

# Reviewing Mangrove Degradation, Conservation, and Restoration: A Sustainability Nexus Assessment on Myanmar Using the DPSIR Framework

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## ABSTRACT

Mangrove forests are vital for supporting local livelihoods and are an integral component of coastal ecosystems in Myanmar. However, they continue to degrade or even disappear across the country's coastal regions even though rehabilitation processes have been initiated in several regions. Still, little research and systematic inquiry into the drivers of mangrove degradation in Myanmar is available. Against this background, this study identifies the primary forces affecting the mangrove ecosystem and the challenges for mangrove conservation in Myanmar by combining a systematic literature review (SLR) on mangrove change with the Driver-Pressure-State-Impact-Response (DPSIR) analytical framework. We find economic activities, predominantly in agriculture, as the main drivers, resulting in pressure to convert mangroves to other land uses and leading to the degradation of mangrove forests and loss of mangrove ecosystem services. However, the regional patterns of crop production, firewood, and charcoal consumption have remained stable during the recent past. Further ground data measurements are still necessary to identify the primary factors causing mangrove degradation in Myanmar. The most commonly identified research methods were remote sensing methodologies while socio-political approaches were rarely considered in the context of mangrove preservation in Myanmar but are strongly needed in the future. This is underlined by the DPSIR analysis which identified adequate policy responses as a crucial element for mangrove protection and restoration. While a few measures on mangrove reforestation were documented in the literature, their long-term success has not been adequately assessed, including the implications that climate change will have on natural and restored mangrove systems. In the future, more studies on the social and actor-related aspects of mangrove ecosystem management are needed and have to consider the sustainability nexus of ecological goals and socio-economic development, considering all levels.

## KEYWORDS

Mangrove forests; Literature review; DPSIR analysis; Research gaps; Socio-political.

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## 1. INTRODUCTION

Southeast Asia is the region with the highest area covered by mangrove worldwide, but at the same time a global hotspot of mangrove degradation (Goldberg et al., 2020; Thomas et al. 2017). Myanmar is a good example of the environmental and socio-economic importance of mangrove forests, but also their degradation across the region. Mangrove forests cover significant parts of Myanmar's coastline, largely distributed in Ayeyarwady, Tanintharyi, and Rakhine regions, but also parts of the coast in the Mon and Yangon regions, together constituting the third largest mangrove inventories in Southeast Asia after Indonesia and Malaysia (MONREC, 2020). In Myanmar, the mangrove forest offers a variety of ecosystem services for both the coastal environment and local communities. Mangroves purify water entering the Bay of Bengal through

several biogeochemical processes, including the trapping of sand and sediment and acting as a natural filter. They play an important role in the water supply of 1.5 million people along the coastal region (Emerton & Aung, 2013). Mangrove serves as breeding grounds for some fish and shrimp species. White (banana) shrimp (*Penaeus merguensis*), the most significant shrimp species in Myanmar, depend on mangrove forests for shelter during their juvenile phase (Win, 2004). About 43% of coastal people in the Ayeyarwady region of Myanmar rely on mangrove forests and non-timber forest products from mangrove ecosystems (Aye et al, 2019).

In Myanmar, seventy percent of the population resides in rural regions, where agriculture accounts for the primary land use. This is not different in coastal areas, which are predominantly rural. Ayeyarwady has the highest percentage of rural residents, followed by Rakhine along mangrove coastal regions (DOP, 2014). Between 1996 and 2016, the mangrove coverage in many sections of Myanmar's coastline was replaced by alternative land uses, either temporarily or permanently (De Alban et al., 2020). Deforestation led to considerable changes in the coastline and ongoing sediment deposition in the Ayeyarwady delta shoreline, which in turn exacerbated the effects of climate change, including an increase in storm frequency and sea level rise (Anthony et al., 2019). At the same time, imbalanced sediment deposition affected mangrove ecosystems and prevented their recovery. Deforestation also increased carbon dioxide emissions but decreased evapotranspiration (Wang & Myint, 2016). These effects then had an impact on the mangrove ecosystem, altering its biodiversity, microclimate, and susceptibility to storms and sea level rise. This is particularly relevant in a region where tropical cyclones occur every year between May and October, resulting in heavy rainfall and increased environmental hazards, particularly floods (Brakenridge et al., 2017).

Myanmar has established forest protection areas (PAs) since 1982. However, only 2.1 % of the country's surface was included in the protected area, which is below the expected protection level of 3.2 % (Aung, 2007). Additionally, mangrove cover continued to degrade due to unsustainable uses of mangrove forests, despite the initiation of mangrove reforestation programs in 1991 (Oo, 2002). In general, mangrove replanting can enhance soil conditions and establish a well-developed canopy within a relatively short period (Aye & Takeda, 2020). However, the success of this process is not guaranteed as the survival rate of replanted mangroves is dependent on salinity and environmental pressures. The adaptive capacity of mangrove tree species plays a key role in species distribution through topography, water quality, and soil formation in different mangrove ecosystems of Myanmar (Win et al., 2019).

Globally, the United Nations's targeted plan is to restore mangrove cover by at least 20 % by 2030 as compared to severe global mangrove loss of up to 67 % in the past century (<https://mangrovealliance.org/>). In Myanmar, the national government in cooperation with UN Habitat included mangroves in their Master Plan for responding to Climate Change (MONREC, 2019). However, unlike in neighboring countries of Southeast Asia, there is currently neither a UN system-wide cross-country analysis for Myanmar nor a UN Sustainable Development Cooperation Framework for the country. Neither Myanmar's Development Assistance Policy (Ministry of Investment and Foreign Economic Relations) nor the UN Country Programme Document mentions mangroves as a topic for development cooperation, which is certainly related to a shift in priorities due to difficult political circumstances, particularly since the outbreak of civil war in 2021 which is still ongoing. Nevertheless, the Ministry of Natural Resources and Environmental Conservation assigned a key target in 2015 to place at least 10% of mangroves under protection by 2020 (Forest Department, 2015). The government promoted community involvement in mangrove protection through a variety of

