Article

**Elizabeth J. Farnsworth and Aaron M. Ellison**

# The Global Conservation Status of Mangroves

Despite considerable focus on mangroves in the scientific literature, an apparent universal appreciation for their biological and economic values, and the enactment of protective legislation, these tropical coastal forests continue to disappear globally, as a direct result of human activity. We report and rank current, primary conservation issues threatening mangrove forests at 38 sites in 16 nations and island states, based on discussions with local professional land managers, university scientists, villagers and village leaders, and regional government officials. While adequate relevant data to inform conservation efforts already exist in the scientific literature, this information must be disseminated more widely in a form that local nonscientists can use. Stand-structure data, analyses of rates and causes of deforestation, techniques for reforestation, and socioeconomic evaluations of benefits and costs to local communities of mangrove conservation must be developed and shared. Communication among biologists and lay people within and among regions should be enhanced, collaborations among social scientists and biologists must be fostered, and government support for conservation and restoration must be strengthened if mangrove ecosystems are to be sustained.

## INTRODUCTION

Mangrove forests comprise up to 50 species of woody halophytes restricted to sheltered saline tidal areas (1), and once occupied ≈ 75% of tropical coasts and inlets (2). Despite centuries of biological research on mangrove structure, productivity, and ecosystem dynamics (3), and a broad recognition by scientists, governments, and local populations of biotic and socioeconomic services mangrove forests provide to humans (4, 5), anthropogenic pressures are reducing the global range of mangrove forests. While accurate estimates of global deforestation rates of mangroves are as yet unavailable, its well-known environmental and socioeconomic impacts are observed and increasingly documented in coastal communities that depend directly on mangroves, and in upland communities with economic links to the coast.

Anthropogenic pressures on mangroves have been summarized extensively in the last decade in peer-reviewed journals and United Nations reports (4, 6–10). However, these studies are limited in distribution and are little known or used by local land managers or regional policy-makers. Throughout the world, complex biotic impacts on mangrove plant growth, forest structure, and ecosystem productivity have been documented exhaustively or demonstrated experimentally for: nutrients and sewage (11–14); petroleum, mine tailings, and other pollutants (15–19); agricultural herbicides and wartime defoliants (20, 21); rotational clearcut forestry (22); urbanization, population growth and reclamation (23–26); impoundment, road construction, water diversion and watertable changes (27–30); and aquaculture and salt-pond construction (31–34). While certain mangrove types, such as overwash island and scrub mangroves (35) may be particularly sensitive to, and slow to recover from perturbations (36, 37), these data overwhelmingly indicate that forest recovery is universally slow in all swamp types following high induced mortality if regeneration proceeds unassisted. Upland activities and pollutants exert substantial effects on productivity of mangrove downstream, and species richness of nearshore seagrass beds and coral reefs may decline when mangroves are destroyed.

The mere existence of these compelling empirical data is insufficient to guarantee effective global stewardship or restoration of mangrove forests. Data and expertise must be promulgated broadly among residents and managers of mangrove areas, in a practical format conducive to local applications and decision-making. This top-down approach to data distribution must be accompanied by grassroots cooperative and restorative activities among local governments and communities that limit mangrove deforestation.

Our primary objective here is to analyze what data are still needed to characterize, monitor, and protect these forests, and

**Table 1. Biogeographic distribution of principal mangrove species encountered in the survey.**

| | Country or Region[b] | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species[a] | Bel | Ecu | Ven | USA | Micro | Palau | Fiji | Tonga | Van | Aust | Mal | India | Mad | SAfr |
| Ac | | | | | | | | | | | | | | |
| Acr | | | | | | | | | | | X | | | |
| Ag | X | X | X | | | | | | | | | | | |
| Am | | | | | | | | | X | X | X | X | X | X |
| Ao | | | | | | | | | | | X | X | | |
| Bg | | | | | X | X | | X | X | | X | X | X | X |
| Bp | | | | | | | | | | X | X | | | |
| Bs | | | | | | | | | | | | | X | |
| Ce | X | X | X | | | | | | | | | | | |
| Ct | | | | | | X | | | X | X | X | X | | X |
| Ea | | | | | | | | X | | X | | | | |
| Lmr | | | | | | | | | | | | | X | X |
| Lr | X | X | X | | | | | | | | | | | |
| Nf | | | | | | | | | | | X | | | |
| Pr | | | X | | | | | | | | | | | |
| Ra | | | | | X | X | | | | X | X | X | X | |
| Rl | | | | | | | | | | X | | | | |
| Rma | X | X | X | X | | | | | | | | | | |
| Rmu | | | | | X | X | | | X | X | X | X | X | X |
| Rsa | | | | | | | X | X | | | | | | |
| Rst | | | | | | | | | X | X | | X | | |
| Sa | | | | | X | X | | | X | | X | X | X | |
| Sc | | | | | | | | | | | X | | | |
| Xg | | | | | X | | | | | X | | X | | |
| Xm | | | | | | | | | | X | | X | | |

[a]Key to mangrove species abbreviations: Ac = *Aegiceras corniculatum*; Acr = *Acrostichum aureum*; Ag = *Avicennia germinans*; Am = *Avicennia marina*; Ao = *Avicennia officinalis*; Bg = *Bruguiera gymnorrhiza*; Bp = *Bruguiera parviflora*; Bs = *Bruguiera sexangula*; Ce = *Conocarpus erectus*; Ct = *Ceriops tagal*; Ea = *Exoecaria agallocha*; Lmr = *Lumnitzera racemosa*; Lr = *Laguncularia racemosa*; Nf = *Nypa fruticans*; Pr = *Pelliciera rhizophoreae*; Ra = *Rhizophora apiculata*; Rl = *Rhizophora x lamarckii*; Rma = *Rhizophora mangle*; Rmu = *Rhizophora mucronata*; Rsa = *Rhizophora samoensis*; Rst = *Rhizophora stylosa*; Sa = *Sonneratia alba*; Sc = *Sonneratia caseolaris*; Xg = *Xylocarpus granatum*; Xm = *Xylocarpus mekongensis*

[b]Country abbreviations are listed in order of their enumeration in Tables 2–5, with the exception of Belize (Bel), which is shown with other neotropical countries.

