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The Impact of Restored Mangrove Forests on Fishery Populations and Biodiversity

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Abstract:

Mangrove forests are one of the most dynamic ecosystems on Earth. They provide many ecosystem services, including shoreline protection, carbon sequestration, as well as food and safety for numerous marine organisms. Their role as a marine nursery is well known, serving as the spawning place and home for many species of juvenile fish. Unfortunately, mangrove forests have suffered major degradation over the past century, due to population growth and expansions in industry. Destruction of mangrove forests has caused the marine populations which rely on them to similarly suffer. This has also been devastating to tropical coastal fisheries, who rely fish populations for their livelihoods. Mangroves can be directly tied to the economy, with some studies illustrating a direct tie between mangrove forest size and fishery landings. In response to this loss, mangrove restoration has become a popular way to return tropical coastal environments. However, the quality of restored mangrove forests varies in their survivability and their restoration of biodiversity. In order to maximize the success of mangrove restoration the locational hydrology, local societal makeup, as well as floral and faunal conditions must be taken into account. If mangrove restoration is successful, populations may serve as a beneficial habitat to endemic marine organisms, including economically viable fish. However, the initial recorded levels of biodiversity are often limited in newly restored mangrove forests. This means that there are fewer marine species and lower biodiversity than in undisturbed mangrove forests. Studies suggest that a lack of time may be the cause for lower levels of biodiversity in restored mangroves. Mangroves which were allowed to grow and expand for decades had the same levels of biodiversity and population size as natural undisturbed mangroves. If restored mangrove

forests are created with the necessary knowledge and information, then fishery populations and biodiversity may increase.

Introduction

Mangroves are one of the most important ecosystems on the planet. As a low-lying saltwater tree, they occupy some of the most biodiverse environments in the world. Found primarily in Southeast Asia, they occur in tropical coastal environments across the globe (Worthington and Spalding, 2018). Their long roots dig deep into the soil and intertwine, preventing erosion and stopping sediment from flowing into waterways. They effectively create land from nothing, extending the coast where the ocean would otherwise dominate (Andradi-Brown et al., 2013). This interwoven, snaking root structure also slows the potentially devastating impacts of waves, tides, and storms. Similar in the way cars are built to crumple to absorb impact in a crash, mangroves crumple and disperse the powerful energy generated by storms and waves, ensuring that the environment within the forest is protected (Kathiresan et al., 2005). The combination of shallow water, a proliferation of hiding places for smaller organisms, and protection from major weather events has made mangroves one of the most attractive marine nurseries (Aburto-Oropeza et al, 2008). Mangroves further sequester considerable amounts of carbon through photosynthesis, as well as filtering the water of salt and other pollutants (Worthington and Spalding, 2018).

Due to their numerous ecosystem services, they are often cited as one of the primary ecosystems capable of halting climate change, restoring coastal biodiversity, and combatting sea level rise (Worthington and Spalding, 2018). However, mangroves are declining around the world (Carugati, et al., 2018). As coastal development occurs in vast numbers, mangrove forests are being destroyed. Oftentimes this destruction is centered around the creation of new homes, in place of industries such as shrimp farming, or by impoverished populations which rely on the harvesting and distribution of mangrove forests for their livelihood (Veettil et al, 2019). Unsurprisingly, this has had negative impacts on the coastal ecosystems in question (Veettil et al, 2019). Destruction of mangrove forests has caused an increase in salt inundation, pushing the shoreline back further and further in conjunction with sea-level rise. The organisms which rely on mangroves to survive have similarly suffered (Veetil et al, 2019).

In response to the consequences of the ecosystem services disappearing, concentrated efforts have been underway to replant and restore destroyed mangrove forests (Worthington and Spalding, 2018). These efforts are run by important institutions, all of which stress that mangrove replanting is one of the largest possible steps to combat climate change and ecosystem collapse (Bosire et al, 2008).

The massive focus on the issue raises certain questions, however. How effective is mangrove restoration at combatting ecosystem collapse? Are there variations in success based on different forms of restoration? In order to determine if mangrove restoration is an effective way of approaching the issue of deforestation and organismal collapse, analysis of the impact restored populations have on the local environment is critical. One particular area to examine is the impact restored mangrove forests have had on fish population numbers and the landings of commercial fisheries. Many studies have highlighted the importance of natural mangrove forests on supporting commercial fisheries and wild fish populations (Aburto-Oropeza et al, 2008). However, are these restored populations of mangroves as important a factor in the health of commercial fisheries and wild fish populations?

