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A Meta-analytical Comparison of Fish Assemblages from Multiple Estuarine Regions of Southeastern Louisiana Using a Taxonomic-Based Method

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ABSTRACT

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The estuarine ecosystems of southeastern Louisiana are threatened by numerous environmental impacts such as wetland loss, coastal development, and overharvesting of natural resources. If the relative health of different estuaries can be determined, then management efforts might be focused on those regions needing the most protection. Unfortunately, estuaries are by definition dynamic, precluding easy comparisons of relative environmental health. Meta-analyses can be used to overcome problems associated with this natural variability. Analyzing sizable ecological data sets that cover large spatial and temporal scales is helpful in assessing relative ecosystem health among different regions. To compare the health of four estuarine regions of southeastern Louisiana (the Barataria Basin, Lake Maurepas, Lake Pontchartrain, and the Biloxi Marsh and Chandeleur Islands region), we calculated taxonomic distinctness and variation in taxonomic distinctness for fishery-independent data collected from three habitats: demersal, nearshore, and pelagic habitats. Taxonomic distinctness is a biodiversity index that measures taxonomic distance between species collected in a single sample. This taxonomic-based method is robust to differences in sample size and generally more useful for large-scale meta-analyses than other diversity measures. We analyzed data collected by trawls (demersal habitats), beach seines (nearshore habitats), and gill nets (pelagic habitats) over various periods in the last half century. Demersal fish assemblages from Lake Pontchartrain and pelagic fish assemblages from the Barataria Basin were more affected than fishes collected in similar habitats in the other regions. Nearshore fish assemblages, though, were equally healthy across all regions studied.

ADDITIONAL INDEX WORDS: *Environmental health, coastal systems, Lake Pontchartrain, Lake Maurepas, Barataria Basin, Biloxi Marshes, Chandeleur Islands.*

INTRODUCTION

Over the last half-century the estuarine ecosystems of southeastern Louisiana have been affected by numerous environmental stressors such as wetland loss, coastal development, pollution, channelization of natural waterways, barrier island erosion, and overharvesting of natural resources (Chesney, Baltz, and Thomas, 2000; Day *et al.,* 2007; O'Connell *et al.,* 2005). In this region both the Pontchartrain and Barataria–Terrebonne basins contain productive estuaries that are adjacent to areas of high human density, namely the Greater New Orleans Metropolitan Area (GNOMA), which is the most populous area of the state (Penland *et al.,* 2002). This proximity to human development means that these estuaries are particularly vulnerable to multiple anthropogenic impacts as was seen in the aftermath of Hurricanes Katrina and Rita. However, different estuarine ecosystems may have different sources of environmental stress with different levels of impact. For example, the artificial corridor created by the Mississippi River Gulf Outlet (MRGO) into Lake Pontchartrain may have more of a significant impact on that estuary than does recreational harvesting of game fishes in lower Barataria Bay (O'Connell *et al.,* 2005). As we attempt to protect and properly manage these estuaries, it will be valuable to not only determine which regions need the most help but also ascertain which stressors most influence the health of these ecosystems.

Unfortunately, evaluating the relative health of multiple estuarine regions is often a case of comparing "apples and oranges." Even without anthropogenic influences, the estuarine portion of the Pontchartrain Basin, which extends west to east from Lake Maurepas to the Chandeleur Islands, differs from the more north–south oriented Barataria Bay, which is the estuarine portion of the Barataria Basin. Although these two estuarine regions share typical estuarine fish species, a comparison of their fish assemblages using traditional biodiversity indices (*e.g.,* species richness, evenness, *etc.*) may not be appropriate. In the past, these indices

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identified impacted assemblages as those with reduced numbers of species and reduced species evenness; in assemblages undergoing environmental stress, more common, generalist species become more numerous. However, species richness can also increase with disturbance if large numbers of generalist species replace small numbers of specialist species (Williams *et al.,* 2005). Species richness and evenness should not be used when comparing whole ecosystems for evidence of environmental impacts (*i.e.,* meta-analysis) because species biodiversity may naturally differ among sites. For example, the presence of larger rivers upstream of an estuary may influence the number of local species (*e.g.,* in most river systems of North America the diversity of fish species is higher in downstream regions; Vannote *et al.,* 1980). If fish assemblages from different estuarine regions are to be compared to assess relative ecosystem health, then possible biases associated with meta-analyses need to be addressed.

