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Unpacking Changes in Mangrove Social-Ecological Systems: Lessons from Brazil, Zanzibar, and Vietnam

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Abstract: Mangroves provide multiple benefits, from carbon storage and shoreline protection to food and energy for natural resource-dependent coastal communities. However, they are coming under increasing pressure from climate change, coastal development, and aquaculture. There is increasing need to better understand the changes mangroves face and whether these changes differ or are similar in different parts of the world. Using a multiple case study approach, focused on Vietnam, Zanzibar, and Brazil, this research analyzed the drivers, pressures, states, impacts, and responses (DPSIR) of mangrove systems. A qualitative content analysis was used on a purposively sampled document set for each country to identify and collate evidence under each of the DPSIR categories. Population growth and changing political and economic processes were key drivers across the three countries, leading to land use change and declining states of mangroves. This had an impact on the delivery of regulatory and provisioning ecosystem services from mangroves and on the welfare of coastal communities. Responses have been predominantly regulatory and aim to improve mangrove states, but without always considering ecosystem services or the consequences for welfare. The issue of scale emerged as a critical factor with drivers, pressures, impacts, and responses operating at different levels (from international to local), with consequences for response effectiveness.

Keywords: coastal management; complex systems; welfare; livelihoods; forests; environmental management

1. Introduction

Mangrove forests cover over 152,000 km^2 in 123 countries across the world [1]. They protect shorelines from erosion, flooding, and storm damage, and help maintain water quality by filtering pollutants [2]. The habitat they create is a useful nursery area for fish, crustaceans, and other sea life, as well as supporting a range of threatened and endangered species at various stages of their life cycles [3]. In addition, they provide food, timber, medicines, and energy for natural resource-dependent coastal communities [4,5]. Mangrove forests are also internationally important, storing roughly two and a half times the amount of annual global carbon dioxide emitted [6].

Despite these multiple benefits provided at different levels, mangroves are under increasing pressure. With 44% of the global population living within 150 km of the coast, there has been widespread clearance of mangrove forests because of local resource overuse, but also due to coastal

development and aquaculture, resulting from larger scale drivers [7]. Between 1980 and 2005, the coverage of mangrove forests declined by 36,000 km^2, resulting in losses of 20% of the global mangrove area [1]. In at least 26 countries mangroves are now critically endangered or approaching extinction [4].

Given their importance in providing a range of ecosystem services and estimated losses of 1%–8% per year [4,7], there is increasing need to better understand the changes mangroves face, as well as whether and how these changes differ or are similar in different parts of the world. While there have been attempts to unpack the causes and consequences of mangrove degradation and loss through local case studies (e.g., [8,9]), the literature provides few comparative analyses of the drivers, impacts, and responses to these changes across continents. A multiple case study approach allows us to capture differences within and between locations [10] and enables cross-continental lesson learning. We argue that novel cross-continental analyses, such as that provided in this paper, where we focus on Brazil, Zanzibar, and Vietnam, are vital to identify appropriate management responses. Such responses could be tested and rolled out to other locations. In this way, lessons can be learned and shared across mangrove countries to support conservation and restoration efforts that provide benefits both locally and more widely, whilst also maintaining local livelihood options.

The objectives of this paper are to: (a) identify the similarities and differences in the drivers, pressures, states, and impacts of mangrove changes in our case study countries, taking into account the scale(s) of impacts; (b) assess response strategies that have been implemented in response to similar and different pressures, states, and impacts; and (c) by looking across the three countries, draw out wider lessons that can guide decision-making and investments in measures to conserve and restore mangroves more widely. The next section sets out our research framing.