I hypothesize that restored mangrove populations provide a vital resource and present an important factor in the health of coastal fisheries. I believe this due to the importance mangroves have on these ecosystems, and how devastating their removal has been. I expect to find that any form of restored mangrove forests, even if they are lacking the intricacies and specific effectiveness enjoyed by natural mangrove forests, are better than none.

Over the course of conducting research, it has become apparent that restored mangrove populations are effective in increasing levels of biodiversity among the coastal tropical fisheries (Enchelmaier et al, 2018). The mere presence of restored mangroves provides ecosystem services, albeit ones with decreased impact. However, they were hampered by limited growth time and species diversity (Benzeev et al, 2017). Restored mangrove forests provide much-needed habitat for marine organisms, boosting fish populations despite the new mangroves' limitations. This, in turn, helps to increase the size and health of commercial coastal fisheries.

Section 1: Natural Mangrove Forests Are Vital Natural Ecosystems

Mangroves are globally found in tropical regions around the equator. They are mainly centered in the Southern Hemisphere and in the largest concentrations in the Eastern Pacific region (Polidoro, et al., 2010). They exist at the boundary between coastal and marine environments, being exposed to tidal flow and strong sun. They are saltwater resistant and subsequently one of the few trees capable of surviving in the dynamic boundary ecosystem provided by the intersection of land and sea (Polidoro, et al., 2010).

The location they occupy has led to them being considered a useful form of shoreline protection (Kathiresan et al., 2005). Much like salt marsh grasses, mangroves hold onto sediment with their long intertwined prop roots. This prevents erosion and slows the flow of water, creating land from which there was only water (Polidoro, et al., 2010). In addition, their interlocking roots and stem systems create an effective buffer against the strong winds and rising waves which otherwise can devastate coastal landscape and cause erosion (Kathiresan et al., 2005). The forests crush inward, absorbing the force of storms in the same manner as cars are built crumple in response to force, diffusing the energy around the forest and limiting destructive forces (Kathiresan et al., 2005).

Their unique position as an intersection between the environment and land provides a home for numerous organisms. The importance of mangrove forests, or Mangals, as a tropical coastal nursery is well known. They play important roles in the life cycles of many marine organisms, especially fish, which change drastically in size and lifestyle as they grow. Fish are one of the few vertebrates to undergo a larval stage, making them exceedingly vulnerable to numerous predators as they grow in size (Lefcheck, et al., 2019). As a result, juvenile and larval organisms require a safe place to grow until they can better fend for themselves in their natural environments. Larger predators are not able to infiltrate deep into mangrove habitats due to a variety of factors, including their lack of space from interlocking root structures and relatively low levels of dissolved oxygen (Lefcheck, et al., 2019). Juvenile fish are then able to be spared from close interaction with predators. In addition, these mangrove nurseries are highly productive ecosystems, generating lots of food and nourishing smaller organisms until they can leave their relative safety (Lefcheck, et al., 2019).

Mangroves are also renowned for their ecosystem biodiversity. Mangroves themselves vary in size, location, and species, with over 80 species on record (Lefcheck, et al., 2019). This biodiversity is magnified when the species which call mangroves home are considered. Mangroves are as biodiverse in species size and diversity as tropical rainforests (Al-Khayat, Abdulla, & Alatalo, 2018). Mangroves are large primary producers, generating lots of photosynthetic biomass which are consumed by secondary consumers, feeding a vast and robust ecological web (Lefcheck, et al., 2019). In addition, the interflow of waters from the ocean to the land creates a healthy microbial loop which further generates species growth and ecosystem health (Lefcheck, et al., 2019).

