Mangrove Management, Assessment and Monitoring

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Mangrove Management, Assessment and Monitoring

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Abstract

This chapter provides an overview of mangrove management, assessment, and monitoring. It addresses the need for integrated planning and management, based on sound legal principles. The central part of the chapter covers mangrove conservation and planting. Conserving existing mangrove forest is often more effective than planting new forests. When a decision for planting has been made, one has to differentiate between planting on degraded and non-degraded sites and distinguish between replanting, rehabilitation, restoration, and afforestation. Emphasis is put on the need for careful selection of appropriate sites and species and on an ecosystem-based approach to mangrove planting and management which uses and supports natural regeneration and other natural processes. Since the primary intention with any rehabilitation intervention works is for improved protection of existing seedlings and forests from degradation or destruction, then planting should be undertaken only if absolutely necessary. Involving local communities in mangrove management is an effective way of maintaining and enhancing the protection function of the mangrove forest while providing livelihood for local people and contributing to better assessment and governance of natural resources. Assessment of the status of mangrove forests is essential for better conservation planning and management. This includes research and economic assessment and valuation. The last section highlights the importance of applied/participatory as well as academic and long-term monitoring (see also chapter "► Mangroves: Unusual Forests at the Seas Edge").

Keywords

Mangrove management; Planting; Rehabilitation; Restoration; Monitoring; Co-management; Site assessment; Hydrology; Coastal dynamic and protection; Climate change; Ecosystem services; Economic values

Introduction

Mangroves, as forested wetland habitat, provide a wide range of ecosystem services (Millennium Ecosystem Assessment 2005; Barbier 2007) including protection of beaches and coastlines from storms, waves, and floods; reduction of beach and soil erosion; and carbon sequestration. They also provide nursery grounds, food, shelter, and habitat for a wide range of aquatic species and thereby increase income through fisheries (Barbier 2007; Nagelkerken et al. 2008; Walters et al. 2008; Alongi 2009, 2014; Lee et al. 2014; Duke and Schmitt 2015). Yet, despite their importance, mangroves all over the world have been degraded and converted to other forms of land use on a large scale (Alongi 2002; Duke et al. 2007;

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Fig. 1 The coastal zone of Sóc Trăng Province (Mekong Delta, Vietnam). An approximately 200 m wide mangrove belt protects the earth dike from erosion and the shrimp ponds and land behind the dike from flooding and storms. Just below the center of the picture, erosion has destroyed all the mangroves and is threatening the integrity of the dike (Photo: K. Schmitt 2010)

Duarte et al. 2009; Giri et al. 2011). As a result of their reduction in area and their important functions, many attempts have been made to protect, sustainably use, and plant mangroves. Protection of mangrove habitats from direct human impacts (felling, destructive fishing methods and resource use, livestock) and indirect human impacts (changes in hydrology through dykes, dams, etc.) will often lead to natural regeneration, whereas planting, particularly if the wrong species are planted in unsuitable sites, often produces limited success (Samson and Rollon 2008; Pham et al. 2009).

Increasingly, mangroves are being recognised as specialist coastal ecosystems rather than as unusual terrestrial forested vegetation. In their management, account must be taken of their physical and biotic attributes, including their position along tidal creeks, mud flats and coastal waterways, as well as the physicochemical and biological processes that function at the ecosystem level (Macintosh et al. 2011). Effective conservation, rehabilitation, restoration, and sustainable management will, in most cases, best be achieved through an ecosystem-based approach (Shepherd 2008).

Integrated Planning for Mangrove Management

Mangroves often grow in narrow bands along coastlines and estuaries, forming parts of a complex coastal ecosystem (Fig. 1). Therefore, effective management should follow an integrated approach to coastal zone management (ICZM), guided by the key principles of integration of sectors and agencies, participation and co-management, ecosystem-based management, zonation, and adaptive management. ICZM requires an appropriate institutional framework to cope with the often overlapping jurisdictions in coastal zones. Management issues do not stop at administrative or natural boundaries and ICZM should therefore also include transboundary collaboration (Macintosh et al. 2013). Sustainable mangrove management should be included in integrated planning of coastal zones and be addressed in relevant documents such as coastal

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(protection) master plan, coastal strategy, or ICZM strategy – these are just different names for comprehensive and integrated coastal area planning documents.

Planning approaches for future development in general and for disaster risk planning in particular have traditionally been based on historic data such as historic flood and storm intensity and frequency. In the context of climate change, future climate predictions provide important additional inputs for planning. As a result of the uncertainties inherent in predicting the effects of climate change, a number of ecosystem-based adaptation strategies should be used. This approach addresses the uncertainty, diversity, connectivity, and adaptive capacity and may contribute to avoiding adaptation conflicts, maladaptations, or path dependencies (Bernhardt and Leslie 2013; Smith et al. 2013).

Mangrove conservation should, where appropriate, also be part of national-level policies, actions, and reporting such as a "National Adaptation Plan (NAP)," "National Adaptation Programme of Action (NAPA)," and "Nationally Appropriate Mitigation Action (NAMA)" under the United Nations Framework Convention on Climate Change (UNFCCC). Mangroves have recently been included in the forest categories eligible for REDD+ (Reducing Emissions from Deforestation and Forest Degradation) which assigns a financial value for the carbon stored in forests. The management of coastal ecosystems (including mangroves, tidal salt marsh, and sea grass) is often still missing from national climate change mitigation strategies, despite the fact that they sequester large amounts of carbon (Donato et al. 2011; see also section "Mangrove Assessment and Monitoring").

In addition to integrated planning, institutional framework, and national-level policies, actions, and reporting, sustainable mangrove management requires an enabling legal framework. However, existing national legal frameworks commonly relate to the environment and forests in general, rather than to mangroves in particular. In Bangladesh, forest policies have changed over time from pre-British rule to the present day, but the Sundarbans, the largest mangrove forest in the world, has no separate agenda or policy directives for its management (Kumer et al. 2012). "National and international legal frameworks are required to provide overall guidance for the conservation and sustainable use of mangrove resources and to ensure protection for mangrove-associated biodiversity" (Macintosh and Ashton 2003, p. 16).

Mangrove Conservation and Planting

The first sentences in the chapter "Mangrove Silviculture and Restoration" in Saenger's book "Mangrove Ecology, Silviculture and Conservation" provide an appropriate introduction to this section: ". . . mangrove systems . . . are changeable, they are dynamic, they are unpredictable, they are subject to aperiodic and periodic fluctuations of the extreme kind, and . . . each mangrove community has a history. Reading that history from the tell-tale signs of today, is the artful skill of the silviculturalist or restoration ecologist who is likely to succeed" (Saenger 2002, p. 229).

