

Ecosystem of the Mangroves

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Introduction to Mangroves

Mangroves are the dominant ecosystems that line the coasts of subtropical and tropical coastlines around the world. Mangroves are survivors. With their roots submerged in water, mangrove trees thrive in hot, muddy, salty conditions that would quickly kill most plants. A series of adaptations allow these plants to not only live in these conditions but thrive, including a filtration system that keeps out much of the salt and a complex root system that holds the mangrove upright in the shifting sediments where land and water meet. Mangrove ecosystem also supports an incredible diversity of creatures, including some species unique to mangrove forests. And, as scientists are discovering, mangrove swamps are extremely important to our own well-being and to the health of the planet. There are four species of mangroves that range in size, characteristics, and preferred habitat. Mangroves act as natural buffers between the land and sea. Mangroves absorb the force of strong waves that have been built up on the open seas. This is especially important during times of tropical storms. Additionally mangroves counteract erosion which waves cause over time. From a filtration standpoint mangroves neutralize sediment runoff from both natural and human activities, mangroves are often referred to as carbon sinks. Mangroves hold vital habitat to animals like birds that nest in their tight knit canopy. More importantly aquatic organisms that we as humans rely on are found in the tangled roots of the mangroves. Many juvenile fish from the nearby coral reefs, like snapper and grouper, come to take refuge in the tangled roots of the mangroves. Here the young fishes can grow with much less competition and predation. Mangrove lagoons are an

important habitat for juveniles of many fish species (Cintron-Molero, 1987 ; Thayer et al., 1987; Boulon, 1992), and can provide nursery areas for estuarine as well as reef fishes (Odum et al., 1982; Boulon, 1992). Crustaceans such as shrimp, crabs, and lobster also take hold and grow in these ecosystems. Some smaller species of fish never leave the tangled root systems of the mangroves. The area surrounding the edges of mangroves is the favorite hunting grounds for fish like the tarpon, rays, and lemon sharks. Another bounty for humans is the massive gastropods known as conch. Conchs are large slow moving snails that are highly sought after in the tropics of the Caribbean for their delectable meat. The mangrove wood itself has been collected for ages for fuel by those living in close proximity to the coastline. In recent years however mangroves are in decline as they are cleared for development, converted to aquiculture ponds, or wood chipped to aid in the production of rayon. This destruction displaces organisms that rely upon the mangroves for a rearing ground, hunting ground, and home. Additionally it puts its new human residents in danger of harsh waves and consequently the erosion that comes along with them.

Mangrove Species

Mangroves—forests of tropical trees and shrubs rooted in saltwater sediments between the coast and the sea—are crucial nurseries for coral reef fish, according to a new study (John Roach, 2004). The tallest and most distinctive mangrove is the red mangrove (*Rizophora mangle*). Under optimal conditions this tree can reach 80 feet in height in some parts of the world, but on average reaches a height of 20 feet. The distinctive characteristic of this species

is its reddish prop roots which can extend out of the water up to 3 feet. These roots are the primary home for the many species of organisms that thrive in the ecosystem. The red mangrove is the most tolerant of turbulent water. This mangrove is the first specie to meet the aggressive waves from the open ocean. The black mangrove (*Avicennia germinans*) is smaller and grows closer to the shoreline in areas slightly higher in elevation, more susceptible to tidal fluctuations. In the times of low tide pencil-like projections, or pneumatophores, extend into the atmosphere to provide oxygen for the underwater root systems. This specie can reach over 65 feet in some locations, but on average it will reach heights up to 50 feet. This tree appears similar to that of the red mangrove with opposite leaf arrangement. However the presence of pneumatophores and lack of prop roots sets them apart. The white mangrove (*Laguncularia racemosa*) is found at even higher elevations where soils are least saturated. The most distinguishing feature is the lack of aerial roots. Unlike the black and red mangroves the white mangrove conceals its roots underground, with the exception of prolonged flooded areas where the tree will develop a sort of peg root to obtain oxygen. The fourth specie of mangrove is associated with the upland transitional zone is restricted in its range by its extreme sensitivity to cold. The buttonwood mangrove (*Conocarpus erectus*) is a shrub-like tree and is least like the other mangroves but still plays a vital role in the mangrove ecosystem being home to terrestrial animals and avian nesters.