**Felling mangrove logs for charcoal production, peninsular Malaysia. Photo: E.J. Farnsworth.**

to articulate current hindrances to their conservation. We discuss primary conservation threats to 38 mangrove forests in 16 countries and island states that we visited during 1994–1995. This information was amassed through site visits and extensive discussions with local scientists, managers, lay people, and government representatives. As field biologists, we are most competent to discuss ecological impacts of anthropogenic stresses on mangrove forests. However, we stress that the severity of these impacts, and the prognosis for conservation, restoration, or management of degraded mangrove forests depend integrally on three other factors: i) socioeconomic status of associated communities; ii) local and global demands for mangrove products; and iii) accurate evaluation of the efficacy of existing mangrove management and conservation programs (4, 38, 39). We, therefore, urge biologists and social scientists to collaborate in interdisciplinary analyses of mangrove degradation (40).

## SURVEY METHODS

Between October 1994 and March 1995, we surveyed 38 coastal, island, and estuarine mangrove stands in 16 nations and island states throughout the neo- and paleotropics. These visits constituted part of an expedition characterizing global biogeography of animal-plant interactions in mangroves, and sites were chosen for accessibility by foot or boat, and for known invertebrate species richness. The sites we visited are a diverse subset of mangrove forest types found throughout the world. Site physiography was categorized according to Lugo's classification system (36); many sites contained more than one physiographic type. Because we focused on mangroves with correspondingly high diversity of associated fauna, we visited more fringing mangrove wetlands (28 of 38 sites) than riverine (13 sites), basin (11 sites), or scrub (5 sites) stands. Carbonate-based overwash islands were particularly frequent in the Caribbean and Pacific (8 sites). We did not visit any hammock forests. Our potential sample bias toward accessible, and thus well-exploited areas, may be offset by our bias toward relatively "pristine" sites known for high invertebrate species richness. Mangrove species richness increases from east to west globally (1), peaking in the Indo-Pacific region; the numbers of mangrove species encountered in our survey reflect this biogeographic pattern (Table 1).

We discussed at length, species composition, forest structure, productivity, principle conservation issues, perceived health or decline, and recent demographic shifts in canopy dominants of mangrove forests with local scientists, students, residents, village landowners, and government workers who hosted and accompanied us on site visits. Our objective was to compile sufficient standardized information to document major anthropogenic impacts impinging on these forests. While the format of our expedition did not permit us to conduct a survey using standardized instruments such as questionnaires or recorded interviews, clear commonalities emerged in our conversations with diverse constituencies. The types of data we collected are relatively simple to gather consistently and rapidly during site visits, can be standardized and shared widely, and can form the foundation for comparative databases.

## RESULTS

*Conservation issues*: Several broad conservation problems were repeatedly identified throughout the world (Tables 2–5). Their ranked frequency of occurrence generally was not correlated with the perceived significance of their impact (Table 6). The primary exception was clearcutting and reclamation, which was the most common activity we witnessed and the most serious threat perceived by local constituencies. Clearcutting and reclamation of several hectares to many km$^2$ for agriculture and aquaculture (6 sites), urban expansion (5 sites), and resort development (10 sites) threatened the majority (55%) of all sites visited. Within 1994, prior to our visit, several north and south Pacific islands

**Table 2. Survey findings on the regeneration and conservation status of mangroves from 5 sites in Central and South America, listed in chronological order of site visits.**

| Country | Location | Coordinate[a] | Type/ Area[b] | Principle conservation issues[c] |
|---|---|---|---|---|
| Ecuador | Galapagos Islands | 0° 36'S 90° 50'W | b, c 4 | Firewood use by sea cucumber harvesters; isolation from enforcement; difficult regeneration. (*) P |
| | Esmeraldas - Majagual | 0° 36'N 80° 10'W | e, f 2 | Shrimp ponds; cattle ranching; clearing for village expansion; sewage. (*) |
| Venezuela | Morrocoy | 10° 55'N 68° 16'W | b, c 2 | Garbage disposal, clearing for coconuts and firewood. P |
| | Isla Margarita | 10° 58'N 64° 10'W | b, c 3 | Clearing for tourism. (*) P |
| Belize | Cays | 16° N 88° W | a 3 | Allocation of leases for tourism development; solid waste; cutting wood for contruction, fuelwood. (*) P |

[a] Sites were located using a portable global positioning system (Trimble Instruments, Torrance, California). Because certain regions surveyed encompass several sites (i.e. the Galapagos Islands), coordinates are reported to nearest degree and minute only.

[b] "Type" indicates the primary mangrove community types encountered at each site, using Lugo's 1980 categories (36): a) overwash island; b) fringing coastal mangal; c) mangrove scrub; d) hammock formation; e) riverine mangal; f) wetlands occupying basin depressions. Approximate "area" inspected directly by us is denoted as: 1) < 1 ha; 2) 1-10 ha; 3) 10-50 ha; 4) > 50 ha.

[c] An asterisk denotes sites that were described by local authorities as "recently declining" in terms of increased mortality or morbidity of trees, and "P" indicates that the site is nominally protected as a national/local park, Biosphere Reserve, or private holding.

