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Title: Blue Carbon Ecosystems in Malaysia – Status, Threats and the Way forward for Research and Policy

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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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Blue Carbon Ecosystems in Malaysia – Status, Threats and Ways forward for Research and Policy

Abstract

Malaysia hosts some of the most productive blue carbon ecosystems globally. Here we review the status of and known threats faced by local mangroves and seagrass and examine conservation prospects using carbon financing. Based on lessons learnt from blue carbon projects worldwide, Malaysia needs to address governance and financing hurdles that include clarifying land tenureship, ensuring local community involvement and benefits, and obtaining sustainable financing for long term success. Research to clarify uncertainties on the extent of seagrass, and trajectories of both seagrass and mangrove ecosystems is needed to determine baseline scenarios and demonstrate additionality in carbon projects. A clear, definitive national approach to blue carbon is essential to streamline accounting and inventory of carbon stocks and benefits. Addressing these barriers and gaps requires a whole of society approach and public-private partnerships and will ultimately allow Malaysia to fully tap into the global voluntary carbon market, local businesses, philanthropy and multilateral carbon financing.

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Introduction

Addressing the climate crisis requires rapid emission reductions through decarbonisation across all economic sectors, along with the management and restoration of carbon dense ecosystems (Chausson et al., 2020). Actions to preserve and restore natural carbon sinks are critical since land use change that damages these sinks is responsible for around 14% of all anthropogenic emissions, and net negative emissions, utilising carbon dioxide removal via sinks, are assumed in most IPCC scenarios that stabilise the climate. There are a range of policy options for expanding these carbon sinks that would bring multiple co-benefits. Terrestrial ecosystems, especially forests, have long been known for their ability to sequester large amounts of carbon dioxide from the atmosphere (Sha et al., 2022). On the other hand, understanding of the current and potential role of marine ecosystems to sequester organic carbon, also known as 'blue carbon', has emerged more recently. The blue carbon ecosystems (BCEs), specifically seagrass, mangroves, and salt marshes, store between 10-24 Pg of carbon in their sediments and biomass. They account for about 50% of the annual organic carbon storage in coastal oceans (Lovelock & Reef, 2020), and may have carbon densities – stocks per unit area – of up to 10 times those found in terrestrial forests. Coastal seagrass beds alone sequester approximately 10% or 27.4 Tg of the carbon buried in ocean sediment annually (up to twice as much carbon as terrestrial forests) (Fourqurean et al., 2012). Mangroves store an average of 885 tC ha^{-1} in their biomass and underlying soils (Kauffman & Bhomia, 2017) and salt marshes have an annual carbon sequestration rate that averages between 6 to 8 Mg CO_2e ha^{-1}, which is about two to four times greater than that observed in mature tropical forests (Brevik & Homburg, 2004; Bridgham et al., 2006). In addition to the carbon storage benefits that mitigate climate change, these ecosystems also support healthy fisheries, improve water quality and mineral cycling, and provide coastal protection against floods and storms (Barbier et al., 2011; McLeod et al., 2011).

Globally, blue carbon projects could make a small but important contribution towards the Paris Agreement goals. If all blue carbon habitats were protected and areas amenable to restoration were rehabilitated, estimated carbon benefits would equal around 3% of global emissions (Macreadie et al., 2022). An evaluation of total annual carbon sequestration in all blue carbon habitats in 170 countries found that Australia has the highest value (10.6 MtC yr^{-1}) with Malaysia ranked 19th with 1.05 MtC yr^{-1} (Bertram et al., 2021). Given the accepted science (particularly for mangroves) and the national importance of blue carbon for the top twenty countries of this list, it might be expected that multiple blue carbon projects - funding protection, restoration and livelihoods by quantifying and selling carbon benefits - would already be operating in these nations. However, as of 2022, only three of the top twenty countries (India, Mexico and Madagascar) hosted projects that were selling blue carbon credits (Friess et al., 2022). This could be due to difficulties in starting and sustaining projects and/or site selection factors that are in addition to ecological considerations. Significant technical, social, and financial barriers to project implementation must be overcome (Macreadie et al., 2022) – these include addressing local socioeconomics, the ability of affected communities to shape or control projects, the legal status and tenureship of intertidal land, and carbon benefit sharing mechanisms.

Despite their importance, BCEs are highly threatened with between 0.13-7% (depending on habitat type and estimate) of these ecosystems lost annually to urban and industrial development, pollution, and pressures from agriculture and aquaculture (Costanza et al., 1997; Valiela et al., 2001; Waycott et al., 2009; McLeod et al., 2011; Goldberg et al., 2020). When degraded or destroyed, BCEs can turn from carbon sinks to sources as the sequestered carbon is oxidised and released. Moreover, anthropogenic global heating is driving multiple oceanic changes, including increases in wave energy, marine heatwaves and sea level rise leading to coastal squeeze that will exacerbate stress on these BCEs (Thorhaug et al., 2020; Lovelock & Reef, 2020; Hisham et al., 2018).

International policy has started to acknowledge BCEs and to encourage their conservation. The 26th United Nations Climate Change Conference of the Parties (COP26) held in Glasgow in 2021 recognized the importance of blue carbon in addressing climate change and laid down policies and frameworks for countries to follow (Lennan & Morgera 2022). The efficacy of such international efforts depends on local and national implementation (Jones et al., 2008; Rose, 2014). For example, the mangroves in Belize have been heavily degraded due to anthropogenic pressures despite being legally protected for many years under Belize's Forests Act (Government of Belize, 2003). As a result of both bottom-up (grassroots non-governmental organizations and local stakeholders) and top-down (governmental) approaches in addressing mangrove degradation along with evidence-informed decision making (Cooper et al., 2009; Ellison et al., 2020), the Government of Belize has recently enacted new laws with higher fines and stronger regulations to support mangrove conservation (Government of Belize, 2018). This in turn is ramping up the country's effort in restoring mangrove and seagrass, in line with their updated Nationally Determined Contributions (NDCs) to the Paris Agreement. The case study of Belize clearly demonstrates the role of international policy in helping to drive local legislation and to stimulate new conservation efforts. Establishing synergy between international and national policy, at various governmental levels, is an important step to encourage BCE conservation. In most countries, however, it is not enough to achieve this, because the resources available to governments are limited, and governments will need to work with other stakeholders, particularly communities, for success (Huxham et al., 2023). Finding sustainable sources of project finance, using familiar routes such as grants or bilateral loans, or new and emerging mechanisms such as carbon or biodiversity credits, must accompany appropriate policy for blue carbon ecosystem protection and restoration efforts to succeed (Vanderklift et al., 2022).

Malaysia is a country characterized geomorphologically by a peninsula situated on the Asian continent and a substantial upper part of the Borneo Island. This dual landmass configuration contributes to the country's diverse landscapes and ecosystems. Additionally, Malaysia operates under a distinctive governance structure as a federation of states, each with its own set of authorities and responsibilities. Despite the presence of globally significant BCEs and major potential for restoration, Malaysia currently lacks mangrove or seagrass projects that can access blue carbon finance. Furthermore, there is a lack of specific policy measures focusing on blue carbon in Malaysia, although general protection and conservation measures for mangroves are in place (Jusoff & Taha, 2008; Goh, 2016). In 2021, Malaysia updated its NDC during COP26, stating its commitment to reducing its economy-wide carbon intensity (relative to GDP) by 45% in 2030 compared to the 2005 level. This reduction target is unconditional and represents a 10% increase from the previous submission. Since then, Malaysia has started several strategies to fulfil its commitment, such as to develop the Long-Term Low Emissions Development Strategy (Bank Negara Malaysia, 2022) and the launch of the Bursa Carbon Exchange (Bursa Malaysia, 2022). Specific blue carbon initiatives in Malaysia are however hindered by the lack of a supporting regulatory framework and limited baseline data. Therefore, the current paper aims to examine the status of and key threats to BCEs, i.e., mangrove and seagrass, in Malaysia and their potential for carbon sequestration. Additionally, the paper highlights best practices and lessons learned from successful blue carbon initiatives elsewhere, and identifies barriers and gaps faced by Malaysia in implementing these practices. Finally, the paper outlines a way forward for blue carbon in Malaysia, emphasizing priority research and policymaking.