Terrestrial Inhabitants

There is a wide range of mammals that visit the mangroves to hunt and forage for food. Some small like raccoons, opossums or agoutis, but there are also large animals that rely on these ecosystems. The very rare Florida panther was last seen in the everglades mangrove system, and due to habitat destruction it is estimated that roughly 50 individuals remain in the wild. The endemic key deer is only among the mangrove systems in the Florida Keys. In many other parts of the world monkeys are very common in mangroves, and in fact have been captured on video diving in the shallows collecting food. The greater flamingo and other special birds also visits these ecosystems were they forage in the shallows for tiny crustaceans. Many waterfowl species in North America spend their wintering months in and around the mangroves searching for food before their counter migration back north. To one particular sort of bird, mangrove canopies are among one of the few options for nesting. Pelagic birds, or sea birds, are birds that spend the majority of their lives at sea. These birds are highly efficient at staying aloft and use little energy when flying. They come to land rarely and often only to nest. To these birds the thick tangled canopy of the mangroves is ideal to build for nesting and rearing young. The seeds from a parent tree drift across the sea and rest upon an exposed section of sand, taking root and virtually creating a bird paradise. Black mangrove grows in the intertidal zone throughout the Gulf of Mexico. It will establish in nature from seed that floats and can travel some distance on the tides (Houck, M., Neill, R. 2009). These specialized birds, such as the magnificent frigate bird, can nest on an island free from predation and have an open buffet on either side to feed their young.

Aquatic Inhabitants

Among the tangle of the mangrove prop roots (*Rizophora mangle*) lays an absolute flourish of life. Nearby are beds of seagrass which are considered part of the mangrove ecosystem. The organisms from the mangroves interact with those of the seagrass beds. In the Caribbean, juvenile reef fish occupy the submerged prop roots of *Rizophora mangle* and make frequent foraging runs into adjacent seagrass beds (Mumby, Peter J., 2006). Mangroves serve either as nurseries for juveniles or as feeding areas for transient fish and crustaceans (Robertson and Duke 1990; Sheridan 1992). For many fish they start their lives in the adjacent sea grass beds, they migrate into the mangroves as they grow slightly larger, and then when they are just about fully mature they migrate across the flats to the coral reefs. This is known as ontogenic migration. It has been found that certain coral reefs are correlated to certain mangrove systems. Therefore if a mangrove forest is removed, the fish populations of the correlating coral reef are negatively affected. Just as waterfowl seem to have a sixth sense when it comes to direction, reef fish also seem to know where their desired destination is as they set off on their final migration to the coral reef where they will live out the rest of their lives. Migrating fishes can move directly between mangroves and reef habitats, passing over deep water and seagrass beds (Mumby, Peter J., 2006). The reasons for undertaking such a stage-structured lifecycle are varied and include: (i) requirements for different food sources as the organism grows (Werner and Gilliam, 1984; de la Moriniere et al., 2003a), (ii) changing risks of predation with size, such that sheltered habitats, where predator foraging efficiency is low, are chosen when the organism occupies its smaller, more vulnerable stages (Shulman, 1985; Laegdsgaard and Johnson, 2001), and (iii) a need to reproduce in habitats which offer the

greatest dispersal or survival of larvae. The maximum distance covered during migration, observed in a study by Peter J. Mumby in the cays of Belize, was 10 km.

Mangroves as a Nursery

There is a wide range of fish species that live in the nursery of the mangroves. There are some fish species that live in the mangroves fulltime, some come and go with the seasons, and some just live in the mangroves until they reach maturity. Species that live here full time are a variety of gobies, spotted trout, pipefish, and others. These full time residents never grow too large for their habitat and therefore never have reason to leave. During the rainy season, the increased flow of freshwater results in the appearance of freshwater species, such as the predatory Florida gar. This increased flush of freshwater has been known to drive some species further off shore in search of higher saline waters. Among the resident species and seasonal guests are the juvenile fish species which migrate to the coral reefs once they have reached maturity. Of these juvenile reef fish are various species of grouper, snapper, jacks, schoolmasters, and others. Among the grouper species that live in these habitats is the endangered Goliath grouper. These spectacular fish can reach weights of over 800 lbs. when mature. Goliath grouper breed in mass swarms in the open ocean and their fry grow in the seagrass beds and then they migrate to the nearby tangle of the mangroves. Goliath grouper remained in mangrove habitats for 5–6yrs (validated ages from dorsal spine sections), then emigrated from mangroves at about 1.0 m total length (Christopher C. Koenig, et al. 2007).