**Table 3. Survey findings on the regeneration and conservation status of mangroves from 15 sites in the North and South Pacific Islands, listed in chronological order of site visits. Superscripts and symbols as in Table 2.**

| Country | Location | Coordinate[a] | Type/ Area[b] | Principle conservation issues[d] |
|---|---|---|---|---|
| USA | Oahu, Pearl Harbor | 22°N 158°W | a,b 2 | *Rhizophora* is an introduced species; oil pollution; sewage. |
| | Oahu, Kaneohe Fishpond | 21° 30'N 157° 47'W | a,b 2 | Boat traffic; clearing for tourism. |
| Micronesia | Kosrae, Walung | 5° 17'N 162° 54'E | b,e 2 | Road construction; damming and water diversion; sewage; boat traffic. (*) |
| | Pohnpei, Southwest of Kolonia | 6° 48'N 158° 11'E | b 2 | Road construction; boat traffic; commercial fishing; artesanal timbering; solid waste. (*) |
| | Pohnpei, Temwen Island | 6° 50'N 158° 18'E | a 1 | Agricultural conversion and runoff; boat traffic; village timber use. |
| | Yap, Gurong | 9° 33'N 138° 06'E | b 2 | Storms; road construction; sewage; timber use in construction. (*) |
| | Yap, Colonia Channel | 9° 34'N 138° 09'E | b,e 3 | Storms; sewage; road construction; boat traffic; agricultural conversion/runoff. (*) |
| Palau | Koror | 7° 21'N 134° 29'E | a,b 1 | Boat traffic; sewage; garbage dumping. (*) |
| | Rock Islands, Jellyfish Lake | 7° 09'N 134° 22'E | b 1 | Tourist traffic. P |
| Fiji | Nadi | 17° 41'S 177° 34'E | b,e,f 1 | Agricultural conversion and runoff; sewage; garbage dumping. |
| | Ba river delta | 17° 30'S 168° 20'E | e,f 2 | Agricultural conversion and runoff; sewage; garbage dumping, tourist traffic. |
| Tonga | Faloha, Tongatapu | 21° 10'N 175° 11'E | b 2 | Agricultural conversion and runoff; sewage. (*) |
| Vanuatu | Port Vila | 17° 41'S 168° 20'E | b 2 | Cyclones; tourism development. |
| | Lakatoro, Malekula | 16° 06'S 167° 25'E | b 2 | Commercial fishing dredging; agricultural conversion; artesanal harvesting. |
| | Litslits, Malekula | 16° 06'S 167° 26'E | b 3 | Commercial fishing dredging; agricultural conversion; artesanal harvesting. |

(5 sites) had been approached by foreign interests with offers to clearcut mangroves to produce wood chips for industrial manufacture of rayon. At several sites, international ventures were supported by local government incentives promoting mangrove conversion (Ecuador, Belize, Malaysia). These interests were described as overriding recommendations of local biologists and the stated policies of village land-managers. The unregulated clearcutting we witnessed entailed removal of all trees (± stumps) without subsequent seedling replanting. Compaction and hypersalinization of soil, and diversion of freshwater were observed side-effects of clearcutting.

At smaller areal scales (0.1–10 ha), we observed harvests of individual mangrove stems for fuelwood, poles, and artesanal materials at 13 sites, four of which were parks where such harvests are nominally prohibited (Tables 2–5). At these 13 sites, low-intensity harvesting exceeded re-sprouting rates, and many mangroves are physiologically unable to coppice (1). Because young stems were taken preferentially, reproductive potential of standing trees was projected to be limited, and concomitant seedling regeneration was sparse. Understory seedling density, an indicator of natural regeneration capacity, was ≤ 1 $m^{-2}$ at 10 sites (Table 6).

Non-point source impacts, including sewage, agricultural runoff, industrial and oil pollution, affected 25 (66%) sites (Tables 2–5), but ranked low in perceived significance because it was difficult to gauge scale and severity of damage directly attributable to them (Table 6). Dumping of garbage and solid waste into mangroves was particularly visible in South America (Table 2) and the Pacific Islands (Table 3), but was regarded more as an eyesore by residents and visitors than as a threat to mangroves. Nonanthropogenic disturbances, including seasonal cyclonic storms and regionally changing tidal and hydrologic regimes, were sporadic agents of long-term, landscape-level changes primarily in the Pacific islands (Table 3) and the Indian Sundarbans (Table 4).

Seventeen (44%) sites were identified by local biologists as having declined significantly within the past decade, in terms of areal shrinkage or increased mortality and morbidity of trees (Tables 2–5). In 10 sites, local fishermen and aquaculturalists articulated mangrove degradation in terms of observed declines in marine productivity. In 5 areas in the Pacific islands, mangrove decline was attributed to sudden alterations in hydrology where road or bund construction had diverted freshwater stream flow away from mangrove swamps (Table 3). Pollution, increased sewage input, and uncontrolled logging were blamed for decline in the other cases. In 6 areas, local biologists explicitly predicted that the current mangrove community would completely disappear (through die-back or conversion) within the coming decade if present trends were not reversed. Only in 4 mangrove areas, which were being developed for ecotourism and education, did local biologists note an improvement in mangrove survivorship. No mangrove areas were described as actively expanding.

*Local attitudes toward mangroves*: Village leaders, professional naturalists and land managers, local biologists, fishermen, and regional government officers—all with a range of educational training, expertise, and incentives—evinced broad comprehension of mangrove values. Without prompting by us, they articulated empirical and intuitive links between mangroves and harvestable marine products, and between mangroves and adjacent seagrass beds and coral reefs. The most significant mangrove functions for human welfare were identified and ranked as: i) habitat for juvenile phases of commercially important fish, prawns, gastropods and bivalves; ii) protection of coasts from erosion and storm surges; iii) production of polewood, timber, thatch, carving wood, fuelwood and charcoal; iv) extraction of tannins, cellulose and other chemicals for manufacturing; and v) provision of livestock fodder, food and medicinals. Two exceptions in attitudes were noted among shrimp-farm owners in Ecuador and India, who viewed mangroves as physical impediments to aquaculture development. These individuals did not recognize either benefits of maintaining mangrove plantings or buffers around shrimp ponds, or the demonstrated role of mangroves as habitat for juvenile prawns (6, 41, 42).