Mangrove nursery ecosystems have been proven to provide a home for numerous species of fish, many of which are commercially important (Aburto-Oropeza, et al., 2008).. One study surveyed nursery ecosystems across the world and found that of the 315 organisms identified, 230 are fished or farmed at a commercial level (Aburto-Oropeza, et al., 2008). This suggests that mangroves are vital for the working of commercial fisheries. In fact, numerous studies have established links between the health of mangrove forests and the size of local fishery populations. One such study centered on the mangroves of Baja California in Mexico and the fisheries which were associated with those ecosystems. Largely examining the Blue Crab and coastal fish such as Snapper and Snook, the study found that 31% of fish landings alone can be directly linked to mangrove forests level (Aburto-Oropeza, et al., 2008). The study valued one hectare of fringe mangrove habitat at $37,500 in annual ecosystem productivity level (Aburto-Oropeza, et al., 2008). Mangroves are essential in supporting small scale and coastal fisheries in the tropical and subtropical regions and their health is necessary for the robustness of local marine populations.

Section 2. Mangrove Destruction

Despite the obviously important role mangroves play in natural ecosystem functioning and in the economy of coastal fisheries, mangrove forests have suffered extensive degradation over the past several decades (Carugati, et al., 2018). Over 35% of mangrove forests have been destroyed over the past 20 years (Carugati, et al., 2018). As development occurs, populations are rising and industries are growing in the tropical and equatorial regions of the globe. Mangroves are subsequently being cut down for space. Population growth and industrialization is particularly present in Southeast Asian nations such as Malaysia, where populations have experienced large growth over the past several decades. In Malaysia, the population has risen from 22 million in 2000 to 33 million in 2015, a roughly 30% growth in population size (Shahbudin, Zuhairi, & Kamaruzzaman, 2011). The new massive population has placed a strain on the environment and is occurring simultaneously with a mass migration to coastal cities, where new homes, schools and places of business are being built (Shahbudin, Zuhairi, & Kamaruzzaman, 2011).

Some of these businesses include coastal tourism. Many of the places where mangroves are found are popular tourism spots due to the warm waters and beautiful beaches. However, while tourists love the white sands and amazing snorkeling, they do not appreciate having to navigate through muddy mangrove swamps. In response, hotel owners and other coastal industries which appeal to tourists cut down mangroves (Shahbudin, Zuhairi, & Kamaruzzaman, 2011).

In addition, mangroves are being destroyed for agriculture such as rice (Richards & Friess, 2015). Rice currently accounts for the largest use of land-based agriculture in the Southeast Asian regions where mangroves are prevalent. In Myanmar for example, 20% of all mangrove deforestation occurred as a result of expansion in rice agriculture between 2002 and 2012 (Richards & Friess, 2015). According to one study, this loss represents “the fastest rate of mangrove deforestation of any country in Southeast Asia” (Richards & Friess, 2015). As a valuable food staple, Southeast Asian countries have been supporting growth in the rice industry as a way of feeding its rapidly expanding population (Richards & Friess, 2015).

Another agricultural crop taking the place of mangroves is palm oil. While not as significant as rice, it is the second leading agricultural cause of mangrove deforestation in Southeast Asia (Richards & Friess, 2015). In addition, it is theorized that as the global desire for palm oil grows, so will the palm plantations, replacing mangroves (Richards & Friess, 2015). Mangroves are typically undervalued coastal habitats, due to their intertidal location and may fall between the laws and jurisdiction of terrestrial and marine ecosystem protections (Richards & Friess, 2015). These countries may already have very relaxed environmental laws, leaving mangroves a prime habitat to deforest and replace (Richards & Friess, 2015). One study theorized that the manufacturing of Indonesian palm oil is expected to “grow by 30% between 2012 and 2019” (Richards & Friess, 2015). Palm oil is ubiquitous in many foods and household products (Wilcove & Koh, 2010). It is infamous for its role in deforestation across Asia, with media campaigns drawing attention to the role it has played in the destruction of jungle habitat (Wilcove & Koh, 2010). Not as much attention has been drawn to palm oil’s impact on mangrove destruction, yet it appears to present a major threat as the industry grows alongside public demand (Richards & Friess, 2015).

While agriculture is one of the leading causes of mangrove deforestation, aquaculture is currently the largest reason for mangrove loss (Richards & Friess, 2015). Shrimp farming, in particular, has taken hold in many of the regions with mangrove cover due to the close access to water (Páez-Osuna, 2001). While the various forms of shrimp farming differ in size and style, larger shrimp farms make up 50-60% of the industry (Páez-Osuna, 2001). These farms require a regular exchange of water to ensure the relative health of the shrimp and subsequently are often placed in the intertidal zones mangroves occupy (Páez-Osuna, 2001).

