Hydrobiologia 444: 101-109, 2001.

Monitoring of black mangrove restoration with nursery-reared seedlings on an arid coastal lagoon

Gerardo Toledo, Adriana Rojas & Yoav Bashan*
Environmental Microbiology The Center for Biological Research of the Northwest (CIB), P. O. Box 128, La Paz B.C.S., 23000, Mexico. Fax: 52-(112)-54710 or 52-(112)-53625. E-mail: bashan@cibnor.mx

Received *19* January *2000;* accepted 30 October *2000*

Key words: *Avicennia germinans*, black-mangrove, mangrove reforestation, mangrove restoration

Abstract

Black mangrove (*Avicennia germinans*) seedlings (*n*=555) were grown from field-collected propagules for 3 months in a new type of terrestrial nursery. They were grown in clusters of five plants, and then they were transplanted to a clear-cut zone in a lagoon fringed by a mangrove forest at Laguna de Balandra, Baja California Sur, Mexico. Survival and plant development of transplants were monitored at 6-monthly intervals for 2 years. After 1 month, the survival of seedlings was 96%, later stabilizing at approximately 77%. After 24 months, 74% of the plants were still alive. The best cluster, showing maximum growth under mangrove swamp conditions in this arid zone, was a two-plant cluster. The lagoon has a low natural regeneration rate of 48 plants per 350 m2 per 6 years of monitoring. This study shows the feasibility of restoring destroyed arid-coast lagoons with black mangroves. áó

Introduction

Mangrove forests can be essential for sustainable coastal fisheries. Once a mangrove forest has been cleared, nearby coastal fishing may be irreversibly reduced or even destroyed (Por, 1984).

Most of Mexico's approx. 660 000 hectares of mangroves (Aksornkoae et al., 1984) is in the humid tropics. However, there are numerous mangrove ecosystems in the arid zones of Baja California Sur (precipitation < 150 mm per year). There, mangrove trees are much smaller than in the tropical areas (Cintrón et al., 1980) and the ecosystems generally cover a smaller area.

Mangroves are harvested for wood on a commercial scale in many countries (Aksornkoae et al., 1984; Jiménez, 1988; Lacerda et al., 1993), generally by clearcut. Mangrove swamps are also converted to aquaculture. All these activities have systematically reduced the world's mangrove area (Alvarez-Leon, 1993; Honculada-Primavera, 1993; Quarto A., 1996. Mangroye Action Project; via Internet at: mangroveap@aol.com). To maintain a sustainable mangrove ecosystem, three strategies are common; forest management, reforestation of clearcuts and conservation (Devoe, 1992). Unfortunately, many conservation programs failed because mangroves are mainly located in the poorer areas of the world where their wood is considered a valuable resource (Lewis, 1979; Aksornkoae et al., 1984). Although small (1-3 ha) clearcuts may regenerate naturally, mangrove reforestation is a better strategy (Thorhaug, 1990), calling for simple and economically feasible reforestation techniques.

Natural regeneration and small-scale reforestation of mangroves is a common practice for their sustainable management in Southeast Asia (Hassan, 1981 cited in Aksornkoae et al., 1984) involving the sowing of propagules directly into the surface of the wet sediment (Aksornkoae et al., 1984). In the U.S.A., transplanting of seedlings from other mangrove areas or from nurseries is more common (Paterson et al., 1993). However, the mangrove area there is small compared to the tropics. A nursery system in a labor-

* Author for correspondence.

atory has been proposed for *Rhizophora* sp., but no attempt has yet been made to evaluate whether the seedlings would survive under natural conditions (Kulkarni & Blosale, 1991). Wakushima et al. (1994) demonstrated, with other mangrove species, the feasibility of growing mangrove seedlings in a flooded nursery supplemented with NaCl. However, the plants were not transferred to the swamps. In Mexico, reforestation is uncommon. When done, direct propagule sowing is used (Flores-Verdugo E, 1996, pers. commun.). To our knowledge, no successful mangrove reforestation has been reported in arid coastal areas.

The aims of this study were (i) to develop a simple and inexpensive nursery method for producing seedlings for the reforestation of mangrove swamps in an arid zone, (ii) to monitor, as a case study, the development of such plants under natural conditions, and (iii) to compare the efficiency of artificial reforestation to natural regeneration in an arid-zone mangrove ecosystem.

