# The application of forestry principles to the design, execution and evaluation of mangrove restoration projects

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**Whether the motives are economic**, practical or aesthetic, the success of any mangrove planting programme can be enhanced by the application of sound forestry principles and practices. These apply to all phases of the operation, from selection of suitable germplasm, to its macro- or micropropagation, site-species matching, selection of planting densities, and assessment of stand performance.

**Photo 1.**
Mature stands of *Sonneratia alba* on the cyclone-prone Kimberley coast of northwestern Australia.
Photo P. Saenger.

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## RÉSUMÉ

**LES PROGRAMMES DE RESTAURATION DES MANGROVES : APPLICATION DES PRINCIPES DE LA GESTION FORESTIÈRE POUR LEUR CONCEPTION, LEUR RÉALISATION ET LEUR ÉVALUATION**

Des programmes de reboisement de la mangrove sont réalisés aujourd'hui dans de nombreux pays du monde, que ce soit pour des raisons économiques (production de bois d'œuvre, développement de la pêche), écologiques (protection et stabilisation des littoraux et des canaux côtiers, restauration et protection des écosystèmes et de la vie sauvage) ou politiques (évolution des législations, développement social). La définition précise des objectifs et des priorités de chacun de ces programmes est essentielle pour assurer leur bon déroulement et leur évaluation. L'application d'une gestion forestière saine, à toutes les étapes de leur réalisation, est aussi la clef de leur réussite : du contrôle des caractéristiques génétiques des plants à l'application raisonnée des techniques de macro- ou micro-propagation, de l'adéquation entre choix des espèces et caractéristiques écologiques des sites au suivi de la densité des plantations et à l'évaluation des résultats.

**Mots-clés :** mangrove, valorisation, restauration, gestion forestière, protection du littoral.

## ABSTRACT

**THE APPLICATION OF FORESTRY PRINCIPLES TO THE DESIGN, EXECUTION AND EVALUATION OF MANGROVE RESTORATION PROJECTS**

Mangrove planting is carried out in many parts of the world for a great variety of reasons, including timber production, shoreline protection, channel stabilization, fisheries and wildlife enhancement, legislative compliance, social enrichment, and ecological restoration. Clear definition and prioritization of the objectives of any planting programme is essential to its planning, execution and evaluation. Whether the motives are economic, practical or aesthetic, the success of any mangrove planting programme can be enhanced by the application of sound forestry principles and practices. These apply to all phases of the operation, from selection of suitable germplasm, to its macro- or micropropagation, site-species matching, selection of planting densities, and assessment of stand performance.

**Keywords:** mangrove, value, restoration, forestry, silviculture, coastal protection.

## RESUMEN

**LA APLICACIÓN DE LOS PRINCIPIOS DE MANEJO FORESTAL PARA DEFINIR, REALIZAR Y EVALUAR LOS PROYECTOS DE RESTAURACIÓN DEL MANGLAR**

Se efectúan plantaciones de manglares en distintos puntos del planeta por múltiples razones, entre las que se incluyen la producción de madera de construcción, la protección costera, la estabilización de los canales, la mejora de las pesquerías y de la vida salvaje, la conformidad con la legislación, el enriquecimiento social y la restauración ecológica. En cualquier programa de plantación, definir claramente los objetivos y establecer las prioridades es esencial para su planificación, ejecución y evaluación. Aunque las motivaciones sean de carácter económico, práctico o estético, el éxito de cualquier programa de plantación puede verse favorecido por la aplicación de algunos principios y prácticas de manejo forestal sano. Esto se aplica a todas las fases de la operación, desde la selección de genomas adaptados hasta la macro o micropropagación, las elecciones de asociaciones sitio-especie, de densidades de plantación y la evaluación del desempeño del rodal.

**Palabras clave:** manglar, valor, restauración, manejo forestal, silvicultura, protección costera.

## Introduction

In the 1830s, the acclaimed naturalist Alexander von Humboldt described South American mangroves in the following terms: "the mangle trees produce miasmas… all settlers in the tropics are well familiar with the noxious perspirations of those plants. They attribute the unhealthy air to the root-stocks of the mangle trees… we assume that chemical gases are generated which defy all chemical investigations." Such negative perceptions of mangroves persisted well into the late twentieth century, representing the mangroves at least as a nuisance, if not as downright dangerous and sinister. With increasing knowledge, they came to be viewed as interesting scientific curios. Later a more utilitarian view became prevalent. Increasingly today, mangroves are being protected, managed and restored because of their perceived value in providing products and services.

The values of a mangrove system (photo 1) are manifold, but four broad categories can be identified: economic, usefulness, intrinsic and symbolic values. Economic values are readily recognized in the direct and indirect products obtainable from mangroves. Direct products consist of various wood products (photo 2) and related materials such as tan-bark and fodder, while indirect products include fish, crustaceans, shellfish and honey. These economic values can easily be quantified as, for example, the annual value of a mangrove fishery or timber yield (table I).

Usefulness values (also referred to as "instrumental values", "free services" or "ecological functions") include the provision of habitat, shoreline protection, chemical buffering, water quality maintenance, recreational and education opportunities, and reservoirs of genetic material. These values are difficult to quantify in monetary terms.

The acceptance of intrinsic values, i.e. that organisms, communities and ecosystems have an inherent right to exist independently of any human interest in them, is becoming more widespread. Such a view forms the basis of much of the rationale of the conservation and animal welfare movements and underpins our efforts at heritage and biodiversity conservation. Since these values cannot be quantified (and, perhaps, should not be), they are often overlooked.

Symbolic values, derived from religious, totemic or mythical beliefs, are probably attached to many mangrove areas by indigenous people. Thus, the sacred groves in India, the sacred sites of the Australian Aborigines, or the fetish forests of Benin, represent areas of considerable symbolic value to their custodians. While such values may be rather difficult for non-believers to understand or appreciate, they should not be overlooked. As with intrinsic values, symbolic values cannot be quantified.

Using an alternative scheme, it is also possible to assess the value of mangrove communities in terms of their components, functions and attributes (table II). Components have a direct use value which can be assessed on the basis of costs (i.e. labour expended both as paid labour and as labour time) and prices; functions are indirect use values which support other activities and can be assessed on the basis of replacement costs or the value of the damage avoided; and attributes are qualities that have a non-use value even though they may also contribute to direct and indirect use values.

## Mangrove silviculture and restoration

The basis of mangrove planting today may be economic, practical, or aesthetic (photos 3 and 4). Objectives may include timber production, shoreline protection, channel stabilization, fisheries and wildlife enhancement, legislative compliance, social enrichment, or ecological restoration. For example, in countries such as Bangladesh, Indonesia, Malaysia, Thailand, and Myanmar (Burma), there are large commercial mangrove forestry operations which require the replenishment of harvested mangrove stands. In China, Vietnam, and Bangladesh, mangroves are planted for purposes of stabilizing and protecting the coastline and coastal towns and villages from cyclone damage and seawater intrusion. Mangrove plantings are also undertaken to provide amenity values or to augment the ecological functioning of prawn (Philippines and Indonesia) and fish ponds (India). The remainder of this article examines the various reasons for mangrove planting and then considers how forestry principles can be applied to the design, execution, and evaluation of those plantings in order to meet their original objectives.

**Photo 2.**
Debarking of *Rhizophora mangle* and *R. harrisonii* near Corinto, on the Pacific coast of Nicaragua. These poles are used for construction and the removed bark is not used further.
Photo P. Saenger.

