Mangrove forests are home to a rich and diverse flora and fauna of both terrestrial and marine origin.

Photos: Martin Zimmer

Mangrove forests – a nature-based solution for climate change mitigation and adaptation

The mangrove is a true jack-of-all-trades. Mangrove forests are excellent carbon sequesters, they protect coastal regions from erosion and storms, and they provide habitats for countless organisms. However, the forests have suffered severe area losses, and here, our authors take a look at approaches which might compensate for the decline and enable a sustainable conservation of this valuable natural asset.

By Martin Zimmer and Véronique Helfer

While in very rare cases, relict mangrove forests can reflect past sea-level and develop far inland (up to 170 km according to Aburto-Oropeza et al.), mangrove trees and shrubs generally grow along tropical and subtropical coasts, inhabiting the mid and upper intertidal zones of soft sediment shores. They can form dense and extensive monospecific stands or multi-species assemblages, covering sheltered coastlines, bays and lagoons, or estuaries. The global distribution of mangrove forests ranges from approximately 30° N to approximately 30° S – except for the west coast of Africa and South America and the south coast of Australia, where the distribution limit coincides with the 20°C isotherm of sea surface water. Some 65 "true mangrove" species (plant species which only occur in mangrove environments, as opposed to "mangrove associates", which can occur in mangrove forests but also in other terrestrial or aquatic habitats) are known from the Indo-West Pacific region; the Atlantic-East Pacific region is home to only a mere dozen of "true mangrove" species.

Like salt marshes and seagrass meadows, mangrove forests are renowned for their high rate of carbon sequestration and carbon storage per unit area. The values they generate with these services, often referred to as blue carbon ecosystem services, are higher than for any other forests, and are recognised as key contributors to climate change mitigation. Interestingly, some mangrove forests of the Atlantic-East Pacific exhibit similarly high productivity and biomass stocks to those of the species-rich forests of the Indo-West Pacific. Hence, the major driver of mangrove productivity, growth and carbon sequestration, does not seem to be species richness (taxonomic biodiversity); recent studies rather suggest that the functional (trait) distinctiveness of the coexisting species is the major driver.

Besides the blue carbon ecosystem service, which is of value to humankind world-wide, mangroves provide many other co-benefits to local stakeholders of tropical coasts, who often depend on natural resources from mangroves for their livelihood and well-being, and rely on mangroves to protect their coasts and homes from erosion and storm damage. For example, mangrove trees act as ecosystem engineers and foundation species in a dynamic soft-sediment environment by providing habitats for organisms that require a hard substratum. Their aboveground structures (aerial roots and stems) release stress and disturbance of the benthic and epibiotic fauna by slowing down currents and attenuating waves. Their aerial roots are used as substratum by organisms such as mussels, oysters, barnacles, sponges and algae, and offer shelter and feeding ground for animals like fish and shrimps during high tide. Thus, mangrove forests are home to a rich and diverse flora and fauna of both terrestrial and marine origin. Many of these species, along with other natural resources, provide food and income to local stakeholders. Mangrove crabs and various shellfish species are collected and used as food. Mangroves act as habitat, shelter and feeding ground (nursery) for juveniles of numerous fish and shrimp species that spend their adult lives

Mangrove reforestation – not at all costs

Nowadays, the approach of mangrove reforestation is well perceived in society, possibly because of the many successful forest reforestation activities on land. Numerous advertisements for diverse commercial products these days promise the planting of trees upon purchase, and more and more of them explicitly refer to mangrove reforestation. However, some of these offers have been reported in the media to be unserious or even fraud. This development warrants the implementation and establishment of effective control mechanisms and internationally accepted certificates.