Materials and methods

Plant material and nursery procedures

Black mangrove propagules *(Avicennia germinans* (L.) Stern) were collected from the same location at Laguna de Balandra described in a previous study (Toledo et al., 1995). Propagules (4 cm long) were picked directly from the trees in August 1994, transferred to the laboratory and examined. Those with small insect holes were discarded. Propagules were washed and disinfected as previously describes (Toledo et al., 1995). Because our previous nursery techniques failed (see `Discussion'), only one nursery method was evaluated in this study.

White sand was collected from a beach in Laguna de Balandra, sieved (1 mm mesh), and washed 10-12 times with pressurized salty tap water (2560 ìmhos cm^{-1}) until the discarded supernatant was completely clear. Sand (approx. 800 g) was then loosely packed into cylindrical, 900-ml plastic biodegradable bags. Each bag was supplemented once with the mineral salt solution of Murashige & Skoog (1962) medium. The bags did not have a drainage hole. The volume of the solution in the bags was adjusted to maintain approximately 3 mm of water over the sand surface at all times. To prevent potentially damaging salt accumulation (which at high concentration might inhibit seedling growth or cause death (Cintrón et al., 1980) in the nursery bags due to high evaporation rates, seedlings were watered daily with desalinized water (325 ìmhos cm^{-1}; equi. 0.2 g salts 1^{-1}) to the required water level above the sand surface. The total accumulation of salt during the entire growth period did not exceed salt concentration in seawater (33 g 1^{-1} salts). As this is a critical step of the nursery procedure, the salt level was routinely verified by conductivity measurements.

Five propagues were planted in each bag, 1-2 cm apart, on the sand surface, and incubated indoors at a light intensity of 200 ìmole m^{-2} s^{-1} for 1 week at 25+3 °C. Once the propagules developed a few roots, they were transferred outdoors and incubation continued in a shaded (<3 h direct sunlight per day), outdoor nursery for 90 d. The average ambient day:night temperatures were 37, 34 and 30 °C and 24, 20 and 19 °C in September, October and November 1994. The relative humidity was 25-40% with no rain and no strong winds during this period. Light intensity ranged from 116 in the shade to 1622 ìmole m^{-2} s^{-1} in full sun. Because the information we had at the beginning of this study was of high seedling mortality after transplanting in the arid zone lagoon, we decided to introduce our nursery seedlings in clusters, to achieve a meaningful plant population. Only bags containing 5 developed seedlings each (approx. 10 cm high with 4-6 leaves each) were transferred to the mangrove swamp.

Reforestation site

The mangrove swamp of the study site in Laguna de Balandra is well described geographically (Holguin et al., 1992), and geologically (Pedrín-Avilés et al., 1990). It has a total size of 53 ha, and is in an arid zone receiving less than 150 mm of rain per year. Its only supply of fresh water is from rare flash-floods in small dry wash. The zone chosen for reforestation was a clearcut black mangrove forest. All the white *(Laguncularia racemosa* [L.] Gaerth) and black mangrove trees had been poached for firewood in 1991 leaving a barren flat, muddy tidal area of about 1500 m^2. The average tidal change is 10 cm, and the maximum 30 cm in this area, which is above sea level at low tide. At the edges of the area, there is still a forest comprising the three mangrove species of the zone, black, white and red *(Rhizophora mangle* L.). The clearcut area was naturally regenerated from 1991 to 1996 at a very low rate (see results section) and was partially covered at its edges by annual salicornia plants (*Saliconia bigelouii* Torr.). A vegetation

