Fragmentation in Mangrove Forest ecosystems

NRS 534: ECOLOGY OF FRAGMENTED LANDSCAPES

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Fragmentation has been termed as one of the greatest worldwide threats to biodiversity and the primary cause of species extinction (Laverty and Gibbs, 2007). In generally, fragmentation is the subdivision of a formerly contiguous landscape into smaller units. It reduces continuity of habitat and interferes with species dispersal and migration, thereby isolating populations and disrupting the flow of individual plants and animals across a landscape. Fragmentation is an issue for biodiversity in both terrestrial and aquatic (including marine) environments. In marine environment, mangrove forests are among the most vulnerable ecosystems (Laverty and Gibbs, 2007).

Mangroves are an assemblage of tropical and sub-tropical halophytes (i.e., salt tolerant) woody plants which grow in loose wet soils of brackish-to-saline estuaries and shorelines in the tropics and sub-tropics. Globally, they are known to be the most productive and unique coastal ecosystems that support a wide range of goods and services. The ecosystem goods and services that mangroves provide include protecting the coastline from tidal waves and storm surges; acting as biological filters in polluted coastal areas; supporting aquatic food-chains; shielding a large number of juvenile aquatic organisms; and sequestration of green house gases.

Despite their ecological benefits, the health and persistence of mangroves continue to be threatened. It has been estimated that the world had lost a total of about 35% of the area once covered by mangroves since the 1940s, and these important ecosystems are still reducing at a current loss rates of about 1 to 3% per year. The main causes of fragmentation in mangroves could be natural or anthropogenic. Natural causes of fragmentation in mangroves include natural disturbances like hurricanes and tsunamis, however most of the disturbance to mangroves are human induced. Anthropogenic factors that contribute to mangrove fragmentation and habitat loss include agricultural conversion, deforestation, redistribution of water resources and the growth of human settlements (Seto and Fragkias, 2007; Laverty and Gibbs, 2007).

Similar to many other plants, mangroves have strong relationships with the surrounding environment. The occurrence of mangrove species at a certain location is related to the surrounding
ecological gradients such as elevation, tidal inundation, water salinity, and soil pH. In other words, mangrove species are likely to grow within their own niches. This phenomenon, in many cases, causes strip-like patterns (i.e. mangrove zonation) that are usually found in tropical mangrove forests. Thus mangroves depend heavily on the surrounding hydrology and the substrate therefore the fragmentation of this ecosystem could have great impacts. It is important to note that fragmentation of mangroves mimics terrestrial fragmentation more closely than that of other marine systems. As stated above, mangrove species create their own niches in parts of the intertidal landscape where better opportunities than others are provided to fulfill their ecological requirements. Fragmentation and degradation can however increase the patchiness of the landscape in terms of meeting a species’ needs. Like many other ecosystems, fragmentation impacts species principally by reducing available resources and microenvironments. Fragmented mangroves also affect the movement and dispersal of propagules and eventually lead to modified species behavior. Laverty and Gibbs (2007) indicate that three major consequences are apparent as fragmentation progresses in a landscape. These are decreasing patch size; increased edge effects; and increased patch isolation.

The consequences of mangrove fragmentation and loss are well documented in the literature. Mangrove fragmentation is said to be responsible for decreases in abundance and diversity of fish. It increases light penetration, visibility and proximity to open water, reducing protection from predators. Mangrove loss and fragmentation also reduces the resilience and increases the sensitivity of the natural, as well as the human, environment to stochastic oceanic or climatic events such as cyclones and tsunamis. Of the 418 villages hit by the December 2004 tsunami along the Andaman coast, only 30, or 7%, were severely devastated. Whereas areas where mangroves have been fragmented and lost to aquaculture or the tourist industries, this percentage reaches an estimated 80 to 100%. Mangrove fragmentation and loss could also result in large scale erosion and siltation of surrounding environment.

A number of metrics have been developed to characterize habitat loss and fragmentation, mostly in the terrestrial environment. Some of these metrics have been successfully applied for mangrove ecosystems due to their similarity to terrestrial systems. This characterization is often based on categorical or thematic or choropleth maps derived from remotely sensed data. Mangrove fragmentation is a landscape-level process in which a contiguous mangrove forest stand is progressively sub-divided into smaller, more dispersed and/or disjunct (i.e., subdivided),
geometrically more complex (initially, but not necessarily ultimately), and more isolated patches as a result of both natural processes and human land use activities. This process involves changes in landscape composition, structure, and function and occurs on a backdrop of a natural patch mosaic created by changing landforms and natural disturbances. In FRAGSTATS for instance, different metrics that focus on subdivision of the landscape, isolation, dispersion, shape indices and many others can be computed to understand the extent of fragmentation of the mangrove forest in the landscape. Though some of these suites of metrics have been criticized for some inherent limitations, many of them have been used successfully in the mangrove environment to inform management and conservation planning in several areas. Seto and Fragkias (2007) reports on how they successfully used metrics like the Contiguity index and the Euclidean Nearest Neighbor distributions to characterize mangrove fragmentation in Ramsar sites in Vietnam.