**Table I.**
**Estimates of the economic value of mangroves. No corrections have been made for time-related fluctuations in the US$. (After Saenger, 2002).**

| Country | Year | Value (US$/ha/year) | Yield or benefit |
|---|---|---|---|
| **Traditional goods** | | | |
| PNG | 1977 | 1 | Crocodile skins, game |
| Benin | 1989 | 12 | Salt production |
| Indonesia | 1990 | 33 | Traditional products |
| Indonesia | 1992 | 33 | Traditional products |
| Thailand | 1982 | 230 | Traditional products |
| Philippines | 1984 | 650 | Alcohol from *Nypa* |
| **Forest products** | | | |
| Fiji | 1976 | 6 | Timber and fuelwood |
| Indonesia | 1990 | 66 | Chipwood production |
| Indonesia | 1992 | 67 | Timber, fuelwood and chipwood |
| Trinidad | 1974 | 70 | Timber and fuelwood |
| Malaysia | 1984 | 110 | Fuelwood |
| Malaysia | 1985 | 150 | Charcoal |
| Philippines | 1996 | 151 | Timber and fuelwood |
| Thailand | 1982 | 230 | *Nypa* shingles |
| Thailand | 1985 | 500 | Timber and fuelwood |
| Malaysia | 1986 | 566 | Timber and fuelwood |
| **Aquaculture after mangrove conversion** | | | |
| India | 1986 | -145 | Extensive shrimp production |
| Philippines | 1978 | -180 | Milkfish (*Chanos chanos*) |
| Thailand | 1982 | -206 | Extensive shrimp production |
| Ecuador | 1982 | -390 | Extensive shrimp production |
| Philippines | 1979 | -1 600 | Intensive shrimp production |
| Thailand | 1982 | -2 106 | Intensive shrimp production |
| Philippines | 1996 | -7 124 | Aquaculture |
| **Fisheries products** | | | |
| Philippines | 1996 | 60 | Mangrove fisheries catch |
| Thailand | 1982 | 30 | Small-scale fisheries |
| Fiji | 1976 | 100 | Mangrove fisheries catch |
| Indonesia | 1992 | 117 | Mangrove fisheries catch |
| Trinidad | 1974 | 125 | Small-scale fisheries |
| Thailand | 1977 | 130 | Wild-caught shrimps |
| Fiji | 1985 | 166 | Small-scale fisheries |
| Indonesia | 1977 | 1 010 | Wild-caught shrimps |
| Malaysia | 1982 | 2 770 | Mangrove fisheries catch |
| **Agriculture after mangrove conversion** | | | |
| India | 1984 | -35 | Coconut |
| Fiji | 1976 | -52 | Agricultural production |
| Senegal | 1984 | -80 | Rice |
| Thailand | 1983 | -165 | Rice |
| Indonesia | 1992 | -220 | Rice |
| **Ecosystem services** | | | |
| Indonesia | 1992 | 3 | Erosion control |
| Indonesia | 1992 | 15 | Biodiversity conservation |
| Trinidad | 1974 | 200 | Ecotourism park fees |
| Fiji | 1976 | 5 820 | Polishing treated sewage |

## Objectives for mangrove planting

It is essential that objectives be clearly defined and prioritized as a first step in the mangrove planting process. The coastal afforestation project in Bangladesh, for example, has several objectives, the foremost of which are the production of commercial timbers, acceleration of the rate of accretion of new land areas, and improvement of the protection of nearshore agricultural and residential lands from storm damage (Saenger, Siddiqi, 1993). All of these objectives are being achieved, but in some situations, success in achieving one objective has meant less success in achieving another. For example, trees were buried and timber production was negligible in planting sites where very high sedimentation rates occur. In assessing the significance of high sedimentation rates at particular sites, it is important to determine whether the production of timber or the reclamation of new land has the highest priority.

Clearly, if timber production is most important then sites likely to experience high sedimentation should be avoided or the first planting should be considered as sacrificial, serving solely to help raise the land to the point where another more desirable species would survive. If stabilization and reclamation are paramount, then the burial of an initial plantation by sediment should be regarded as a success, and replanting should be undertaken to extend the gains already made.

Prioritized objectives underpin the planning process; they help to identify the elements which must be included to provide the undertaking with a clear framework for operation and implementation. They are also essential for evaluating the extent of success of the planting project.

**Table II.**
**Values of mangroves as components, functions, and attributes. (Source: Saenger, 2002).**

| | |
|---|---|
| **Components** | Plant resources |
| | Fisheries resources |
| | Wildlife resources |
| | Water supply resources |
| | Agricultural resources (incl. salt production and aquaculture) |
| | Forage resources |
| | Water transport resources |
| | Recreational resources |
| | Energy resources |
| | Pharmaceutical resources |
| **Functions** | Shoreline protection |
| | Windbreak and storm protection |
| | Sediment regulation |
| | Nutrient retention |
| | Water quality maintenance |
| | External support |
| | Groundwater discharge and recharge |
| | Local microclimatic stabilization |
| **Attributes** | Biodiversity |
| | Uniqueness and heritage |

## Shoreline protection, channel stabilization and storm protection

Because of their intricate above-ground root systems, mangroves reduce the velocity of waters flowing through and around them. Such a reduction in water velocity gives them a significant role in coastal protection and there are numerous examples of mangrove plantings that were specifically undertaken for such purposes (photo 6).

Early last century, there were proposals to stabilize the banks of the newly constructed Suez Canal and the North African shorelines generally with *Rhizophora* spp., based on these mangrove characteristics. More recently, in 1966, a coastal afforestation programme was initiated in Bangladesh specifically to protect coastal villages from surge and storm damage during the frequent cyclones that sweep into the Bay of Bengal during the monsoon season (Saenger, Siddiqi, 1993). The effectiveness of these mangrove plantations in stabilizing newly deposited sediments in the Bay of Bengal is confirmed by the fact that 160 000 ha of mangrove plantations have been established over the past 35 years.

## Timber production

Mangrove silviculture and timber extraction (photo 5) has a long history, formalized by the colonial forest departments of the European powers that usurped tropical lands. Thus, Dutch, Belgian, French, Spanish, German, Portuguese and British colonial forestry agencies managed many mangroves of Africa, South America and Australasia, generally on the management constructs of the spruce and oak forests of Europe, and always with the need for colonial advancement firmly at the forefront of their organisational objectives. While some of these mangrove forestry projects have been oustandingly successful (e.g. Matang, Malaysia; Chan, 1996), others have experienced problems.

**Photo 3.**
A twelve-year-old plantation of *Sonneratia apetala* for the dual purpose of timber production and coastal stabilization. Bangladesh.
Photo P. Saenger.

## Fisheries and wildlife enhancement

Where mangroves have been depleted, there may be an associated decline in nearshore productivity which, in turn, may prompt a mangrove replanting programme. BACON (1993), for example, reports the increase of waterfowl usage of wetlands in the Caribbean following mangrove enhancement through a planting programme.

## Legislative compliance

In many countries with mangroves, strict protective measures have been implemented, and compensatory requirements also often exist. In most Australian states, mangroves are protected and mangrove losses resulting from public activities must be legally compensated for by the planting of similar areas. In Ballina (New South Wales), for example, the re-alignment of a major arterial road through a mangrove community caused a net loss of 7 hectares, and an equivalent area of coastal land was set aside to be replanted with mangroves to offset the ecological losses sustained. Such "no net loss" policies are increasingly being used by land-use management agencies.

