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Climate Change Mitigation and Adaptation: Role of Mangroves in Southeast Asia

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Definitions

*Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer (*IPCC 2014*). Managing the risks of climate change involves mitigation and adaptation decisions with implications for future generations, economies, and environments.*

Climate change mitigation refers to actions to limit the magnitude or rate of long-term global climate change and its related effect. This mainly involves reducing the anthropogenic emissions of greenhouse gases and stabilizing the levels of these heat-trapping greenhouse gases in the atmosphere within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.

Climate change adaptation is the adjustment of natural or human systems to the changing climate, which reduces the vulnerability to the impacts of climate change. This involves taking practical actions to manage risks from climate impacts, to protect communities, and to strengthen the resilience of the economy.

*Ecosystem services are the goods or benefits derived, directly and indirectly, from natural ecosystems and the associated species to sustain and fulfill human well-being. The Millennium Ecosystem Assessment (*MA 2005*) categorized ecosystem services into four main types,* i.e., *provisioning, regulating, supporting, and cultural, while TEEB (*2010*) omitted supporting services for habitat services. The valuation of ecosystem services is a way of evaluating what society is willing to trade off to conserve a particular ecosystem service by either quantitatively or qualitatively assessing its value.*

*Mangroves are tropical maritime trees or shrubs that grow in coastal saline or brackish water, due to their ability to adapt to conditions of high salinity, low oxygen, and changing water levels. They play an important role in both climate change mitigation (*e.g., *through the sequestration of carbon) and adaptation (*e.g., *through stabilizing shoreline erosion, reducing storm surges, and preventing inland soil salinization).*

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Introduction

Climate change (CC) affects Southeast Asia (SE Asia) coastal zones, particularly the mangrove habitats, in many ways. SE Asia coastal zones are vulnerable to CC due to poor socioeconomic conditions and large populations living near to low-lying coasts. Yet awareness among multi-stakeholders on the grave CC challenges confronting the region and its mangrove ecosystems is still weak. Likewise, collaborative deliberations are rare among the government, business, and civil society for incorporating climate change mitigation and adaptation (CCMA) measures into national coastal zone development policy and processes. With benefits that go beyond the borders of country, people, and generation, CCMA is a global public good that requires a global solution built on common but differentiated responsibility. With high coastal populations in Indonesia, the Philippines, Vietnam, and Thailand, SE Asia is highly vulnerable to CC and is in great need for adaptation to reduce the impact of changes already locked into the climate system (Weiss 2009). Nevertheless, SE Asia has great CCMA potential because of robust education and improving socioeconomic condition. Hence, SE Asia should play an important role in providing solutions to this global problem. As a good long-term neighbor and trading partner of China, SE Asia has the golden opportunity and unique obligation to collaborate with China to achieve CCMA goals. This is particularly the case for collaboration on conservation and restoration of mangroves since they are present in Guangdong and Southern China, which share similar climatic, socioeconomic, and geopolitical features with SE Asia.