Overview of Blue Carbon Ecosystems (BCEs) in Malaysia

Malaysia is a tropical country rich in BCEs. Most of its 4809-km long coastline is fringed by shallow-water areas where light can penetrate and support the growth of vegetation. The marine landscape contains complex archipelagos with many small islands that host significant areas of BCEs. The brackish waters and sheltered muddy sediments are dominated by mangroves (Kathiresan & Rajendran, 2005; Omar et al., 2020) whereas the shallow, sandy coastal slopes, coral reef flats, and semi-enclosed lagoons are colonized by seagrass meadows (Bujang et al., 2006; Bujang et al., 2018). These BCEs provide a number of life-sustaining ecosystem services, in addition to carbon sequestration. The coastal artisanal fishers are among the main resource users of mangrove habitats (Rahman, 2022). Limited by traditional gears, these fishers are typically restricted in their capacity to fish offshore and are therefore confined to harvesting close to predominantly mangrove-lined shores. Mangroves also offer other provisioning services to the local people in the form of timber for construction and fuelwood (Goessens et al., 2014; Adame et al., 2018). Seagrass meadows provide habitat and shelter for many valuable species including finfish, shellfish, and crustaceans (Sasekumar et al., 1989; Arshad et al., 2001), and support the livelihoods of adjacent communities.

1. Mangroves – Distribution, Status and Threats

The extent of mangroves in Malaysia remains contested since different definitions and remote sensing methodologies give different estimates. The Forest Research Institute of Malaysia reported that the extent of mangroves in the years 2000 and 2017 were 642,063 ha and 629,038 ha, respectively (Omar et al., 2020), derived from ~30 m resolution satellite imagery (Landsat). Global Mangrove Watch (GMW) reported a total extent of 524,575 ha of mangroves in 2020 – this estimate, however, relies on datasets that contain regions with considerable errors due to the limitations of data sources and classification methods (Bunting et al., 2022). Based on a recent assessment of global mangrove extent using 10-m resolution satellite imagery and object-based image analysis, the total mangrove extent in Malaysia in 2020 was estimated at 552,092 ha (Jia et al., 2023). This latest estimate is likely to be more accurate than others because of the higher spatial resolution of Sentinel-2 as opposed to Landsat imagery (Astola et al., 2019; Jia et al., 2023), and the use of maximum spectral index composite that overcomes the uncertainties derived from tidal variations present in most type of vegetation indexes (Chen et al., 2017; Baloloy et al., 2020). Object-based image analysis uses spectral, textural, and neighborhood information which has advantages over pixel-based classification (Anguilar et al., 2016; Gilbertson et al., 2017). For this review, we extracted the data from Jia et al. (2023) to indicate the mangrove extent in each state of Malaysia (after correction of some state boundaries; see Figure 1 and Table 1).

-FIGURE 1 ABOUT HERE-

-TABLE 1 ABOUT HERE-

The largest extent of mangroves in Malaysia (82.4%) is found in Sabah and Sarawak, located in East Malaysia, on the island of Borneo. In Peninsular Malaysia, the largest areas of mangroves occur in the state of Perak, covering about 38% of the total mangroves found in Peninsular Malaysia, followed by the states of Johor, Selangor, Pahang, Kedah, Terengganu, Negeri Sembilan, Pulau Pinang, Melaka, Kelantan, and Perlis (Table 1). Mangroves in Peninsular Malaysia are mostly found in states on the western coast, facing the Straits of Malacca; whereas mangroves in Sabah mainly occur in the eastern coast, facing the Sulu Sea. Mangroves in Sarawak all face the South China Sea.

The threats to mangroves in Malaysia have changed over time, reflecting shifts in human activities and land-use practices, but the country has lost approximately 30% of its mangroves since the 1970s. Losses proceeded at ~ 0.13% per year since 1990 due to aquaculture, erosion, sea level rise, deforestation, water pollution, sand mining, illegal encroachment, overexploitation, timber extraction, and mass tourism (Omar et al., 2020; Omar & Misman, 2020; Gopalakrishnan et al., 2021; Nordin et al., 2022). Of these, aquaculture activities like shrimp and fish farming were the most important causes of mangrove degradation and fragmentation. The expansion of aquaculture activities, which often involve the clearance of mangrove forests, and the building of ponds, canals, and other infrastructure, have fragmented or destroyed mangrove forests on the west coast of Peninsular Malaysia, including in the states of Kedah (Halim et al., 2019), Perlis (Sahriman, 2021), Penang (Yin et al., 2020; Stiepani et al., 2021), Perak (Yamashita, 2021; Abd Latif et al., 2023), Selangor (Hamzah et al., 2009; Amran et al., 2020; Sayad et al., 2021), and Johor (Kanniah et al., 2015; Kang et al., 2021), and in several coastal regions of Sarawak (Hassan et al., 2013) and Sabah (Tangah et al., 2020; Buchwinkler, 2022), either directly through deforestation or indirectly through water pollution or nutrient enrichment. The expanding aquaculture industry was empowered by the National Agro-Food Policy 2011-2020 which promoted the growth of the agricultural sector (including aquaculture), with very limited environmental concerns (Witus & Vun, 2016). Using remote sensing, Ottinger et al. (2021) estimated that the Malaysian coastal shoreline has an area of 17,168 ha of land-based aquaculture ponds.

Erosion is another major threat to mangroves in Malaysia, particularly in regions where there is significant coastal development, land-use change, and infrastructural development (Mohamed Rashidi et al., 2021; Topah et al., 2022). Although mangroves are naturally adapted to coastal erosion, human activities can exacerbate erosion rates and pose a significant threat to both degraded and healthy mangroves. Coastal development, such as the construction of ports and resorts, has been shown to alter natural sediment flows and wave patterns, leading to either increased erosion or increased sedimentation in mangrove habitats (Omar et al., 2019; Fitri et al., 2019). An assessment by the Department of Irrigation and Drainage (2015) using satellite imagery indicated that 1,348 km (15%) of Malaysia's coastline (8,840 km including the islands) was eroding landward at an average rate of 5.86 m yr^{-1} and 4.77 m yr^{-1} on the east and west coasts of Peninsular Malaysia, respectively. Meanwhile, the eroding coastal areas of East Malaysia showed an average erosion rate of 2.92 m yr^{-1}.

An emerging threat that will worsen erosion is sea level rise combined with increasing storm surges and flooding (Muhammad Nor, 2019; Ehsan et al., 2019; Sahriman, 2021). Besides erosion, rising sea levels can also cause the loss of mangroves through inundation and submergence at the fringe of mangrove forests (Hassan et al., 2013; Ehsan et al., 2019; Sahriman, 2021). This in turn can lead to a loss of biodiversity and productivity in mangrove ecosystems, as well as reduced ecosystem services such as coastal protection, carbon sequestration, and fisheries support (Anizawati et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) has projected that global sea levels will continue to rise throughout the 21st century.

