CHAPTER 4. Mangrove Recovery and Restoration

Key Points

- Mangroves can take more than 30 years to recover from severe oil spill impacts.
- Adequate tidal exchange is critical to restoration success.
- Mangrove seedling and tree density and health are the only widely measured recovery indicators at many spills.
- Restoration that works with natural recovery processes to reestablish mangrove habitat is the best course of action over the long term.

Mangrove ecosystems around the world suffer degradation from logging, coastal development, spraying of herbicides, conversion to fish ponds, and from oil spills and other pollutants. The continued loss of mangrove forests worldwide underscores the importance of projects focusing on restoration of forest structure and functions.

Since mangroves take 20–30+ years to recover from severe oil spill impacts, restoration projects attempt to speed up this recovery process. Adequate tidal exchange is most critical to restoration success. Mangrove restoration projects in Florida and the Caribbean often involve re-establishing natural hydrologic and tidal regimes, planting mangrove propagules, and/or planting marsh plants to provide a "nurse" habitat that can be colonized more easily than bare areas by mangrove trees.

An oil spill alone rarely changes the basic geophysical appearance and shape of the mangrove ecosystem; this is left for hurricanes, clear-cutting, and development. For this reason, restoration after an oil spill may be easier than after an event that substantially changed tidal elevation or hydrology or decimated mangrove trees. However, an oil spill may come as an additional impact on a mangrove ecosystem already degraded by human and industrial development, such as near refineries (Bahía las Minas), ports, or airfields (Roosevelt Roads). Cumulative or chronic impacts may decrease the resiliency of the mangrove ecosystem and increase the time it takes the system to recover or make it more difficult for the system to recover at all.

As with other marsh ecosystems adversely impacted by oil spills, we have learned valuable lessons from past mangrove restoration projects, including those that failed. Restoration projects need a clear goal from the outset that is based on understanding the mangrove ecosystem's natural ability to recover. The most effective role for restoration projects is to correct or assist when natural recruitment mechanisms are impeded or no longer functioning.

Recovery

Recovery of any impacted ecosystem following a perturbation such as an oil spill is interpreted by many to mean a return to the system in place at the time of the spill. Mangroves' specialized niche is in a unique, changeable zone, subject to sediment flow that accretes and erodes, varying amounts of fresh water, impacts from storms and hurricanes, invasion by foreign species, and predation. Thus, even if we had a precise description of ecosystem conditions just before the spill, we still might not be able to return it to its pre-spill state.

Figure 4.1 Restoration project showing forestry technicians planting Rhizophora harrisonii *propagules in the Congal Biological Station, Esmeraldas Province, Ecuador (Arlo H. Hemphill).*

A more practical way to measure recovery is to compare the impacted system with an unimpacted one (hopefully, nearby), using metrics such as tree height, density, canopy cover, above-ground biomass, and abundance and diversity of associated invertebrates, fish, and plants. Since compromised ecosystems can be more vulnerable to stresses such as disease or predation, the recovering habitat must also show the resilience of a functioning ecosystem.

Mangal - a mangrove forest and its associated microbes, fungi, plants, and animals.

Sadly, it is rare to find long-term, follow-up studies on mangroves beyond 1-2 years post-spill. It is even rarer to find studies that measure associated communities of invertebrates or other components of the mangal (mangrove forest habitat) besides the mangrove trees themselves. Even when mangrove *trees* appear to have recovered, restored mangal may differ from unimpacted mangal in its functioning and ecosystem complexity. Even with its limitations, mangrove tree density and health are the only widely measured recovery indicators at many spills, so we are using mangrove tree recovery to compare between spills shown in Table 4.1. Keep in mind that the recovery times indicated would probably be even longer if more comprehensive and ecological recovery measures were used.

Table 4.1 summarizes impacts and recovery times for mangrove trees at eight oil spills impacting five regions. Mangroves in the Bahía las Minas region of Panama were oiled by the *Witwater* spill in 1968 and again in 1986 by a refinery spill. Mangroves at Roosevelt Roads Naval Air Station in southeastern Puerto Rico were impacted by spills in 1986 and again in 1999, though different sections of mangroves were oiled at each spill. Because of the short duration of the follow-up studies, no cases were able to document recovery, except for fringe mangroves at the *Witwater* spill. In most of these studies, mangroves were regrowing in the oil-impacted areas but tree height, percent area of open canopy, and other parameters remained different from controls.

Da Silva et al. (1997) diagrammed generalized mangrove impact and recovery from an oil spill in four stages. These timeframes are approximate and will likely vary in different systems. See also Table 2.1 in Chapter 2 for additional details on timeframes for oil impacts to mangroves.