This entry is organized as follows. Section "Introduction" lays the foundation for the deliberation of the remaining sections. Section "Global Distribution of Mangroves" describes the distribution of mangroves globally and within SE Asia. This highlights the important role of SE Asia, which harbors about thirty-five percent (Giri et al. 2011) of the global mangrove forests, in CCMA strategies. Mangroves link many associated sub-ecosystems, via their interdependence of each other. Hence, mangrove must be managed as an integrated coastal zone, comprising marine seagrass beds, coral reefs, terrestrial marshes, and wetlands. The failures in managing mangroves effectively over the past 50 years have resulted in the loss of more than 50% of mangrove coverage in SE Asia (Macintosh and Ashton 2002; Ilman et al. 2016; Feller et al. 2017). This failure stems from an undervaluation of the importance of mangrove ecosystem to the well-being of humans. The valuation of any ecosystem, including mangroves, is not a simple exercise of routine economic algebra. The ecosystem services (ES) rendered by mangroves consist of interlinked components. Accounting for ES and associated benefits is not straightforward (TEEB 2010) because different values can be attached to a particular service or benefit. Further, unlike components like fuel wood and timber, biodiversity and deforestation cannot be given readily acceptable prices because these services are not traded in the open market. However, it is beyond doubt that mangrove ecosystem serves many valuable functions to support human needs. Section "Ecosystem Services of Mangroves" elaborates on the various ES rendered by mangroves, from the abiotic to the biotic and from the physical to the cultural and spiritual. Ecosystem services economic valuation (ESEV) is the process of placing monetary value on goods and services provided by an ecosystem. The ESEV of a mangrove ecosystem is site-specific and can vary significantly on a per hectare per year basis from USD 33 ha^{-1} $year^{-1}$ to USD 57,000 ha^{-1} $year^{-1}$ (UNEP 2014) due to differences in economic activities, cultures, and lifestyles of the local community. Nevertheless, ESEV provides useful narratives about the social-economic-cultural and ecological benefits and costs associated with alternative coastal policies. Awareness of the importance of mangroves has prompted efforts to rehabilitate abandoned fishponds back to mangrove forests in SE Asia, including in Guangdong, Indonesia, the Philippines, Thailand, and Vietnam, with varying degree of success. Section "Rehabilitation of Abandoned Fishponds in SE Asia" examines the various issues related to the rehabilitation of abandoned fishponds in these SE Asian countries as a means of implementing CCMA strategies. Property ownership right is an important determinant of success in the rehabilitation of abandoned fishponds in Indonesia and Vietnam as they are in Guangdong, Thailand, and the Philippines. Section "Loss of Mangrove in SE Asia" suggests that the extensive loss of mangrove coverage in SE Asia is a direct consequence of giving very low ESEV to mangroves because of the attitude known as the "tragedy of open access" and the "tragedy of the commons." In resource-abundant countries in SE Asia, this pervasive and entrenched attitude turns these resource-abundant countries into resource-dependent, a phenomenon known as the resource-curse. However, improving regulatory institutions and robust education appear to have initiated a process of declining rate of mangrove loss in SE Asia, giving rise to emerging rays of hope for the future. Threats to mangroves long-term survival in SE Asia are aplenty, from traditional human overexploitation to other major natural disturbances. Section "Threats to Mangroves in SE Asia" conveys the importance of implementing effective CCMA strategies to overcome this myriad of threats confronting mangroves in SE Asia. Section "Mangrove Restoration and Conservation in SE Asia" provides narratives to support the argument that socioeconomic prerogatives (e.g., community education and involvement), hydrological conditions (e.g., tidal inundation), and mangrove ecology (e.g., species to site matching) are major determinants for successful restoration of mangrove in SE Asia. Explosive growth in human populations in coastal regions in SE Asia over the coming decades may present conditions that are not conducive to mangrove conservation unless regulatory framework and supportive institution are put in place to facilitate mangrove conservation and restoration. Section "Two Examples of Successful Mangrove Conservation in SE Asia" introduces two successful examples of mangrove conservation in Malaysia and Vietnam. Section "Conclusion" concludes this entry, expressing hope for the future in which the Brundtland aspirations will be a reality. The Brundtland Report (Brundtland 1987) was published following the 1983 World Commission on Environment and Development (WCED). Embracing the aspiration for sustainable development, the Report introduced the concept of sustainable development and proposed long-term strategies for achieving it. The predicted environmental crisis (e.g., extreme climate events, debilitated habitats, and stressed ecosystems) and social crisis (e.g., widespread poverty, growing inequality, and pressures from migration) are proven accurate and relevant at present, more than three decades after its publication. Therefore, the key insights from the Report and suggested actions that can be taken to address these challenges should be earnestly implemented. The Brundtland Report inspired the United Nations Millennium Development Goals to be achieved by 2015, followed by the post-2015 agenda called "Transforming Our World: The 2030 Sustainable Development Agenda."

Global Distribution of Mangroves

Environmental factors, including temperature, salinity, and rainfall, are key determinants that have a strong influence over the growth, survival, and distribution of mangroves. Consisting of halophytic trees and shrub species, mangroves are intertidal wetland forests that live in the tropical and subtropical regions between latitude 30° north (e.g., Florida) and 30° south (e.g., southern Australia). A plethora of coastal and terrestrial fauna, including fish, crustaceans, snakes, and mammals, share the wetland habitats with some 70 vegetation species of mangroves. In the literature, mangrove also refers to the tidal forest that includes trees, shrubs, palms, epiphytes, and ferns (Tomlinson 1986). The distinctive community of plants and animals associated with mangroves is sometimes referred to as the "mangal." These forests grow around the mouths of rivers, in tidal swamps, and along coastlines. Mangroves are regularly inundated by saline or brackish water and subjected to constant salinity stresses due to vast variations in salinity over the diurnal and seasonal cycles. Mangroves must adapt to constant salinity stresses, in addition to high temperature and oxygen deprivation in waterlogged environment, at the expense of growth and development. This has resulted in the very low species diversity of the mangrove vegetation today, compared to the high biodiversity found in, e.g., coral reefs and tropical rainforests (Ricklefs and Latham 1993). For example, 223 tree species per hectare have been recorded in lowland tropical rainforest in Sarawak (Proctor et al. 1983). On the other hand, there may be only two or three mangrove species per hectare.

