THE STATE OF THE WORLD'S
FOREST GENETIC RESOURCES –
THEMATIC STUDY

# GENETIC CONSIDERATIONS IN ECOSYSTEM RESTORATION USING NATIVE TREE SPECIES


**Editors**

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# Foreword

One of the major and growing environmental challenges of the 21st century will be the rehabilitation and restoration of forests and degraded lands. Notwithstanding the large-scale restoration projects initiated in Africa and Asia as of the 1970s, the current level of interest in forest and landscape restoration is more recent. With the adoption of the strategic plan of the United Nations Convention on Biological Diversity for 2011-2020, a strong new impetus has been given not only to halt degradation, but to reverse it. The plan states that, by 2020, 15 percent of all degraded lands should be restored. This target is consistent with the Bonn Challenge, which calls for restoring 150 million hectares of degraded land by 2020.

Forests play a crucial part in resilient landscapes at multiple scales. Restoring forest ecosystems is therefore a key strategy not only for tackling climate change, biodiversity loss and desertification, but can also yield products and services that support local people's livelihoods.

Restoration is not only about planting trees. Its success requires careful planning, as painfully demonstrated by numerous past restoration projects that have not attained expected goals. Restoration practices must be based on scientific knowledge, particularly so in these times of progressive climate change. The trees we plant today and other associated measures for restoration and rehabilitation of degraded ecosystems must be able to survive abiotic and biotic pressures, including social ones, in order to be self-sustaining and generate the products and services vital to supporting the world's population and environment for the years to come.

Biodiversity International coordinated this thematic study as an input to FAO's landmark report on *The State of the World's Forest Genetic Resources*. The report was requested by the Commission on Genetic Resources for Food and Agriculture, which guided its preparation, and agreed, in response to its findings, on strategic priorities which the FAO Conference adopted in June 2013 as the *Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources*.

The publication of this study is an important step in the implementation of the *Global Plan of Action*. It provides fundamental information for the achievement of knowledge-based ecosystem restoration using native tree species. It draws attention to the importance of embedding genetic considerations in restoration activities, an aspect which is often overlooked both by restoration scientists and practitioners, but is nonetheless crucial to rebuilding resilient landscapes and ecosystems. We trust that it will contribute to informing future restoration efforts and help to ensure their success.

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Chapter 14

# Habitat-specific approaches

## 14.1. Mangrove forest restoration and the preservation of mangrove biodiversity

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Mangrove forest ecosystems covered 13.8 million ha of tropical shorelines in 2000 (Giri *et al.*, 2011), down from 19.8 million ha in 1980 and 15.9 million ha in 1990 (FAO, 2003). These losses represent about 2 percent per year from 1980 to 1990 and 1 percent per year from 1990 to 2000. Therefore, achieving no net loss of mangroves worldwide would require the successful restoration of approximately 150 000 ha per year, unless all major losses of mangroves ceased. Increasing the total area of mangroves worldwide towards their original extent would require an even larger effort.

An example of documented losses of mangroves is the combined losses in Malaysia, the Philippines, Thailand and Viet Nam of 7.4 million ha (Spalding, 1997). These figures emphasize the magnitude of the loss. The opportunities that exist to restore areas back to functional and biodiverse mangrove ecosystems are also significant, including mosquito-control impoundments in Florida (Brockmeyer *et al.*, 1997) (several tens of thousands of hectares) and abandoned shrimp aquaculture ponds in Southeast Asia (Stevenson, Lewis and Burbridge, 1999) (several hundreds of thousands of hectares).

While great potential exists to reverse the loss of mangrove forests worldwide, most attempts to restore mangroves fail completely or fail to achieve the stated goals (Erftemeijer and Lewis, 2000; Lewis, 2000, 2005, 2009). Previously documented attempts to restore mangroves (Field, 1996, 1999), where considered successful, have largely concentrated on creation of plantations of mangroves consisting of just a few species with the objective of providing wood products (Kairo *et al.*, 2002) or collecting eroded soil and raising intertidal areas to usable terrestrial agricultural elevations (Saenger and Siddiqi, 1993).

### *Restoration of a biodiverse mangrove forest*

Successful mangrove forest restoration requires careful analyses of a number of factors before attempting actual restoration. Lewis (2005, 2009) notes that existing hydrology of a proposed restoration site needs to be characterized and compared with that of a reference forest to establish what conditions preclude natural recovery in damaged forests, or what conditions prevent natural recolonization of supratidal and subtidal flats that might be proposed for conversion to mangrove forests. A six-step process called ecological mangrove restoration has evolved from earlier attempts to standardize successful approaches (Stevenson, Lewis and Burbridge, 1999), and is now taught around the world (Lewis 2010). This method emphasizes getting the hydrology right first and then observing and documenting natural recovery through volunteer mangrove propagule recruitment (Figure 14.1) before large-scale planting of mangroves is even considered. As seen in Figure 14.1, mangrove propagules can voluntarily recruit to a restored site and establish the natural biodiversity of mangrove species. Planting is therefore not needed in most cases. Situations where planting of mangroves is needed are described as "propagule limited" sites (see below).

