Mangroves

FNAI Global Rank:	**G3**
FNAI State Rank:	**S3**
Federally Listed Species in S. FL:	**9**
State Listed Species in S. FL:	**46**

Red Mangrove. (*Rhizophora mangle*) *Original photograph courtesy of Florida Department of*

The mangrove forests of South Florida are a vital component of the estuarine and marine environment, providing a major detrital base to organic food chains, significant habitat for arboreal, intertidal and subtidal organisms, nesting sites, cover and foraging grounds for birds, and habitat for some reptiles and mammals. The relationship between mangroves and their associated marine life cannot be overemphasized. The mangrove forest provides protected nursery areas for fishes, crustaceans, and shellfish that are important to both commercial and sport fisheries.

The value and central role of mangroves in the ecology of South Florida has been well established by numerous scientific investigations directed at primary productivity, food web interactions, listed species, and support of sport and commercial fisheries. Mangroves are important in recycling nutrients and the nutrient mass balance of the estuarine ecosystem. They are one of the highest primary and associated secondary biologically productive ecosystems in the world. Mangroves provide one of the basic food chain resources for arboreal life and nearshore marine life through their leaves, wood, roots, and detrital materials. This primary production forms a significant part of the base of the arboreal, estuarine, and marine food web. Mangroves have a significant ecological role as physical habitat and nursery grounds for a wide variety of marine/estuarine vertebrates and invertebrates. Many of these species have significant sport fishery and/or commercial fishery value. Approximately 224,579 ha (554,515 acres) of mangroves remain in central and South Florida. This tropical ecosystem is a habitat unique in the continental United States. They deserve special protection because of this uniqueness and because of the multiple ecological functions they provide. Mangroves have a significant ecological role as habitat for endangered and threatened species, and species of special concern. For several of these species, the habitat is critical and vital to their continued survival. Mangroves serve as storm buffers by functioning as wind breaks and through prop root baffling of wave action. Mangrove roots stabilize shorelines and fine substrates, reducing turbidity, and enhancing water clarity. Mangroves improve water quality and clarity by filtering upland runoff and trapping waterborne sediments and debris. Unaltered mangroves contribute to the overall natural setting and visual aesthetics of Florida’s estuarine waterbodies. Through a combination of the above functions, mangroves contribute significantly to the economy of the coastal counties of South Florida and the State of Florida.

Synonymy

The sense of synonymy for mangroves is unusual in that the same term is used to describe both the individual tree species and the total plant community including the individual tree species. Synonyms for the term mangrove include tidal forest, tidal swamp forest, mangrove community, mangrove ecosystem, mangal (Macnae 1968), and mangrove swamp (Odum *et al.* 1982). The term mangal is used by researchers, authors, and the general public in the United Kingdom and other countries. Often mangal, or mangle, is used both for the red mangrove and the mangrove forest of which it is a part. The FLUCCS codes for mangroves include: 612 (mangrove swamps).

Distribution

There are approximately 55 mangrove species worldwide, with the center of diversity in Southeast Asia. Four species occur in South Florida: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*).

Mangroves are tropical species restricted by frost and vegetative competition to intertidal regions in tropical and subtropical sheltered waterbodies. Mangroves in the subtropical regions of South Florida represent the northern limits of tropical species that have been able to colonize because of the warm ocean waters and warm currents along the Florida coastline and dependably warm winters (Tomlinson 1986). The red mangrove is the mangrove tree most susceptible to damage from frost. White mangrove and buttonwood are less susceptible and the black mangrove is the most cold-tolerant of the Florida mangroves. Freeze damage to mangroves is well documented (Chapman and Ronaldson 1958, Lugo and Patterson-Zucca 1977) and frequently reported anecdotally.

The distribution of mangroves in North America has changed through geologic time. When the red mangrove evolved in the Cretaceous, Florida was a great coral reef in shallow seas. There may have been a few mangroves surrounding small islands and on the coastline in what is currently Georgia. Black and white mangroves evolved during the Eocene and extended as far north as South Carolina. During the Pleistocene, mangroves were absent from the Florida coastline and *Spartina* marshes dominated the estuarine intertidal zone. During the past few centuries, mangrove distribution has changed in response to short-term climatic fluctuations (Odum *et al.* 1982).

Red and white mangroves have been reported as far north as 29N latitude: near Ponce de Leon Inlet on the east coast and Cedar Key on the west coast of Florida. Black mangroves occur further north than reds and whites and have been

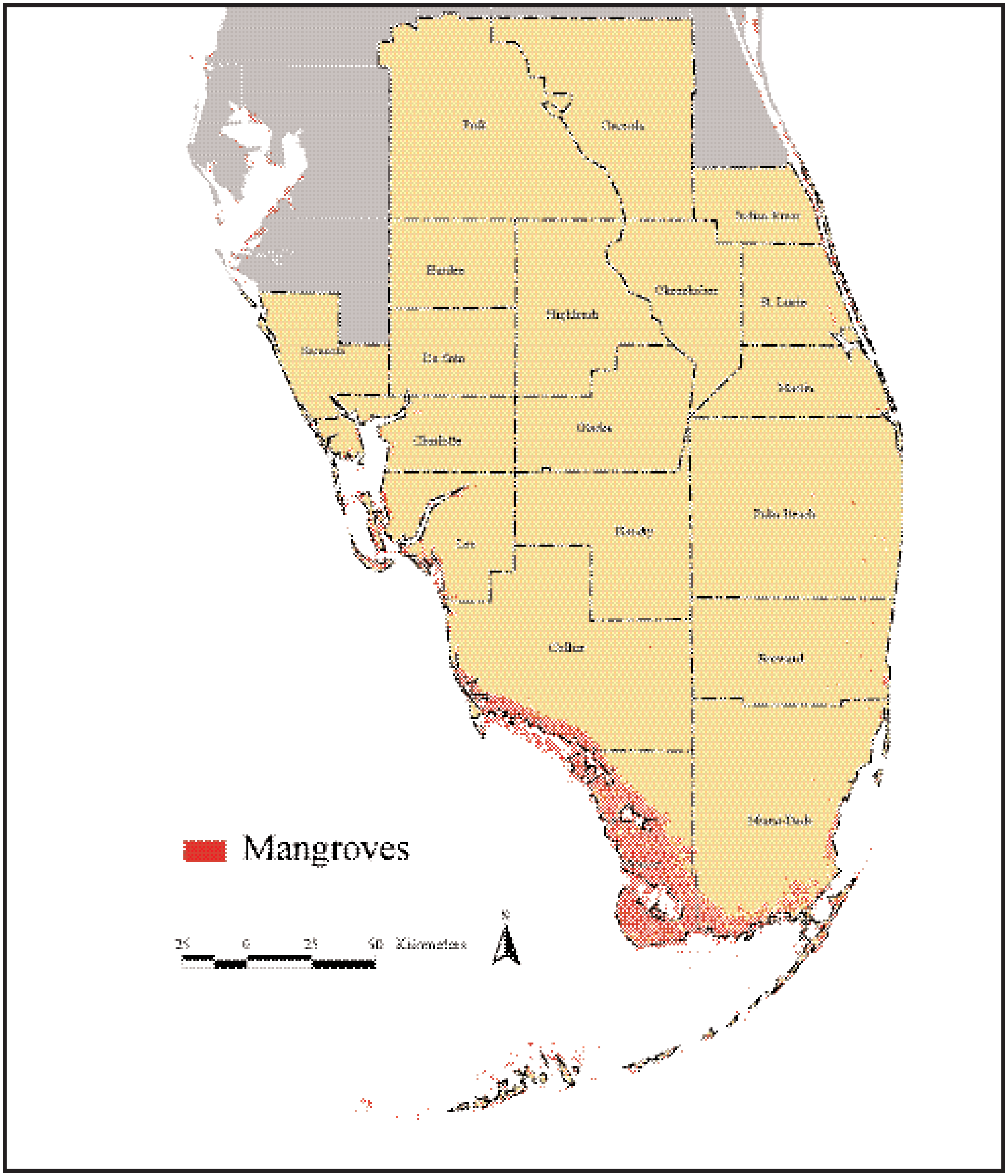

Figure 1. **The distribution of mangroves in South Florida (adapted from USGS, BRD 1996).**

reported as far north as 30N latitude on the east coast of Florida (Odum *et al.* 1982) and are distributed as a shrub around the Gulf of Mexico where vegetated shorelines have survived development. Over 90 percent of the mangroves in Florida occur in the four southern counties of Lee, Collier, Miami-Dade, and Monroe (Figure 1).

The availability of fresh water and nutrients influences the location, size, structure, and productivity of mangrove communities in South Florida. Mangroves reach their greatest abundance in southwest Florida where the positive interaction of fresh water and nutrient inputs with lower wave energy shorelines occur. In southeast Florida, mangrove development has historically been limited by the lack of fresh water and nutrients combined with narrow intertidal zones and high wave energy. Along the central east cost (Indian River Lagoon) and parts of the west coast (Charlotte Harbor and Sarasota Bay), mangrove communities support the continued existence of barrier islands against tidal and wave forces. The Everglades system changes from fresh water to an extensive mangrove community at its seaward margin of Florida Bay.