Although mangrove plant species themselves are not biodiverse, the mangrove ecosystem is. The abundance of fish is high in the creeks, pools, and inlets of mangrove forests. Many of the fish are juveniles suggesting that the mangrove habitat is a nursery area. The high abundance and productivity of mangrove plant and animal species make them an important fundamental ecological unit linking mangroves to other terrestrial and marine habitats. Therefore, management of this important coastal resource should be based upon an integrated approach, integrating the marine and the terrestrial habitats. Hence, the success in mangrove management "kills three birds with one stone," one on land (SDG 15) and the other below water (SDG 14), with good climate action (SDG 13). Integrated coastal zone management is a term used to describe a continuous and dynamic process that unites government and the community, science and management, and sectoral and public interests, in preparing and implementing an integrated plan for the protection and development of coastal systems and resources. Mangroves play an important role in the functioning of adjacent ecosystems, including terrestrial wetlands, peat swamps, saltmarshes, seagrass beds, and coral reef (Macintosh and Ashton 2002). Hence, integrated mangrove management must provide adequate assurance for mangrove to be functionally connected to other associated sub-ecosystems. Distributed unevenly over 118 countries (Tomlinson 1986), the center of diversity and development of mangroves occurs in a triangular area of tropical SE Asia, comprising the southern half of the South China Sea and the eastern half of the "Coral Triangle" (Giri et al. 2011). With four million hectare of mangrove cover, Indonesia alone hosts one fifth of the world's mangrove in 2001. Malaysia is a close second, with more than half million hectare under mangrove. Globally, frost frequency and severity as well as minimum temperature requirements limit poleward expansion of this tropic-adapted group of vegetation. Hence, global warming may give mangrove the window of opportunity to migrate poleward in the coming decades.

Ecosystem Services of Mangroves

These highly productive mangrove ecosystems provide a myriad of invaluable ES to human, wildlife, and the habitats they occupy. The ESEV of mangroves has not been adequately recognized nor properly assessed (Barbier et al. 2008). The provision as habitats for diverse fauna such as fish, birds, reptiles, and shellfish is probably the most acknowledged. Mangroves provide nursery habitats for juvenile coral reef fishes of many species. The prop roots of *Rhizophora* provide structural heterogeneity that is favorable to both fish prey attempting to avoid predators and to predatory fish searching for invertebrate prey hiding within the root structures. Mangroves also serve as sinks for carbon, through accumulation of living biomass and through litter and deadwood deposition, as well as the trapping of organic sediments delivered from the uplands. Carbon in mangrove sediments does not turn over in the same way it does in terrestrial soil, because it builds up vertically in response to SLR, offering a mechanism to combat SLR (McLeod et al. 2011). However, their recognition as carbon (C) sequestration and carbon burial, helping to regulate CC, is more recent (Donato et al. 2011). Mangrove forests serve as effective long-term C storages and as agents for mitigating urban C emissions in populous tropical SE Asian estuaries. Alongi (2009) reported a typical carbon burial rate for mangroves at 181.3 g C m^{-2} $year^{-1}$. Mangrove forests in tropical SE Asia are some of the most C-rich forests in the world (Donato et al. 2011), storing ~40% of their net C production underground as long-term C sinks. By comparison, agriculture, aquaculture, and urban settlement typically have extremely fast C throughput (e.g., through conversion of leached labile organic C into CO_2 via bacterial respiration) but negligible C storage capacity. Mangroves have been shown to provide protection to shorelines from persistent erosion caused by the ubiquitous tidal currents (Mazda et al. 1997). They reduce the damage inflicted by frequent storms and waves (Horstman et al. 2014). They provide some protection from lower intensity tsunamis, hurricanes, and cyclones (Alongi 2008). By dissipating incoming wave energy, they are particularly effective in flood defense against lower category hurricanes (Zhang et al. 2012).

