Effects of Marsh Fragmentation and Patch Area On Fish and Nekton Assemblages in Mississippi

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by

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Abstract

Fragmentation divides continuous habitat into smaller patches. Fragmentation can also produce smaller populations of species, because fragmentation can split a population into smaller groups. Both terrestrial and aquatic ecosystems suffer from fragmentation. There are a variety of fishes that live along marsh, each depending upon the marsh for protection, food, and sometimes even competition. Species richness of fishes can be altered due to marsh fragmentation. I predict islands with a larger patch index should have a higher species richness of fishes. For this study, fish assemblages at 20 islands of marsh were sampled in the months of June and July of 2016 with two 5m pulls of a 9.1 × 1.2 m bag seine. A total of 3305 fishes, representing 34 species, and 190 *Farfantepenaeus aztecus* and 18 *Litopenaeus setiferus* were collected across all samples. A drone was used to take aerial images of the smaller islands of marsh and Google Earth was used for the larger islands to determine the patch size and fragmentation index of each island. I found a positive relationship between species richness and patch area. I also found that there was not a significant effect of fragmentation index on the species richness.

Introduction

The Gulf of Mexico is surrounded by a vast area of coastal wetlands, fed by the Mississippi River, creating an elaborate marine ecosystem (Chesney *et al.*, 2000). The Mississippi River provides sediment and nutrients needed to create coastal marshes and sustain its productivity that support habitats off the Gulf of Mexico (Reed *et al*., 1995). Salt marsh ecosystems support many diverse species of marine organisms (Goldstein and Watkins, 1999), and also play a vital environmental role for humans. Marshes provide protection from weather by creating a barrier between ocean and land (Shepard *et al*., 2011). The salt marsh will absorb more force from severe weather being the first barrier between water and land. Marshes also play a role in water purification and carbon fixation (Zedler and Kercher, 2005). Tourism and food production are also economic services provided by salt marshes (Holon *et al.*, 2015).

Despite the value and services provided by wetlands, humans have had a negative impact on them. Coastal wetlands are altered every year due to human disturbances (Chesney *et al*., 2000). Human impacts such as dam building and agriculture are some of the causes for the diminishing marshes (Zedler and Kercher, 2005). It is estimated that 53% of the U.S population lives near the coast (Tralli *et al*., 2005). Coastal infrastructure, such as bridges, highways, and homes, vastly change marsh habitat (Holon *et al*., 2015). Overfishing due to a growing human population, invasive species and pollution are other human impacts to the marshes (Holon *et al*., 2015). These disturbances are leading to trends of fragmentation in the marsh ecosystems.

All of these different disturbances lead to areas of marshes becoming fragmented, creating an increased proportion of edge habitats. Fragmentation is a process that divides continuous habitat into smaller patches (Wilcove *et al*., 1986). Edge habitats (outer boundary between the vegetation and open water) is created when fragmentation occurs. These edge habitats will function differently than the core habitats (area of vegetation that is intact and can support an individual or species) due to the edge having more disturbances and different abiotic and biotic factors (Ewer and Didham, 2006). Forest ecosystems experience these edge habitats. This edge habitat can become unsuitable for the original (Murica, 1995).

Fragmentation may also lead to habitat heterogeneity. Habitat heterogeneity can provide more niches and diversity of biotic and abiotic factors to increase species diversity while habitat homogeneity can decrease species diversity (Bazzaz, 1977). Depending on the species, and the amount of fragmentation occurring, habitat heterogeneity can be detrimental to species diversity and habitat homogeneity can be instrumental to species diversity. (Tews *et al*. 2004).

Both terrestrial and aquatic ecosystems suffer from fragmentation. Coyotes (*Canis latrans)* are just one example of terrestrial mammals that have been negatively impacted by fragmentation. Highway development in coyotes' home ranges causes habitat fragmentation (Tiagas *et al*., 2002). Fragmentation of any habitat, whether terrestrial or aquatic, can have a potential risk of extinction (Ewers and Didham, 2006). In aquatic ecosystems, dams are the most common type of fragmentation (Ward and Stanford, 1983). This fragmentation disrupts the river, impacting the headwaters to downstream (McCully, 1996) and also isolates fish assemblages (Ward and Stanford, 1983). A paper discusses the results show a negative impact on species of fishes that nest on the bottom of streams and do not keep their nests areas clean of silt (Jones *et al*., 1999). This is just one example of how fragmentation can impact aquatic ecosystems.