Fluctuations in sea-level rise along the Florida peninsula can limit the distribution of mangroves, particularly if the rate of sea-level rise exceeds the rate of mangrove forest growth and substrate accretion, and if the landward slopes provide no suitable habitat for forest retreat as sea-level rises (Wanless 1998). Areas with seawalls behind mangrove habitat prevent such shoreline adjustment.

The local distribution of mangroves is affected primarily by a variety of interacting factors that include microclimate, substrate type, tidal fluctuation, terrestrial nutrients, wave energy, and salt water. Sea-level rise, shore erosion, interspecific competition, and seed dispersal also affect local distribution to a lesser degree. The interrelations of these factors can alter the intertidal distribution of mangrove species. Mangroves are unique in that their morphological specialization, such as aerial roots, vivipary, and salt excretion or excluding abilities, allow them to adapt to these different rigorous environmental factors.

Description

Mangrove ecosystems are a mosaic of different types of forest, with each type providing different physical habitats, topology, niches, microclimates, and food sources for a diverse assemblage of animals. Mangroves have important structural properties including: the trapping and stabilization of intertidal sediments; the formation of organic soils and mucks; providing protection from wave and wind erosion; providing a dendritic vegetative reef surface in the subtidal and intertidal zones; and forming a structural complex of a multi-branched forest with a wide variety of surface habitats (Savage 1972).

Red mangrove

Red mangroves are distinguished by the dendritic network of aerial prop roots extending from the trunk and lower branches to the soil. The prop roots are important adaptations to living in anaerobic substrates and providing gas exchange, anchoring system, and absorbing ability. Within the soils, micro-roots stabilize fine silts and sands maintaining water clarity and quality. Red mangroves may attain heights of 25 to 38 m (82 to 125 ft) in the rich deltas of riverine forests, but average 8 to 10 m (26 to 33 ft) on most fringing shorelines, and occur as smaller trees at their northern extents or in marginal habitats such as the coral rock salt ponds of the Florida Keys. Bark is grey and the interior red. Red mangroves can form a variety of crown shapes from short continuous scrubby crown to uneven discontinuous crowns. As trees age, gaining size and putting down large prop root supports, significant horizontal as well as vertical growth occurs. This horizontal growth habit has led to the metaphor of "walking trees." The leaves are shiny, deep green on the surface and paler underside. Flowers are small, white, four-petalled, four-bracted, and wind pollinated. The germinated seed produces a long (25 to 30 cm, or 10 to 12 in) pencil or torpedo-shaped propagule.

Black mangrove

Black mangroves have distinctive horizontal cable roots that radiate from the tree with short, vertically erect aerating branches (pneumatophores) extending 2 to 20 cm (0.8 to 7.9 in) above the substrate. The trees grow straight, attaining heights of 40 m (131 ft) and averaging 20 m (66 ft). The bark is dark and scaly. They have narrow, elliptic or oblong leaves that are shiny dark green above and pale almost cream green with short dense hairs below. The upper surface of leaves can be encrusted with salt excreted by the tree. The bilaterally symmetric white flowers are showy and pollinated by Hymenoptera (Tomlinson 1986). The black mangrove is the source of mangrove honey. The germinated seed produces a "lima bean size and shaped" propagule (Odum and McIvor 1990). Black mangroves are shade tolerant and sun intolerant when immature (Snedaker 1982). As it matures, the black mangrove becomes shade intolerant. This provides different growth forms in immature and mature trees.

White mangrove

White mangroves grow either in tree form or shrub form up to heights of 15 m (49 ft) or more. The growth form tends to be erect. Some white mangroves form erect, blunt-tipped pneumatophores if growing in anaerobic or chemically stressed soils. Bark is white and relatively smooth. Leaves are fleshy, flattened ovals with rounded ends. The same pale green color is on both upper and lower surfaces. Two glands are found at the apex of the petiole that excrete salt and extra floral nectar. Small yellowish flowers are found in alternate rows on the terminal ends of branches. These germinate into small "football-shaped" propagules (1 to 1.5 cm, or 0.4 to 0.6 in). In the northern part of their range, white mangroves may not propagate on the tree and true propagules are not formed.

All three mangrove species flower in the spring and early summer. Propagules fall from late summer through early autumn.

Buttonwood

Buttonwoods grow to 12 to14 m (39 to 46 ft) in height in a shrub or tree form, but do not produce a true propagule in Florida (Tomlinson 1986). Bark is grey and very furrowed providing attachment for epiphytes. Leaves are thin, broad-to-narrow, and pointed. There are two morphotypes: the green with medium green leaves found on peninsular Florida and the silver with pale pastel green leaves historically limited to the Florida Keys but now widespread by nursery practices. It is thought the silver buttonwood is an adaptation to the rocky, dry habitats associated with the Keys archipelago. Two glands are found at the apex of the petiole that excrete extra floral nectar and salt. Tiny brownish flowers are found in a sphere on the terminal ends of branches. These produce a seed cluster known as the button. Buttonwoods are able to grow in areas seldom inundated by tidal waters. The mangrove adaptations to the osmotic desert of salt water, also adapted buttonwoods to arid areas of barrier islands and coastal strands.

Community Types

Six mangrove community types have been characterized based on their different geomorphic and hydrological processes (Lugo and Snedaker 1974). Overwash mangrove forests are islands frequently inundated or washed over by tides, resulting in high rates of organic matter. They usually contain red mangroves with a maximum height of 7 m (23 ft). Fringe mangroves form thin forests bordering waterbodies with standard mangrove zonation, attaining a maximum height of 10 m (33 ft). Riverine mangroves are in the floodplains and along embankments of tidal creeks and rivers but still get flooded by daily tides. Riverine forests have higher levels of productivity than the other mangrove community types as a result of increased nutrient availability, litter fall, and tidal flushing. All three species are present and the canopy layer can reach heights of 18 to 20 m (59 to 66 ft).

Basin mangrove forests occur in depressions along the coast and further inland that collect precipitation and sheetflow that are tidally influenced and can attain heights of 15 m (49 ft). Red mangroves are more common along the coastal areas, while black and whites dominate further inland. Influences from daily tides decrease further inland. In areas where salinity is concentrated by evaporation, black mangroves dominate and major tidal flushing occurs seasonally. Hammock forests grow on higher elevated, typically highly organic grounds and rarely exceed 5 m (16 ft) in height. These are often surrounded by other wetland types such as salt marsh. Scrub or dwarf forests are found in peninsular South Florida and the Florida Keys and rarely grow taller than 1.5 m (4.9 ft), which may be a result of fewer available nutrients and rocky substrates.

Mangrove forest canopy heights depend upon climate, topography, substrate type, and the extent of human disturbance. Undisturbed mature mangrove communities have a high, dense, complex, continuous canopy; whereas, in naturally disturbed mangrove areas, the canopy is lower with more irregular growth (Tomlinson 1986). Dense mangrove forests do not typically have understory plant associations, except for mangrove seedlings.

Areas of tree fall or other open canopy provide opportunity for other halophytic plants and young mangroves to flourish in available sunlight. Mangrove associates including up to 30 species of vascular plants occur in transitional areas with mangroves, but are not restricted to mangrove communities. Several saltmarsh grasses (*Juncus*, *Sporobolus*, *Monanthochloe*, *Distichlis*) and succulent herbs (*Salicornia*, *Sesuvium*, *Batis*) occur with mangroves along transition zones of saline marshes. Smooth cordgrass (*Spartina alterniflora*) communities often colonize bare emergent areas near mangrove forests, but are eventually displaced by mangroves shading them.

Wildlife Diversity

Mangrove ecosystems are important habitat for at least 1,300 species of animals including 628 species of mammals, birds, reptiles, fish, and amphibians. They provide areas for breeding, nesting, foraging, and shelter (Odum *et al.* 1982, Beever 1989, Day *et al.* 1989, Odum and McIvor 1990). The mangrove forest provides a multitude of habitats for resident, seasonal, and transient organisms from adjacent terrestrial and marine habitats (refer to Appendix C). Many of the larger motile species are not restricted to mangroves, but are seasonal or opportunistic visitors. However, most invertebrate and some resident vertebrate species are totally dependent upon mangroves to survive and complete important life cycle functions (Tomlinson 1986). Fish and invertebrates from the marine environment are frequent visitors to mangrove communities, as are birds and mammals from nearby terrestrial systems.

Vertebrate species that utilize mangroves throughout the year are capable of tracking the changes in food availability as mangroves bloom, germinate, and fruit, and the subsequent changes in invertebrate and small vertebrate populations in response to these food resource changes. Other vertebrate species visit the mangrove habitat during the period that best suits their life cycle. The most seaward habitat is the mangrove fringe area containing red and/or black mangroves. The littoral and benthic components of this microhabitat contribute to the structure and resources available to organisms. As previously discussed, prop roots of red mangroves support a specific microhabitat for resident species (*e.g.*, tunicates, crustaceans, mollusks, fishes) that spend their entire life cycle either on or among the root systems. Transient species are not dependent upon prop roots, but use them intermittently for shelter, feeding, and/or breeding. The prop root system also provides an important nursery for organisms (*e.g.*, crustaceans, mollusks, fishes) that develop here and spend their adult lives elsewhere (Odum and McIvor 1990).

