Chapter 48. Mangroves

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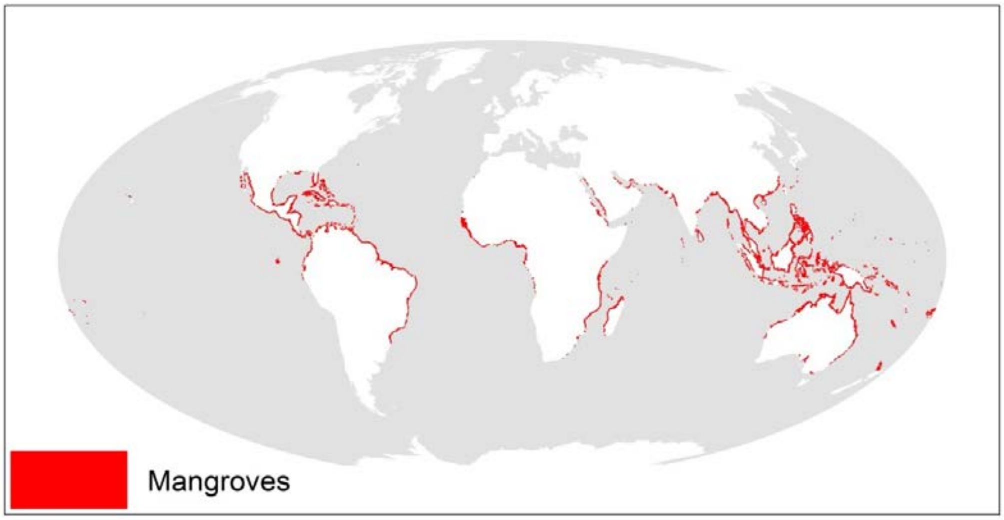
1. Definition and significance

Mangroves dominate the intertidal zone of sheltered (muddy) coastlines of tropical, sub-tropical and warm temperate oceans. The word 'mangrove' is used to refer to both a specific vegetation type and the unique habitat (also called tidal forest, swamp, wetland, or mangal) in which it exists (Tomlinson 1986; Saenger, 2003; Duke et al., 2007; Spalding et al., 2010). Mangrove areas often include salt flats, which are mostly observed in arid regions or areas with well-defined dry seasons, and where the frequency of tidal flooding decreases progressively toward the more landward zones of the forest leading to an accumulation of salts. In such mangrove areas, a continuum of features may be observed, which, as described by Woodroffe et al. (1992), may include: (a) mudflats in the zone below mean sea level; (b) mangrove forests in the zone between mean sea level and the level of higher neap tides; and (c) salt flats in the zone above the level of higher neap tides. These transition zones and their tidal positions vary globally as they are dependent on many factors (e.g. climate, topography and hydrology). Mangrove trees, along with other floral inhabitants of the mangrove area, such as shrubs, ferns and palms, are highly adapted with aerial roots, viviparous seeds and salt exclusion/excretion mechanisms (Tomlinson, 1986; Hogarth, 2007), thus coping with periodic immersion and exposure by the tide, fluctuating salinity, low oxygen concentrations in the water and sediments, and sometimes high temperatures (Hogarth, 2007). Mangroves have been used by coastal inhabitants for centuries with the earliest reports from 10,000 - 20,000 years ago (Allen, 1987; Luther and Greenburg, 2009). Mangroves continue to be of tremendous value to humanity through a range of ecosystem services. Several reviews are dedicated to mangrove forests, addressing their global distribution (area covered and biomass), ecology, biology and value/uses (Dittmar et al., 2006; FAO, 2007; Walters et al., 2008; Ellison, 2008; Costanza et al., 2008; Spalding et al., 2010; Giri et al., 2011; Horwitz et al., 2012; McIvor et al., 2012; Hutchinson et al., 2014).