For the current study we chose a statistical method that bypasses some of the problems associated with traditional biodiversity indices (Warwick and Clarke, 1995). This approach measures the taxonomic relationships among organisms collected in a given region and compares the result to samples taken in other regions. The same technique has been used to successfully assess temporal and spatial differences in estuarine fish assemblages (Chavez-Lopez *et al.,* 2005). For each collection of organisms two indices are calculated: average taxonomic distinctness ($\Delta+$) and variation in taxonomic distinctness ($\Lambda+$). These two indices are sample-size independent, meaning they were developed to compare assemblages representing different sampling efforts or assemblages that differ in their number of species. More specifically, these indices are measures of diversity where the taxonomic distance between every pair of species in a given assemblage is the basis for determining relative biodiversity (Warwick and Clarke, 1995). This approach incorporates randomization to test for departure from expected values and the statistics directly reflect phylogenetic diversity, unlike species richness. These indices are also less sensitive to differences in habitat type and are more responsive to anthropogenic disturbances. Used in combination, measurements of $\Delta+$ and $\Lambda+$ have the ability to: (1) compare presence–absence species data from unequal sampling efforts collected from areas that do not share species, (2) detect a monotonic response to environmental impacts, (3) measure true phylogenetic diversity, and (4) measure deviations from expected values. While other tests used for comparing communities (*e.g.,* Mantel tests, partial ordinations, analysis of similarity [ANOSIM]) have some of these abilities, only $\Delta+$ and $\Lambda+$ have all four.

Our goal was to use this taxonomic method on fish assemblage data to compare the relative health of four estuarine regions of southeastern Louisiana: the Barataria Basin, Lake Maurepas, Lake Pontchartrain, and the Biloxi Marsh and Chandeleur Islands region. We calculated taxonomic distinctness and variation in taxonomic distinctness for fishery-independent data collected from three habitats: demersal, nearshore, and pelagic habitats. More specifically, we addressed two questions: Do any of the estuarine regions appear relatively less healthy than the others, and, if so, which habitat within that disturbed region appears most affected?

METHODS

Study Location and Data Sources

For our analyses we used fishery-independent data collected from one estuarine region in the Barataria Basin and three estuarine regions in the Pontchartrain Basin: Lake Maurepas, Lake Pontchartrain, and the Biloxi Marsh and Chandeleur Islands region (Figure 1). Along with using data collected by our own laboratories (Lake Pontchartrain and Biloxi Marsh and Chandeleur Islands region: MTOC and Lake Maurepas: RWH) we also analyzed data collected by the Louisiana Department of Wildlife and Fisheries (Coastal Study Area III) and historical data collections by Tulane University and Louisiana State University (Table 1). Data used for these analyses were limited to multispecies collections from three gear types: 16-ft otter trawls, 50-ft beach seines, and gill nets (herein referred to as trawls, seines, and gill nets). Collections with less than two species could not be used for the assemblage analyses but were noted for comparative purposes (Table 1). When data from all four regions were combined to construct species lists, the total number of species collected by trawls, seines, and gillnets was 144, 137, and 87, respectively (Appendix). These lists were used to create classification trees where the relatedness of all species within each tree could be compared and are available upon request at auzeeoco@uno.edu. For each species, higher taxonomic levels were identified based on Nelson (2004) and Eschmeyer (2005).

