

Creation and Restoration of Coastal Plant Communities

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Chapter 8

Mangrove Forests

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Chapter 8

MANGROVE FORESTS

Roy R. Lewis, III

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I. INTRODUCTION

The protection, restoration, creation, and enhancement of mangrove forests has, in recent years, received a lot of attention.¹⁻⁴ The primary reason for this is that the long ignored ecological values of mangrove forests as habitat and detrital food sources were scientifically documented for the first time in a U.S. mangrove forest^{5,6} at the same time that ecologists realized that large scale losses of mangroves, due to coastal development, were occurring throughout the world.⁷⁻¹² Following the breakthroughs in the early 1970s in techniques for artificially creating tidal marshes (predominantly *Spartina alterniflora* L.)¹³ techniques for mangrove forest restoration and creation were developed.¹

II. THE NATURAL PLANT COMMUNITY

A. Distribution

Mangrove forests are intertidal areas along protected tropical and subtropical shorelines which are vegetated with woody plants that may exist as trees, shrubs, or bushes depending on the climate of the region. Chapman¹⁴ recognizes 72 species as being mangroves including one genus of fern and three genera of palms.

Maximum development of the forest system usually occurs in areas of high rainfall, high temperatures, and low incidence of typhoons or hurricanes.^{15,16} Forests with 20+ species and maximum canopy heights of 20 to 30 m are found in Southeast Asia, while at the northern or southern limit away from the equator (about 30° of latitude) the occurrence of frost reduces the forest to monospecific stands (usually *Avicennia*) 1 to 2 m in height.

B. Primary Productivity

Lugo and Snedaker⁹ list nine values for net primary productivity from a number of sites in Florida and Puerto Rico. The mean of the nine values (range 0 to 7.50 gC/m²/day) is 3.04 gC/m²/day or 1109.6 gC/m²/year. Thayer et al.¹⁷ lists two values for mangrove primary productivity, 400 gC/m²/year for *Rhizophora mangle* L. and 1022 gC/m²/year for *Avicennia germinans* L. Stearn.

C. Secondary Productivity

As noted by Lugo and Snedaker⁹ "quantitative studies of the secondary productivity of the consumers associated with mangrove ecosystems have not been performed".

Studies have shown, however, that detritus formed from mangrove leaves in South Florida is the basis for a food web that includes many species of invertebrates, fish, birds, and man.^{5,6} Similar studies on fish in Puerto Rico¹⁸ have found the same results.

Many authors have found the fauna of mangroves to be abundant and diverse, and often include species important to commercial and sport fisheries throughout the world.^{6,15-17}

In addition to providing a source of food, mangroves also serve as habitat for many adult and juvenile fish and invertebrates^{5,6} as well as providing nesting sites for many species of colonial waterbirds.¹⁹⁻²¹ Woolfenden and Schreiber²² note that mangrove forests in Florida: "... are absolutely essential to the existence of a large number of water birds that breed in Florida, for essentially all of the breeding colonies of pelicans, cormorants, herons and ibises of saline environs are in mangrove."

MacNae¹⁵ also notes the occurrence of many species of birds in the mangroves of southeast Asia and Chapman¹⁴ lists 48 species of birds and 13 species of mammals recorded from mangrove forests around the world.

Table 1
DOCUMENTED MANGROVE LOSSES

Location	Original areal cover(ha)	Existing areal cover(ha)	Loss (%)	Ref.
Florida (U.S.A.)				
Tampa Bay	10,053	5,630	-44	12
Biscayne Bay	63,300	11,100	-82	10
Puerto Rico				
Main Island	24,300	6,405	-75	35
Vieques Island	446	367	-18	43
El Salvador	No areal figures given		-50	36
Australia				
Botany Bay	1,500	1,000	-33	44
South Vietnam	286,400	104,123*	-36	38

* Natural recovery from herbicide damage has not been documented since 1973.

D. Silviculture

In addition to their ecological value, mangroves have been used for centuries as sources of firewood, construction timber, salt, tannins, dyes, and even food.^{15,23,24}

Because of these many uses, mangroves have been grown and harvested using standard silviculture practices in the Adaman Islands,²⁵ Thailand,^{26,27} Malaya,²⁸⁻³⁰ India,³¹ Puerto Rico,^{32,33} and Indonesia.³⁴ Rotation times vary with the species and range from 20 to 100 years. The earliest active attempts to plant mangroves developed from silviculture practices and will be discussed in later sections.

E. Historical Losses

Due to overharvesting,³¹ dredging and filling for development,^{7,10,12,35} various hydrological modifications,^{9,36,37} aerial defoliation during the Vietnam war,³⁶ and various other human impacts including oil spills,³⁹ tens of thousands of hectares of mangroves have been either permanently destroyed or temporarily impaired. Table 1 lists the available figures for documented losses. The list is very short since most of the data on mangrove losses has not been gathered together in one publication. Such a compilation is presently in progress⁹⁰ and will hopefully put the problem in better perspective.