Multiple mangrove reforestation activities have been undertaken over the past years, often mobilising the public to plant vast numbers of mangrove seedlings in unvegetated mud flats. But most of them proved to be failures with high plant mortality rates of up to 100 per cent. Recently, the Mangrove Specialist Group (MSG) of the International Union for Conservation of Nature Species Survival Commission (IUCN SSC) expressed their concerns about simplistic calls for mass planting, for four reasons:

- First, an emphasis on tree-planting may distract from the priority of protecting existing mangrove forests.
- Second, studies from around the world have shown that most attempts at mass planting of mangroves fail.
- Third, mass planting often focuses on only one or two species that are easy to plant and creates species-poor stands that may not perform all the ecosystem processes of a natural forest.
- Fourth, growing and planting mangroves can be very expensive and time-consuming. If planting is not necessary, then this diverts funds from other conservation activities and breeds cynicism.

in adjacent ecosystems, such as seagrass meadows or coral reefs, or in the open sea. Thus, they provide both rich fishing grounds for local fisher people and feeding areas for predators. Fodder, teas and (alcoholic) beverages, food, honey and medicine are traditionally produced from mangrove leaves, fruits and flowers. The wood of many mangrove species is dense and hard, and it exhibits high caloric value, rendering it an excellent construction material, particularly for use in seawater, and well suited for the use as firewood or for charcoal production.

The attenuation of waves and currents by the complex three-dimensional structures of aerial roots and stems leads to sediment deposition and stabilisation. The resulting hydrodynamics inside the forest also significantly contribute to ecosystem services of relevance for humankind world-wide. Fallen leaf litter, dead wood or rotting fruits from inside the forest are kept from tidal out-washing by the tree architecture. Drifting seagrass blades or algal wrack are deposited by the tides and retained inside the forest. This huge pool of organic matter – called blue carbon, when referring to only the carbon components – is incorporated into the sediment by the burrowing fauna or by sediment deposition. Blue carbon stocks in the saline and anoxic environment of the mangrove sediment are stable against decay over centuries and millennia. Together with the extraction of carbon dioxide (CO_2) from the atmosphere and its long-term storage in the above- and belowground tree biomass, these processes render mangrove forests one of the most efficient nature-based solutions for climate change mitigation. Further, protecting and rehabilitating mangroves has an immense potential for climate change adaptation.

Stingless bees produce honey from mangroves.

How the ecosystem can be preserved and protected

Despite the increasingly acknowledged relevance of mangrove forests for local societies and their value world-wide, they have encountered drastic area losses over the last decades through human activities. Even though current loss rates are well below 0.5 per cent on a world-wide average, we are still losing some 50 hectares of mangrove area every day. The major threats to mangrove forests encompass clear-cutting and habitat degradation by pollution (from nearby settlements or industries) or eutrophication (from hinterland agriculture or untreated sewage).

After large-scale forestry, the second major driver of mangrove clear-felling is the construction of aquaculture ponds. In many regions of the world, extensive mangrove forests had been transferred into aquaculture areas over the past decades. While decreasing productivity and increasing risk of diseases often force the owners to abandon ponds after around a decade, the changes in topography and hydrodynamics upon constructing the ponds render the area inaccessible to natural recolonisation by mangroves afterwards. In recent years, novel concepts have been applied to try to avoid, or compensate for, large-scale area losses through implementing, for instance, Integrated Mangrove Aquaculture.

Ecosystem-based management. For the sake of societal acceptance, any reasonable protection measure has to take into account requirements for the (sustainable) use of natural resources by local communities. Thus spatial conservation prioritisation, the choice of areas for protection versus use, needs to consider both the present situation and integrity of mangrove forests and projections, predictions and scenarios of their future distribution, extension and status. Along this line, Ecosystem-Based Management (EBM) takes in-depth information for ensuring the persistence of mangroves in a given area into account. Recognising previous management failures, e.g. disregarding societal perceptions and needs, or lacking knowledge of particular ecosystem processes, EBM aims at combining conservation, sustainable use and fair allocation of benefits from natural resources. It requires detailed and reliable information about the ecosystem to be managed. However, we are still lacking the knowledge of e.g. drivers of ecosystem processes or impacts of resource-use.

Restoration – from natural recolonisation to active planting. Degraded mangrove areas may be suitable for mangrove (re-)establishment, ranging from facilitating natural recolonisation of restored habitats to the active planting of a selected set of species that provide a locally or regionally urgently needed set of ecosystem services. One approach of the former is Community-Based Ecological Mangrove Restoration (CBEMR), based on the concept of Ecological Mangrove Rehabilitation (EMR) described by Lewis & Brown in 2014. To facilitate natural regeneration, CBEMR acts on mitigating mangrove stressors through re-instating conditions of e.g. topography and hydrodynamics from before the anthropogenic disturbance. One focal aspect of EMR and CBEMR is the engagement of local communities and sincere consideration of social, economic and ecological factors before undertaking any action, and the monitoring of the success of all actions.