2. DPSIR Framework and Methodology

This paper uses an adapted version of the Driver-Pressure-State-Impact-Response (DPSIR) framework as an organizing tool for a comparative analysis of mangrove social-ecological systems (SESs) in Brazil, Zanzibar, and Vietnam. Our three study countries were selected from the 123 countries globally that have mangroves because they, like many others, have each undergone rapid coastal development, altering the ability of the environment to deliver essential goods and services [11], so they provide representative cases in this sense. They also share important political and economic pathways in their recent histories. Socialist approaches in all three countries instigated to protect national productivity in the 1970s actually had the opposite effect, with all three facing declining agricultural production, shortages, and economic crisis in the 1980s [12–14]. In each country, a combination of internal factors (grass roots reform to agriculture (e.g., in Vietnam [12]); recognition of the need for reform at government level in all three countries) and external factors (readjustment and liberalisation as a condition for debt relief and aid; pressures to participate in the global economy; the need to trade with and/or emulate "successful" neighbouring countries) drove economic liberalisation and the removal of trade restrictions [12–14]. These far reaching reforms since the 1980s have facilitated periods of rapid economic growth with significant increases in living standards for some, while the drivers of mangrove change have become increasingly international in nature. At the same time decentralisation programmes, in particular the transfer of authority over natural resources to local government, have been met with varying success [15–17]. As such, they provide a set of cases that enable us to examine mangrove SES change in the context of increasing connectedness from local to international level.

SESs are integrated and dynamic systems incorporating both humans and nature [18,19], and a growing body of theory and approaches has been developed for their study drawing on complexity theory, systems ecology, and social theory [19] The DPSIR framework was developed by the Organization of Economic Cooperation and Development (OECD) and the European Environment Agency (EEA) to examine the interplay between environmental and socio-economic activities [20]. A key strength of DPSIR is its ability to highlight the interlinkages and relationships between different aspects of society and the environment [21]. For this reason, we find it an appropriate guide through which to organize our analysis of an SES. The DPSIR framework has been used to study policy

responses in SESs [22] and to develop adaptive management approaches [23]. It has been applied to identify responses to coastal vulnerability [24], the impacts of aquaculture [25], and the effects of pollution in marine environments ([26], see also the review in [23]), but it has not yet been used to specifically consider change in mangrove SESs.

The DPSIR approach is not without criticism, however, and this has led the original OECD DPSIR framework to be modified to address some of the shortcomings. For example, Cooper's DPSWR approach (Drivers-Pressures-State-Welfare-Response) seeks to increase focus on the social components of the system examined, while keeping the overall analysis within the confines required by policy makers [27]. He defines welfare broadly to encompass "what matters" through human agency [27] (p. 20). Kelble et al.'s EBM-DPSER (Driver-Pressure-State-Ecosystem Service-Response) framework seeks to address the inherent negative association within the traditional Impacts element of the DPSIR framework [28]. By replacing Impacts with Ecosystem Services, the EBM-DPSER model explicitly includes positive ecosystem changes alongside recognition of negative impacts [29]. Both the DPSWR and EBM-DPSER versions also stress the need to account for wider system dynamics. This is particularly important, as the DPSIR framework has been criticized for assuming linear causal relations that do not always account for the dynamics in systems [30].

In this paper, we integrate these developments into the DPSIR framework. We adapt the original DPSIR framework to include both ecosystem services impacts (to acknowledge the EBM-DPSER development to account for wider ecosystem dynamics) and welfare impacts (to account for the DPSWR development to increase focus on social elements) (Figure 1). We follow Cooper's broad definition of welfare. We also recognize the linkages between elements in the framework so as to account for dynamics and feedbacks. Finally, we acknowledge the importance of scale, as each element of the framework affects and is affected by processes occurring at and across multiple (temporal and spatial) scales.