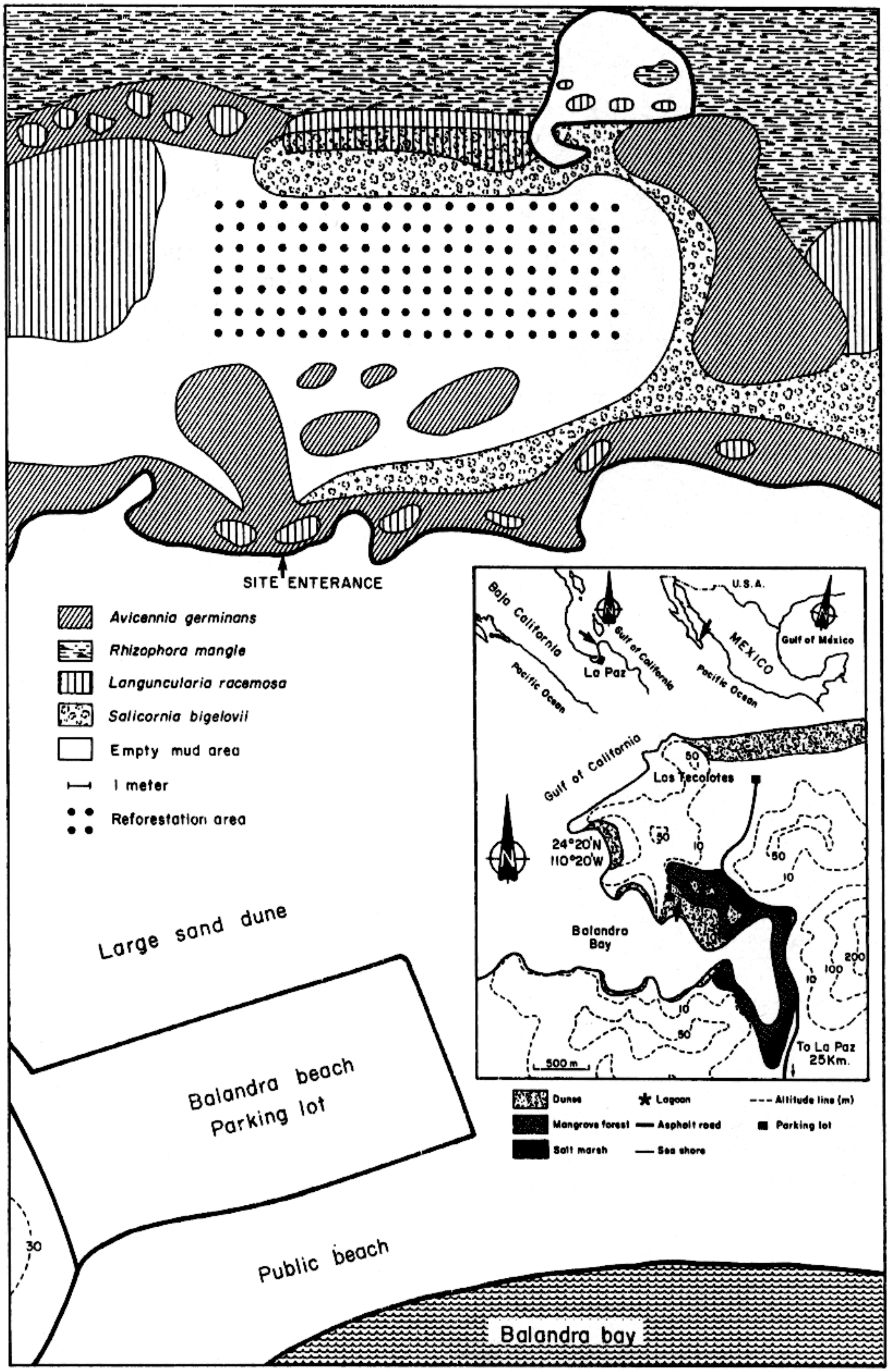

Figure 1. Details of the reforestation area in the mangrove swamp at Laguna de Balandra. Geographical location is a modification of a previously published map (Holguin et al., 1992) and arrows (in the different submaps) indicate the reforestation location.

