Broadcasting seedling propagules of black (*A. germinans*) and white (*L. racemosa*) has generally not met with a great deal of success (Lewis and Haines 1981). The reason typically cited for this is a requirement for stranding without tidal flooding for periods of at least 5 (*L. racemosa*) or 7 (*A. germinans*) days (Cintron 1992, Rabinowitz 1978). Planting nursery-grown seedlings has met with success (Cintron 1992), especially when they are first acclimated to ambient salinity conditions. Where plans include planting *A. germinans* and *L. racemosa* seedlings, methods, such as first planting marsh grasses, to trap and contain mangrove propagules to be broadcasted, may speed establishment of high densities of these species.

(7) Initiate Quantitative Monitoring/Assessment Program (see later discussion). If restoration goals are not being met then perform remedial actions such as re-planting the site.

b) Re-establishment of a Mangrove Ecosystem Where One Was Eradicated by Disturbance or Pollution:

(1) Physically-disturbed mangrove forests, such as by hurricanes or bulldozers, can be restored much as described in (a) above. In these cases, site regrading of slopes and elevations will probably not be necessary, although removal of fallen trees and other debris may facilitate natural colonization.

(2) Polluted sediment, such as occurs with oil spills, is a more serious problem to same-site restoration. Oil contamination in highly organic mangrove sediments can persist, and be toxic to species in mangrove forests, for years (Duke 1991, Garrity et al. 1994, Levings et al. 1994, Snedaker et al. this report). In these cases pre-restoration studies of the extent of contamination, rate of natural breakdown of oil in the sediment, degrees of sediment toxicity to mangroves and fauna, and the effectiveness of any pollution remediation techniques applied to the site will have to be conducted in order to determine when the site is ready for ecosystem restoration. Determination of when the site is clean enough for restoration is a management decision that needs to be firmly supported by data and scientific opinions of those conducting the studies mentioned. Sediment should be free enough of contamination that it is not toxic to resident forest fauna and the mangroves. Ideally, contamination levels should be lower than those reported to increase mangrove mutation rates (see Klekowski et al. 1994a,b, Klekowski and Corredor 1995, and Lowenfeld and Klekowski 1992), although restoration should not be held up for this reason. Mangroves growing on somewhat contaminated sediment may facilitate phytoremediation of sediment possibly by, for example, pumping oxygen into the sediment. These mangroves will also retard soil loss to

erosion. However, regardless of mangrove survival and growth, a restoration project on contaminated soil should not be considered "successfully restored" until contamination levels approach background.

c) Ecological "Enhancement" of Selected Mangrove Functions in a Degraded System:

Enhancement of ecological functions usually entails removal of some physical problem such as a barrier to tidal flow or eradication of an infestation by exotic species such as Brazilian pepper and Australian pine. Such activities can produce benefits by increasing mangrove growth and productivity, and utilization by marine animals.

Exotic removal alone does not often greatly "enhance" mangrove productivity, growth, reproduction, or colonization; nor, does it affect marine faunal utilization. This is because these exotics in most cases are restricted to the edges of the mangrove system and are having their shading or crowding effects only in that area. As such, this activity, by itself, is not generally a sound form of "mangrove restoration," except in isolated instances.

Removal of barriers to tidal flow can be an important form of habitat enhancement restoration. However, in large areas, this may best be coupled with exotic removal and complete or selective replanting of the site if mangroves are stunted or if many have died in order to truly enhance the rate of ecosystem recovery.

3. Design and Implementation of Studies to Address Restoration Goals:

The "success" of restoration of a mangrove ecosystem is a function of the goals that are set and the assessment of whether or not these goals are attained. Thus, adequate design of a mangrove restoration project should include goals and metrics of these goals that extend over the entire time frame required for development of a mature mangrove forest. Estimates of this time course typically range from 20 years and up. We suggest that 20 years be viewed as a minimum time frame for goal setting and assessment, until studies of restoration and mangrove succession suggest longer (or, less likely, shorter) periods are appropriate.

In some instances requirements for success are dictated by agency permit stipulations. Often the success requirements include simply such physical factors as elevation and slope grade and biological factors such as percent survival and percent cover over some period of time (usually 3-5 years). These are certainly good variables to measure but by no means should they be used as sole criteria for success in true ecological sense. We recommend determining "success" of a restoration project through establishment of quantifiable goals in terms of environmental and biological parameters that are associated with "important" ecosystem functions. These can be established as a series of null hypotheses that can then be falsified or not falsified through studies over time that compare the restoration site with an appropriate natural reference mangal. Where possible, we further recommend that studies include one or more carefully selected natural mangrove systems as "reference sites." The reference site is used as a yardstick by which to judge the rates of attainment of values typical of mangrove systems for a suite of ecological variables.

Many biological and physiochemical features of mangrove systems can be selected for studies that can provide important data on restoration success. Below, we provide a recommended list, but recongnize that each restoration project study need not contain all of

these. Our list of variables to include is not exhaustive but reflects our experience and study preferences.

A. Initial Data (after site preparation, but before planting): A mapping of the spatial dispersion of these variables over the study site may help explain localized differences in survival and growth (and other variables) later.

1. Site elevations and slope
2. Sediment grain size, organic content, and nutrient concentrations.
3. Tidal inundation (depth and frequency).

B. Post Planting (or post "natural colonization" for unplanted sites) Data:

1. Physiochemical factors to be quantified
   a) Annual (if necessary) analyses of sediment grain size and especially of organic content.
   b) Salinity of standing and pore water.
   c) Air and sediment temperatures in open areas and below plants.
   d) Percent light penetration to ground level.
   e) Tidal inundation (depth and frequency).
   f) Rainfall and other freshwater inputs.
   g) Nutrients

2. Biological factors
   a) Survival of planted mangroves and those colonizing the site. Tagging should be used to ensure that these can be distinguished.
   b) Growth (at least height and trunk diameter) and reproductive output of mangroves.
   c) Density of planted and volunteer plants. Also, dominance in the canopy and leaf area index should be determined.
   d) Litterfall and litter "fate" (% exported vs % decomposing in situ) should be assessed. Primary mechanisms of decomposition including relative importance of microbes and invertebrate littervores should be studied.
   e) Colonization and population densities of selected "typical" mangrove fauna (to include species in the canopy, on the forest floor, and those encrusting prop roots) should be studied.
   f) Population sizes and grazing rates of important herbivores especially insects and the crab *Aratus pisonii*.

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This document contains papers produced from a workshop held in August of 1996 in Lake Charles on issues related to oil spills in mangrove ecosystems. Topics include four papers on the effects of oil and modeling these effects and three papers devoted to issues of spill containment, cleanup, remediation, and habitat restoration. Papers are either summaries of work conducted or reviews and overviews of a topic.

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