Some areas have been impacted more severely by mangrove loss than others. The states of Selangor and Johor on the west coast of Peninsular Malaysia are purportedly areas with the highest rates of mangrove degradation in the country. Selangor has experienced significant mangrove degradation due to coastal development, aquaculture activities, and pollution (Stanley & Lewis, 2009; Sayad et al., 2021). The state has lost about 50% of its mangrove forests over the past few decades, with only around 3,000 hectares remaining (Hamzah et al., 2009; Omar & Misman, 2020). Johor has also experienced significant mangrove degradation due to coastal development, aquaculture activities, and land-use change (Kanniah et al., 2015; Kang et al., 2021). The state has allegedly lost more than 20% of its mangrove forests over the past few decades, with only about 5,000 hectares remaining (Sarmin et al., 2017; Omar & Misman, 2020). The remaining mangrove forests in these two states, and in most other states, are often highly degraded and fragmented. Fragmentation has been shown to be as important, if not more, than total loss rate when it comes to determining mangrove health status and conservation priority (Bryan-Brown et al., 2020).

2 Seagrass – Distribution, Status and Threats

With 16 recorded species of seagrass, Malaysia ranks third in the world for seagrass diversity (Bujang et al., 2018). The most diverse and highly developed seagrass communities are found in Sabah, Sarawak, and the southern and eastern portions of Peninsular Malaysia. Previous data show that seagrass was present in 21 separate locations in Malaysia (Figure 2) and they are usually found inhabiting sheltered shallow intertidal associated ecosystems, with mangroves, coral reefs, semi-enclosed lagoons, shoals, and subtidal zones (Bujang et al., 2006; Zakaria & Bujang, 2011). More recent surveys have documented and mapped extensive subtidal meadows around the south-eastern islands of Peninsular Malaysia that are significant dugong and turtle feeding grounds (Ooi et al., 2011a; Ooi et al., 2014; Heng et al., 2022). Compared to mangroves, the study of seagrass extent and distribution is relatively underdeveloped, due to difficulties associated with mapping consistently in different environments that vary in water clarity and depth (McKenzie et al., 2001) and seagrass meadows' naturally changing distribution in the absence of human activities (Unsworth et al., 2019). Estimates of the extent of seagrass vary greatly between different sources (Table 2), and must be treated with caution. The UNEP-WCMC global seagrass distribution map was built upon the first published global map of seagrass distribution by Green and Short (2003), where seagrass data were composed of both polygon (i.e., with surface area) and point occurrence data. However, as stated in the dataset's metadata, there are risks of overlapping polygons in some regions as well recognized spatial gaps in information. For instance, the extensive seagrass meadow in the northern region of Peninsular Malaysia and Sabah reported by Bujang et al. (2006) was not indicated in the UNEP-WCMC dataset. The Maximum Entropy Modelling approach maps the potential distribution of seagrass meadows globally by using point records, and compares model outputs to existing records and polygons, but it does not account for factors such as seabed substratum, or pollution and dredging that can reduce seagrass cover (Jayathilake & Costello, 2018). By rationalizing and updating a range of existing datasets of seagrass distribution around the globe, McKenzie et al. (2020) estimated global seagrass extent of 16 million hectares, and Malaysia's seagrass extent of a mere 892 ha. Coupled with spatial data from the WCMC dataset and updated meadow extent data from the literature (Sudo et al., 2021; Heng et al., 2022), seagrass extent in Malaysia to date is estimated to be at least 6,000 ha. Because there are known meadows in Johor, Sarawak and Sabah that are unaccounted for, this value of 6,000 ha is still a considerable underestimate of the seagrass extent in Malaysia.

-TABLE 2 ABOUT HERE-

Similar to mangrove habitats, seagrass beds in Malaysia are vulnerable to a range of natural and anthropogenic threats (Fortes et al., 2018). Thermal stress, freshwater intrusion, shifting sand during north-east monsoons, and interspecific competition are some of the natural threats for seagrass establishment in Malaysia (Bujang et al., 2018). From a climate change standpoint, the primary effect of increased global temperature on seagrasses is the alteration of growth rates and other physiological functions of the plants themselves (Short & Neckles, 1999). However, site-specific anthropogenic threats to seagrass are more prevalent and intense. Around the coastal waters of Peninsular Malaysia, coastal development, pollution, and activities related to sand dredging, mining, and transportation, have increased sedimentation thus affecting seagrass growth if not completely burying them (Hossain et al., 2019; Ashikin et al., 2020; Hashim and Yahya, 2022). Seagrass communities in the subtidal meadows of south-eastern Johor were unable to tolerate sediment burial exceeding 4 cm for more than 3 weeks (Ooi et al., 2011b). The presence of heavy metals such as mercury and lead was found to negatively impact the local seagrass meadow in the Pulai estuary in Johor (Ahmad et al., 2015). Collection of shellfish, digging activities (for polychaetes and peanut worms) and illegal fishing were listed as the main reasons for seagrass habitat loss in East Malaysia (Bujang et al., 2006).

3 Management of BCEs in Malaysia

Defining the ownership of the BCEs, and therefore of the carbon reserves, would greatly assist in the management of these natural resources. In Malaysia, matters related to land and forests are under the jurisdiction of state governments. The Federal Constitution has provided the federal government with the power to establish the National Land Council, which is tasked to determine national policies pertaining to the administration of law and control of the utilization of land throughout Malaysia. The enforcement of this federal law, however, is undertaken by the respective state forestry that subscribe to the common Malaysian Forestry Policy 2020. Meanwhile, Sabah and Sarawak have exclusive legislative power over land, forestry, conservation, agriculture, local government and physical planning matters not accorded to the Peninsular states. Consequently, these two states have formulated their respective state forestry policies and enacted their own laws on land, forestry, conservation, environmental protection (Collins, 2020).

Mangrove forests in Malaysia can be categorized into three types: permanent reserved forests under the administration of the respective state Forestry Departments, stateland forests under the administration of local state authorities and owned/alienated land forests under the administration of individuals. As of 2017, a majority of the mangrove forest in Malaysia (85%) had been gazetted as either permanent reserved forests or protected within state or national parks (Omar et al., 2020). However, communication and coordination between different departments and tiers of government are complicated, thereby rendering the mangrove management fragmented and poorly integrated with current land-use policy directions (Friess et al., 2016; Amir, 2018).

For seagrass meadows in Malaysia, legal authority typically lies with the localized government authorities responsible for the management and conservation of natural resources. At the federal level, the Marine Park and Resource Management Division, under the Department of Fisheries Malaysia, is responsible for the conservation and management of marine parks, including seagrass areas within their designated boundaries (White et al., 2014; Asian Development Bank, 2014). The department works to enforce regulations, conduct research, and implement conservation measures to protect coastal habitats, including seagrass. Meanwhile, state governments also play a role in the management of seagrass ecosystems within their respective territories. State Fisheries Departments and State Parks authorities are often involved in the conservation and management of coastal and marine resources which include seagrass areas. To date, Malaysia has established 56 marine protected areas covering about 258,000 km^2 or about 1.4 % of its maritime waters, that are managed under national and state agencies (Department of Marine Park Malaysia, 2017). In Peninsular Malaysia, there are a total of 42 marine parks gazetted by the federal government under Marine Parks Order of the Fisheries Act 1985 (Amendment 2012). Meanwhile, in East Malaysia, there are a total of 14 marine protected areas established. Despite these laws, seagrass meadows remain largely unprotected, except for areas opportunistically included within designated marine parks. Overarching legislature at the national level would be necessary to clarify the role of government bodies in forming and regulating policies to oversee the BCEs and their carbon stocks.