## DISCUSSION

Three factors affect how mangroves respond to anthropogenic disturbance: i) the extent, intensity, and duration of perturbation; ii) availability of regenerants (natural or hand-planted seedlings banks); and iii) rate of seedling reestablishment and canopy closure. The scale of damage and potential for recovery also depend critically on the identities, motivations, and activities of responsible agents (40). Before economic alternatives to mangrove conversion can be developed and promulgated, the multiple interacting local, international, and industrial cadres responsible for these activities must be specified.

We observed direct conservation threats to mangroves on scales ranging from $m^2$ to $km^2$, with large-scale deforestation from ha to $km^2$ being the most widespread (Table 6). Mangrove deforestation has been discussed widely in international publications (4–6), but the direct and indirect roles of industries, governments and tourism operations in encouraging this deforestation has received less attention than the activities of local villagers contributing to mangrove decline. While economic and demographic imperatives motivate small-scale clearcutting of mangroves by local residents, government incentives support international ventures promoting large-scale deforestation and conversion. These indirect agents encourage mangrove loss by: i) under-valuing or distorting economic values of intact mangrove

**Table 4. Survey findings on the regeneration and conservation status of mangroves from 14 sites in Australia, Asia and India, listed in chronological order of site visits. Superscripts and symbols as in Table 2.**

| Country | Location | Coordinate[a] | Type/ Area[b] | Principle conservation issues[d] |
|---|---|---|---|---|
| Australia | Townsville Environmental Park | 19° 12'S 146° 44'E | c, f 2 | Hypersalinity; water diversion; storms; sewage. P |
| | Lucinda, Gentle Annie Creek | 18° 31'S 46° 19'E | e, f 3 | Road construction; agricultural conversion and runoff; tourism development. |
| | Lucinda, Dungeness Creek | 18° 32'S 146° 19'E | e, f 2 | Road construction; agricultural conversion and runoff; tourism development. |
| | AIMS mangal | 19° 17'S 147° 02'E | b 3 | Storms; drought; shifting hydrology. P |
| | AIMS beach | 19° 16'S 147° 02'E | b 1 | Storms; drought; sewage; boat traffic. |
| | Magnetic Island | 19° 10'S 146° 49'E | b, f 2 | Storms; tourism development; road construction; water diversion. P |
| Malaysia | Sungei Sementa Kecil, Selangor | 3° 04'N 101° 22'E | e 3 | Poaching wood for poles, fuelwood, city development (*) |
| | Matang | 4° 50'N 100° 37'E | b, e, f 3 | Edge erosion, solid and sewage waste; trampling; *Achrostichum* fern invasion. |
| | Sarawak - Bako National Park | 1° 42'N 110° 26'E | a, b 3 | Edge erosion, over-fishing; coastal development. (*) P |
| | Terengganu - Marang | 5° 40'N 103° 20'E | e 3 | Road-building; resort development; industrial and oil pollution. (*) |
| | Sibu Island | 2° 13'N 104° 04'E | a, b, f 3 | Cutting for fuelwood; resort development; clearing for livestock and coconut. |
| India | Andamans - Jolly Buoy Island | 11° 30'N 92° 37'E | b 1 | Protected; boat traffic; poaching for fuelwood. |
| | Andamans - Wandoor Village | 22° 07'N 88° 49'E | b 1 | Clearing for village expansion, livestock, timber, fuelwood; sewage. (*) |
| | Sundarbans Reserve | 22° 07'N 88° 49'E | b, e, f 4 | Village expansion; sewage; shrimp culture; changing river hydrology. (*) P |

**Table 5. Survey findings on the regeneration and conservation status of mangroves from 4 sites in Madagascar and Africa, listed in chronological order of site visits. Superscripts and symbols as in Table 2.**

| Country | Location | Coordinate[a] | Area[b] | Type/ Principle conservation issues[d] |
|---|---|---|---|---|
| Madagascar | Nosy Be - Lokobe | 13° 22'S 48° 11'E | b 2; | Village cutting for fuelwood; clearing for crops and livestock resort development. |
| South Africa | St. Lucia Estuary | 28° 21'S 32° 24'E | e 3 | Resort development; boat traffic; over-fishing; squatter poaching. P |
| | Durban - Beechwod Park | 29° 48'S 31° 02'E | b,e,f 2 | Real estate development; changes in city water outflow; urban pollution. (*) P |
| | Durban Bay Head | 29° 53'S 31° 00'E | a,b 1 | Urban sewage and oil pollution; clearing for port expansion. (*) |

systems; ii) exacerbating economic stresses of largely low-income, fast-growing local populations who are driven to exploit mangroves despite clear signs of degradation (43); iii) usurping property and land-use rights from communities inhabiting mangrove areas (44, 45); iv) subsidizing mangrove destruction to meet short-term market demands and discounting long-term costs of resource loss; and v) confounding ethical consumption choices by both local users and remote consumers of mangrove products or ecosystem services (38). A complete analysis of the complex indirect driving forces in global mangrove deforestation is beyond both our expertise and the scope of the present paper; insightful reviews of links between economic forces and biodiversity loss are emerging (e.g., 38). However, it is critical to recognize both proximate and indirect agents that propel the process of mangrove decline. Changes in both scientific data-sharing and economic policy are needed to bring personal and societal ethics and market practices in line with sustainable management.

**Table 6. Distribution and perceived significance of major conservation challenges affecting mangroves in survey areas.**

| Conservation impact | Number (%) of sites | Importance[a] |
|---|---|---|
| Reclamation for village expansion, agriculture, tourism, shrimp ponds | 21 (55.3) | 10 |
| Sewage release into mangroves from nearby settlements | 19 (50.0) | 1 |
| Commercial or artesanal timbering for poles, lumber, chips, fuelwood | 13 (34.2) | 4 |
| Freshwater diversion due to construction of roads, bunds | 12 (31.6) | 5 |
| Oil and other pollutants | 11 (28.9) | 0 |
| Boat wakes and other tourist activities in mangroves | 11 (28.9) | 3 |
| Lack of seedling regeneration at time of survey: sparse seedling bank (<1 $m^{-2}$) or high mortality of seedlings | 10 (26.3) | 0 |
| Storm damage | 7 (18.4) | 6 |
| Garbage and solid waste dumping in mangroves | 6 (15.8) | 1 |
| Erosion or naturally shifting hydrology | 4 (10.5) | 3 |
| Depletion of mangrove detritivores - commercial fishing and dredging | 4 (10.5) | 4 |

[a] Importance was defined as the number of areas for which the problem was ranked as the primary threat to mangroves.