initiatives from the Ministry of Environmental Conservation and Forestry. Additionally, local and international NGOs encouraged mangrove plantations to raise local awareness of the issue (Otsuyama et al., 2017). However, despite the considerable benefits that mangrove ecosystems offer to local communities, particularly including higher incomes after the conversion of rice farms and the provision of a wide range of aquacultural products, local people were often unaware of the necessity of preserving mangrove forests (Saw & Kanzaki, 2015). The drivers of deforestation and forest degradation in Myanmar are still complex, having socioeconomic, demographic, and political implications (Tun et al., 2021). As these pressures on the mangrove ecosystem of Myanmar, there is a growing need for a framework to conceptualize the complex sustainability issues and for organizing research that improves the knowledge of how social, ecological, and economic processes interact to lead to sustainable mangrove ecosystems in Myanmar. This study systematically synthesizes mainly scientific, and some verified practical literature on mangrove degradation, conservation, and restoration in Myanmar, and identify the challenges for sustainable mangrove ecosystems in Myanmar. This is done by combining a systematic literature review based on a sustainability nexus assessment (Bleischwitz et al. 2018; Brouwer et al. 2024) of all relevant aspects of mangrove studies with the driver-pressure-impact-state-response (DPSIR) framework.

## 2. MATERIALS AND METHODS

### 2.1 Review method

This review study is based on the systematic literature review following the guideline of the “Preferred Reporting Items for Systematic Reviews and Meta-Analysis” (PRISMA) protocol (Page et al., 2021). The Driver-pressure-state-impact-response (DPISR) framework was used as a structuring tool to extract the key findings from each selected literature. This was done to explain the forces that have influenced changes in mangrove forest cover and to trigger the options for upcoming mangrove forest restoration efforts in Myanmar. DPISR is an analytical framework originally developed by the European Environmental Agency (EEA) in 1999 to understand the forces that drive patterns of ecosystem changes. It was here applied to determine interlinkages between the environmental problem of mangrove degradation to causative ecological and socio-economic factors and solution strategies (Ahmed et al., 2021). Moreover, future studies can consider the potential responses from those that influence the state of variable (such as ecological restoration conditions) from initiative factors underlying drivers and pressure in the DPSIR framework (Lewison et al., 2016). The DPISR approach has been applied to mangrove degradation in Indonesia in a recent literature review by Quevedo et al., (2023) who identified a multiple stressor system as the root cause, but also responses to changes in mangrove forest cover in Indonesia. With the DPSIR framework, Kyere-Boateng & Marek (2021) analyzed the social and ecological causes of forest degradation in Ghana and observed the knowledge and practice gaps related to forest deforestation in Ghana.

In this review, we defined drivers (**D**) as economic, ecological, or political factors that influenced the dynamics of mangrove ecosystems (State (**S**)): resulting in the declaration of mangrove deforestation and reforestation statements. Pressure (**P**) is represented as the consequences of driving forces that cause mangrove ecosystem changes. Impact (**I**) refers to the ecological and economic effects of mangrove forest changes. Response (**R**) were the challenges, suggestions, and/or recommendations for future sustainable mangrove restoration that were extracted from the literature. These

defined indicators were used in extracting key findings from the included literature for this review.

## 2.2 Data collection and screening process

The field of study included all investigations into natural and human influences on mangrove forest ecosystems in Myanmar by analysing the scientific articles, reviews, and grey literature such as project reports and policy documents. The PRISMA protocol was followed throughout the paper screening process (figure 1). Firstly, we searched for all research themes including “mangrove” keywords from three academic databases: Web of Science, Scopus, and the electronic library of TU Dresden by using the search string Title keyword (“mangrove” and “Myanmar”) between April and June 2023. Land use studies in Myanmar’s coastal region that were indirectly connected to the mangrove forest ecosystem were included. Moreover, government reports, project reports, conference articles, and book chapters that are directly or indirectly related to mangrove forests were included by purposely searching for ‘mangrove and Myanmar’ keywords through Google search.

A total of 277 references from peer-reviewed journals and grey literature specially related to the mangrove ecosystem of Myanmar were identified after completing the literature search from both databases and the Google search engine. The initial screening was completed by removing duplicate documents and reviewing the title and abstract of each document. This yielded 118 papers in the English language. The second screening was conducted by reading full-text articles aligned with the defined DPSIR indicators. 51 works of literature that provided insights into one or more steps of the DPSIR framework were included in the literature analysis. Out of 51 references, 45 were peer-reviewed articles, while the remaining were grey literature. The 6 grey literatures were two government documents (MONREC 2019, 2020), three reports (Zöckler et al., 2013; Wood, 2015; Myanmar Center for Business Responsible, 2018), and one proceeding report (Win, 2000). Moreover, the secondary data from the Government was used to compare the research findings with important variables that directly and/or indirectly affect the mangrove ecosystem. These variables included the area of mangrove forest, population number, major crop production areas, and the percentage of households that use firewood and charcoal.

## 2.3 Data analysis

We conducted data extraction by retrieving general information on each study including author(s), title, year of publication, publication source, study region, general research method, publication type, and all key findings linked to the defined DPSIR framework for this review study. MAXQDA software was used to code and retrieve paragraphs on the included literature and extract the DPSIR component indicators for further statistical analysis. After compiling all keywords, we tabulated the keywords and grouped them based on similarities. R programming (version R 4.3.0) was used to display descriptive statistical results. To visualize the identified DPSIR indicators, we applied the alluvial diagram with the ‘ggalluvial’ package in R (Brunson & Read, 2023). The alluvial diagram is a type of Sankey diagram commonly used to visualize the information flow between entity groups where the related entities are grouped into columns aligned along a common axis. The height of flow between entities indicates the data quantity among factors on each axis (Arunkumar et al., 2021). In this review, the flow charts illustrate the relationships of driver, sub-drivers, and pressure from entity to entity with the evidence of frequency display on identified key finding on each indicator, reflects the situation of mangrove forests in Myanmar (figure 4) and visualize the multidimensional identified key findings of State (S), Impact (I) and Response (R),

reflecting the evidence of frequency display on the challenges for sustainable mangrove ecosystem in Myanmar (Figure 7).