## Social enrichment

Planting for social enrichment covers a wide variety of objectives, ranging from aesthetics to income generation through eco-tourism. In the Middle East, for example, where green vegetation is scarce, the planting of mangroves is viewed as an achievable means of "greening" and beautifying the landscape. In the United Arab Emirates, mangrove planting programmes have been ongoing since the late 1970s. Although the only objective there has been to provide a green backdrop to an otherwise stark landscape, the plantations have not only met that objective but have provided additional benefits such as roosting and feeding sites for migratory waders, flamingoes, and a range of other wildlife.

In any programme aimed at social enrichment, it is important that economically impoverished people who depend on the direct exploitation of mangroves for their livelihood obtain benefits from the planting programme. A replanting programme can be used to improve the economic opportunities and well-being of rural people by providing direct employment for them in the planting programme, by restoring the productivity of lands and ecosystems they use, and by increasing the diversity of plants and animals they harvest.

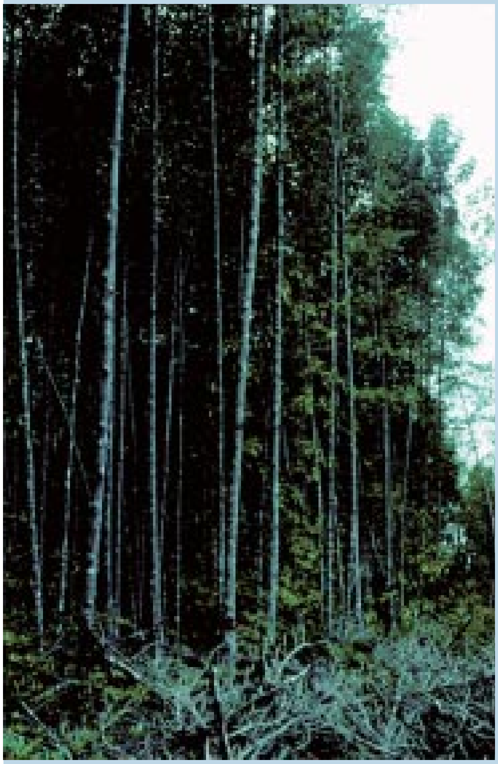

**Photo 5.**
In the Matang Forest Reserve, timber harvesting is in alternating rectangular parcels to ensure that mature mangroves surround the cleared area.
Photo P. Saenger.

**Photo 4.**
Fish traps in the *Nypa fruticans* swamps of southern Sulawesi, Indonesia.
Photo P. Saenger.

## Ecological restoration

Although mangrove restoration has recently become topical, such projects, in one form or another, have been around for many years. Some of the earliest mangrove harvesting programmes included replanting conditions (e.g. in the Belgian Congo, now Zaire; PYNAERT, 1933). WALTERS (2000) reports on village-based mangrove restoration programmes in the Philippines going back for 90 years. Nevertheless, there is now increasing awareness of the benefits of ecological restoration of mangroves after degradation or destruction by human activities or natural phenomena.

One of the driving forces behind the restoration of mangrove ecosystems to something like their presumed original states is the spectacular rise in environmental consciousness over the past 30 years. The restoration of mangrove lands for conservation remains a matter of choice and, while such choice should be determined by the socio-economic priorities of the communities involved, more often it is influenced by external pressure from conservation organisations advocating the preservation of nature (FIELD, 1999).

Another important driving force for mangrove restoration is the worldwide depletion of mangrove resources through increasing population (especially in coastal areas), food production, industrial and infrastructural development, excessive extraction of materials and chemical contamination and hydrological alteration of mangrove land (HAMILTON, SNEDAKER, 1984; FIELD, 1996).

LEWIS (1982) was one of the first to advocate planting mangroves specifically for the environmental services they can provide. One of the necessities of such an approach is to avoid monocultures of mangroves that still frequently characterize timber production. Most restoration projects, however, are still mainly based on one or two species. Nevertheless, a number of restoration programmes have achieved a degree of ecological functioning similar to natural mangrove systems (MC KEE, FAULKNER 2000).

### Project success

Two main types of criteria are generally used in judging the success of a mangrove planting programme: (1) the effectiveness of the planting, which can be considered as the closeness to which the new mangrove forest meets the original objectives of the planting programme; and (2) the efficiency of the planting, which can be measured in terms of the amount of labour, resources and material involved during the establishment and maintenance phases (FIELD, 1999).

**Photo 6.**
A seawall with a protective mangrove fringe of *Kandelia candel* encloses arable land adjacent to the Juilong estuary in Fukien Province, southern China.
Photo P. Saenger.

A major objective of any restoration programme should be to facilitate natural regeneration and to select target areas where some assisted regeneration is feasible and needed. Secondary objectives might include the enhancement of growth of existing mangroves and the selective introduction of additional species into the community.

Moreover, success with any mangrove restoration is considerably enhanced when (1) restoration is viewed by local people as offering them economic or other tangible benefits; (2) restoration is compatible with local patterns of resource use and land tenure; (3) local knowledge and skills relevant to restoration are successfully embedded in the project; (4) local social groups and organizations are effectively mobilized to support and implement restoration activities; and (5) relevant policies and political factors are supportive of restoration efforts.

## Macropropagation of mangroves

Once objectives have been established for mangrove planting in a particular area, locating and propagating suitable germplasm is the next phase. Several approaches have been adopted for macropropagation of mangroves, including the following.

### Direct planting of propagules collected from the wild

As propagules are generally only available for 2-3 months of the year, direct seeding needs to be scheduled according to seasonal availability. Spacing distance is difficult to control but distances from 0.4-1.5 m have been used. The generally high susceptibility of propagules to desiccation, dislodgment by waves and tides, and damage by predators and debris, make this material unsuitable for sites of medium to high energy. HAMILTON, SNEDAKER (1984) suggest that planting of propagules should be carried out during cool weather and on flood-free days.

### Outplanting of up to one-year-old nursery-raised propagules

Propagules of different species can be collected during the fruiting season and then grown on freely drained sandy substrate. For most species, the soil should be kept damp, preferably with 25-50% seawater (to reduce fungal infection). Relatively high temperature and humidity are essential for mangrove growth. Indirect sunlight is more effective than direct sunlight in producing a large leaf area (Youssef, 1997). As mangroves respond to fertilizers in early stages, fertilizer can be added once roots have started to develop and the first pair of leaves have expanded. This has resulted in greater root growth and healthier shoots (Youssef, 1997).

The benefit of raising seedlings in nurseries (photos 7 and 8) is that a year-round supply is available, which is of particular importance in large-scale projects (Saenger, Siddiqi, 1993; Field, 1996; Youssef, 1997). Nursery-grown seedlings also generally show higher success rates (survival rates, increases in height, number of leaves) than propagules (Saenger, Siddiqi, 1993), although nursery costs and increased planting difficulties when compared to propagules may sometimes offset these advantages.

### Direct transplanting of seedlings and shrubs

Where young seedlings are removed from a natural mangrove forest and transplanted to sites under rehabilitation, the most common seedling height is <50 cm. Young seedlings are best removed by using a 10 cm PVC pipe as a corer, pushed 20-25 cm into the substrate around the seedling. Transplants should be kept moist and protected from direct heat and wind during collection and transportation.