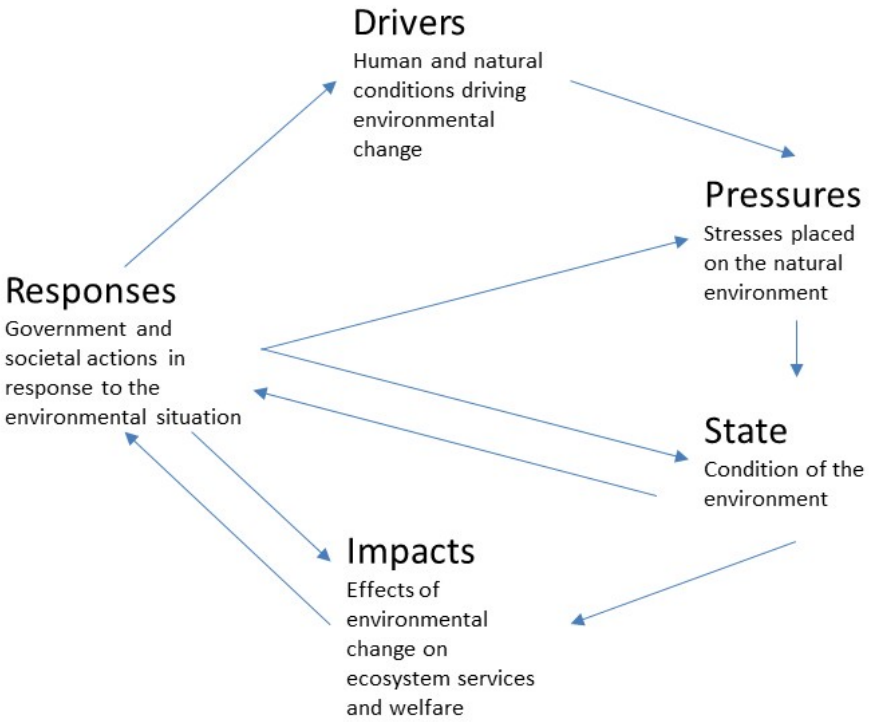


Figure 1. The Driver-Pressure-State-Impact-Response (DPSIR) framework (adapted from [31]).

In the context of mangroves, drivers of social, demographic, and economic change relate to the need for food, fuel, energy, economic development, space, and so on, delivered through mangrove forests, aquaculture, fisheries, and coastal land. These drivers often stem from the global level, but also

originate from national and local levels. Each driver puts pressure on the system through exploitation of mangrove resources, demands for conservation or land conversion. Pressures tend to manifest at national and local levels. As a result, the state of the mangrove system changes, negatively, through the degradation or loss of mangrove forests, or positively, e.g., through appropriately applied rehabilitation or restoration. System changes impact both the ecosystem services that the system provides (such as the availability of resources for consumption, storm protection or climate regulation), and human welfare (the social component of the system), e.g., via effects on livelihoods that depend on these services at the local level. Livelihoods underpin the needs necessary for a reasonable and adequate life in society, which is critical to human welfare. Human welfare impacts can reinforce and exacerbate social differentiation as different costs and benefits ensue for different members of the population. Indeed, impacts often encompass trade-offs across different stakeholder groups, scales and types of ecosystem service. Finally, responses to pressures (originating at different levels) to changes in system state (often stemming from international or national level initiatives enacted at the local level), or to the impacts of changes in system state, can vary from doing nothing at one end of the spectrum, to the control and regulation of drivers and pressures or the protection of mangrove forests in order to directly modify its state, e.g., through exclusion of all human activities, at the other. Successful responses improve the SES state over a given timeframe.

Data collection for this study involved a desk-based literature search in 2014–2015. Published and grey literature and secondary sources were purposively sampled using key words ("country name" AND "mangrove*" AND "ecology" OR "species" OR "manage*" OR "livelihood*" OR "policy" OR "threat*" OR "benefit*") to create a document set for each country. An initial search revealed 90 documents for Vietnam, 427 documents for Brazil, and 36 documents for Zanzibar (excluding duplicates). These documents were further sifted by reading the abstracts/executive summaries as appropriate, to create document sets of 30, 101, and 12 documents, respectively, covering the period 1984–2013. We use 1984 as the baseline year as it represents the time at which political and economic reforms were taking place in each of our case study countries. Our analysis focused on documents within a specified time period and focused on documents that included the names of our study countries in their titles, keywords or abstracts. We acknowledge that this could affect the identification of, in particular, impacts and responses at other levels. A total of 18, 17, and 10 documents, respectively, are included in the narrative presented here.

A qualitative content analysis approach was used [32] to analyze each document set. Through a directed approach (following [33]), each document set was coded to identify and collate evidence for each of the DPSIR categories (see also [34]) and the level at which they operate. Three levels were identified: local—factors that operate at the community, village, and household level; national—factors that operate at the state level; and international—factors that operate beyond the level of the state. The evidence from each country was then brought together to identify similarities and differences in drivers, pressures, states, and impacts (both on ecosystem services and welfare) across countries, assess responses, and draw out wider lessons, in line with our research objectives.