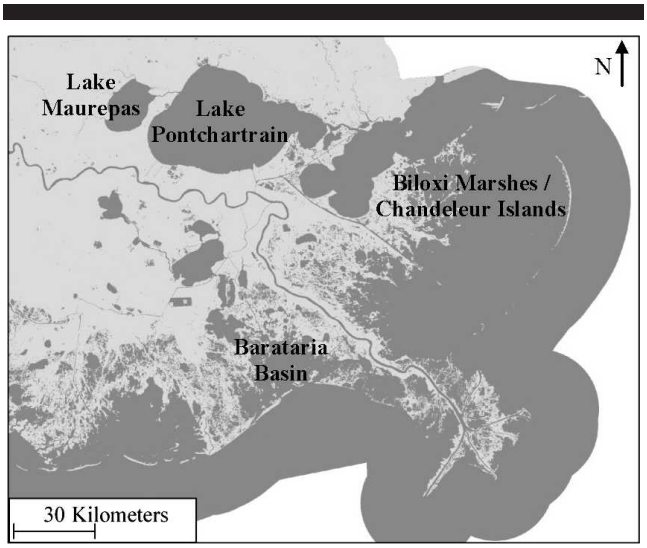


Figure 1. Map of the four estuarine ecosystems of southeastern Louisiana used for meta-analysis of trawl, seine, and gill net data. Samples were taken from the Barataria Basin, Lake Maurepas, Lake Pontchartrain, and the Biloxi Marshes and Chandeleur Islands.

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Table 1. *Sources of fishery-independent data from four estuarine regions of southeastern Louisiana (Barataria Basin, Lake Maurepas, Lake Pontchartrain, and the Biloxi Marsh and Chandeleur Islands region).*

			Collections with Two or More Species			Collections with One Species		
Estuarine Region	Data Source	Period	Trawl	Seine	Gill Net	Trawl	Seine	Gill Net
Barataria Basin	LDWF FIM program Coastal Study Area (CSA) III	1990–2000	2094	835	977	159	57	181
Lake Maurepas	Southeastern Louisiana University	1983–1984; 2000	148	NA	161	17	NA	55
Lake Pontchartrain	Tulane University; Louisiana State University; University of New Orleans	1954; 1977–1978; 1996–2003	719	457	167	156	6	46
Biloxi Marsh and Chandeleur	University of New Orleans	2003–2004	174	182	56	28	22	11

Collections were made in the specified periods using three gear types: trawls, seines, and gill nets. Only collections with two or more species could be used for assemblage analyses while collections with fewer than two species were omitted. Note that no seine collections were made in Lake Maurepas (NA).

Analyses: Calculating Taxonomic Distinctness—Average and Variation

We calculated $\Delta+$ and $\Lambda+$ for each of the 3135 trawl, 1474 seine, and 1361 gill net samples using PRIMER (v. 5) software. Only collections containing greater than one species were used because neither index can be calculated for a single species. Reductions in either of these indices indicate loss of biodiversity as compared with the possible "average" species composition based on the overall list of species (Warwick and Clarke, 1995). Average taxonomic distinctness ($\Delta+$) measures the path lengths (taxonomic distance) through the classification tree between every pair of individuals in the sample and averages these distances for the sample. Reduced $\Delta+$ indicates an assemblage consisting of more related species and a loss of diversity. Variation in taxonomic distinctness ($\Lambda+$) measures the spread in the path distances between each pair of species in the sample (Warwick and Clarke, 1995).

To identify those trawl, seine, and gillnet collections with significantly reduced $\Delta+$ and $\Lambda+$, we plotted these two indices for each collection. For each actual collection of a given number of species, a plot was generated representing 1000 random samples taken from the total species list. Each of these 1000 random samples had the same number of species as the actual sample. An ellipse was used to depict the 95% contour line for that number of species. The $\Delta+$ and $\Lambda+$ values for each actual collection were then plotted in relation to this ellipse (Warwick and Clarke, 1995). A collection occurring outside of the 95% confidence intervals is considered to have reduced biodiversity (Figure 2). This procedure was repeated for each of the gear types for all four regions with the exception of Lake Maurepas, where no seine data were available. A chi square test and residual analyses (with residual values >1.96 or <-1.96 indicating significant deviations from expected) were then calculated to determine which regions had significant numbers of collections with reduced $\Delta+$ or $\Lambda+$. Finally, when possible, the localities and dates of collections with reduced $\Delta+$ or $\Lambda+$ were identified within each region to assess possible temporal or spatial within-region patterns of impact.