In any case, the losses are assumed to affect fisheries and other faunal components of the food web but little documentation exists. Lewis¹² reports a 20% decline in commercial fisheries catches along Florida's Gulf coast after two peaks of 61,400,000 kg in 1960 and 61,500,000 kg in 1965. During this same period, 40% of the mangroves of one of the main estuaries (Tampa Bay) in the area was lost due to residential and commercial fills. Lindall⁴⁰ reports that 85% of the commercial fish and shellfish caught in South Florida is dependent on estuaries like Tampa Bay for at least a portion of their life cycle and that hydrological alterations and habitat loss threatens the \$10 million commercial harvest and \$575 million sports harvest of estuarine dependent species.

Crowder⁴¹ notes that only 35,000 breeding pairs of native wading birds remain in South Florida from an estimated 2.5 million in 1870. Modifications to and loss of both freshwater and marine wetlands (mangroves) are cited as one of the main causes for this decline.

Daugherty³⁶ reports a 50% decline in the shrimp catch for El Salvador since 1964 and other declines in reptile, bird, and mammal populations associated with a nearly 50% loss of mangroves for El Salvador.

DeSilva and Michel⁴² were unable to demonstrate conclusively that the partial or

Table 2
SPECIES OF MANGROVES USED IN PLANTINGS FOR
SILVACULTURE, MITIGATION, AND EXPERIMENTATION

Species	Type of Planting	Ref.
Rhizophoraceae		
<i>Rhizophora mangle</i> L.	P, T, AP, N	1, 2, 4, 23, 33, 45—56
<i>R. mucronata</i> Lamk.	P	23, 30
<i>R. apiculata</i> Blume	P	15, 27, 29, 30, 38, 57
<i>Bruguiera gymnorhiza</i> (L.) Lamk.	P	23
<i>B. parviflora</i> (Robt.) W. and A. ex Griff.	T	30
<i>B. sexangula</i> (Lour.) Poir.	P	58
Sonneratiaceae		
<i>Sonneratia caseolaris</i> (L.) Engler	P	58
Avicenniaceae		
<i>Avicennia germinans</i> (L.) L.	P, T, N	1, 46, 49—53, 59—61
<i>A. marina</i> (Forsk.) Vierh.	T	62, 63
<i>A. officinalis</i> L.	T	62
Combretaceae		
<i>Laguncularia racemosa</i> (L.) Gaertn. f.	T, N	1, 33, 46, 51—53, 56, 59, 64, 65
Theaceae		
<i>Pelliciera rhizophora</i> Ponce and Triana	T	64
Palmae		
<i>Nypa fruticans</i> Wurm	N	30

Note: P = Propagules — fresh seeds or seedlings T = Transplants, AP = Aerial drops of propagules, and N = Nurseried seedlings.

complete defoliation of 104,123 ha of mangroves in South Vietnam permanently damaged the estuarine ecology of the area although they noted increased turbidity and erosion due to the lack of vegetative cover and a dramatic decrease in fisheries harvests. It was not possible to separate overfishing impacts from social and defoliation causes.

III. PLANT MATERIAL TYPES AND SOURCES

Table 2 lists the 13 species of mangroves which have been used in silviculture, mitigation, or experimentation involving planting mangroves. The 13 species fall into 6 families, each with its own variation on the generally viviparous methods of sexual reproduction shown by mangroves.^{14,15}

For the sake of this discussion, the word "propagule" will be used when referring to the seeds or seedlings of a species that are collected directly from the tree, or very soon thereafter, and have not exhibited any additional expansion or root formation. This would correspond to the Type A or B seedling of Teas et al.⁴⁷ This is preferable to using "seed" or "seedling" since these words are often used interchangeably for the same thing, depending on the writer's determination as to how viviparous a particular species is. MacNae¹⁵ considers that the members of both the Rhizophoraceae and Avicenniaceae exhibit "apparent vivipary" while Chapman¹⁴ notes that the Avicenniaceae along with some other groups "differ from the other viviparous mangroves in that the seedling remains enclosed within the testa whilst on the mother plant". Chapman¹⁴ also notes that "retention of the testa inhibits seedling growth in *Avicennia*".

The term "seedling" will be used to apply to propagules that have germinated and show additional changes such as the loss of the testa in *Avicennia* or root growth from the radicle in *Rhizophora*. This would correspond to the types C and D seedlings of Teas et al.⁴⁷

Air-layering has been successful in experiments with *R. mangle*, *A. germinans*, and *Laguncularia racemosa*²⁰ but has not been used for any actual production of planting materials. Its ease and cost effectiveness warrant further research. Table 2 indicates the type of plantings that have been tried for each species; propagules (P), transplanting (T), aerial planting (AP), and nursured seedlings (N). Aerial planting has only been tried with propagules of *Rhizophora*⁴⁸. As can be seen from the table, the use of propagules or transplanting seedlings or small trees have been the two most widely used techniques.