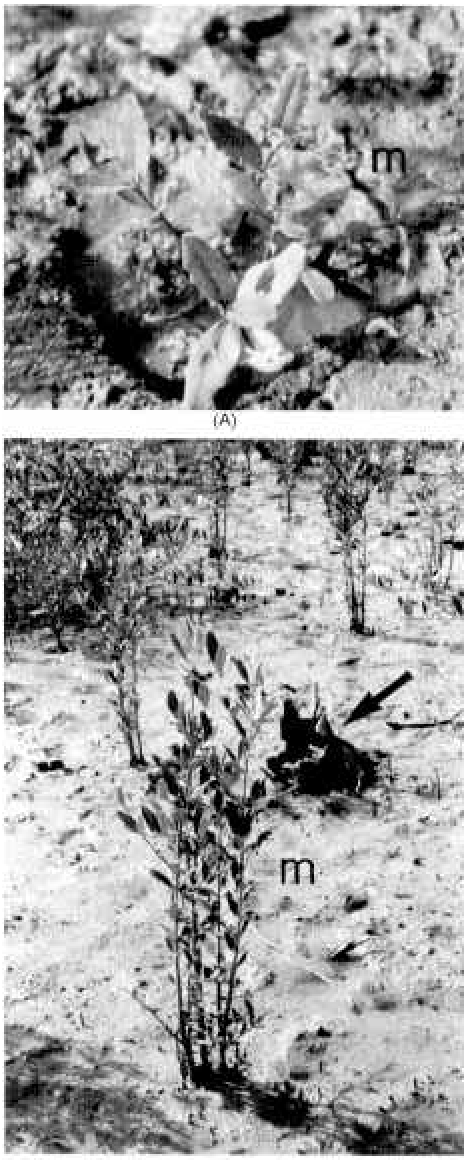

Figure 2. (A) Mangrove seedling cluster (circled) immediately after planting, and (B) two years later. Arrows indicate stumps of poached black mangrove trees. m: flat mud bed.

map of the reforestation area is given in Figure 1. Soil structure, salinity and mineral content in the restoration area were previously describes (Giani et al., 1996).

Reforestation

Nursery-reared black mangrove seedlings (555 plants in 111 bagged clusters) were transferred to Laguna de Balandra in December 1994. They were planted during one morning at low tide in their plastic bags (to avoid damage to the root system and to reduce the shock due to an abrupt change in their growth environment) in holes dug with a hole digger (Fig. 2A). Five to six long cuts were made in each bag from the top to the bottom. The cuts did not directly expose the roots to the environment. The roots emerged from the bags only after an additional growing period and biodegradation of the bags. The distance from one cluster to another was 1 ±0.20 m as recommended for *Avicennia* transplantation in other ecosystems (Teas, 1977). The few natural mangrove seedlings (see `Results' section) in the study area were left in place, reducing the distances between clusters. In no case was a cluster planted <60 cm from a volunteer plant. To distinguish transplanting from natural regeneration, all transplants were arranged in a grid plot with marked borders. Four years after the clearcut, no organic-matter residues (except tree stumps) were found on the surface of the entire area at planting. Plant debris is known to inhibit the natural regeneration of mangrove (Aksornkoae et al., 1984). Also, no seedlings were planted close to the existing forest, since this increases seedling mortality (Aksornkoae, 1981 cited in Aksornkoae et al., 1984). Although the reforestation zone was near a popular beach (Fig. 1), it was protected from vandalism by a soft, deep natural mud barrier which denied access, and by warning signs. After planting, the reforestation area was not further treated. Plant survival was monitored initially 1, 2 and 4 weeks after planting and every 6 months thereafter. Data on plant height, number of leaves and survival rates were collected.

Statistical analysis

Results were evaluated by frequency histograms, linear regressions, and Analysis of Variance (ANOVA) all at $P \leq 0.05$ using Statgraphics software.

Results

Seedling development in an outdoor nursery

The propagule vigor of black mangroves collected from the wild was high; the survival of propagules in the nursery for the initial 3 months was 100%. A small number of