In many cases, the characterization of mangrove fragmentation and loss is not an end, but required to help managers make appropriate management decisions. These management decisions often border around conservation and restoration. In terms of mangrove restoration efforts, either a natural recovery method or mangrove replanting have been implemented. Lewis and Marshall (1997) have suggested five critical steps necessary to achieve successful mangrove restoration. These are to understand the autecology of the mangrove species at the site, in particular the patterns of reproduction, propagule distribution and successful seedling establishment; understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species; assess the modifications of the previous mangrove environment that occurred and currently prevents natural secondary succession; design the restoration program to initially restore the appropriate hydrology and utilize natural volunteer mangrove propagule recruitment for plant establishment; and finally, replanting when natural restoration is not feasible.
Annotated Bibliography


In this synthesis paper, Laverty and Gibbs (2007) dissect the phenomenon of ecosystem fragmentation and loss in general. Though the emphasis is not directly on mangrove ecosystems, the paper undoubtedly sets the stage for our discussion on fragmentation in mangroves. Laverty and Gibbs (2007) established the relationship between ecosystem fragmentation and loss, and concluded that fragmentation is usually a product of ecosystem loss. Habitat loses in the terrestrial (Forests - Tropical and Temperate and; Grasslands - Tropical, Temperate, and Tundra) and aquatic (Wetlands and riverine systems) environment were discussed with a meta analysis of earlier works on the extent of these biomes over time. They also highlighted some of the challenges associated with efforts to quantify the extent and rate of loss of the world’s major biomes at various scales and for different time periods. Other important aspect of ecosystem fragmentation that were discussed include the causes of fragmentation (natural and anthropogenic); the effects of fragmentation and recommendations for the management of fragmented landscapes. Interestingly, the paper confirmed that though mangroves are in the aquatic environment, they mimic the terrestrial fragmentation more closely than that of other marine systems, making it possible to apply most of the management techniques of the terrestrial ecosystems. In my estimation this is a well organized paper and is definitely a good source of general information about the general issue of ecosystem fragmentation.


This overly scientific study examined the genetic structure of Datronia caperata populations from four Panamanian mangrove forests using amplified fragment length polymorphism (AFLP) markers. D. caperata, a basidiomycete fungus, is one of the dominant polypore species found in neotropical mangrove forest fragments, where it is locally specialized on Laguncularia racemosa. The objective of the study was to assess the scale of genetic structure of D. caperata on Laguncularia racemosa among fragmented stands of mangroves. Though very complex, this paper demonstrated that despite production of copious basidiospores capable of long distance dispersal, some homobasidiomycete fungi may be susceptible to genetic isolation due to habitat fragmentation.

This paper is a report of a study that was conducted in the red mangrove (*Rhizophora mangle*) stands along the coast of South Hole Sound on Little Cayman Island (Anthilles). In this study, Marlow et al compared the abundance, species richness, and community composition of fish communities in four habitat types: continuous mangrove, fragmented mangrove, stretches of sandy shore between mangrove patches and boat docks. They observed that fish abundance and species richness of both dock and sandy shore habitats were lower than in mangrove habitats. Although they didn't see differences in the fragmented and patchy mangroves with respect to abundance, species richness, and community composition, they observed large fish individuals in continuous mangroves, but not in patch mangroves. The inability of their analysis to detect differences, in my opinion, could be attributed to fact that the continuous and patch mangrove habitats differed in the spatial scale of their mangrove root coverage.

One of the major threats to mangrove fragmentation and loss is aquaculture including large scale shrimp farming. The objective of the present study was analyze the land use changes caused by shrimp farming in the coastal landscape of Mexico, one of the main producers worldwide, using remote sensing and (GIS) tools within a landscape change framework to contribute to a better understanding of the impacts of shrimp farming on coastal wetlands. To accomplish this Berlanga-Robles et al (2011) performed a change detection analysis in three main steps. The first step was to conduct a shrimp farm location and inventory in the study area. This was followed by a thematic data extraction of Landsat TM images from 1986 to 1999. Finally a change analysis of the 1986 and the 1999 thematic maps were conducted. They concluded that though shrimp aquaculture in Mexico is not the main cause of mangrove fragmentation, the industry is still far from sustainable because almost half of the pond area has resulted in the direct removal of other natural wetlands. They reiterate that, the entire associated infrastructure interrupts local and regional ecological process by fragmentation of the intertidal zone.

- **Saudamini Das and Jeffrey R. Vincent** 2009. Mangroves protected villages and reduced death toll during Indian super cyclone. PNAS vol. 106 no. 18. 7357–7360
This reiterates the ability of "unfragmented" mangroves to reduce the damage damage caused by tsunamis and tropical storms. In this controversial study, Das and Jeffrey (2009) showed skeptics that mangroves are not only capable of protecting communities against storm surges but also tropical storms
and even tsunamis. The objective was to show that mangroves were associated with statistically significant reductions in human deaths during a super cyclone that struck the eastern coast of India in October 1999. They analyzed the number of storm-related deaths in the 4 administrative units (tahasils) in the state of Orissa in India. They tested the null hypothesis that, conditional on population and other relevant factors, villages with wider remaining mangroves between them and the coast had the same average number of deaths during the 1999 storm as villages with narrower or no mangroves. Using socioeconomic data of the area, GIS spatial characteristics and controlling for potentially confounding variables, Das and Jeffrey concluded that villages with wider (contiguous) mangroves between them and the coast experienced significantly fewer deaths than ones with narrower (fragmented) or no mangroves and that human impacts on the mangrove ecosystems (i.e., deforestation) thus affected the death toll. Few studies on mangroves are conducted to incorporate not only the ecological dimensions with remote sensing GIS technology as well as the human dimensions of the area. This paper happens to be one of the few.