Most studies find that fragmentation is detrimental to species. Fahrig (2003) states that habitat loss has negative impacts on the species that live there. Fragmented habitats vary in quality, and some may be too small to maintain populations of resident species (Tiagas *et al*., 2002). This can then lead to a problem of isolation if there is not suitable habitat for dispersal, resulting in over-crowding (Ewers and Didham, 2006). Fragmentation can also produce smaller populations of species, because fragmentation can split a population into smaller groups. According to Chesney *et al*, (2000), the marsh ecosystem may depend on this fragmentation to produce more marsh edge. It is possible that some species of the marsh ecosystem may prefer this fragmented area due to the possible increased habitat heterogeneity.

Studies have shown that species richness is related to patch area. Species richness is a metric that describes community and regional diversity (Magurran, 1988). There is a hypothesis, which suggests that a larger patch of habitat will contain more biotic and abiotic factors that contribute to a species niche and can support more species (Williams, 1964). Species richness slowly becomes affected when the edge of the patch increases. This patch area effect may also lead to a decline in species numbers when the whole area of the habitat shrinks (Fahrig, 2013). It can be concluded that the smaller the patch area sampled, the fewer species this area will contain (Russel *et al*., 2006). Patch area may not be the only factor affecting species richness. Different biotic and abiotic variables like vegetation and habitat can also influence species richness. A study conducted on a coral reef in Japan saw that variables other than area could affect the species richness. In this study, they found that coral cover and the height of coral also played a role in the number of Damselfish species present, not just the area of the coral reef (Hattori and Shibuno, 2015). This is also an example of habitat complexity, because the coral cover and height are a part of the niche. The more complex an ecosystem is, the higher the survivorship of the species will be (Beukers and Jones, 1998). With a larger patch area, there are more biotic factors involved that may influence the species richness in that area.

When marsh ecosystems become fragmented, edge essentially increases as the solid marsh is broken down and the edge will turn into open water (Chesney *et al*., 2000). As edge increases, the area of the original habitat or patch will decrease (Jacobus and Webb, 2015). The purpose of this project was to assess the effect of marsh fragmentation and patch area on fish and nekton assemblages in Mississippi. Using a combination of assemblage data collected from 20 independent marsh islands in the northern Gulf of Mexico, we can examine this effect. I predict that more fragmented patches will have a negative effect on species richness. The second prediction is the patch area will have a positive effect on species richness. The third prediction is that there will be more generalist's species as the marsh becomes more fragmented.

Methods

Determining Area

Islands of marsh habitat were sampled in Biloxi Bay and the Pascagoula Sound in the summer of 2016 (Fig. 1). I attempted to sample islands of marsh that varied in size with areas of 7.438 - 10.9 m^2. Sites were chosen based on larger sizes of marsh patches with *Juncus* vegetation. Twenty sites were sampled. Every site contained this *Juncus* vegetation. Coordinate points were taken at each island by using a Global Positioning System (GPS). I quantified patch size (area) and geometry (fragmentation index) using aerial photography taken from a drone for smaller patches and Google Earth from larger patches with areas larger than 9 m^2. These aerial images were then imported into tpsDig and a series of x,y coordinates defining the patch border were digitized. Digitized points (Fig. 4) were then imported into R to calculate the total patch area (m^2) and a fragmentation index (FI) based on the commonly used shoreline development ratio FI was defined as $P/(2*(\pi A)^{0.5})$ where P is patch perimeter (meters) and A is patch area (m^2) (Wetzel, 2001) (Table 2). To test our predictions, we correlated measures of species richness with patch area and the fragmentation index.

Fish and Nekton Sampling

Fish assemblages were sampled at each island with two 5m pulls of a 9.1 × 1.2 m bag 6.35mm mesh seine. Captured fishes were fixed in 10% formalin. Along with fish, two species of shrimp, *Farfantepenaeus aztecus* and *Litopenaeus setiferus*, commonly eaten shrimp, were collected (Table 1). After preservation, fish and nekton were taken back to the laboratory, enumerated, identified to species, and ultimately deposited into The University of Southern Mississippi Ichthyological Collection (http://ichthyology.usm.edu/usm/).

Data Analyses

Species richness for each patch was quantified as the number of sampled taxa. Separate linear regression models were used to test the null hypothesis that patch area and FI of marsh islands have no effect on species richness. A log 10 transformation was applied to the area to normalize the residuals (how far above or below the line of best fit). Species richness was the dependent variable and the patch area and FI were the independent variables. An alpha of 0.05 was used indicating a 5% chance of concluding that a difference exists when there is no actual difference. To summarize assemblages and look for patterns of abundance associated with fragmentation, Ie used nonmetric multidimensional scaling (NMDS) of Bray-Curtis similarity indices. The NMDS (K=3) was based on proportional abundances (by site) after dropping rare species (only one occurrence) to eliminate things that could skew the results.

