CAN THE MATANG MANGROVE FOREST RESERVE PROVIDE PERFECT TEETHING GROUND FOR A BLUE CARBON BASED REDD+ PILOT PROJECT?

AA Ammar[1], *, P Dargusch[1] & I Shamsudin[2]

[1]*School of Geography Planning and Environmental Management, The University of Queensland, Queensland 4072, Australia*
[2]*Forest Research Institute Malaysia, 52109 Kepong, Selangor Darul Ehsan, Malaysia*

Received April 2013

AMMAR AA, DARGUSCH P & SHAMSUDIN I. 2014. Can the Matang Mangrove Forest Reserve provide perfect teething ground for a blue carbon based REDD+ pilot project? Mangroves provide a variety of ecosystem services and are among the most carbon-rich forest types on earth. While much attention has been given in policies and scientific literature to the opportunities mangrove blue carbon can potentially provide for climate change mitigation, sustainable development and ecological conservation, little attention has been paid to identifying a location that can serve as a conducive site for the development of a climate change mechanism. This paper proposes to address this gap by analysing the advantages of integrating a blue carbon based REDD+ pilot project at the Matang Mangrove Forest Reserve. The Matang Mangrove Forest Reserve is an interesting case study because it is a large contiguous mangrove forest area (40,466 ha) that has been primarily managed for the production of charcoal for more than a century and has been well managed to achieve favourable outcomes for local communities and ecological health. It is also one of the most studied mangrove forests in the world. However, of late, there have been clear evidences of drastic deterioration in the provision of several of its ecosystem services. REDD+ could offer the Matang Mangrove Forest Reserve an alternative management tool to formulate an enhanced sustainable forest management plan. On the other hand, the unique characteristics and structure of the mangrove forest reserve could serve as a conducive pilot project site for the development of the climate change mechanism into a reliable and effective climate combating tool. The proposed blue carbon based REDD+ pilot project could potentially be a crucial building block in the development and implementation of Malaysia's National REDD+ Strategy.

Keywords: Climate change mechanisms, ecosystem services, co-benefits, carbon offsets

INTRODUCTION

Reducing emissions from deforestation and forest degradation (REDD) in developing countries is an international mechanism designed to mitigate climate change based on the concept of carbon-based incentives for environmental services (Bond 2009). Its primary objective is to reduce the impact of climate change through the reduction of emissions from the forest sector. The idea was initially proposed at the international climate change negotiations in 2005, which at that time focused solely on deforestation. However, during the 2007 conference of parties to the UN Framework Convention on Climate Change (UNFCC) in Bali, it was decided that forest degradation played an equally important role in the reduction of emission from the forest and should be included in the scheme. The climate change mitigation mechanism has since gone through a series of evolutionary processes, and today has come to be known as the Reducing Emissions from Deforestation and Forest Degradation Plus (REDD+).

REDD+ has broadened the scope of the initial climate change mitigation mechanism to include conservation, sustainable management of forests and enhancement of forest carbon stocks (Lawlor et al. 2010, Pistorius 2012). It is designed to embrace and promote co-benefits that result from the reduction of activities that cause forest-based greenhouse gas emissions. These co-benefits, also known as non-carbon benefits, include food and water security, biodiversity protection, poverty reduction and improved livelihood of forest-dependent communities. REDD+ is viewed as one

**a.abdulaziz@uq.edu.au*

of the most important and advanced concepts to have emerged from international climate change policy negotiations (Westholm et al. 2011).