Few reports have described trials of transplantation of young mangrove trees from natural forests. The extensive root system of young mangrove trees offers the promise of greater and faster success of establishment than could be expected from seedlings. These individuals would therefore have a higher resistance to wave erosion and debris and can be transplanted into sites of higher energy where propagules or seedlings are unlikely to survive.

### Outplanting after nursery-raising small seedlings collected from the wild

Where propagules are unavailable, newly-established seedlings have been used to establish nursery stock. The seedlings are dug out, washed free of soil, and replanted in acid-washed coarse sand. With this approach, the advantages of both nursery-raised seedlings and small seedling transplantation (<50 cm) have been combined. Damage to the donor site can been avoided by using small seedlings. The technique can also reduce the time required for propagules to grow to the height (50-70 cm) where a high survival rate could be expected after transplantation in the field (Youssef, 1997).

**Photo 7.**
Intertidal nursery beds in Bangladesh for raising *Sonneratia apetala* seedlings for subsequent planting out in the coastal areas.
Photo P. Saenger.

**Photo 8.**
Municipal nursery for Dubai, United Arab Emirates, raising mangrove seedlings for use in landscape beautification.
Photo P. Saenger.

**Photo 9.**
Micropropagation of *Avicennia marina*: these plantlets were vegetatively propagated in half-strength MS medium through three generations in aseptic culture.
Photo P. Saenger.

### Raising of air-layered material

Air-layering involves the removal of short sections of bark and phloem of mature lateral branches until the cambium becomes exposed. The injured area of the stem is then wrapped with *Sphagnum* moss or similar material in aluminium foil to retain moisture. After roots have developed, the stem is then cut below the layering area to form a new plant.

Unlike raising young seedlings, the air-layering method reduces the risk of root damage by insects and crustaceans, especially in the early stages of establishment. However, the technique utilizes mature trees in the field, and is thus subject to many other biotic and abiotic variables that cannot be controlled (e.g. fungal and bacterial infection, fluctuation in temperature and rainfall, and tide height). Most importantly, the technique is relatively expensive (Carlton, Moffler, 1978).

### Use of stem cuttings

Mangrove stem cuttings can be induced to form roots after treatment with various growth hormones (Basak *et al.*, 1995; Youssef, 1997). Eganathan *et al.* (2000) reported the large-scale propagation of *Excoecaria agallocha, Heritiera fomes* and *Intsia bijuga* using cuttings and air-layers.

### Use of propagule segments

In the early 1980s, Thai foresters developed a method of cutting viviparous propagules of *Rhizophora apiculata* into segments, generally three, and planting each segment separately. Many of these segments formed roots and shoots, particularly when treated with auxins. This cut-piece method offers the potential to increase the availability of planting material from a limited number of propagules.

While it seems that the presence of the radicle has an inhibitory effect on shoot formation when applying this cut-piece method, the results are promising. Ohnishi, Komiyama (1998) estimated that by using >3 cm segments, a 1.5-2-fold increase in available planting material can be obtained for *Kandelia candel*. This approach also seems to have substantial potential for species with even longer propagules (e.g. *Rhizophora mucronata* with propagule lengths of 40-75 cm).

## Tissue culture or micropropagation of mangroves

While considerable work has been carried out on terrestrial plants, only very limited tissue culture experimentation has been undertaken with mangroves to date. Limited tissue culture work on the mangrove *Bruguiera gymnorhiza* has been conducted by Satuwong *et al.* (1995). Progress in micropropagation of mangroves, including *Avicennia marina*, has been reported by Rao *et al.* (1998). Working with *A. marina* from eastern Australia (photo 9), a tissue culture protocol has been established by Cousins, Saenger (in press). Despite these very limited studies, micropropagation is also a potentially significant area for mangrove germplasm improvement.

## Nursery and planting techniques

Nursery and planting techniques vary considerably among various mangrove species. By way of example, a summary of the techniques employed for *Avicennia* spp. is given below. Similar summaries for several other important species are given in Saenger (2002).

The crypto-viviparous propagules of *Avicennia* species are usually collected from around the base of mother trees when they mature. When kept in air, these propagules lose their viability within a few days. They may be directly planted into sheltered areas by “dibbling”—where the propagule is gently pushed into the soft sediment until firmly wedged. “Dibbling” is usually undertaken during neap tide periods to allow the seedling to develop roots. Pre-treatment of propagules has sometimes been used to decrease the establishment time. Such treatment consists of placing propagules in small nets and exposing them to daily tidal inundation to hasten decay of the pericarp. Removal of the pericarp by pre-treatment reduces the establishment time to 2-3 days, compared to 5-6 days without pre-treatment. Alternately, propagules may be raised in nursery beds that are exposed to daily tidal inundation. Seedlings are raised for about 1-2 months after which they are gently pulled out of the ground and packed for transport to prechosen afforestation sites where they are usually planted out in 3 cm diameter holes at 1.0 x 1.0 m spacing.

Propagules for nursery raising are simply placed on the surface of freely draining sand and vermiculite mixtures, kept in full sunlight and watered once daily, preferably using 25% seawater which suppresses fungal infections in the seedlings and acclimates them to the saline conditions that will prevail after they are planted. For example, growth and survival rates are significantly higher for *Avicennia marina* in 25% seawater than in freshwater. Humid conditions and the single addition of a slow-release fertilizer such as “Osmocote” (NPK 18:2.6:10 at approximately 3 g per 10 cm pot) will enhance and ensure optimal growth.

## Site-species matching

From studies of their natural occurrences, some insight has been gained into the soil conditions under which specific mangroves perform optimally. Site selection is of primary importance at the commencement of any planting programme when the most favourable sites should be the initial target. Detailed surveys should be carried out to determine potential planting sites, followed by consultation with other stakeholders to ensure that there will be no interference with other valuable ecosystems, activities or conservation initiatives.

### Site selection and characterization

Site surveys should examine at least the following parameters in assessing suitability: (1) Exposure: Mangrove seedlings will not survive in areas exposed to periodic high wave energy or persistent wind-generated turbulence. Thus, sites should be sheltered from wave energy in semi-enclosed embayments or lagoons, or where shelter is provided by coastal features such as headlands or offshore reefs and sandbanks. (2) Substrate stability: This is another requirement for mangrove growth, at least during the establishment phase. Sheltered localities generally exhibit stable substrates but tidal scour or littoral drift can occur in sheltered locations and cause erosion or accretion of sediments. Such areas are often easily recognized by their sedimentology (e.g. coarse gravelly sediments, pronounced sand ripples, absence of crab burrows, etc.) and should be avoided. Where such areas cannot be avoided, temporary stabilizing techniques (e.g. grass matting, chicken wire, tyre barriers) may be necessary. (3) Shoreline morphology/sedimentology: Mangroves generally grow best in muds and clays which have been deposited under sheltered conditions and which are regularly inundated by tidal waters. Topographic positions for optimal growth are generally in the top third of the tidal range, and some recontouring may be necessary to achieve this at any particular site.

Once a site has been selected, the site characteristics can be assessed to identify species best suited to the site. The degree of waterlogging (soil Eh), depth and frequency of tidal inundation, and porewater salinity are probably the main factors determining species suitablity (figure 1). Conversely, if a plantation of a particular species is to be established, the requirements of that species will govern plantation site choices.