In this mangrove nursery there are many species of fishes that flourish in a predator reduced environment. The larger predatory fish are too large to pursue their prey in the mangroves. While within the mangroves themselves there are very few predators, in the more open waters are predator fish that await any small wanderers that may stray away from the protection of the mangroves. Fish like the tarpon, snook, bone fish, red fish, rays, and lemon shark work with the tides. They are fairly large fish and need deeper water to enter the shallows surrounding the mangroves. Once these predators get into the shallows they are on a race against the clock to hunt as much as they can before the tides retreat and they become stranded. These fish are opportunistic feeders taking whatever they can fit in their mouths; just about everything is fair game. These fish don't have any natural predators in these waters. However they are highly sought after by the saltwater angler.

Other Mangrove Inhabitants

The ecosystem of the mangroves is not just home to fish species. Also calling home to these parts is a wide variety of invertebrates. The extensive root systems, muddy bottoms, and open waters are all home to invertebrates that are well adapted to the temperature and salinity fluctuations as well as the tidal influences common to mangroves. These wide array of organisms feed on leaf litter, detritus, plankton, algae, and other small animals. Barnacles, mollusks, shrimp, crabs, lobsters, jellyfish, tunicates, etc. can all be found among the roots of the mangrove. There is also a very ancient animal that can be found living in the mangroves, the earliest fossils of the horseshoe crab dates back to roughly 450 million years ago.

Horseshoe crabs are scavengers and may be found among mangroves feeding on algae, invertebrates, and dead organisms. They are especially adapted to low oxygen waters, possessing up to 200 book gills used for respiration. On the edges of the mangroves and out in the seagrass beds one can find colorful anemones with their feeding tentacles sent up to catch food, sea urchins crawling about munching algae, and large gastropods known as conch scooting about the bottom. These large slow moving snails are known for their iconic shells, and have been collected for years for their meat. Also commonly found in these waters and collected for their meat is the Caribbean spiny lobster. Their habitat usage is similar to that of the juvenile reef fish. Depending on their maturity they sought different habitat type. Largely influencing their preference for habitat was predation. Predation on newly settled juveniles was greater in seagrass and coral crevices than in mangrove prop roots, whereas the survival of larger juveniles was higher in mangroves and coral patch reefs than in seagrass. These results suggest that mangrove habitats may function as a nursery for juvenile spiny lobsters but that the use of this habitat depends on shelter characteristics and the isolation of islands (Charles A. Acosta and Mark J Butler IV, 1997).

Along with invertebrates and fishes, sea turtles are also associated with mangrove vegetation, at least point in their life. The Atlantic ridley sea turtle is commonly observed in the mangroves that line the bays of south Florida. The loggerhead and green sea turtles have been known to utilize the mangroves as juvenile nurseries as well, receiving protection from predation and ample access to a food rich environment. The green sea turtle and the Hawksbill sea turtles have been observed feeding on the roots of mangroves as well as other submerged vegetation. Another reptile known to the mangroves are saltwater crocodiles. Mangroves are

particularly well suited for juveniles. All around the world species of water snakes can be found living in mangroves, as well as some saltwater tolerant amphibians. The most common of these amphibians is the giant toad (*Bufo marinus*). The giant toad, or more commonly known as the cane toad, is native to Central and South America but has been introduced in the Caribbean and some Pacific Islands. Originally introduced to control the cane beetle it is now considered a pest. There are also two quite different aquatic animals that also are very common in and around mangroves. Feeding on the small fish species dolphin are quite common to mangroves. Feeding on seagrass and submerged vegetation manatees are also often seen swimming around the edges of mangroves along the coast of Florida. Another species of manatee that can be seen in coastal marine habitats is found in West Africa.