3. Results

3.1. Similarities and Differences in Drivers, Pressures, States, and Impacts

3.1.1. Drivers and Pressures

Across the three study countries, the drivers of mangrove change were population growth (demographic change), political, economic, and technical developments (economic change), and changing consumption patterns (social change) (Figure 2). Population growth has increased the demand for provisioning services from mangroves such as food (all countries) and wood for fuel and construction—particularly Vietnam (as in Malaysia and Thailand, see [35]) and Zanzibar [36,37])—and regulating services such as waste decomposition—particularly Brazil [38,39]). At the same time, the changing political, economic, and technical processes that have shaped each country's economy

have also had consequences for mangrove SESs. In Vietnam, the transition to a socialist market economy since the 1980s has led to decentralization of land management and market liberalization; opening up mangroves to new commercial demands from aquaculture [40]. Decree 773-TTg, Decision 97/2007/QD-TTg and government policy have stipulated that open coastal areas and waterfronts seaward of mangrove areas may be used for shrimp and crab farming and have actively encouraged aquaculture for export markets. In Zanzibar, the growth of the tourist industry since 1990 has been a key economic process fueling mangrove clearance for coastal development [41]. Institutional change has resulted from the significant contribution that tourism makes to GDP (22% of GDP and about 80% of government revenues [42]). The Investment Protection Act of 1986 and reforms to the Act in 2004 have promoted and supported growth in the tourism industry in mangrove areas. In Brazil, a growing economy following stabilization plans in the early 1990s has driven industrial development, including the development of ports and other transport links, in coastal areas [38,43]. The opening up of access to once remote mangrove areas has enabled the transport of mangrove products to larger and more distant markets. Changing consumption patterns have also been a critical driver of mangrove change, particularly in Vietnam. Here, a shift in consumption patterns towards higher protein diets at local, national [44], and international levels (e.g., in China [45]) has opened up markets both within and outside of Vietnam and has led to changing demands for products from mangroves and from aquaculture [17,46].

As a result, pressures on mangrove SESs are manifest as increased exploitation of resources provided by mangroves and as land use change (Figure 2). Both pressures result from each broad category of driver (demographic, economic, and social change) and from the interactions between them. For example, the tourism industry in Zanzibar has led to both the increased exploitation of mangrove resources for materials to build hotels and the clearance of mangroves for hotel developments [41]. In Vietnam, the combination of population growth and changing consumption patterns both at home and abroad [47,48] have resulted in significant land use change as the area under shrimp farming has doubled from approximately 250,000 ha in 2000 to more than 500,000 ha in 2003 [49].