The first step in any mangrove conservation and planting program is to set clear objectives. These objectives largely fall into the following categories: sustainable timber production, coastal/shoreline protection, channel stabilization and conservation, support of ecological functions for shrimp and fish aquaculture/contribution to fishery production, ecological restoration, and landscaping/enhancement of aesthetic quality of the landscape (e.g., Field 1999; Ellison 2000). Objectives vary according to the type of forest; for example, fringe forests are important for shoreline protection, riverine forests are particularly important to animal and plant productivity, while basin or interior forests are important nutrient sinks and sources of wood products (Ewel et al. 1998). There may also be very specific objectives such as to provide seawater agriculture to relieve hunger and poverty (Sato et al. 2005) or peri-urban mangrove management to provide local offsets for carbon emissions (Lee et al. 2014). Objectives have changed over time, and Ellison (2000) provides a comprehensive analysis of these changes. Before 1982, the main goal of

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Fig. 2 *Sonneratia caseolaris* forest along the mouth of the Mekong River during high tide (Photo: K. Schmitt 2011)

Fig. 3 Mangrove forest in the Everglades, Florida (Photo: K. Schmitt 2013)

mangrove restoration was afforestation for silviculture, with coastal stabilization and environmental mitigation or remediation being additional objectives. Later, more emphasis was put on ecological values, sustainable utilization, animal habitats, food sources for in-shore and pelagic food webs, and the provision of livelihood for coastal populations and compliance with legal requirements to restore or create compensating areas for clearing of mangroves in other location (Stubbs and Saenger 2002). More recently, resilience to climate change has become an important objective for mangrove management (McLeod and Salm 2006). In the future, the ability of mangroves to respond to certain levels of sea-level rise may become an objective (Gilman 2006; McKee et al. 2007; Krauss et al. 2013; McIvor et al. 2013).

Mangroves occur most extensively on low-energy, sedimentary tropical and subtropical shorelines (Fig. 2). In the Pacific region, they grow in intertidal sites from the mean sea level up to the point reached by the highest spring tides. Here they often display a typical shore-parallel, band-like zonation pattern which is linked to soil type, salinity, and hydrology (flooding and drainage) (see Fig. 11 in Duke and Schmitt 2015, 129-1). The zonation pattern changes with the position along estuaries between

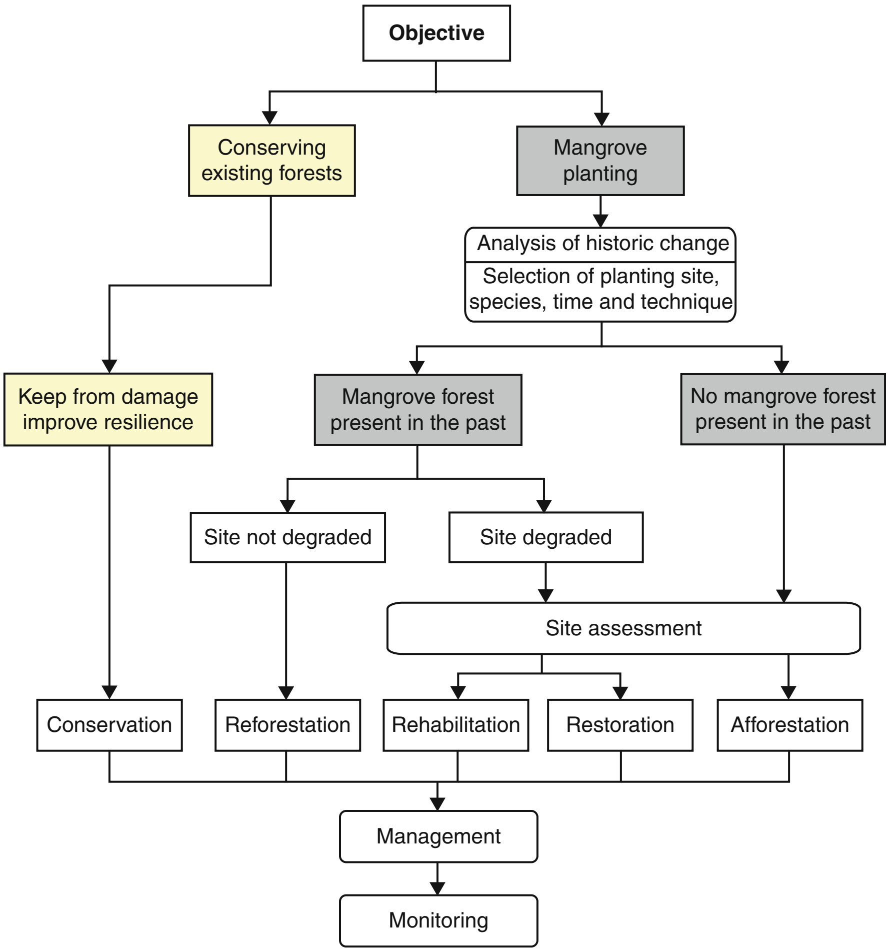

Fig. 4 Decision-making flow chart for mangrove conservation and planting

downstream, midstream, and upstream sites. Mangrove forests in the Atlantic East Pacific are often found in extensive, low-lying, and inundated coastal wetlands and lack clear zonation of species (Fig. 3). In these areas, a functional classification based primarily on physiognomy is used to distinguish overwash, fringe, riverine, basin, scrub, and hammock mangroves. Mangroves grow in different hydrogeomorphic settings such as river, tide- or wave-dominated, or interior mangrove forests. Rainfall, temperature, and freshwater supply also affect mangrove growth. Their habit ranges from shrubby with a height of around 3 m to forests with 65 m tall trees. Mangrove species display distinct biographic patterns and two major floral realms can be distinguished with 61 unique species and hybrids in the Indo West Pacific, 17 in the Atlantic East Pacific, and just two occurring naturally in both global regions (Lugo and Snedaker 1974; Smith and Duke 1987; Woodroffe 1992; Lacerda et al. 1993; Duke et al. 1998; Saenger 2002; Giesen et al. 2006; FAO 2007; Spalding et al. 2010; Duke and Schmitt 2015).

Given this wide range of sites and forest structures, no simple, generalized recommendations can be made for mangrove planting; this is reflected in the large number of publications on mangrove planting and "grey literature" often available as reports on the Internet. A comprehensive overview of mangrove planting has been provided by Saenger (2002). The importance of different regional approaches has been highlighted in reports such as Macintosh et al. (2012), and intra-country variation has, for example, been shown by Primavera and Esteban (2008) for the Philippines.

Having defined objectives, a decision must be made whether to focus on *conserving existing mangrove forests* or on *mangrove planting* (Fig. 4). Given the clear dependence of species distribution on a specific

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set of site conditions, attention must be focused on the *selection of a suitable planting site*, followed by *selection of appropriate species* and *the best-suited planting technique and planting time*, for the given site. Site selection should be based on an analysis and understanding of historic changes and natural processes. Information about historic distribution of mangrove species and shoreline changes can be gained from documents, maps, and aerial photos from archives and supplemented by analysis of satellite images (Joffre 2010). Analysis of historic information contributes to a better understanding of coastal dynamics (accretion and erosion) and enables the selection of species growing naturally in a given site before human intervention. This should be complemented by observation of natural regeneration, which indicates that a particular site is suitable for mangroves and provides information on suitable species, planting techniques, and time.

Conserving Existing Mangrove Forests

The term conservation is generally used in a broad sense of protection, management, and sustainable use, while here it is used in a narrower sense, to mean keeping existing mangrove forests safe from being damaged or destroyed.