Erosion Resistance

Besides for crucial for wildlife habitat both above and below the surface, mangroves also serve a purpose to the land beyond them. Mangroves are very efficient at counteracting erosion. In many areas around the world mangroves are removed for various reasons, and in these areas the effect of erosion can be seen almost immediately. Mangroves act as a natural wave block from the strong waves that have built up on the open ocean. Even a small band of mangrove is an efficient blocking waves. Mangroves are extremely important in times of increased wave strength, such as during tropical storms. The best example on finds is the super-cyclone which occurred on the 29th October 1999 with a wind speed of 310 km hr⁻¹ along the Orissa coast (India) and played havoc largely in the areas devoid of mangroves. On

the contrary, practically no damage occurred in regions with luxuriant mangrove growth (Kathiresan). This example alone should be evidence enough to prove that mangroves are essential in protecting coastal lands. Ironically the highly populated areas most in need of protection from tropical storms are the areas most likely to remove mangroves. A prime example of this would be Cancun, Mexico. Cancun is situated at the very tip of the Yucatan Peninsula, which is a relatively large piece of land situated in the middle of the Caribbean Sea. Given its location, the peninsula is highly susceptible to hurricane activity and with the removal of their mangroves they are rendered helpless to any strong tropical storm. The logic for the removal is for more pleasing aesthetics, yet less aesthetically pleasing are the sandbags set in place to combat the waves and high water. Without the mangroves to hold sediment in place, even the gentlest of waves will take some amount of sediment out into the ocean. A well-known and credible institute has witnessed this first hand. The Smithsonian Institute operates a field station on a small island, 0.4 hectare in size, 14 miles off the coast of Dangriga, Belize. The Carrie Boy Field Station is located on the Meso-American Barrier Reef, and is devoid of mangroves. Due to this absence of mangroves the already small island shrinks every year, at an average decreasing rate of 2 inches. Along with keeping sediment in place, mangroves also filter the water passing through the sediment. "Black mangrove is valuable in restoring brackish and salt water marshes due to its ability to filter and trap sediments. Mangrove forests, which include black mangrove, have a high capacity as a sink for excess nutrients and pollutants. It also mixes well with other native plants to reduce wave energy (Houck, M., Neill, R. 2009)". Mangroves are so efficient at filtering nutrients from water that in some places they are being used on a municipal level to treat sewage. A mangrove wetland was constructed in Futian,

Shenzhen, China to do just this. Three belts of mangroves were planted, housing three different species. The belts through which the water was fed held dimensions of 33 m in length, 3m in width, and 0.5 m in depth. Expectedly the removal of organic matter and nutrients were positively correlated with plant growth. The results indicated that mangroves could be used in a constructed wetland for municipal sewage treatment, providing post-treatment to remove coliforms was also included (Q. Yang, et al., 2008). In the natural setting filtration is key as well, especially in areas where development is prevalent. The filtration of runoff is particularly important where the surrounding region contains seagrass or coral reefs. These habitats are particularly vulnerable to deterioration if water quality declines. If coral reefs and seagrass habitats were to be lost, numerous highly valuable ecosystem goods and services would also be lost.

Economic Importance

Mangroves are economically important as well. The value of mangrove ecosystem services worldwide has been estimated as an annual global flow of US\$ 1,648 billion (Costanza, et al., 2007). The problem is when harvest exceeds production. Of 2500 households in 21 rural communities (about 13.000 people) near the Caeté estuary, 83% derive subsistence income, and 68% cash income through use of mangrove resources (Glaser, 2003). Near this estuary on the northern Brazilian coast, everything is used in the ecosystem from the sea, to the land, and even the wood itself. The mangrove crab (*Ucides cordatus*) is collected and sold by 42% of households, and constitutes a main income source for 38%. Including processing and trading

occupations, over half of the investigated populations depend on the mangrove crab for financial income (Glaser, 2003). In addition to the mangrove crab in these regions, many households depend on the use and sale of the mangrove wood and bark. Not only in Brazil but virtually worldwide mangrove wood is collected on both the small scale and commercial scale. Mangrove wood is high in tannin therefore is very sought after for its durability in the timber industry. As with any wood harvest it is done both sustainably and not sustainably. In fact, mangroves can be very successfully managed for sustainable timber production – the Matang Mangroves in western Peninsular Malaysia are a classic example. The management system, first started at the beginning of the 20th century, is based on a 30 year rotation. Small areas are clear-felled in a patchwork manner, and allowed to regrow before the next harvest (In Eong Ong, 2002). Mangrove wood burns with a high heat output and no smoke, making it ideal fuel wood. Coastal rural inhabitants have been using mangrove as fuel for many generations. Consequently these characteristics make it very attractive for mass collection coal production. One ton of mangrove wood is equivalent to 5 tons of Indian coal. Due to its durability the rayon industry also ravages the mangroves for their wood, as does the wood chip industry. These three industries are highly responsible for the destruction of mangroves. The pneumatophores can be used to make bottle stoppers and floats for fishing. A perhaps unexpected industry is the mangrove honey industry. During full bloom bees and other insects are found buzzing about mangroves as they are any patch of wild flowers. And in doing so collect pollen on their bodies which is later brought to the hive and put to use. Many people in foreign lands know of the sweet nectar produced and harvest this honey produced. For instance, the Sundarbans provide employment to 2000 people engaged in extracting 111 tons of honey annually and this

