecosyst. Serv.* 23, 146–155. doi: 10.1016/J.ECOSER.2016.12.007

Tinh, P. H., MacKenzie, R. A., Hung, T. D., Hanh, N. T. H., Hanh, N. H., Manh, D. Q., et al. (2022). Distribution and drivers of Vietnam mangrove deforestation from 1995 to 2019 *Mitig. Adapt. Strateg. Glob. Change* 27, 29. doi: 10.1007/s11027-022-10005-w

Ulfa, M., Ikejima, K., Poedjirahajoe, E., Faida, L. R. W., and Harahap, M. M. (2018). Effects of mangrove rehabilitation on density of Scylla spp. (mud crabs) in Kuala langsa, aceh, Indonesia. *Reg. Stud. Mar. Sci.* 24, 296–302. doi: 10.1016/j.rsma.2018.09.005

Valenzuela, R. B., Yeo-Chang, Y., Park, M. S., and Chun, J.-N. (2020). Local people's participation in mangrove restoration projects and impacts on social capital and livelihood: a case study in the Philippines. *Forests* 11, 580. doi: 10.3390/f11050580

Valiela, I., Bowen, J. L., and York, J. K. (2001). Mangrove forests: One of the world's threatened major tropical environments: At least 35% of the area of mangrove forests has been lost in the past two decades, losses that exceed those for tropical rain forests and coral reefs, two other well-known threatened environments. *BioScience*. 51, 807–815. doi: 10.1641/0006-3568(2001)051[0807:MFOOTW]2.0.CO;2

Villamayor, B. M. R., Rollon, R. N., Samson, M. S., Albano, G. M. G., and Primavera, J. H. (2016). Impact of haiyan on Philippine mangroves: Implications to the fate of the widespread monospecific rhizophora plantations against strong typhoons. *Ocean Coast. Manag.* 132, 1–14. doi: 10.1016/j.ocecoaman.2016.07.011

Walters, B. B. (2003). People and mangroves in the Philippines: fifty years of coastal environmental change. *Environ. Conserv.* 30, 293–303. doi: 10.1017/S0376892903000298

Waltham, N. J., Elliott, M., Lee, S. Y., Lovelock, C., Duarte, C. M., Buelow, C., et al. (2020). UN Decade on ecosystem restoration 2021–2030—What chance for success in restoring coastal ecosystems? *Front. Mar. Sci.* 7. doi: 10.3389/FMARS.2020.00071/BIBTEX

Wee, A. K. S., Mori, G. M., Lira, C. F., Núñez-Farfán, J., Takayama, K., Faulks, L., et al. (2019). The integration and application of genomic information in mangrove conservation. *Conserv. Biol.* 33, 206–209. doi: 10.1111/cobi.13140

Wernick, I. K., and Kauppi, P. E. (2022). Storing carbon or growing forests? *Land Use Policy*. 121, 106319. doi: 10.1016/j.landusepol.2022.106319

Winterwerp, J. C., Albers, T., Anthony, E. J., Friess, D. A., Mancheño, A. G., Moseley, K., et al. (2020). Managing erosion of mangrove-mud coasts with permeable dams – lessons learned. *Ecol. Eng.* 158, 106078. doi: 10.1016/j.ecoleng.2020.106078

Winterwerp, J. C., Erftemeijer, P. L. A., Suryadiputra, N., van Eijk, P., and Zhang, L. (2013). Defining eco-morphodynamic requirements for rehabilitating eroding mangrove-mud coasts. *Wetlands*. 33, 515–526. doi: 10.1007/s13157-013-0409-x

Wodehouse, D. C. J., and Rayment, M. B. (2019). Mangrove area and propagule number planting targets produce sub-optimal rehabilitation and afforestation outcomes. *Estuar. Coast. Shelf Sci.* 222, 91–102. doi: 10.1016/j.ecss.2019.04.003

Worthington, T., and Spalding, M. (2018). *Mangrove restoration potential: A global map highlighting a critical opportunity*. (Virginia, USA: IUCN/The Nature Conservancy/University of Cambridge). doi: 10.17863/CAM.39153

Zari, M. P., Kiddle, G. L., Blaschke, P., Gawler, S., and Loubser, D. (2019). Utilising nature-based solutions to increase resilience in pacific ocean cities. *Ecosyst. Serv.* 38, 100968. doi: 10.1016/j.ecoser.2019.100968

Zhang, Y. S., Cioffi, W. R., Cope, R., Daleo, P., Heywood, E., Hoyt, C., et al. (2018). A global synthesis reveals gaps in coastal habitat restoration research. *Sustainability (Switzerland)* 10, 1–15. doi: 10.3390/su10041040