The primary aim of a mangrove management strategy should be to maintain the health of the remaining mangrove ecosystems (thereby improving their resilience) and to reduce the rate of mangrove loss. This is often more effective than trying to plant new mangroves and is less expensive than other approaches. In addition to legal mechanisms, local people can play an important role in keeping existing mangrove forests safe from degradation and destruction. Awareness raising about the importance of mangrove ecosystems and involvement of local communities in their management can contribute to better protection.

Conservation of mangroves has a long history. For example, in 1891, the first forest protection decree was established by the colonial administration in Cochinine (present-day Vietnamese Mekong Delta up to Đồng Nai Province). Several “reserves” included mangrove forests, indicating that the administration recognized the importance of this ecosystem and its growing economic value. Nevertheless, in the early twentieth century, the perception of mangrove forests and inundated forests in general ranged from a hostile and useless environment, to a source of fuel wood, to a protective belt against waves and erosion (Joffre 2010).

Nowadays, protected areas are widely used to help prevent mangrove loss and degradation in specific locations. They provide social, economic, and environmental benefits through sustainable management and protection of ecosystem services. Chape et al. (2008) state that worldwide approximately 1,200 protected areas cover about 25 % of the remaining mangrove habitat. The figures provided by Jenkins and Joppa (2009) are slightly lower, namely, 20.7 %. However, only 7.8 % of the mangrove area is protected in IUCN protected area categories I–IV (Strict Nature Reserve, Wilderness Area, National Park, Natural Monument or Feature, and Habitat/Species Management Area) which have a higher protection status than categories V and VI (Protected Landscape/Seascape and Protected area with sustainable use of natural resources) (IUCN 1994). Protected areas which include mangrove forests are widely distributed, but there are important areas along the Red Sea, Myanmar, the Solomon Islands, Fiji, and West and Central Africa that should be better represented in the protected area system (Spalding et al. 2010).

Protected area reserve design should ensure ecosystem connectivity and consider ecological processes along nursery-reef boundaries, as well as linkages with marine and terrestrial food webs (Mumby et al. 2004; Ellison 2008; Nagelkerken et al. 2012). Protected areas should be designed and managed to protect against the broad range of threats affecting mangrove ecosystems, including threats from sea-level rise, eutrophication, coastal development, and sedimentation, which are often not addressed by protected area management programs (Valiela et al. 2001). For example, reduction of negative impacts from adjacent land-use practices or setting aside land for landward mangrove migration in response to

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sea-level rise should be part of protected area management plans. Torio and Chmura (2013) provide a tool to identify locations where "coastal squeeze" is likely to occur which can be used for protected area planning. Barbier et al. (2008, p. 321) conclude "that reconciling competing demands on coastal habitats should not always result in stark preservation-versus-conversion choices."

Mangroves are also protected under international conventions. At the end of 2008, mangroves were protected in 31 World Heritage Sites in 18 countries (UNESCO: The World Heritage Convention), and in 2009, 215 out of more than 1,800 Ramsar Sites included mangroves (The Convention on Wetlands of International Importance). Although the Man and the Biosphere (MAB) Programme of UNESCO is not a legally binding convention, it is an intergovernmental scientific program that aims to establish a scientific basis for the improvement of relationships between people and their environments. In 2008, mangroves were included in 34 out of 501 MAB sites worldwide. Countries should aim to have more sites included in these international mechanisms because they offer not only prestige but also some degree of support and collaboration (Spalding et al. 2010). The Convention on Biological Diversity includes mangrove protection in some of its thematic programs and in the Aichi Targets; the convention has been signed by 194 parties. The UNEP Regional Seas Programme has more than 143 participating countries and addresses the degradation of the world's oceans and coastal areas (including mangrove ecosystems) through the sustainable management and use of the marine and coastal environment, by engaging neighboring countries in comprehensive and specific actions to protect their shared marine environment.

Conservation of mangroves can be enhanced through well-designed and managed protected areas, as well as by the implementation of international conventions. Community involvement through community-protected areas and co-management (see section "Mangrove Management") can also make an important contribution. Mangrove conservation should be integrated into a broader spatial framework of coastal zone management involving all relevant sectors and stakeholders. There is also scope for small-scale and site-specific interventions, such as urban industrial estuarine shoreline mangrove gardens, shoreline parks, and bank stabilization.

Mangrove conservation will only be successful when backed up by sound data and a broad knowledge, understanding, and awareness of the need for mangrove conservation. Research and maintenance of accessible, long-term databases on mangrove coverage, management and protection, value, and their response to pressures are essential for sound policy and management decision-making. Important issues are improved knowledge management, information sharing, and communication on mangrove-related issues at all levels, from policy-makers to local government and the general public.

Mangrove Planting

Mangrove environments along tropical coasts are extremely dynamic (erosion and accretion) and subject to destructive storms. Mangroves are well adapted to these natural phenomena and generally recover quickly from both minor and major periodic disturbances through natural regeneration, without the need for planting (Jimenez et al. 1985; FAO 1994; Alongi 2008, 2009; Duke and Schmitt 2015). In contrast, human interventions, such as dike and dam construction, usually lead to permanent changes which may create conditions which are unsuitable for natural regeneration of mangroves.

Mangroves have developed unique characteristics to cope with shoreline evolution which do not necessarily follow succession of other forest types (Alongi 2013). Therefore, traditional forestry and silviculture approaches cannot be transferred one-to-one to the coastal zone. Mangrove foresters need a sound understanding of mangrove ecology but also of coastal processes (waves, tides, currents, and sediment transport) and morphodynamics (spatial and temporal) and use it for conservation, planting, and management decisions. Whenever possible, foresters should mimic natural processes (mimic nature), taking into account the unique and dynamic environment between the land and the sea (Schmitt et al. 2013). For example, when planting mangroves along mud coasts in Southeast Asia, the typical

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band-like zonation should be imitated because this also considers what happens below ground and leads to better protection of the soil from erosion and wave attenuation (see Fig. 11 in Duke and Schmitt 2015; Fig 12).

In sites where mangroves have been present in the past, there is a need to distinguish between sites which have and have not been degraded since the mangrove cover was removed or destroyed. Based on this distinction and having determined that planting is necessary, three different types of mangrove planting can be employed: reforestation, rehabilitation, and restoration. In addition, afforestation is used in sites where mangroves have not grown in the past.

A detailed plan of operations should be prepared before planting starts, including a description of the site and if necessary the proposed restoration measures; species to be planted, the planting techniques and timing, and if applicable zonation of planting; numbers and quality of seeds, propagules, or seedlings required; work schedule, organization, equipment, and budget; and a monitoring plan.