accounts for about 90% of honey production among the mangroves of India (Krishnamurthy, 1990). In Bangladesh, an estimated 185 tons of honey and 44.4 tons of wax are harvested each year in the western part of the mangrove forest (Siddiqi, 1997).

Fisheries

Perhaps the most exploited, but economically profitable, parts of the mangrove ecosystem are the fisheries. On a subsistence level, fishing can be done sustainably and is quite crucial for some populations of people. On a local level many individuals dive for the Conch and keep themselves as well as sell them to local restaurants. But on a commercial level, animals are taken out of the mangroves for money and often at a rate at which the ecosystem cannot supply for the demand. Most common are shrimp and the various species of fish, although other crustaceans and shellfish are also sought after. Implementing the proper techniques the fisheries can be harvested from on a sustainable level. Most of the time the fishermen are often overwhelmed by greed, which ultimately leads to the down fall for the fishery. And when the ecosystem does not provide enough for what the demand is, aquaculture is established. Typically this means that the natural mangrove ecosystem is destroyed, and what remains is manipulated to better suit for a certain organism in order to gain cash profit. Consequently this only suits those particular organisms banishing the others from existing there. The food and other chemicals put into the water also adversely affect the rest of the surrounding waters around these man made ponds. The driving force is the high demand for shrimps in the

developed countries and the governments of developing countries grossly undervaluing their mangroves (Jin Eong Ong, 2002).

Carbon Sequestration

Beyond the economical possibilities and the crucial wildlife habitat for so many varieties of organisms, is yet an even more important value of the mangrove. This is one that is important not only in small communities or even whole countries, but on a global scale. This unique characteristic is the mangroves ability to remove carbon from the atmosphere. Much like the wetlands of the inlands and the boreal forests of the temperate climates, mangrove systems are referred to as carbon sinks. The ocean itself does a great job through its direct air-to-sea exchange activity. This more or less is the action of waves capturing air and bringing the carbon into the ocean. With the combined oceanic air-to-sea exchange and the mangroves ability to seize atmospheric carbon, the two seize a huge amount of carbon. Measurements show that mangroves have the ability to seize around one and half tons of carbon per hectare per year. This is approximately equivalent to the amount of carbon a motor vehicle releases to the atmosphere each year (assuming each car uses approximately 2,500 liters of petrol per year) (Jin Eong Ong, 2002). Indonesia has 4.5 million hectares of mangrove, and from this previous information we can conclude that the emission from 5 million cars can be erased by

the mangrove ecosystem in Indonesian alone. A high amount of carbon is stored in the upper layer of mangrove sediment, around 10 %. Each hectare of mangrove sediment consequently contains about 700 tons of carbon per every meter of depth, and digging up the sediment to create ponds for aquaculture results in the potential oxidation of 1/400 tons per hectare per year. Naturally only about half of this would become oxidized over the span of about ten years. The sequestration rate is then catalyzed to a rate of around 50 times the natural rate, thus eliminating the mangroves ability to absorb atmospheric carbon.

Case Study: Red Mangrove Prop-Root Habitat as a Nursery

A case study was done by Aaron J. Adams and William J. Tobias in the U.S. Virgin Islands to try and understand how important mangrove systems are as nurseries for fishes in the marine world. The mangrove prop-root habitat of Salt River Bay, St. Croix, U .S. Virgin Islands, was sampled monthly from October 1990 to April 1993 to assess the importance of mangroves as nursery habitat for economically important finfish species (Adams, Tobias, 1993). The red mangrove prop-root habitat was sampled monthly with standard fish traps and visual transects for a 30 month period. The visual transects were conducted with snorkel gear by two individuals, and the traps set varied in number with the individual partitions. The total area observed was partitioned into five sites. Each site was based on the mangrove cover, human impact and water turbidity. There were contrasting sites studied, some with extreme mangrove cover and little development, and some with reduced mangrove cover and development. All traps were sampled within a five day period. All individuals captured were identified and then released back to their habitat. There were a total of 3,642 individuals,