Up until recently, the most available source of plant materials were the forests themselves where propagules can be gathered during certain seasons of the year or seedlings on small trees can be transplanted year-round. More recently, commercial sources of mangrove plant materials have appeared (Appendix 1). These are presently limited to providing the four North American species of mangroves (*R. mangle*, *A. germinans*, *L. racemosa*, and *Conocarpus erecta* L.) but other commercial ventures are to be expected.

The seasonal availability of propagules needs to be closely monitored by anyone anticipating their need for mangrove propagules. Several authors have noted the August to October peak in availability of the propagules of the North American species^{1,46} and Steinke⁷¹ has noted the main fruiting period for *A. marina* in Natal, South Africa, was March/April. It is obvious that anyone planning to use propagules for a planting should also schedule their installation during the peak availability of propagules, otherwise there will be none available.

IV. TECHNIQUES USED IN REVEGETATION

As noted before, four techniques have been used: direct planting of propagules, aerial planting of propagules, transplanting of seedlings or small trees, and planting of nursured seedlings.

Table 3 lists, in approximate chronological order, 34 individual cases where mangrove plantings have occurred. The author is aware of several dozen more in various stages of planning and implementation.

Most of the plantings prior to 1970 were for silvaculture and date back to the 19th century in the Phillipines.^{15,27,29,30,33,38,57} These are the largest plantings with individual areas of up to 15,000 ha being reported as being planted.²⁷ Plantings also were used for erosion control^{15,45,58,62} and experimental analysis of mangrove biology.^{46,56,64} Beginning with the realization of the ecological value of mangroves and the passage of laws protecting them from destruction, particularly in the U.S., many smaller scale plantings for restoring damaged areas or mitigating environmental damage have occurred.^{1-4,47,49-56,59-61,63-69}

Along with the listing of the planting, some comment about the project is included. It is apparent that depending on the technique of planting, the type of plant material used, and the site of the planting, success can vary from 0 to 100%. Several authors have noted that two of the most critical factors in successful projects are (1) a planting site with little or no wave action against the shore to dislodge plantings^{1-4,49-55} and (2) proper elevation within the intertidal zone.^{1-4,49-55} It is not surprising that these are also critical factors in the success or failure of plantings of tidal marsh plants (see Chapter 5).

Concerning the first factor, wave energy, a number of plantings have been tried along eroding shorelines,^{1,54} on shifting sand deposits,⁵¹ or simply on high energy shores to protect them and to see if the plants could survive.^{55,60-61,66} Even with some sort of wave barrier^{60,61} or erosion protection such as tires,⁵⁴ the plantings were nearly 100% unsuccessful. In some of the experiments, simultaneous plantings were also made in low wave energy sites^{54,55,66} and much greater success (65 to 90%) occurred.

Table 3
 ATTEMPTED PLANTINGS OF MANGROVES IN APPROXIMATE CHRONOLOGICAL ORDER

Location	Species	Dates	Comment	Ref.
India Adaman Islands Philippines	<i>Rhizophora mucronata</i> Lamk.	1898--1908	Silviculture, 277 ha	23
Manila Bay	<i>R. mucronata</i>	Mid 19th century to 1910s	Silviculture	30
Malaysia Matang	<i>R. apiculata</i> Blume	Since 1900	Large scale silviculture of 45,000 ha -- 20% of which is planted	29, 57
Perak and Selangor	<i>R. mucronata</i> , <i>R. apiculata</i>	1920s	Large scale silviculture, 100,000+ ha	30
	<i>Nypa fruticans</i> Wurb.			30
	<i>R. sp.</i> , <i>Bruguiera parviflora</i> (Roxb.) W. and A. ex Griff.			30
Hawaii	<i>R. mangle</i> (L.)	1902	Introduced seedlings planted on mudflats to control erosion	58
	<i>R. mucronata</i> , <i>B. sexantula</i> (Lour.) Poir., <i>Sonneratia caseolaris</i> (L.) Eh- glor	1922	Introduced from the Philippines	58
U.S. Florida Keys Jewish Creek (Monroe County)	<i>R. mangle</i> <i>R. mangle</i> , <i>Avicennia germinans</i> (L.) L., <i>Languncularia racemosa</i> (L.) Gaertn. f.	1915--16 1938	Planted to control erosion adjacent to the overseas highway 200 Experimental transplants -- only 7 survived after 9 months	45 46
Dry Tortugas	<i>R. mangle</i>	1938	4100 fresh propagules -- 3300 survived to July 1939; none found in 1970	1, 46
South Vietnam Ca-Mau Peninsula Puerto Rico	<i>R. apiculata</i> <i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	1930s to date 1930s	Long scale silviculture 38,000 ha <i>Rhizophora</i> planted from seed; <i>Avicennia/Laguncularia</i> transplanted	38 33
Thailand	<i>R. apiculata</i> <i>R. mucronata</i>	1946	Large scale silviculture 15,300 ha planted	27