2. Spatial patterns and inventory

Mangrove distribution correlates with air and sea surface temperatures, such that they extend to ~30^{o}N, but to 28^{o}S on the Atlantic coast (Soares et al., 2012), and in the Indo-West Pacific (IWP), to 38^{o}45'S to Australia and New Zealand (Hogarth, 2007). The latitudinal distribution of mangroves is limited by key climate variables such as aridity and frequency of extreme cold weather events (Osland et al., 2013, Saintilan et al., 2014). The distribution and structural development within areas with suitable temperatures is further limited by rainfall or freshwater availability (Osland et al., 2014; Alongi 2015) The area covered by mangroves (between 137,760 and 152,000 km^2) and the number of countries in which they exist (118 to 124) have been the focus of many studies (FAO, 2007; Alongi, 2008; Spalding et al., 2010; Giri et al., 2011). The accuracy of these ranges is affected by the different methods (with varying spatial resolutions) used for area surveys and the exclusion of some countries with small mangrove stands (FAO, 2007; Giri et al., 2011). However, what is more generally accepted is that mangrove coverage is extremely low, accounting for less than 1 per cent of tropical forests and 0.4 per cent of global forest areas (FAO, 2007; Spalding et al., 2010, Van Lavieren et al., 2012). Mangrove area has declined globally over the last 30 years (1980 – 2010), (Polidoro et al., 2010; Donato et al. 2011) and this decline continues in many regions.

Uncertainty also surrounds the number of mangrove species found globally. Spalding et al. (2010) reported 73 mangrove species (inclusive of hybrids), of which 38 were called 'core species', , also called 'foundation species', indicating those which typify mangroves and dominate in most areas (Ellison et al., 2005, Osland et al., 2014. Polidoro et al. (2010) listed a similar number of species (70), which did not include hybrids, but used the criteria of "anatomical and physiological adaptations to saline, hypoxic soils". Thus their list included both 'true' mangroves and mangrove 'associates', classifications by Tomlinson (1986) and Hogarth (2007). Tomlinson (1986) lists the criteria of 'true or strict' mangroves as: (i) occurring in the mangrove environment and not extending into terrestrial communities; (ii) having a major role in the structure of the community; (iii) possessing morphological specialization that adapts them to their environment; (iv) possessing physiological mechanisms for salt exclusion; and (v) having taxonomic isolation from terrestrial relatives, at least at the generic level.



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1. The global range of mangroves is demarcated in red (Giri et al., 2011). Used with permission from UNEP-WCMC.

It has been argued that ignoring the distinction between 'true' mangroves and mangrove 'associates' may lead to cryptic ecological degradation, as the latter may include species, such as *Acrostichum aureum,* which can totally replace mangrove trees in some regions, with an accompanying change in mangrove functionality (Dahdouh-Guebas et al., 2005), but without change in areal extent. This idea is controversial and is made more problematic by the inclusion by some of beach grass and scrub vegetation in the category of 'mangrove associates'. It is also difficult to resolve the issue of the exact number of mangrove species recognized worldwide due to taxonomic inconsistencies caused by the use (or not) of the most recent phylogenetic listings. Angiosperm phylogeny listings are constantly updated, most recently with the APGIII (2009). Addressing issues with mangrove taxonomy would enhance our ability to track global species extinctions (Polidoro et al., 2010). Furthermore, it would be useful to base species identification on molecular attributes (not just morphological descriptions), which could address many controversies surrounding use of terms like 'mangrove associates' or 'mangrove hybrids'.

Globally, the IWP and the Atlantic, East Pacific (AEP) have different mangrove species groups (Hogarth, 2007; Spalding et al., 2010). The IWP region has over 90 per cent of species and 57 per cent of global area coverage; the AEP has less than 10 per cent of species and 43 per cent of global area coverage. Fifteen countries account for 75 per cent of global mangrove area (Giri et al., 2011) and these countries are distributed across both regions. Indonesia in the IWP accounts for 22.6 per cent of global mangrove area, and Brazil in the AEP has 8.5 per cent (Spalding et al., 2010). Brazil has the largest continuous mangrove forest (6,516 km^2), which lies between Maranhão and Pará in northern Brazil. In the IWP, the Sundarbans, located in India and Bangladesh, extend 85 km inland and cover an area of 6,502 km^2 (Spalding et al., 2010). These regions have no true mangrove species in common, except for *Rhizophora mangle*/*R. samoensis* (Duke and Allen, 2006). *Acrostichum aureum*, which is classified by some as a mangrove 'associate', is also found in both regions. The genera *Rhizophora* and *Avicennia* are unique in having worldwide distribution (Duke et al., 2002).