We propose that two primary research programs are needed to address the primary, direct conservation threats we identified in this survey: i) detection and quantification of mangrove forest loss; and ii) development of restoration techniques. We also suggest that benefits and costs to local communities should be incorporated explicitly in economic analyses of mangrove conversion.

### Quantification of Mangrove Forest Loss

Reliable data on the areal extent of mangrove forests are difficult to obtain or nonexistent for many countries. While local experts identified 40% of visited sites as "declining," few tools, beyond our own eyes, substantiate these claims. Existing data generally reflect inaccurate, uncorroborated, and decades-old estimates repeated apocryphally throughout the literature (4, 6). Since precise areal ranges of mangroves are unknown for many regions, prognoses for their relative sensitivity, loss, or recovery cannot yet be developed. Remote-sensing (Landsat thematic mapping) has been used successfully to quantify mangrove losses in India (46), Ecuador (33), and Thailand (47); aerial reconnaissance and shuttle aperture radar can be used in cloudy areas (31, 48). Ground-truthing of mangrove forest structure by locally-trained volunteers is feasible in these species-poor forests. While FAO recommended that these types of analyses should be employed more widely (6), they failed to assert that legislative impediments and military bans on aerial data-gathering must be lifted and adequate in-country resources for training, equipment, and ground-truthing efforts be made available. Monitoring can help identify the scope of mangrove decline, and provides a necessary, but insufficient, enforcement tool for conservation.

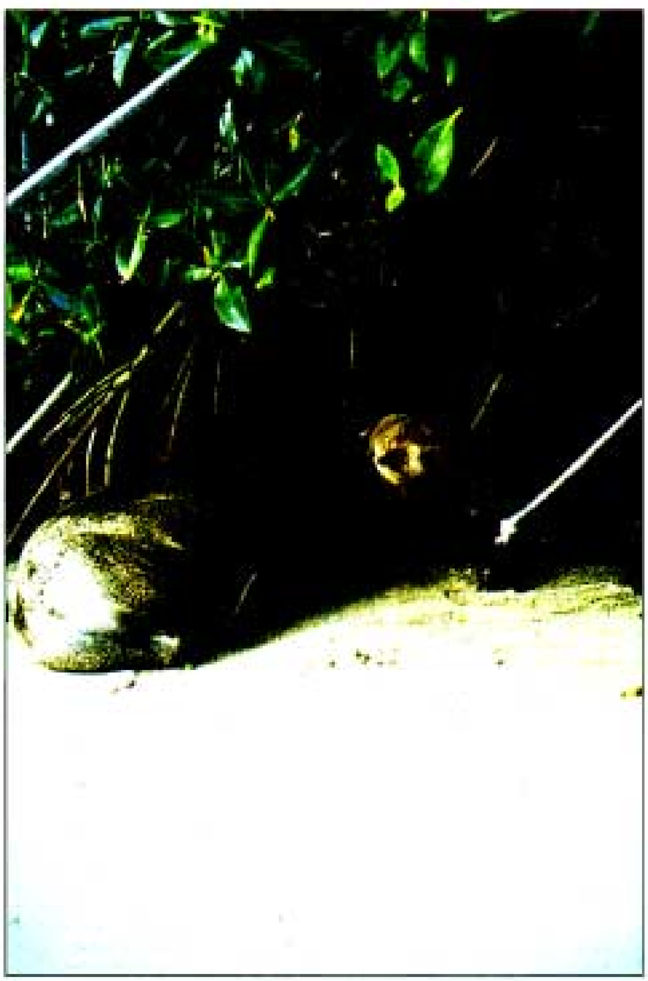
### Reforestation

Although mangrove forestry is demonstrably feasible when seedling replanting occurs (6, 22), most clearcuts that we witnessed were unmonitored and unaccompanied by afforestation. Clearcutting rapidly alters geomorphology and soil chemistry of tidal wetlands; if reforestation is not swift, erosion, hypersalinity, acidification, accumulation of soil sulfides, and invasion by aggressive early colonizers can preclude unassisted re-growth of mangroves (6). Sustainable mangrove agroforestry should incorporate adequate adult seedling sources and understory seedling banks to permit successional regeneration following perturbation (45, 49). Our data indicating a species-poor and sparse seedling bank were derived from a single static survey; seedling recruitment densities vary seasonally and among species

**Poles of mangrove (*Rhizophora stylosa*) are used for house construction in Yap, Federal States of Micronesia. Photo: E.J. Farnsworth.**

(50). Long-term demographic studies are needed to determine which sites support sufficient advance regeneration and which will require supplemental plantings. Asian studies have shown that seedling banks alone are insufficient, especially where invasive ferns (*Achrostichum* spp.) colonize the understory (51). Hand-planting is labor- and time-intensive, but can provide employment for local residents, as in the Indian Sundarbans (52). Plantation productivity can decline over many decades (49), though the generality of this phenomenon has not been widely tested. Concomitant long-term changes in species richness of associated mangrove fauna in plantations have not been quantified, and a challenge in replanting schemes will be to restore simultaneously the soil profile and microbial richness in degraded mangrove systems (53).