Planting can be done using seeds, propagules, or seedlings; the latter can be from nurseries (bare root or with root bags) or transplanted from other sites. Spacing for direct planting of propagules collected from the wild commonly ranges from 0.4 to 2 m. Seedlings can be planted in plots of 100 m^2 to 1,000 m^2 with gaps of 10–20 m between plots to allow for natural regeneration. Consecutive rows should be offset to avoid linear empty space between rows of seedlings. Closer spacing is used to enhance the ability of the propagules or seedlings to withstand wave impact (Melana et al. 2000; Stubbs and Saenger 2002; Duke 2006; Duke and Allen 2006; Primavera et al. 2012). Huxham et al. (2010) showed that higher planting density significantly increased the survival of seedlings at high and low tidal sites and enhanced sediment accretion and elevation at low tidal sites. However, too dense spacing may have a negative impact on sedimentation patterns (Burger 2005). The use of stem cuttings, air-layered material, propagule segments, and tissue cultures are described in Stubbs and Saenger (2002) but will not be elaborated here because of their still-limited practical use. Planting techniques vary among species and examples are provided in many publications (e.g., Macintosh and Ashton 2003; Pham et al. 2009). Pham et al. (2009) emphasize not only the species and site-appropriate planting techniques but also the importance of the planting time. For example, seedlings planted directly before the flooding season will most likely be buried by sediment. The importance of sediment dynamics during primary colonization has been highlighted by Balke et al. (2013); and seedling establishment of pioneer mangrove species requires a suitable “window of opportunity” without disturbance by physical forces, such as inundation, and hydrodynamic forces from waves and currents (Balke et al. 2011, 2014).

Propagules collected from the wild while nurseries are necessary to provide seedlings of the quality and in the amounts required for planting programs. Four types of mangrove nurseries can be set up: a permanent nursery, a temporary nursery to produce seedlings for a specific planting project, a “floating mangrove nursery” in upland areas above the highest tidal range, and a “flooded mangrove nursery” which is flooded regularly by tidal water. Nursery techniques vary from species to species (see, e.g., Saenger and Siddiqi (1993), Melana et al. (2000), Clarke and Johns (2002), Ravishankar and Ramasubramanian (2004), and Hoang and Pham (2010)).

Reforestation

Reforestation refers to planting trees in areas which were formerly forested and where the site conditions have not been degraded since removal of mangrove cover. An example of reforestation as part of mangrove silviculture follows.

Mangrove silviculture was introduced by colonial forestry agencies at the beginning of the last century. One example of a mangrove forest managed for sustainable timber harvest is the Matang Mangrove Forest Reserve in Malaysia where management started in 1908. Current objectives remain the production of maximum sustained yields of raw materials for fuel, mainly charcoal, and poles. The silvicultural system

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Fig. 5 Matang Mangrove Forest Reserve, Malaysia; *top*: clear-felling; *bottom*: thinning after 20 years (Photos: K. Schmitt 2007)

consists of a 30-year crop rotation, harvested by clear-felling of annual coupes of a thousand hectares with retention of stands for natural regeneration (Fig. 5 top). Enrichment planting is carried out, where necessary, during the first 3 years after clear-felling. Thinning for the production of poles is carried out at 15 and 20 years (Fig 5 bottom; Ong 1982, 2012). Management of the area follows a 10-year management plan. Lots are tendered to private charcoal producers. The contractors carry out all management operations while the forestry department ensures compliance with the management plan.

In sites where mangroves have been destroyed, or degraded, a site assessment must be undertaken to determine whether or not soil and hydrological restoration measures need to be carried out before planting.

Site Assessment

Mangroves usually grow in intertidal areas and display a clear zonation of species in areas with different elevations. Therefore, the frequency of tidal flooding and the drainage characteristics are two of the most important factors that need to be considered when assessing a site for rehabilitation and when selecting the

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most appropriate species to plant. The flooding and surface drainage characteristics of a site are determined largely by topography (elevation and slope) and tidal amplitude. In addition, the physical properties of the soil influence water infiltration, subsurface drainage, and root penetration. All these factors also influence soil salinity.

Site assessments should be simple and affordable and at the same time provide fairly robust results for decision-making about whether or not a site is suitable for planting or restoration and to help with the formulation of a rehabilitation or restoration plan. Clough (2014) provides such guidelines and describes techniques which combine visual assessments of indicators of irregular tidal flooding and poor drainage with techniques for measuring elevation and topography, tides, and key soil properties that are likely to influence flooding and drainage characteristics. Lewis and Brown (2014) describe in detail the assessment of eight biophysical factors which influence mangrove establishment and early growth (temperature, protected coastlines, currents, edaphic conditions, sedimentation patterns, salt water, tidal inundation, and frequency and presence and functioning of tidal creeks). Connectivity, biophysical interactions, and biogeomorphological feedback processes among intertidal wetland such as mangroves and salt marsh should also be considered where possible (Friess et al. 2012).

In sites where mangrove habitat loss or degradation has occurred to such an extent that natural processes can no longer self-correct or self-renew, appropriate, site-specific, and affordable rehabilitation or restoration methods are needed.

Rehabilitation

The terms rehabilitation and restoration are often used synonymously, but they have distinct meanings. This becomes clear when looking at the Latin origin of the terms. Rehabilitate comes from *habilitare* which means to enable or make suitable and the prefix *re* means again. Therefore, rehabilitation means “to make suitable again.” Restoration comes from the Latin verb *restaurare* which means “to rebuild, to reestablish.”

In an ecological context, rehabilitation refers to “return … degraded mangrove land to a fully functional mangrove ecosystem regardless of the original state of the degraded land” or in other words to convert a degraded system to a more stable condition (Field 1999, p. 47).

Mangrove forests can regenerate rapidly after damage. For example, after super typhoon Loleng (known generally as Babs) hit the northeastern Philippines in October 1998, significantly damaged areas of mangrove regenerated naturally as long as they were protected from human destruction (Primavera personal communication 2014). A large reservoir of below-ground nutrients facilitates the reestablishment of new seedlings after disturbance (Alongi 2008). If site elevations are suitable, planting will be unnecessary in areas with abundant mangrove propagules (Shafer and Roberts 2008). However, active or artificial regeneration can speed up the natural recovery process, particularly in severely degraded systems where there may be shortages of propagules (Field 1998; Ellison 2000). Microhabitats such as hollows, logs, tree trunks, and seedlings/shrubs can be used as recruitment refuges to initiate seedling establishment (Metcalfe 2007). Rehabilitation methods, which rely on natural recruitment, should be the first choice. This would also make enhancement planting in degraded sites unnecessary.

Community-based mangrove rehabilitation has been used successfully to revert tens of thousands of hectares of abandoned ponds into mangrove forests. Such ponds are ecologically appropriate sites for rehabilitation as they were former mangrove forests. By rehabilitating former ponds, the problems associated with afforestation of mudflats and more complex restoration activities are avoided (Primavera and Esteban 2008; Primavera et al. 2012, 2014).

Many attempts have been made to rehabilitate mangroves in erosion sites including the use of fertilizers to enhance initial tree growth in heavily eroded areas (Matsui et al. 2012). However, rehabilitation is often unsuccessful when the reasons for mangrove degradation were not removed prior to planting. In some

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Fig. 6 Canopy gap with planted seedlings of *Avicennia marina*, *Bruguiera cylindrica*, and *Ceriops tagal* in a *Rhizophora apiculata* plantation (Photo: R. Sorgenfrei 2013)

sites it may even be impossible to rehabilitate mangroves because events such as construction of dikes, cutting of upriver sediment supply, or blocking runoff flows which connect mangroves with adjacent systems have permanently altered hydrologic and edaphic conditions and thereby reduced the ability of mangroves to regenerate naturally.