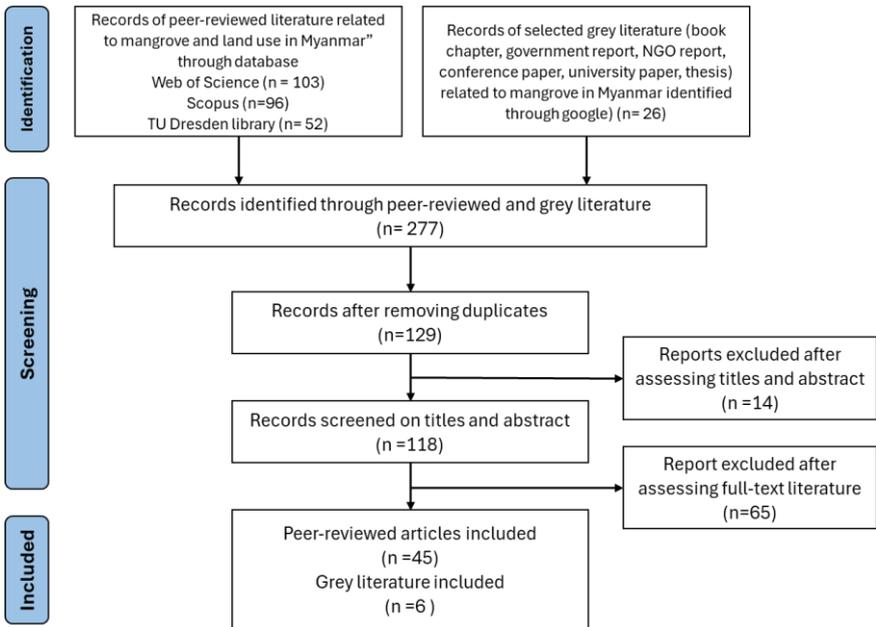


Figure 1. Article screening process based on PRISMA guidelines

### 2.4 General profiles of sampled studies

We selected 51 reports out of 118 literary works by considering their main findings and keywords by assessing their contribution toward understanding mangrove degradation and conservation and rehabilitation under a DPSIR framework perspective. References were classified according to publication year, type of literature, study region, and methodological approaches (Figures 2 and 3). Most of the selected studies were research papers published between 2013 and 2023 while the oldest article was in 2000.

Among these identified studies, eighteen studies investigated the overall mangrove area in Myanmar. The majority of area-specific studies were identified in mangrove areas in Ayeyarwady (n = 17), followed by the Tanintharyi region (n = 10). A few studies focused on Rakhine and Yangon regions were observed. Most identified research approaches were remote sensing and GIS methodologies, while the inventory approach was the second most commonly used method. Three studies were conducted on the assessment of mangrove species and biodiversity in coastal regions (n=3), as well as on the socioeconomic assessment of mangrove resource utilization (n=3), and the analysis of the context of local communities’ dependence on mangrove ecosystem (n=3). Very limited studies on economic analysis, policy assessment, land use assessment, and actor analysis of mangrove-related ecosystems were identified.

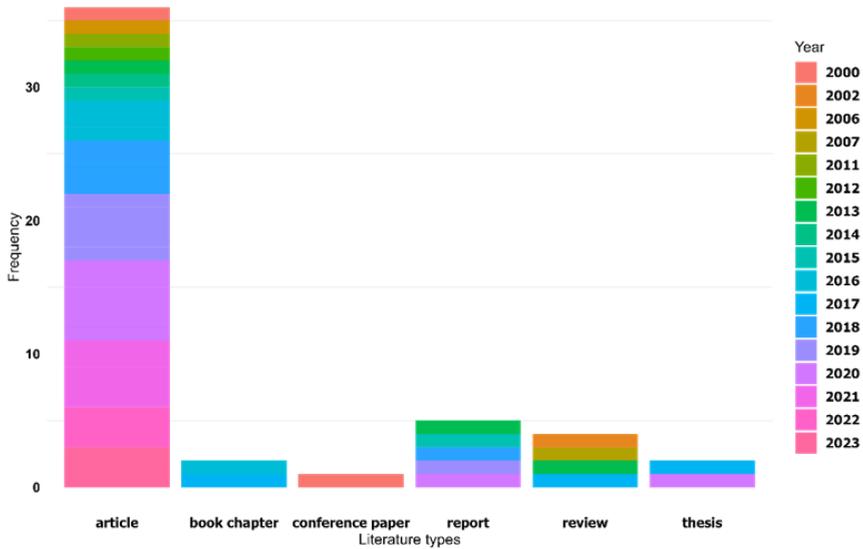


Figure 2. The frequency distribution of published years to literature types (n=51)

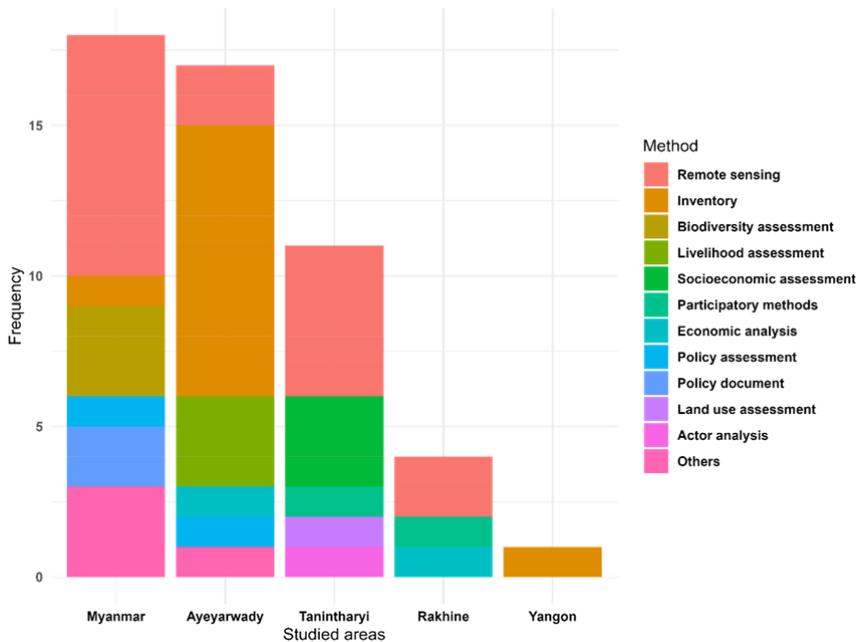


Figure 3. The frequency distribution of different study methods to mangrove areas in Myanmar (n=51)