By removing organic and inorganic nutrients from the water column, mangroves enhance water quality and inhibit eutrophication. Mangroves serve as a nutrient sink. Denitrification in the anaerobic environment and nitrogen fixation by certain bacteria and cyanobacteria associated with mangrove mud and with aboveground root systems can improve water quality from wastewater inputs. Their dense root-trunk systems slow down flow and enhance sediment deposition. The ESEV of mangroves needs to be adequately and systematically quantified for inclusion in policy decision beyond mere advocacy. ESEV has increasingly been developed and utilized in conservation management and policy decision. Consistent with the Millennium Ecosystem Assessment concept (MA 2005), ES is defined broadly as the well-being provided to humans by natural ecosystems. Therefore, ES must be evaluated through their linkage with human well-being and social-economic-cultural values. The process of placing monetary value on goods and services that do not have accepted market prices has always been a difficult process (Himes-Cornell et al. 2018). Many environmental goods and services, such as biodiversity, do not enter the traditional market and therefore have no commonly accepted market prices. ESEV provides useful narratives about the social-economic-cultural benefits and costs associated with alternative coastal policies. It facilitates the assessment of the trade-offs and synergies inherent in ecosystem-based management and policy. An estimated ESEV in the order of USD2000–9000 ha^{-1} $year^{-1}$ has been suggested (UNEP-WCMC 2006). The mean and median values of ESEV, in 2007 prices, for mangrove ecosystem services in SE Asia are estimated at USD4185 ha^{-1} $year^{-1}$ and USD239 ha^{-1} $year^{-1}$, respectively. This vast difference in ESEV reflects high variability across study sites due to vast variations in the biophysical characteristics of the site and the socioeconomic characteristics of the beneficiaries of ES including GDP (Brander et al. 2012).

Rehabilitation of Abandoned Fishponds in SE Asia

Vast tracks of mangroves in SE Asia have been lost in the past several decades, mostly to mangrove clearance to give way to shrimp cultivation. Many of these aquaculture ponds were abandoned when they were no longer commercially viable after several years of operation. Some of these abandoned former fishponds were subsequently converted back to mangrove areas. The pros and cons of these rehabilitations are constantly debated from various perspectives, including policy and community engagement. Duncan et al. (2016) evaluated the potential of carbon storage and coastal protection provided by rehabilitated fishponds in the Philippines. The study sites covered areas from the low-intertidal seafronts to the mid- and upper intertidal zones previously occupied by abandoned fishponds. For areas with large sizes and appropriate site conditions, reversion of abandoned fishponds back to mangrove was found to be favorable for enhancing ES. To combat mangrove losses, and to enhance CCMA efforts in SE Asia and elsewhere in the tropics, rehabilitation has become an essential CCMA management tool (Primavera et al. 2012). The blue carbon-based schemes of payments for ecosystem services (PES) projects related to rehabilitated mangroves are emerging (Wylie et al. 2016), and governments are increasingly recognizing the significance of mangrove ESEV in carbon stocks and coastal protection. There are two major potential sources of variation in the ability of rehabilitated mangroves to deliver high CCMA ES. Firstly, the low-intertidal seafront areas have sub-optimal hydrological conditions that limit survival and growth of replanted mangroves (Primavera and Esteban 2008). Rehabilitation in such areas may result in low mangrove biomass and low density, contributing to low associated carbon stocks and low coastal protection potential, particularly in areas where rehabilitation failure has historically been high. Secondly, rehabilitated mangrove carbon stocks are expected to increase linearly with site area, while coastal protection potential increases exponentially with mangrove greenbelt width (Koch et al. 2009). This is because wave energy reduction increases exponentially with the mangrove greenbelt protection width (Koh et al. 2009; Teh et al. 2009). Larger rehabilitation sites in the middle to upper intertidal zone may thus be expected to deliver much higher multiple CCMA ES benefits than narrow, low-intertidal rehabilitated mangroves. In short, C-rich sediments and large areal coverage of rehabilitated mangrove areas would enhance the overall carbon stocks and coastal protection potential of rehabilitated fishponds in the Philippines and throughout SE Asia (Duncan et al. 2016).

However, the area with available land suitable for mangrove rehabilitation is often constrained by land tenure conflicts in the coastal zone in the Philippines. Similarly, reversion of abandoned fishponds for mangrove replanting is difficult in Guangdong and in most of southern China, because of unresolved land tenure issues due to the ownership of massive ponds being held by numerous private stakeholders (Peng et al. 2016). Nevertheless, restoring mangroves and semi-mangroves in abandoned ponds is feasible in most nature reserves in Guangdong and southern China (Peng et al. 2013). To restore such abandoned fishponds successfully would require the restoration of the altered hydrological conditions back to the normal condition with suitable salinity and sedimentation regimes needed by mangroves. The mangrove plantations with introduced species currently account for approximately 16% of the total mangrove area in China. Their fast growth and high adaptability of introduced species ensure their continuing expansion in the future. But this “artificial” growth has aroused much criticism over the long-term ecological impacts on native mangroves. Further, such mangrove “plantations” tend to be dominated by low diversity, often with only one or two dominant species. From ecological perspective, mixed-cultured mangroves with higher diversity are preferred as they can deliver higher ES and higher carbon sequestration potential (Chen et al. 2012) in addition to improved nursery functions. Further, mixed mangrove cultures are also more resilient to human and natural perturbations due to their intrinsic “portfolio effects” of diversification.