One hundred and ninety-one bird species known from South Florida are found in mangrove communities. Many of the birds associated with mangroves are neotropical migratory birds that utilize the habitat in their migration from northern breeding grounds to southern wintering grounds in autumn and their subsequent return in spring. The high productivity of mangrove ecosystems provides an energy source important for migrating bird species traveling on long distance routes (Day *et al.* 1989). These neotropical migratory birds are a focus of considerable concern since many species are apparently in decline due to habitat loss in northern breeding grounds, southern wintering grounds, and the stopovers in the migratory corridor in coastal Florida. Other birds, including shorebirds, ducks, and perching birds, migrate to their wintering grounds in South Florida and are found only in late autumn, winter, and early spring.

Mangrove canopies provide habitat for some species of songbirds that occur only in this habitat type, such as the black-whiskered vireo (*Vireo* *altiloquus*), mangrove cuckoo (*Coccoyzus minor*), yellow warbler (*Dendroica petechia*), and Florida prairie warbler (*D. discolor*). The black-whiskered vireo nests primarily in red mangroves up to 5 m (15 ft) above the ground. Considered a rare bird species by FCREPA, the mangrove cuckoo requires large expanses of undisturbed forested mangrove and hardwood hammock habitat found primarily in the southernmost parts of Florida, from Charlotte Harbor to the Florida Keys (Smith 1996). The mangrove cuckoo nests on horizontal branches of mature mangrove trees. The yellow and Florida prairie warblers nest 3 to 6 m (10 to 20 ft) high in mangroves.

In addition to these mangrove endemic species, many estuarine birds utilize fringing mangrove forest as loafing areas and foraging perches. Included in this group are osprey (*Pandion haliaetus*), northern harrier (*Circus cyaneus*), sharp-shinned hawk (*Accipiter striatus*), Cooper's hawk (*Accipiter cooperii*), red-shouldered hawk (*Buteo lineatus*), broad-winged hawk (*Buteo platypterus*), short-tailed hawk (*Buteo brachyurus*), red-tailed hawk (*Buteo jamaicensis*), American kestrel (*Falco sparverius*), peregrine falcon (*Falco peregrinus tundrius*), bald eagle (*Haliaeetus leucocephalus*), merlin (*Falco columbarius*), kingfisher (*Megaceryle alcyon*), eastern brown pelican (*Pelecanus occidentalis*), double-crested cormorant (*Phalacrocorax auritus*), anhinga (*Anhinga anhinga*), and a variety of wading birds. As loafing areas, this habitat provides resting areas near their food supplies. This allows the use of foraging habitat distant from nighttime roosts or nesting areas without the added energy cost of flight. For other species in this group, the height of the mangroves offers a better view of prey.

Twenty-four taxa of reptiles utilize the aquatic and arboreal habitats of the mangroves. Resident species include the mangrove water snake (*Nerodia fasciata compressicauda*), the threatened Atlantic salt marsh snake (*Nerodia fasciata taeniata*), rough green snake (*Opheodrys aestivus*), the threatened eastern indigo snake (*Drymarchon corais couperi*), yellow rat snake (*Elaphe obsoleta quadrivittata*), green anole (*Anolis carolinensis*), mangrove terrapin (*Malaclemys terrapin rhizophorarum*), American alligator (*Alligator mississippiensis*), and the endangered American crocodile (*Crocodylus acutus*). The threatened loggerhead sea turtle (*Caretta caretta*) and the endangered green sea turtle (*Chelonia mydas*) are found in association with mangrove-lined shorelines along tidal passes and within estuarine embayments.

Five amphibian species utilize the mangrove habitat for feeding and/or breeding. The most frequently encountered and abundant amphibians are tree frogs (*Hyla* spp.) and, unfortunately, the exotic marine toad (*Bufo marinus*). No State listed amphibians are found in mangrove habitats. The amphibian life cycle is poorly adapted to the saline environment required by mangroves.

The value of the red mangrove as the basis of the detrital food chain of estuarine waters is well documented (Odum *et al.* 1982, Seaman 1985, Hutchings and Saenger 1987). It is recognized that over 90 percent of commercial fishery species and at least 70 percent of sport fishery species depend upon the natural mangrove forest for food and habitat as a critical part of their life cycles (Lewis *et al.* 1985). In concert with seagrass beds, macrophytic algae, phytoplankton, benthic microalgae, and emergent marshes, the mangroves provide the primary productive food base of the estuarine system. The detritus provided by decomposition of seasonally shed mangrove leaves is the food base for microcrustaceans and other detrital processors that are consumed by macrocrustaceans, small fishes, and other first order predators. The animals in turn are the prey of larger fish species such as snooks (*Centropomus* spp.), snappers (*Lutjanus* spp.), jacks (*Caranx* spp.), tarpon (*Megalops atlantica*), sheepshead (*Archosargus probatocephalus*), spotted seatrout (*Cynoscion nebulosus*), and redfish (*Sciaenops ocellatus*). Based on surveys performed during the preparation of the Charlotte Harbor Aquatic Preserve Management Plan, at least 230 species of fish utilize the mangrove ecosystem of Charlotte Harbor for food, shelter, breeding and/or nursery grounds (Beever 1988).

The dominant fish species of the basin mangrove forests are poeciliids, the mosquitofish (*Gambusia* spp.), the least killifish (*Heterandria formosa*), and the sailfin molly (*Mollienesia latipinna*). These cyprinodont fish are a fundamental link between primary producers and higher trophic level fish and wildlife species. The typical cyprinodont diet consists of plant and animal tissue, including periphyton, insect larvae, and vascular plant detritus. They subsequently are food for sport fish and wading bird species. Fourteen of the 54 freshwater fish species found in South Florida (Kushlan and Lodge 1974) utilize the mangrove wetlands during the wet season, high-runoff flow events (Odum *et al.* 1982).

Most of the 350 species of marine invertebrates in Charlotte Harbor are found in or depend on mangroves for habitat or food. The arboreal canopy provides habitat to both aquatic and amphibious resident and transient species (Simberloff and Wilson 1969, Beever *et al.* 1979, Odum and McIvor 1990). Approximately 264 species of arboreal arthropods inhabit the mangrove canopy, branches, and wood (Beever *et al.* 1979). Aquatic organisms, such as crabs and snails, spend part of their time in the water, but can also migrate up into the canopy of mangroves.

Wildlife Species of Concern

Federally listed species that depend upon or utilize the mangrove community in South Florida include: Florida panther (*Puma (=Felis) concolor coryi*), Key deer (*Odocoileus virginianus clavium*), Lower Keys rabbit (*Sylvilagus palustris hefneri*), West Indian manatee (*Trichechus manatus*), wood stork (*Mycteria americana*), American crocodile (*Crocodylus acutus*), bald eagle (*Haliaeetus leucocephalus*), rice rat (=silver rice rat) (*Oryzomys palustris natator*) (=*O. argentatus*), and eastern indigo snake (*Drymarchon corais couperi*). Biological accounts and recovery tasks for these species (except Gulf sturgeon) are included in "The Species" section of this recovery plan. Refer to Appendix C for a list of other species of concern that utilize the mangrove community.

The **Florida black bear** (*Ursus americanus floridanus*), listed as threatened by the State, is a forest habitat generalist with seasonal preference for wherever food is most available. Black bears utilize all the natural forested systems of South Florida, with a decided preference for ecotones, including the boundaries between mangroves and other plant communities. Documented movements of radio-collared Florida black bear in Lee and Collier counties and documented signs/sightings of Florida black bear in Charlotte, Collier, and Lee counties indicate that the large areas of relatively undisturbed mangrove forest, in combination with hydric and mesic forests and the major wetland basins, provide the principal habitat of the black bear in southwest Florida (Maehr 1984, Brady and Maehr 1985, Maehr *et al.* 1988, Maehr and Wooding 1992). Bears are omnivores that feed on readily available food resources, such as the seasonal abundances of propagules and insects. Occasionally, fish and carrion are also eaten. Movement by individuals can be extensive and may be related to both mating and food availability. Black bears will swim between mangrove islands in Collier County.

The **Big Cypress (=mangrove) fox squirrel** (*Sciurus niger avicennia*), listed as threatened by the State, is found in mangroves south of the Caloosahatchee River, along the estuarine coast south to the western edge of the Everglades sawgrass marshes. The Big Cypress fox squirrel utilizes a wide variety of forested and non-forested upland and wetland systems including mangroves. The Big Cypress fox squirrel possesses a large territory from which it harvests seasonally available bounties of cones, nuts, and seeds. The fox squirrel forages on mangrove propagules, in particular, the black mangrove. Nesting occurs in pines, hardwoods, cypress, cabbage palms, bromeliad clumps, and black mangroves.

The **Everglades mink** (*Mustela vison evergladensis*) is found in the Big Cypress Swamp; the western edge of the Everglades; southern Lee County; Collier County; mainland Monroe and Miami-Dade counties (Allen and Neill 1952, Humphrey and Setzer 1989, Humphrey 1992). Mink are nocturnal and crepuscular predators of mammals, reptiles, birds, amphibians, fishes, and eggs. The species does not appear to be numerous and, given its period of activity, the literature on distribution is based primarily on road kills. The Everglades mink is found in a wide variety of shallow wetland systems, including mangrove swamps.