Unfortunately, as noted in Stevenson, Lewis and Burbridge (1999) and Samson and Rollon (2008), massive attempts to plant mudflats where mangroves have never existed have been the norm for many decades and have almost uniformly failed. Where they occasionally do work because local topographic conditions are conducive to planting of mangroves, the results are typically plantations of a single species of mangrove. Various species of *Rhizophora* are commonly used in plantings as they have large propagules that are easily collected, grown and planted. This emphasis on single-species plantings ignores the mix of species found in most mangrove forests. Mangrove forests in the New World typically contain four species of mangrove, and a single forest in a location such as the Philippines, Viet Nam and northern Australia may contain up to 30 species (Duke, 1992). There are 69 species worldwide called mangroves (Duke, 1992).

Biodiversity is also threatened by the introduction of non-native species of mangroves for restoration. Chen *et al.* (2009) notes that *Sonneratia apetala* Buch.-Ham. has been introduced to China from Bangladesh and, surprisingly, used to control another introduced plant species, *Spartina alterniflora* Loisel, "even though the invasiveness of this exotic mangroves species was not fully understood" (Chen *et al.* 2009: 49).

An important goal of many restoration projects is to provide habitats for fish and invertebrates to restore local fisheries. Maximizing use of such habitats usually means maximizing biodiversity of the plant species, and therefore a monotypic stand of mangroves in an area that normally supports 20 or more mangrove species is not a logical goal. Establishment of persistent tidal creeks to assist with entry and exit of juvenile and adult fish and invertebrates is also an essential restoration objective. Lewis and Gilmore (2007) discuss the use by fish of both natural and restored mangrove forests and report specifically on monitoring a successful 500 ha mangrove restoration project in Hollywood, Florida, United States (see Figure 14.1), where fish populations sampled in both reference and restored sites were statistically indistinguishable within three to five years of restoration. They emphasize three restoration and design goals to ensure functional and naturally biodiverse ecological restoration of mangrove forests:

1. Achieve plant cover similar to that in an adjacent relatively undisturbed control area of mangrove forest.
2. Establish a network of channels that mimic the shape and form of a natural tidal creek system.
3. Establish a heterogeneous landscape similar to that exhibited by local mangrove ecosystems.

Lewis (2005) introduced the term "propagule limitation" to define a condition in which natural recovery is slowed or halted because no natural mangrove propagules are available to volunteer at a damaged site. The absence of propagules may be caused by a large-scale loss of adult trees capable of producing propagules or by hydrologic restrictions or blockages (e.g. dykes) that prevent natural waterborne transport of mangrove propagules to a restoration site. Since propagules are produced at different times of the year by different species in different locations (Tomlinson, 1986), more than one site visit may be necessary to correctly identify a propagule limited site. Lack of propagules at a single time of year does not necessarily define a propagule-limited site, and therefore careful evaluation of this parameter is important. If a damaged forest will recover on

**Figure 14.1.**
Time sequence photographs of a portion of the 500 ha West Lake Park mangrove restoration project utilizing non-native exotic plan removal, site excavation, tidal creek restoration and natural recruitment of mangrove propagules. No planting of mangroves took place.


its own within an acceptable time frame, any attempt to introduce propagules, plant propagules or plant nursery-grown mangroves is likely to be a waste of time and money. Recovery is here defined as the recolonization of a restoration site and growth of plant materials on that site reaching some predefined numerical target (e.g. percent cover, total basal area). Priority should be given to restoration sites that would indeed benefit from human intervention at the least per unit cost, given that time and money to devote to any restoration project are always limited.

These suggestions may seem obvious, but there are very few documented examples of successful mangrove forest restoration. More commonly, well-intentioned, but often faulty, mangrove restoration efforts target areas on which mangroves were not previously present, such as mudflats or seagrass meadows seaward of natural mangroves or damaged areas without a properly documented history (Field, 1996; Erftemeijer and Lewis, 2000; Lewis, 2005). The result of unsound evaluations of restoration opportunities has, unfortunately, emphasized first establishing a mangrove nursery and then planting mangroves at a casually selected site as the primary tool in restoration, rather than first assessing the reasons for the loss of mangroves in an area and working with the natural recovery processes (Lewis, 2009).

Both Brockmeyer *et al.* (1997) and Stevenson, Lewis and Burbridge (1999) present examples of successful mangrove restoration following re-establishment of historical tidal connections to adjacent estuaries. This is termed "hydrologic restoration" (see discussion in Turner and Lewis, 1987). In the examples discussed, volunteer propagules of mangrove and mangrove nurse-plants were sufficient to allow for rapid establishment of plant cover. No planting of mangroves was required.