This is occurring despite the extensive repercussions from destroying mangrove environments. Erosion is a leading concern. As the interwoven prop roots are eliminated, the soil is eroded through natural longshore transport (Carugati, et al., 2018). This erosion is leading to the land and beaches which tourists so enjoy being washed away (Shahbudin, Zuhairi, & Kamaruzzaman, 2011). Furthermore, the removal of mangrove forests has made the human populations more vulnerable to strong storms and high tides which cause extensive economic and physical damage (Kathiresan et al., 2005).

In addition, the mangrove biodiversity and the intrinsic services which make mangroves such a vital ecosystem nursery are being destroyed. Studies have shown that biodiversity decreases significantly in areas where mangroves have been destroyed (Carugati, et al., 2018). One study examined the amount of biodiverse photosynthetic organic matter within the sediment of two different sites. One site was an undisturbed mangrove forest, the other was impacted by anthropogenic activities such as mangrove harvesting. The undisturbed site had five times the amount of chlorophyll matter within its sediment compared to the disturbed site (Carugati, et al., 2018). Photosynthetic material makes up the backbone of marine environments, serving as the primary source of energy in the food web, nourishing primary and secondary consumers (Carugati, et al., 2018). In addition to a decrease in photosynthetic material within the sediment, studies have found a significant decrease in the number of macro-organisms present within disturbed or degraded mangrove forests (Carugati, et al., 2018). One study examined the impact degraded mangrove habitats had on the organisms within the Niger River Delta in Nigeria. The mangroves in the delta had been felled in large numbers as population size in the area increased

(Oribhabor & Udo, 2018). A subsequent survey of animals native to the area found a decline in the assemblage of mangrove dependent fish, as well as a decrease in the size and number of periwinkle snails, oysters, and mudskippers (Oribhabor & Udo, 2018). The marine organisms previously listed are vital to the health of coastal Nigerian fisheries and their decline has led to unrest among fisherman communities within the nation (Oribhabor & Udo, 2018).

Section 3: Mangrove Restoration Effort

In response to the devastation of an integral plant species which is vital to the health of coastal ecosystems and the livelihoods of local fisherman, mangrove restoration has become a commonly suggested solution (Worthington and Spalding, 2018). Mangrove restoration varies wildly in its implementation. The scale, type of mangroves used, and who implemented the planting is different on each project (Worthington and Spalding, 2018). However, despite a lack of standardization in practice, mangrove restoration has become incredibly popular and restoration efforts are underway across the tropical and equatorial regions (Worthington and Spalding, 2018). The ICUN states that over 160 restoration efforts have occurred in 24 different countries, resulting in approximately 2,000 square kilometers of mangroves planted in the past 40 years (Worthington and Spalding, 2018). The large scale use of restoration has led some to question its effectiveness at restoring the ecosystem services which make mangroves so valuable in the first place (Andradi-Brown et al., 2013). The inconsistencies in various forms of restoration and the lack of a standardized restoration format or technique have led to differences in the quality of the environments. Certain attempts at mangrove restoration have resulted in large monocultures of one species, which is both ineffective for promoting biodiversity and for the ecosystem functioning of mangrove forests (Andradi-Brown et al., 2013).

Mangrove forests consist of interlocking stands of different species, each with their own variation in salinity resilience and ability to compete with its fellow plants (Mangroves: Multi-Species Recovery Plan for South Florida, 1999). These patterns vary across the globe depending on which species of mangroves are endemic to the area of study. For example, in The Florida Keys, *Rhizophora mangle* serves as the first mangrove to interact with the salty waters of the ocean (Mangroves: Multi-Species Recovery Plan for South Florida, 1999). It is more resilient to salinity, water exposure, and other factors which make life as a tree in the ocean difficult (Mangroves: Multi-Species Recovery Plan for South Florida, 1999). As one moved away from the ocean, *Rhizophora* was slowly replaced by *Avicennia germinans*, which was more suited to surviving in the muddy, more terrestrial environments (Mangroves: Multi-Species Recovery Plan for South Florida, 2009). These patterns vary based upon the specific parameters of the environment in question, stressing the importance of selecting mangrove species which are native to the area and thrive in their specific hydrological conditions. It is also important to account for species diversity when undergoing restoration, ensuring that mangrove forests are best able to mix various species and provide the maximized ecosystem services.