The **white-crowned pigeon** (*Columba leucocephala*) is a resident of the mangrove arboreal habitat for nesting and nearby tropical hardwood hammock areas for foraging. This herbivorous pigeon found from Biscayne Bay south through the Marquesas Keys is listed as a threatened species by GFC and FCREPA (Bancroft 1996). The white-crowned pigeon requires undisturbed mangrove communities for nesting and foraging. Over half of the State's pigeon population nest on islands in the Upper Florida Keys (Bancroft 1996). Nesting on the mainland is rare, but does occur (Strong *et al.* 1991). Most of the population migrates to the Caribbean for the winter breeding season, but some birds are present in South Florida year-round. Breeding occurs from March to June. The white-crowned pigeon's mangrove and hardwood hammock habitat continues to decline as residential and commercial development increases. The continued existence of this species in Florida and the Caribbean is dependent upon the integrity of its nesting and foraging habitat here in South Florida.

The **eastern brown pelican**, a State species of special concern, nests predominantly on overwash mangrove islands and forages over open water, mudflats, and seagrass beds in the shallow waters of estuaries, creeks, and nearshore areas. Brown pelican rookeries are located on isolated red mangrove islands with a substantial water depth barrier that protects the nests from mainland predators. Diet consists of fish of all sizes. Foraging consists of plummeting dives, short plunges, and swimming scoops of fish. Historically, brown pelican populations were reduced as a result of pesticides. Today, the greatest threats to brown pelicans are still human-caused. Brown pelicans and their nesting/roosting/loafing sites are vulnerable to disturbance from construction activities and monofilament line entanglement. Brown pelicans are especially susceptible to death and injury caused by sport fishing equipment. It has been estimated that over 500 individuals die each year as a result of entanglement with fishing tackle (Schreiber 1978).

The **osprey** is a State species of special concern only in the Lower Florida Keys. It nests in a variety of trees (*i.e.*, principally tall mangroves) and on artificial structures, and forages in a variety of marine and estuarine habitats.

Tricolored heron (*Egretta tricolor*), **little blue heron** (*Egretta caerulea*), **white ibis** (*Eudocimus albus*), and **snowy egret** (*Egretta thula*) forage and nest in mangroves. Little blue herons and white ibis are the most common of the listed wading bird species observed in mangroves in southwest Florida (Beever 1992). Diet consists of small fish, crustaceans, insects, frogs, and lizards (Ogden 1978a). Nesting in mangroves typically occurs on overwash islands. They appear to prefer to forage in freshwater habitats even when nesting in saltwater wetlands. The little blue heron forages throughout the wet and dry season in mangroves. Adjacent tidal wetlands are used throughout the year with greater emphasis during low tides on seagrass beds. The snowy egret forages throughout the wet and dry season in mangrove wetlands of the proper depth to allow for their foraging methods. Snowy egrets are the third most abundant listed wading bird observed. Preferred foraging areas are the seagrass beds and mudflats adjacent to the mangroves. Their diet consists of crustaceans, insects, and small fish (Ogden 1978c).

Reddish egrets (*Egretta rufescens*) and **roseate spoonbills** (*Ajaia ajaja*) are obligate mangrove breeders. Reddish egrets forage on the sandbars and mudflats adjacent to mangroves, in an active fashion with spread wings and rapid steps over unvegetated bottoms. Reddish egrets are the least abundant of the listed wading birds associated with mangroves. Reddish egrets utilize a limited set of saltwater habitats that allow for use of their unique foraging method. Diet consists of crustaceans and small fish. Kale and Maehr (1991) indicate that red mangrove rookeries are used during the December through June breeding period. Roseate spoonbills use dry-down pools in the high marsh,and during low tides, adjacent to mangroves. Preferred foraging areas included sheltered coves. They often forage in groups and with other wading birds including wood storks, great egret (*Casmerodius albus*),white ibis, and snowy egret. Roseate spoonbills nest exclusively in mangrove forests, typically on overwash islands, and forage wherever concentrations of small fish and crustaceans allow the birds to utilize their unique bills for feeding (Ogden 1978b).

A wide variety of shorebird species forage on the mudflats of mangrove estuaries. Among the State listed species are the threatened **least tern** (*Sterna antillarum*); the **black skimmer** (*Rynchops niger*), a species of special concern; and the **American oystercatcher** (*Haematopus palliatus*) a species of special concern. Least terns and roseate terns require open beach or bare

Roseate spoonbill. *Original photograph by Betty Wargo.*

substrates for nesting near areas where schools of forage fish concentrate. American oystercatchers utilize oyster bars and mudflat areas in mangroves and nest on bare unvegetated shores. Foraging occurs throughout the year with seasonal movements tracking warmer conditions.

Mangrove clapper rails (*Rallus longirostris*) use high marsh and basin black mangrove forest areas. They forage on fiddler crabs and other small crustaceans. Mangrove clapper rails are resident in South Florida's mangrove and marsh ecosystems. Little is known of their life history due to their crepuscular to nocturnal activity period, the heavy cover of their preferred habitat, and the excellent camouflage of their plumage.

The **Lower Keys striped mud turtle** (*Kinosternon baurii*) is found in small ponds with salinities less than 15 ppt in the Lower Florida Keys typically in or at the edge of elevated hardwood hammocks (Dunson 1992). Pond vegetation includes mangroves, buttonwood, and cattails. When ephemeral pools dry down, turtles will seek refuge in rock ledges and in mangrove prop roots.

From Lemon Bay, Sarasota County, to the Ten Thousand Islands, Collier County, the estuaries of southwest Florida support at least 384 species of bony and cartilaginous fish (Beever 1988), including the **common snook** (*Centropomus undecimalis*), a State listed species of special concern, and the **Key silverside** (*Menidia conchorum*), listed as threatened by the State.

Some species that depend wholly, or primarily on the mangrove habitat are now imperiled because of loss and degradation of their habitat. **Mangrove rivulus** (*Rivulus marmoratus*) is a small fish living only in and around mangrove areas as far north as Indian River County south through the Keys and north to Tampa Bay on the west coast of Florida (Taylor and Snelson 1992). It is the only species of *Rivulus* in North America and has adapted to conditions of varying water levels and low oxygen levels of the mangrove community. It is an important link in the food chain, as it has been found to constitute part of the diet of many organisms including the wood stork (Ogden *et al.* 1976). It is listed as a species of special concern by the State because of its limited distribution and vulnerability to loss of its habitat.

The **mangrove gambusia** (*Gambusia rhizophorae*) is another small fish species associated with red mangrove roots in southeastern Florida, mainly in Miami and the Florida Keys (Gilbert 1992).

The **mangrove tree crab** (*Aratus pisonii*) is found only in estuarine areas from the Indian River Lagoon and Tampa Bay south to the Florida Keys (Gore 1994a). This species is restricted to mangroves for its adult life cycle, especially red mangroves. It is one of the few crabs that also uses the arboreal canopy and can climb to the uppermost branches which it forages upon (Beever *et al.* 1979). The **mangrove crab** (*Goniopsis cruentata*) is restricted to mangrove forests in central and southern Florida mangrove areas (Gore 1994b).

Ecology

The value and central role of fringing red mangroves in the ecology of the South Florida estuarine ecosystems has been well established by numerous scientific investigations directed at primary productivity, food web interactions and support of sports and commercial fisheries (Odum and Heald 1972, Odum *et al.* 1982). Mangrove swamps are among the most productive plant communities in the world and are often a large proportion of the total area of tropical estuaries (Day *et al.* 1989). The high level of animal diversity in a community of so few plant species occurs because of the wide variety of spatial and temporal microhabitats. The complex structure of prop roots, pneumatophores, and main trunks provides living spaces for numerous organisms and cover from predation for large populations of small fishes, nektonic and benthic crustaceans, annelids, mollusks, and echinoderms. Aside from providing refuge, mangrove prop roots also provide shade which is important for thermoregulation in some organisms. This combination of shelter and food source makes the mangrove forest a rich nursery and feeding ground for the juvenile and adult forms of many commercially and ecologically significant species of fish and other vertebrates.

Many animals associated with mangroves, oyster bars, and open unvegetated waters by day forage in seagrass beds at night. Many estuarine fishes spend their early life in mangroves and then move as adults to complete life cycles in seagrass habitats. The highest quality seagrass beds are associated with mangrove-fringed shorelines. Animals associated with the mangrove/seagrass communities include herbivores, such as green turtles, manatees, sea urchins, blue crabs, fiddler crabs, and many fishes.

Landward from the shoreline, the mangrove forest intermixes with salt marsh species and provides habitat to organisms that can withstand changing water levels. Common saltmarsh species found in this ecotone are saltwort (*Batis maritima*), perennial glasswort (*Salicornia virginica*), and saltgrass (*Distichlis spicata*). As water levels change with daily tides and seasonal influences, the organisms here migrate to adjacent permanent aquatic habitats. This area is an important foraging area during periods of low water because organisms get concentrated into small pools of water, making it easy for predators to capture prey. Juvenile endangered wood storks (*Mycteria americana)* are especially dependent on these conditions.