### Field trials

Field trials in which different species are matched against different edaphic conditions are essential prior to any planting programme. For example, Li *et al.* (1996) introduced *Bruguiera sexangula, Sonneratia caseolaris* and *Rhizophora apiculata* to Shenzen and North Bays (~22° N), Guangdong, from material collected

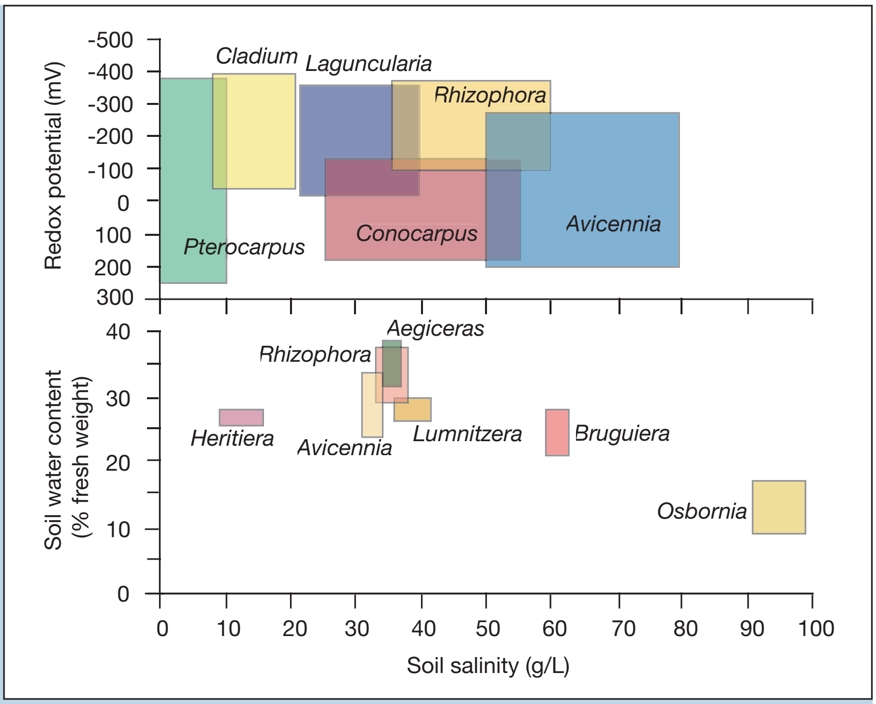


**Figure 1.** The upper graph shows the distribution of dominant species against soil salinity (g $L^{-1}$) and soil Eh (mV) at 25 cm depth at Guadeloupe. The lower graph shows selected species against soil salinity (g $L^{-1}$) and soil water content (% fresh weight) measured over 1.5 year at Proserpine, Queensland. (After Saenger, 2002).

from Dongzhai Harbour (~20° N) on Hainan Island in 1993. Three years later, both *B. sexangula* and *S. caseolaris* were growing well (maximum height of 1.5 and 3.0 m, respectively), while *R. apiculata* was unable to survive at the more northerly site. Although it is tempting to suggest that the colder conditions were responsible, the latitudinal change is rather small and it seems likely that certain specific soil conditions suited some species but not others. Such site-specific characteristics can only be determined through field trials.

# Silvicultural management of planted areas

The major objectives for managing any plantation or restored area should be to facilitate natural regeneration, to enhance productivity through fertilization and weed or herbivore suppression, and to select target areas where some assisted regeneration is required. The selective introduction of additional species may also be considered either to increase the biodiversity of the community or to enhance the standing stock with suitable understorey species.

### Site management

Many mangrove plantations or restored areas require stringent site management, including temporary regulation of access to minimize damage to the area by human or animal trampling, grazing, and trailbikes, etc. In addition, some form of temporary shelter from current scouring may be needed to assist in stabilizing the sediments after disturbance and to allow the seedlings to become established. Once the site has been re-stabilized after construction, or once assisted regeneration has been carried out, the mangroves are likely to require little in the way of on-going management.

### Natural and assisted regeneration

Self-regeneration is an important aspect of a plantation or restoration project as costs of establishing plantations or maintaining restored areas will vary significantly depending on the extent of artificial planting that may be required.

Blanchard, Prado (1995) used clearcut strips in *Rhizophora mangle* forests in Ecuador to study the factors involved in determining natural levels of regeneration. They concluded that large trees produce more propagules, resulting in more being available locally for recruitment without any input from long-distance propagule dispersal (figure 2). Given the degree of local recruitment, they suggested that a 20 m wide clearcut strip would allow for adequate regeneration in most cases. On sites with less tidal inundation (<20 tides/month) or where bordering trees have a DBH <25 cm, well-shaped, reproductively active seedling mother trees should be left during felling.

Impediments to natural regeneration include infestation of cleared areas by the mangrove fern *Acrostichum*. Natural regeneration of plantations may also be affected by fauna, i.e. quite apart from propagule predation, grazing of established seedlings and saplings may be locally significant. In Bangladesh, for example, spotted deer (*Axis axis*) play a significant role. Biotic interactions can also affect the regeneration process. The climber, *Derris trifoliata,* may seriously affect growth and survival in some areas, while insect infestations have been reported to cause failures in recruitment in *Avicennia germinans* and *Rhizophora mucronata* plantations.

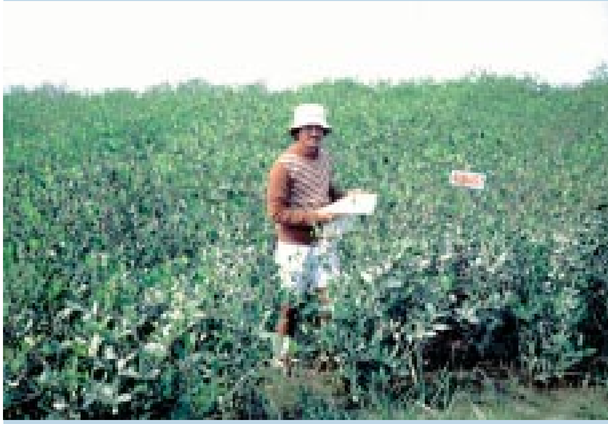

**Photo 10.**
Monitoring the survival rates of *Sonneratia apetala* planted in different months. Bangladesh.
Photo P. Saenger.

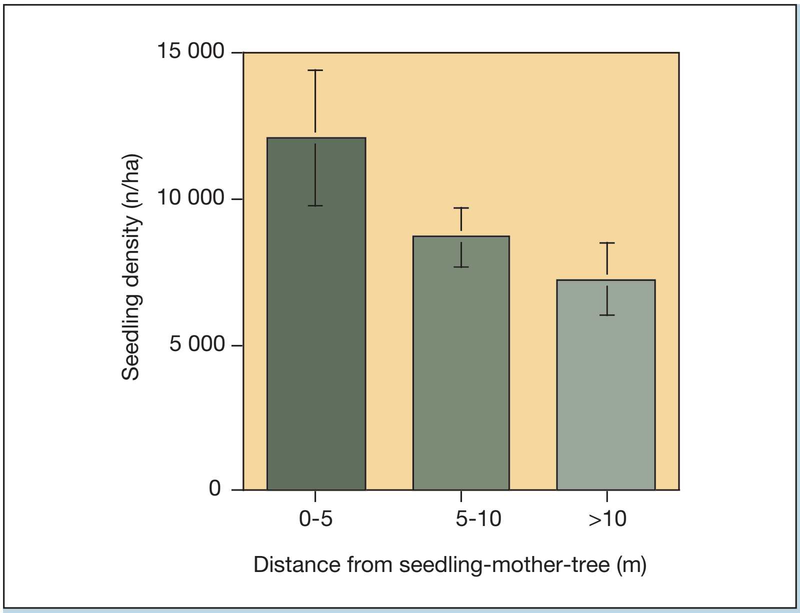


**Figure 2.** *Rhizophora mangle* seedling density (number $ha^{-1}$) in relation to distance from seedling mother trees in strip clearcuts in Ecuador. Vertical bars are standard errors. (Data from Blanchard, Prado, 1995).