Enrichment planting has been carried out with the aim to improve ecological conditions. However, there is no clear scientific evidence about the effectiveness of such forest enhancements. Furthermore, enrichment planting in bare areas within mangrove forests may actually degrade the system by, for example, removing feeding habitats for wading birds or blocking tidal flushing channels (Lewis and Brown 2014).

Through evolution mangrove plants have adapted effective characteristics and strategies for their survival and success (see chapter "▶ Mangroves: Unusual Forests at the Seas Edge"). These strategies can be used to improve the resilience of existing forest. This does not mean enrichment planting but the imitation of successful natural processes. For example, the transformation of even-aged, single-species plantations into more diverse forests, both in terms of structure and species composition, mimics the natural occurrence of canopy gaps and the natural regeneration that takes place in such gaps (Fig. 6 and Duke and Schmitt 2015). In natural forests, regeneration is a continuous process with young plants concentrated close to parent trees in contrast to man-made plantations (Fig. 7). Mimicking small-scale, dense planting close to established trees and repeating this type of planting leads to a tapering forest edge which resembles the structure of a natural forest (Schmitt et al. 2013).

Planting techniques based on an understanding of the species ecology can be the same for rehabilitation and restoration, but restoration of the hydrologic pattern and/or appropriate topography has to be carried out to ensure that natural regeneration or rehabilitation can be successful.

Fig. 7 *Top*: natural regeneration of *Rhizophora apiculata*, *bottom*: *Rhizophora apiculata* planted at a spacing of 1 m (Photos: K. Schmitt 2010)

Restoration

Restoration refers to a process that aims to return a system to a preexisting condition whether or not this was pristine (Lewis 1990).

Lewis (2005) provides a comprehensive review of mangrove restoration which presents the basic guidelines and the technical foundations. The restoration principles outlined have evolved over time and Lewis (2009) describes them in six steps which are necessary to achieve ecological mangrove restoration (EMR). EMR requires site selection for restoration based on the autecology of the mangrove species, the normal hydrologic patterns, and an assessment of reasons that prevent natural secondary succession, following which the appropriate hydrology needs to be restored (Fig. 8). Planting is only necessary when natural recruitment does not result in sufficient numbers of successfully established seedlings or adequate rates of stabilization and growth of saplings.

An illustrated EMR manual was published by the Mangrove Action Project (Lewis et al. 2006). Wherever possible, local people should get involved in restoration projects through community-based EMR (http://mangroveactionproject.org/mangrove-restoration-and-reforestation-in-asia/), but due to the

Fig. 8 Restoration of a site with compacted soil after the mangrove cover was cut down. The site was first drained through canal dredging, and then *Lumnitzera racemosa* and *Xylocarpus moluccensis* were planted on the mounds and *Bruguiera cylindrica* 1 year later in the canals (Bạc Liêu Province, Mekong Delta, Vietnam; Photo: L. Steurer 2011)

complexity of restoring normal hydrologic patterns, such projects still rely on input from outside experts. The complexity of EMR is highlighted, for example, by Bosire et al. (2008) who present a 10-step scheme of possible mangrove restoration pathways depending on site conditions. Mangrove restoration will receive more community support if it is combined with alternative livelihood opportunities, such as improved fishery-based livelihoods or aquaculture (Mangroves for the Future 2012).

In 2014 Lewis and Brown published a comprehensive and detailed "Ecological Mangrove Rehabilitation field manual for practitioners" in which they define ecological mangrove restoration (EMR) as "an approach to coastal wetland rehabilitation or restoration that seeks to facilitate natural regeneration in order to produce self sustaining wetland ecosystems" (Lewis and Brown 2014, p. 13). The authors mainly use the term rehabilitation because of the relative difficulty of achieving pure restoration through returning a system to the exact conditions that existed before change occurred. It is for sure easier and more convenient to use the term rehabilitation in a broader sense, but there are situations where a clear distinction between restoration and rehabilitation can and should be made. Engineering measures, for example, are often used to restore a degraded site (e.g., restoration of eroded floodplains) while, in the absence of natural regeneration, mangrove forests are rehabilitated on the restored sites.

Lewis and Brown (2014) suggest eight steps of EMR and emphasize that EMR is a general approach (not a mandated method or sequence of steps), that is designed to provide a logical sequence of tasks that are likely to succeed in restoring or creating mangrove habitat with a diverse plant cover similar to that of a natural reference mangrove forest, with functional tidal creeks connected to upland freshwater flows if available, and supporting a diverse faunal community (Lewis and Brown 2014, p. 13).

Hydrological manipulations can support natural regeneration. For example, mangrove restoration has been achieved by using a combination of excavation of dredged material and hydrological restoration without the need for artificial planting (Lewis et al. 2005). Often, reconnection of a degraded site to normal tidal influence will be sufficient to start natural recovery (Turner and Lewis 1997). At erosion sites, mangrove forests can be rehabilitated through natural recruitment once natural or man-made stressors are removed and suitable morphodynamic conditions, especially appropriate hydrology and topography, are provided through environmental restoration techniques (Lewis 2005; Winterwerp et al. 2013). Detached breakwaters can shelter the restoration area from wave action, preventing ongoing erosion and promoting

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Fig. 9 Restoration of eroded floodplains using T-shaped bamboo fences in Bạc Liêu Province (Mekong Delta, Vietnam). The long-shore elements close the eroded gap in the mangrove forest by connecting the remaining headlands. They reduce incoming wave energy while the cross-shore constructions reduce the long-shore currents. The gaps between the long-shore elements allow for faster sediment input during flood tides and enhance drainage during ebb tides. The latter will accelerate the consolidation process of the sediment deposited inside the fenced area (Photo: Cong Ly and GE Wind 2013)

sediment deposition (Babak and Roslan 2011). However, care must be taken to design detached breakwaters in such a way that negative effects such as down-drift erosion can be avoided as far as possible (Kamphuis 2010). More recently, an ecosystem-based or area coastal protection approach to mangrove rehabilitation in erosion sites has been successfully implemented along eroded mangrove mud coasts. This approach uses T-shaped bamboo fences to reduce erosion and stimulate sedimentation, thereby restoring the eroded floodplains (tidal flats) (Fig. 9) as a precondition for mangrove rehabilitation (Schmitt et al. 2013; Temmerman et al. 2013; Schmitt and Albers 2014).

In sites with high wave energy, where natural recruitment no longer occurs and where conventional planting methods would be ineffective, cost-intensive "single-seedling protection" can be used for planting in rehabilitation and restoration projects. The Riley encased methodology has been used to establish mangroves along high energy shorelines, revetments and bulkheads. The aim was to isolate and protect individual seedlings from waves and currents using tubular encasements made from PVC pipe (Fig. 10) so that juvenile plants might adapt to external conditions (Riley and Kent 1999; http://mangrove.org/). However, this method not only is cost- and labor-intensive but also has largely proven unsuccessful. Survival rates were low and it has been shown that encasements can constrict the growth of mangrove roots. Furthermore, this kind of planting introduces PVC into the environment (Johnson and Herren 2008).