State of Carbon Science and Gaps in Malaysia

Globally, the science of blue carbon has been growing rapidly ever since the term blue carbon was coined in 2009 by Nellemann et al. (2009). The assessment of total coverage, carbon storage, and sequestration rates both above- and belowground (Bunting et al., 2018; Kauffman et al., 2020), remain essential foundations for blue carbon science. In addition, other applied branches of blue carbon science have been developed and used to inform blue carbon policy and management actions, including the restoration potential of BCEs (Herr & Laffoley, 2012) and connectivity between different BCEs (Hidayah et al., 2022; Tuntiprapas et al., 2019). In this section, we review the current state of blue carbon science and identify key gaps as applied to Malaysia.

1 Blue Carbon Stock Estimates

Of 33 research articles and reports on Malaysian mangrove carbon stocks published from 1986 to 2021 (Appendix 1), all reported aboveground carbon but only 8 include estimates for soil (belowground) carbon as well. Aggregated estimates of above and belowground carbon stocks in different states of Malaysia are tabulated in Table 3. The highest aboveground carbon stock (288.0 Mg C ha^{-1}) was reported from Matang Mangrove Forest Reserve dominated by *Rhizophora apiculata*. The forest is regarded as an exemplary of sustainable mangrove management (Jusoff & Taha, 2008). The Carey Island Mangrove Forest in Selangor state was reported to have the highest amount of soil carbon (642.9 Mg C ha^{-1}) to 30 cm depth. On the East Malaysian side, despite having the highest and second highest amount of mangrove extent in Malaysia, the number of carbon stock studies is lower compared to those in Peninsular Malaysia (Table 3). Considering both above and belowground (down to 100 cm depth) carbon, Malaysia has an average of 500.8 Mg C ha^{-1} of ecosystem carbon stocks. For comparison, the Philippines has an estimated 491 Mg C ha^{-1} (Dimalen & Rojo, 2019), Indonesia an estimated 1023 ± 87 Mg C ha^{-1} (Arifanti et al., 2022) and the globally estimated mean is 856 ± 64 Mg C ha^{-1} (Kauffman et al., 2020); it is critical to note that a very important source of variation in estimates of belowground carbon stock is the depth to which soil carbon is reported and this varies between studies. Some mangrove forests have very deep soils containing thousands of tonnes of C ha^{-1} (Gress et al, 2016). The Malaysian average of 409.5 ± 50.3 Mg C ha^{-1} is for down to 1 m depth, which is likely a serious underestimate of average soil depth.

-TABLE 3 ABOUT HERE-

The Malaysian Ministry of Energy, Science, Technology, Environment and Climate Change reported in the Fourth Biennial Update Report that the aboveground biomass carbon sequestration rate for Malaysian mangrove is 5.17 Mg C ha^{-1} yr^{-1} (Yap et al., 2022). However, the primary source for this estimated rate could not be determined. Meanwhile, a study by Adame et al. (2018) in the Matang Mangrove Forest Reserve indicated that within the first 10 years after replantation, the forest sequesters carbon at 9.5 Mg C ha^{-1} yr^{-1}. However, after 10 years, the rate of accumulation decreased to 2.8 Mg C ha^{-1} yr^{-1}.

A recent study by Stankovich et al. (2021) has estimated a stock of 108.63 ± 89.43 Mg C ha^{-1} of carbon stored in Malaysian seagrass, as opposed to the estimated average organic carbon storage within seagrass ecosystems in the Southeast Asian region at 121.95 ± 76.11 Mg C ha^{-1}. These values were upscaled to national level by using limited areal estimates based on local literatures compiled by Fortes et al. (2018) (Table 2), thus the seagrass carbon stocks in Malaysia are very underestimated, as most of these studies focus on the southeastern portions of Peninsular Malaysia (Bujang, 2013; Ooi et al., 2014; Hossain et al., 2015). On the other hand, early studies of blue carbon at Sungai Pulai Estuary, Malaysia by Rozaimi et al. (2017) found that the organic carbon storage at sediment depths down to 1 m ranged from 43 to 101 Mg C ha^{-1}. The relatively low carbon stocks at this site compared to others was attributed to either increasing anthropogenic disturbance locally or natural processes in the seagrass meadow. The latter was further explored by Hidayah et al. (2022), demonstrating that the sediment organic carbon stock ranged from 51 to 223 Mg C ha^{-1}. It appeared that allochthonous inputs of mangrove and macroalgal had contributed up to 81% of those stocks (Hidayah et al., 2022). This is consistent with complementary work on algal signatures in surficial (5 cm sediment depth) stocks; Coralinalles, Cladophoraceae and Ulvaceae were significant macroalgal contributors while diatoms were the predominant microalgal sources of organic carbon (Arina et al., 2023).

2 Blue Carbon Dynamics and Monitoring Needs

Carbon connectivity typically exists between mangrove and seagrass meadows (e.g., Hidayah et al., 2022; Tuntiprapas et al., 2019). The question of the origin of the carbon found in the stocks of a connected habitat is raised in this regard. Seagrass meadows in estuarine habitats may be important sites of accumulation for mangrove-derived carbon that had escaped burial in mangrove forests via direct coastal-runoff or down-stream riverine transport (Hidayah et al., 2022). This would lower the potential for the remineralisation of this exported blue carbon, which may subsequently be buried in a different blue carbon compartment (i.e., the seagrass meadows in this instance). The reciprocal transport of seagrass detritus buried in mangrove soils is possible but, thus far, has not been widely reported. In contrast, terrestrial-derived carbon exported to mangrove forests had been more widely reported (e.g., Baldock et al., 2004; Adame et al., 2012). This brings to light the likelihood of carbon transport from other carbon-rich ecosystems such as peat swamps, which may be ecologically connected to mangrove systems. Peat swamps occur in both the Peninsular and Malaysian Borneo sides (Melling, 2016; Manzo, et al., 2020). However, the exact areas of these swamps, which border mangrove forests, is another knowledge gap to investigate. Therefore, future monitoring efforts on the spatial distribution of mangrove forests in Malaysia should account for the actual extant of the stock contained in the forest, either as scaled-up estimates or empirically quantified at the finest spatial resolution. At present, most of the studies that quantify blue carbon in the mangrove forests of Malaysia did not include investigations into the factors driving long-term storage (e.g., Omar et al., 2013; Hemati et al., 2014; Zakaria et al., 2021). Additionally, contemporary site-specific environmental land use and land cover changes would invariably modify the blue carbon inventory and would therefore need to be reassessed to ensure the baseline estimates are still applicable. A comprehensive effort of mapping of the BCEs and measuring the carbon components – ideally in the living, detrital, and the soil compartments contained therein – would increase the reliability of the mangrove and seagrass meadow blue carbon stock estimates. This is important because reliable estimates of the cover and stocks are among the top criteria for financing schemes in blue carbon (Macreadie et al., 2022; UNFCCC, 2022).

3 Restoration Versus Rehabilitation

In ecological science, 'restoration' refers to activities that aim to return ecosystems to their original condition (Elliott et al., 2007). This can be difficult or impossible and many conservation efforts now aim, instead, for rehabilitation, which attempts to restore some of the salient ecological features of a system (such as canopy cover) and to establish a natural trajectory towards restoration (Zimmer et al., 2022). Global efforts to restore or rehabilitate mangroves (Ellison, 2000; Lewis et al., 2019) and seagrass beds (Greening et al., 2011; Matheson et al., 2017; Paulo et al., 2019) in the past three decades have met with either varying degrees of success (Bayraktarov et al., 2016; Ellison et al., 2020; Tan et al., 2020) or unassessed outcomes.