**Photo 11.**
A four-year-old plantation of *Avicennia marina* for landscape beautification in Dubai, United Arab Emirates.
Photo P. Saenger.

If an assisted regeneration programme is required, the following approach is suggested: propagules need to be collected and either planted out or raised in the nursery. For planting, propagules can be scattered over the target areas or alternatively pushed into the substrate. The propagules should be dispersed when the area is not expected to be flooded for a few days, thereby allowing them to become firmly established prior to subsequent inundation. Some losses can be expected and it is important to ensure that distribution of propagules to the site is repeated as necessary. If losses are high, propagules may need to be held in place temporarily using chicken wire, seagrass matting, etc. In some situations, there is greater survival and growth of propagules if they are nursery grown before planting out. This allows seedlings to develop healthy root systems before implantation. Propagule extablishment success rates are clearly site specific but were found to range from 30-90%. Nursery-grown seedlings generally show higher success rates than propagules. Planting out of seedlings should be done at the most favourable growth period, i.e. midsummer, to ensure maximal survival. At other seasons, a decline of 10-20% in seedling survival can be expected.

### Cost of assisted regeneration

Costs for any of the described approaches are difficult to quantify. The cost of restoration of mangrove areas is highly variable, depending on factors such as local labour costs, the site characteristics (including its accessibility and size), its proximity to propagule sources, and whether propagules, seedlings, or transplants are to be used. Examples from Australia and the USA are provided by Saenger (1996) and Snedaker, Biber (1996), respectively.

## Plantation performance

### Optimal planting season

In Bangladesh, planting from June to August appears to result in maximum survival of newly planted *Sonneratia apetala* seedlings (figure 3, photo 10). Not only the time of planting, however, but the age of seedlings is a contributing factor, and seedlings older than 12 months generally have low survival rates. In some areas such as the Chittagong and Noakhali Divisions, winter planting is considered to result in higher survival rates but, to date, no experimental data support this view.

### Optimal initial spacing

A wide range of plant spacings have been used in mangrove planting programmes. Determining proper spacing should be based on minimizing competition (photo 11). Thinning will occur naturally, and artificial thinning can be delayed to later vegetation development stages by proper spacing. For *Avicennia marina,* 1.5 m spacing was used at the Brisbane airport site (Saenger, 1996); after 4 years no evidence of self-thinning was apparent.

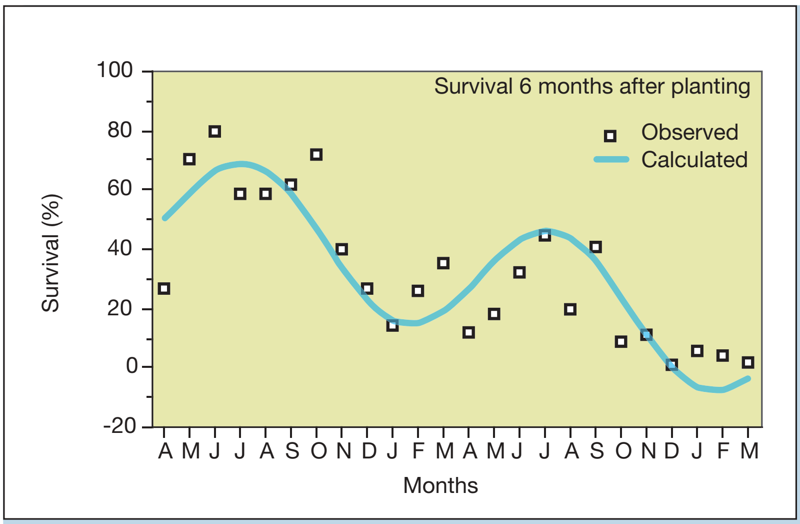


**Figure 3.** Percent survival of *Sonneratia apetala* seedlings 6 months after planting out from the same nursery stock over a 24-month period. Both the seasonal changes in survival and the declining trend due to increasing age of seedlings can be recognized in the fitted curve ($r^2 = 0.7$, $p < 0.001$). (Data from Islam *et al.,* 1992).

The growth performance of *Sonneratia apetala* planted at various densities is given in table III. For timber production without thinning, an initial spacing of 1.2 m appears to be optimal. For coastal protection, however, where features such as multiple stems or reduced height are desirable, initial spacings in excess of 2 m might be more suitable.

Where thinning products are tapped for economic benefit (e.g. charcoal production in Matang Mangrove Reserve), higher initial planting densities are generally used. Where thinning products have little or no economic value, it is preferable to adjust initial spacing to reduce the need for thinning and to optimize plant growth.

## Survival

Because of the highly dynamic nature of the Bangladesh coastline, the survival of mangroves is generally poor and replacement planting is often required for up to 3 years. In sheltered localities, however, survival is generally around 70%. Long-term survival is also highly variable, but survival in 5-year old *Sonneratia apetala* ranged from 29-52% in experimental plots at Barisal (table III).

## Assessment of standing stock

The general assessment of standing stock or biomass is similar in plantations and old-growth mangroves, and many techniques developed for natural mangrove areas can be directly applied to the evaluation of planted mangroves. Biomass estimation methods fall into three broad but overlapping categories: clear-felling, representative tree sampling, and the establishment of allometric relationships.

Clear-felling involves harvesting of the entire above-ground biomass (AGB) from a specified area. The plant material is usually sorted into the component parts (wood, branches, leaves, fruits, and flowers) within the individual species constituting the stand. The weight of each component and the summed total are converted into dry weight values per unit area. Examples of the use of this approach for mangrove old-growth forests include Lugo, Snedaker (1974) and Christensen (1978), while its applicability to mangrove plantations was demonstrated by Aksornkoae (1975). While efficient in young and small-sized stands, the clear-felling method becomes more difficult to use for biomass estimation as the stand or tree size increases.

Representative tree sampling is particularly suitable where stands are even-aged or have an obvious series of ages. Under such conditions, suitable representative trees can be selected for felling and harvesting of the individual components. The dry weights obtained per tree are then multiplied by the stand density (trees $ha^{-1}$) to estimate the stand biomass (Choudhuri, 1991).

Allometric techniques have been widely used to estimate stand biomass in terrestrial forests (Brown *et al.*, 1989). Such methods involve establishing a relationship between the biomass of whole trees, or their component parts, and some readily measured parameter such as diameter of the stem at breast height (DBH), and/or height of the tree (H). Once the allometric relationships have been established, the technique can be applied in a non-destructive way at other sites; in contrast, the other two techniques are site-specific and likely to introduce considerable error when applied at other localities. Allometric relationships between AGB and DBH (and/or H) have been reported for a range of mangrove species, including those of high forestry interest.