The objectives of this study was to map the current extent of the mangrove ecosystems of the Belize Barrier Reef System, identify areas of change and identify mangrove areas potentially at risk of being cleared. Taking advantage of available existing mangrove extent data, Cherrington et al (2010) used this past mangrove data as baseline to conduct multi-temporal remote sensing based change detection on Landsat satellite imagery for the years 1980, 1989, 1994, 2000, 2004, and 2010. They analyzed different mangrove ecosystem parameters and dynamics, including the mangrove fragmentation. They did not only evaluate mangrove fragmentation, but also computed the fragmentation potential of the mangroves, which is outstanding. They used the Ecosystem Patch Irregularity Index (EPII) to indicate how easy it is for a mangrove patch to become fragmented due to its inherent geometry.


This work by Seto and Fragkias (2007) emphasizes the role of remote sensing in evaluating wetland habitats and assessing the impact of Ramsar convention on wetlands. The study was conducted in two sites in Vietnam; Xuan Thuy Natural Wetland Reserve (the only Ramsar site in Vietnam) and Tien Hai
Nature Reserve. The objective of the study was to use time series analysis of landscape pattern metrics to assess land cover conditions before and after designation of Ramsar status to monitor compliance with the Convention. They used four metrics (total mangrove extent; mangrove fragmentation; mangrove density; and aquaculture extent) to evaluate the success of the Ramsar convention in the country. In terms of mangrove fragmentation, they used FRAGSTATS to calculate a variety of landscape metrics associated with habitat loss and fragmentation. Seto and Fragkias successfully applied these metrics (such as average contiguity index, mean and median patch size, the largest patch index and Euclidean Nearest neighbor distributions) to evaluate the mangrove fragmentation in the 2 sites over time.


In this study, Strong and Bancroft (1994) used the available technology of their time to determine the changes in mangroves and deciduous forest coverage in the Upper Florida Keys, from the original condition. Within the ATLAS desktop GIS package, 1991 aerial photographs were digitized to map the remaining mangrove and deciduous seasonal forests using minimum size criteria of 24 m X 24m. They made assumptions for the original map of these habitats. To estimate fragmentation, they used canopy closure and potential for vegetation regeneration as criteria for separation of fragments. For example, adjacent fragments with continuous canopy coverage separated by a paved road were considered different fragments. They concluded that deforestation has caused a 41% decrease in the area of deciduous seasonal forest and a 15% decrease in the area of mangrove forest. Fragmentation has resulted in much of the current forest remaining in small parcels with a high edge to area ratio. This paper, as I mentioned earlier, took advantage of the available technology then which is impressive, but there is a lot more that could be done. In the first place, the assumption of the original map of the habitats and the choice of canopy closure as a proxy for fragmentation will definitely affect the figures.

This paper looks broadly at forest fragmentation in the state of Selangor in Malaysia with the objective of developing a single forest fragmentation index to describe the degree of forest fragmentation and to understand the relationship between forest fragmentation and human land use change. The pattern change of forest fragmentation and its relationship to human land use were analyzed in 1966, 1981 and 1995. In this study, Abdullah and Nakagoshi (2007) developed a forest fragmentation index based on a combination of three landscape metrics. These metrics were non-forest area; forest edge bordered by human land uses; and patch size coefficient of variation. They concluded that this study showed that, over the three time periods of this study, human land use activities increasingly fragmented the forest in the state of Selangor and that this occurred particularly in wetland landscape, dominated by wetland forests of peat swamps and mangroves. They therefore recommend that the state of Selangor should give priority to wetland forests in conservation strategies and sustainable land use planning and management. This paper revealed that knowledge of forest fragmentation through a single index in different natural landscapes provides a pathway for identifying which forested areas are highly threatened for management decisions.


In this interesting study, the authors were interested in the spatial-temporal changes in the extent and width of fringe mangroves, and changes in adjacent land use. The total mangrove extent was estimated at seven points in time using four Landsat TM images (1989, 1992, 2003, and 2006) and three SPOT images (1995, 2003 and 2009). Supervised classification was conducted for image classification and mapping changes using a Maximum Livelihood Classifier approach. Changes in mangrove width were calculated for 2003 and 2009 using the Digital Shoreline Analysis Application (DSAS). It was interesting to see how the DSAS model was applied to detect changes in extent of mangroves. This model was developed by the USGS for modeling coastal erosion and coastal related changes over time. Though interesting, I think the Nguyen et al (2013) could have benefited from other models other models like the Land Change modeler or GeoMod to achieved better and more results (rather than just the changes in the width).

Other References