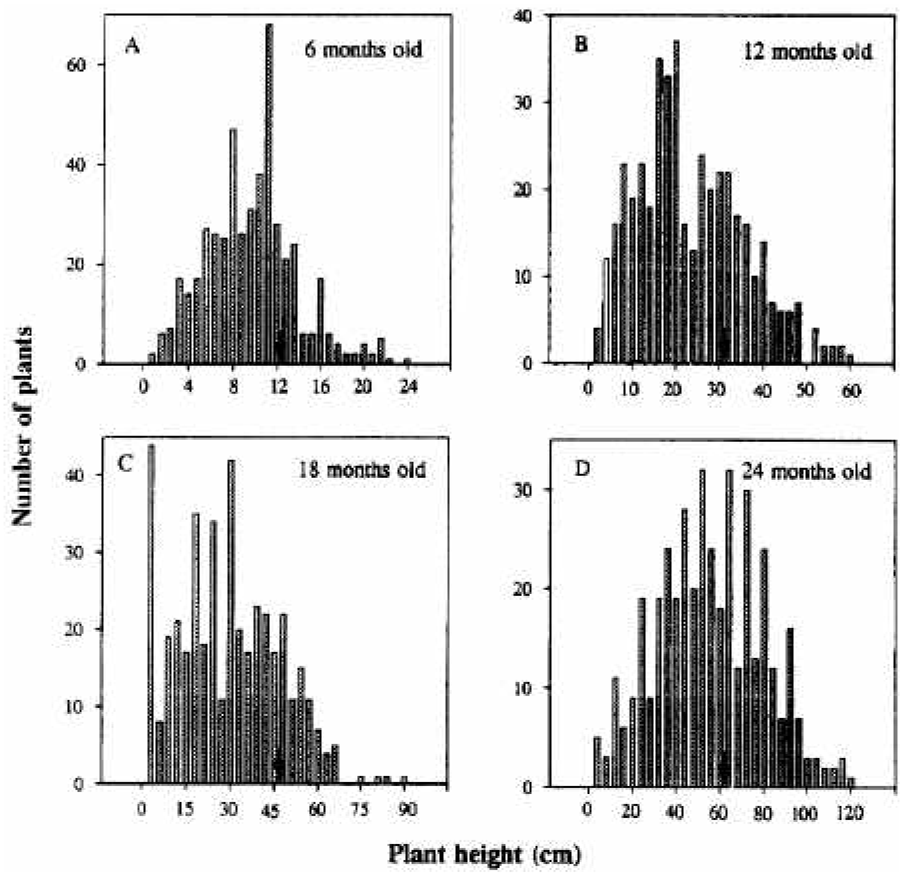

Figure 3. Total height of growing mangrove seedlings in the swamp. Arrows on each subfigure indicate the average height of all plants at specific evaluation time.

propagules (<5%) developed relatively small seedlings (1-2 Leaves, <10 cm height) and were discarded. The seedlings growing in the nursery showed no disease symptoms. Biocides were, therefore, not used.

Seedling development in the swamp

Plant population histograms drawn from measurements taken during 2 years in the reforestation area revealed that plant heights followed a normal distribution pattern in most sampling periods (Fig. 3). Average seedling heights were 13, 31, 46 and 62 cm, after 6, 12, 18 and 24 months (Fig. 3 A-D). The tallest plants were 24 cm (after 6 months), 63 cm (after 12 months), 90 cm (after 18 months), and 120 cm (after 24 months) (Figs 2b and 3).

The number of leaves per plant did not follow a normal distribution (Fig. 4). The average number of leaves per plant was 10, 32, 48 and 178 after 6, 12, 18 and 24 months (Fig. 4 A-D), with the largest number of leaves of 22 (after 6 months), 56 (after 12 months), 118 (after 18 months) and 432 (after 24 months). There was a significant linear correlation between plant height and the number of leaves (Fig. 5 A-D).

Survival of transplants in the swamp

Weekly visits after transplantation of the seedlings to the swamp revealed that after 4 weeks 96% of all plants survived. Later, the survival rate declined and was 86% (6 months), 77% (1.0 and 1.5 years). After 2 years, 74% of all original seedlings were alive, and all were still growing after 4 years.