3. Rate of loss/changes and major pressures

Despite widespread knowledge of their value, mangroves are being lost globally at a mean rate of 1-2 per cent per year (Duke et al., 2007; FAO, 2007), and rates of loss may be as high as 8 per cent per year in some developing countries (Polidoro et al., 2010). Between 20 and 35 per cent of mangroves have been lost since 1980 (FAO, 2007; Polidoro et al., 2010), which is greater than losses of tropical rain forests or coral reefs (Valiela et al., 2001). Spalding et al. (2010) report losses of over 20 per cent in all regions except Australia over a 25-year period (1980-2005). However, their assessments of loss indicate that the global rate of loss has been declining over the last three decades (1.04 per cent in the 1980s; 0.72 per cent in the 1990s and 0.66 per cent in the five year period up to 2005 (Spalding et al., 2010). This could be an indication of increasing resilience of the remaining mangroves or the result of effective conservation and restoration/rehabilitation efforts.

Unfortunately, in some regions, responses to mangrove loss and mitigation remain inadequate, along with the realization that it is more economical to conserve than to restore mangroves (Ramsar Secretariat, 2001; Gilman et al., 2008; Webber et al., 2014). Particular species of mangroves or specific geographic areas have been identified as being more threatened by extinction than others (Polidoro et al., 2011). Although the primary threats to all mangroves are destruction through conversion of mangrove habitat and over-exploitation of resources, pressures that result in loss of area and ecosystem function vary somewhat across regions (Vaiela et al., 2001). Two areas have shown the greatest per cent loss between 1980 and 2005: the Indo-Malay-Philippine Archipelago (IMPA) with 30 per cent reduction, and the Caribbean, with 24-28 per cent reduction in mangrove area (McKee et al., 2007b; Gilman et al., 2008; Polidoro et al., 2010). The major pressure resulting in losses in the IMPA is conversion of mangrove habitat for shrimp aquaculture; while in the Caribbean numerous pressures cause habitat loss, including coastal and urban development, solid waste disposal, extraction of fuel-wood, as well as conversion to aquaculture and agriculture (Polidoro et al., 2010).

Climate change, particularly sea level rise, is considered a threat to mangrove habitat and functionality in all regions (McLeod and Salm, 2006; Gilman et al., 2008; Van Lavieren et al., 2012; Ellison and Zouh, 2012). Mangrove areas most vulnerable to sea level rise are believed to be those of low-relief carbonate islands with a low rate of sediment supply and little available upland space (Schleupner, 2008) as well as those in arid, semi-arid, and dry sub-humid regions (Osland et al., 2014). Mangroves on wet, macrotidal coastlines (>4 m tidal amplitude) with significant riverine inputs, are believed to be least vulnerable (Ellison and Zouh, 2012). While there are varying opinions on the nature and level effects on mangroves from climate change drivers, it is widely agreed that the vulnerability of mangrove forests is increased by occupation and urbanization of the coastal zone, including the conversion of mangrove area to other land uses (Soares, 2009).

Some of the other effects of climate change (e.g., increased precipitation, temperature and atmospheric CO_2 concentration) may actually increase mangrove productivity (Gilman et al., 2007) and the ability of mangroves to keep pace with sea level rise (Henzel et al. 2006; McKee et al., 2007a; Langley et al., 2009; McKee, 2011; Krauss et al., 2014) because elevated CO_2 increases productivity and biotic controls of soil elevation. Increased temperatures are correlated with mangrove range expansion (Osland et al. 2013), due to the reduction in intensity, duration and frequency of extreme cold-weather events that are expected to support mangrove poleward migration. The genus *Avicenna* has already proliferated at or near their polar limit at the expense of salt marshes (Saintilan et al., 2014). Mangroves may therefore be more resilient to climate change than was previously thought (Alongi, 2007) and certainly the effects will vary greatly depending on local conditions (e.g., geomorphology and shoreline stability). Indeed, the role of mangroves in carbon sequestration and mitigation of climate change effects (Siikamäki et al., 2012) is such that there may be net global economic gains from their protection, especially when all other economic and ecological uses are factored in to the calculation. Mangroves have high rates of atmospheric carbon capture and storage, (Mcleod et al., 2011; Van Lavieren et al., 2012). Their productivity and substantial below- and above-ground biomass, although varying with geomorphology and coastal conditions, can yield sequestration rates of over 174 gCm^{-2} yr^{-2} (Alongi, 2012), making them prime targets for not just conservation but active reforestation and restoration. Although mangroves account for a small percentage of the earth's forest cover (Donato et al., 2011; Giri et al., 2011) and hence only 1% of global forest sequestration (Alongi, 2012), they account for 14% of carbon sequestration by the global ocean.