The general question of the reliability of allometric relationships for estimating biomass and their application to forests of similar species in a range of environmental settings has been widely considered (Brown *et al.*, 1989; Henry, Aarssen, 1999). Where sampling takes place from relatively dense, closed-canopy forests, tree shape may be influenced by neighbour effects such as self-thinning of lower branches. Similarly, the crown proportion may differ between dense and more open forests where crown expansion is less restricted. Thus, a crowded tree would be expected to have a smaller DBH and crown than an open-grown tree of the same height (H).

The appropriateness of statistical techniques used to derive allometric relationships is theoretically of greater importance. For example, all allometric relationships for mangroves (as for most forest systems) have been derived by least-squares regressions, where either DBH (and H) or AGB must be selected as an independent variable and regressed against the other. The use of reduced major axis regression, which does not assume that either axis is fixed, is more appropriate than least-squares regression (McArdle, 1988).

**Table III.**
**Mean survival (±SE), height and diameter at breast height (DBH), stemwood production and tree quality at different initial spacings for 5-year-old *Sonneratia apetala* plantations at Barisal, Bangladesh, from three replicated random blocks. (Data from Saenger, Siddiqi, 1993).**

| Spacing (m) | Survival (%) | Height (m) | DBH (cm) | Stemwood production ($m^3$ $ha^{-1}$ $y^{-1}$) | Unforked trees (%) |
|---|---|---|---|---|---|
| 0.85 x 0.85 | 29±14 | 9.1±0.8 | 8.8±1.3 | 16.1±2.3 | 90±7 |
| 1.2 x 1.2 | 52±9 | 8.7±0.3 | 7.9±0.3 | 18.5±2.7 | 90±2 |
| 1.7 x 1.7 | 42±15 | 8.9±0.2 | 9.7±0.5 | 11.8±2.2 | 84±2 |
| 2.4 x 2.4 | 37±21 | 7.8±0.5 | 13.6±2.5 | 5.6±1.2 | 73±6 |
| 3.4 x 3.4 | 39±21 | 7.9±0.8 | 12.5±3.1 | 2.0±1.0 | 38±16 |

Despite the practical and theoretical shortcomings of allometric relationships, they nevertheless provide useful and consistent results; internal consistency can be evaluated for any given species by summing the estimates of biomass for individual components (derived from their allometric relationships) at a particular DBH, and comparing this value with the estimate obtained for total AGB at the same DBH. As Clough, Scott (1989) showed, the independent estimates for total AGB thus obtained were within 10% for most species over the size-classes sampled.

Selected allometric equations for major species for AGB or other components (in g dry wt.) in relation to DBH (cm) for individual trees are provided in table IV. These include significant allometric relationships for the major Old and New World mangrove species. Allometric equations for a similar range of species in relation to both DBH (cm) and H (m), or leaf area ($m^2$), are provided in Saenger (2002).

**Table IV.**
**Allometric equations for various mangroves and their component parts based on diameter at breast height (DBH). (After Saenger, 2002).**

| Species & component | Equation | Regression coefficient |
|---|---|---|
| ***Avicennia germinans*** | | |
| Above-ground biomass | $AGB = 140.0DBH^{2.4}$ | $r^2 = 0.97$, n = 25 |
| Above-ground biomass | $AGB = 94.2DBH^{2.54}$ | $r^2 = 0.99$, n = 21 |
| Trunk biomass | $TB = 9.79DBH^{3.20}$ | $r^2 = 0.97$, n = 21 |
| Branch biomass | $BB = 392.6DBH^{1.44}$ | $r^2 = 0.94$, n = 21 |
| Leaf biomass | $LB = 23.6DBH^{1.82}$ | $r^2 = 0.95$, n = 21 |
| ***Laguncularia racemosa*** | | |
| Above-ground biomass | $AGB = 102.3DBH^{2.5}$ | $r^2 = 0.97$, n = 70 |
| Above-ground biomass | $AGB = 208.8DBH^{2.24}$ | $r^2 = 0.99$, n= 17 |
| Trunk biomass | $TB = 76.2DBH^{2.51}$ | $r^2 = 0.98$, n = 17 |
| Branch biomass | $BB = 224.3DBH^{1.59}$ | $r^2 = 0.83$, n = 17 |
| Leaf biomass | $LB = 10.65DBH^{2.02}$ | $r^2 = 0.92$, n = 17 |
| ***Rhizophora mangle*** | | |
| Above-ground biomass | $AGB = 177.9DBH^{2.47}$ | $r^2 = 0.98$, n = 17 |
| Trunk biomass | $TB = 0.939DBH^{4.03}$ | $r^2 = 0.92$, n = 16 |
| Branch biomass | $BB = 749.9DBH^{1.39}$ | $r^2 = 0.88$, n = 17 |
| Leaf biomass | $LB = 300.7DBH^{1.25}$ | $r^2 = 0.72$, n = 17 |
| Leaf biomass | $LB = 27.551DBH^{1.7914}$ | $r^2 = 0.81$, n = 26 |
| Proproot biomass | $PB = 12.62DBH^{2.97}$ | $r^2 = 0.97$, n = 17 |
| ***Rhizophora* spp.** | | |
| Above-ground biomass | $AGB = 128.2DBH^{2.6}$ | $r^2 = 0.92$, n = 9 |
| Above-ground biomass | $AGB = 105.0DBH^{2.6848}$ | $r^2 = 0.99$, n = 23 |
| ***Bruguiera gymnorhiza*** | | |
| Above-ground biomass | $AGB = 185.8DBH^{2.3055}$ | $r^2 = 0.99$, n = 17 |
| ***Bruguiera parviflora*** | | |
| Above-ground biomass | $AGB = 167.9DBH^{2.4167}$ | $r^2 = 0.99$, n = 16 |
| ***Ceriops australis*** | | |
| Above-ground biomass | $AGB = 188.5DBH^{2.3379}$ | $r^2 = 0.99$, n = 26 |
| ***Xylocarpus granatum*** | | |
| Above-ground biomass | $AGB = 82.3DBH^{2.5883}$ | $r^2 = 0.99$, n = 15 |

Note: Biomass of all components is measured in grams dry weight for an individual tree. Diameter at breast height (DBH) is in cm.

## Mean annual increment

Assessing the performance of any plantation depends largely on the objectives of the planting exercise, and monitoring parameters need to be selected accordingly. Generally, however, assessment is usually done annually by monitoring the survival rate and one or more structural characteristics of the stand, generally including DBH and H, although other parameters such as basal area (BA), diameter other than at breast height (D), above-ground biomass (AGB), and timber volume (V) are commonly used in forest inventories. For example, in an ecological restoration at Laguna de Balandra, Baja California Sur, Mexico, the following parameters were deemed to provide an assessment of performance (Toledo *et al.*, 2001): survival rates of plantlets at weekly, monthly and then 6-monthly intervals for 4 years, together with data on height increments and number of leaves per plant.

Measuring the increasing AGB with variously aged mangrove plantations is time-consuming and merely provides pseudo-time-series, although allowing some comparison between the performance of a particular plantation against other plantations or old-growth mangroves in the same region. Data on AGB from variously aged plantations can be divided by the age of plantations to provide a time-averaged increase or mean annual increment (MAI) in AGB. As shown in figure 4, these MAIs range from 3.2 t $ha^{-1}$ $y^{-1}$ for 5-year old plantations to 17.1 t $ha^{-1}$ $y^{-1}$ in 15-year old plantations in Malaysia.