REDD+ is currently being developed as a climate change mitigation mechanism to promote forest conservation which can potentially offer low-cost option for the reduction of carbon emissions (Eliasch 2008), but it will still take a considerable amount of time and effort to iron out issues often associated with policy instruments in their infancy (Angelsen 2008). For example, forest tenure has been identified as a major stumbling block in the implementation of REDD+. Poor classification and insecure tenure prevent equitable distribution of the benefits derived from the climate change mitigation mechanism. This results in poor control over forest management (Sunderlin et al. 2009, Larson 2011). The presence of organisational fragmentation and complex sociological, ecological and economic factors further complicates the implementation process (Law et al. 2012). Technical and managerial issues concerning the monitoring, reporting and validation process are still being refined and developed (Wertz-Kanounnikoff et al. 2008, Herold & Skutsch 2011). While the mechanism has the potential to become a straightforward solution in the reduction of forest-based emissions, it is a solution that is intertwined with a significant amount of internal and external challenges (Angelsen 2008, Clements 2010).

Despite issues surrounding the implementation of REDD+, there have already been several pilot projects launched around the world (Murdiyarso et al. 2012). The USD1 billion deal between Norway and Indonesia to protect and conserve the forests of South-East Asia can be viewed as a bold initial step in preparing a nation towards the implementation of REDD+ (Edwards et al. 2012). However, despite the noble intentions, there are indications that the moratorium may not be able to reduce deforestation or forest emission relative to recent trends (Sloan et al. 2012). There are concerns over the issue of additionality, which refers to the additional prevention of deforestation and carbon emission, that plaque the dryland moratorium forest as much of it has either already been in some form of protection or are located in areas with low possibility of conversion (Murdiyarso et al. 2011, Edwards et al. 2012).

Numerous studies have put forward solutions to remedy the shortcomings of REDD+ (Blom et al. 2010, Clements 2010, Law et al. 2012). While this paper aspires to do the same, it proposes an entirely different concept to solving the woes that plaque REDD+. This study postulates that in order for the policy instrument to positively benefit from ideas of developing an effective climate change mitigation mechanism, it has to be tested in a controlled environment, for example, a project area which will enable policy-makers to focus their attention on the mechanism itself rather than on negative external issues that can influence the outcome of the implementation. Site selection continues to be a critical step in implementing a newly proposed REDD+ project (Lin et al. 2012). The combination of a loose policy and weak site selection can further complicate the implementation process, and should be avoided from the very beginning. An implementation process weighed down by the presence of multitude problems on all accounts will ultimately turn into a huge problem-solving task.

However, a project area with clear and well defined sociological, economic and ecological structure will ensure that the mechanism can be developed under an optimum and controlled environment. It can eventually lead to the establishment of a formidable foundation which can be potentially replicated elsewhere. It can result in a mechanism that can deliver benefits sustainably and within a reasonable time frame. This paper aims to highlight the possible advantages that blue carbon and the Matang Mangrove Forest Reserve can provide in providing REDD+ with the optimum landscape to be developed and nurtured to its full potential. The objective of the paper is not intended to underestimate or ignore the significance of external issues, but it is an attempt to propose the prioritisation of the examination of underlying internal factors of the mechanism in isolation. It is hoped that it can serve as a starting point to solving the problems systematically and strategically. It is based on the idea that addressing internal issues of the mechanism can be achieved if the mechanism itself is implemented in a project area that is relatively free from influences and limitations posed by surrounding sociological, ecological and economic conditions.

MANGROVES AND BLUE CARBON

Mangroves are an ecological assemblage of trees, shrubs, palms and ferns adapted to grow above mean sea level in the inter-tidal region of coastal and estuarine environments (Duke 1992, Feller et al. 2010). A unique characteristic of mangroves is that they are inundated regularly with sea water and exposed to harsh environmental settings such as high salinity, high temperatures, extreme tides and currents, high rates of accretion (sedimentation) and muddy and often acidic anaerobic soil (Chong 2006). They are commonly found in sheltered coastlines and estuaries of tropical and subtropical regions (Giri et al. 2011).