Analyses: Nonmetric Multidimensional Scaling (NMDS)

Because our meta-analyses compared data from different estuarine regions, we needed a method to assess how similar fish assemblages actually were among the tested areas. That is, we needed to determine to what extent we were comparing "apples and oranges." To show how similar the samples were to each other in regard to species composition, we used NMDS to plot an assemblage diagram for each of the three gear types (trawl, seine, and gill net) using samples of greater than one species. These NMDS diagrams are based on all pairwise comparisons of Bray-Curtis similarities such that in the resulting scatter plot, sample assemblages that are more similar in species composition appear closer to each other than dissimilar assemblages. Because NMDS is useful for

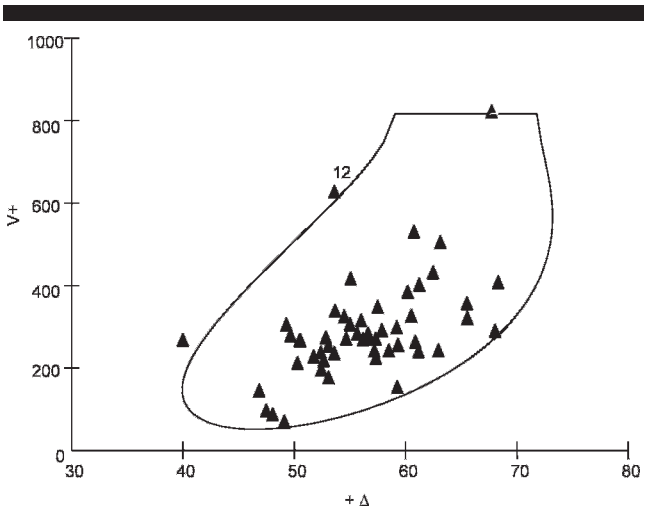


Figure 2. Example plot of $\Delta+$ and $\Lambda+$ values demonstrating how collections with significantly reduced $\Delta+$ are determined. The ellipse depicts the 95% contour line for seine collections that contained 12 species. This ellipse is generated by 1000 random samples of 12 species taken from the total species list for seine data; 95% of the random samples fell within this ellipse. The $\Delta+$ and $\Lambda+$ values for actual seine collections are plotted in relation to this ellipse (black triangles). One collection outside and to the left of the ellipse ($\Delta+ = 40$) is shown to have significantly reduced $\Delta+$ compared with the remaining samples.

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nonnormal ecological data sets like ours (O'Connell *et al.,* 2004), which contain large amounts of zero values, we used this technique rather than other analyses that are more appropriate for Gaussian data (*i.e.,* principal components analysis). Bray-Curtis similarities can be graphically interpreted by techniques such as group average clustering (Clarke and Warwick, 2001). Our large data sets (*e.g.,* 3135 trawl samples alone) prompted our decision to use only NMDS plots. These plots were better than clustering diagrams at capturing the gradient of species change along each estuary. We also chose not to use ANOSIM to test for significant differences in Bray-Curtis similarities among the estuaries because these data originated from different studies (representing different levels of effort) with uneven sample sizes (which could potentially confound the results). Using the NMDS method allowed us to graphically determine if the fish assemblages collected from different estuarine regions were similar. The NMDS diagrams also allowed us to evaluate if assemblages with reduced Δ+ and Λ+ values were similar to the remaining assemblages. This is important in that outlying collections with abnormal species compositions might occur with an atypical influx of either marine or freshwater fishes. In these cases, the result may artificially produce assemblages with reduced Δ+ and Λ+. We wanted to confirm that any collections with reduced index values were actually similar in composition to nonaffected assemblages.