Especially in the neotropics, where transient shrimp ponds are replacing mangroves at unprecedented rates, trials for companion planting or reforestation with mangroves are necessary. The advantages of "intercropping" mangroves and fisheries were acknowledged by aquaculturalists whom we met, but to our knowledge, restoration or mangrove-shrimp intercropping have not been attempted in the neotropics. However, creative efforts directed at both these aims can now be launched, given existing knowledge and more inter-regional data-sharing. Guidelines for mangrove plantation agroforestry to rehabilitate degraded coastal areas used for tambak and shrimp aquaculture have been developed in Asia (6, 54–56). These silvicultural techniques could be combined with neotropical studies of seedling demography and ecophysiology (50, 57) in the management and restoration of shrimp ponds. We emphasize that *a priori* conservation of mangroves is preferable to *a posteriori* restoration. However, the success of either depends ultimately on the motivation and economic ability of diverse mangrove exploiters to effect reforestation: an institutional infrastructure of supports and incentives must be in place.



**Mangroves of the Galápagos Islands support highly unusual faunal associates, including these sea lions. Photo: E.J. Farnsworth.**

**Benefits and Costs of Mangrove Conversion**

Translating utilitarian values of many ecosystems into economic gain is problematic. Despite high economic returns from mangrove agroforestry (6), associated fisheries and ecotourism (58, 59), local communities as yet appear to receive little income from these activities. For example, although four areas developed for mangrove ecotourism were characterized by local biologists as "improving," ecological effects of increased solid waste, erosive boat wakes, and noise (three side-effects of tourism we witnessed first-hand) have not been characterized empirically in mangroves (60). Managers and coastal residents pointed out that unless adjacent communities receive a proportionate share of economic benefits, few incentives accrue to leaving mangroves in place. Mangrove declines can be reversed when local communities assume control over common property rights and adopt alternative strategies for resource use (61). Fifteen years ago, Saenger et al. highlighted the need for data on socioeconomic status of communities associated with mangroves (4); this remains a lacuna in need of attention.

## CONCLUSIONS AND RECOMMENDATIONS

Human activities are not necessarily inimical to mangroves. Many of the problems we identify have emerged relatively recently, within the memories of our colleagues. Likewise, "success stories" in apparently sustainable mangrove use exist, and can provide the foundation for future management decisions (4, 22, 61). The time is ripe and critical for practical and direct reform at both local and national levels, and thousands of pages of scientific literature already exist to inform this process (over 2500 in the references to this paper alone). Yet, distribution of this literature among managers, government personnel, and scientists with whom we spoke was limited, due to both a paucity of academic libraries and a lack of communication among international researchers and in-country constituencies. We were told that data from local field studies, collected by foreign agencies and personnel, were not made readily available to local biologists, especially in South America and some Pacific islands. Likewise, minimal international discourse occurs among biologists in developing countries who lack resources to participate in workshops and conferences. We encourage researchers to 'publish globally but disseminate locally' lest their findings remain unused by professional and unpaid land managers who need them most.

Conservation biologists can—and in many areas, do—promulgate useful information on mangrove benefits and effects of their destruction to local populations exploiting mangroves on small scales. Where multinationals are involved in wholesale clearing of mangroves, international pressure must be brought to bear on national governments and international corporations, using the enormous weight of existing empirical evidence regarding consequences of coastal deforestation. Legislative reform is undermined by politically-driven reductions in resources, climates in which scientists are discouraged from speaking out against "development," and poor communication among underfunded enforcement agencies. In countries where mangrove management plans exist, we saw little evidence that monitoring or restoration occurs. Although the majority of countries we visited have instituted laws protecting mangroves and requiring *a priori* review of conversion projects (4), enforcement is lax (62).

Although much useful scientific information is available, data of theoretical and practical interest still should be garnered from continued basic field research. For example, little is as yet known about mangrove genetic diversity (1), biodiversity of mangrove associates, or potential responses to projected global climate change and sea level rise (7). At all scales, simplistic but long-standing paradigms still persist, and can be applied inappropriately by people who are under-informed of new data or removed from policy decisions. Beyond data, the nested hierarchy of complex interactions among local, national, and international economic imperatives—to which we alluded earlier—influences both the rate of mangrove destruction and the strength of conservation efforts. Scientific understanding can inform local and national policy decisions, but only if data are widely shared, all parties affected by decisions are involved in the decision-making process, and mangroves are designated a genuine administrative priority.