Mangroves have been acknowledged for decades for the provision of numerous types of ecosystem services which directly or indirectly contribute to human well-being (TEEB 2010). This includes timber for commercial charcoal production, food for subsistence, coastline barrier against natural disasters as well as breeding and nursing grounds for fish (Alongi 2002, Barbier 2003, Mumby et al. 2004). More recently, mangroves have been deemed to play an important role in the global carbon cycle as a major coastal carbon sink (Laffoley & Grimsditch 2009). They are among the most carbon-rich forests in the tropics (Donato et al. 2011). The burial of carbon in sediments or soil organic carbon and the aboveground and belowground living biomass are the carbon pools that are critical to the role of mangroves as efficient and intense carbon sinks (Laffoley & Grimsditch 2009, Murray et al. 2011). In fact, the amount of carbon sequestered in non-wetland forest is significantly lower than in mangroves and it has been estimated that the destruction of a hectare of mangrove forest can potentially release as much carbon as a destruction of 3 to 5 ha of tropical forest (Ong 1993, Murray et al. 2011). The carbon captured and stored by coastal marine and wetland ecosystems such as mangroves is known as blue carbon (Nellemann et al. 2009, Murray et al. 2011).

The emergence of carbon as a globally-traded commodity has undoubtedly caused a shift in the trade-off equation of the provision of ecosystem services. A constantly updated and observable carbon price means that carbon offsets can be considered as a tangible commodity produced by mangroves. However, it is by definition a commodity that generates value through conservation rather than consumption and has the potential to increase the value of contiguous ecosystem services. Figure 1 illustrates an example comparing the possible flow of benefits between the production of commercially harvested wood and the production of carbon offsets. However, this does not imply that a single valuation is applicable to all mangrove forests because mangroves in different countries are subject to multiple factors that affect the valuation differently. These factors include cost structures, differences in opportunity costs, land costs and the different drivers of conversion and disturbance (Murray et al. 2011). Therefore, each country possesses its own unique blue carbon mitigation potential and blue carbon based economic valuation.

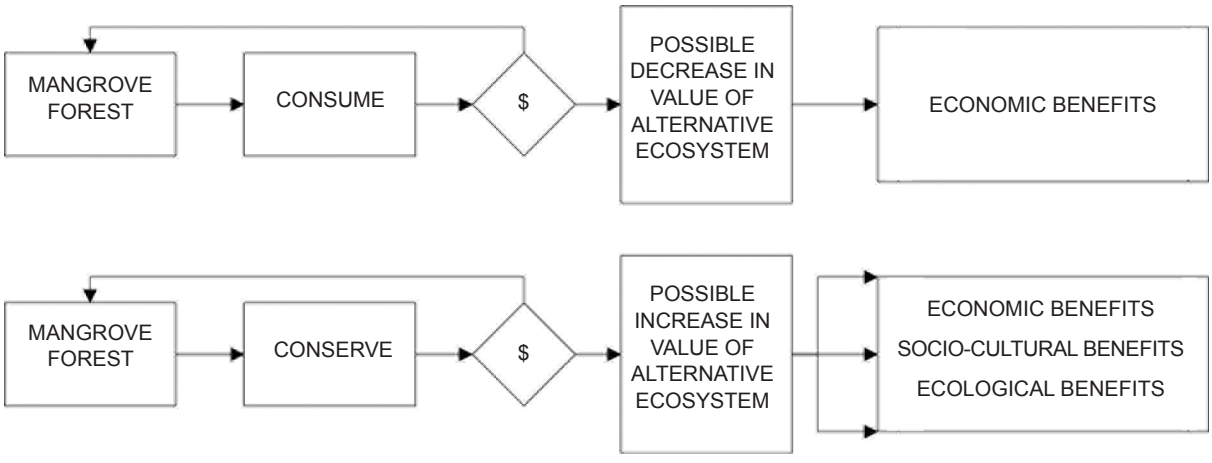

Figure 1 A simplistic conservation-orientated view of the potential flow of benefits from the production of commercially harvested wood (top) and from the production of carbon offsets (bottom)

In the context of the Matang Mangrove Forest Reserve, the existing trade-off between these ecosystem services and the emergence of blue carbon as a potential climate change combating tool does not necessarily spell an end to the production of commercially harvested timber in mangroves. There are still communities and businesses that are dependent on the production of commercially harvested timber for charcoal production and this has to be considered in the management of the respective ecosystem. Moreover, mangroves can be managed sustainably for timber production in ways that complement and support contiguous ecosystem services. The production of timber and improved ecosystem services (for example, through the production of carbon offset) can occur concurrently and if integrated appropriately may serve to provide enhanced overall financial and economic outcomes as depicted in Figure 2.