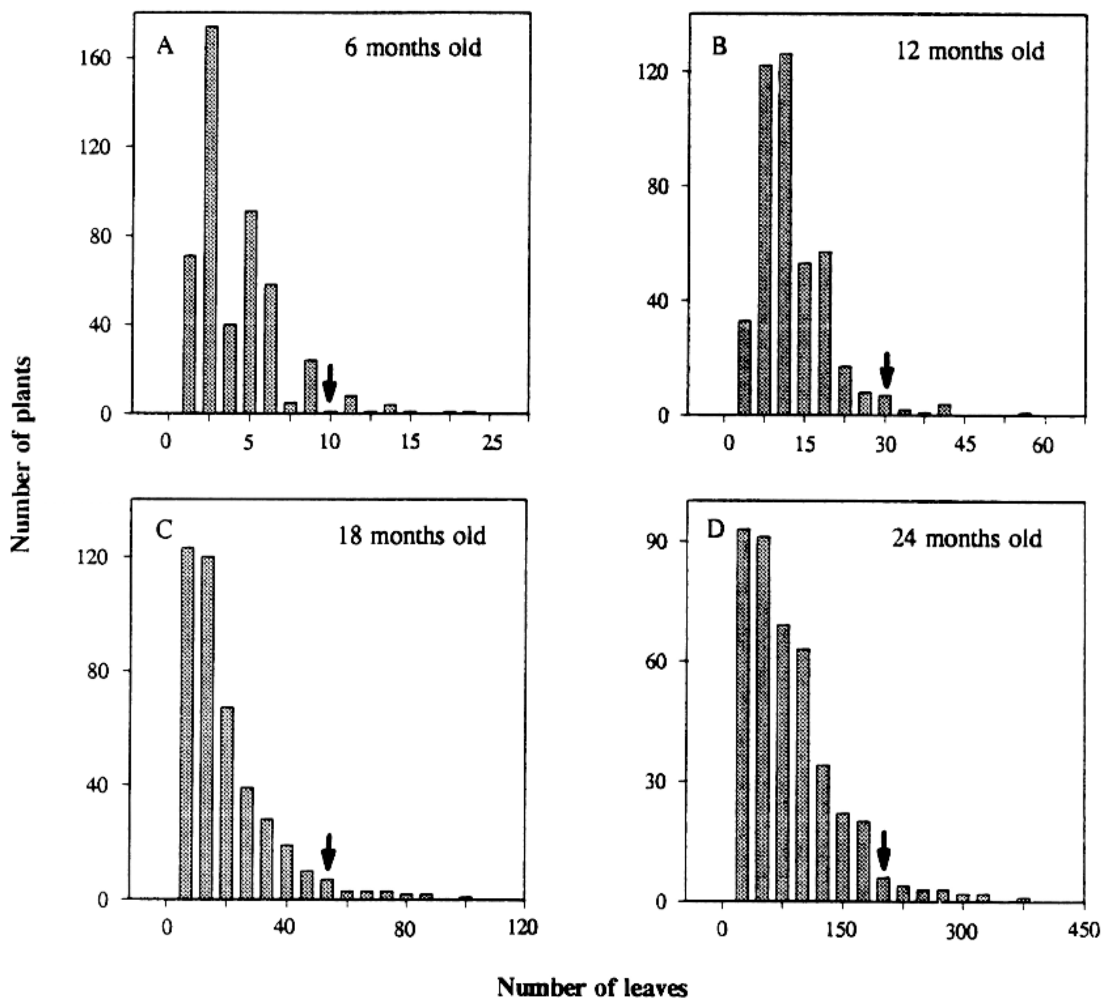

Figure 4. Number of leaves per plant of growing mangrove seedlings in the swamp. Arrows on each subfigure indicate the average number of leaves of all plants at specific evaluation time.

Plant development and dependence on cluster size

All nursery clusters used for reforestation were originally planted in the swamp with 5 seedlings per cluster. With time, the number of the plants in each cluster declined, forming clusters with 1-5 plants. The number of clusters with different plant densities varied from 140 clusters with 5 plants to only 6 clusters with one plant. One-way ANOVA of the heights of plants in each cluster revealed that plants growing in 2-plant clusters were the tallest (Fig. 6).

Natural regeneration in the swamp during 1991 to 1996

Because we did not remove the seedlings naturally established in the study zone, we could follow the annual rate of natural regeneration. Except for 1995, when 25 white mangrove plants were established, the natural regeneration was slow and consisted of 8 plants per year per 350 m^2 of swamp. The slowest natural regeneration was exhibited by red mangroves, with only a single plant established in 6 years (Fig. 7).

Discussion

Mangrove ecosystems may be managed sustainably by reforestation, especially when trees are commercially harvested (Jiménez, 1988; Lacerda et al., 1993) or where natural regeneration is slow. In many tropical areas, mangroves are able to regenerate, given sufficient recovery tune (Aksornkoae et al., 1984). However, in dry zones with little tidal flux, mangroves regenerate poorly after clear-cutting. For example, in Bahia de La Paz, Baja California Sur, Mexico, hardly any survive although many seedlings germinate naturally at the end of the propagule season (Bashan, 1999 unpublished). Six years after a