4. Implications for services to the marine ecosystem and humanity

Mangroves provide a suite of regulating, supporting, provisioning and cultural ecosystem services from which humanity benefits (MEA, 2005; Haines-Young and Postchin, 2010; Van Lavieren et al., 2012). Supporting and regulating ecosystem services provided by mangroves include: (i) habitat for a wide range of organisms (Nagelkerken et al., 2000; Granek et al. 2009) including juvenile reef fishes that are essential components of coral reef ecosystems and, in many cases, are important food fish in their own right (Robertson and Duke, 1987; Laegdsgaard and Johnson, 1995; Mumby et al., 2004; Manson et al., 2005); (ii) carbon sequestration (Fujimoto, 2004; Lal, 2005; Donato et al. 2011; Alongi, 2012; 2014); (iii) climate regulation (Mcleod et al., 2011); (iv) shoreline stabilization and coastal protection (Kathiresan and Rajendran, 2005; Wells et al., 2006, 2005; Alongi, 2008; Barbier et al., 2008; Koch et al., 2009), water filtration (Alongi et al., 2003) and pollution regulation (Harbison, 1986; Primavera, 2005; Primavera et al., 2007). Mangroves also provide a suite of provisioning ecosystem services, including: (i) fisheries production (Nagelkerken et al., 2000; Dorenbosch et al., 2004; 2005); (ii) aquaculture production (Minh et al., 2001); (iii) pharmaceutical generation (Goodbody, 2003; Abeysinghe, 2010); (iv) production of timber and fuelwood (the latter being important in the Caribbean and Pacific) (Lugo, 2002; Walters, 2005; Walters et al., 2008). Finally, mangroves provide cultural services that include: (i) recreation and tourism (Bennett and Reynolds, 1992; Thomas et al., 1994; Brohman, 1996); (ii) educational opportunities (Bacon and Alleng, 1992; Field, 1999); (iii) aesthetic and cultural values (e.g., Field, 1999; Ronnback, 1999). The provision of these services is reduced or lost when mangrove habitat is degraded or transformed; this loss of services frequently declines in a non-linear fashion such that beyond a certain threshold (which varies spatially, temporally, and by species), mangroves are no longer able to provide significant coastal protection or fisheries benefits (Barbier et al., 2008; Koch et al., 2009).

Mangrove management is not currently practiced on a global scale. However, there are examples of intensive management of large forests in Asia (Spading et al., 2010). Many such forests are managed for commercial purposes but it would be useful to consider management in light of the tradeoffs among ecosystem services. Because provisioning services are easiest to quantify and assign an economic value, mangroves are frequently managed for one or a few provisioning services at the cost of managing for the full suite of services mangrove ecosystems provide. For example, mangrove ecosystems may be converted to produce aquaculture services; such management can contribute to the decline of other supporting and regulating services, such as pollution regulation and shoreline stabilization. When mangrove management focuses on maximization of one ecosystem service to the detriment of others, some individuals (e.g., aquaculture operators) gain, while others (e.g., coastal residents requiring shoreline protection) often lose. Policies and management of the coastal region that focus on preserving the functional diversity of mangrove ecosystems (multiple services), including the associated salt flats, enhance the possibility of having the highest number of beneficiaries. Whether state management or community-based management will be most effective may be context-dependent and worth consideration (Sudtongkong and Webb, 2008).

5. Conservation responses

The dramatic decline in global mangrove cover (Giri et al., 2011) and the on-going removal of mangrove habitat have led both governmental and non-governmental organizations to take actions to protect mangroves. Worldwide, commercial organizations have exerted, and continue to exert, strong pressures to modify policies that conserve mangroves (Brazil offers one example among many other countries (Glazer, 2004)), yet progress is being made through legislation, new partnerships between governments and local communities, and the REDD+ programme (Reduced Emissions from Deforestation and forest Degradation) in developing countries. Mangrove conservation measures range from traditional approaches including creation of designated areas protected from clearing and legislation restricting or prohibiting clearing, to conservation, education and restoration projects on local, national, regional, or international scales. These often involve local communities and organizations as stewards of mangrove ecosystems and may allow sustainable harvest within the project areas (Lugo et al. 2014).