RESULTS

Taxonomic Distinctness—Average and Variation

Demersal Habitat Assemblages (Trawl Data)

Of the four estuarine regions, Lake Pontchartrain was the only one with significantly more occurrences of reduced Δ+ values (45 of 719 collections) than expected for trawl data (observed $\chi^2 = 9.73$; $p = 0.016$; adjusted residual = 5.17; Table 2). While the other three regions also had occurrences of reduced Δ+ values (Barataria Basin: 50 of 2094; Lake Maurepas: 2 of 148; Biloxi Marsh and Chandeleur Islands: 5 of 174), none of these was significantly more than expected (Table 2). Interestingly, Barataria Basin had significantly *fewer* records with reduced Δ+ values than was expected (observed $\chi^2 = 9.73$; $p = 0.016$; adjusted residual = −3.88).

In Lake Pontchartrain, most collections with reduced Δ+ values occurred in recent years (*i.e.,* 1999–2002) and were mostly located the eastern portion of the lake (Figure 1). In the Barataria Basin, reduced Δ+ values occurred throughout the region and the years sampled, but slightly more occurred in more recent years (*i.e.,* 1995–2000). In Lake Maurepas, reduced Δ+ values occurred in 1984 and not in later samples. These two samples were collected in the southwestern part of the lake (Figure 1). The few reduced Δ+ values in the Biloxi Marshes and Chandeleur Islands occurred in 2004, the second year of sampling. These samples were collected from the area of Grand Pass at the eastern edge of the Biloxi Marshes and in both the southern and middle areas of the Chandeleur Islands (Figure 1). Barataria Basin and Lake Maurepas were the only regions with collections having reduced variation in taxonomic distinctness (Λ+), but just one collection each (Table 2). Neither of these regions had significantly more records with reduced Λ+ than expected.

Nearshore Habitat Assemblages (Seine Data)

For seine data, none of the three regions had significantly more records with reduced Δ+ values than expected: Barataria Basin: 8 of 835; Lake Pontchartrain: 2 of 457; Biloxi Marsh and Chandeleur Islands: 6 of 182 (Table 2). In the Barataria Basin, reduced Δ+ values occurred mostly in the earlier collections and throughout the sample region. The six reduced Δ+ values in the Biloxi Marshes and Chandeleur Islands occurred mostly in 2004 and in both the Chandeleur Islands and in the Biloxi Marshes. The two reduced Δ+ values in Lake Pontchartrain occurred in later years and in the eastern portion of the lake. Just one record from Barataria Basin exhibited reduced variation in taxonomic distinctness (Λ+), but this was not significantly more than what was expected (Table 2).

Pelagic Habitat Assemblages (Gill Net Data)

Of the four estuarine regions, the Barataria Basin was the only one with significantly more occurrences of reduced Δ+ values (46 of 977 collections) than expected for gill net data (observed $\chi^2 = 14.63$; $p = 0.049$; adjusted residual = 3.76; Table 2). Lake Maurepas only exhibited two occurrences of reduced Δ+ values (out of 161: not significant) while Lake Pontchartrain and the Biloxi Marsh and Chandeleur Islands had no reduced Δ+ collections for gill net data (Table 2). For Lake Pontchartrain, having no reduced Δ+ collections meant the region had significantly *fewer* records with reduced Δ+ values than was expected (observed $\chi^2 = 14.63$; $p = 0.049$; adjusted residual = −2.63).

In the Barataria Basin, reduced Δ+ values occurred over all years sampled and throughout the region. In Lake Maurepas, the two reduced Δ+ values occurred in 1984 and were collected in the southern and northern parts of the lake. Just one record from the Biloxi Marshes and Chandeleur Islands had reduced variation in taxonomic distinctness (Λ+), and this was significantly more than what was expected (observed $\chi^2 = 23.32$, $p = 0.046$; adjusted residual = 4.83; Table 2).