## References and Notes


1. Tomlinson, P.B. 1986. *The Botany of Mangroves*. Cambridge University Press, Cambridge, UK.
2. Chapman, V.J. 1976. *Mangrove Vegetation*. Cramer, Vaduz, Lichtenstein.
3. Rollet, B. 1981. *Bibliography on Mangrove Research, 1600–1975*. UNESCO, Paris, France.
4. Saenger, P., Hegerl, E.J. and Davie, J.D.S. 1983. Global status of mangrove ecosystems. *The Environmentalist 3 (Suppl. 3)*, 1–88.
5. Japan International Association for Mangroves (JIAM) and International Society for Mangrove Ecosystems (ISME). 1993. *The Economic and Environment Value of Mangrove Forests and their Present State of Conservation*. Report PCF(XII)/14 of the International Tropical Timber Association, Kuala Lumpur, Malaysia.
6. Food and Agriculture Organization of the United Nations. 1994. *Mangrove Forest Management Guidelines*. FAO Forestry Paper 117, Rome.
7. Field, C.D. 1995. Impact of expected climate change on mangroves. *Hydrobiologia 295*, 75–81.
8. Groombridge, B. (ed.). 1992. *Global Biodiversity: Status of the Earth's Living Resources*. Chapman and Hall, London, UK.
9. Marshall, N. 1995. Mangrove conservation in relation to overall environmental considerations. *Hydrobiologia 285*, 303–309.
10. Hatcher, B.G., Johannes, R.E. and Robertson, A.I. 1989. Review of research relevant to the conservation of shallow tropical marine ecosystems. *Oceanogr. Mar. Biol. Ann. Rev. 27*, 337–414.
11. Dwivedi, S.N. and Padmakumar, K.G. 1984. Ecology of a mangrove swamp near Juhu Beach, Bombay, with reference to sewage pollution. In: *Biology and Ecology of Mangroves*. Teas, H.J. (ed.). Tasks for Vegetation Science vol. 8. Dr. W. Junk, The Hague, pp. 163–170.
12. Boto, K. 1992. Nutrients and mangroves. In: *Pollution in Tropical Aquatic Systems*. Connell, D. and Hawker, D. (eds). CRC Press, Boca Raton, Florida, USA, pp. 129–145.
13. Mackey, A.P., Hodgkinson, M. and Nardella, R. 1992. Nutrient levels and heavy metals in mangrove sediments from the Brisbane River, Australia. *Mar. Pollut. Bull. 24*, 418–420.
14. Petr, T. 1979. Possible environmental impact on inland waters of two planned major engineering projects in Papua New Guinea. *Environ. Conserv. 6*, 281–286.
15. Walsh, G.E., Ainsworth, K.A. and Rigby, R. 1979. Resistance of red mangrove (*Rhizophora mangle* L.) seedlings to lead, cadmium and mercury. *Biotropica 11*, 22–27.
16. Lewis, R.R. 1984. Impact of oil spills on mangrove forests. In: *Biology and Ecology of Mangroves*. Teas, H.J. (ed.). Tasks for Vegetation Science vol. 8. Dr. W. Junk, The Hague, pp. 171–184.
17. Wolanski, E. 1992. Hydrodynamics of tropical coastal marine systems. In: *Pollution in Tropical Aquatic Systems*. Connell, D. and Hawker, D. (eds). CRC Press, Boca Raton, Florida, USA, pp. 3–27.
18. Garrity, S.D., Levings, S.C. and Burns, K.A. 1994. The Galeta oil spill. I. Long-term effects on the physical structure of the mangrove fringe. *Estuar. Coast. Shelf Sci. 38*, 327–348.
19. Klekowski, E.J., Jr., Corredor, J.E., Morrell, J.M. and Delcastillo, C.A. 1994. Petroleum pollution and mutation in mangroves. *Mar. Pollut. Bull. 28*, 166–169.
20. Westing, A.H. and Westing, C.E. 1981. Endangered species and habitats of Viet Nam. *Environ. Conserv. 8*, 59–62.
21. Culic, P. 1984. The effects of 2,4-D on the growth of *Rhizophora stylosa* Griff. seedlings. In: *Physiology and Management of Mangroves*. Teas, H.J. (ed.). Tasks for Vegetation Science vol. 9. Dr. W. Junk, The Hague, pp. 57–64.
22. Gong, W.K. and Ong, J.E. 1990. Plant biomass and nutrient flux in a managed mangrove forest in Malaysia. *Estuar. Coast. Shelf Sci. 31*, 519–530.
23. Moll, E.J., Ward, C.J., Steinke, T.D. and Cooper, K.H. 1971. Our mangroves threatened. *African Wildlife 25*, 103–107.
24. Singh, V.P., Garge, A., Pathak, S.M., and Mall, L.P. 1986. Mangrove forests of Andaman Islands in relation to human interference. *Environ. Conserv. 13*, 169–172.
25. Balaparameswara Rao, M., Rao, P.N., Reddy, D.L., Rambabu. A.V.S., and Prasad, B.V. 1987. Ecological changes in a tropical mangrove ecosystem due to human impact. *Trop. Ecol. 28*, 232–238.
26. Nurkin, B. 1994. Degradation of mangrove forests in south Sulawesi, Indonesia. *Hydrobiologia 285*, 271–276.
27. Harrington, R.W. and Harrington, E.S. 1982. Effects on fishes and their forage organisms of impounding a Florida salt marsh to prevent breeding by salt marsh mosquitos. *Bull. Mar. Sci. 32*, 523–531.
28. Zucca, C. 1982. The effects of road construction on a mangrove ecosystem. *Trop. Ecol. 23*, 105–124.
29. Gordon, D.M. 1988. Disturbance to mangroves in tropical and western Australia: hypersalinity and restricted tidal exchange as factors leading to mortality. *J. Arid Env. 15*, 117–145.
30. Maragos, J.E. 1993. Impact of coastal construction on coral reefs in the U.S.-affiliated Pacific Islands. *Coast. Mgmt 21*, 235–269.
31. Terchunian, A., Klemas, V., Segovia, A., Alvarez, A., Vasconez, B. and Guerrero, L. 1986. Mangrove mapping in Ecuador: the impact of shrimp pond construction. *Environ. Mgmt 10*, 345–350.
32. Mepham, R.H. and Petr, T.(eds). 1994. *Papers Contributed to the Workshop on Strategies for the Management of Fisheries and Aquaculture in Mangrove Ecosystems, Bangkok, Thailand, June 1986*. FAO Fisheries Report 370, Supplement. Rome, Italy.
33. Ministerio de Agricultura y Ganaderia (MAG) and Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos (CLIRSEN). 1991. *Inventario de Manglares del Ecuador Continental*. Quito, Ecuador. (In Spanish).
34. Lee, S.Y. 1992. The management of traditional tidal ponds for aquaculture and wildlife conservation in Southeast Asia: problems and prospects. *Biol. Conserv. 63*, 113–118.
35. Lugo, A.E. and Snedaker, S.C. 1974. The ecology of mangroves. *Ann. Rev. Ecol. Syst. 5*, 39–64.