In addition, efforts to replant mangroves need to consider the hydrology of a specific area. This goes beyond a simple understanding of tidal systems, but also requires an acknowledgment of which areas are inundated with water, which areas are left in drought during seasonal changes, sources of water influxes, etc (Bosire, et al., 2008). Each mangrove system is unique and subsequently so is the hydrology of each area. Simply planting mangroves with no knowledge of how these systems work will lead to seedling death or an uneven proliferation of certain mangrove species (Bosire, et al., 2008).

Taking into account the social dimensions of mangrove restoration is similarly important. There is little to no point in planting mangroves if they will simply be destroyed again by the humans who live nearby. Understanding the needs and wants of nearby populations is vital in restoring mangrove populations (Bosire, et al., 2008). If a community is reliant on coastal fisheries related to mangroves, they may be more willing to accommodate the restoration of forests if their importance is explained (Bosire, et al., 2008). In opposition, if a community is reliant on palm oil production and have deforested the landscape as a result, they may subsequently be less supportive of reforestation efforts (Bosire, et al., 2008).

J.O. Bosire et al. (2008) constructed a four-step process to creating a framework for mangrove reforestation and ensuring that the process is occurring successfully. During the reforestation process, "four different key factors in mangrove ecosystem functioning; the flora, the fauna, the environment, and human subsidence use" must be considered as a measure of success (Bosire, et al., 2008). If these assessments are determined to be negative, then efforts must be undertaken to determine what has gone wrong and how it can be fixed to maximize ecosystem effectiveness (Bosire, et al., 2008).

The survival rate of restored mangrove populations is not ideal in certain cases (Kodikara, et al., 2017). A case study of attempts in restoring mangroves in Sri Lanka found significant mortality among planted trees. The study surveyed twenty-three project sites totaling around 1000-1200 hectares of newly planted mangrove seedlings (Kodikara, et al., 2017). However, out of the 1000-1200 hectares, only 200-220 hectares appeared to have taken root successfully (Kodikara, et al., 2017). In addition, nine out of twenty-three restoration sites had no surviving plants (Kodikara et al, 2017). The sites which did have plant survival were limited in the success rate at each site, with only three sites having a plant survival rate above 50%

(Kodikara, et al., 2017). The study mainly blamed topographic issues for the limited success, citing a standardized practice of planting largely *Rhizophora mangle* regardless of the climate conditions of the area (Kodikara, et al., 2017). Of the sites which had mass mortality, 2/3 were in arid conditions (Kodikara, et al., 2017). *Rhizophora* are naturally the mangroves which exist in the most inundated parts of the coastline and subsequently are not as well adapted to arid conditions (Kodikara, et al., 2017). This relates back to the criteria outlined by Boisre et al 2008, which focuses on the importance of improving the topographical factors in the health of restored mangroves. The hydrology of the area was not taken into account in the large majority of these restoration efforts and the study attributes a large amount of the seedling failure to this (Kodikara, et al., 2017).

The mangroves in Sri Lanka were also damaged by secondary interactions with human beings and their cattle, as well as by natural factors such as barnacle and insect infestation (Kodikara, et al., 2017). These interactions represent the faunal elements impacting mangrove populations in the terms of barnacles and insects, as well as the social factors from cattle and human beings. The study found that the sites which best survived took into account the hydrological and topographical characteristics of the area before planting (Kodikara, et al., 2017). In addition, the best surviving plots also had local communities come in and assess what was plaguing the mangrove populations (Kodikara, et al., 2017). This corresponds with the assessment plan in Bosire et al., 2008, which focuses on primary and post-planting assessments to ensure that the mangroves survive. However, the Sri Lankan study did focus on locations which planted entirely in a monoculture, which is believed to be less effective for achieving increases in biodiversity.

The data regarding the effectiveness of mangrove restoration highlights that restoration does not occur within a vacuum. It is important to approach restoration from a place of knowledge. Recognizing the need for species diversity and a focus on selecting the mangrove species best adapted for a specific set of environmental conditions is crucial. In turn, this knowledge needs also to be informed on the current conditions in the area. Knowing what information is vital to have, such as the local flora, fauna, hydrological, and human conditions in the area, allow restoration plans to maximize success and mortality.