Another type of "single-seedling protection" is the Reef Ball. Dome-shaped containers made of concrete with holes are used for planting red mangrove propagules (Fig. 11). The propagules are protected from waves and ocean debris until they become established. The concrete is mixed in such a way that it will erode within a few years and thus will not impede the growth of the established seedlings. More complex is the use of armored concrete cultivators with wrack protection, which also provide slow-release fertilizer to young red mangroves until they are self-sufficient (http://www.reefball.org/). Less complex and less costly methods protect newly planted mangroves through barriers made of plant material such as coconut fiber or fruit bunches from oil palms. Other strategies, like planting coast-parallel rows of mangroves with gaps in between, may contribute to better protection from wave action. The seedlings at forest edges facing the sea will develop stronger roots because there is less competition compared with those growing inside the dense forest stand.

Key lessons learned from both successful and unsuccessful restoration projects include: "do not plant mangroves where they did not exist previously . . .; do not undertake mangrove restoration without adequate knowledge of the site history . . .; hydrological manipulation, by itself, can be adequate for natural mangrove restoration" (IUCN 2011, p. 44), and sometimes rates of natural recruitment can exceed planting, and planting operations can damage site recovery (Duke 1996).

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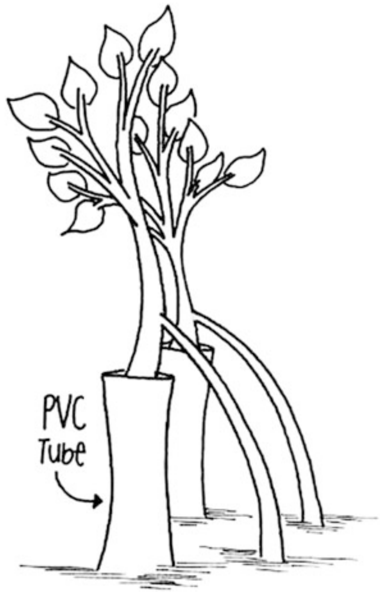

Fig. 10 Some planting practices require further evaluation, like planting seedlings in PVC encasements (Drawing: H. Schmitt)

Fig. 11 Planting mangrove seedlings in concrete balls sounds interesting, but the method requires further validation (Drawing: H. Schmitt)

Afforestation

Afforestation refers to establishing a forest by planting trees on land that was not previously forest. If the site assessment is favorable, then facilitation of natural regeneration or planting will be uncomplicated. An example is accretion sites in front of existing mangrove forests along muddy coasts with a shallow gradient above the mean sea level.

Large-scale afforestation of treeless mudflats has been carried to establish mangrove forests to act as "bio-shields." However, these mudflats are often treeless due to being below the mean sea level. In such

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sites, afforestation requires elaborate planting techniques which include seeds planted on-site in metal can cylinders, held in place with iron rods, protected by wire mesh and provided with slow-release fertilizer (Sato et al. 2005) or bank and mound planting, and such plantings are often not successful in the long term.

In areas of low tidal amplitude, planting techniques include "canal bank planting" (planting of propagules on the banks of artificially constructed feeder and distribution canals) or strip planting on mounds and block planting or island planting on higher ground created on mudflats to avoid prolonged submergence (Selvam et al. 2012; Tsuruda 2013). However, large-scale planting on low tidal mudflats in order to create more forest as a "bio-shield" ignores the principles of selection of appropriate sites and preferential use of natural recruitment and therefore often fails.

Samson and Rollon (2008) assessed mangrove afforestation in the Philippines and documented that planting of often monospecific *Rhizophora* stands in areas that are not natural mangrove habitats was unsuccessful. In contrast, treeless mudflats were afforested successfully, for example, in Vietnam in areas where mangroves were planted in accretion sites which provided suitable soils and hydrology.

Afforestation of treeless intertidal mudflats should only be done after careful site assessment and species selection. In addition, a full assessment of environmental and social impacts should be carried out when attempting to convert intertidal mudflats to mangrove forest. The ecological importance and economic attributes of these mudflats must be considered as well as coastal protection provided by mangroves (Erftemeijer and Lewis 1999). Large-scale planting on intertidal mudflats has shown only limited success rates, and planting as many propagules as possible in the shortest possible time (in 2013 "The Sindh Forest Department [in Pakistan] . . . set a Guinness World Record for planting . . . 847,275 saplings [in a day], breaking an earlier record . . ." (http://www.iucn.org/about/work/programmes/forest/fp_news_events/?13198/Pakistan-makes-it-to-the-Guinness-World-Records-by-planting-847275-mangrove-saplings-in-a-day)) makes good headlines but not good forests.

Mangrove Management

Just planting mangroves is of little use without protection. After planting, seedlings must be protected from human impacts such as destructive fishing methods or grazing by cattle and sheep. In specific sites, they must be protected from waves. Furthermore, established mangroves must be managed effectively and protected from human impact like felling and conversion into other forms of land use.

The type of management required after planting depends on the objective. If the objective is coastal protection and mangroves are growing in suitable sites and are protected from destruction and degradation, then they will develop naturally without the need for tending or maintenance activities (Fig. 12; Khan et al. 2013). But if, for example, the objective is sustainable yield of wood and timber, then thinning needs to be performed depending on the expected age at final tree harvest. In estuarine ecosystems in South Africa, where coastline protection is not important, an annual harvest of 5–10 % has been shown to be sustainable (Rajkaran and Adams 2012). In the early years after planting, regular removal of debris may be required and dead plants can be replaced. If fences are necessary to keep livestock away, they need to be maintained regularly (Melana et al. 2000).

Mangrove seedlings can also be destroyed by barnacles, crabs, and insects. Barnacle (Crustacea: Cirripedia) attacks can be minimized by planting the right species at the right site and by planting in shallow inundation sites. Planting fully hardened seedlings will also minimize barnacle damage. Barnacles can be removed by hand to prevent them from killing seedlings in afforestation sites. This is very time consuming and can be avoided by better site selection and not planting in low elevations with too much inundation. Sesarmid crabs (Crustacea: Grapsidae) eat propagules and young leaves of mangroves. When crab damage is severe, bamboo tubes can be used to protect seedlings, or larger seedlings, which are more

Fig. 12 Natural regeneration of *Avicennia marina* on restored floodplains in Sóc Trăng Province (Mekong Delta, Vietnam). The plants are about 10 months old, have developed strong root systems, and are not affected by crabs or barnacles (Photo: D. Meinardi 2014)

resistant to attack, can be planted. The provenance of the seedlings may also play a role in minimizing crab attacks. In several planting sites in the Mekong Delta, almost all seedlings from the nursery were destroyed by crabs, while natural regeneration was not affected (pers. observation K. Schmitt). Various insects such as beetles and scale insects can cause seedling mortality. Insects can be washed off with seawater or removed by hand (Macintosh and Ashton 2003; Miyagi 2013). The common boring weevil, *Coccotrypes fallax*, attacks newly established propagules of *Rhizophora* and *Bruguiera* but only when these are kept cool and shaded (Brook 2001; Sousa et al. 2003). This requires that propagules and seedlings should never be shaded, either before planting, within the nursery, or in the field. High temperatures gained from full sunlight are needed to kill the weevil and promote greater survival of seedlings.