Further inland, the mangrove forest mixes with tropical hardwood hammock species. Organisms rely on the arboreal and terrestrial components of this transition community. Commonly associated hardwood species include cabbage palms (*Sabal palmetto*), Jamaica dogwood (*Piscidia piscipula*), West Indian mahogany (*Swietenia mahogani*), stopper (*Myrtus verrucosa*), poisonwood (*Metopium toxiferum*), black bead (*Pithecellobium keyense*), and gumbo limbo (*Bursera simaruba*) (Schomer and Drew 1982). The transition between these two adjacent communities provides an important ecotone, where species can take advantage of resources from both communities. Mammals and reptiles move from the hardwood forests to feed in the mangrove community.

Zonation

The standard zonation of mangroves consists of red mangroves in the lower and middle intertidal zone, black mangroves in the upper intertidal areas that are occasionally flooded, and white mangroves in patches on higher elevations that are less frequently flooded. Buttonwoods are located further inland in areas that are within the limits of the highest tides (Tomlinson 1986).

Mangrove forests are different than other vegetative communities in not experiencing traditional plant succession. Instead, mangrove communities experience replacement succession primarily as a function of sea-level rise, where mangroves must either keep up with the rise in sea-level or retreat from rising water levels. On shorter time scales, the mangrove community can experience fluctuations in habitat type and species composition as a result of changes in such factors as hydrologic patterns.

Substrate

Mangroves can grow on many different types of substrates and can alter their substrate through peat formation and sedimentation. Mangroves are found on fine inorganic muds, muds with high organic content, peat, sand, rock, coral, oysters, and some man-made surfaces if there are sufficient crevices for root attachment. Black mangroves grow best in soils of high salinity, red mangroves grow best in areas of estuarine salinity with regular flushing, and white mangroves grow best in areas with freshwater input on sandy soils. Red, black, and white mangroves can grow in completely anaerobic soils (Lee 1969).

Mangroves grow better in areas of low wave-energy shorelines, river deltas, and floodplains where fine sediments, muds, and clays accumulate and peats will form (Odum *et al.* 1982). Fluctuating tidal waters are important for transporting nutrients, controlling soil salinities, and dispersing propagules. Mangroves are denser along coasts with high levels of rainfall, heavy runoff, seepage, and a resultant increase in sedimentation which provides a diversity of substrate types and nutrient levels higher than that of sea water (Tomlinson

1986). Mangroves can grow in waters from high-to-low nutrient concentrations. In removing nutrients from surface waters, mangrove forests can be important nutrient sinks for an estuary.

Mangroves can modify soils by organic contributions and peat formation, particularly in southwest Florida and the north shoreline of Florida Bay. This peat appears to be primarily from red mangrove root material and can reach thicknesses of several meters. When mangrove soils are drained by human activity, they experience dramatic increases in acidity due to oxidation of reduced sulfur compounds in the formerly anaerobic soils. This creates “cat clays” which can kill all vegetation including the mangroves.

Salinity

Mangroves are facultative halophytic species (*i.e.*, salt water is not required for growth). They are limited to areas that are partially inundated by brackish or saline water and cannot persist solely in fresh water principally as the result of interspecific competition from much faster-growing freshwater wetland plants. Mangroves grow in surface waters with a range of salinities from 0 to 40 parts per thousand (ppt). Coastal salinities generally range from 18 to 30 ppt throughout South Florida, except in parts of the Indian River Lagoon, Florida Bay, and the Florida Keys, where hypersaline conditions of over 40 ppt seasonally occur. Red mangroves address salinity by excluding or storing salt, whereas black and white mangroves and buttonwood secrete salt.

Reproduction

All mangroves share two common reproductive strategies: dispersal by means of water and vivipary (*i.e.*, the embryo develops continuously while attached to the parent tree and during dispersal) (Odum *et al.* 1982). Dispersal of mangrove propagules is primarily by water currents and tides. The propagules of all three mangrove species float and remain viable for extended periods of time. During this dispersal period, the propagules continue to germinate in preparation for seedling establishment. Black and white mangrove propagules require a stranding period of 5 days or more beyond the influence of tides in order to take hold in the substrate; whereas, red mangrove propagules have the potential to become established in shallow water.

Mangroves are considered pioneer species because of their ability to establish on otherwise unvegetated substrates. Once individuals begin to colonize a disturbed area, same age communities are established with little variance in the structure because new development of successive colonizers is arrested by the closed canopy.

Biomass

The biomass of mangroves and the mangrove forest is predominantly above ground. Measures of biomass in a 1.5 m (5-ft) tall canopy are: 712 dry kg/ha (131 lb/acre) in the leaves; 1,140 dry kg/ha (210 lbs/acre) in leaf litter; no fruit and flowers; 3,959 dry kg/ha (729 lbs/acre) in the wood; and 3,197 dry kg/ha (588 lbs/acre) in the roots. In contrast, a 6.1 m (20-ft) tall canopy has 5,843 to

7,031 dry kg/ha (1,075 to 1,294 lbs/acre) in the leaves; 22,730 to 98,410 dry kg/ha (6,209 to 18,110 lbs/acre) in leaf litter; 28 to131 dry kg/ha (5 to 24 lbs/acre) in fruit and flowers; 57,960 to 128,510 dry kg/ha (10,666 to 23,649 lbs/acre) in the wood; and 17,190 to 27,200 dry kg/ha (3,163 to 5,005 lbs/acre) in the roots. The standing crop of a short canopy whether young, naturally stunted, or hedged is from 3.6 percent to 8.3 percent of an untrimmed mature red mangrove fringe. With reduced standing crop, annual gross primary production can be expected to be proportionally less.

The annual net primary production of a 1.5 m (5-ft) high red mangrove system is 18 percent of the annual net primary productivity of a mature system, which produces 20.5 metric tons C/ha/year (Teas 1979). In the form of mangrove detritus, the net primary production exported from a natural red mangrove fringe has been measured at 9.9 metric tons C/ha/year by Pool *et al.* (1975). Teas (1979) derived 10.6 metric tons C/ha/year for mature red mangroves and 1.3 metric tons C/ha/year for shrubby 5-foot tall red mangrove fringes. Short canopy mangroves provide only 12 to 19 percent of the detrital export of a mature untrimmed red mangrove fringe.

Due to special adaptations to anaerobic soils, mangroves can grow in areas of very low dissolved oxygen concentrations. Since photosynthesis is occurring above the water column, mangroves can grow in waters of relatively high color and turbidity. Mangroves contribute to the tannin colors of estuarine waters while stabilizing and settling turbidity. Mangroves can contribute total organic carbon to surrounding waters as part of the net primary production export to the food web.

Productivity

The primary production ability of mangrove leaves varies. The upper canopy contains “sun leaves” which are smaller with heavy cuticle and tannin cells which protect against the heat and ultraviolet (UV) radiation encountered in the upper parts of the tree. The lower canopy is composed of “shade leaves” which have larger surface area, more chlorophyll, less cuticle, and which are oriented to obtain maximum light in shade conditions. Once a leaf is formed to one of these morphologies, it cannot be changed. Lugo *et al.* (1975) demonstrated that in the red and black mangrove, sun leaves demonstrated twice the photosynthetic rate of shade leaves. At night, shade leaves have four times the respiration rate of sun leaves. Because of these morphologic differences, when a red or black mangrove is topped, frozen, or defoliated the tree loses its most efficient leaves. Exposed leaves not adapted to the heat, light, and UV rays are exposed to adverse conditions. As a result, both gross primary production and net primary production are severely reduced until new sun leaves are set if the tree lives. It is occasionally observed that shade leaves on surviving branches will wither, die, and drop under the heat of the sun when cutting is performed in the summer.

The detrital food base in natural mangrove systems follows seasonal cycles of leaf growth, chemical changes in leaf composition, and natural leaf drop. Although it is not yet fully investigated, a sequence of leaf chemistry changes occurs in the mangrove leaf which the red mangrove naturally drops. The naturally dropped leaf is the oldest leaf in the red mangrove leaf cluster, has had chlorophyll removed rendering a yellow coloration from carotenes and xanthophylls, and has other substances including excess sodium and chloride. It is suspected that in most mangroves, the annual properly timed leaf fall is also a mechanism for the removal of excess salt prior to and concurrent with new growth and fruiting (Joshi *et al.* 1975, Saenger 1982). It is not unlikely that essential limited nutrients and trace elements are mobilized and removed from a leaf before it is dropped for use in the growth of new leaf.

Studies of South Florida estuarine food webs have found that 85 percent of the detrital food base is from red mangroves (Lewis *et al.* 1985). This detritus is predominantly leaves, but also includes leaf and propagule stalks, small twigs, roots, flowers, and propagules. These are fragmented by processors into detritus, decaying organic material coated and created by algae, fungi, bacteria, and protozoa. This detritus is further fragmented, consumed, and excreted by a number of primary consumers dominated by small crustaceans. The leaf base material itself is not directly consumed, but the algal, fungal, bacterial, and protozoal biomass is. This results in the excretion of a smaller detrital particle which again becomes the base for a detrital garden of microorganisms. This process is repeated many times utilizing the detrital particle to its full nutritive value to the estuarine ecosystem. Eventually, the particle attains a small enough size for use by filter and deposit feeders.