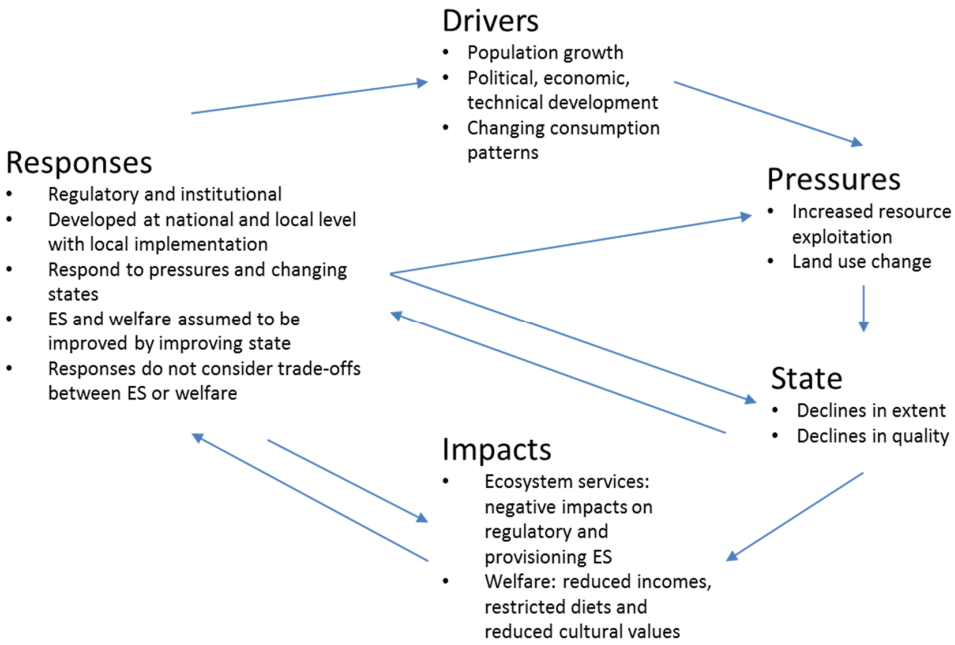


Figure 2. Summary DPSIR framework for mangroves across the three study countries.

3.1.2. State of Mangroves and Impacts on Ecosystem Services and Welfare

In all three countries, the state of mangroves (extent and condition) has generally declined, although with significant variation depending on location. While it is difficult to tell the exact

magnitude of change during the time period we considered, general trends in state were discernible from the literature sampled. The area under the mangrove cover has reduced in all three countries: from 252,000 ha in Vietnam in 1983 [50] to 160,000 ha in 2012 [51] (36% in 29 years); by at least 25% in Brazilian mangroves since the 1900s [52] (100 years); and by 33% since the 1960s in Zanzibar [53] (50 years). At the same time, the condition of mangroves has declined. In Vietnam and Zanzibar, biodiversity has been lost and mangroves have become more fragmented (Vietnam [54] and Zanzibar [36,55]). In Zanzibar, mangroves are being used at unsustainable levels [56] with resulting loses in over half of the growing stock in some places [55]. In Brazil, habitat fragmentation has been identified along the east coast and while the large mangrove areas of northern Brazil have remained relatively intact, aquaculture is growing threat to the extent and condition mangroves in the region through land use change and because of establishment of farmed shrimp species in the wild [57,58]. These changes in states of mangroves have consequences for both the ability of mangroves to deliver ecosystem services and for local communities to benefit from mangrove resources. Across all three study countries, the changing state of mangroves has led to a reduction in the provision of regulating ES. In Brazil, pollutants and nutrient flows into mangroves are reducing water quality [57]. In Vietnam, loss of mangrove area has increased vulnerability of the coast to tidal surges and hurricanes, and increased coastal salinity [59]. Provisioning ecosystem services were also found to be declining across all study countries, with reduced yields of resources necessary for livelihoods. In Brazil, while mangrove extent has been maintained, in many areas the quantity of livelihood resources such as fish and crustaceans have reduced due to over-harvesting [60–66]. In Vietnam, the quantity of fish and crustaceans collected per ha in mangroves decreased by half between the 1980s and 1990s because of mangrove degradation and loss [67]. In Zanzibar, clear-cutting of mangroves has led to reduced availability of poles for construction and boat building, along with increased erosion and sedimentation which have had negative effects on seaweed farming primarily conducted in shallow intertidal areas [68].

The declining state of mangroves and the resulting impacts on ecosystem services has led to negative impacts on welfare at the local level, on the communities that depend on mangrove resources for their livelihoods. In both Vietnam [40] and Zanzibar [69] there have been significant negative impacts as incomes that rely on mangrove resources fall and diets are affected by a reduction in the availability of food from mangroves, and as tourism values have been reduced. In Brazil, these negative impacts have been less significant, but evidence suggests that in at least some places mangrove resources are becoming scarcer [70], with likely impacts on livelihoods. Important social differentiation of impacts has also become apparent. For example, in Vietnam the poor have been unable to invest in aquaculture but have seen their access to mangrove resources curtailed as land has been privatized and converted into shrimp farms by the better off [17,46]. As a result the income gap between the poor and the better off has increased, leading to local conflicts [71,72]. While in Brazil, competition for crab, fish and wood is driving conflicts between local and commercial interests [62] leading to decreased incomes and increased poverty in local communities [73]. These findings highlight the multi-level nature of social and ecological interlinkages, as e.g., national level reforms result in particular mangrove SES-level impacts.