Common examples of mangrove rehabilitation techniques include monoculture plantation (Matsui et al., 2012; Chow, 2018) and incorporation of engineered hard coastal defence structures within mangrove habitat (Lai et al., 2015; Morris et al., 2018). Despite the growing sophistication of these approaches and the considerable resources that have been spent, mangrove restoration often fails; this can result from poor ecological understanding, the application of inappropriate incentives, a lack of community involvement, inappropriate governance structures, and lack of follow-up monitoring (Field, 1998; Gann et al., 2019; Mazón et al., 2019; Wodehouse and Rayment, 2019; Zimmer et al., 2022). Nevertheless, there is growing sophistication in mangrove restoration approaches, which includes understanding the need for knowledge of the autecology of the mangrove species (Primavera et al., 2016) and hydrological patterns at the site (Lewis et al., 2019) to achieve successful mangrove restoration. On the other hand, implementation of engineering measures with various designs on breakwaters has led to wave dissipation, reduced coastal erosion, and increased natural regeneration (Suripin et al., 2017; Le Xuan et al., 2022). In contrast to mangrove restoration, seagrass restoration is often deemed too expensive due to a multitude of reasons such as high labour costs, challenges of seed supply and propagation and difficulties in accessing sub-tidal sites (Bayraktarov et al., 2016). Whilst direct rehabilitation and planting has worked at some sites, successful seagrass restoration often focuses on addressing the anthropogenic drivers of loss, such as sewage outfalls and agricultural run-off that cause eutrophication, and then allowing natural regeneration (Bryars & Neverauskas, 2004; Riemann et al., 2016).

In Malaysia, there are a number of documented restoration efforts of BCEs, with varying degrees of success when post-project monitoring was conducted (see Chee et al., 2021). For mangroves, replanting efforts were stimulated as a response to the 2004 Indian Ocean tsunami event. In 2005, the Malaysian government formed a taskforce called the "National Planting Program for Mangroves and Other Suitable Coastal Species to coordinate replanting works (Muhamad et al., 2019). An initial evaluation by the Forestry Department of Peninsular Malaysia estimated a total area of 8,416 hectares of coastal land suitable for replanting and rehabilitation works. Replanting in these areas was not limited to true mangrove species (especially *Rhizophora apiculata* and *R. mucronata* seedlings) but also included other suitable coastal species such as *Casuarina equisetifolia* (local name: Rhu Pantai), *Fragraea fragrans* (Tembusu) and *Calophyllum inophyllum* (Bintangor Laut). Since the inception of the country-wide mangrove replanting programme, numerous mangrove replanting efforts have been funded by the federal authorities with actual replanting carried out by state authorities and frequently supported by NGOs. Up until 2013, a total of 2,461.66 ha of area were planted with

5,806,865 mangrove trees (94%) and 373,371 other species of coastal trees (6%) (Muhamad et al., 2019). While monoculture plantation of mangrove species was the most commonly used method, more innovative methods involved the introduction or ecological engineering of additional engineered structures, such as the installation of geotubes to slow erosion and allow higher success rates observed in Selangor (Tamin et al., 2011; Motamedi et al., 2014). Despite these efforts, the overall success rate for local mangrove replanting was deemed low with numerous documented failures (Tamin et al., 2011; Tangah et al., 2012; Roscoe et al., 2019). The use of inappropriate species and young saplings unable to survive strong currents were among the causes, as was often the case for failed restoration efforts globally (Bayraktarov et al., 2016).

In terms of seagrass meadow restoration efforts in Malaysia, there are only two documented cases: Forest City in Southern Johor (Chee et al., 2021) and Pulau Gaya in East Malaysia, Sabah (Yap 2019; Saleh et al., 2020). The former case has a questionable success rate whereas the latter was deemed to have failed with low success rate in initial stages due to strong water currents from monsoons (Yap, 2019). The high wave energy brought about by the monsoon in Malaysia can lead to sediment movement that buries or erodes seagrass and planted areas that have not yet reached sufficient abundance or fully taken root (van Katwijk et al., 2016; Yap, 2019). Therefore, sediment stabilization plays an important role in keeping sediment and sprigs in place and preventing them from being swept away by strong currents and waves (van Kuelen et al., 2003; Lanuru, 2011).

Despite these multiple challenges and questionable outcomes from restoration/rehabilitation efforts of local BCEs, more and more examples of restoration successes have emerged elsewhere, using a variety of tools and techniques to improve the efficiency, cost effectiveness, and scalability of restoration programs (Tan et al., 2020; Ellison et al., 2020). Moreover, the incorporation of BCEs into existing national and international policy frameworks and developed carbon financing mechanisms, such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) and the voluntary carbon market is bringing new impetus and funding for blue carbon restoration activities (Herr & Laffoley, 2012).

Lessons Learnt from Blue Carbon Projects Elsewhere

Currently, the Voluntary Carbon Market (VCM) remains one of the key arenas for innovation and development in blue carbon projects. It involves elective purchases, by individuals and corporations, as part of their carbon abatement and management strategies. The market is growing rapidly, mitigating an estimated 155 Mt greenhouse gas (GHG) in 2022 with an investment of USD 1.3 billion, which represents a growth of 252% over the past five years (South Pole, 2023). Projections over the next decade suggest further rapid growth to possibly 13 times larger than the market in 2022 (World Economic Forum, 2023). The first VCM blue carbon project, Mikoko Pamoja in Kenya, was launched in 2013. It has proved an enduring success, inspiring a sister project in Kenya, Vanga Blue Forest, stimulating interest at numerous other sites and experiencing high demand for its credits. Despite this real-world demonstration of feasibility, the development of new VCM blue carbon projects elsewhere has been slow and Malaysia still hosts none. There are three key structural, social and financial reasons for this:

First, for communities, developers and funders to invest time and effort in projects there must be reliable tenure ship over carbon benefits, often for a minimum of 20 years (Wylie et al., 2016; Macreadie et al., 2022). However, the allocation of tenure or property rights is often complicated on the coast, particularly in relation to the intertidal mangrove management frequently shared across different government ministries with conflicting mandates for mangrove ecosystems (Friess et al., 2016; Banjade et al., 2017; Vanderklift et al., 2019). As mentioned in sections above, the legal mechanisms for the management of mangrove and seagrass in relation to carbon stocks are often unclear in Malaysia.

Second, most BCEs are socio-ecological systems in which the condition and fate of non-human nature are linked closely with the actions and welfare of people. Successful conservation and restoration of habitats is therefore contingent on genuine engagement with local communities. Under some VCM standards, such as Plan Vivo, there are rules that stipulate minimum levels of community benefit. In Malaysia, the mechanisms that allow community tenureship and benefits are opaque and mostly missing. As mentioned earlier, the tenureship for most mangrove forests lies under the jurisdiction of state forestry departments (as permanent reserved forests) or state governments (stateland forest), apart from private land areas. There are mechanisms for individuals to own land privately through Land Titles based on the National Land Code 1965 but these are restricted to agricultural, building or industry use only. State authorities are empowered by National Forestry Act 1984 to allow individuals with licenses to collect forest produce from permanent reserved forests and stateland forest (Forestry Department of Peninsular Malaysia, 2023). Major forest produce includes round timber, poles, fuelwood, charcoal, and all types of rattan. Other forms of forest produce not included as major forest produce are regarded as minor forest produce; carbon is not presently acknowledged as a forest 'produce'. Additionally, there is uncertainty over national and local policy on carbon benefits and how sales of carbon credits generated by Malaysian projects might be integrated into national policy via NDCs or taxed as contribution to national income. In the updated NDC declaration in August 2021, Malaysia does not intend to use voluntary cooperation under Article 6 of the Paris Agreement to achieve its NDC. In response to that, the then Minister of Environment and Water stated that a framework to improve and enforce climate change laws and a new carbon trading scheme was underway. At the time of writing, the drafting of policies and processes regarding carbon markets is still in progress under the new Ministry of Natural Resources and Environmental Sustainability. For these reasons, the VCM is presently difficult or impossible to access for blue carbon projects in Malaysia. However, there are other potential sources of support. These include 'insetting', in which corporate backers provide direct funding for projects as part of their carbon strategies and funding from international climate finance. Such approaches may not require the expensive third-party accreditation used by VCM carbon standards, but this increases the risks of greenwash and wasted investment.