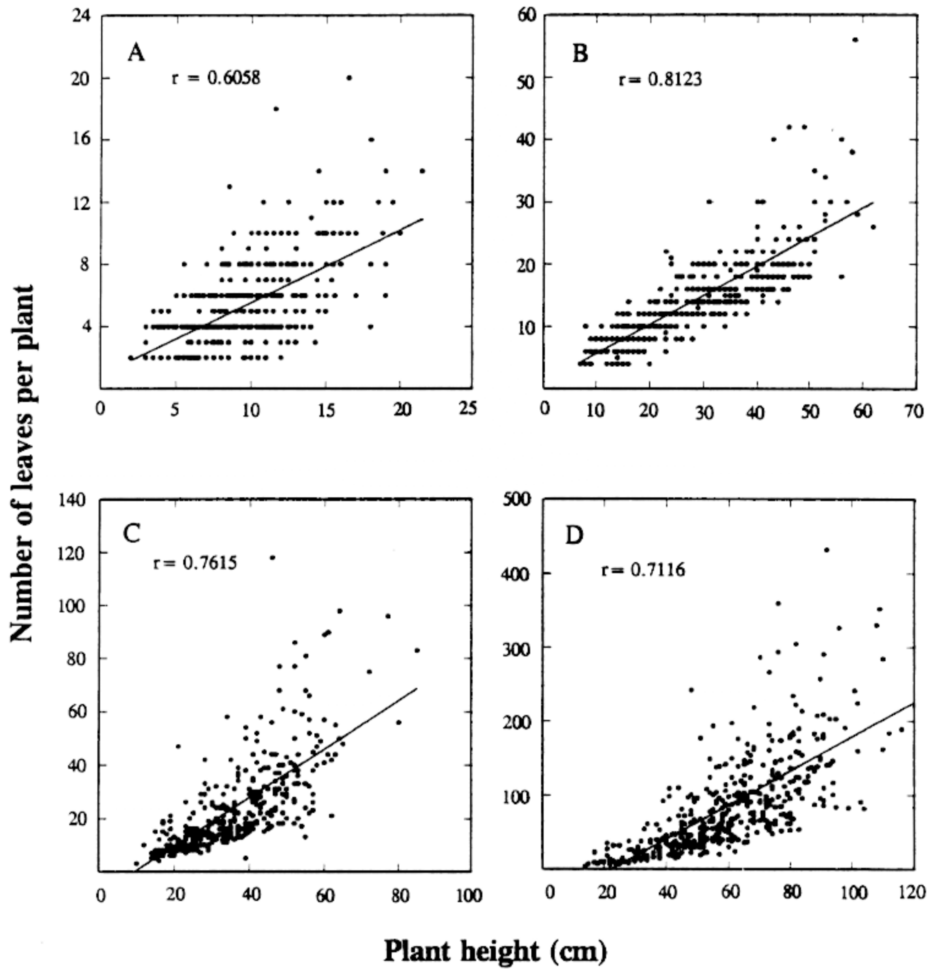

Figure 5. Linear correlations between the number of leaves and plant height in mangrove seedlings growing in the swamp. All correlations are statistically significant.

clear-cut in Laguna de Balandra, only 48 new seedlings were found per 350 m^2 (this study). The cause for this low rate of natural reforestation and the limited development of mangroves in arid zones (high evaporation rate without compensation by fresh water) was attributed by Cintrón et al. (1980) to the high level of salts in the soil. Although mangroves are basically tolerant of high salt levels and low oxygen levels, very high salinity results in sparse vegetation and small, slender trees and eventually a high mortality of both seedlings and trees (Cintrón et al., 1978, 1980; Jintana et al., 1992).

Direct sowing of propagules in these dry-climate ecosystems (as practiced in Southeast Asia) is usually unsuccessful. Though initial establishment of the seedlings may be successful, they eventually die within a few months. So far, our experience shows that propagules successfully grown under controlled conditions in growth chambers hardly withstand the stress of transfer to the harsh environmental conditions of Baja California Stir (Toledo, 1994, unpublished). Our previous attempts to create a nursery in pots submerged in the tidal zone or to use tissue-culture seedlings have been disappointing (Holguin et al., 1991, unpublished). Therefore, we needed to develop an outdoor nursery system, independent of tides, to overcome the salt-stress susceptibility of the seedlings for transplant production. We chose black mangrove as a model because of the availability of propagules and their compact size, which makes them easier to transplant as seedlings (Canton, 1974; Teas, 1977), although the wood of red mangroves is preferred commercially, and although most of the Pacific coast of Central America is colonized by this species

(Jiménez, 1988).