- Initial impact ~ 1 year
  propagules and young plants are most likely to die during this time
- Structural damage ~ 2 1/2 years
  trees begin to die
- Stabilization ~ 5 or more years
  deterioration of mangroves ceases, but no improvement noticeable
- Recovery ~ timeframe unknown
  system improves via colonization, increased density, etc.

Additional impacts such as from hurricanes, or other natural or human-caused disturbances could significantly delay these recovery processes.

Mangrove Restoration

Restoration success has rarely been studied quantitatively, but we know restored mangrove ecosystems often do not equate with natural ones. Shirley (1992) found that plant diversity was similar in restored and natural forests one year after restoration, but that environmental conditions were different and a number of fish and invertebrate species were absent from the restored site. McKee and Faulkner (2000) found that development of structure and biogeochemical functions differed in two restored mangrove stands because of different hydrological and soil conditions. Tree production and stand development was less where tidal exchange was restricted, and some waterlogging occurred due to uneven topography. Other assessments of restoration success, in terms of initial survival and percent cover after one or several years, have been mixed. Cintron (1992) reviewed a number of these projects.

These experiences emphasize the need for developing clear restoration goals that incorporate the mangrove ecosystem and its functions, as well as the growth and health of the trees themselves. Once the goal is defined, the project is designed and implemented, followed by monitoring to ensure that restoration is proceeding as anticipated. Projects should be monitored for 10 or more years to adequately assess long-term survival, resiliency, and complexity of the restored system (Field 1998). Depending on the type of impact and the state of the impacted mangal, restoration may take several approaches:

- Replant mangroves
- Remediate soils
- Encourage natural regeneration through improved site conditions
- Restore an alternate site to provide similar habitat (in-kind restoration)

Location	Oil type	Mangrove Impacts	Mangrove Recovery	Published reports
Era, Australia August 1992	Bunker fuel	*Avicennia marina* 75-100 ha impacted	> 4 yr.	Wardrop et al. 1997
Santa Augusta, US Virgin Islands 1971	Crude	*Rhizophora mangle*	>7 yr. (little to no recolonization)	Lewis 1979
Zoe Colocotronis, Puerto Rico March 1973	Venezuela crude	*Rhizophora mangle* *Avicinnia nitita*	>6 yr. (mangrove fringe)	Nadeau and Bergquist 1977, Gilfillan et al. 1981
Witwater, Panama, 1968		49 ha deforested	23 yr. (fringe) > 23 yr. (sheltered)	Duke et al. 1997
Bahía las Minas, Panama April 1986	Crude	*Rhizophora mangle* *Laguncularia racemosa* *Avicennia germinans* *Pelliciera rhizophorae*	>5 yr. (fringing mangroves) >6 yr. (recovery underway)	Garrity et al. 1994 Duke et al. 1997
Roosevelt Roads NAS, Puerto Rico Nov 1986 October 1999	Jet fuel (JP-5)	*Laguncularia racemosa* 6 ha killed (1986) 31 acres impacted (1999)	> 1yr. > 1.5 yr.	Ballou and Lewis 1989 Wilkinson et al. 2001
Tampa Bay, August 1993	No. 6 & No. 2 fuel	*Avicennia germinans* *Rhizophora mangle* *Laguncularia racemosa* 5.5 acres oiled	> 2 yr.	Levings et al.1995, 1997

Table 4.1. Impacts and recovery times for mangrove trees at eight oil spills impacting five regions.

Replant Mangroves

There is an extensive body of technical information on replanting mangroves. Specific details on elevation, use of fertilizer, planting density, species selection, etc. can be found in Snedaker and Biber (1996) and Field (1996, 1998). Today, restoration projects have moved away from broad use of planting except in those cases where natural processes are inadequate to naturally repopulate the area with recruits from surviving trees or more distant sources. Examples include mangrove forests where hydrology has been substantially altered, or where physical barriers such as dead trees, debris, or berms restrict circulation such that propagules have no access to denuded areas.

If planting is chosen as the best course, seedlings will survive best when they are planted in a sheltered location and at appropriate tidal elevation levels for each species. Planted seedlings are lost primarily because of erosion, predation, death from natural causes, planting at incorrect elevations, and residual oil toxicity (Getter et al. 1984). Planting one- to three-year old trees (usually supplied from nurseries) costs more but results in much better survival rates, especially in locations exposed to higher wave energy. Seedlings and propagules can survive even when planted in soils with residual oil contamination, though generally only after oil has weathered for 9-12 months.