Section 4: Fish Biodiversity and Fishery Populations in Restored Mangrove Forests

Mangrove restoration varies in the survival rate of the trees themselves (Andradi-Brown et al., 2013). However, less analysis exists on the effectiveness of restored mangrove environments to bring back public biodiversity. If a mangrove forest was successful in its recruitment of new saplings, how would this new forest impact fish biodiversity? In turn, how would coastal fisheries which rely on mangrove forests be impacted by restored mangrove ecosystems?

Restored ecosystems often have a lesser degree of biodiversity than in undisturbed, natural ecosystems (Andradi-Brown et al., 2013). One study found that through looking at 89 different assessments of biodiversity in restored ecosystems, there was an average of a 44% increase of biodiversity in the ecosystem (Andradi-Brown et al., 2013). While certainly better than what was occurring in the prior degraded habitat, these ecosystems are functioning at a level of biodiversity lower than that of undisturbed environments (Andradi-Brown et al., 2013). This may simply be a question of time, as the ecosystems may need more time to grow and change to bring back similarities to the past structures. A study conducted in Qatar found that there was no difference in the levels of total species richness and in the diversity of benthic fauna between replanted and natural mangrove forests (Al-Khayat, Abdulla, & Alatalo, 2018). This study examined mangrove forests which had been planted for 30 years and found that the levels of biodiversity were virtually the same as an undisturbed mangrove forest in the same environment (Al-Khayat, Abdulla, & Alatalo, 2018). The results of the study directly contradicted a previous study in the same locations which found a significant disparity between naturally occurring mangroves and a planted forest which was 10 years old (Al-Khayat, Abdulla, & Alatalo, 2018). This suggests that when considering the ability of restored mangrove forests to effectively increase the biodiversity and population size of fisheries, it is important to know how long the mangroves have had to grow.

Andradi-Brown et al., 2013 also found that aquatic environments struggled with restoring levels of biodiversity to pre-disturbance levels, more so than terrestrial environments. For mangroves this poses an issue, since the question of restored mangrove populations on fish biodiversity is reliant on the ability of aquatic ecosystems to recover. The same study, however, also found that tropical ecosystems respond better to biodiversity restoration than temperate ecosystems (Andradi-Brown et al., 2013). This places mangroves in an interesting position, being in a tropical environment but on the edge of terrestrial and aquatic ecosystems.

A study of fish biodiversity and relative abundance in a restored mangrove ecosystem in Florida found mixed results. The study examined the different types of fish in several newly restored mangrove forests in Biscayne Bay. The mangrove forest in question is a 30-hectare section of newly planted *Rhizophora*, with 28 tidal channels, mangrove creeks and pools built into the environment (Enchelmaier, Babcock, & Hammerschlag, 2018). This was done to mimic the natural hydrology of mangrove forests, which had been altered due to the presence of invasive pine trees (Enchelmaier, Babcock, & Hammerschlag, 2018). This ecosystem presents an interesting opportunity for study. The restored mangrove forest is a monoculture of *Rhizophora,* which based on the findings of studies on mangrove restoration, is an ineffective form of restoration (Enchelmaier, Babcock, & Hammerschlag, 2018). However, the incorporation of previously destroyed hydrology characteristics presents an understanding of local hydrology and faunal needs. The data for the study was obtained through the use of underwater cameras and seine netting within the study environments. The survey found that the amount of fish as a whole had increased from years prior, with higher levels of abundance and species richness (Enchelmaier, Babcock, & Hammerschlag, 2018). In addition, the types of fish had changed from years prior, with more fish which are generally associated with mangroves, such as *Atherinomorus stipes* and *Gambusia rhizophorae,* found than before (Enchelmaier, Babcock, & Hammerschlag, 2018). The study believed that the increased presence of such small fish represented the potential for an increase in the population numbers of large predatory fish. These predatory fish are important for coastal commercial fisheries and may include the Atlantic Tarpon, *Megalops atlanticus,* and the Grey Snapper *Lutjanus griseus* for example. The study noted, however, that the assembled fish taxa did not present evidence to conclude that there is a healthy nursery ecosystem (Enchelmaier, Babcock, & Hammerschlag, 2018). The levels of fish which use mangroves as a home for nursery fish, such as *Lutkanus griseus, Cynoscion nebulosus,* and *Sciaenops ocellatus* were not determined to be high enough to conclude that the Biscayne Bay mangrove forest is currently serving as a sufficient nursery (Enchelmaier, Babcock, & Hammerschlag, 2018). The authors went on to conclude that the forest itself may not be old enough to serve as a sufficient nursery and that through more time to develop it may become a more complete nursery.