Java	<i>A. marina</i> (Forsk.) Vierh., <i>A. officinalis</i> L.	1950s	Planted to stabilize fish ponds	62
Ceylon	<i>R. apiculata</i>	1960s	Planted to encourage deposition of silt	15
Bahamas				
Exuma	<i>R. mangle</i>	1968--69	Small scale experiments 0--71% survived depending on wave regime	55
Panama	<i>Rhizophora</i> sp., <i>Peltiera rhizophorae</i> Planch and Trilana, <i>L. racemosa</i> , <i>Avicennia</i> sp.	1960s	Small scale experimental transplantations of seedlings -- good survival	64
U.S.				
Tampa Bay and Sarasota Bay, Fla.	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	1969--71	Large scale experimental plantings and transplantings	52--53
Tampa Bay, Fla.	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	1973	40 of each species (0.5--1.5 m high) were transplanted successfully	56
Marco Island, Fla.	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	1973	2447 transplants (15.7% survival) on dredged material	51
Texas	<i>L. racemosa</i>			
St. Lucie Inlet, Fla.	<i>A. germinans</i>	1974--75	Transplants of 0.10--0.75 in high trees 0--17% survival	60, 61
Charlotte County, Fla.	<i>R. mangle</i>	1975	Transplants of 4--6 year old trees 65--85% survival	54
St. Lucie County, Fla.	<i>R. mangle</i>	1975	2.23 ha planted with 60,000 propagules 85--90% survival.	47
Siesta Key, Fla.	<i>R. mangle</i>	1975	3 sites -- 2628 propagules and seedlings planted; 0--90%	47
Miami	<i>L. racemosa</i>	1976	Transplants 0.75--1.0 m high -- 100% survival	65
	<i>L. racemosa</i> , <i>A. germinans</i>	Mid-1970s	Transplants of 14 trees to 6 m high -- no survival after 6 months	1
Tampa Bay, Fla.	<i>R. mangle</i>	1975	Small scale experimental plantings of propagules in 3 wave energy zones -- only protected plantings survived.	66
Key West, Fla.	<i>R. mangle</i>	1977	Propagules and seedlings showed about 45% survival -- 2--3 year old trees transplanted showed 98% survival	3
Miami	<i>R. mangle</i>	1977	Experimental aerial planting	48
St. Croix, U.S. Virgin Islands	<i>R. mangle</i> , <i>A. germinans</i>	1978--79	86,000 <i>R. mangle</i> propagules and 36,000 <i>A. germinans</i> propagules planted in oil damaged site (6.15 ha); 40% survival of <i>Rhizophora</i> and 1--2% survival of <i>Avicennia</i>	49, 50

Table 3 (continued)
 ATTEMPTED PLANTINGS OF MANGROVES IN APPROXIMATE CHRONOLOGICAL ORDER

U.S. Tampa Bay, Fla.	<i>A. germinans</i> , <i>L. racemosa</i> <i>R. mangie</i>	1979	1513 transplants (0.3—1.9 m tall) 73.3 survival after 13 months	59, 67
Punta Gorda, Fla. Australia	<i>R. mangie</i> <i>A. marina</i>	1980 1980—81	2.83 ha planted with 35,000 propagules 70% survival Transplanting of 0.5—1.0 m trees; essentially 100% survival in low wave energy, 0% in medium wave energy	68 63
Sydney, New South Wales U.S. Key Largo, Florida	<i>R. mangie</i> , <i>A. germinans</i>	1981	2 ha of <i>R. mangie</i> propagules 90+ % survival — 0.75 ha of <i>A. germinans</i> propagules — 25+ % survival 2.25 ha of nursured <i>A. germinans</i> seedlings — (1% survival)	69

The only reported success at establishing mangroves on an eroding shoreline is that of Goforth and Thomas.³ At their highest wave energy site, propagules and 12- to 18-month-old seedlings of the red mangrove showed very poor survival. Some 2- to 3-year-old small trees (0.4 to 0.8 m tall), however, showed excellent (98%) survival after 23 months. The use of a power auger to provide a hole for planting was, no doubt, a deciding factor for this high success.