Third, financial planning over the lifetime of a blue carbon project is essential for success. This includes initiation, validation, annual and five-year reporting and options for moving beyond carbon as the world transitions to net zero. Start-up costs, covering planning, measurement, and verification methods, can be high, particularly in developing countries (United Nations Framework Convention on Climate Change, 2022; Macreadie et al., 2022). Even with forecasted increases in credit prices and increasing demand for carbon credits to meet voluntary targets and compliance requirements, many blue carbon projects may not be financially viable on carbon crediting alone in the short to medium term (Vanderklift et al., 2019). Therefore, additional financial support such as public funding (government support, research grants), philanthropy (corporate social responsibility, corporate-cause marketing programs) and private investment need to be secured during the early stages of the project. For example, the proponents and funders of the VERRA Indian Sundarban Mangrove Restoration projects, Nature Environment and Wildlife Society (NEWS) and Livelihoods Fund, are working together with the local communities of the Sundarbans to restore heavily disturbed and shrinking mangrove forests (Verra, 2021). In addition to anticipated carbon finance, the Badabon Harvest brand has been created to help marginalized farmers improve their revenues through livestock breeding, the commercialization of organic products, the improvement of agricultural practices and fish farming. By generating economic opportunities for farmers and linking to markets such as Kolkata, this brand helps couple nature conservation with economic benefits to the farmers. Nevertheless, the opportunities for income based solely on carbon benefits are increasing due to growing demands for carbon credits and offsetting in recent years, particularly from the financial services, petrochemical/oil and gas, and consumer goods sectors (World Bank Group, 2020; Climate Change Committee, 2022). In Malaysia, new funding programmes and tax incentives encourage the adoption of green technology in the form of the Green Investment Tax Allowance (GITA) and the Green Income Tax Exemption (GITE); however support for blue carbon projects is not adequately outlined.

Opportunities and Ways Forward for Blue Carbon Research and Policymaking

Despite the gaps and barriers, the immense potential and multiple co-benefits of conserving and restoring BCEs can be unlocked once the relevant policy alignments are made, followed by appropriate support mechanisms put in place by the Malaysian government. A clear and definitive approach for blue carbon needs to be implemented at the national level to ensure streamlined accounting and inventory of carbon stocks and benefits. Specifically, blue carbon policy alignment would allow Malaysia to: (1) synergize actions in response to multiple relevant international commitments, including UNFCC, CBD, SDGs and Ramsar Convention on Wetlands; (2) streamline accounting and inventory of carbon stocks and benefits; (3) improve decision making when considering land use trade-offs; (4) ensure community involvement and equitable distribution of benefits.

In this section, we identify opportunities within the current policy and governance structure in Malaysia for BCEs, based on key gaps summarized from previous sections. We also highlight the areas in need of future policy developments in order to advance the state of blue carbon in Malaysia (Table 4). Relevant stakeholder groups and their respective roles are identified, building on a previous stakeholder mapping exercise for mangroves in the Selangor state

(Edward-Jones et al., 2022). Key actors with the authority to co-develop or interest to inform policies relevant to BCEs and blue carbon projects in Malaysia are identified, i.e. agencies directly involved in land ownership/ land tenure issues, mangrove forest and seagrass management and conservation, carbon stock accounting and verification, carbon credit trading, legal implementation, land use planning and community involvement in conservation projects (Table 4).

-TABLE 4 ABOUT HERE-

1 Addressing Blue Carbon Mapping, Monitoring and Reporting Gaps

As highlighted in the prior sections, mapping the spatial distribution of BCEs in Malaysia is one key priority for blue carbon research and enabling policy. A comprehensive national map will aid in identifying carbon stock hotspots that should be prioritized as protected areas. Inclusion of relevant information such as the legal land classification status (e.g., permanent reserved forests, protected area, unprotected area, etc.) and health of ecosystems (disturbed, degraded, natural, or restored) in the maps will expedite the efforts to determine priority areas for future restoration and to mitigate threats of carbon “leakage” due to adjacent or downstream effects of restoration (Ullman et al. 2013). To achieve this, collaborative efforts between researchers in academia, Ministry of Natural Resource and Environmental Sustainability (NRES), Forestry Department Peninsular Malaysia (FDPM), the state Forestry Departments, PLANMalaysia and the state land planning departments are crucial.

Nationwide estimates of carbon stocks from vegetated coastal ecosystems are required in order to incorporate BCEs in the NDCs to help meet climate change mitigation targets. Field data generated from ground truthing would greatly improve the estimations of carbon stock in the local and national scales. Generating national estimates of carbon stocks in BCEs based on scaled-down global or regional data can result in large errors compared to bottom-up approaches of measuring carbon stocks (Morisette et al., 2023). Reliable baseline data on blue carbon stocks and their changes over time is helpful in showing additionality (that is the efficacy of proposed interventions compared with business as usual) when trying to access funding for protecting BCEs (Ullman et al. 2013). National blue carbon stock accounting also provides information on the carbon sequestration potential of different mangrove ecotypes, different mangrove heights, habitat locations, and species providing more data for improving mangrove protection in NDC commitments and enabling predictions of future vulnerability of BC sites to projected climate change (Young et al. 2021).

To improve gaps in ground truthing and regular site-specific monitoring, establishment of nationwide monitoring networks and demonstration sites for BCEs is important. To raise public interest in blue carbon, citizen science has often been suggested as a viable means for community-level involvement (de Sherbinin et al., 2021). Training citizen scientists to conduct field surveys is a two-pronged approach to overcome limitations in human resources in research, while also promoting awareness and education opportunities in the community (Conrad & Hilchey, 2011). To empower members of the public and local community to participate in scientific monitoring of these BCEs, investments in capacity building and training programs are needed. In addition, publication of a standardized national guideline adopting existing approaches from global blue carbon manuals (Howard et al., 2014) for measuring and monitoring of blue carbon stock would be a useful resource for training non-experts, and to ensure reliable and transferrable estimates to be generated at local sites and reconciled at the national scale. Development of an openly accessible national data repository for blue carbon, such as those done in the Philippines (Dimalen & Rojo, 2019) and Indonesia (Arifanti et al., 2019) would be highly beneficial for the purposes of data sharing and data validation.