The production of timber from mangroves offers obvious direct financial benefits, but the production of carbon offsets has the potential to also offer additional economic, socio-cultural and ecological benefits. The ability to combine the two different ecosystem services through the integration of climate change mitigation mechanisms such as REDD+ will enable stakeholders to further diversify their management strategies and provide the opportunity to further enhance the economic and financial outcomes. The combination can result in an effective risk management tool for coastal habitat management and has far reaching impacts on policies governing these valuable ecosystems. Most importantly, the Matang Mangrove Forest Reserve and blue carbon have the potential to play a pivotal role in the refinement of REDD+ which can be designed to provide stakeholders with economic incentive that encourages rehabilitation and conservation of mangroves under favourable carbon market prices (Murray et al. 2011). The ability to implement a pilot blue based carbon project in a conducive location can allow research efforts to focus on the development of an effective monitoring, reporting and verifying process for REDD+.

The Matang Mangrove Forest Reserve

Malaysia's current official definition of a forest is land with a 30% minimum crown cover, 0.5 ha minimum land area, a minimum tree height of 5 m and it includes planted forest such as oil palm and rubber which differs from the definition of the Food and Agriculture Organization. However, under the REDD+ framework that is being developed for Malaysia, REDD+ activities are only focused in permanent reserved forest and protected areas. Mangrove is one of the 10 types of forests found in Malaysia and more than 70% of the mangrove forest found in Peninsular Malaysia has been gazetted as permanent reserved forests, which makes it eligible for REDD+ activity (Kamaruzaman & Dahlan 2009).

The Matang Mangrove Forest Reserve is a designated permanent reserved forest and the largest single tract of mangrove forest in Peninsular Malaysia which has been sustainably managed primarily for the production of charcoal for more than a century. It is located on the north-west coast of Peninsular Malaysia. Over 85% of the Matang Mangrove Forest Reserve is tidal swamp and 70% of its landscape comprises islands. It covers a stretch of coastline that stretches 51.5 km from Kuala Gula in the north to Bagan Panchor in the south, forming a crescent

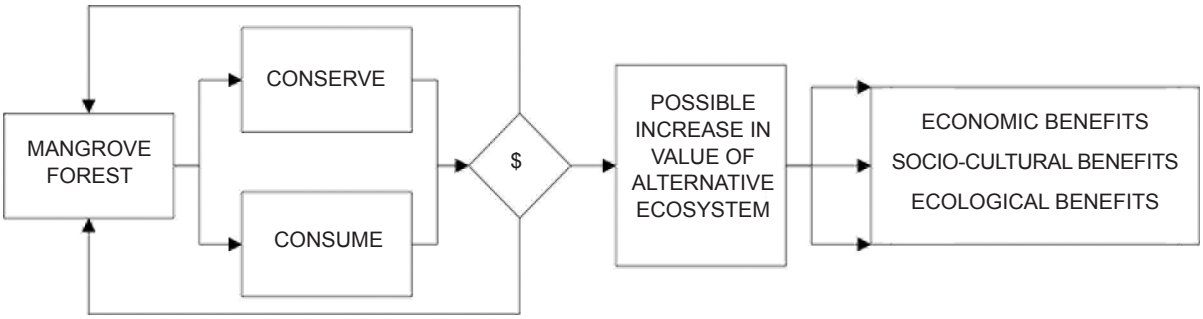

Figure 2 A simplistic view of the potential flow of benefits from the combination of the production of commercially harvested wood and the production of carbon offsets

(Figure 3). The coastlines are irregular and characterised by extensive mangroves, mudflats, islands and shallow seas. It is bordered by agricultural plantations, fruit orchards, settlements, aquaculture ponds and agricultural bunds located inland. The total acreage has actually increased by 1498 ha to a total extent of 40,466 ha since it was first gazetted in 1902 (Kamaruzaman & Dahlan 2009).