Property rights have profound consequences for the patterns of resource use and management. Land tenure is a critical factor in how people manage and use the resources. The changes in land use over time and willingness to participate in rehabilitation efforts are related to these. In Vietnam and Thailand, the local people’s interest in participating in mangrove reforestation was severely constrained by the lack of land ownership by the local people. Tenants with limited ownership rights and poor farmers were unwilling to invest in mangrove management and opted for short-term economic benefits from shrimp aquaculture. In South Sumatra, there has been some resistance among the local people to the replanting of mangroves because the status of the trees would revert the land back to the government once the trees become productive. This is unacceptable to the local community members that are currently making a living in these areas.

Loss of Mangrove in SE Asia

About 50% of the world’s population now live within the coastal zone with most of the world’s megacities (>10 million population) located near or in major estuaries (Martinez et al. 2007), where mangroves are mainly located. Because of intense anthropogenic activities around the estuaries, around half of total global mangrove coverage has been lost since pre-industrial times (Giri et al. 2011). Many SE Asian countries now support less than 50% of their original mangrove resources 50 years ago. The percentage loss of original mangrove areas in countries in SE Asia based upon data available in WRI (1996) are as follows in descending order: Thailand (87%), Singapore (76%), Vietnam (62%), Myanmar (58%), Indonesia (45%), Malaysia (32%), and Brunei (17%). This suggests that restoration of mangroves in SE Asia is an important contribution to worldwide effort in CCMA. The different quantities and qualities of organic carbon in the disturbed tropical estuaries may affect the remaining mangrove and could result in fundamental shifts in ecosystem dynamics and could impair their ability to sustainably provide beneficial ES. Large-scale extraction of water from catchments for domestic, agricultural, and industrial uses in virtually all countries in SE Asia affects habitat hydrological connectivity. Disruption of hydrological connectivity is a main factor causing mangrove forests to currently disappear at an alarming annual rate of 1% globally. The "blue carbon" source in the major estuaries in the tropical SE Asia would normally be dominated by mangrove-derived carbon, as the turbidity and low salinity due to riverine discharge would suppress contribution from seagrasses or the marine phytoplankton, the other major components of coastal blue carbon (Fourqurean et al. 2012). The loss of mangroves would therefore have severe impact on the blue carbon ES valuation in mangrove-disturbed areas and would therefore impair CCMA achievement.

Regulation of access to and use of natural resources such as mangroves, forests, fisheries, aquaculture, and agricultural lands in SE Asia have historically been weak. The pervasive regulatory and institutional weakness in managing mangrove utilization and exploitation in many countries in SE Asia is a contributing factor to this rapid loss of mangrove worldwide. In the recent past decades, many of these resource-abundant countries in SE Asia (e.g., Indonesia, Vietnam, Laos, Cambodia, and Myanmar) have become highly resource-dependent, heavily relying on aquaculture, agriculture, fisheries, timber, and other extractive industries that exploit natural resources. Several empirical studies of a cross section of developing countries suggest a negative relationship between measures of institutional quality and deforestation rates (Ferreira 2004). In countries where such institutions are stronger, the likelihood of resource overexploitation is lower. Malaysia and Thailand are countries making good progress toward robust governance institutions in governing resource exploitation. In Vietnam where the institution is weak, shrimp farming area alone has more than doubled since 1995 to more than 530,000 ha to support seafood exports accounting for 15% of the value of non-oil exports. The conversion of coastal mangrove forests, estuaries, and lagoons for intensive shrimp farming in Thailand, Indonesia, Vietnam, and elsewhere is aided by weakness in the "tragedy of open access" (Coxhead 2007), in countries with weak regulatory institution. Improving socioeconomic status in SE Asia should give a boost to strengthening regulation and institution in this region. This would upgrade the ES provided by mangroves overall and effectively contribute to CCMA in SE Asia.