Results

A total of 20 marsh patches were sampled in the Biloxi Bay and Pascagoula Sound (Figure 1) with areas ranging between 7.438 - 10.9 m^2. A total of 3305 fishes and nekton (invertebrates) were collected at the 20 patches. Thirty-four fish species were collected and identified along with 190 *Farfantepenaeus aztecus* (brown shrimp) and 18 *Litopenaeus setiferus* (white shrimp). The most abundant fishes collected were *Menidia beryllina. Micropterus punctulatus, Lepomis microlophus,* and *Dormitator maculatus.* These are considered generalists species and were predominately found in patches with increased FI. *Lagodon rhomboides, Mugil cephalus, and Anchoa mitchill* were the most abundant in patches with larger area. These are considered specialists species. The 20 marsh patches had a mean species richness of 7.3± 3.3.

The marsh patches had a mean FI (± 1 SD) of 1.81 ± 0.42 with a range 1.24-2.51. When the core patch area was tested to see if there was any significance between species richness and patch area, it was concluded that patch area did not have a significant effect on species richness ($F_{1, 18} = 2.18$, $r^2 = 0.11$, p=0.16; Fig. 2). While not significant, there was slight positive trend for patch area. Fragmentation index also did not correlate with species richness ($F_{1, 18} = 0.0023$, p = 0.96, $r^2 < 0.01$; Fig 3).

The most frequently occurring species were *Menidia beryllina* (90% of 20 samples), *Lagodon rhomboids* (75%), *Mugil cephalus* (55 %), *Leiostomus xanthurus* (55%), *Lepomis microlophus* (50%), *Farfantepenaeus aztecus* (25%), *Litopenaeus setiferus* (30%), *Gobiosoma bosc* (20%). The highest frequencies of occurrences all occurred for species that prefer waters with higher saltinty.

The final NMDS stress value, the measure of the lack of fit between rank order and dissimilarities and rank order Euclidean distance in NMDS space, was 7.0% (Fig. 4). The NMDS identified two different assemblages separated along NMDS axis 1. The species towards the left of the figure are more predominately found in brackish or lower salinity waters. These species include *Micropterus punctulatus, Lepomis microlophus,* and *Dormitator maculatus, Oligoplites saurus, Syngnathus scovelli*. The species to the right of the figure are predominately found in higher saline content waters. These species include *Anchoa mitchilli Bairdiella chrysoura, Cynosion arenarius*, *Fundulus grandis, Gobiosoma bosc*, *Lagodon rhomboides, Menidia beryllina*, *Mugil cephalus, and Farfantepenaeus aztecus* (also known as *Penaeus).*

Correlations between FI and individual species abundance tested for species specific responses to fragmentation. Only two of the 34 species of fishes, *Dormitator maculatus*, *Micropterus punctulatus* had abundances that were significantly correlated with FI.

Discussion

It has been hypothesized that edge effect that is created by fragmentation may cover some of the negative effects of habitat loss in both terrestrial and aquatic habitats, since some species seem to thrive in edge habitat (Chesney *et al*., 2000). As stated by Kneib (1987) and Baltz *et al*. (1993), the shallow water created by the edge is extremely valuable to small fishes. This allows easier access to flooded marsh, which can provide safety and protection (Chesney *et al*., 2000). Given the fragmentation index not having a significant effect on the species richness, it is possible there is a positive edge effect with fragmentation. The NMDS also may support Chesney's hypothesis. According to the NMDS (Fig. 3), within each assemblage, there was fragmented and less fragmented marsh. The assemblages showed differences in species' preference of water salinity. Within each assemblage, there were different amounts of fragmentation, meaning that the fragmentation didn't have a significant effect on the species.

Fragmentation can also increase habitat heterogeneity. Habitat heterogeneity can provide more niches for individual species, therefore increasing species diversity within the ecosystem (Bazzaz, 1977). The effect of edge tends to be species specific (Sevick, 2010). Generalists tend to prefer the edge compared to specialist species. According to the correlation to see if the fragmentation index effects any of the species, only *Dormitator maculatus* and *Micropterus punctulatus* show significance to fragmentation. This may be because these two species prefer the edge like Chesney claims. These two species may also be considered generalist species because they do show a significance to the fragmentation.