3.2. Assessment of Responses

The responses to declining mangrove states were assessed in relation to the level at which they were developed and implemented (incorporating scale issues), whether they targeted particular aspects of the DPSIR framework (i.e., drivers, pressures or states), and whether they were developed in response to and/or had an effect on particular impacts (on ecosystem services or welfare). Responses to changes in mangrove SESs have generally been regulatory or institutional in nature (Figure 2).

In Brazil, extractive reserves are protected areas that also allow sustainable use by local populations and were implemented into federal law in 2000. This initiative began as a regulatory response to the conflicts and struggles faced by various social groups in the Amazon (e.g., smallholder farmers and rubber-tappers) in the face of expansion by commercial farmers and loggers into

forested areas [70]. While extractive reserves were initially developed for forests more widely, rather than specifically for mangroves, institutional structures in relation to extractive reserves have been developed to manage and protect specific mangrove areas. Of the over 1 million hectares of mangroves found in Brazil in 2010, more than 80% is covered by Protected Areas (PAs), and nearly all are sustainable development or Extractive Reserves [57]. Moreover, in the large areas of mangroves in Northern Brazil, three Federal Extractive Reserves and two State PAs were created in 2014 and 2016, respectively. There are also other federal laws and regulations that determine rules for mangroves, such as the Forestry Code (Law 4771/1965), declaring mangroves as permanent protection areas and allow restricted uses, the Coastal Management Law (Law 8617/1993), which defines general rules for the Economic Exclusive Zone (ZEE) along the Brazilian coast, and the National Policy for Biodiversity (Decree No. 4.339/2002). These initiatives represent a significant response by the national government, in conjunction with local communities, to both changing mangrove states (particularly in condition but also extent) and welfare (in terms of local livelihoods that rely on the provisioning services from mangroves).

In Zanzibar, the national government has taken measures to protect mangroves through the establishment of conservation areas (such as Menai and Chwaka Bay in Unguja and Ngezi mangrove creek in Pemba) and through replanting mangroves in degraded and deforested areas [68]. Policy Number 4 of the National Forest Policy (1999) has been used to develop an integrated coastal area management (ICAM) programme with the specific aim of conserving and sustainably managing Zanzibar's mangrove resources. One example is the Menai Bay Mangrove Management Plan [74], which was prepared for the period 2005–2010 as a strategy to ensure the sustainable management of mangroves as enshrined in national policies. The zoning plan defined different zones according to their uses—from strict protection and restoration, to recreation, multiple use, sustainable use, and buffer zones. Again, this represents a response to changes in both the extent and condition of mangrove states and to changes in welfare of local communities resulting from provisioning service declines.

In contrast, Vietnam lacks any direct regulatory response to mangrove degradation and loss specifically. Mangroves are managed and protected through various forest, aquaculture, and conservation policies [75] rather than through a specific mangrove policy. Forest policy changes in the mid-1980s devolved responsibility for forests generally from state to local government as a way of resolving the corruption and other institutional problems that were believed to have led to forest degradation and loss [17]. The 2003 Land Law in particular clarified rights of use of forested land and for the first time allocated rights to communities and households. However, over 60% of mangroves still remain under some kind of state control, as special use or protection forests for conservation or environmental protection purposes [17]. Responses in Vietnam have therefore tended to be much more focused on responding to changes in mangrove states, or socio-political drivers at the national level, rather than changes in welfare.

National level policy development has been a common response across all three countries in response to changing states of mangroves. These national level responses have then been implemented at the local level by various combinations of local, national, and sometimes international actors. International actors have been particularly vital in Vietnam (USAID Vietnam Forest and Deltas Program) and to a lesser extent in Zanzibar (WWF), in instigating and implementing national level programmes. In Brazil, extractive reserves have been implemented through deliberative councils composed of national and local representatives, including government, researchers and civil society [60]. In contrast, responses that have been both developed and implemented at the local scale have been far less common. Although initial co-management processes in Brazil were very much driven by local communities suffering from conflict over natural resources, they still required federal government to designate an area an extractive reserve and confer rights [62]. However, in Zanzibar, there is some evidence of locally designed and implemented responses, where local communities have introduced rotational harvesting and protection for mangroves in response to increased awareness of mangrove degradation and loss [76].