### 2.5 Classification of DPSIR components

A detailed description of selected DPSIR component indicators extracted from the literature is presented in Table 1. There were 10 drivers identified from the literature review. These drivers were sub-categorized into ecological, economic, and political drivers. The ecological drivers included the ecological factors that positively or

negatively influenced the circumstances of mangrove forests. Most of these were ecological evidence to regenerate the mangrove ecosystem while some were climatic factors affecting the mangrove ecosystem. Economic drivers included typical economic activities such as agriculture, aquaculture, special economic zones, dam construction, charcoal production, as well as local livelihood activities on the mangrove ecosystem that were identified from the literature review. Political drivers were the politically direct or indirect influence on the changes in the mangrove ecosystem. Politically indirect influences on land use decisions, political frameworks in mangrove management, and preservation systems were observed as political drivers.

Concerning the pressures arising from the identified drivers, 19 components were documented and further categorized into land conversion, research and innovation, social and institutional pressures, political frameworks, and natural pressures. Land conversion pressures were derived from the agricultural sectors and other economic development including mining, fisheries, socioeconomic zones, and the construction of roads and dams. All land conversion pressures were observed as a negative impact on mangrove forest changes in Myanmar. As we identified research and innovation as positive pressures on mangrove systems, we recommend including them in future response strategies as rehabilitation guidelines for future sustainable mangrove ecosystems. Social and institutional pressures revealed from the literature included weak law enforcement, exploitation of mangrove resources, lack of awareness, low conservation investment, and conflicts that disrupted the mangrove forest ecology. However, some pressures linked with governmental strategies for mangrove restoration were positively documented.

Overall, the impacts identified from the literature were sub-grouped into positive and negative impacts on the ecological and economic ways of the mangrove ecosystem. The reforestation research attempts had a positive impact on the existing mangrove ecology. This impact was evident in the form of increased biodiversity, carbon sequestration, and mangrove regrowth rates. The most frequent impact in the publications was the loss of mangrove ecosystem services and environmental changes caused by mangrove degradation.

The literature-identified responses through the DPSIR framework included the challenges, suggestions, and recommendations regarding the sustainable mangrove ecosystem in Myanmar. In total, 12 responses were documented and grouped into four categories: policy-related responses, rehabilitation guidelines, reforestation responses, and community-based managements. The policy responses required national and regional policy implementation for addressing various issues: environmental protection, protected areas, and forest conservation, which have direct and/or indirect impacts on the sustainable mangrove ecosystem of Myanmar. Reforestation responses have been identified as important research areas for maintaining and rehabilitating mangrove ecosystems. Practices for mangrove-friendly agriculture play a key role in these recommendations. Regarding community-based management, the literature underlines the importance of involving local communities and stakeholders in the conservation of mangrove ecosystems.

**Table 1.** Lists of keywords for Driver (D), Pressure (P), Impact (I), and Response (R) collated from literature (n=51).

Driver	Pressure	Impact	Response
<b>Ecological driver (16)</b>	<b>Land conversion (20)</b>	<b>Positive impact (18)</b>	<b>Policy-related responses (24)</b>
1. <sup>(+)</sup> rehabilitation methods (11)	1. <sup>(+)</sup> socio-economic development (6)	1. richness in biodiversity (6)	1. land use planning(11)
2. <sup>(+)</sup> natural regeneration (4)	2. <sup>(+)</sup> agricultural expansion (5)	2. increasing mangrove recovery rate (6)	2. strengthening forest conservation policy(4)
3. <sup>(+)</sup> climate change (1)	3. <sup>(+)</sup> rice expansion (4)	3. carbon sequestration (3)	3. strengthening the protected area system(3)
	4. <sup>(+)</sup> aquacultural expansion(2)	4. mangrove provision service (2)	4. strengthening sustainable forest management policy(3)
	5. <sup>(+)</sup> oil palm expansion(2)	5. mangrove regulation service (1)	5. strengthening environmental protection (2)
	6. <sup>(+)</sup> plantation expansion (1)		6. strengthening eco-tourism(1)
<b>Economic driver (26)</b>	<b>Research and Innovation (15)</b>	<b>Negative impact (33)</b>	<b>Rehabilitation guidelines (16)</b>
4. <sup>(+)</sup> economic activities(12)	7. <sup>(+)</sup> identification of mangrove species (7)	6. loss of ecosystem services (14)	7. ecological rehabilitation guidelines (16)
5. <sup>(+)</sup> agriculture (8)	8. <sup>(+)</sup> preservation effort on carbon stock(4)	7. environmental changes (8)	
6. <sup>(+)</sup> livelihood dependency(5)	9. <sup>(+)</sup> assessment of mangrove recovery rate(1)	8. threaten on biodiversity (6)	<b>Reforestation responses (6)</b>
7. <sup>(+)</sup> aquaculture (1)		9. carbon emission (5)	8. implication of environmental assessment (2)
<b>Political driver (9)</b>	10. <sup>(+)</sup> different replanting techniques(1)		9. practices of mangrove friendly agriculture(2)
8. <sup>(+)</sup> land use management (3)	11. <sup>(+)</sup> mangrove friendly aquaculture(1)		10. implication of ecological assessment (1)
9. <sup>(+)</sup> mangrove management(3)	12. <sup>(+)</sup> resilience to subsidence in tidal channels (1)		11. implication of ecosystem risk assessment (1)
			<b>Community-based management (5)</b>
10. <sup>(+)</sup> preservation system(3)	<b>Social and institutional pressures (13)</b>		12. community engagement (5)
	13. <sup>(+)</sup> weak law enforcement (6)		
	14. <sup>(+)</sup> exploitation of mangrove resources (4)		
	15. <sup>(+)</sup> lack of awareness on mangroves (1)		
	16. <sup>(+)</sup> low conservation investment(1)		