Micropterus punctulatus, and *Dormitator maculatus,* may be considered more generalist species that benefit from a heterogeneous environment (Devictor *et al.* 2008). These species were more abundant with fragmented habitat. A specialist species should be found within larger patches with less fragmentation because this habitat is more homogeneous (Devictor *et al*. 2008). These specialist species should be more abundant with non-fragmented marsh patches.

With the more fragmented areas, generalist species will colonize that area because they are better adapted for these fragmented areas. This could be because they are better predators, more mobile and able to swim patch to patch. Consequently, the species (specialists) that were there before the patch became fragmented were no longer there. This could be due to the new species that moved in once the patch fragmented, because they weren't as mobile, or a loss of food. With the more complete less fragmented patches, these generalists did not have an ideal habitat. The specialists do prefer this more complete patch, because of a lack of mobility, or more food in the marsh.

The method of seining to sample the patches of marsh may have led to a sampling bias. Seines have a lead line. When pulling a seine through emergent marsh, the lead line can often be lifted off the bottom, allowing fish and nekton to escape (Sevick, 2010). This can reduce the effectiveness of using a seine to sample patches of marsh (Sevick, 2010). One method that has been effective in sampling marsh is a throw trap. With a throw trap, patches of marsh can be sampled even with dense emergent marsh.

Our results support Chesney's hypothesis that fragmentation does not have a negative effect on species. As a whole, the species were not affected by the fragmentation of the marsh patches. Chesney 2011 states that even though species depend on the edge habitat, at some point, there will be a tipping point. This point is when there is so much fragmentation, that the ecosystem and species can't tolerate the fragmentation. This is when the fragmentation becomes detrimental to the ecosystem. The question is, what is this tipping point.

Further research on the importance of edge to marsh fishes should be conducted to better understand marsh fragmentation and the effects it has on the ecosystem. In future studies, the tipping point of a marsh ecosystem could be studied to see how much fragmentation the species can handle before the fragmentation becomes detrimental. There needs to be an increase in power to get a statistically significant result for this project. Increasing the sample size could potentially raise the power.

Figures

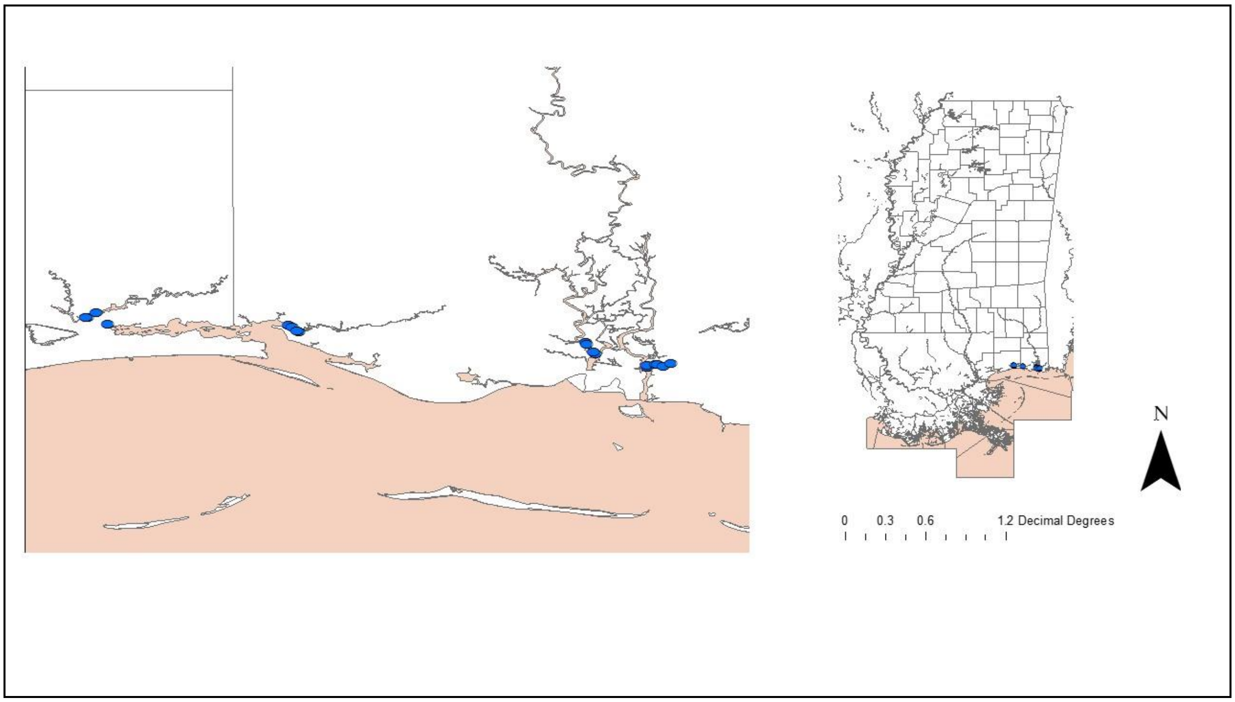

Figure 1: A map of the Biloxi Bay and Pascagoula Sound where the 20 patches of marsh were sampled.