Nonmetric Multidimensional Scaling (NMDS)

The NMDS plot for trawl data based on assemblage similarities shows an expected pattern of fish assemblage change along an estuarine gradient (Figure 3). Trawl collections from upper-estuary habitats of Lake Maurepas appear in the upper left of the diagram. These overlap slightly with the oligohaline collections taken from Lake Pontchartrain in the middle of the diagram (white squares). The Biloxi Marshes and Chandeleur Islands collections appear split into two portions, which represent the more inshore Biloxi Marshes collections (overlapping with the Lake Pontchartrain collections) and the more offshore Chandeleur Islands collections in the lower right of the diagram. These three regions represent the entire geographical breadth of the Lake Pontchartrain Estuary and are connected via aquatic corridors (Figure 1). It is interesting to note that when the Barataria Bay samples (gray triangles) are included in the

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Table 2. *Summary of fishery-independent collections with reduced taxonomic distinctness (Δ+) and reduced variation in taxonomic distinctness (Λ+) from four estuarine regions of southeastern Louisiana (Barataria Basin, Lake Maurepas, Lake Pontchartrain, and the Biloxi Marsh and Chandeleur Islands region).*

Habitat and Gear Type	Estuarine Region	Total Collections Analyzed	Collections with reduced Δ+	Significance and Adjusted Residual (χ^2)	Collections with reduced Λ+	Significance and Adjusted Residual (χ^2)
Demersal/Trawl	Barataria Basin	2094	50	NS*	1	NS
	L. Maurepas	148	2	NS	1	NS
	L. Pontchartrain	719	**45**	***p* = 0.016/5.17**	0	NS
	Biloxi/Chand.	174	5	NS	0	NS
Nearshore/Seine	Barataria Basin	835	8	NS	1	NS
	L. Pontchartrain	457	2	NS	0	NS
	Biloxi/Chand.	182	6	NS	0	NS
Pelagic/Gill net	**Barataria Basin**	977	**46**	***p* = 0.049/3.76**	0	NS
	L. Maurepas	161	2	NS	0	NS
	L. Pontchartrain	167	0	NS†	0	NS
	Biloxi/Chand.	56	0	NS	**1**	***p* = 0.046/4.83**

Collections were made in three types of habitats (demersal, nearshore, and pelagic) using three gear types (trawls, seines, and gill nets, respectively). Chi square (χ^2) tests and residual analyses (with residual values >1.96 or <-1.96 indicating significant deviations from expected) were conducted to determine which regions had significant numbers of collections with reduced Δ+ or Λ+. Estuarine regions and habitats with significantly more collections with reduced Δ+ values than expected (*i.e.*, environmentally affected are bolded).

* Barataria Basin had significantly *fewer* trawl collections with reduced Δ+ values than expected (adjusted residual = −3.88).

† Lake Pontchartrain had significantly *fewer* gill net collections with reduced Δ+ values than expected (adjusted residual = −2.63).

NMDS diagram, they overlap most of these other samples and "fill the gap" formed between the Biloxi Marshes and Chandeleur Islands samples. While lower stress values correspond to better representations of the data, the stress value of 0.17 indicates that this graph is still a potentially useful two-dimensional depiction of the similarities among the regions (Clarke and Warwick, 2001).

For all four estuarine regions, the collections with reduced Δ+ values (black symbols) appear well-within the multivariate dispersal of the remaining, nonreduced samples for the given region. This suggests that the reduced taxonomic distinctness of these collections is not due to them being composed of atypical assemblages.

The NMDS plot for seine data shows that the four estuarine regions are more similar to each other in regard to nearshore habitat assemblages compared with those assemblages collected by trawls (Figure 4). There is a vague pattern associated with the estuarine gradient with many Barataria Basin collections located on the right of the diagram while many of the oligohaline Lake Pontchartrain collections are on the left. However, in general, the data show great overlap for all regions. The high stress value (0.25) reflects the poor separation of samples and indicates that this graph cannot be used to clearly discern differences among the regions. For these three regions sampled by seine, the collections with reduced Δ+ values appear within the realm of the remaining, nonreduced samples for the given region. Those for Lake Pontchartrain and Biloxi Marshes and Chandeleur Islands appeared toward the left edge of the diagram, however.