Although these time-averaged increases in AGB are useful, there are changes in the MAI over the age of a stand, with an initial increase up to around 15-20 years followed by a decline as the stand matures and when biomass accumulation decreases on a yearly basis (figure 4). Thus, measuring MAI at shorter intervals will more accurately reflect the current annual increment (CAI) of the stand at any particular time. While the terms MAI (mean growth rate to

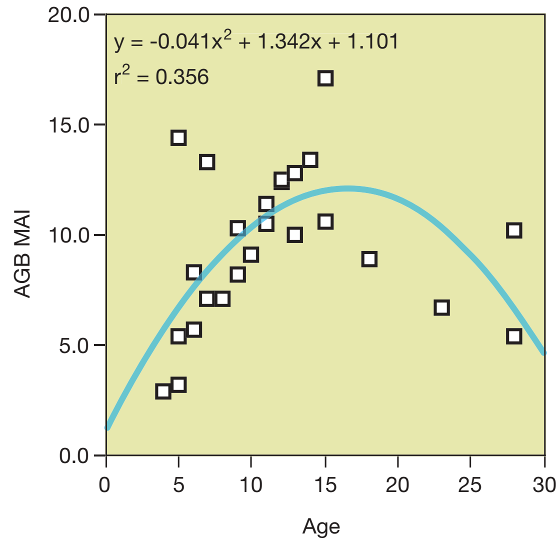


**Figure 4.** Changes in mean annual increment of the above-ground biomass AGB MAI (in t $ha^{-1}$ $y^{-1}$) with age of variously aged mangrove plantations in Indonesia, Malaysia and Thailand. (After Saenger, 2002).

any age) and CAI (instantaneous growth rate at any age) measure growth rates, CAI should be used for shorter assessment intervals when the actual (presently occurring) increments in AGB (or any other characteristic) are being measured.

As for AGB, MAI can also be calculated for any other parameters, such as DBH, BA or H, resulting in DBHMAI, BAMAI or HMAI. These measurements are commonly used for rapid assessment as they are relatively easy to obtain.

**Table V.**
**Rotations (in years) for various mangrove forestry products. (After Saenger, 2002).**

| Country | Fuelwood Fence posts Charcoal (10 cm DBH) | Poles Pilings (25 cm DBH) | Sawn timber (40 cm DBH) | Pulp chips |
|---|---|---|---|---|
| Bangladesh | 15-20 | | | 20 |
| Fiji | 15-25 | 40 | 40 | |
| Gambia | 30 | | 30 | 30 |
| India | 15-20 | | | |
| Indonesia | 20-35 | | | 20 |
| Malaysia | 15-30 | 15-30 | | 20-25 |
| Micronesia | 25-50 | 70-100 | 100-140 | |
| Myanmar | | | 295 | |
| Philippines | 7-15 | | | |
| Puerto Rico | 30 | | | |
| Thailand | 15-30 | 15-30 | | |
| Venezuela | 15-30 | 30 | 30 | |
| Vietnam | 20 | | | |
| Virgin Islands | 25 | | | |

In plantations where timber production is an objective, measurement of timber volumes in permanent plots is used to monitor stands (Saenger, Siddiqi, 1993; Devoe, Cole, 1998). Such detailed forest inventories are costly and time-consuming and rarely carried out on an annual basis. Rather, they are performed at longer intervals and the changes in volume between successive surveys expressed as mean (or current) annual increments in volume (VMAI or VCAI in $m^3$ $ha^{-1}$ $y^{-1}$).

Volumes (or standing stock) of mangrove stands are generally derived from permanent plots using allometric equations, and expressed as $m^3$ $ha^{-1}$. Relatively few data are available on volume standing stock and even fewer on volume or other increments (VMAI, DBHMAI, HMAI); some of these have been collated in Saenger (2002).

## Rotation and thinning schedules

Determining rotation times and thinning schedules requires some data on growth rates (as VMAI) and standing stock (as V), as well as the effect of natural thinning in the stand or plantation. More importantly, the main products to be obtained from the stand (e.g. fuelwood, fence posts, poles, piles, sawn timber, pulp chips, charcoal) will determine the rotation time in a commercial operation. Some examples of various rotation times are summarized in table V.

In Bangladesh, thinning is generally not required because of the relatively slow rate of tree growth, the low returns from the thinning products, and the loss of trees in plantations due to stem borer attack. However, in some dense *Sonneratia* and *Avicennia* plantations, thinning is carried out after 9-10 years when up to 50% of the stems may be removed (Saenger, Siddiqi, 1993). Thinning of these plantations consists mainly of removing stunted trees and cutting smaller stems from multi-stemmed trees.

## Indices of "health" in mangrove communities

Apart from monitoring the structural development of old-growth or plantation mangroves as a measure of growth performance, it is also useful to assess the "health" of the trees, stands or forests. Such assessments are commonly made on the basis of indicators that have been found to occur under certain pathological conditions or other forms of environmental stress.

A preliminary list of such indices of mangrove "health" (table VI) has been compiled from observations on *Avicennia* and *Rhizophora* (Saenger, 2002). Although this listing is tentative, it is intended to provide an easy and rapid means of assessing a mangrove stand in terms of the presence or absence of certain characteristics symptomatic of pathological or other stressful conditions. In this sense, this list may be used as an early diagnostic tool.

## Conclusions

Modern perceptions of mangroves comprise a complex system of economic, usefulness (or functional), intrinsic, and symbolic values. A great variety of motives therefore currently underpin mangrove planting activities throughout the world. As has been illustrated, these range from purely commercial motives such as the replenishment of mangrove forests for timber production, to solely aesthetic ones, such as the beautification of degraded coasts. In between, the enhancement of biodiversity is assuming greater significance. Whatever the objectives of planting mangroves, and these may be multiple, the application of forestry principles to all phases of the planting programme, from design through execution to evaluation, will promote the achievement of these objectives. Given the rapid rate of mangrove loss around the world, the development of effective replanting techniques and procedures will become increasingly important in the future.

**Table VI.**
**Indices of "health" in mangrove trees, stands and forests: "healthy" communities will not display these features. (After Saenger, 2002).**

| | |
|---|---|
| **Aerial roots** | proliferation of undersized prop roots |
| | twisting and curling of pneumatophores |
| | adventitious aerial roots |
| | death of prop root tips |
| | fissuring or peeling of periderm |
| **Trunks and branches** | top-dying of uppermost and outermost sun branches |
| | fissuring and cracking of bark |
| | expanded and/or more numerous lenticels |
| | shortened internode distances |
| | cessation of terminal shoot growth |
| | appearance of trunk sprouts from secondary meristems |
| **Foliage** | reduced leaf number per branch |
| | reduced leaf size, twisting and curling |
| | abscission of buds and immature leaves |
| | altered leaf maturation sequence |
| | spotty chlorosis or necrosis |
| | change in leafing and shedding processes |
| | reduced leaf area index |
| **Reproductive structures** | change in timing of flowering and fruit set |
| | absent or grossly excessive flowering |
| | deformed seeds and propagules |
| | development failure of fruit |
| | excessive abortion of immature fruit |
| **Regeneration** | failure to orient geotropically |
| | seeds and propagules fail to establish primary root system |
| | abnormal growth forms in established seedlings |
| | failure to initiate primary branching |
| | chlorosis or necrosis of propagules |

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