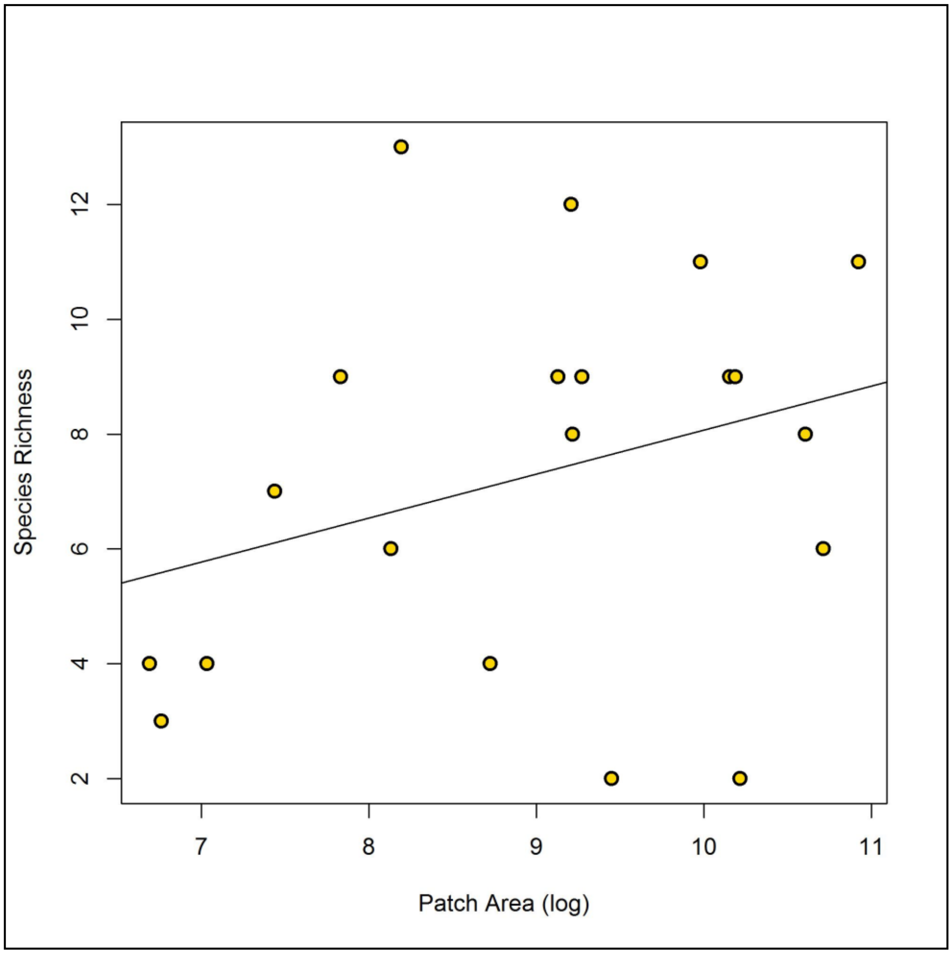

Figure 2: The relationship between the species richness and the patch area of the marsh patches (log_{10} – transformed).