Driver	Pressure	Impact	Response
	17. <sup>(-)</sup> conflict on land use patterns(1)		
	<b>Political frameworks (2)</b>		
	18. <sup>(+)</sup> policy strategies (2)		
	<b>Natural pressure (1)</b>		
	19. <sup>(-)</sup> salt intrusion and temperature rise(1)		

Note: (+), (-), (±), shows the mangrove forest status of Myanmar resulting in the declaration of mangrove deforestation and/or reforestation statements. The quoted number represents the frequency distribution of each component extracted from the literature

### 3. RESULTS

#### 3.1 Factors influencing mangrove forest changes in Myanmar

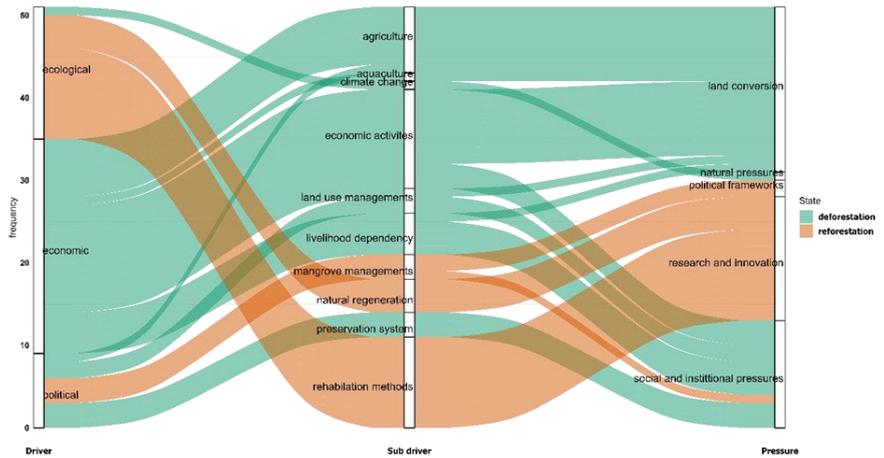
The frequency distribution of identified drivers, sub-drivers, and pressures related to the state of the mangrove ecosystem of Myanmar is described in Figure 4. Two-thirds of the DPSRI frequency distribution indicated the extent of mangrove deforestation resulting from several different factors (n=33), while a third of the identified literature addressed the mangrove reforestation strategies and their success (n=18). The results are aligned with a comparison of secondary data on changes in mangrove forests in Myanmar's total mangrove areas and the region-specific areas of Ayeyarwady, Tanintharyi, and Rakhine from 1980 to 2020 (figure 5). Within 20 years from 2000 to 2020, there was a severe degradation of the entire mangrove forest area of Myanmar and, by 2020, around 35 % of the mangrove forest had disappeared. The Ayeyarwady region was the one experiencing the most serious deterioration, with a dramatic decline of 37 % between 1980 and 2000 and another 67% between 2000 and 2020. Mangrove forests in the Rakhine area were continually degrading; by 2020, the percent change was 46% as compared to 1980. However, there has been less mangrove forest change in the Tanintharyi region over the past 40 years. The expansion of the mangrove area in Rakhine and Tanintharyi before 2010 is closely linked to the political and economic reform in that region. Subsequently, from 2010 onwards, the establishment of special economic zones (SEZ) (as an example; Dawei SEZ in Tanintharyi, Kyaukphyu SEZ in Rakhine) along with other developments, had a significant impact on the dynamics of forest area in that region (Aung et al., 2022). Moreover, the natural mangrove forest regeneration in the northern region of Myanmar exhibited more than the Delta region, likely due to a lower incidence of natural disasters (e.g., Tropical Cyclone Nargis in the Delta region in 2008) (Gaw et al., 2018).

Economic factors were the most frequently cited causes of mangrove deforestation (n=26). Economic activities including the establishment of special economic zones, agricultural operations, mining, logging, and tourism (n=12) were the most often mentioned causes of mangrove degradation, followed by specific examples of agriculture including the expansion of rice and plantation crops (n=8). These economic drivers consequently led to the conversion of mangrove areas to other land uses, constituting the dominant negative pressure (n=20). The social and institutional pressures (n=13) resulting from the impact of economic activities such as livelihood activities and land use management on mangrove ecosystems were identified as the second major negative pressure on the mangrove ecosystem of Myanmar. Weak law enforcement on the use of mangrove forests (n=6) and exploitation of mangrove resources (n=4) were the predominant social and institutional pressures (Table 1).