5.1 Conservation through conventions and protected areas

Multiple international conventions and programs protect mangrove habitats. The Convention on Wetlands of international importance especially as waterfowl habitat[1] (Ramsar convention), an international treaty whereby member countries commit to maintaining the ecological characteristics of their "Wetlands of International Importance", protects mangrove forests at 278 Ramsar mangrove sites in 68 countries (numbers as of 2014). World Heritage sites, UNESCO-designated sites of cultural and natural heritage of outstanding value to humanity, include 26 Sites that protect mangrove habitat within their boundaries and UNESCO Man and the Biosphere Programme sites, many of which include mangrove habitat.

Establishing terrestrial and marine protected areas, including national parks and marine reserves is often used as a management tool to protect mangrove habitat. Examples of national parks that protect mangroves include Mangroves National Park in the Democratic Republic of Congo; Parc Marin de Moheli, Comoros, Kakadu National Park, Australia; Bastimientos Island National Park, Panama; Kiunga Biosphere Reserve, Kenya; Everglades National Park, United States of America; Sirinat National Park, Thailand; Subterranean National Park, Philippines; among others. Despite these efforts, Giri et al. (2011) report that only 6.9 per cent of the world's mangroves fall within existing protected areas networks (IUCN I- Category IV in the IUCN Protected areas management categories).

5.2 Conservation through legislation

In some countries, states, or regions, mangroves are protected through legislation limiting or prohibiting mangrove clearing. Legislation may be national, such as Brazil's Federal Forestry Code (Brazil, 2012), which has been interpreted to prohibit the use of any components of mangrove trees or plants. Other legislation exists at more localized scales, , such as The Mangrove Trimming and Preservation Act enacted in 1996 in the

[1] United Nations, *Treaty Series*¸ vol. 996, No. 14583.

state of Florida, (United States of America), to regulate trimming, disturbance or removal of mangroves in the state.

5.3 *Conservation through management, education and restoration projects*

The decline in global mangrove cover, combined with the highly recognized ecological and ecosystem services values of mangroves, have given rise to a number of non-governmental organizations engaged in education about and conservation and restoration of mangroves. These include organizations with projects around the world, such as the Mangrove Action Project, Western Indian Ocean (WIO) Mangrove Network, the Mangrove Alliance, and Mangrove Watch, as well as domestic organizations, including Honko, a mangrove conservation and education organization in Madagascar, and the Mangrove Forest Conservation Society of Nigeria, among others. Some countries such as Cuba and Ecuador have invested significant resources and are testing new approaches to mangrove conservation through engagement of local communities in natural resource governance (Gravez et al. 2013; Lugo et al. 2014).

Restoration projects have met with mixed and limited success with many documented efforts resulting in large failure rates in achieving successful mangrove restoration. These failures highlight the importance of considering factors that can doom mangrove restoration including poor site and species selection and failure to utilize advances in the recent science of mangrove restoration (Lewis 2005, Lewis and Brown 2014). For example, the use of biotechnological interventions to produce improved mangrove plantlets (e.g., faster growing plants) could improve the success rate of restoration. It would be useful to have better training at all levels on the concepts and application of mangrove restoration (Lewis and Brown 2014).

5.4 *Emerging conservation strategies*

The movement to implement “Blue Carbon Solutions” (the carbon sequestered by coastal vegetation, namely mangroves, sea-grasses and salt marsh grasses- McLeod et al., 2011) to reduce atmospheric CO_2 has led to the consideration of tools such as payment for ecosystem services (PES) and REDD-+ schemes to improve conservation outcomes for mangroves (Alongi, 2011; Locatelli et al., 2014). Such approaches may provide novel strategies for mangrove conservation in countries that lack sufficient resources for conservation and management.

Although raising financial resources for whole ecosystem conservation has historically been beneficial, new risks arise from this approach in the emerging paradigm of conservation through commodification of ecosystem functions, such as those related to carbon storage (McAfee, 1999; Igoe and Brockington, 2007; Kosoy and Corbera, 2010; Corbera, 2012). The emerging commodification paradigm, challenges an old ethical and inter-generational argument that nature needs to be managed and protected for the survival of ecosystems and species; it would be useful for mangrove conservation and restoration efforts to consider the risks of trading preservation of ecosystems for their intrinsic value and the emerging paradigm of prioritizing some elements of nature that are economically useful, at the potential cost of other values that are less economically valuable or are useful only to certain groups. In this process of assigning a monetary value to an ecosystem service, cultural and social values, such as those held by communities that live near and depend directly on the forests and that possess a deep cultural connection with the system, may be strongly devalued. In this way, power asymmetries in the valuation process may further fuel socio-environmental conflicts involving those interested in carbon and the communities interested in the maintenance of the diversity of functions and services, including cultural values, as recently described by Beymer-Farris and Bassett (2012) for the mangrove forests in Tanzania. However, Ecuador's Mangrove Ecosystem Concessions program provides an example of how government agencies can engage local stakeholders by simultaneously providing resource rights and bestowing management responsibilities on those users (Gravez et al. 2013).