Mangroves were reported to occupy 18 million ha worldwide (Spalding et al. 1997), but this was revised downward to 14 million ha (Giri et al. 2011), and then to 8 million ha (Hamilton and Casey 2016). Concurrently, the estimated area of tidal marshes associated with mangroves has decreased from 165 million ha in 1997 to 128 million ha in 2011. Indonesia had lost more than 200,000 ha of its mangroves by the 1960s, followed by another 800,000 ha being lost in the subsequent three decades, mainly in Java, Sumatra, Kalimantan, and Sulawesi. Over the following two decades, shrimp farming known as "tambak" in Indonesia and the timber industry cleared another 600,000 ha of mangroves (Ilman et al. 2016). The vast decline in mangrove coverage in Indonesia is another example of the consequence in weak regulatory institution and the curse of the "tragedy of open access." Following the global declining trend of mangrove loss (Alongi 2002), in part due to conservation and improving regulatory institution, the net loss of mangroves in Indonesia in the coming two decades is anticipated to be reduced to around 23,000 ha (Ilman et al. 2016). Promotion of sustainable mangrove conservation and its integration with human livelihoods is thought to lead to long-term sustainability of mangrove forests throughout Indonesia, Thailand, Vietnam, and the wider world. Improving policy framework and regulatory institution in SE Asia gives a ray of hope for sustainable mangrove conservation.

Threats to Mangroves in SE Asia

Mangrove forests in SE Asia and worldwide have been threatened by many forms of anthropogenic encroachments such as conversion of mangroves to agriculture (traditionally rice) and aquaculture (notably shrimps) and unsustainable harvesting of mangroves for timber, food, fuel, fibers, and medicine. Further, sustained environmental stresses due to CC and influx of sewage and industrial effluents containing high metals and organics contents will affect the health of the mangrove ecosystem. Where the mangrove sediment surface levels are not keeping pace with sea level rise (SLR), warming climate and its associated SLR will pose the greatest threat to mangroves. The greatest impact of SLR on mangroves will take place where the area for landward migration is limited. Most of coastal regions in SE Asia fall under this category with limited space for landward migration of mangrove due to very high human settlements. In such SE Asia coastal areas, there are speculation that mangrove may face collapse if confronted with SLR in the order of 1.0–2.0 mm per year over an extended period of decades. However, this speculation has not been duly substantiated by adequate data. On the other hand, mangroves may move inland if the pace of SLR and other environmental and hydrological conditions are suitable. Most coastal regions in SE Asia do not appear to have such benign endowment, with dire consequences under CC worst-case scenarios. On the other hand, mangroves in the Key West of Florida have shifted in land by 1.5 km since the mid-1940s under a SLR regime of 2.3–2.7 mm year^{-1} (Ross et al. 2000). Globally, however, mangroves appear to keep pace with SLR, because average sedimentation rates are in equilibrium with mean SLR rates.

Underestimation of the total ESEV of mangroves and of the impacts of human activities is a major factor contributing to the widespread loss and degradation of mangrove ecosystems (Gilbert and Janssen 1998). Global warming could be a significant threat to mangrove cover and biodiversity. Rising seawater (because of melting ice caps and thermal expansion of seawater) could drown coastal mangrove. The presence of existing aquaculture, agricultural, and urban development and dikes would in many cases prevent the establishment of new mangrove areas. Projected CC could have other effects, such as changes in ocean currents, salinity, and surface temperatures. These would alter the species compositions and perhaps trigger local and global extinction. Many of the problems and causes for mangrove loss stem from failures in policy regarding land ownership. Reserved land should be allocated for the protection of mangroves. The usual requirement is a minimum of 100 m. But reserve belts of up to 500 m at the open coasts have been advocated for the Mekong Delta in Vietnam and elsewhere, which is subject to typhoons, and 50 m along riverbanks (Macintosh and Ashton 2002). The ecological links between habitats consisting of water catchment areas, mangroves, seagrasses, and coral reef connectivity should be maintained.