Concerning proper elevation of plantings, it is important to first determine the general intertidal zone elevations which will depend upon the tidal range. Once this general zone is delineated, the best zone for each species is then determined. The easiest way to do this is simply survey the elevations of existing mangroves at the closest location to the proposed planting site. In general, the Rhizophoraceae can be planted in zones of greater inundation than species found in the upper intertidal (*Avicennia*, *Laguncularia*). Rabinowitz,⁶⁴ utilizing transplant experiments, tested the survival of four species at elevations different from that where they are normally found. *L. racemosa* did not do well in the lower elevations normally occupied by *Rhizophora* spp. and *Peliciera rhizophorae*, but *Avicennia germinans* did appear to do well in all zones. Goforth and Thomas³ found that survival of both propagules and seedlings of *R. mangle* was twice as great at the +0.1 m tidal level as at a 0.0 m elevation. Teas et al.⁴⁷ noted that "elevation with respect to tidal levels was a significant factor in mangrove establishment" and that *A. germinans* and *L. racemosa* did not naturally establish among planted *R. mangle* below +0.4 m mean sea level but above that elevation gradually became more common as "volunteers" or naturally established (no planting) seedlings from water borne propagules. The importance of understanding this natural secondary succession is discussed in a later section.

Regarding transplanting Pulver⁵⁶ states that "each tree regardless of species should be planted at an elevation similar to that at which it originally grew."

Regarding what type of plant material propagule, seedling, transplant, or nursured tree) to be used, a balance between cost, expected success, and time lapse until the planting is mature must be struck. Table 4 lists the expected costs of various methods of planting mangroves. The amounts vary from \$1140 to \$216,130/ha depending on the plant material used and the spacing of the installations. It is apparent that for a given spacing, the costs increase substantially from the lower end, using propagules, to the higher end, using larger trees. It is also apparent that spacing is also a critical factor. It is important for anyone recommending a plant spacing to understand that reducing the distance by $\frac{1}{2}$ (0.91 m [3 ft] to 0.61 m [2 ft]) more than doubles (12,100 to 26,896) the number of installations required and a further reduction to 0.30 m (1 ft) spacing increases it to 110,889. Failure to understand this has caused many costly misunderstandings. The increased costs of growing propagules to seedlings or trees is the other cost factor.

If it is determined that a damaged or cleared forest needs to be put back in its original form immediately, then larger trees can be moved. Teas' reports no success in moving *A. germinans* and *L. racemosa* trees up to 6 m tall while Pulver⁵⁶ indicates that five of six *R. mangle* (4.5 to 6.5 m tall) moved by Gill⁷⁷ in 1971 were thriving in 1973. Two factors rule this method out for general use. The first is the cost (as yet undetermined — but probably high) and the second is the availability of donor sites. The only time this might be useful would be to "salvage" larger trees that are to be destroyed by development. The general rules for transplanting mangroves as outlined by Pulver⁵⁶ should be followed. They are summarized below for 0.5 to 1.5 m pruned mangroves.

1. Top and side branches should be pruned to $\frac{2}{3}$ their original length.
2. Trees should be removed with a root ball diameter about half the original tree height.

Table 4
ESTIMATED COST (\$/ha) FOR PLANTING
MANGROVES BY USING VARIOUS TECHNIQUES

Species and technique	Spacing (m)			Ref.
	0.30	0.61	0.91	
<i>Rhizophora Mangle</i>				
Propagules (collected)	10,175	2,470	1,140	1
			12,500*	49
			6,250	49
Propagules (purchased)	26,000	13,000	6,545*	4
	11,251	2,742	1,261	1
	30,000	14,000	7,000	4
<i>R. mangle, Avicennia germinans, Laguncularia racemosa</i>				
6-month-old seedlings (purchased)	22,400	5,400	2,510	1
	107,593	27, 2 32	12,103	4
3-year-old trees (purchased)			216,130	1
			40,755	4
			70,000	4
<i>R. mangle</i>				
3-year-old trees (transplanted)			45,386	3
<i>A. germinans, L. racemosa</i> (transplanted)			11,459	59

* Actual cost of commercial project.

Modified from Lewis, R. R., Proc. U.S. Fish Wildl. Serv. Workshop Coastal Ecosystems Southeastern U.S., Markouts, P. S., Ed., February 18--22, 1980, Big Pine Key, Fla., U.S. Fish and Wildlife Service, Washington, D.C., 1981, 88.

3. The rootball should be watered and stamped down while replacing soil to and sealing between the rootball and the sides of the hole.
4. Trees should be replanted at approximately the same level in the ground and at approximately the same tidal elevation as in the original habitat.
5. Trees should never be planted in unstable substrates.

Previous experience at transplanting from nature of 0.5 to 2.0 m trees has met with varying success. Evans⁶⁵ had 100% success with *L. racemosa*; Pulver⁶⁶ had essentially the same results with *R. mangle*, *A. germinans*, and *L. racemosa*, while Hoffman and Rodgers⁶⁹ reported a 73.3% survival for *L. racemosa* and *A. germinans*. All these transplants were less than 2 m in height. Kinch⁵¹ on the other hand had only 15.7% survival with these same species on unstable dredged material and Watson³⁰ indicates transplanting of *Rhizophora* spp. and *Bruguiera parviflora* in Malaysia "have been only partially successful... in spite of great care in planting." Gibbs⁶⁸ has had variable success transplanting *A. marina* with no survival along eroding or higher wave energy shores but essentially 100% survival in protected areas.