representing 40 species and nineteen families captured in the traps. There were 20,606 individuals observed via snorkeling in the transects, representing 48 species and 26 families. The numbers seen in the contrasting areas were somewhat interesting. In the more developed areas there were more fish found in the traps. This is because in these disturbed areas the fishes were looking for cover to take refuge, and found the trap instead. Most of these species of fish captured were dominated by juveniles. Although mortality among smaller fish may have partly reduced the number of individuals reaching larger sizes (i.e., Type III survivorship curve), much of the reason for low abundance of larger individuals was migration to other habitats (Adams, Tobias, 1993). It was found that many of these species found represent species sought after for recreational fishing, a few even as commercial fishing species, and others are aesthetically appealing to sport divers. The abundance of juveniles throughout the study indicates that the mangrove prop-root habitat is utilized primarily as a nursery, similar to other mangrove systems (Baelde, 1990; Van der Velde et al., 1992; Rooker and Dennis, 1991; Thayer et al., 1987; Tzeng and Wang, 1992; Dennis, 1992). This habitat is not important only to recreational fishing, but commercial as well. Many of the species present in mangrove lagoons are potential prey for recreationally or commercially targeted species (Odum and Heald, 1975; Robertson and Duke, 1987; Thayer et al., 1987). This study accurately portrayed the abundance of fishes in mangrove systems of the U.S. Virgin Islands, and how crucial mangroves are to the existence of numerous fish species world round.

Case Study: Mangrove-Fishery Linkages

Edward B. Barbier (Department of Environmental Economics and Environmental Management University of York) and Ivar Strand (Department of Agricultural and Resource Economics from the University of Maryland) composed a case study on the value of mangrove systems as a breeding and nursery for off-shore fisheries. The study aims to link the destruction of mangroves with the dwindling fish and shrimp populations off the coast of Campeche, Mexico, in Laguna de Terminos. The five Gulf States of Mexico - Campeche, Tabasco, Tamaulipas, Veracruz and Yucatan - all have important mangrove-lagoon systems, but by far the largest and most important of these systems is the Laguna de Terminos in Campeche (Barbier, Strand, 1997). One of the main reasons of mangrove destruction in this area is that from an aesthetic standpoint. Mangroves are just seen as a tangled mess and a waste of space. For this reason the areas holding mangroves have a lower price than those properties without, thus the areas are more susceptible to conversion to something other than natural uses. In particular, the expansion of the city of Carmen, adjacent to Laguna de Terminos has led to mangrove deforestation in the last decade (Barbier, Strand, 1997). The area of mangroves was estimated to decline to about 835 km² in 1991, a loss of around 2 km² per annum (Barbier, Strand, 1997). In addition to the concern of increasing deforestation is the concern of an encroaching, lucrative, shrimp aquaculture activities. Not only was this study done to draw attention to the problem in Campeche, but also to develop a general methodology that can be applied to mangrove systems around the world. It is not just the deforestation that is hindering the shrimp populations, but as you get an increase in development (human populations) you also get an increase in the need for food. Our estimate of the marginal productivity of fishing effort is actually negative over the entire period of analysis, reflecting the rapid expansion of

fishing vessels over this period, from around 4,500 combined industrial and artisanal vessels in 1980 to 7,200 in 1990 (Barbier, Strand 1997). From 1980-1987, production fluctuated steadily between 7-8 thousand metric tons (KMT) but by 1990 production had fallen to 4.6 KMT (Barbier, Strand, 1997). Open access conditions and over-fishing appear to lower the economic value of natural habitat (Barbier, Strand, 1997). An open access condition refers to open access to the fishery of Laguna de Terminos. While regulation of this is important, the general over-fishing is much more critical. The Gulf of Mexico is the source of nearly half of all fisheries production in Mexico and nearly one third of the total production in shrimp (Yañez-Arancibia and Aguirre-Léon 1988). With this information it can be seen just how crucial the protection of these mangroves is. There are several commercial fish species that are known to be dependent on the mangrove habitats for both breeding grounds as well as a nursery, however the shrimps found in this habitat are the most economically important species. For example, in 1990 shrimp catches accounted for over 55% of the total production tonnage of the mangrove dependent fisheries in Campeche, and shrimp is by far the most commercially valuable of these species (Barbier, Strand, 1997). Through a series of equations pertaining to the carrying capacity of the shrimp fishery of Campeche, the fishing efforts, and deforestation, Barbier and Strand have determined that deforestation is affecting the shrimp fishery of Campeche but it is not near any danger of collapsing. It is also determined that loss of mangrove area results in a lower level of equilibrium of fishing efforts. A fall in mangrove area will therefore result in a decline in both steady-state shrimp harvest and the gross revenue of the fishery (Barbier and Strand 1997). By employing one of the above equilibrium conditions of our model, it is possible to establish a relationship between shrimp production, effort and mangrove area that can be estimated over