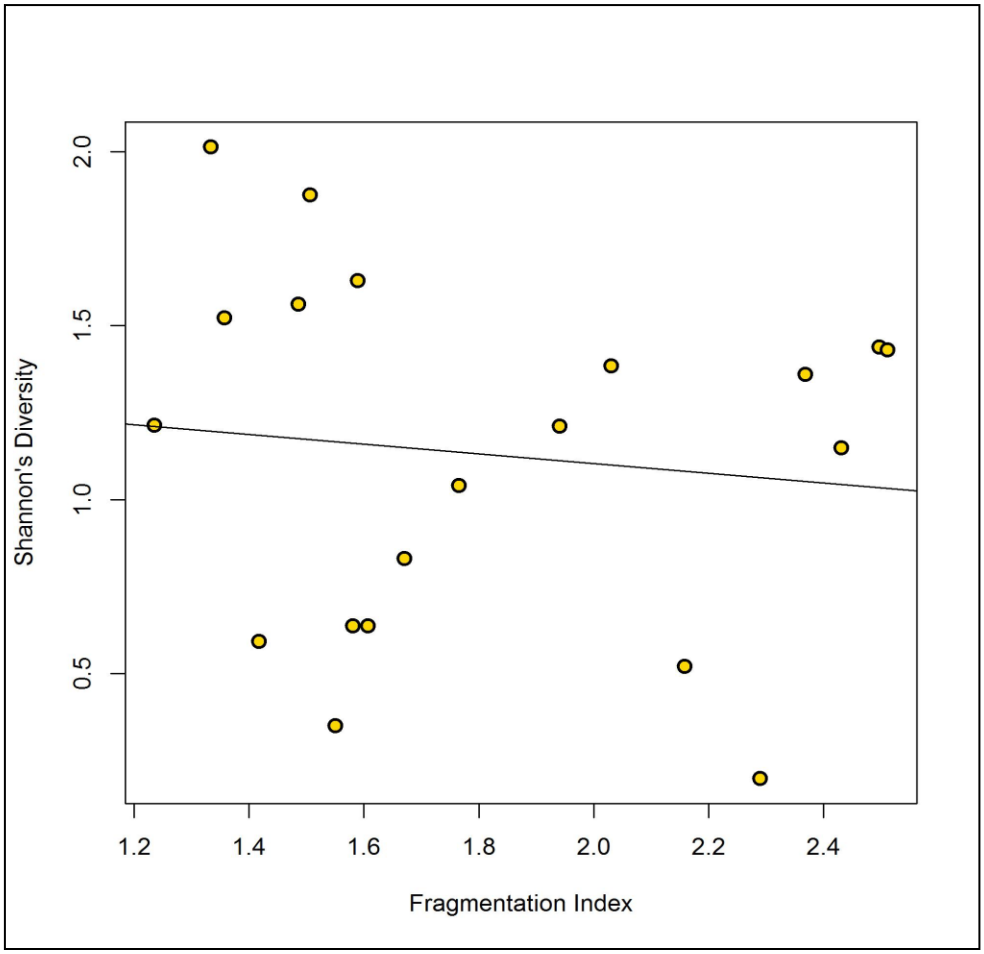

Figure 3: The relationship between species richness and the fragmentation index.