Under most circumstances to date, the decision on what type of plant material to use has led to the use of propagules or seedlings because of their ready availability, low cost, and ease of installation. Propagules, in particular, have been used widely and over 50 years ago, the following comments about use of propagules of *Rhizophora* spp. and *Bruguiera* spp. were written: "Where seed-bearers of the *Rhizophoras* are wanting, it may be necessary to collect germinating seeds {propagules} from trees

nearby, and stick them in the mud... care should be taken to select healthy seed {propagules} for the purpose, and to use only those that have recently fallen from the trees, or that will come away without pulling... the seeds should be struck into a depth of a few inches only, so that they will not fall over; deep insertion is not recommended... the seedlings {propagules} are thrust into the mud at intervals from 40-100 centimeters... young plantations are protected from damage by floating objects."³⁹

These recommendations are equally valid today when used with the previous comments about tidal elevations of plantings and recognition of the wave energy regime of the site.

Figure 1 shows a mangrove restoration site in St. Croix, U.S. Virgin Islands, where 86,000 *R. mangle* propagules were installed in August 1978. Figure 2 is the same area in April 1980. The site was a mangrove forest that had been damaged by an oil spill in 1971.^{39,49-50} Survival after 20 months and 2 hurricanes was 40%. The main causes of loss of propagules or seedlings after the propagules germinated were⁴⁹

1. Physical removal due to erosion, accumulations of seagrass wrack, or floating debris.
2. Eating of the planted seeds by unknown biological agents, possibly crabs.
3. Death of seedlings due to natural causes or residual oil.
4. Apparent planting at too high an elevation.

Figure 3 shows a typical seedling that has been attacked by some organism. Watson³⁹ also reports on problems with crabs eating the propagules or monkeys pulling them out and Savage⁵² notes that marsh rabbits have been seen eating *R. mangle* propagules.

In addition to hand-planting of propagules, aerial planting by dropping the propagules enclosed within a bag with stabilizing streamers, called a "missile", has been tried experimentally in Florida and Vietnam with some success.⁴⁸ The main question about the feasibility of using this method involves the cost differential between hand planting and use of "missiles". As noted by Teas and Jurgens,⁴⁸ the method has potential for use for establishing mangroves at isolated sites not easily reached on foot or by vehicle and could be used with other members of the Rhizophoraceae including *Ceriops*, *Bruquiera*, and *Kandelia*.

Direct planting of propagules of other species has not met with much success. Lewis and Haines⁵⁰ report that only 1 to 2% of their 32,000 propagules of *A. germinans* became established due to the tendency for them to be carried by the tides away from the site where they were broadcast. Those that did become established, however, grew quite well (Figure 4). Steinke⁷¹ has noted that propagules of *A. marina* will not germinate unless they have enough moisture to shed the seedcoat (testa). The same property has been seen in *A. germinans*.⁷² For this reason, if the *Avicennia* propagule is placed in the ground with the seed coat on, its chances of success are much less than if the testa is allowed to naturally drop off or is manually removed.

For species other than those in the Rhizophoraceae, it appears that germination of the propagule in a nursery to produce a potted plant that is then planted after a short growing period (usually 3 to 6 months) is presently the most viable option for using those species. This technique, using either nursured seedlings or naturally established ones that were transplanted, has been used with *R. mangle*.^{3,47} The evidence to date indicates that "rooted seedlings had no advantage over unrooted propagules"⁴⁷ and "seedlings showed no advantage over propagules in terms of growth or transplant".³ In addition, as can be seen in Table 4, the cost of using seedlings of *Rhizophora* is 2 to 3 times that of using propagules.

Nursured seedlings of the other species have not had widespread use due to their limited availability but in small scale experimental use they work quite well.⁷³ The