time (Barbier and Strand 1997). This is increasingly important as mangroves are destroyed and the fishing fleet stays constant or increases. Before any physical evidence is provided, these models provided by Barbier and Strand can predict the outcome of the fishery in the future. The loss of mangroves between 1980-90 overall impact was relatively small. However as previously stated the over-fishing of the fishery was of greater concern. As the number of combined vessels increased by 61.5% over this period, the corresponding loss in shrimp harvest was 45.5% (Barbier and Strand 1997). As these numbers suggest due to the current rate of deforestation is relatively small, this could potentially be a concern in the future. If as expected mangrove deforestation accelerates in the region, perhaps as a result of urban expansion and the conversion of mangrove swamps to mariculture ponds, then it is likely that more substantial losses to the off-shore shrimp fishery will occur (Barbier and Strand 1997). From a purely economic standpoint, this loss of mangroves, and thus the potential loss of shrimp in the Campeche fishery could be catastrophic. As the world grows around this mangrove nursery the demand and pursuit of these species will increase. Only with proper management techniques can this fishery (and others like it) continue to be prosperous for harvesting for years to come.

Critique and Comparisons

Both of the case studies discussed give very good proof of the importance of the mangrove ecosystem, from the economic and ecological standpoint. The study done in Campeche, Mexico really explores the importance of the mangroves for the shrimp industry in the area as well as the threat of deforestation for development. Well known by now is the

other qualities of the mangroves, and the other study explores the amount and species of fish in the U.S. Virgin Islands.

The first study discusses the species, and numbers of them, surrounding several mangrove systems of the coast of the U.S. Virgin Islands. This was done in a very hands-on approach. The fish were physically trapped and visually counted in their natural habitat. The only shortcoming of this study might be as the snorkelers went about on their transects there is probable chance of error in counting the same individuals both in the same swim, as well as the next time out. The same goes for the trapping done; unless the individuals are tagged the chance for recapture is high.

The second was done on a more quantitative level discussing the economic importance of the shrimp fishery found in and around the mangrove system of Campeche, Mexico. The study involves many numeric models showing how the introduction of certain factors either hinder or help the fishery. The most important model introduced allows the predicting of the future of the fishery. These models are not only useful in the specific fishery off Campeche, but can be applied to areas all around the world. There is not much to improve on this study, but perhaps other factors can be discussed, such as the mangroves ability to filter potentially harmful runoff. The topic of deforestation for development is brought up; another topic that goes along with development is runoff. This could be a very interesting topic to be further explored with the success of fisheries around the world.

Conclusion

By now it is well known that the ecosystem of the mangroves hold numerous benefits to both the ecological world and society alike, many of them which are overlooked. It is also well known that mangroves are currently under threat by the human race, despite all of the good that they do. From a wildlife point of view, to say that mangroves are important would be a tremendous understatement. Mangroves hold refuge to virtually every single organism of nature. Some are just raised there, some only visit and some spend their entire lives there. These special animals however might very well be under serious threat with this steady increase of deforestation. If the current rate of destruction continues the world will realize the implications of their actions, and soon. It is debatable that the world is warming and that the intensity of storms will increase. What is not debatable is that mangroves sequester carbon, aid in the breaking of waves, counteract erosion, and filter runoff water from the inland. All of these will be very vital as the world continues to develop. Also extremely important as the human population grows is the need for the food that the mangroves undoubtedly provide. However if the destruction continues these very precious fisheries will struggle to provide. The bounty available from the mangroves is immense, and just like any other ecosystem this bounty can be harvested in a sustainable manner. If the exploitation of this ecosystem continues the human race will be without one of the greatest and productive ecosystems this world has to offer.

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