36. Lugo, A.E. 1980. Mangrove ecosystems: successional or steady state? *Biotropica 2 (Suppl.)*, 65–72.
37. Parkinson, R.W., DeLaune, R.D., and White, J.R. 1994. Holocene sea-level rise and the fate of mangrove forests in the wider Caribbean region. *J. Coast. Res. 10*, 1077–1086.
38. Perrings, C., Folke, C. and Mäler, K.-G. 1992. The ecology and economics of biodiversity loss: the research agenda. *Ambio 21*, 201–211.
39. Folke, C. 1996. Conservation, driving forces, and institutions. *Ecol. Appl. 6*, 370-372.
40. Blaikie, P. and Brookfield, H. 1987. *Land Degradation and Society*. Methuen, London, UK.
41. Flores-Verdugo, F., Gonzalez-Farias, F., Ramirez-Flores, O., Amezcua-Linares, F., Yañez-Arancibia, A., Alvarez-Rubio, M. and Day, J. 1990. Mangrove ecology, aquatic primary productivity, and fish community dynamics in the Teacapan-Agua Brava lagoon-estuary system. *Estuaries 13*, 219–230.
42. Larsson, J., Folke, C. and Kautsky, N. 1994. Ecological limitations and appropriation of ecosystem support by shrimp farming in Colombia. *Ecol. Mgmt 18*, 663–676.
43. Perrings, C. 1989. An optimal path to extinction? Poverty and resource degradation in the open agrarian economy. *J. Develop. Econ. 30*, 1–24.
44. Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge, UK.
45. Johannes, R.E. 1992. Marine resources managements in the context of customary tenure. *Mar. Res. Econ. 7*, 249–273.
46. Nayak, S.A., Pandeya, A., Gupta, M.C., Trivedi, C.R., Prasad, K.N., and Kadri, S.A. 1989. Application of satellite data for monitoring degradation of tidal wetlands of the Gulf of Kachchh, Western India. *Acta Astron. 20*, 171–178.
47. Aschbacher, J., Ofren, R., Delsol, J.P., Suselo, T.B., Vibulsresth, S. and Charrupat, T. 1995. An integrated comparative approach to mangrove vegetation mapping using advanced remote sensing and GIS technologies: preliminary results. *Hydrobiologia 295*, 285–294.
48. Ong, J.E., Gong, W.K., Wong, Y.P. and Wong, H.K. 1992. Identification of mangrove vegetation zones using MicroBRIAN and LANDSAT imagery. In: *Third ASEAN Science and Technology Week Conference Proceedings, Volume 6*. Chou, L.M. and Wilkinson, C.R. (eds). National University of Singapore, Singapore. pp, 383–386.
49. Gong, W.K., Ong, J.E., Wong, C.H. and Dhanarajan, G. 1984. Productivity of mangrove trees and its significance in a managed mangrove ecosystem in Malaysia. In: *Proceedings of the UNESCO Asian Symposium on Mangrove Environments—Research and Management*. Soepadmo, E., Rao, A.N. and Macintosh, D.J. (eds). Universiti Malaya, Malaysia, pp. 216–225.
50. Ellison, A.M. and Farnsworth, E.J. 1993. Seedling survivorship, growth and response to disturbance in Belizean mangal. *Am. J. Bot. 80*, 1137–1145.
51. Srivastava, P.B.L., Keong, G.B. and Muktar, A. 1987. Role of *Achrostichum* species in natural regeneration of *Rhizophora* species in Malaysia. *Trop. Ecol. 28*, 274–288.
52. De, S. 1990. *The Sundarbans*. Oxford University Press, Calcutta, India.
53. Alongi, D.M. 1994. The role of bacteria in nutrient recycling in tropical mangrove and other coastal benthic ecosystems. *Hydrobiologia 285*, 19–32.
54. de la Cruz, A.A. 1984. A realistic approach to the use and management of mangrove areas in Southeast Asia. In: *Biology and Ecology of Mangroves*. Teas, H.J.(ed.). Tasks for Vegetation Science vol. 8. Dr. W. Junk, The Hague, pp. 65–68.
55. Weinstock, J.A. 1994. *Rhizophora* mangrove agroforestry. *Econ. Bot. 48*, 210–213.
56. Gong, W.K. and Ong, J.E. 1995. The use of demographic studies in mangrove silviculture. *Hydrobiologia 295*, 255–261.
57. Smith, T.J. III, Robblee, M.B., Wanless, H.R. and Doyle, T.W. 1994. Mangroves, hurricanes and lightning strikes. *BioScience 44*, 256–262.
58. Torhaug, A. 1987. Restoration of mangroves and seagrasses and attendant economic benefits for fisheries and mariculture: management, policy and planning. In: *Papers Contributed to the Workshop on Strategies for the Management of Fisheries and Aquaculture in Mangrove Ecosystems*. Bangkok, Thailand. Mepham, R.H. and Petr, T. (eds), pp. 142–160.
59. Ruitenbeek, H.J. 1994. Modelling economy-ecology linkages in mangroves: economic evidence for promoting conservation in Bintuni Bay, Indonesia. *Ecol. Econ. 10*, 233–247.
60. Klein, M.L., Humphrey, S.R., and Percival, H.F. 1995. Effects of ecotourism on distribution of waterbirds in a wildlife refuge. *Conserv. Biol*. 9, 1454–1465.
61. Smith, A.H. and Berkes, F. 1993. Community-based use of mangrove resources in St. Lucia. *Int. J. Environ. Stud. 43*, 123–132.
62. Lugo, A.E. 1988. The mangroves of Puerto Rico are in trouble. *Acta Cient. 2*, 124.


63. Acknowledgements. We thank the many people and organizations who kindly hosted us, showed us mangrove sites and shared extensive knowledge and unpublished data. Special thanks to William Alverson, Jill Belsky, Katherine Ewel, and Carl Folke and anonymous reviewers for very helpful comments on the manuscript. Travel, writing and analyses for this study were funded in part by the National Science Foundation (grants BSR 91-07195 and DEB 92-53743), Mount Holyoke College, NSF Graduate Research Training Grant GER 95-54522, the Explorer's Club Exploration Fund, and a Harvard University Merit Fellowship.
64. First submitted 9 Januay 1996. Accepted for publication after revision 19 June, 1996.



**Elizabeth Farnsworth is a PhD candidate, Harvard University, and Stewardship Ecologist with The Nature Conservancy. Her address: TNC - Connecticut Chapter, 55 High Street, Middletown, CT 06457, USA.**

**Aaron Ellison is professor of biology and Marjorie Fisher Professor of Environmental Studies at Mount Holyoke College. His address: 50 College Street, South Hadley, MA 01075 USA.**