As the survival rate of seedlings in our terrestrial nursery was very high, we monitored the development of the trees, after transplanting them to their natural environment, without special tending for 2 years and survival for 4 years. The data on seedling survival in the wild are diverse. High survival rates in Southeast Asia vs. lower survival elsewhere have been reported (Rabinowitz, 1978; Aksornkoae et al., 1984; Patterson et al., 1993). Information on the survival of mangrove seedlings in arid zones is scarce (Cintrón et al., 1978). Our nursery system, apart from confirming the possibility of production of nursery-reared seedlings, also demonstrated that these seedlings will survive well in the swamps of arid-zone mangroves. Because the area has low natural regeneration in clearcuts, we could not assess the comparative growth rates of nursery plants and naturally regenerated plants.

In conclusion, a procedure for nursery-reared transplants was developed for reforestation of black mangroves in arid-zone coastal lagoons and estuaries. The transplants survived and developed well under natural conditions. This nursery procedure showed the feasibility of reforestation of mangroves in areas where natural regeneration is slow.

Acknowledgements

We thank Mr Juan-Carlos Ruíz-Rubio, Delegado Federal de la Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP, Baja California Sur, Mexico) for granting us a large part of Laguna de Balandra as an experimental field. We appreciate the field assistance of Mr Angel Carrillo and Dr Zeev Pancer, Dr Gabor Bethlenfalvay for critical reading of the manuscript, Mrs Luz E. Gonzalez-Bashan for inserting the numerous modifications and Dr Ellis Glazier for English corrections, Mr Renato Mendoza-Salgado (CIB, Mexico), Prof. David A. Zuberer (Texas A&M University, U.S.A.) and Dr Jaime Polania (COLCIENCIAS, Colombia) for providing literature on mangroves and Mr. Oscar Armendariz Ruiz for artwork. Yoav Bashan participated in this study in the memory of the late Mr. Avner and Mr Uzi Bashan from Israel. This study was partially supported in part by grants #28362 B and #26262 B from Consejo Nacional de Ciencia y Tecnología (CONACyT), Mexico and by the Bashan Foundation. GT was partially supported by grants No. 83916 from Consejo Nacional de Ciencia

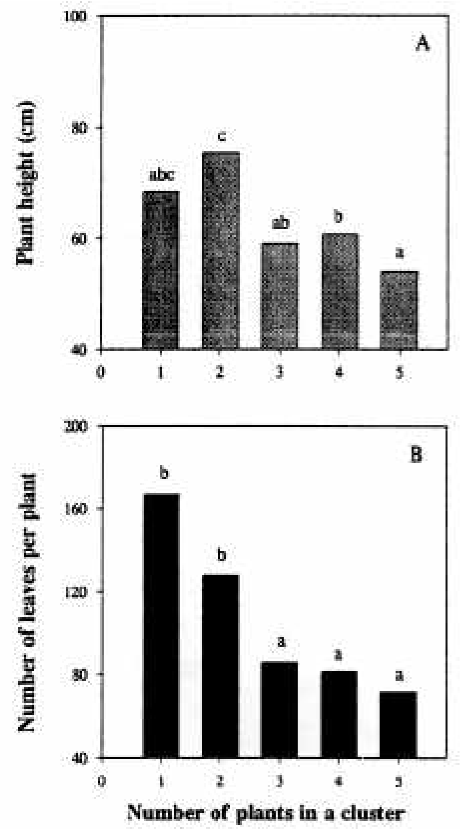

Figure 6. (a) Height, and (b) number of leaves of plants growing in different clusters each having 1–5 plants per cluster. Columns denoted by different letters differ significantly at $P \leq 0.05$ using one-way ANOVA.

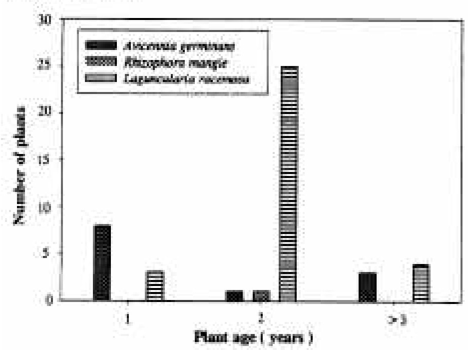

Figure 7. Natural reforestation in the mangrove swamp in Laguna de Balandra.

y Tecnología (CONACyT) and No. 930108 from Instituto Politécnico Nacional. Centro Interdisciplinario de Ciencias Marinas, Programa Institucional de Form ación de Investigadores (CICIMAR-PIFI) (Mexico).

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