2 Inclusion of Local Communities

Including local communities in conservation is important as it acknowledges their traditional knowledge, fosters sustainable resource management, instils a sense of stewardship and ownership, respects cultural values and traditions, creates opportunities for alternative livelihoods and acknowledges the real-world limitations of top-down approaches (Bajrachya et al., 2007). Their active involvement is often essential for the long-term sustainability of blue carbon conservation and management efforts (Wylie et al. 2016). In addition, community agency and engagement are requirements for most VCM standards. Community owned and operated projects, such as those reported elsewhere (e.g., in Kenya and Sundarban; Huxham et al., 2023) have proved successful and may be replicated in Malaysia if governance hurdles can be overcome. Hattam et al. (2020) pointed out that the multiple stakeholders with interests in the mangrove forest in question will need to be identified and directly involved in the decision-making process. Continuous engagement with the relevant parties at every stage of a blue carbon project helps minimise conflicts among the stakeholders, which indirectly ensures the sustainability of the blue carbon project over extended periods of time (Conservation International, 2022). Projects that bring equitable benefit-sharing and that enable local communities to derive economic benefits such as through revenue-sharing arrangements, sustainable livelihood opportunities, or eco-tourism initiatives with direct benefits to local communities creates a win-win situation, incentivizing active community engagement and fostering long-term commitment to blue carbon conservation.

One positive development is the acknowledgement of the roles of communities as a way forward for sustainable management of forests within the 2021 Malaysian Policy on Forestry, and efforts to strengthen community participation and forest management were included in the action plans. To bring this one step further, legal and policy mechanisms for empowering community action and clearing tenureship stipulations will need to be clarified. For example, establishing a standard protocol for establishing integrated co-management of blue carbon sites such as the one established between Selangor State Forestry and Malaysian Nature Society (MNS) for the management of Kuala Selangor Nature Park (KSNP) could be highly beneficial. Initial steps towards formalization of these collaborations can be through the signing of MoUs, written deeds or agreements. Ongoing research on the socio-economic impacts of blue carbon projects on the local community is essential.

3 Integration of Blue Carbon Projects into National Climate Mitigation and Adaptation Plans

In Malaysia, a range of initiatives focused on coastal management have been designed, adopted, and implemented to conserve and restore coastal ecosystems. The current NDC includes national programs like the Integrated Shoreline Management Plan and the Tree Planting Program with Mangroves and Other Suitable Species Along National Coastlines, demonstrating the nation's commitment to utilizing coastal ecosystems for climate change adaptation, particularly in response to sea-level rise. Moreover, Malaysia's NDC acknowledges the importance of wetlands in the land use, land use change, and forestry (LULUCF) sector by incorporating them into the GHG emissions and removals inventory, implemented using Tier 1 method of the IPCC Wetlands Supplement. However, there is an opportunity to further enhance the existing NDC by integrating blue carbon as both an adaptation and mitigation strategy, aligning with Malaysia's climate targets. To maximize the potential benefits of BCEs, it is crucial to explicitly include belowground biomass and soil carbon stocks into the national GHG inventories, providing a clear assessment of their estimated contribution to the total carbon stock and annual carbon sequestration. Improved national blue carbon data acquisition would allow application of Tier 2 methods that ultimately widen alternatives for decreasing national GHG emissions and enable the documentation of GHG benefits arising from enhanced management of BCEs. By incorporating blue carbon into these inventories, countries like Malaysia can effectively recognize and account for the valuable role of these ecosystems in mitigating climate change. This inclusion not only enhances the protection of BCEs at the national level but could also open opportunities for accessing international financing schemes specifically designed for climate change mitigation through nature-based solutions.

4 Blue Carbon Financing

As mentioned in earlier sections, blue carbon financing can be channelled through public funding, philanthropy and private investment, particularly during the early stages of a project. Nevertheless, financing for blue carbon projects is ultimately constrained by how active investors are in project development and in supplementing blue carbon project income (Friess et al., 2022).

As a custodian of the reserved forests and marine parks the government is among the most important blue carbon project funders in Malaysia. Blue carbon financing from government sectors can come from public funding such as grants, subsidies, environmental levies and covenanted tax deductions (Macreadie et al., 2022). In a recent report by World Bank Groups and Bank Negara Malaysia (2022), the Malaysian Central Bank acknowledged the potential of nature-related financial risks for the Malaysian banking sector and is exploring more sustainable ways forwards. Therefore, the Malaysian Central Bank, as the financial regulator in Malaysia, could act as a central coordinator for a financial sector action plan, working closely with multiple stakeholders and in line with the government's national biodiversity strategy (World Bank Groups and Bank Negara Malaysia, 2022). Additionally, the Malaysian Central Bank could support the development of short-term financial incentives for companies to implement blue carbon projects or transition to a nature-smart economy.

Blue carbon projects could benefit from a pool of philanthropic sources in Malaysia, such as the country's sovereign wealth funds and government-linked companies and investment supporting the sustainability agenda. Khazanah Nasional Berhad, as the sovereign wealth fund of the Government of Malaysia, plans to provide MYR150 million to boost the development of environmentally friendly projects, including supporting the carbon market and the restoration of degraded forests (Khazanah National, 2023); this clearly has potential for BCE restoration.

The recently launched Bursa Malaysia's Voluntary Carbon Exchange could be expanded to include smaller scale local carbon projects and other accreditation bodies such as Plan Vivo into their accepted carbon projects repertoire. This strategic expansion would enable the exchange to capture a broader spectrum of carbon reduction initiatives, facilitating the participation of local communities, organizations, and businesses in contributing to climate change mitigation efforts. By including smaller scale projects, the exchange would encourage grassroots-level action and empower individuals to actively engage in carbon market activities, promoting a bottom-up approach to sustainability. Additionally, private-public partnerships facilitate the mobilization of financial resources by combining public funding with private sector investments. Regardless, there are reputational risks associated with investment in blue carbon projects where investors and buyers need to ensure their actions are credible and are not greenwashing.

Conclusion

Malaysia has globally significant blue carbon resources and there are multiple opportunities for BCE restoration and rehabilitation. However, the establishment of effective blue carbon projects that are based on rigorous science and respect for climate justice and the rights of local communities must address and overcome a number of socio-political barriers. These include establishing clear blue carbon monitoring and reporting mechanisms, clarifying rights to land tenureship and carbon benefits for local communities, and policy integration between local, regional and national levels to ensure alignment. Addressing these barriers will require collaborative efforts among various stakeholders, particularly the government agencies, local communities, research institutions, and non-governmental organizations. Meanwhile, the government sector can do more in accelerating public investment to finance blue carbon projects. Modest and short-term targets could include establishing and promoting high quality demonstration sites, perhaps funded directly through philanthropy or grants, to help exemplify BCE restoration and build capacity.

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Figure Caption

Figure 1: Distribution of mangroves in (a) Peninsular Malaysia and (b) East Malaysia in 2020 as extracted from Jia et al. (2023).

Figure 2: The major and important seagrass areas, associated habitats, utilization by coastal communities and other users in Peninsular Malaysia (A) and East Malaysia- Sabah (B) and Sarawak (C). Lagoon[1], inter-tidal[2], sub-tidal[3]. Aquaculture[a], turtle sanctuary[b], traditional capture fisheries[c], dugong feeding ground[d] and marine park[e]. Source from Bujang et al., (2006).

Table and Table Caption

Table 1: Mangrove extent by states in Malaysia for years 1990, 2000 and 2017 (Omar et al., 2020 using Landsat 5, 7, 8; 15-30m resolution; normalized difference vegetation index) and 2020 (Jia et al., 2023 using Sentinel 2; 10m resolution; object-based image analysis).

State	1990	2000	2017	2020
Perlis	23	38	49	95
Kedah	8,576	7,972	7,725	7,724
Penang	1,075	1,371	1,967	2,392
Perak	46,603	46,376	44,990	35,668
Selangor	22,961	21,695	20,853	20,658
Negeri Sembilan	1,718	1,757	1,557	1,895
Melaka	1,225	1,333	1,241	1,080
Johor	29,233	28,316	26,818	26,504
Pahang	4,589	4,722	3,759	7,231
Terengganu	352	367	1,571	4,473
Kelantan	390	405	422	1,029
Peninsular	116,746	114,352	110,952	108,750
Sabah	385,630	382,448	378,195	297,952
Sarawak	147,936	145,263	139,890	145,389
Grand total	650,311	642,063	629,037	552,092

Table 2: Seagrass extent in Malaysia reported by various sources.