Red mangrove seedlings (*R. mangle*) survived when planted in areas with one-year old residual oil at Bahía las Minas. A restoration planting project at St. Croix in the U.S. Virgin Islands planted seedlings 8 years after heavy oiling from the *Santa Augusta* spill, with 40% survival after two years (Lewis 1989).

Planting is still used to establish new mangrove forests in areas where they have not previously existed (such as in newly accreted shorelines or along human-built structures), or to replant in forests that have been logged. Survival of planted mangroves ranges from 0% to as high as 80% after one year. Lowest rates are often in areas with high wave energy where propagules are simply washed away. A planting technique that successfully increases survival rates of planted mangroves in exposed areas is called the Riley encasement method. Seedlings are planted inside PVC tubes (bamboo can also be used) to anchor and protect the seedlings until they become established (Rothenberger 1999).

Survival rates drop as the time after planting increases (e.g., one to two years or more). Even when plantings survive and grow, densities of planted trees may be lower than those naturally recruited, as found at the Bahía las Minas spill. Five years post-spill, replanted *R. mangle* survived well (especially in sheltered areas), but trees were less dense than in areas that recolonized naturally (Duke 1996). Restoration that enhances natural recovery processes to reestablish mangrove habitat has proven to be the best course of action over the long term.

Remediate Soils

Residual oil that has contaminated soils in mangrove forests degrades very slowly, since these soils are anaerobic below the top 1-2 mm (Burns et al. 2000). Experiments and field studies examining the possibility of accelerating oil degradation through addition of nutrients or increased aeration have shown little advantage to these methods. During the first year after a spill, biodegradation occurs at very low levels, and the main routes of oil removal are dissolution and evaporation. Thus, it is critical during spill response to attempt to keep oil from penetrating into sediments. Some restoration-planting projects surround seedlings with clean, fertilizer-augmented soil so the new trees can establish themselves and develop root structures in uncontaminated soils, before having to contend with possible toxic effects from residual oil.

Erosion of soils in mangrove forests following a disturbance can impede future re-establishment of new trees, since mangroves thrive only at specific tidal elevations. Since mangrove root mass comprises 40-60% of the total forest biomass, any substantial die-off of adult trees, as may occur after an oil spill, could cause subsidence of soils and erosion as a secondary impact. In such cases, augmenting soils, or assisting processes of sediment accretion may be a necessary part of restoration activities.

Encourage Natural Regeneration

Restore hydrology

Adequate hydrology is tagged as the most important parameter for mangrove recruitment (Lewis and Streever 2000). When tidal connections have been cut off or altered, as is common along developed coasts, re-establishing these connections can promote natural recruitment and improve the overall health and functioning of the mangrove ecosystem. Roosevelt Roads NAS is an example where impounded mangroves were impacted by a jet fuel spill in 1999. These mangroves suffered both from toxic fuel impacts and from extended submersion of roots when tidal conduits were closed to contain the spill during response. Facilitating or increasing tidal exchange to these impounded mangrove forests could be a promising restoration activity. In-kind restoration conducted after the Tampa Bay spill involved, in part, restoring tidal circulation at a previous dredge disposal site where mangroves had been impounded by dikes.

Plant "nurse" habitat

Since mangrove propagules and seedlings grow best in sheltered conditions, one strategy for more exposed areas is to plant indigenous marsh plants such as *Spartina alterniflora* to create a nurse habitat. These plants grow quickly (one to two years), trap and hold sediments (which decreases erosion), and create a more sheltered habitat where young mangroves can establish themselves. This staged approach is modeled after natural successional patterns and boosts natural recruitment of mangroves (Mauseth et al. 2001).

Propagules may be available only during certain times of the year or may not distribute far from the parent tree due to poor circulation or blocking by debris. Removing floating debris that may block channels enables propagules to reach and recolonize denuded areas naturally.

Restore in-kind resources

Increasingly, in-kind restoration is used for projects in the United States, especially for resource damage settlements after oil spills. In-kind restoration restores habitat in a different location in the same ecosystem and is meant to contribute to the overall habitat function of the region.

A recent example of in-kind restoration is Tampa Bay, Florida, where several mangrove islets were heavily oiled during a spill in 1993. Restoration efforts purchased a former dredge disposal site within Tampa Bay that included degraded mangrove forest. Tidal connections were restored, marsh grasses were planted along the shoreline, and the land was deeded to the County to function as wildlife habitat and provide water filtering functions for the waters of Tampa Bay (see Case Studies for more detail).

For Further Reading

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