### Establishing success criteria

Once a site is finally chosen for restoration and a design developed, quantifiable success criteria should be established. Establishing such criteria is important in order to actually measure progress towards successful restoration. The first step in establishing numeric criteria for success is to prepare a brief narrative goal or set an objective for the project (Saenger, 2002). This will define the next steps. For example, a goal may be to establish a monotypic plantation of *Rhizophora apiculata* Bl. to be harvested after 12 years as poles. It may be an acceptable goal to local stakeholders in the project, such as local villages and fishermen, and harvest of wood products from locally managed forests is a typical goal (see discussion of timber production in the Matang Forest, Malaysia, in Saenger [2002]: 231–234).

A second example of a goal might be to maximize biodiversity. In this case, the restoration site might be left alone and not planted immediately to allow for volunteer colonization of the largest number of different species of mangroves from propagules produced by trees adjacent to a restoration site.

The next step is to look at available information on both plantation and natural recruitment indices of success. Saenger (2002: 256–270) discusses in great detail what is to be expected in terms of biomass and stem density, for example, from typical plantation projects. There has been much work on plantation projects in which just a few species of mangroves are managed, and thus there is a wealth of data to examine. In contrast with this, data on natural recruitment within a mixed forest are generally not available. McKee and Faulkner (2000) report on the results of sampling for density and basal area within two restored mangrove forests in Florida, United States, and compared these with two adjacent control areas. Their data show that density and basal area of volunteer mangroves in the restoration areas exceeded that of planted mangroves. Proffitt and Devlin (2005) report similar results from one of the same sites sampled by McKee and Faulkner (2000) but that they sampled in later years as the system matured. Lewis, Hodgson and Mauseth (2005) report on the results of cover sampling over a period of five years within a restored mangrove forest in another location in Florida, United States. These studies help define parameters that need to be sampled and sampling methodologies, but provide limited data to apply to local situations in other parts of the world.

Few studies exist on trends in biodiversity in restored mangroves, and the range in age, species and inundation class of restored sites makes generalizations difficult. However, the co-occurrence of many animal species in both restored and comparable natural forests suggest that colonization of restoration sites by both mobile and non-mobile fauna is a rapid process, and equivalent populations of mangrove fauna in both natural controls and restored mangrove sites can typically be found within 5–10 years of restoration (Lewis and Gilmore, 2007; Bosire *et al.*, 2008).

### *Concluding remarks*

Restoration of mangrove forest has not been generally successful except where timber production was the goal and monotypic stands were established. Establishment of a biodiverse mixed-species forest cover and restoration of functions equivalent to those of an adjacent reference forest, have not typically been design criteria, and most restoration projects with some general ecological goals have not been successful (Erftemeijer and Lewis, 2000; Lewis, 2005). The chosen restoration sites for many of these projects have been mudflats or seagrass beds lying seaward of the outer edge of existing mangrove forests. These sites are typically planted with nursery-grown mangrove seedlings which do not survive because of frequent inundation and waterlogging.

Although there are relatively few studies on trends in biodiversity in restored mangroves, it appears that colonization of restoration sites by both mobile and non-mobile fauna is a rapid process that may take 5–10 years to reach levels comparable to natural sites (Bosire *et al.*, 2008). The scientific basis for optimum design of restoration projects to meet certain established criteria, such as increased fish production or more use by wading seabirds, is, however, very minimal.

In future, mangrove restoration projects should be more carefully designed to ensure successful establishment of a biodiverse plant cover over large areas at minimal cost. This can be achieved, for example, by restoring hydrologic connections to impounded mangrove areas, as has been done in Florida (Brockmeyer *et al.*, 1997), Costa Rica and the Philippines (Stevenson, Lewis and Burbridge, 1999) using the basic principles of ecological mangrove restoration (Lewis, 2010). Use of non-native species of mangroves in management and restoration projects should be avoided.

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## 14.2. Forest restoration in degraded tropical peat swamp forests

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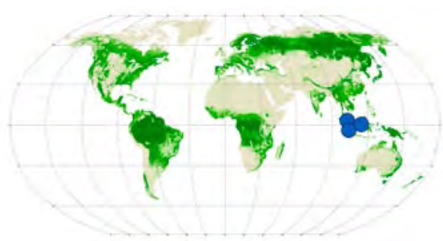
### *Tropical peat swamp forests and their degradation*



Tropical peatlands in Southeast Asia are the most extensive in the world; they contain ~69 Gt of carbon, equivalent to 11–14 percent of global peatland carbon, and cover 247 778 km$^2$, the majority being in Indonesia (206 950 km$^2$; 57 Gt of carbon;