Seagrass extent (ha)	Methodology or approach	References
793,256	Maximum Entropy Modelling from polygon data in waters shallower than 200m with high risks of overestimation.	Jayathilake & Costello, 2018

64,498	Estimation composed of two subsets of point and polygon occurrence data from World Conservation and Monitoring Centre database.	UNEP-WCMC and Short, 2018
4,900	Estimation based on 73 polygon occurrence data from peer-reviewed literature.	Sudo et al., 2021
1,630	Estimation based on limited sources from peer-reviewed with high risks of underestimation.	Fortes et al., 2018
892	Estimation based on merged quantitative (field validated mapping) and qualitative (anecdotal/expert interpolation with no documented/visual evidence) spatial data.	McKenzie et al., 2020

Table 3: Published mean and standard deviation of carbon stock estimates for Malaysian mangroves in different states. Mangrove extents are based on estimates from Jia et al. (2023).

State	Total mangrove forest area (ha)	Number of studies	Aboveground carbon stock (Mg C/ha)	Belowground Carbon Stock (Mg C/ha)	Total carbon stock (Mg C/ha)
Perak	35,668	9	122.0 ± 77.9	471.0 ± 53.1	727.2 ± 100.8
Johor	26,504	3	65.6 ± 35.2	384.6 ± 206.9	435.3 ± 0.0
Selangor	20,658	7	60.7 ± 48.0	385.0 ± 0.0	462.9 ± 170.8
Kedah	7,724	2	77.7 ± 14.7	-	-
Pahang	7,231	1	180.8 ± 30.1	-	-
Terengganu	4,473	-	-	-	-
Penang	2,392	2	55.9 ± 31.7	-	-
Negeri Sembilan	1,895	-	-	-	-
Melaka	1,080	-	-	-	-
Kelantan	1,029	3	82.4 ± 74.1	413.3 ± 0.0	512.5 ± 0.0
Perlis	95	-	-	-	-
Peninsular	108,750	27	98.0 ± 69.9	418.9 ± 150.6	540.0 ± 183.9
Sabah	297,952	5	95.1 ± 52	288.9 ± 89.2	366.1 ± 75.6
Sarawak	145,389	1	58.4 ± 0.0	-	-
Malaysia	552,092	33	97.2 ± 67.9	404.5 ± 149.2	500.8 ± 183.3

Table 4: Areas in need of policy development based on lessons learnt.

Aspect	Gaps/barriers	Potential way forward	Key actors	Key policy instruments
Blue carbon monitoring and reporting	• Lack of standardized, open access national data on spatial distribution of BCE cover	• Accelerate mapping of mangroves and seagrass at the national scale, overlaid with clear legal land	• Ministry of Natural Resources, Environment and Climate Change (NRECC)	• Malaysian Forestry Policy • National Biodiversity Policy

	• Lack of ground truth estimates for remotely sensed data • Limited quality estimates of carbon stock and sequestration rates according to different geomorphological setting and conditions • Absence of national guideline for measuring and monitoring blue carbon	and health status information • Incorporate citizen science methods to increase capacity for ground truthing and regular site-specific monitoring • Publication of a national guideline for measuring and monitoring blue carbon stock and sequestration rates • Designate BCE demonstration sites across Malaysia • Clarify relevance of Tier 1 and 2 approaches from the IPCC in Malaysian projects	• Forestry Department Peninsular Malaysia (FDPM) • State Forestry Departments • Academic researchers • NGOs • Local communities	• National Climate Change Policy
Addressing threats to BCEs	• Lack of national-scale data on threats to BCEs from aquaculture, eutrophication, tourism and coastal erosion • Continuing conversion of mangrove ecosystems into other land uses including aquaculture farms • Unchecked impacts of adjacent land use on BCEs	• Periodic assessment on threat from climate change and anthropogenic activities • Identification of priority restorable blue carbon habitats • Encourage and facilitate public-private partnerships for businesses related/adjacent to BCEs	• NRECC • Forestry Department Peninsular Malaysia • State Forestry Departments • Economic Planning Unit – Ministry of Economy • PlanMalaysia • Academic researchers • NGOs	• Environmental Quality Act 1974 (Environmental Impact Assessment) Order 2015 • National Forestry Act 1984 • National Coastal Zone Physical Plan • National Plan (RMK 12) • Malaysian Forestry Policy 2021

		• Raising public awareness and blue carbon policy discourse		• National Climate Change Policy • National Biodiversity Policy 2016-25 • National Environmental Policy
Management of BCEs	• Complex land tenureship • Lack of clear delineation of the authority under which different aspects of the BCE is managed and legislation is enforced	• Establish overarching legislation at the national level to clarify the role of government bodies and land tenureships	• NRECC • Department of Irrigation and Drainage • Forestry Department Peninsular Malaysia • State Forestry Departments • Department of Fisheries • Malaysian Maritime Enforcement Agency • National Advisory Council for Marine Park and Marine Reserve • Department of Wildlife and National Park • Ministry of Agriculture	• National Forestry Act 1984 • Environmental Quality Act 1974 • Fisheries Act 1985 • River Basin Master Plan
Inclusion of local community	• Lack of mechanism/policy to allow co-management of BCEs with local communities or NGOs • Lack of safeguards to ensure equitable transfer of	• Identify the local stakeholders and community groups to be included in blue carbon conservation and restoration discussions	• National Steering committee for NPBD – Working Group on Community-Based Natural Resources Management • NRECC	• Land Conservation Act 1960 • The Aboriginal Peoples Act 1954?

	benefits from carbon financing projects • Lack of scientific and governance capacity in local communities	• Assess the local socio-economic benefits of a blue carbon project • Signing of MoUs, written deeds, and agreement with local representatives on decisions for blue carbon • Set in place plans to safeguard local community access to enter and harvest from the blue carbon sites • Capacity building and support from responsible NGOs	• Ministry of Rural and Regional Development • Department of Orang Asli Development (JAKOA) • Academic researchers • NGOs • Local community councils/elders	
Blue carbon financing	• Lack of explicit incorporation of blue carbon mechanism into national policies • Lack of coordinated effort to evaluate the nationwide potential of blue carbon benefits • Unclear or lack of national policy on carbon benefits • Absence or lack of mechanisms to facilitate public-private partnerships for financing blue carbon beyond direct funding and CSR	• Facilitate inclusion and approval of blue carbon projects into Bursa Malaysia's Voluntary Carbon Exchange as well as the use of alternative accreditation mechanism such as Plan Vivo • Evaluate the potential to incorporate larger mangrove sites to be counted into the national REDD Plus project and NDCs	• NRECC • Ministry of Finance • Economic Planning Unit, Ministry of Economy • National Steering Committee on REDD Plus • National Advisory Committee on Biodiversity and Ecosystem Services • Bursa Malaysia • Malaysia Central Bank	• National Guidance on Voluntary Carbon Market Mechanisms • National Guidance on Forest Carbon Market • Bursa Malaysia Voluntary Carbon Exchange • National REDD Plus Strategy

		• Establish a clear policy for the carbon benefits generated from BCEs • Assessing and incorporating financial opportunities from private sectors • Prioritize loans to fund project implementation • Philanthropic support from local sovereign wealth funds and government-linked companies		