In early 2000, the introduction of a new approach in forest management zoning divided the Matang Mangrove Forest Reserve into four distinct zones, namely, the protective production, restrictive production and the unproductive zones. The protective zone covers a total area of 7360 ha. The production zone is the largest of the all the zones and covers 29,794 ha. The restrictive production zone covers 2892 ha, while the unproductive zone, which is largely built up by agriculture bunds, covers an area of 420 ha. Therefore, timber extraction activity is mainly concentrated in 73.6% of the forest and limited timber extraction is carried out in 7.1% of the forest, while 19.3% is totally free from any human-induced forestry activity (Table 1).

Source: Hamdan et al. (2013)

Figure 3 The location of the Matang Mangrove Forest Reserve

Table 1 The Matang Mangrove Forest Reserve total acreage breakdown of management zones

Range	Compartment	Protective zone (ha)	Restrictive zone (ha)	Productive zone (ha)	Unproductive zone (ha)	Total (ha)
Kuala Sepetang	1–50 62–64	5164	1369	14,357	179	21,069
Kuala Trong	51–61 65–86	834	480	9560	84	10,958
Sungai Kerang	87–108	1362	1043	5877	157	8439
Total		7360 (18.2%)	2892 (7.2%)	29,794 (73.6%)	420 (1%)	40,466 (100%)

Source: Azahar and Nik Mohd Shah (2003)

Since its designation as a permanent forest reserve in 1906, the administrators of the Matang Mangrove Forest Reserve have been constantly refining their management systems resulting in its recognition as the best managed mangrove in Malaysia and also one of the most sustainable ecosystems in the world that has a long and impressive history of sustainable management of timber extraction (Alongi et al. 2004, FAO 2007). Over the years, the management plan has evolved from one that has been strictly emphasising on economic benefits to a more well-balanced management plan that takes ecological properties of the forest into consideration.

In addition to the extraction of timber for production of charcoal and poles, the Matang Mangrove Forest Reserve also plays an important role in providing other ecosystem services. It offers nursery habitats for various commercial and non-commercial species of fish and shrimps (Chong 2007), habitat for migratory birds and local forest birds (Othman et al. 2004), recreational activities such as fishing, bird watching and wildlife observation (Ahmad 2009), and aquaculture activities which include cockle culture (Awang-Hazmi et al. 2007) and fish cage culture (Alongi et al. 2003). It provides protection against coastal erosion (Kamaludin 1993) and also acts as an effective coastal carbon sink (Donato et al. 2011).

However, although the Matang Mangrove Forest Reserve has been deemed to have been successfully managed for the sustainable production of charcoal, the production of commodities such as timber has often been shown to result in the reduction of one or more ecosystem services (Nalle et al. 2004). This occurs when the provision of an ecosystem service has a negative impact on the provision of alternative services (TEEB 2010). For example, in the case of mangroves, commercially harvesting of timber can result in the degradation of its ability to function optimally as a coastal defence mechanism or perhaps erode its function of providing breeding and nursing grounds for fish. This can eventually lead to an overall negative impact on human well-being.

After more than a century of timber extraction, there are indications that the Matang Mangrove Forest Reserve has not gone entirely unscathed from the complex and dynamic ways that the ecosystem services it provides interrelate. The declines that have been documented include:

(1) The aboveground carbon stock in the Matang Mangrove Forest Reserve has been estimated to have declined from a total of 3.04 mil t C in 1991 to 2.15 mil t C in 2011 (Hamdan et al. 2013). This represents an emission of 3.2 mil t CO_2 over 20 years.