Despite the lack of nursery reliant fish, it would appear that the restoration in Biscayne Bay was relatively successful. It reestablished the mangrove ecosystem native to the environment, increasing the number of species and biodiversity within the area. In addition, the fish which were surveyed in the area, while not the commercially viable fish important to fisheries, do serve as food for those organisms and suggest their presence. The results of the Biscayne Bay study conducted by Enchelmaier, Babcock, & Hammerschlag correspond with the previous data that biodiversity improves after mangrove restoration, but not without limitations. Fish biodiversity returned to the ecosystem to a lesser degree and commercial fisheries are also improving in the area.

Another study from India directly examines the impact restored mangrove populations have on coastal commercial fisheries. Das 2017 examined the restored mangrove populations in the Western Indian state of Gujrat. These restorations are being made in the form of monoculture plantations populated entirely by *Avicennia marina* (Das, 2017). However, simultaneously, mangrove populations are being degraded in the rest of the state by expanding population size and industry (Das, 2017). The emphasis on plantations is the only thing keeping the state mangrove habitats from being severely degraded (Das, 2017). As it stands, these plantations of *Avicennia* are controversial among local ecologists and development experts who question whether they are capable of increasing local fishery yields (Das, 2017). The study examined 10 fishermen in six different coastal villages within Gujrat, taking account of total daily fish catch per fisherman per every other day (Das, 2017). This occurred for six weeks, supplying roughly 20 days of fishery yields per fisherman (Das, 2017). In addition, the living standard, education, household income, and opinions on the current state of their fisheries were recorded. This resembles the social aspect of analyzing the effectiveness of mangrove restoration. The fisherman collectively believed that planted mangroves were having no benefit on fish yields (Das, 2017). The study concluded that mangroves have had a considerable benefit on Gujrat's fisheries, determining that the state's total annual fishery landings have increased by 15% (Das, 2017). This represents a yearly contribution of planted mangroves to the state's fisheries of 570,000,000 U.S. dollars, valuing one hectare of mangroves at approximately 7,000 U.S. dollars per year (Das, 2017).

This study illustrates how vital these efforts to replant mangroves are to coastal fisheries. The presence of mangroves brought a vast increase to the region's fish landings. However, the study also brought to light the limitations of these mangrove plantations. The study found that fishermen who harvested in areas with naturally planted mangroves had 4.237 kilograms (kg) heavier fish yields than those who harvested in areas with no mangroves (Das, 2017). In relation, those who fished in areas with relatively recently planted mangroves had only 0.948 kg more than areas with no mangroves (Das, 2017). This data signifies that while the very presence of having mangroves plays a significant role in improving fishery yields, there is a considerable difference between the size and number of organisms which can be sustained in either ecosystem. In addition, the study noted that mangrove dependent fish populations, such as "demersals, mollusks, and crustaceans" had increased since the 1995 planting period, but that larger pelagic fish populations had not (Das, 2017).

The example of Gujrat emphasizes the important role mangroves can play in coastal fisheries. Their very presence can increase the size of annual fishery yields and generate millions of dollars for the industry. However, the quality of newly planted mangroves is significantly less in its ability to support fisheries than natural mangroves. This could be because not enough time has passed for the ecosystem to grow, or it could be due to the monoculture *Avicennia* plantations do not supply the necessary nutrients and biodiversity to match natural Mangal systems (Al-Khayat, Abdulla, & Alatalo, 2018).