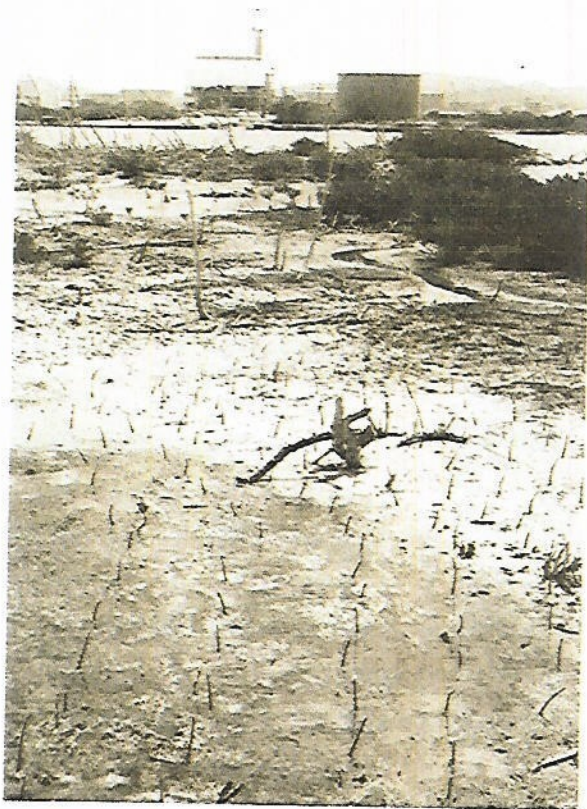


FIGURE 1. Mangrove planting area on the island of St. Croix, U.S. Virgin Islands, August 1978. Red mangrove (*Rhizophora mangle* L.) propagules have been inserted in the ground on 0.8 to 1.0 centers.



FIGURE 2. Mangrove planting area on the island of St. Croix, U.S. Virgin Islands, April 1980. Same area as Figure 1. Mangrove propagules have now germinated and are growing.

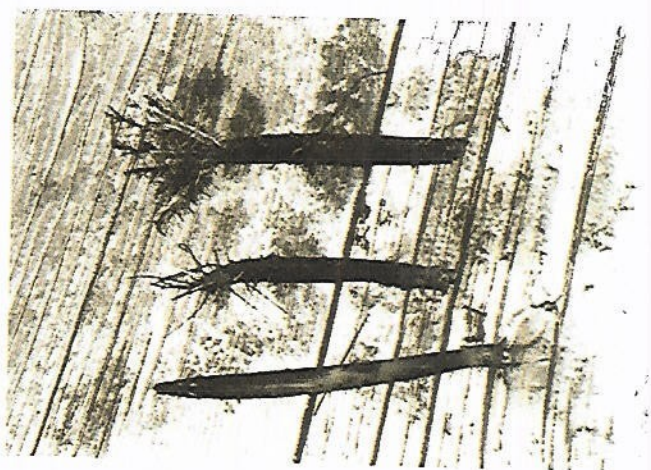


FIGURE 3. Unsuccessful red mangrove (*Rhizophora mangle* L.) seedlings that have had their upper portions grazed by some unknown animal.



FIGURE 4. Black mangrove (*Avicennia germinans* (L.) L.) approximately 1.0 m tall that has grown from broadcast propagules; age 20 months. St. Croix, U.S. Virgin Islands, April 1980.

commercial suppliers in Appendix 1 generally have seedlings of *A. germinans* and *L. racemosa* available year round. Anyone anticipating growing seedlings of mangroves is encouraged to thoroughly familiarize themselves with the extensive literature on experimental culture of mangroves^{71,74-80} to determine the best methods to be used.

A. Mangrove Forest Succession

The classic division of succession into primary and secondary types if attributed to Clements:⁸¹ "... all bare areas fall into... primary and secondary areas. Primary areas present extreme conditions... possess no viable germules of other than pioneer species... and hence give rise to long and complex seres. Secondary bare areas present less extreme conditions, normally possess viable germules of more than one stage, often in large numbers... and give rise to relatively short and simple seres." Chapman⁸² describes nine patterns of primary succession for mangroves and notes one secondary succession pattern because of silvicultural practices in India.

It is important to understand these patterns of succession for a given area because natural patterns of colonization of bare areas such as a new dredged material island (primary succession) or regrowth after clear-cutting (secondary succession) are generally not preventable, except by extraordinary means, and can either assist in the revegetation process or inhibit it. Heavy emphasis on planting an area with a species that will naturally flood the site with propagules and revegetate quickly and naturally is obviously a waste of time and money. Knowing which species will *not* return quickly by themselves gives direction to any wetland restoration or creation effort.

Actual observation of primary succession in mangroves has generally been limited to shallow or emerged sand bars,⁴⁶ man-made dredged material deposits,^{83,84} or sea-grass meadows.^{46,77}

Shallow grass beds or sand bars are usually colonized by *Rhizophora* or a related species with a long radicle (up to 1 m). Man-made dredged material deposits are, conversely, usually colonized by upper intertidal species such as *L. racemosa*^{83,84} or grasses such as *Spartina alterniflora*^{46,83} or *S. brasiliensis*.⁸²

Secondary succession in mangrove forests has been studied by Holdridge³³ and Wadsworth³² in Puerto Rico; Durant,²⁸ Watson,³⁰ and Noakes²⁹ in Malaya; Banijbata²⁷ in Thailand; Detweiler et al.⁵ in Florida; and MacNae¹⁵ in the Indo-Western Pacific. In nearly all situations, the species that first colonize and dominate a recently cleared forest are not the dominant species of the mature forest. This is the classic case of several seres leading to a climax community. Detweiler et al.⁵ compared an undisturbed mangrove forest with an adjacent forest that had been cleared in Tampa Bay, Fla. They found that *Salicornia virginica* L. and *Spartina alterniflora* Loisel were the dominant plants in the sere present 3 years after disturbance. *Rhizophora*, in particular, were not recolonizing the site. As a result, the developer who originally cleared the site was required to plant approximately 25,000 *R. mangle* propagules. Part of the reason this species may not have been recolonizing was the presence of dead trees and slash from the original clearing. MacNae¹⁵ mentions this same problem.