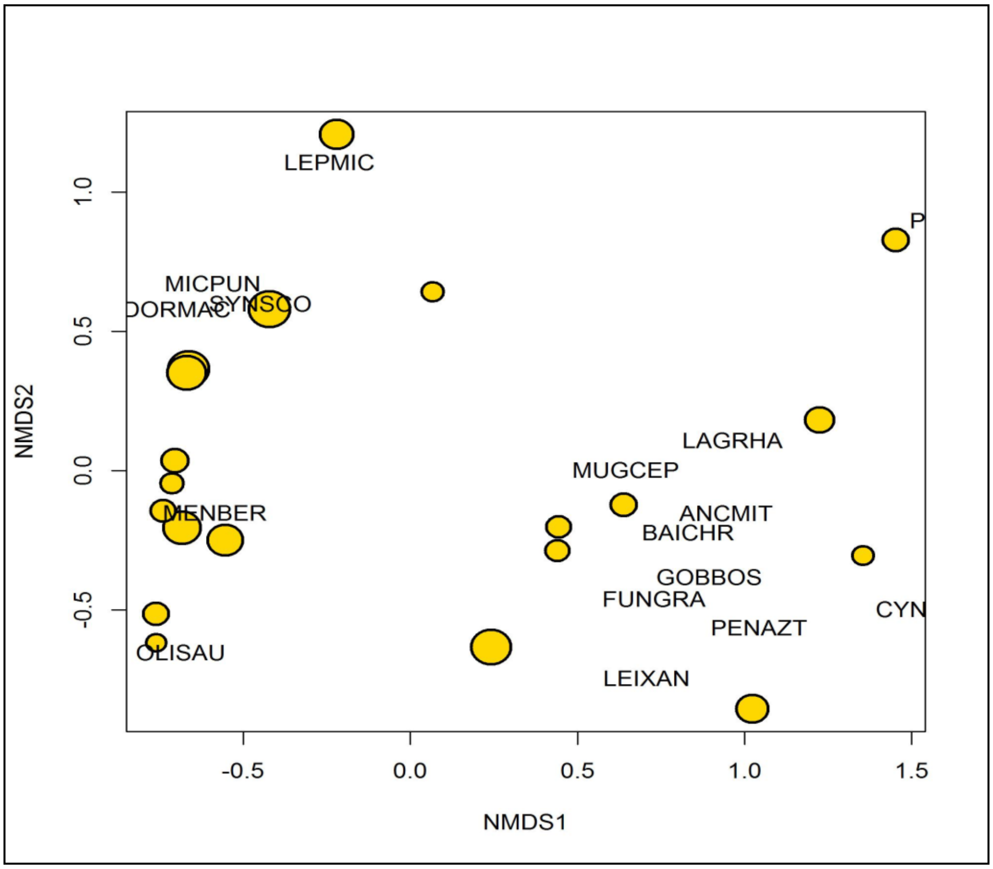

Figure 4: NMDS representing fragmentation related to species abundance. Each dot size is proportional to the fragmentation index. Only the most abundant species are noted. The species names are shortened on the figure. LEPMIC= *Lepomis microlophis,* MICPUN= *Micropterus punctulatus,* DORMAC= *Dormitator maculatus,* MENBER= *Menidia beryllina,* OLISAU= *Oligoplites saurus,* LAGRHA= *Lagodon rhomboides,* MUGCEP= *Mugil cephalus,* ANCMIT= *Anchoa mitchilli,* BAICHR= *Bairdiella chrysoura,* GOBBOS= *Gobiosoma bosc,* FUNGRA= *Fundulus grandis,* LEIXAN= *Leiostomus xanthurus,* PENAZT= *Farfantepenaeus aztecus*