These forms of mangrove management and protection have traditionally been carried out through government-only mangrove management. Protection through policing has often not been very effective, because of limited man power and funding and because of the risk antagonizing local people whose livelihood is dependent on mangrove forests and their resources. As a result of these difficulties, community participation in mangrove management has been introduced. Datta et al. (2012) provide a review on community-based mangrove management which refers to decentralization of rights, responsibilities, and authority from government to local communities in managing natural resources. Another form of community participation, where the focus is not only on management but also on governance, is mangrove co-management or shared governance. Here the decision-making powers, responsibility and accountability, are shared between government agencies and the local communities which depend on natural resources for their livelihoods. Resource users and local authorities negotiate, through a participatory process, a formal agreement on their respective management roles, responsibilities, and rights (Fig. 13) and establish a pluralistic governance body (Borrini-Feyerabend et al. 2013). Mangrove co-management in the Mekong Delta in Vietnam has been shown to be an effective way of maintaining and enhancing the protection function of the mangrove forest, to provide livelihood for local communities and to contribute to better governance of natural resources (Schmitt 2012). Livelihood improvement can be further enhanced by setting up integrated mangrove aquaculture systems such as mud crab fattening or grow out in mangrove pens and cages, mixed shrimp-mangrove-crab-cockle systems, or integrated mangrove fish or shrimp farms (Macintosh and Ashton 2003).

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Fig. 13 Boys catching juvenile mud crab in Cù Lao Dung Island, Sóc Trăng Province (Mekong Delta, Vietnam). Rules for spatial and temporal access, fishing tools, and harvest volumes were negotiated. In the rehabilitation zone, access is only permitted during low tide and fishing gear is restricted to handheld tools with fixed diameters and mesh sizes (Photo: A. Todt 2007)

Mangrove Assessment and Monitoring

There is often a lack of baseline information of the status of mangrove forests which is essential for better conservation planning and mangrove management (Macintosh and Ashton 2003). This highlights the need for widespread assessments and research. However, research on coastal habitats is unevenly distributed: 60 % of all published research is carried out on coral reefs. Mangrove forests and other connected and interdependent coastal ecosystems (salt marsh and sea grass meadows) are covered by 11–14 % each in published research. Media attention follows a similar pattern: 72.5 % of media reporting focuses on coral reefs, 20 % on mangroves, and salt marsh and sea grass ecosystems receive 6.5 % and 1.3 %, respectively (Duarte et al. 2008). Informing the public about the unique features of mangroves, their values, and the potential consequences of their loss is of high importance.

More, effective communication of scientific knowledge about mangroves and coastal habitats is required. Effective use of formal (school curricula, media) and informal (Internet) education avenues and an effective partnership between scientists, the public, and media are essential to raise public awareness (Duarte et al. 2008). The Internet, e-books, and apps (application software designed to run on smartphones, tablet computers, and other mobile devices) are media that can be used to reach a wide audience. An example of an e-book is “Blue Carbon – The Role of Healthy Oceans in Binding Carbon” (http://www.grida.no/publications/rr/blue-carbon/ebook.aspx) that contains animated graphics and is available as both on- and off-line versions.

The “World Mangrove iD” app (Duke 2014) is an e-book and a living expert guide to all mangrove plants. This app not only includes a botanical guide, descriptions, and images of all known mangrove plants around the world but also invites the users to contribute their own observations. It includes a capture facility to send a message, photograph, and location of observations to the author. In this way any interested person can contribute knowledge about mangroves.

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Economic Assessment and Valuation

Mangrove ecosystems are valuable both economically and ecologically, providing a wide range of ecosystem goods and services. They grow between the land and the sea/river in areas which are under immense development pressure. "About 44 % of the world's population live within 150 km of the coast. In 2001 over half the world's population lived within 200 km of a coastline. The rate of population growth in coastal areas is accelerating and increasing tourism adds to pressure on the environment" (the United Nations Atlas of the Oceans, http://www.oceansatlas.org/).

Economic valuations of mangrove ecosystem goods and services provide compelling arguments for effective mangrove protection and management; they show the benefits of healthy mangrove forests to society. Due to differences between valuation methods and between locations with differing socioeconomic settings, considerable variance exists in the estimated economic values of mangroves among different studies. Differences are also based on the type of ecosystem service considered. In the Gulf of California (Mexico), for example, Aburto-Oropeza et al. (2008) estimated that one hectare of mangroves contributes about US$ 37,500 per year to fisheries. Comprehensive overviews of economic valuation are provided in Conservation International (2008), Brander et al. (2012), and Tuan et al. (2012). Mangrove values have been estimated as US$ 2,000–US$ 9,990 per hectare per year (Costanza et al. 1997; UNEP-WCMC 2006). "Coastal ecosystem services have been estimated to be worth over US$ 25,000 billion annually, ranking among the most economically valuable of all ecosystems" (Nellemann et al. 2009, p. 7).

The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative focused on drawing attention to the economic benefits of biodiversity, including the growing cost of biodiversity loss and ecosystem degradation. TEEB presents an approach that can help decision-makers recognize, demonstrate, and capture the values of ecosystem services and biodiversity (TEEB 2008). The benefits of planting and protecting mangroves, for example, have been shown for the northern part of Vietnam. "Some 12,000 ha have been planted and the benefits are clear. An initial investment of US$1.1 million saved an estimated $7.3 million a year in sea dyke maintenance" (Brown et al. 2006, p. 10). Coastal ecosystems attenuate wave and storm surges (see Fig. 3 in Duke and Schmitt 2015), reduce erosion, and in the longer term maintain the coastal profile. These functions provide direct value through their capacity for self-repair and recovery and through co-benefits (Spalding et al. 2013).

Reduced Emissions from Deforestation and Forest Degradation (REDD+) calculates net carbon savings by "avoided deforestation." Under REDD+, developing countries can apply for carbon payments based on the rate of carbon sequestration due to reduced loss of forest coverage, restored areas, and/or increased areas of forest (Donato et al. 2011; Alongi 2014). However, large uncertainties exist about the carbon sequestration potential of mangroves, which varies greatly both within and among mangrove forests. Mangroves are nonlinear, nonequilibrium, and highly dynamic systems which rarely conform to classical concepts of forest development and succession. These factors must be considered in the design, time frame, and execution of REDD+ schemes (Alongi 2011, 2012). Alongi (2013) emphasizes that REDD+ schemes must be designed to conform to the dynamics of mangrove ecosystems, which often develop in relation to shoreline evolution rather than succession of other types of forest. Friess and Webb (2013) ask for better methods to accurately quantify the amount of ecosystem function lost or the deforestation avoided, particularly for confident baseline emission estimates. Mangroves not only contribute to aboveground carbon biomass (Hutchison et al. 2013), but also are hot spots for carbon burial in the ocean (Duarte et al. 2005).