Entire trunks and large branches are not available to this system directly but have to be processed by a much slower system of marine and terrestrial borers and slow decay. If large volumes of cut material enter the aquatic or intertidal system in a short period, one of two things occur. If an abundant resident population of borers is present in the mangrove system and the weather is sufficiently warm at the time of cutting, unnaturally high abundances of wood-boring animals develop in the slash and, through time, their dispersed offspring attack the cut ends of the trimmed mangroves and healthy uncut trees. If the weather is cold and the local population of borers is low or absent, then the slash sits, does not decay, and can mineralize into unavailable cellulose. This has been directly observed in Lee County, where mangrove branches cut in 1979 remain intact and mineralized today and the area where these piles are located has not recruited new mangroves.

Status and Trends

The Coastal Coordinating Council estimated a total of between 162,000 ha (400,000 acres) to 219,000 ha (540,000 acres) of mangroves remaining in central and south Florida in 1974 (Lewis *et al.* 1985). The National Wetlands Inventory estimated a total of 272,973 ha (674,241 acres) of mangroves in 1982 (Lewis *et al.* 1985). By 1989, approximately 224,500 ha (554,515 acres) of mangroves remained in central and south Florida. These mangroves are a unique and critical component of Florida’s estuarine ecosystems. The loss of mangrove productivity to Florida estuarine food chains is well documented for certain locations. Since the early 1900s, mangrove communities in South Florida have steadily disappeared (Lugo and Snedaker 1974). Most of the shoreline of South Florida’s estuaries have been bulkheaded for development or impounded by dikes for mosquito control activities. Along the Indian River

Lagoon, 13,083 ha (32,315 acres) (92 percent) of red and black mangroves were impounded to control mosquito populations between 1955 and 1974 (Odum and McIvor 1990). Lake Worth Lagoon experienced an 87 percent loss of mangrove wetlands due to shoreline development occurring between 1940 and 1975 (P. Davis, Palm Beach County, personal communication 1998). Northern Biscayne Bay has lost 82 percent of its mangrove acreage (Harlem 1979). Lee County has lost 19 percent of its original mangroves (Estevez 1981). In the Upper Florida Keys, over 8,306 ha (15 percent) of the original mangrove forests were cleared for residential and commercial construction purposes by 1991. Statewide estimates vary on total mangrove losses. Conservative values of 3 to 5 percent were derived by Lindall and Saloman (1977); more recent work indicated a 23 percent loss (Lewis *et al.* 1985). This figure includes areas such as Charlotte Harbor where there has been a 19 percent increase in mangrove coverage due to the conversion of high marsh and salt flats through mosquito ditching.

Natural mangrove ecosystems provide a number of ecological functions that benefit humans. The economic importance of mangroves to the State income is significant. From 1980 to 1981, 5,224,539 recreational saltwater anglers spent 58,528,081 angler days fishing, which generated over $5 billion in direct and indirect income to the State economy (Bell *et al.* 1982). Using National Wetland Inventory acreage data, the value of an acre of mangroves in the Indian River Lagoon is $416 per acre ($1,027/ha) per year for commercial fisheries and $1,093 per acre ($2,700/ha) per year for sport fisheries. Using acreage data from the Coastal Coordinating Council (1974), the value of an acre of mangrove is $723/acre/year for commercial fisheries and $1,902/acre/year for sport fisheries. The annual economic estimates for the Indian River Lagoon fisheries dependent upon mangroves are $10,644,695/year for commercial fisheries and $28 million/year for sport fisheries.

Smaller, shorter mangrove canopies contribute less to fishery values than taller, natural canopies due to the reduction in net primary production. Utilizing conservative estimators, an evaluation of mangroves in Lee County found that, in 1970 dollars, a mature 6 m (20-foot) high canopy of red mangroves contributed $2,041/acre/year in commercial fisheries landings. In 1975 dollars, a 1.5 m (5-foot) high red mangrove canopy contributed $144/acre/year; whereas a 11 m (35-foot) high mangrove canopy contributed $6,514/acre/year. The values do not reflect recreational fisheries values which are six times the primary sales of commercial fisheries (Lewis *et al.* 1985).

The in-kind replacement value of a dead mature red mangrove is in the thousands of dollars. One nurseryman estimated the cost to raise a red mangrove from seedling to age 15 prior to transplanting would be over $11,000 with survival as low as 30 percent. The total replacement cost for one acre of dead mangroves to age 15 would be approximately $4.4 million at 100 percent survival or $14.7 million at 30 percent tree survival.

Management

Natural mangrove ecosystems do not require management other than being left alone. Mature mangrove systems are self-renewing and respond to perturbations of the natural cycles of freeze, flood, and storm without the need for significant human intervention. Unfortunately, in South Florida, most mangrove systems have been degraded by human impacts either directly, as in spoil pile deposition or impoundment, or indirectly by alteration of basin hydrology, as in Florida Bay and the Everglades. Most management efforts require the removal of past effects as well as the prevention of continued or future human impacts.

Mangrove ecosystems are susceptible to both natural and human-induced impacts. The two natural forces that may negatively impact mangrove forests are hurricanes and sea-level rise. Large hurricanes are the primary natural factor that can cause extensive damage. In 1960, Hurricane Donna created damage over an area exceeding 40,000 ha (100,000 acres) with 25 to 100 percent loss of mature trees (Craighead and Gilbert 1962). Mangroves were killed by direct shearing at 2 to 3 m (6 to 9 ft) above the ground, by complete washouts of overwash islands, and by strangulation of air exchange from layers of marl, mud, and organic material over the prop roots and pneumatophores. The burial of aerial roots was the largest cause of death. Lugo *et al.* (1976) have hypothesized that severe hurricanes occur in South Florida on intervals of 25 to 30 years and that the mangrove ecosystem has adapted by reaching maturity during this cycle.

The two main human-caused changes affecting mangrove communities today are direct loss of habitat from coastal urbanization (*i.e.*, developing waterfront property and subsequent effects of channel dredging, spoil placement alterations, chemicals, debris, and formal landscaping) and the alteration in freshwater hydroperiod by water management practices (*i.e.*, mosquito control and major flow alterations). Man can alter the distribution and structure of mangrove communities through direct destruction by dredge and fill activities, and cutting those mangroves that remain. Alterations in the natural freshwater flow regime through diking, impounding, and flooding activities affect the salinity balance and encourage exotic vegetation growth. As a result of changing natural sheet flow, mangroves have experienced a change in water and soil salinities. With the decline in natural freshwater flow through the Everglades, red mangroves have invaded freshwater tributaries of the Taylor Slough drainage basin. Australian pine (*Casuarina equisetifolia*) and Brazilian pepper (*Schinus terebinthifolius*) are two exotic plant species that invade mangrove communities as a result of changes in water flow (refer to Appendix E).

Although mangroves often live in areas with rapid sedimentation, heavy loads of fine flocculent material such as suspended dredge spoils that coat aerial roots can kill the trees. Extensive areas of mangrove in Collier County were killed in this way by the actions of hurricanes and by human coastal development with broadcast dredge spoil turbidity (Odum and Johannes 1975). Spoil pile creep is a common phenomenon on barrier islands and in the Florida Keys as adjacent mangroves roots are buried beneath unstabilized shell marl.

The functionality of mangroves in gathering sediments and other material also negatively acts as traps for trash, monofilament, and other marine debris that can significantly harm wildlife and listed bird species in particular. Regular (annual) volunteer clean-ups find tons of debris in mangrove ecosystems with monofilament line from recreational fishing typically in the top two items by weight. Education will be important in this issue, but this needs to be supplemented by stricter enforcement of marine dumping regulations and perhaps development of biodegradable alternatives to current fishing lines.

Diking and Ditching

Diking (or impounding) mangroves to cut off tidal circulation with long-term flooding causes mass mortality in all species of mangroves, especially when the prop roots or pneumatophores are submerged (Breen and Hill 1969, Odum and Johannes 1975, Patterson-Zucca 1978, Lugo 1981). Impoundment flooding, used as a form of mosquito control, resulted in a 76 percent reduction in mangrove wetlands along the Indian River Lagoon. On the west coast, roadway development has killed thousands of acres of mangroves. Partial impounding by roads and fill for development has killed mangroves in places like Clam Bay in Collier County. When these formerly anaerobic mangrove soils are drained, they experience dramatic increases in acidity (ph=3.5-5.0) due to the oxidation of reduced sulfur compounds in the soils which can kill all vegetation including the mangroves within the impoundment.

The **Subcommittee on Managed Marshes**, an interagency task force, was formed to address management problems of mosquito impoundments (Indian River Lagoon NEP 1996). Under the guidance of this task force, improvements in management techniques were developed and implemented in the mid-1980s by local mosquito control districts. Known as Rotational Impoundment Management (RIM), these techniques involve some form of rotational schedule for alternating the flooding-and-drying cycles of impounded marshes. One RIM alternative consists of the installation of culverts through the dikes to allow natural tidal flows across these impounded wetlands and to provide fishery resources access to and from the diked marshes.