Mangrove Restoration and Conservation in SE Asia

The effect of unconstrained human intervention, poor socioeconomic conditions, and limited knowledge on mangrove ecology pose enormous challenges for mangrove restoration in SE Asia. The SE Asian coastal areas are highly populated with the poor and marginalized people, who depend heavily on mangroves for their subsistent livelihood. Because of this dependency, people and local community become a major determinant of the state of mangrove forests and its conservation or restoration. Historically, community participation in mangrove restoration in SE Asia has been weak, often leading to undesired consequences that pose detrimental impact on restoration progress down the road. With few exceptions, most mangrove restoration efforts in SE Asia have followed a trial and error method without any explicit and integrated framework. Lacking baseline ecological information and proper consideration of community involvement, most of the mangrove restoration efforts have met with limited success (Ellison 2000). Mangrove ecology, nature of disturbance, hydrology, and the local community well-being are the primary determinants for mangrove restoration success. Restoration of SE Asian mangroves demands special attention for social and economic issues (Bormthanarat et al. 2007). It is essential to incorporate science and traditional community ecological knowledge in management of natural resources, made possible by a thorough understanding of the driving forces behind community participation. Viability of a system will depend on sufficient economic returns to the community from the restoration. It is important to assign ownership rights to the community to encourage active participation in the restoration program (Biswas et al. 2008). The long-term ecological integrity of the mangrove forests depends on achieving and sustaining three criteria: (i) species diversity, (ii) vegetation structure, and (iii) ecological functions (Ruiz-Jaen and Aide 2005). First, the forests must harbor sufficient mangrove species diversity to improve resilience to human and natural disturbances due to the portfolio effects of species diversity. Second, the mangrove vegetation structure must be robust to enable the mangrove to function as a group. Third, the entire ecosystem comprising the mangroves and their associated sub-ecosystems comprising the seagrasses, the corals in the deeper water, as well as the marshes in the upland must possess complimentary ecological functions that allow them to support each other.

Mangrove systems are diverse at the ecosystem level, although the mangrove plant species themselves are not biodiverse. At the species and ecosystem levels, the following two conditions are critical to the success of mangrove biodiversity conservation: (a) protection of mangrove forest habitats, especially mixed species forests, and (b) preservation of the natural hydrological regime operating throughout the ecosystem. Most mangrove conversion in SE Asia usually leads to initial short-term economic gain but at the expense of greater and longer-term ecological benefits and off-site values. This undesirable situation is a consequence of not giving proper ESEV to the mangrove ecosystem, by either ignoring nonmarket valuation or awarding low valuation. The nonmarket values, for example, of species biodiversity, and off-site functions such as nutrient export and hydrology, are not easily quantified, although they have been shown qualitatively to be significant. In SE Asia, these valuations are conveniently ignored. Long-term ecological benefits and off-site values should be included in ESEV of mangroves, including the functioning of adjacent ecosystems, such as terrestrial wetlands, peat swamps, saltmarshes, seagrass beds, and coral reefs. Awarding proper recognition and designation to mangrove would help to create awareness, strengthen education, enhance community engagement, and justify government commitment on the importance of mangroves in CCMA strategies. Commitment to national parks, nature reserves and gazetted forests at national level, and commitment to Biosphere Reserves, Ramsar sites, or World Heritage Sites at the international level would enhance mangrove conservation and restoration achievements. As much as possible, mangrove restoration should actively involve the local communities who live in the mangroves and utilize the resources. They are in some sense the beneficial “owners” of these mangroves. Experience has shown that local communities have little prospect of improving mangrove management on their own efforts alone because of their limited scientific and technical knowledge and skills. But with support from NGO, government agencies, and local authorities, communities will develop a sense of unity and common purpose and can influence policy and management decisions to the common benefits. Macintosh and Ashton (2002) have suggested that the following activities should be planned and budgeted for in any mangrove restoration project: (1) site selection including detailed assessment of the hydrological conditions; (2) species selection and tree spacing, thinning, and maintenance criteria established; (3) a forest protection and monitoring system developed; and (4) a public information and awareness program incorporated in support of the restoration effort. Unfortunately, in most restoration projects undertaken in SE Asia including Malaysia and Thailand, in the past, some or most of these activities are not fulfilled, resulting in incomplete or failed restorations.

Two Examples of Successful Mangrove Conservation in SE Asia

In many SE Asian countries, federal and local governments have devoted significant resources to creating awareness, strengthening education, and enhancing community engagement for the restoration and conservation of mangroves. These successes contribute to the achievement of CCMA strategies in the region.

Matang Mangrove Forest Reserve (MMFR) in Malaysia

Sustainable management of mangrove has been achieved in the MMFR for the past 100 years. With an area of 40,000 ha, MMFR was created as a permanent forest reserve in 1902, to produce charcoal, firewood, and poles. The silvicultural operation runs on a 30-year rotation cycle with thinning at 15 and 20 years intervals. The forest is subdivided into blocks of a few hectares each and managed in such a manner that they are always surrounded by mature forests to facilitate repopulation with mangrove propagules. Local communities are contracted to cultivate suitable seedlings in small nurseries for this purpose. *Rhizophora apiculata* is the preferred species for charcoal and is planted at 1.2 m intervals. After 15 years the young trees are thinned to 1.2 m intervals to prevent overcrowding, with the timber so removed used for fishing poles. After 20 years the trees are again thinned to 1.8 m intervals and the removed timber used for the construction of village houses. Finally, after 30 years, the block is clear-felled for charcoal production (Gan 1995). Well known for its fireflies, MMFR rich and diverse flora and fauna attract nature lovers to visit and explore the wetlands.