MacNae¹⁵ also mentions the "nurse" effect of one species on another, specifically involving *A. marina* in Natal and *B. parviflora* in Australia and Burma. The nurse effect is described as: "Once established the *Avicennias* and the species of *Sonneratia* cause accretion by impeding water movement, the soil level rises, and other species of *Rhizophora*, *Bruguiera*, and *Xylocarpus*, germinate from stranded seeds and become established. All these trees tend to grow taller than the pioneers, over-top them and these then die off. Hence one rarely finds a well-grown tree of *Avicennia marina* in a *Rhizophora* or *Bruguiera* forest."

→ Watson³⁰ also notes that the marsh fern (*Achrostichum aureum* L.) can act as a nurse in its small form or as a competitor in its large form.

Facilitation of establishment of a species by another species has not received as much study as exclusion phenomena. An example is the invasion of broom-sedge (*Andropogon* spp.) into old fields facilitated by shading of its seeds by tall weed flora (*Solidago* spp., *Aster* spp.).⁸⁶ Lewis and Dunstan⁸⁷ have described such facilitation by *Spartina alterniflora*, which creates a physical trap to hold seedlings of red, black, and white mangroves. Pioneer *S. alterniflora* marshes on dredged material islands in Tampa Bay are thus gradually replaced by mangrove forests. These forests are dominated by black and white mangroves, possibly as a result of selective exclusion of larger red mangrove seedlings.⁸⁶

Exclusion of one species by the establishment of another is widely noted. For example, Niering and Egler⁸⁹ describe the exclusion of trees by a community dominated by a shrub (*Viburnum lentago*). Similarly, Holdridge³³ mentions the physical exclusion of mangrove seeds in marsh fern (*A. aureum*) areas in cutover mangrove areas in Puerto Rico. MacNae¹⁵ mentions similar exclusion by slash, *Acrostichum* spp. or

Table 5
MANPOWER ESTIMATES FOR MANGROVE PLANT MATERIAL
COLLECTION AND INSTALLATION

Species	Plant material	Task	Spacing	Man-hours	Ref.
<i>Rhizophora mangle</i>	Propagules	Collection and installation	0.8—1.0 m	1828/ha	49
	Propagules	Collection only	—	400—1000/hr	48
	0.4—0.8 m tall trees	Transplantation	1.0 m	3098/ha	3
<i>R. mangle, Avicennia germinans</i>	Propagules	Collection and installation	0.8—1.0 m	457/ha	50
<i>A. germinans, Laguncularia racemosa</i>	0.3—1.9 m tall trees	Transplantation	1.0 m	2541/ha	59
<i>Spartina alterniflora</i> Loisel.	0.5—1.0 m	Transplantation	1.0 m	995/ha	59

beach thistle (*Acanthus*). Lewis⁴⁹ attributed the very slow recovery of an oil damaged mangrove forest on St. Croix, at least partially, to physical exclusion of red mangrove seedlings by dead prop roots and fallen limbs. Watson³⁰ and MacNae¹⁵ have both noted the same phenomenon.

The importance of understanding the natural succession in mangrove forests and the nurse and exclusion phenomena is that each forest system has its own unique characteristics that may indicate: (1) natural recovery will be sufficient to provide revegetation and that manual planting is unnecessary, (2) a "nurse" species may be the best species to use in revegetation, or (3) problems of exclusion by other plant species or slash may require large-scale clearing of the site before planting.

B. Manpower Estimates

Very limited information is available on manpower estimates for various phases of collection and installation of mangrove plant materials.^{3,48-50,59} These are summarized in Table 5.

From this limited data, it can be seen that collection and installation of propagules (457 to 1828 man-hours/ha) requires about one half the time that transplantation of small (<2 m) trees (2541 to 3098 man-hours/ha). For comparison, the manpower requirements to use smooth cordgrass (*S. alterniflora*) as a substitute for mangroves are 995 man-hours/ha. As mentioned before, this species is a nurse plant for mangroves in Florida.^{87,88}

C. Recommendations for Future Research

Future research in mangrove forest restoration and creation should concentrate on these areas:

1. Reduction of planting costs through innovative techniques such as aerial planting⁴⁸
2. Greater experimentation with seedlings of species other than those in the Rhizophoraceae
3. Application of horticultural selection techniques to develop lines of species adapted for various latitudes
4. More quantitative analysis of ongoing planting projects including use of control plots to determine rates of natural seedling recruitment

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