As indicated above, although threatened by sea level rise, mangroves have the potential to keep pace with rising sea level if conditions allow them to modify their surface elevation or to adapt through landward migration (Cahoon and Hensel, 2006; Alongi, 2008; Gilman et al., 2008; Soares, 2009, McKee, 2011). It would be useful for mangrove conservation and management efforts to take into account external sediment supply, benthic mats, tree density and root structure, storm impacts, and hydrological factors such as river levels, groundwater inputs and rainfall (McIvor et al., 2012), as well as consider the maintenance and restoration of system resilience (e.g., its capacity to adapt and migrate landward).

6. Capacity building gaps

Capacity building is the process by which individuals, organizations, institutions and societies develop abilities (individually and collectively) to perform functions, solve problems and set and achieve objectives (UNDP, 1997). Capacity building is therefore facilitated through the provision of technical support activities, including coaching, training, specific technical assistance, and resource networking.

Local, regional, national and international initiatives for capacity building in mangrove conservation and sustainable use as a management tool to protect mangrove habitat are widespread around the world, including those led by the United Nations University (UNU), UNESCO's Man and the Biosphere Programme (MAB), Mangrove Action Project (MAP), Mangrove Alliance, Mangroves for the Future (MFF), Mangrove Watch, WIO Mangrove Network and The International Society for Mangrove Ecosystems (ISME). Examples of initiatives specific to different regions include, International Union for the Conservation of Nature - IUCN's Pacific mangrove initiative (PMI), the United Nations Environment Programme's Integrated Coastal Management, with special emphasis on the sustainable management of mangrove forests in Guatemala, Honduras and Nicaragua, the Satoyama Initiative in Benin, and Mangrove Action Project (MPA)-Asia in Thailand, among others.

Although several initiatives are concerned with capacity building, capacity building will be more effective if it is integrated and follows a set of basic assumptions about training and knowledge base. Increased effectiveness can be achieved through: (i) training related to conservation and sustainable use of mangrove forests and their resources; (ii) raising awareness among as many stakeholders as possible (especially policy-makers); (iii) political empowerment of stakeholders; (iv) cooperation within and between governments, institutions, organizations and agencies that are engaged in these activities; (v) identification and development of innovative proposals; (vi) maintaining systems for the reduction and resolution of conflicts; (viii) ensuring that programmes include measures to address threats from climate change and human activities.

Specific ideas for capacity building include: use of standardized methods for mangrove species distribution and area surveys (Manson et al., 2012) and development of capacity in the use of base-maps on digital terrain models. These would display areas where mangroves are mostly at risk from submersion due to sea level rise. Capacity to conduct surveys and geographical information systems (GIS) mapping in all regions would be useful, along with the development of capacity for "climate-smart conservation" (Hansen et al., 2010), which would involve strategies for promoting mangrove adaptation to sea level rise. It would be useful for nations to develop the capacity to better identify and evaluate potential barriers for landward migration in response to sea level rise and have more accurate information regarding the location of landward migration corridors as well as improved strategies for ensuring that these migration corridors are present in the future. It would also be useful to know specifically how other drivers of change (e.g., urbanization, other coastal land uses) may affect the potential for landward migration of mangroves in response to sea level rise.

7. Gaps in scientific knowledge

Comprehensive and comparable data on mangrove species and area distribution from all countries with mangroves would be useful. Lack of information on the current status of mangrove species for the documentation of the various types of mangrove losses in each region has been identified as an important knowledge gap. This could improve a range of conservation and management strategies, along with predictions of habitat loss and species extinctions (Polidoro et al., 2010; Spalding et al., 2010). Other areas of considerations in filling the gaps are: determination of the average changes in the emission or sequestration of greenhouse gases from mangrove forests as a result of human activity; accurate and consistent valuation of mangrove goods and services, and vulnerability mapping.

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