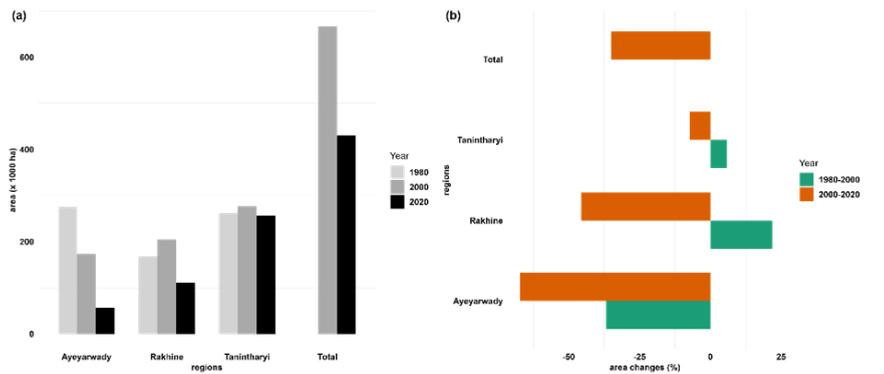
However, a secondary data analysis based on the government report revealed that the proportion of households using firewood and charcoal for cooking (refer to Figure 6 (b) and (c)) diminished across all coastal regions during the period from 2014 to 2019, even as population growth rates in these regions were relatively constant (refer to figure 6 (a)). Furthermore, between 2016 and 2019, rice production in all coastal areas slightly decreased, although oil palm and rubber plantations in Tanintharyi somewhat increased (see Figure 6 (d), (e), and (f)). There were also stable aquaculture pond areas in the delta regions between 2012 and 2017 (Aung, 2021). This finding makes it unlikely that these economic activities will be the main cause of the recent mangrove loss in Myanmar. Further ground data measurements are still necessary to identify the primary factors causing mangrove degradation in Myanmar.

On the other hand, Myanmar has attempted to implement mangrove forest regeneration. One-third of the findings indicated that the investigation of restoration

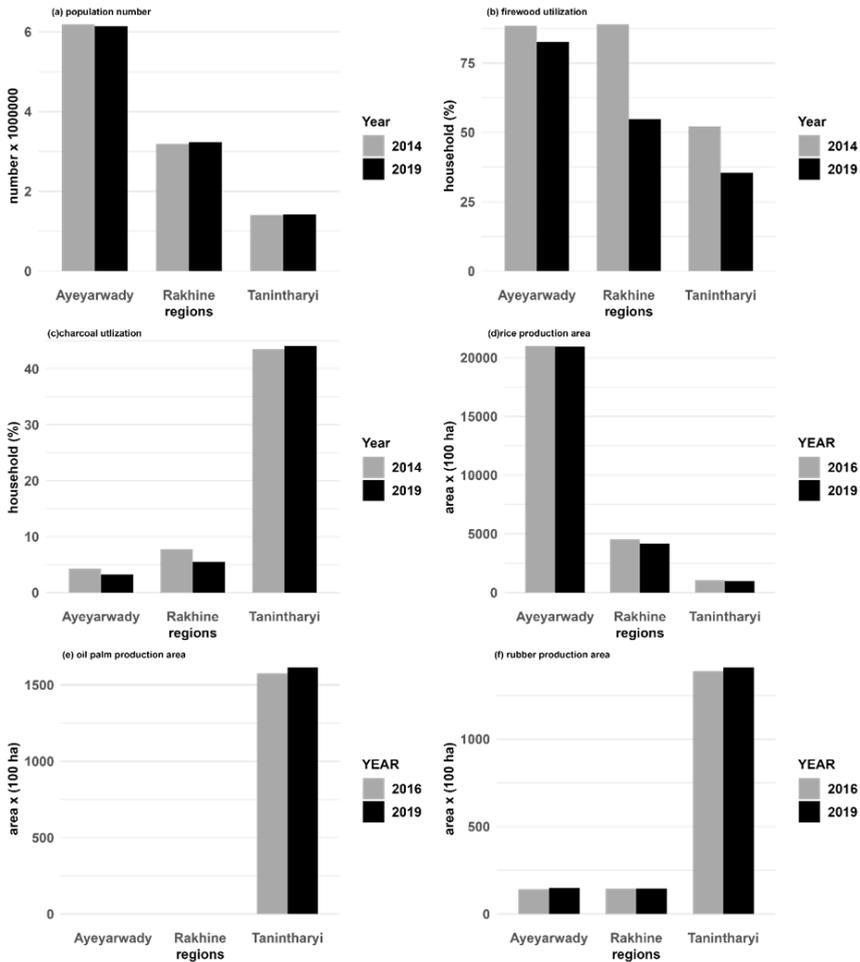
techniques as a sub-category of ecological drivers helped in the implementation of mangrove conservation practices. This has resulted in positive pressure within the research and innovation category (n=15). For instance, Maung & Sasaki (2021) revealed that mangroves have been seen recovering over very short periods. Moreover, the identified political drivers related to policy strategies highlighted the potential success of mangrove restoration in Myanmar. However, a few political drivers that linked with land use management, and preservation systems at local and/or institutional levels still contributed to the mangrove deforestation state of Myanmar. It emphasized the importance of political strengthening to ensure sustainable mangrove management in Myanmar.



**Figure 4.** The frequency relationship among drivers, subcategory drivers, pressure, and status of mangrove ecosystems in Myanmar (n=51).



**Figure 5.** Mangrove forest area changes in Myanmar and its three main coastal regions from 1980 to 2020: (a) mangrove forest area and (b) mangrove area changes between 20-year intervals. Source: mangrove area in 1980 (San, 2020), 2000 (Estoque et al., 2018), 2020 (MONREC, 2020)



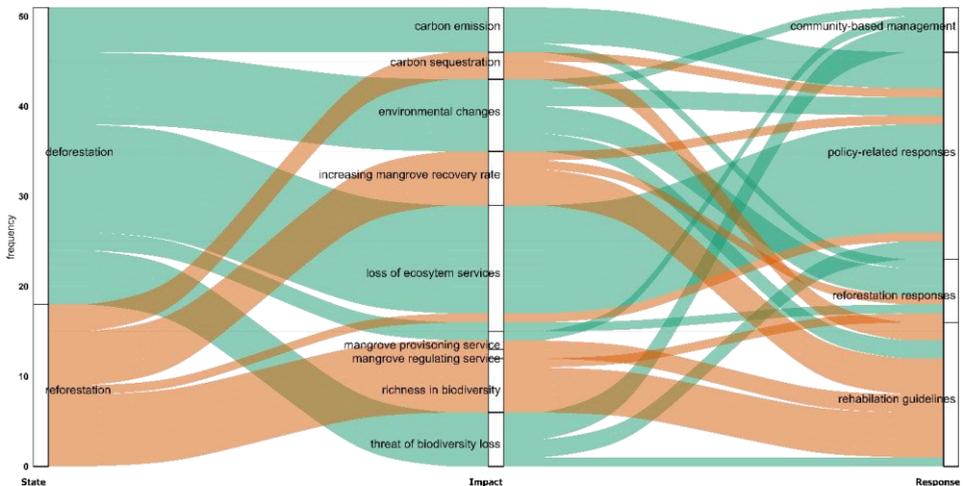
**Figure 6.** Status of population number (a), percentage of households using firewood (b), charcoal (c), production areas of rice (d), oil palm (e), and rubber (f) in the three main coastal regions of Myanmar among reference years. Source: DOP, 2014, 2019; MOALI, 2019.