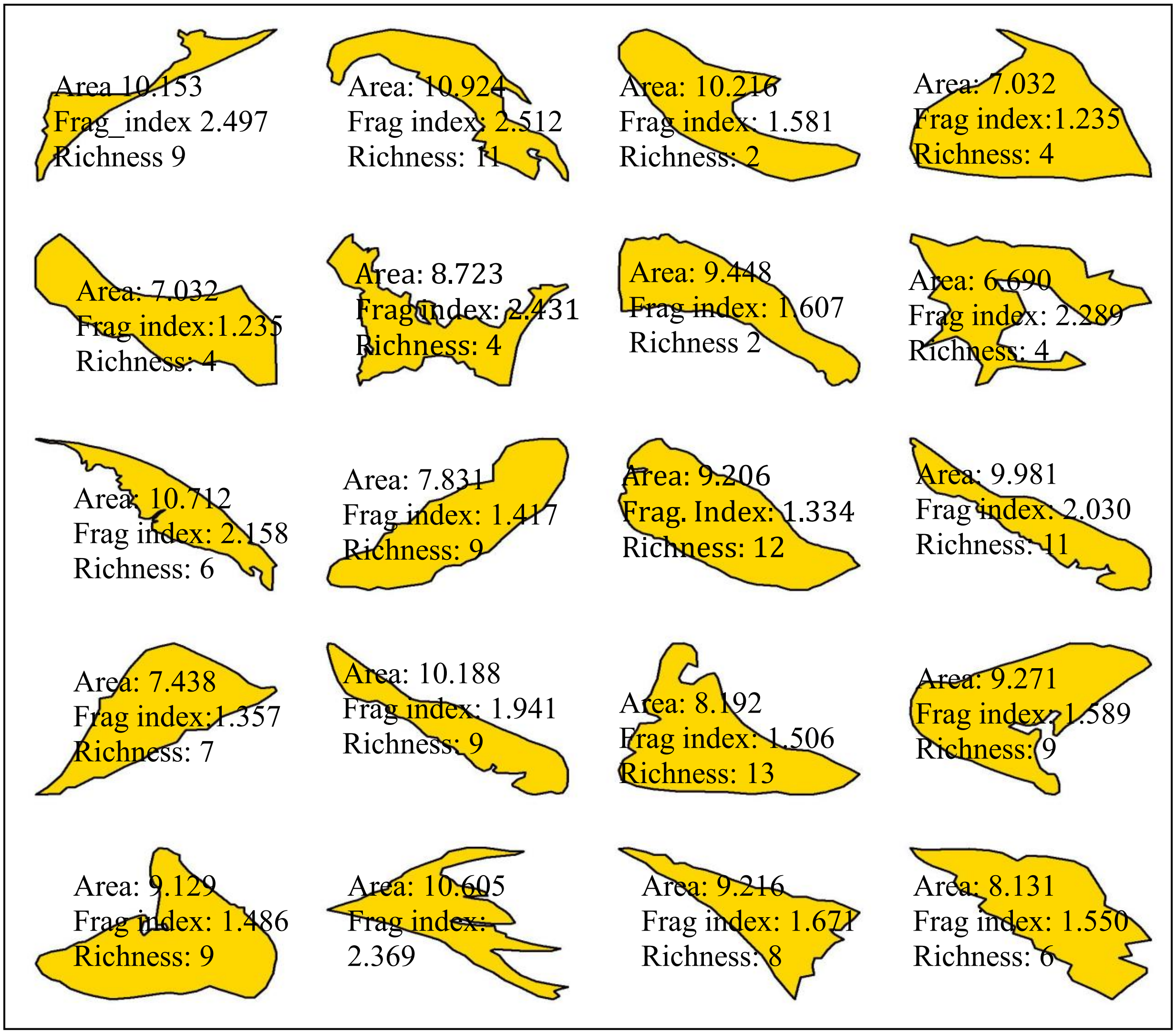

Figure 5: Outline of patches from aerial photography that were digitized by tpsDigs. The units for area here are meters squared. Each patch is matched with its corresponding area, fragmentation index, and species richness.

Taxa	Total	Frequency of Occurrence	Correlation with FI
Anchoa mitchilli	53	0.25	-0.40452212
Bairdiella chrysoura	44	0.3	-0.28625916
Brevoortia patronus	1	0.05	-0.165795
Caranx crysos	2	0.05	0.358491
Citharichthys spilopterus	5	0.1	-0.085296
Ctenogobius bolesoma	1	0.05	-0.290948427
Cynoscion arenarius	39	0.15	-0.281137012
Cynoscion nebulosus	1	0.05	-0.165795312
Dormitator maculatus	38	0.2	0.481304127
Eleotris amblyopsis	1	0.05	0.093972805
Esox niger	1	0.05	0.352532975
Eucinostomus harrengulus	1	0.05	-0.228709532
Evorthodus lyricus	1	0.05	-0.165795312
Fundulus grandis	23	0.2	-0.272083622
Fundulus jenkinsi	5	0.1	0.379660536
Gobiosoma bosc	18	0.2	-0.238476034
Lagodon rhomboides	200	0.75	-0.411760241
Leiostomus xanthurus	248	0.5	-0.029586561
Lepomis macrochirus	14	0.05	0.14011174
Lepomis microlophus	238	0.45	0.040407607

Taxa	Total	Frequency of Occurrence	Correlation
Lepomis miniatus	3	0.1	0.264364693
Lucania parva	8	0.3	0.254927228
Membras martinica	10	0.05	-0.369697958
Menidia beryllina	1707	0.9	-0.191201655
Micropterus punctulatus	331	0.4	0.452103862
Mugil cephalus	24	0.55	-0.240983361
Oligoplites saurus	28	0.45	-0.218277081
Farfantepenaeus aztecus	190	0.25	-0.265713316
Litopenaeus setiferus	18	0.3	-0.147426672
Poecilia latipinna	1	0.05	0.093972805
Pomoxis annularis	1	0.05	0.352532975
Strongylura marina	3	0.15	-0.17103226
Synodus foetens	1	0.05	-0.116254743
Syngnathus scovelli	46	0.55	0.416306639
Grand Total	**3305**		

Table 1: Each species with its corresponding frequency of occurrence and its correlation with fragmentation index.

Patch	Area	Perimeter	Frag_Index	Richness
JM-10-16	10.15305807	1418.489641	2.49754136	9
JM-11-16	10.9239926	2097.755554	2.512089421	11
JM-12-16	10.21605963	926.8973142	1.581384691	2
JM-13-16	7.032753847	147.3950396	1.235193058	4
JM-14-16	6.761816941	183.9777948	1.765430334	3
JM-15-16	8.723031425	675.4729165	2.431200642	4
JM-16-16	9.448047108	641.5016438	1.606850527	2
JM-17-16	6.689885616	230.2008667	2.289875226	4
JM-18-16	10.71215296	1621.684916	2.158972376	6
JM-19-16	7.831252103	252.0961339	1.417184736	9
JM-2-16	9.205992844	471.7768929	1.333754162	12
JM-20-16	9.980637891	1057.915021	2.030382542	11
JM-21-16	7.438013113	198.3229887	1.357138281	7
JM-3-16	10.18814056	1121.95421	1.941080677	9
JM-4-16	8.192502669	321.1052062	1.506825856	13
JM-5-16	9.271784358	580.9917876	1.58936143	9
JM-6-16	9.129264143	505.9394001	1.486274576	9
JM-7-16	10.60569271	1687.206588	2.369007413	8
JM-8-16	9.216899098	594.2861205	1.67096151	8
JM-9-16	8.131057143	320.404435	1.550447133	6

Table 2: Marsh patch sites and the corresponding area, perimeter, fragmentation index, and species richness for each patch.

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