Trimming

The effects of mangrove hedging and improper trimming on productivity can be substantial, with losses of 8.6 tons of C/ha/year when a 6 m (20-foot) high canopy is reduced to 1.5 m (5 ft) in height. In an urbanized estuary where the majority of the shoreline could be subjected to hedging, this could result in the loss of approximately 87 percent of the local annual productivity of that particular mangrove ecosystem.

Of the mangrove species, the red mangrove is the least tolerant to trimming. Cut red mangrove branches do not regenerate well or at all, if they are greater than approximately 2.5 cm (1 in) in diameter (Gill and Tomlinson 1971, Beever 1989). Severe trimming kills mature red mangroves. White and black mangroves are less sensitive to trimming damage than red mangroves because of specific anatomical differences which allow coppicing from trunk and root stock. However, improper severe cutting of both white and black mangroves will kill these trees as well. Recovery potential of mangroves to pruning is as follows: white mangroves, highest recovery; black mangroves, moderate recovery; red mangroves, lowest recovery (Snedaker 1982).

Removing more than 30 percent of a red mangrove canopy produced significantly fewer propagules than those trees pruned less than 30 percent. Trees pruned more than 50 percent were severely impacted. Red mangroves exhibit difficulty in initiating new shoots when severely disturbed (Snedaker 1982). Trimming of trees immediately preceding and during flower set, propagule growth, and major leaf set can reduce and damage the reproductive success and productivity export for that year.

A comparison of cut and adjacent natural mangrove fringes in seven of the eight southwest Florida aquatic preserves was performed, utilizing standardized methods of measurement of mangrove productivity (Heald 1971, Pool *et al.* 1975, Teas 1979, Beever *et al.* 1979, Twilley 1980). Statistically significant reductions in net primary productivity export, standing leaf crop, flower production, propagule production, and leaf clusters resulted from the cutting of a 5 m (16 ft) tall fringing red mangrove to less than 2 m (6 ft). Similarly, reduction in net primary productivity export, standing leaf crop, propagule production, and terminal branches resulted from cutting a 3 m (10 ft) tall fringing white mangrove area to 1 m (3 ft). Mangrove trimming significantly reduced habitat utilization by associated fauna. For the parameters measured, no net positive benefit of mangrove trimming/cutting could be confirmed. The documented evidence of this study and existing literature (Beever 1989) indicate that mangrove cutting is deleterious to the estuarine environment, the mangrove trees themselves, and the fauna which depend upon mangroves for habitat and primary production (Beever 1996).

Mangrove trimming does not match natural, seasonally timed, physiologically mediated leaf drop. In any trimming method, leaves of all ages and biochemistry are removed from the tree. There is no existing evidence in the literature or from field observation that mangrove trimming enhances the habitat value of the mangroves for any native species. For many of the birds and arboreal arthropods, reduction of canopy height and habitat complexity has deleterious effects. Many mangrove-dependent bird species will not roost overnight or nest in short canopies below 2 to 3 m (6 to 10 ft). When rookeries are cut, they are abandoned. The arboreal arthropod community depends directly on the structural diversity of the mangrove canopy including tree height, abundance of branches, and tree age. Trimming fringing mangroves results in shade reduction along the bank; shaded areas selectively attract a number of fish and other aquatic species.

The compliance level of permitted mangrove trimming in Florida is low (20 percent since Chapter 17-27 Florida Administrative Code was implemented) and violations significantly outnumber permitted projects. Enforcement staffing levels of DEP field personnel for South Florida averages one compliance staff per seven counties and one enforcement (independent of permitting) per 3.5 counties. This staff is responsible for all DEP compliance and violations for all permits in all wetlands in DEP jurisdiction. As a result, the ability of this staff to concentrate on, and the time allotted to, mangrove trimming is small compared to the extent of the resource and the number of permits and enforcement cases.

Herbicides

All mangrove tree species are particularly susceptible to herbicide damage (Tschirley 1969, Orians and Pfeiffer 1970, Westing 1971, Walsh *et al.* 1973, and Odum *et al.* 1982). The red mangrove is particularly sensitive due to the small reserves of viable leaf buds (Teas and Kelly 1975). The stress of a single defoliation is sufficient to kill the entire tree. Defoliated forests are slow to recover in part because of high rates of siltation, turbidity, and low dissolved oxygen concentrations in the water from the loss of mangrove roots and the decay of dead mangroves (de Sylva and Michel 1974). Both residential landscape practices and ditch clearing by various entities have resulted in the destruction of mangroves.

Oil and Oil Spills

Oil drilling in or near mangrove shorelines has significant adverse impacts (Longley *et al.* 1978). Petroleum oils and their by-products kill mangroves by coating aerial and submerged roots and from direct absorption (Odum and Johannes 1975, Carlberg 1980). Some severe effects, including tree death, can take place months or years after a spill (Lewis 1979, 1980). Little can be done to prevent damage once it has occurred. Common dispersants used to combat oil spills are toxic to vascular plants (Baker 1971). Damage from the actions of mechanical abrasion, trampling, or compaction during cleanup can exacerbate negative environmental impacts. The continued ban on off-shore oil drilling in Florida is the best preventative for oil spill impacts. Double-hulled shipping of oil and other petroleum-based products should be required in and adjacent to mangrove estuaries.

Fire

Mangroves are not fire adapted and should not be burned (Wade *et al.* 1990). Care needs to be taken in land management controlled burning to not carry fire into mangrove systems from adjacent habitats that benefit from fire. There have been situations on public lands where this has happened.

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Restoration of Mangroves

Restoration Objective: Maintain the structure, function, and ecological processes of mangroves and prevent any further loss, fragmentation, or degradation of this habitat type in South Florida.

Restoration Criteria

South Florida can contribute to the preservation of nationally significant wetlands, hydrology, aquifer recharge, and fish and wildlife habitat values by preserving the only geographic extent of this type of habitat within the continental United States. Benefits of restoring mangrove communities include: the conservation and recovery of listed plant and animal species, wide-ranging species, and neotropical birds; the recycling of nutrients and the nutrient mass balance of the estuarine ecosystem, including high primary and associated secondary biological production; the protection of the base arboreal, estuarine, and marine food web; the provision of physical habitat and nursery grounds for a wide variety of marine/estuarine vertebrates and invertebrates significant to sports and/or commercial fisheries; the protection of public and private lands and property by mangrove storm buffers and wind breaks; the stabilization of shorelines and fine substrates; the improvement of water quality and clarity by filtering uplands runoff and trapping waterborne sediments and debris. Finally, preservation of mangrove systems contributes to the overall natural setting and visual aesthetics of Florida's estuarine waterbodies and the economy of the coastal counties of South Florida and the State of Florida.

The restoration objective will be achieved when (1) the geographic extent of mangrove habitat in South Florida is identified; (2) mangrove habitat is preserved through land acquisition or private landowner cooperative agreements consistent with the GFC's *Closing the Gaps in Florida's Wildlife Habitat Conservation System* and Preservation 2000 Act Study (Biodiversity Conservation Analysis), current State and Federal land acquisition proposals, and regional wildlife habitat protection plans; (3) the hydrology and exotic plant management of mangrove wetlands are regionally applied to enhance, restore, and maintain plant and animal biodiversity; and (4) State regulations are adequately enforced resulting in no-net loss of mangrove habitat.

Community-level Restoration Actions

1. **Identify the extent of mangrove habitat.** Although the existing GIS information, aerial photography, and ground-truthed land cover information are available for this community throughout South Florida, a comprehensive regional analysis has not been conducted.

   1.1. **Detail the geographic extent of mangroves in South Florida.** This task should integrate existing GIS and other databases on land cover, soils, and hydrology, to correctly identify and separate mangrove from other wetland types, particularly Brazilian pepper.

1.2. **Update the GIS database for mangroves to monitor cumulative impacts.** As areas of mangroves are converted to other land uses, changes should be mapped to identify and analyze trends in habitat loss.

1.3. **Identify important habitat linkages.** Important areas include connecting the mangroves of north San Carlos Bay to the Estero Bay Buffer Preserve; Rookery Bay National Estuarine Research Reserve north to Gordon Pass; Charlotte Harbor State Buffer Preserves north and south to other preserves.

2. **Preserve remaining areas of mangrove habitat.** Direct loss of habitat resulting from land conversion, habitat degradation, and fragmentation continues unabated in South Florida. However, some of the best remaining areas of intact mangrove have been identified for land acquisition.

2.1. **Identify and acquire mangrove habitat critical to the recovery of wide-ranging listed species.** The acquisition and preservation of mangroves, including buttonwood forests, is critical to the recovery of federally and State listed species as well as for augmenting habitat for neotropical migrants.

2.1.1. **Complete purchase of the following CARL projects:** Cape Haze/Charlotte Harbor, Cayo Costa, Charlotte Harbor Buffer, Estero Bay Buffer, Myakka Estuary, Rookery Bay, Bear Point, Middle Cove, Blind Creek, King's Island.