Across all three countries, responses have been as a result of changes in pressures and/or the state of mangroves, and all responses attempt to target land use change pressures in order to halt and/or reverse declines in mangrove state. In all three countries, the response has been to protect existing areas of mangroves from conversion to other land uses. In Vietnam and Zanzibar responses have also included replanting and restoring mangroves in areas where they have been removed (Vietnam: Forestry Program 327 Policy to Regreen the Barren Land (1992), 5 Million ha Reforestation Project (1998–2010) of Project 661 (1997), Zanzibar: [69]). In Zanzibar and Brazil, over-exploitation of mangrove resources is targeted through management of uses to moderate what can be harvested from protected areas and to prevent waste disposal. However, in the case of Brazil, PAs also represent a barrier against land privatisation and conversion. None of the responses target the underlying drivers of these pressures because the drivers—population growth, political and economic processes, and consumption patterns—are either beyond the level of influence of local or national actors, or are in sectors beyond the influence of actors working in the environmental sphere.

In all responses identified in our sample, it seems likely that improving the state of mangroves was assumed to improve the provision of ES. Responses aimed to halt mangrove loss and degradation rather than implement management strategies in order to provide particular ES. While specific responses to provide storm protection and flood defence can be found in the wider literature (e.g., see [77]) the responses in our case study countries targeted pressures in order to enhance mangrove states, likely assuming that ecosystem services would be improved as a result. Similarly, some responses seemed to assume that improved mangrove states would also have a positive effect on welfare, mainly through livelihood effects. For example, in Vietnam, community forms of management are promoted because they are considered to be more effective than state management, and are advocated for by local people. Local communities are more likely to manage resources sustainably, and benefits are likely to be shared more equitably (Grassroots Democracy Decree (1998)). However, there are inherent trade-offs between the protection of mangrove states and livelihoods. This can be seen in Zanzibar where mangroves are subject to open and closed access regimes and harvesting permits [74]. While this management response aims to improve mangrove states, it does so at the expense of welfare, as the demand for mangrove resources for livelihoods drives local people into poaching or breaking the law by encroaching on closed sites.

While the data is limited, it is possible to do a preliminary evaluation of the success of the responses in tackling increased exploitation of resources and land use change (pressures), preventing mangrove degradation and loss (states) and improving welfare (impacts)—those elements of the DPSIR framework that they purport to tackle. In Vietnam, policies supportive of aquaculture development mean that responses through devolved management have not been effective in tackling the pressures on mangrove SESs caused by aquaculture. There is some evidence that mangrove extent has remained relatively stable in some areas, but this has mostly been achieved through replanting efforts rather than from the prevention of loss or degradation [53]. As a result, the condition of mangroves continues to decline in Vietnam, reducing their ability to support livelihoods, particularly of the poor [40]. In Brazil, the system of reserves does seem to be achieving some success in halting mangrove loss and degradation, with greater losses and degradation found outside reserved areas [78]. Extractive reserves enable local communities to set rules for extraction of resources based on local conditions and demands [62], something that seems to work in preventing land use changes. However, as Glaser et al. [62] point out, there may be conflicts between levels of resource use needed to support livelihoods (e.g., wood use) and those that can be sustainably supported by mangroves in the longer term. These trade-offs between local welfare and mangrove states have yet to be resolved and may yet lead to mangrove degradation in the future. In Zanzibar, the evidence is much more sparse but suggests that pressures on mangroves continue to increase [36], as mangroves are heavily exploited by both local people and outsiders in the face of a lack of alternative energy sources and construction materials [74]. However, there is some evidence to suggest that protected areas work to reduce

exploitation pressure [68]. However, as yet, the effectiveness of the integrated coastal area management programme to conserve mangroves and improve livelihoods remains unclear.

4. Discussion

The application of the DPSIR framework is challenging in mangrove SESs due to the multiple levels at which, in particular, drivers, pressures, and responses operate. The scale of drivers, pressures, and responses also does not always align with the scale of the states and impacts (e.g., [21]), either temporally or spatially. Additionally, it is often difficult to disaggregate impacts on mangrove states stemming from feedbacks linked to particular responses already in place, from the impacts of drivers and pressures on mangrove states.