Payment for Ecosystem Services (PES) is another form of incentive to conserve mangrove ecosystems through monetary recognition of the vital services provided for human well-being. It is a direct payment by an external beneficiary of a well-defined environmental service to a service provider. Lau (2012) concludes that piloting of PES for mangroves is feasible, though more testing will be required to come up with best practice solutions for the different settings. Findings from rural communities in the Solomon

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Islands showed that mangrove ecosystem surveys are useful as tools for raising awareness of local communities and as an input to the design of PES schemes (Warren-Rhodes et al. 2011). PES could provide additional income and incentives for local resource users to protect mangrove forests and ensure they provide benefits beyond the mangrove forest area which they manage (Schwerdtner Máñez et al. 2014). A case for mangrove PES can be made, for example, from the coastal protection value of mangroves or their function as nursery grounds for commercially exploited fish species.

The economic importance of mangroves can also be shown by using two quantitative indicators to assess the total value of adaptation projects. Saved wealth covers the monetary value of public infrastructure, private property, and income loss, and saved health covers avoided disease, disability, and life loss. Application of this approach, comparing mangrove rehabilitation and an earth dike with the use of a concrete dike as the only element of coastal protection, was carried out in Sóc Trăng Province (Vietnam). The results show that the dike upgrade leads to a negative benefit/cost ratio over 20 years, while the ecosystem-based mangrove/earth dike approach provides five times higher wealth benefits, as well as health and co-benefits (GIZ 2013).

Mangroves can contribute to the livelihood of communities which depend on mangrove goods and services for traditional and commercial uses; and, consequently, the destruction and degradation of mangroves may have severe, negative socioeconomic impacts on them. Community-based poverty reduction programs can provide alternatives to dependency on mangroves for domestic consumption and commerce, and they can improve the ecological conditions of mangroves, as well as the livelihoods of local communities (see section "Mangrove Management").

Mangroves are not traditional tourist attractions or particularly suitable for recreation activities. However, in many locations (especially within short distances from urban centers), they can provide a fascinating educational experience and harbor a range of species that can be observed easily from boardwalks or boats. Mangrove ecotourism can therefore generate income and employment for local communities and be used for outreach and educational purposes.

Monitoring

Mangrove monitoring refers to the systematic collection of data and processing of these data into information about the condition, health, and area of mangrove forests. It can also help to understand why changes are occurring. Mangrove ecosystems are dynamic both in space and time. An understanding of mangrove ecosystem processes is therefore essential in order to distinguish between natural changes which do not require management interventions and degradation which should be prevented (Duke 2015).

The design of any monitoring program must start with the definition of its objective(s). Mangrove monitoring can, for example, be carried out to assess the effectiveness of planting operations and management interventions or to detect changes in forest area and land use. A monitoring protocol detailing the methodology, frequency of sampling, intensity of sampling, sampling unit size, sampling pattern, the location of the plots, when to do the surveys, and when to stop the monitoring, as well as organization of finance and administration needs to be set up. To ensure sustainability, it is essential that all monitoring data are stored in easily accessible databases and that easy-to-use tools for data analysis are made available. In addition, monitoring results must be reported regularly to all stakeholders so that adaptive management responses can be implemented.

For applied monitoring, which can be carried out by forest rangers or local people, schemes which are simple to carry out and not too time consuming are likely to be most effective. In contrast, academic long-term monitoring or monitoring of specific scientific questions should be carried out by research institutes. Standard methodologies are, for example, described in English et al. (1997) and Lewis and Brown (2014).

Mangrove ecosystems are both the subject and object of monitoring. They can be used as indicators of coastal change or sea-level rise (Blasco et al. 1996) and their actual health and area need to be monitored.

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Indicators can be used to monitor mangrove health. Examples for positive indicators are high number of viable fruiting on mangrove trees, high abundance and diversity of birds, and high crab abundance and diversity, while a high number of damaged trees are a negative indicator (Macintosh and Ashton 2003). Mangrove forest health and biodiversity are good indicators for the success of mangrove conservation and planting.

In a review paper, Le et al. (2012) propose four main groups of indicators for assessing reforestation projects in tropical developing countries. The most common indicator of establishment success is the survival rate of planted trees, which is measured within months of planting and up to 3 years later. Indicators of successful forest growth are tree growth, stand density, stem form of timber trees, and the production of non-timber forest products such as fruits and resins. A particularly useful measure of tree growth is nodal scars of primary stems of young seedlings (Duke and Pinzón 1992). These have been used to evaluate not only growth history but also population demography of established saplings (Duke 1996). Vegetation structure, species diversity, and ecosystem functions are indicators of environmental success. The most common indicators used for measuring socioeconomic success are local income, local employment opportunities, other livelihood opportunities, provision of food and fiber, and local empowerment.

Remote sensing can be used to provide spatial and temporal information on mangrove forest area and distribution, as well as on species differentiation, health status, and population changes. Kuenzer et al. (2011) provide a comprehensive overview of a wide range of remote sensing tools and their application, with sensors ranging from aerial photography to high- and medium-resolution optical imagery and from hyperspectral data to active microwave (SAR) data.

The use of airborne video imagery for mangrove assessment dates back to the 1990s (Everitt et al. 1991). More recently, video imagery has been introduced for the qualitative assessment of shoreline habitats of the intertidal zone and along estuary banks. Such shoreline video assessments are often carried out by enthusiastic individuals and community groups as part of the MangroveWatch program which is a partnership between community volunteers, indigenous rangers, and scientists (Mackenzie et al. 2011). The Regional Coastal Health Archive and Monitoring Program (CHAMP) aims to create public-access websites of interactive online maps and oblique aerial imagery taken over time (Duke and Mackenzie 2010) which show the extent, condition, impacts, change, and health of coastlines (www.mangrovewatch.org.au/). The rapid progress in the development of easy-to-use unmanned aerial vehicles, which can take vertical or oblique, georeferenced aerial photos and videos in the coastal zone even in conditions of strong gusts of wind, will make such monitoring techniques more widely applicable.

Public-access online databases are an important monitoring tool that contributes to scientific exchange; and they have the potential to improve regional and transboundary collaboration. The Louisiana Coastwide Reference Monitoring System (http://lacoast.gov/crms2/home.aspx), for example, is used to monitor the effectiveness of individual wetland restoration projects, as well as to monitor the cumulative effects of all projects in restoring, creating, enhancing, and protecting the coastal landscape. The Global Mangrove Database and Information System (http://www.glomis.com) is a database of scientific literature, institutions, and scientists working on all aspects of mangroves, as well as regional projects and programs related to mangroves. It is based at the International Society of Mangrove Ecosystems Secretariat in Okinawa, Japan.

In the future, blue carbon assessment and monitoring will become an important issue. "The ocean's vegetated habitats, in particular mangroves, salt marshes and seagrasses, cover <0.5 % of the sea bed. These form earth's blue carbon sinks and account for more than 50 %, perhaps as much as 71 %, of all carbon storage in ocean sediments" (Nellemann et al. 2009, p. 6).

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