Case Study: *Lutjanus griseus* the Grey Snapper

One example of a fish which relies on mangroves for survival is *Lutjanus griseus* or the Gray Snapper. Also known as the Mangrove Snapper, *Lutujanus* lives in coastal mangrove forests along the Western Atlantic Ocean where they predate on a variety of organisms (Bester, 2017). Throughout their life, they change preferred prey multiple times as they grow from a larval stage to adult size (Bester, 2017). They are fairly small fish, reaching maximum size of 24 inches and 10 pounds (Bester, 2017). *Lutjanus* rely on mangroves and are largely found within or around the boundaries of mangrove forests for the majority of their lives (Bester, 2017). Spawning occurs near the intersection of estuarine bodies, where planktonic larvae travel into estuaries and settle among eelgrass beds and mangroves (Bester, 2017). Here underwater plants provide protected habitats as well as ample food to consumer (Bester, 2017). The strategy continues through their time as a juvenile, where ample resources still provide nutrients and hide from larger predators (Bester, 2017). Once they become adults, *Lutjanus* move offshore to the environment which exists on the fringe of mangrove forests and between coral reefs (Bester, 2017). The diet of adult *Lutjanus* consists primarily of small fish and crustaceans (Bester, 2017).

Lutjanus are important gamefish in Florida, the only state in the United States with sizeable populations of mangroves. In fact, the Grey Snapper represents the largest proportion of fish in the Snapper family caught in Florida among harvest recreational and sport fish (Bester, 2017). While the *Lutjanus* is not extensively fished commercially, it does make up a large portion of the state's recreational fishery. The snapper family represents the 5th largest economic value species in Florida, earning $20,560,507 in 2016 (Florida Seafood and Aquaculture Overview and Statistics).

Snappers are inherently tied to the health of mangroves. As a result, the presence of snappers within restored mangrove populations in the Western Atlantic may signify success in bringing back fish diversity and population size to healthy numbers. Within the survey of fish biodiversity and abundance in Biscayne Bay National Park in Florida, *Lutjanus griseus* was the most frequently observed fish. (Enchelmaier, Babcock, & Hammerschlag, 2018). The presence of *Lutjanus griseus* within these restored mangroves signifies the benefits that mangrove restoration offers. Regardless of whether or not restored mangrove populations are always capable of instantly reaching the level of biodiversity offered by natural mangrove forests, they do improve local fish populations. The amount of *Lutjanus griseus* found within restored mangrove forests illustrates how mangrove restoration efforts can simultaneously improve fishery populations, as well as overall fish biodiversity.

Conclusion

Mangroves are an incredibly vital ecosystem. They exist in the dynamic and difficult zone between land and sea, where salinity and intense competition define reality. They serve as autogenic engineers, building land and structures from where there was nothing (Mangroves: Multi-Species Recovery Plan for South Florida, 1999). Thousands of organisms depend on mangrove forests for the survival of their food web (Aburto-Oropeza et al, 2008). The loss of mangrove habitat presents a devastating reality for the tropical ecosystems which depend on them (Veettil et al, 2019). These ecosystems include the biodiversity and population of coastal fisheries. The economies of many tropical nations depend on the income generated by these fisheries and the loss of mangroves inadvertently contribute to economic decline (Das, 2017). In response to this loss, countries, NGOs, and international organizations have led massive efforts to replant mangrove forests (Mangroves: Multi-Species Recovery Plan for South Florida, 1999). However, the quality of restored mangrove forests varies greatly in their quality and survival rate (Worthington and Spalding, 2018). In order for mangroves to properly take root, the locational hydrology, local societal makeup, as well as floral and faunal conditions must be taken into account (Bosire, et al., 2008). In addition, the planting of mangrove monocultures should be avoided, so that biodiversity may be maximized and limit the threat of weakness due to lack of diversity (Bosire, et al., 2008). If restoration occurs with a high mangrove survival rate, then these populations may serve as a beneficial habitat to endemic marine organisms, including fish Enchelmaier, Babcock, & Hammerschlag, 2018. However, the biodiversity recorded within the Mangal is limited in newly restored mangrove forests, often registering with fewer fish species and biomass than in undisturbed mangrove forests (Andradi-Brown et al., 2013). The reason for this may be due to time, as studies have shown that mangrove forests record higher levels of biomass and biodiversity the longer the forests exist and expand (Al-Khayat, Abdulla, & Alatalo, 2018). This boost in fish populations and biodiversity can in turn help benefit coastal fishery size and economic landing (Das, 2017).

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