(2) There have been cases of periodical and notable declines in the average yield of greenwood extraction at the Matang Mangrove Forest Reserve (Putz & Chan 1986, Gong & Ong 1995). While this may or may not be the result of prolonged timber extraction, the 40% increase in the number of operating kilns to 489 in the current working plan will undoubtedly exert additional pressure on the coastal ecosystem.

(3) The production levels of blood cockles at the Matang Mangrove Forest Reserve are now less than a quarter of its historic high of 120,000 tonnes in the 1980s. Benthic invertebrates can be a reliable indicator of the state of a managed mangrove forest and the continuing drastic decline in the production of blood cockles at Matang is a cause of concern (Ellison 2008).

(4) The Matang Mangrove Forest Reserve is an important habitat for migratory birds (Othman et al. 2004). Despite the creation of permanent bird sanctuaries and increased efforts in the preservation of mudflats (Azahar & Nik Mohd Shah 2003), there is evidence of a catastrophic decline in the population of water birds. It is estimated that there is a decline of 75 to 95% in the overall wintering water bird population at the Matang Mangrove Forest Reserve (Wei et al. 2006, 2007). The population of vulnerable milky stork (*Mycteria cineria*) has seen a massive 90% decline, with only five individuals recorded during an observation in 2009 (Ismail et al. 2012).

From the observed and documented declines in the provision of different ecosystem services at the Matang Mangrove Forest Reserve, it is essential to acknowledge and manage the potential trade-offs and synergies that exist between the different ecosystem services. It is crucial to maintain a desirable balance in the mix of services to ensure continuity in the provision of these services in a sustainable manner as a whole. It also shows that there is still room for improvement and there are possibilities of implementing management strategies that are based on conservation or sustainability such as the implementation of a blue carbon based REDD+ pilot project. It has the potential to provide a win–win situation for the development of both the forest reserve and the climate change mechanism. It will not only lead to a better understanding of how the ecosystem services respond to changes in time and space but will also enable the formulation of management strategies that could minimise trade-offs and increase synergies which will promote efficient and sustainable use of ecosystem services (Bennett et al. 2009).

Advantages of implementing a blue carbon based REDD+ pilot project at the Matang Mangrove Forest Reserve

The unique characteristics and structure of the Matang Mangrove Forest Reserve have the potential to offer incentive-based policy instruments the perfect testing ground for the integration of blue carbon management projects. The management structure and governing frameworks that are already in place create a project site that will minimise or even eliminate the costs of overlap, gaps, poor coordination and uncertainty that can possibly occur if the mechanism is implemented in an area with opposing characteristics.

The process of developing and implementing effective and equitable incentive-based mechanisms such as REDD+ will be further enhanced by the following factors:

(1) The extensive records and research at the Matang Mangrove Forest Reserve can be a major contributor in our efforts of building a solid understanding of this coastal carbon sink. This will ensure the enhancement of cumulative advancement in the knowledge of mangrove carbon storage which is required to facilitate the implementation of any mangrove related carbon offset production mechanism (Komiyama et al. 2007, Donato et al. 2011, Lovelock et al. 2011, Murray et al. 2011). The key drivers of deforestation and degradation can be accurately identified and records dating back to the 1920s will provide valuable insight for any performance-based mechanism.

(2) It allows the mechanism to be applied in a less complex social interface because the community and stakeholders, which in this case includes the state of Perak, are well defined and have similar objectives in which the ultimate goal is to protect the Matang Mangrove Forest Reserve to ensure sustainable flow of ecosystem services for the benefit of surrounding communities. It can provide REDD+ with a potential demonstration site of an effective integration of local governments and communities within regional and national climate change policies.

(3) The economic interest of the different groups of stakeholders complement each other. This will reduce the complexities of structuring economic objectives and goals of a particular activity within the mangrove forest reserve. It will also reduce the challenges in identifying effective and equitable benefit-sharing mechanisms.