The evidence from this research indicates that current responses are not able to target drivers at larger scales. Responses need to ideally target the larger-scale drivers and pressures in order not only to mitigate declining states or enhance those that are improving, but also to allow the root causes of changes to mangrove SESs to be tackled. This suggests there is value in using DPSIR to identify "causal clusters" of particular states and impacts [79] (p. 20) as opposed to using it in a reductionist way to isolate individual biophysical or socio-economic factors that shape states and impacts.

While DPSIR offers a useful framework to identify entry points for improving states, scale is important in determining the most effective level(s) of governance and management of responses. Many of the responses identified in our analysis focus on national policies or laws that target (often single) symptoms of, e.g., land use change, attempting to arrest or halt mangrove loss and degradation. In the case of Vietnam, it is starkly apparent that mangroves sometimes "fall between the cracks", as they are not necessarily covered by forest laws and policies or by coastal management laws and policies.

Responses can tend to focus either on improving social welfare or on ecosystem conservation, but the responses identified across the study countries often seek to address both social and ecological system components simultaneously. Response mechanisms include mangrove protection and sustainable use (e.g., Brazil's extractive reserve approach enacted through national legislation, but which involves representatives from local mangrove user associations in decision-making). The use of economic incentive mechanisms (e.g., PES for carbon sequestration) are not yet widely evident, although PES schemes are currently under discussion in Vietnam for mangroves as well as other types of forests [80]. Nevertheless, these responses (and potential responses) do not tackle the drivers and root causes (and their interactions) that stem from different scales. This is in spite of Vietnam and Zanzibar's engagement in programmes that target different levels (e.g., community based natural resource management at a local level and engagement in REDD+ activities coming from the international level). The fit (see [79,81]) between the local level impacts, the responses of national institutions, and the often-international drivers of pressures as well as international response initiatives remains far from ideal.

In the case of Zanzibar, national integrated coastal management planning approaches are seeking to target multiple drivers, pressures, and impacts. Larger scale drivers such as tourism in conjunction with institutional tensions (e.g., between different government sectors seeking coastal protection versus those promoting coastal development) add to the complexity in tackling the root causes of change in Zanzibar's mangrove SESs. Additionally, mangrove systems function ecologically in complex ways, and the goals that are emphasized in the national and local management plans of mangroves in Brazil may differ from those in Vietnam or Zanzibar. Similarly, national goals and local goals may not align. Responses need to relate directly to the human uses and values placed on particular mangrove SESs at particular points in time [82]. Despite our disaggregation of DPSIR's impacts category to permit specific focus on welfare and ecosystem services impacts, human values are not easily integrated. The case of Vietnam provides useful insights. Decision-making and policy responses that sought to improve the welfare of mangrove-dependent communities by opening up new spaces for diversified livelihood options in the form of aquaculture initially seemed to show positive local impacts on the social component of the SES. However, over time, trade-offs have become apparent

(see [17,40]). The short-term income benefits have yielded longer-term costs in the form of increased social differentiation within mangrove-dependent communities, while state variables have declined as aquaculture has introduced new pressures (e.g., pollution).

5. Conclusions

Our research targets an important gap in the current literature, which lacks comparative analyses. Across the three countries, despite some variation, mangrove SESs in different continents are facing several similar drivers, pressures, states, and impacts that are being addressed through a range of similar responses. The changing ecological states of mangroves affect a similar range of ecosystem services in each of our study countries, provisioning services in the form of food (e.g., crabs, crustaceans, fish etc.) and building materials (e.g., wood poles) and regulating services (such as storm protection and flood control). There is also a similar lack of evidence for the success of responses (as well as analysis of the interactions and feedbacks between different responses) in terms of their effects on declining states. While we recognize this may be a product of the sampling approach used in our document selection, this gap suggests there is an urgent need for such evaluation in order to elucidate lessons on what works where and under what conditions, so that they can be shared across different mangrove SESs.

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