Can Gio Biosphere Reserve in Vietnam

There are nine designated biosphere reserves in Vietnam. Designated in 2000, the Can Gio Mangrove Biosphere Reserve is in the coastal district southeast of Ho Chi Minh City. With an area of 75,740 ha, Can Gio encompasses diverse habitats including mangroves, wetlands, salt marshes, mud flats, and sea grasses. It functions as the "green lungs" of Ho Chi Minh City, absorbing carbon dioxide and other polluting agents and providing green space for recreation and relaxation. It hosts the highest biodiversity of mangrove floral and faunal in the subregion, consisting of plants, invertebrates, fish, and shellfish, as well as exotic creatures such as king cobra, saltwater crocodile, and fishing cats. Catering to a variety of activities such as hiking, bird watching, fishing and boat cruises, the mangrove ecosystems are a popular tourist attraction for locals and foreigners. It is easily accessible by road and ferry from Ho Chi Minh City.

Conclusion

The CCMA issues in SE Asia are examined in this entry with a focus on the role of mangrove. Rising temperature, elevating sea levels, and increasing frequency and intensity of extreme coastal storm events have cast severe consequences to coastal populations and ecosystems. Having large populations living near to low-lying coasts in addition to poor socioeconomic conditions, SE Asia is particularly vulnerable to these impacts of CC. Decreasing precipitation exacerbates water insecurity, adversely affects agriculture production, and accelerates forest degradation, particularly the mangroves. Mangroves provide numerous ES by supplying natural resources such as timber and fuel wood (provisioning services); by controlling erosion, flood, and storm (regulating services); by being dominant primary producers (supporting services) in tropical coastal marine environments; by providing aesthetic, recreational, and tourism value (cultural services); and by providing habitats for birds and various marine species (habitat services). Threats to mangroves' long-term survival in SE Asia are aplenty, from traditional human overexploitation to other major natural disturbances. With around 50% of mangrove forests lost in the past 50 years, SE Asia should put priority on efforts to prevent further loss, encourage reforestation, and promote sustainable mangrove forest management. Mangroves play an important role in both CC mitigation (e.g., through the sequestration of carbon) and adaptation (e.g., through stabilizing shoreline erosion, reducing storm surges, and preventing inland soil salinization). Conservation of forests and mangroves will undoubtedly contribute to SDG 13 in reducing GHG and in helping to contain the "epidemic" of global warming.

Multi-stakeholders should remain wary of the grave CC challenges confronting SE Asia and its mangrove ecosystems. Deliberations for incorporating CCMA measures into national coastal zone development policy and processes must be characterized by collaborative engagement among government, business, and civil society. SE Asian countries must incorporate CCMA as an essential part of SDGs to minimize the costs already locked into the climate system and to build resilience against future climate shocks. Many countries are introducing green fiscal stimulus that creates jobs, shores up economies, and reduces poverty, all of which create opportunity for CCMA. In SE Asia, incidence of poverty remains very high and will continue to pose a daunting challenge to achieving CCMA and the broader SDGs, unless effective actions are taken to reduce poverty. Rapid economic growth in past decades has, however, lifted millions of people out of the extreme poverty in SE Asia. Robust education and improving socioeconomic conditions in SE Asia offer some comfort to the belief that CCMA and SDG in SE Asia would help to arrest the continuing decline in mangrove coverage in SE Asia. Endowed with improving socioeconomic capitals, SE Asia has the capability and responsibility to forge ahead a long-term program to achieve the goals of CCMA and SDGs. Key elements of CCMA and SDGs include (a) adapting water management to mitigate increase risk of floods and droughts, (b) adapting integrated coastal zone management to counter higher sea levels, and (c) protecting forests from fires and degradation. The fundamental principles of the SDGs can be traced to the Brundtland report that proclaimed that sustainable development is "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). Let us look forward to a future in which our children will look back with appreciation for our foresight and actions.

Cross-References

- ▶ Adaptation and Mitigation Synergies and Trade-offs
- ▶ Climate Change Adaptation (CCA)
- ▶ Climate Change Effects on People Livelihoods
- ▶ Climate Change Impacts and Resilience
- ▶ Climate Change Mitigation
- ▶ Climate Resilient Communities
- ▶ Vulnerable Communities: The Need for Local-scale Climate Change Adaptation Planning

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