(4) There is no conflict over land and natural resources. Clear, distinct and effective regulatory frameworks governing the forest and its natural resources have been placed for decades. Resource use rights and land tenure

are clearly defined and recorded. Clear land titles resulting in the lack of complications that often arise from competing customary and statutory rights reduce the risk of implementing a benefit-sharing mechanism such as REDD+.

(5) There are 34 settlements (28 of which are fishing villages), which will allow the project to monitor and evaluate the impact of the mechanism on a large and diverse community that depends on the mangrove forest. Direct and indirect dependents of the mangrove forest reserve can be easily identified and the impact on them can be gauged for further development of the mechanism.

(6) It is easier to promote equity because the income can be put to full use of managing the forest which will increase the quality and value of other ecosystem services that will be enjoyed by the community that depends on the mangrove. Due to the diverse stream of ecosystem services provided by mangroves, REDD+ will extend beyond the narrow carbon objective. At this project site, a single act of mitigation can yield multiple streams of adaptation advantages. For example, the act of conserving some parts of the forest will not just lead to the sequestration of carbon but also potentially protect or rehabilitate other ecosystem services such as bird habitat which can then possibly lead to an increase in tourism.

A pilot REDD+ project can make significant contribution towards Malaysia's commitment to adopt voluntary reduction of 40% emissions (in terms of gross domestic product) by 2020. It has the potential to provide the country with nature-based solution for climate change mitigation and adaptation strategies, which will help contribute to the overall global effort of combating climate change. The formulation of an effective management regime for the mangrove ecosystems and their services can help build social resilience to climate change and support sustainable economic growth. A successful REDD+ project can highlight Malaysia's large blue carbon mitigation potential and help with capacity building and the development of other blue carbon demonstration projects and pilot policies. It can potentially be a crucial building block in the development and implementation of Malaysia's National REDD+ Strategy.

From the perspective of the management regime of the Matang Mangrove Forest Reserve, an integration of a climate change mechanism such as REDD+ can be a step towards refining its management strategy and enhancing Malaysia's role in climate change mitigation. It will foster better understanding of the dynamics of governance and management of ecosystem and ecosystem services by attempting to identify the appropriate mix or balance of ecosystem services. It can be the first step towards integrating carbon and timber management in supporting multiple ecosystem services. Ultimately, the project can induce successful integration of natural and human capital by encouraging the incorporation of ecosystem services assessment and valuations in decision-making (Bateman et al. 2010).

DISCUSSION AND CONCLUSIONS

Mangroves provide a variety of ecosystem services and are among the most carbon-rich forest types on earth. A combination of these characteristics makes it an ecosystem with great potential to be incorporated into existing climate change policy frame works (Siikamaki et al. 2012). The Matang Mangrove Forest Reserve provides a unique and interesting pilot project location for a climate change intervention mechanism such as REDD+. It provides the ability for policy-makers to isolate the mechanism and implement it in a conducive location that allows the focus to be primarily on the internal structure of the mechanism such as the monitoring, reporting and verifying process.

Although the Matang Mangrove Forest Reserve has been managed well to achieve favourable outcomes for local communities and ecological health, there are evidences of an alarming decline in the provision of certain ecosystem services. Researchers can scrutinise the interaction between the different ecosystem services that are interlinked in a complex way, which can result in positive or negative impact on the other services (Heal et al. 2005, Tallis et al. 2008). This will minimise trade-offs and increase synergies in the ecosystem and enable study on the co-benefits mooted by REDD+.

A study of the Matang Mangrove Forest Reserve will be able to provide insight into the characteristics of carbon flux associated with timber harvesting. Future research can focus on the advantages or disadvantages of managed forest on carbon flux and its association with the

delivery of other ecosystem services. However, in order to fully realise the potential of any study, we will need to continue building on the current understanding of carbon stocks in mangroves. This will facilitate the implementation process of any climate change mechanism and ensure that the whole ecosystem carbon storage, which consists of two carbon pools, namely, carbon in living biomass and soil organic carbon, can be incorporated into these schemes. This will also contribute towards the development of an established and globally accepted method of measuring, reporting and verifying carbon stocks in mangroves.