**3.2 Mangrove management in Myanmar: realities and needs**

The dynamics of mangrove ecosystems have positive and negative impacts on both the environment and the people living in mangrove regions, and the complex interplay between these factors needs to be considered for mangrove preservation and restoration. The connections between state, impact, and responses concerning mangrove ecosystems and their management are displayed in Figure 7. Overall, the impacts identified were mostly related to the loss of ecosystem services (n=14), followed by environmental changes (n=8), biodiversity losses (n=6), and a decline in carbon stock (n=5). These frequent impacts have been attributed to the state of mangrove deforestation rates. At the same time, mangrove reforestation efforts have resulted in a recovery of the mangrove ecosystem in some localities (n=18). Documented impacts of mangrove reforestation include increasing mangrove recovery rates, followed by improving mangrove biodiversity, and ultimately increased carbon sequestration and ecosystem service provisions.

The most frequent response documented in the literature was policy interventions (n=24) for sustainable mangrove ecosystems, specifically regarding land use allocation, making up 11 out of 24 documented responses. Following this, policy strengthening in protected areas, forest conservation, management, environmental protection, and eco-tourism were identified as policy-related responses. These policy-driven actions were linked to deforestation and reforestation statements, resulting in positive and negative impacts on the surrounding environment and communities in the mangrove region. It indicated that policy implications and actions were still needed to justify not only in the context of reducing mangrove deforestation but also performing mangrove reforestation in Myanmar. The high demand for mangrove forest resources coupled with conflicting interests among different ministries, and the complexity of the administrative structures for sharing equitable responsibilities and benefits in the context of mangrove policies for social, economic, and environmental reasons, are still leading to the mangrove forest degradation (Khan et al., 2020; Khan & Giessen, 2021).

In this study, the second most frequent responses were rehabilitation guidelines (n=16) and reforestation (n=6) which were also linked with documented deforestation and reforestation statements. The literature analysis yielded the rehabilitation guidelines primarily focused on mangrove ecological development parameters and measures for ensuring sustainable mangrove ecosystems. However, the documented guidelines did not address the current implications of implementing them in the mangrove reforestation programs. On the other hand, the reforestation response included further implications for ecological, and environmental assessment, ecosystem-based approaches, and practices for mangrove-friendly agriculture in the mangrove ecosystem of Myanmar. Few responses regarding community-based management were also documented (n=5). The identified results suggested the importance of the involvement of local communities and stakeholders in the mangrove conservation programs incorporating traditional practices and raising among local communities about the value of forests.



**Figure 7.** The frequencies and interlinkages among state, impact, and response factors in mangrove ecosystems of Myanmar (n=51)

## 4. DISCUSSION

### 4.1 The research gaps and future research agenda for mangrove ecosystem restoration in Myanmar

The present study identified the causes of mangrove forest cover changes and sustainable mangrove restoration options through literature analysis using the DPSIR framework. Majority of papers focused on mangrove deforestation states with the explication of its drivers and pressures. The conversion of mangrove land to other land uses has been a long-standing phenomenon as evidenced by various spatial analyses cited in this study. As an example, the deforestation rates for the Delta from 1979 to 2011 were the consequence of the rapid expansion of rice agriculture (Webb et al., 2014). However, the crop production areas have remained relatively stable in all mangrove's coastal areas recently, particularly during the 2016 to 2019 period (Figure 6). There was limited data availability to evaluate crop production areas before 2014. Practically, the assessment of rotation, failed crops, and fallow land use within the same land were significant challenges due to the lack of available data (Torbeck et al., 2017). It is therefore evident that further analysis is required to identify the changes in land use practices associated with the conversion and/or restoration of mangrove forest land.

Additionally, livelihood dependency on mangrove ecosystems was identified as the third economic driver for mangrove degradation, however, firewood and charcoal utilization in three coastal regions decreased steadily from 2014 to 2019. Following the substitution of crude oil and natural gas particularly in urban areas, the national energy requirement from firewood and charcoal declined after 2010. However, the use of firewood is still widespread in rural areas. Furthermore, the demand for firewood in the Delta region is still increasing for the fish paste and dry shrimp-making business where 80 % of energy consumption is based on firewood and the rest relies on charcoal and rice husk pellets (World Bank, 2020). Nevertheless, the extent to which the harvesting of mangrove firewood affects the health of mangrove ecosystems remains uncertain, despite the existence of a community forestry programme and the establishment of village supply firewood plantations in these regions, particularly in the Delta region. The positive attitude toward mangrove conservation is directly linked with the socio-economic and demographic characteristics of mangrove forest-dependent people who have largely admitted their illegal access due to a lack of alternative economic opportunities (Roy, 2016). Therefore, the nexus assessment of social, economic, and political concerns of mangrove users and their involvement on different mangrove management practices at the ground level are necessary to ensure a sustainable mangrove management system in Myanmar.