When and where previous conditions cannot be restored or propagule supply from nearby systems is limited, assisted recolonisation of degraded mangrove areas through active planting of seedlings or saplings might prove necessary. However, planting efforts can only succeed if species also fit into an area, for example with respect to tidal regime, hydrodynamics or sediment supply. A recent White Paper of the IUCN Mangrove Specialist Group pledges for thorough consideration of strategies and alternatives before investing in, and wasting efforts on, planting hundreds and thousands of mangrove seedlings in vain (see Box on page 24).

Villagers help preparing coastal protection measures in Fiji.

One special case of mangrove restoration is the establishment of mangroves in and around aquaculture ponds (Integrated Mangrove Aquaculture, silvo-aquaculture), aiming at optimising the compromise between the economic gain from aquaculture and the multiple socio-ecological benefits of mangrove ecosystems (also see article on pages 28–29). While mostly considered in the context of blue carbon-storage and climate change mitigation, other beneficial effects of mangrove stands, such as the above-mentioned protection of the coastline and nearby infrastructure from damage through storm surges or other extreme events, stress the value of these approaches to ecosystem-based (climate change) adaptation as a special case of nature-based solutions.

"Building with nature"

Most mangrove restoration and rehabilitation efforts focus on high biodiversity and near-to-natural ecosystem structure. A recent approach concentrates on the provision of ecosystem services according to human needs and demands. Ecosystem Design (ESD) aims at (re-)establishing those (simple) communities that most efficiently provide (a set of) ecosystem services of high demand by local societies (or humankind world-wide). Thus, while traditional restoration focuses on the ecosystem, Ecosystem Design has the use of ecosystem benefits by local communities at its very heart. Designed ecosystems do not (necessarily) aim at high biodiversity but rather restrict the community to a number of species which, in concert and interaction, are most efficient in driving those ecosystem processes that underlie the required ecosystem service(s). Thus, for instance, species-specific differences in rates of CO_2 sequestration and storage as measure of climate change mitigation would result in establishing those species that are most efficient in this regard. Along the same line, species that are particularly efficient in wave attenuation or sediment stabilisation would be established with priority, if coastal protection were the ecosystem service aimed at. Like EBM, Ecosystem Design requires in-depth understanding of the environmental requirements and ecophysiology of a multitude of species, as well as of their interactions with other species – for many inhabitants of mangrove forests, we still lack this detailed knowledge. As for EBM, Ecosystem Design for now has to rely on "informed guesswork". Ellison et al. consider the anthropocentric and high-intervention approach of "building with nature" through Ecosystem Design – as opposed to the ecocentric "bringing nature back" approach of EMR – a strategy of the future.

DEFINITIONS

Ecosystem-Based Management (EBM): environmental management approach taking into account the multitude of interactions within an ecosystem, including humans, rather than considering societal issues, species or ecosystem services in isolation.

Ecological Mangrove Rehabilitation (EMR): rehabilitation of mangrove forests via community engagement for consideration of social, economic and ecological factors, and relying on monitoring to inform corrective actions over time.

Community-Based Ecological Mangrove Restoration (CBEMR): holistic approach, aiming at recovery of mangrove areas through including local stakeholders, such as local or international NGOs, or regional government units, taking into account both ecological and societal aspects to combat specific challenges to mangrove recovery.

Ecosystem Design (ESD): implementation of novel ecosystems in degraded areas, or steering of existing ecosystems and their use, in order to sustain or improve ecosystem service-provisioning and ensure the sustainable use of these services.

Restoration: returning a degraded ecosystem back to its former state or condition.

Rehabilitation (also referred to as Ecological Restoration): re-establishing conditions of a degraded habitat in order to initiate a trajectory of development towards ecosystem recovery.

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References: **www.rural21.com**