Eventually, the evaluation process to determine the success rate of the integration of REDD+ will require information on the financial and economic value of the ecosystem services. The ecosystem services can be related to economic values through the total economic value (TEV) framework. The concept of TEV is defined as the sum of the values of all service flows that natural capital generates both now and in the future (TEEB 2010). It is an aggregation of all the values of ecosystem services into a single matrix using a common unit of account that allows comparisons of the benefits of various goods and services. Since money is generally accepted as a familiar unit of account, valuations and assessments in terms of monetary values will enable the evaluation results to be effectively conveyed and utilised in the planning process of formulating optional management strategies for the Matang Mangrove Forest Reserve and the incorporation of a pilot REDD+ project.

Unlike schemes implemented around the world, where the choice of conservation ultimately limits the interaction of the community or stakeholders with the forest and at times gives rise to challenging issues, the implementation of REDD+ in the Matang Mangrove Forest Reserve can potentially provide a solution of ways to integrate forest interaction (for example, timber harvesting) and conservation. As it is, to a certain extent, void of sociological, ecological and economic complexities, the financial and broader economic repercussions can be studied without jeopardising the integrity of the current ecosystem structure. It can result in a mechanism which can deliver benefits sustainably and in reasonable time.

This review believes that blue carbon and the Matang Mangrove Forest Reserve can fit the criteria of providing REDD+ or other incentive-based policy instruments the optimum landscape to be developed and nurtured to its full potential. In order to fully harness the advantages and opportunities of integrating blue carbon management project and timber harvesting in the management of the Matang Mangrove Forest Reserve, three areas of research require further attention.

Firstly, there is a need to conduct a complete and detailed ecosystem services assessment and valuation to understand and characterise the relationship between the different ecosystem services and benefits rendered. The understanding of the way ecosystem services in the Matang Mangrove Forest Reserve interrelate will enable the formulation of management strategies that can minimise trade-offs and increase synergies which will promote efficient and sustainable use of ecosystem services. The assessment and valuation of ecosystem services will be a crucial component in the designing and development stage of any proposed incentive-based policy instruments including REDD+.

Secondly, it is essential to measure and quantify the carbon fluxes at the Matang Mangrove Forest Reserve over time. This can be achieved through the estimation of the aboveground biomass, as timber harvesting primarily removes the aboveground biomass but leaves the belowground and soil carbon intact. It will provide valuable insight into the effect of timber harvesting on the carbon stock and carbon sequestration rate of the ecosystem. The adoption of recent advancements in the techniques of satellite imagery can provide a cost-effective solution in covering an extensive but largely inaccessible study area. This will allow future research to establish and develop an understanding of the dynamic relationship between the carbon flux and other ecosystem services, allowing trade-offs and synergies to be identified.

Finally, once the ecosystem services have been clearly defined and the relationships that exist have been established, a detailed financial and economic assessment of the integration of a blue carbon incentive-based policy instrument at the Matang Mangrove Forest Reserve should be performed. The focus should be on analysing the impact of integrating a blue carbon incentive-based policy instrument such as REDD+ on the direct and indirect financial and economic

performance of the Matang Mangrove Forest Reserve. A sensitivity analysis based on the carbon market price can also be conducted in order to identify the potential mix of timber production, ecological conservation and carbon offset projects in the Matang Mangrove Forest Reserve that can possibly produce an enhanced financial and economic outcome for the forest and its stakeholders.

ACKNOWLEDGEMENTS

We would like to thank the Forest Research Institute Malaysia, Forestry Department Peninsular Malaysia, Department of Fisheries Malaysia and Yayasan Dayadiri for their support.

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