2.1.2. **Complete purchase and management implementation of mangrove habitat within 15 km (9.3 mi) of wading bird rookeries and 30 km (18.6 mi) of wood stork rookeries.** This should include Lemon Bay, Gasparilla Sound, Charlotte Harbor, Pine Island Sound, Matlacha Pass, Estero Bay, San Carlos Bay, Rookery Bay, the Ten Thousand Islands, the Florida Keys, Florida Bay, Biscayne Bay, Lake Worth Lagoon, and the Indian River Lagoon.

2.1.3. **Protect coastal mangroves as raptor and bald eagle nesting habitat as well as neotropical migratory bird habitat.** Bald eagles prefer nest and perch sites on the largest, tallest trees available near large, open waterbodies in coastal South Florida. Neotropical birds require available foraging habitat as close to the coast as possible to facilitate migration across the Gulf of Mexico and Caribbean. Coastal mangroves in urban areas are subject to hedging. Pine Island in Lee County is an example of a mangrove area that should be protected.

2.1.4. **Complete purchase and management implementation of mangrove habitat within Priority I/II areas identified in the Florida Panther Habitat Preservation Plan.**

2.1.5. **Identify and acquire potential shoreline nesting habitat available to the American crocodile and mangrove terrapin in South Florida.**

2.2. **Complete purchase and management implementation of mangrove habitat in contiguous, connected, unfragmented patches for the conservation of biodiversity in South Florida.** Acquiring and preserving mangrove habitat will benefit nongame species, rare and unique species, and keystone species such as the mangrove tree crab, mangrove rivulus, mangrove prairie warbler, and various owl and raptor species.

2.2.1. **Develop additions to existing Federal and State land acquisition proposals in areas identified as GFC Strategic Habitat Conservation Areas and in the 1990 Statewide Charrette, including the following:** Estero Bay Watershed, San Carlos Bay, Cocohatchee River, West and East Charlotte Harbor, and the Imperial River drainage.

2.3. **Use existing regulatory mechanisms to protect mangrove wetlands.** Mangroves have significantly declined in areal extent, patch size, and quality in South Florida, primarily because of exemptions, inaccurate rules, lack of compliance review, and inadequate mitigation practices.

2.3.1. **Stress avoidance of impacts of this habitat type as a regional wetlands permitting concern.** Both consultants and permitting entities need to be educated on the importance of this habitat to fish and wildlife resources and the economy.

2.3.2. **Re-evaluate the Federal and State permitting process and permit exemptions to assess impacts on mangrove habitat.** Piecemeal development and speculative land clearing in urbanizing areas under exemptions results in fragmentation and loss of mangroves in the South Florida Ecosystem.

2.3.3. **Require in-kind on-site and off-site wetland mitigation when avoidance and minimization criteria have been exhausted.** Both consultants and permitting entities often assess credit mitigation on the basis of the wetland depth, not the landscape importance or biodiversity value. This results in mitigation plans using red mangroves even when black, white and buttonwoods are being impacted.

2.4. **Protect mangrove communities from point source and non-point source pollution.**

2.5. **Implement cooperative habitat preservation and management programs with private landowners.** Some mangrove habitat is in private ownership and some private landowners may not choose to participate in fee-simple land acquisition projects. Protection and management through alternate methods may conserve important ecosystems by providing landowners with economic incentives (*e.g.*, tax relief) and promoting good stewardship by ensuring that landowners view habitat as an asset, not a liability.

2.6. **Support and implement cooperative regional greenways programs with landowners and other agencies.** Greenways planning has successfully developed cooperative, local conservation plans that will establish, maintain, and manage landscape connections between important resource areas.

2.7. **Promote the protection of mangroves by local governments.** Use the GIS database to provide local governments with the location and areal extent of mangrove habitat to promote and improve resource planning within local comprehensive plans.

3. **Manage and maintain mangrove habitat on public lands.**

3.1. **Implement effective habitat management techniques to maximize the biodiversity of the mangrove community.** Mangrove may benefit from alternate management practices that are sensitive to hydrology, herbicide susceptibility, and subtropical vegetation. Diversification of management techniques may increase biodiversity of impounded and marsh managed systems. Management of mangroves on a landscape scale will benefit listed species, wide-ranging species, wading birds, neotropical migrants, and endemic bird species, including the mangrove cuckoo, black-whiskered vireo, and Florida prairie warbler. Effective management techniques should include controlling exotic plants and animals without impacting non-target native species and preventing collection of rare plant species, such as bromeliads and orchids, on public lands.

3.2. **Ensure the continuance of habitat management on public lands.** State and Federal land managers are faced with funding deficits that prevent or reduce management actions. Perpetual funding sources for staff and equipment should be secured.

3.3. **Maintain important habitat linkages.** Public landowners should coordinate land acquisition and habitat management activities to ensure the protection of large, contiguous tracts of land that include a mosaic of native habitat types, including mangroves.

3.4. **Identify and prohibit incompatible public uses that degrade mangrove habitat.** Incompatible public uses that disrupt hydrology, pollute, encourage exotic plant or animal invasion, overharvest resources, or destroy habitat beyond the ability for effective management should be identified and eliminated.

3.5. **Monitor compatible adjacent land uses to protect the ecological function of mangroves.** Secondary and cumulative impacts to public lands can result from adjacent development, including loss of habitat, litter, chemical discharges, dumping, promoting exotic plant and animal invasion, alteration of adjacent hydrology, use of pesticides/herbicides, and noise/light pollution. Implementing land-use regulations to establish a wide buffer between mangrove habitat and upland development can eliminate or minimize these secondary and cumulative effects.

4. **Restore and enhance mangrove habitat, where feasible.**

4.1. **Identify locations of mangrove habitat that can be restored.**

4.1.1. Coastal areas where mangrove restoration efforts are either currently being conducted or should be considered include Indian River Lagoon, Lake Worth Lagoon, Biscayne Bay, Florida Keys, Charlotte Harbor, and Sarasota Bay.

4.2. **Restore the natural hydroperiod and tidal regime of mangrove communities.**

4.3. **Restore sheetflow hydrologic conditions by restoring the regional landscape to natural contour.** Much of South Florida has been significantly altered by public and private drainage projects that have resulted in both overdrainage and flooding of natural systems. Where possible, off-site, regional hydrological restoration actions may be necessary to restore mangrove functions. Areas where restoration should occur include the South Golden Gate Estates and Camp Keais Strand in Collier County, the Estero Bay Watershed in Lee County, and the Babcock-Webb Wildlife Management Area in Charlotte County and the Charlotte Harbor Flatwoods CARL project in Lee and Charlotte counties.

4.4. **Re-establish important habitat links by constructing wildlife crossings.** A wide variety of development and linear infrastructure projects fragment mangrove habitats. Future design and retrofit or rebuild of these projects should include culverts, undercrossings, overpasses, and other features that reduce wildlife mortality, preserve hydrology, and increase connectivity to adjacent habitat.

4.5. **Encourage mitigation banks that restore and enhance mangrove systems, not monocultures.**

5. **Perform additional research on mangroves.**

5.1. **Continue and update studies on the utilization of mangrove communities by endemic and wide-ranging species, including the development of landscape-scale management recommendations for the recovery of these species in South Florida.**

5.1.1. **Inventory and characterize the importance of mangroves to avian populations, including neotropical migrants and wading birds.**

5.1.2. **Survey mangroves in southwest Florida for the American crocodile.** Updated surveys for the American crocodile have not been conducted. The complete range of this species should be documented in order to recover the population.

5.1.3. **Examine reptile and amphibian populations associated with ponded wetlands in mangrove ecosystems.** Investigate the habitat requirements for the American crocodile and mangrove terrapin.

5.1.4. **Examine invertebrate diversity and life cycles in mangrove habitat.**

5.2. **Monitor mangrove communities to evaluate biodiversity.** Monitor community-level processes, structure, and composition, including rare and imperilled species. Improve reference information for community composition, biodiversity, and site-to-site variability.

5.3. **Perform a hydrologic study of the flood attenuation and storm buffering potential of mangrove habitat under natural sheetflow conditions.**

5.4. **Examine the population dynamics by invasive exotics in the understory of mangrove habitat.**

5.5. **Examine the habitat value of buttonwood forests in South Florida.**

5.6. **Identify historical and geological trends in mangrove distribution relative to hydrology and sea-level in the mangrove communities of South Florida.**

6. **Increase public awareness concerning mangrove habitat.** Identify mangroves in text, maps, and on resource presentations to raise public awareness of the different types of mangroves. Stress the important ecosystem function of isolated and ephemeral wetlands included in the mangrove community. Establish the landscape-scale importance of this community to wide-ranging species and the significance of regional losses of this habitat in South Florida.

6.1. **Inform the public about the harm caused by marine debris,** particularly monofilament line for fishing and polypropylene lines for lobster and stone crab traps, encouraging the use of biodegradable fishing line, proper fishing stewardship, and enforcement of marine dumping regulations.

6.2. **Inform the public about the need to maintain the off-shore drilling ban** in Florida waters with mangrove estuaries, and the need for double-hulled transportation of petroleum products in mangrove estuaries.

6.3. **Inform the public about the need to not trim mangroves** for view on public lands and on private waterfronts particularly in Aquatic Preserves.