From 1980 to 2020, the most severe mangrove degradation was in the Ayeyarwady region while the second mangrove-depleted region was Rakhine. However, there have been only a few studies conducted on the Rakhine mangrove region which is not very surprising in light of Rakhine having experienced decades of ethnic and military conflict (UN Human Rights Council 2018). Moreover, although the restoration projects were ongoing in the degraded mangrove forest sites in the Ayeyarwady and Tanintharyi regions, mangrove restoration projects and field research in the Rakhine region are difficult to conduct because of ongoing armed conflict in that region. The mangrove ecosystem in Rakhine is critically endangered and requires restoration to at least 10% of its historical distribution to be a sustainable mangrove ecosystem. Planting mangroves alone is not enough to be successful in mangrove restoration where proper

resource allocation with collaboration with local communities is still required (Lee et al., 2024).

Additionally, this review study identified the most frequently used spatial analysis and ecological inventory measurements for the mangrove ecosystem of Myanmar. However, the assessment of the nexus between different stakeholders in all mangrove management programs positively and indirectly influenced the sustainability of mangrove ecosystem management through better support of mangrove ecological sustainability (Suswadi et al., 2023). Schusser et al., (2013) proposed that analysing social interactions for particular forest ecosystem management through an actor-centered power (ACP) approach can help predict sustainable social, ecological, and economic outcomes for these forest ecosystems. ACP is based on powerful actors who can alter the behaviours of other actors, and influence resource management practices. Analysing the interaction of these actors in forest management can deliver valuable preliminary information for designing the real outcome in the performing sustainable forest ecosystem (Krott et al., 2014).

On the other hand, the majority of the study's findings identified the mangrove reforestation states in Myanmar through various mangrove rehabilitation assessments. The importance of mangrove species adaptability (San, 2020), biodiversity (Than et al., 2006, Win et al., 2019) in preservation and regeneration programs, the requirement of proper sediment management in natural coastline (Glover et al., 2023), naturally mangrove regeneration with high feasibility (Aye et al., 2022) were so far from the useful application guidelines for mangrove reforestation in Myanmar. However, the role of climate change in the vulnerability and fragility of mangrove ecosystems has only been addressed by a small number of studies. The effect of climate change, particularly sea level rise, was strongly correlated with the distribution of mangrove species and the reduction of mangrove vegetation cover (Zhang et al., 2023). Climate variability has had detrimental impacts on coastal resources including fish stock and the provisioning services of mangrove ecosystems, confronting coastal communities with reduced resource bases (Yanda et al., 2019). In sum with the example of a conceptual framework for mangrove restoration and conservation in Nigeria, the integration of community science and effective environmental data gathering, policy-driven restoration, and co-management are aligned as key drivers of sustainable mangrove management (Sam et al., 2023).

#### **4.2 Implications for sustainable mangrove ecosystems in Myanmar**

In this review, nearly half of the responses studied were policy approaches to the mangrove conservation and restoration system in Myanmar. The conflicts on mangrove resource utilization (Htay, 2016), and encroachment to the reserved forest were common challenges throughout Myanmar since forest law did not take into account the social and economic needs of the people (Saw & Kanzaki 2015). A good example is the national land use policy which was launched in 2016 to implement and manage land use and tenure rights throughout the country, both in urban and rural areas (MONREC, 2020). However, the lack of community ownership and/ or tenure right over mangrove areas in participatory mangrove rehabilitation programs was identified as the major challenge in promoting mangrove conservation (Camacho et al., 2020). This stands in contrast to Lundsgaard-Hansen et al.'s (2018) suggestion that the significance of social networks and power relations in land use decisions should be considered as a key factor when implementing sustainable land use management. Moreover, trust building between the communities and governments for forest land tenure is critical for community forestry development in Myanmar (Tun et al., 2021). Apart from these identified recommendations suggestions, Aung et al. (2013) suggested that wise use

scenarios in mangrove management should carefully consider the basic needs of local people paralleling with the mangrove conservation, although the mangrove recovery rate increased in a short time.

As Myanmar joined the Paris Agreement in 2016, and consequently introduced the Myanmar Reforestation and Restoration Program, the preservation and rehabilitation of mangrove forests is now a high priority (Win et al., 2020). According to the Conservation of Biodiversity and Protected Areas Law (2018), local people's rights and co-management in forest ecosystems have been recognized with the declared goal of establishing community-based forestry (Win et al., 2020, MONREC, 2020). However, this law does not provide detailed guidance on implementing community-based forestry in specific mangrove regions. There is still a need to understand the actors' involvement and their interaction within the context of community-based mangrove forest management practices and/or other mangrove management practices. Even though Myanmar's Reforestation and Rehabilitation Programme (2017-18 to 2026-27) aims to restore the degraded forests including mangroves for climate change mitigation and enhanced ecosystem services, the percentage of mangrove plantations has so far been low when compared to other forest types (MONREC, 2020). Apart from these policy responses, the available literature identified a need for environmental assessments leading to a better understanding of the vulnerability of mangrove ecosystems, and research on mangrove-friendly agriculture practices (Table 1). This is particularly meaningful as policies explicitly call for mangrove-friendly agriculture. This is in line with the recommendations of Win (2000) who concluded that many improvements were still necessary in terms of land use policy, particularly regarding the integration of environmental impact assessment with socio-economic perspectives of mangrove-friendly aquaculture. The implementation of policies should be adopted as a strategic scientific-based policy by both local and national stakeholders to reduce greenhouse gas emissions, protect coastal ecosystems, and rehabilitate coastal aquatic and vegetation ecosystems (Wahyudi & Afdal, 2018).

## 5. CONCLUSION

Our study analyzed various research themes and topics related to the mangrove forest ecosystem in Myanmar through the DPSIR framework. Economic activities, including agriculture, have been identified as key drivers of land conversion, resulting in mangrove forest degradation. Despite the existence of the mangrove restoration status identified, the ongoing mangrove degradation in Myanmar underlines an urgent need for further action. As some of the findings are based on limited empirical evidence, further ground-based research is necessary, but impeded by the difficult and volatile political situation in the country. The findings ultimately show the necessity of addressing mangrove management as a comprehensive task that takes into account the sustainability nexus of social, economic, political, and ecological development, and more specifically, assessing actors' involvement and the resulting outcomes from the mangrove forest management systems for the sustainable mangrove conservation and restoration in Myanmar.

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