The NMDS plot for the gill net collections, which covered all four estuarine regions, shows a pattern that is similar to that for the seine with much overlap between the data sets and a

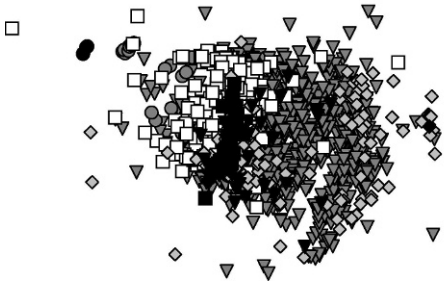


Figure 3. NMDS plot of trawl samples collected from Barataria Basins (gray triangles), Biloxi Marshes and Chandeleur Islands (light gray diamonds), Lake Maurepas (gray circles), and Lake Pontchartrain (white squares). Black symbols indicate those samples with reduced taxonomic distinctness.

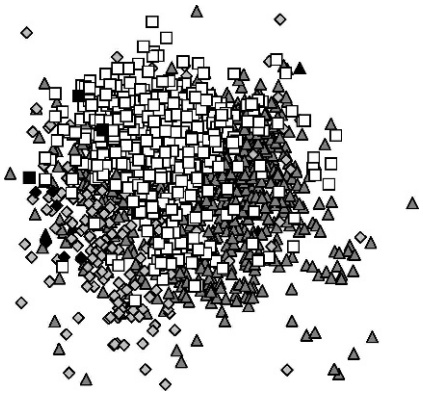


Figure 4. NMDS plot of seine samples collected from Barataria Basin (gray triangles), Biloxi Marshes and Chandeleur Islands (light gray diamonds), and Lake Pontchartrain (white squares). Black symbols indicate those samples with reduced taxonomic distinctness.

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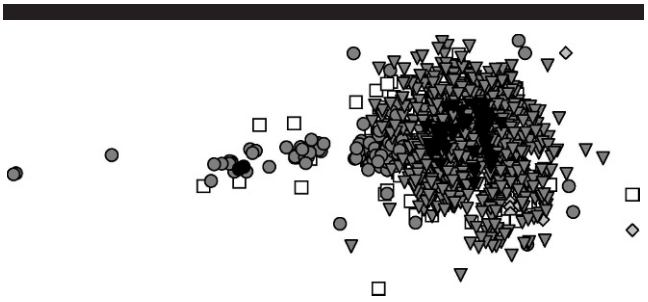


Figure 5. NMDS plot of gill net samples collected from Barataria Basins (gray triangles), Biloxi Marshes and Chandeleur Islands (light gray diamonds), Lake Maurepas (gray circles), and Lake Pontchartrain (white squares). Black symbols indicate those samples with reduced taxonomic distinctness.

high stress value (0.21; Figure 5). The resulting plot, however, exhibits slightly more distinct groupings of collections by area than that of the seine data. This is somewhat similar to the trawl results, but the pattern is less distinct than that of the trawl data set. As with the seine and trawl data, gill net collections with reduced $\Delta+$ values appear well within the general dispersion pattern of the remaining nonreduced $\Delta+$ values for their respective estuarine regions.

DISCUSSION

Fish assemblages from demersal habitats in Lake Pontchartrain and pelagic habitats in the Barataria Basin were the only collections to exhibit significant differences from expected, healthy assemblages. Our meta-analyses incorporated data collected along large spatial and temporal scales that allowed us to identify these two specific regions and habitats as areas of environmental concern. The strength of this approach is that we were able to compare different estuarine regions with different levels of potential environmental stressors (*e.g.,* urbanization in Lake Pontchartrain *vs.* the less-developed Barataria Basin and Lake Maurepas). We were also able to identify nearshore fish assemblages as appearing resilient and apparently unaffected by a half-century of natural and anthropogenic impacts in southeastern Louisiana. These results can serve as baseline information representing estuarine health for the last 50 years in the area. As local coastal conditions either improve (*e.g.,* restoration efforts in Lake Pontchartrain) or decline (*e.g.,* sea-level rise; proposed corridor alterations for hurricane protection) over the next 50 years, we will be able to measure the responses of fish assemblages.

We show that Lake Pontchartrain demersal fish assemblages are more affected than those from the other three estuarine regions, and these results agree with previous work addressing both long-term and recent fish assemblage stability in this area (O'Connell *et al.,* 2004, 2006). The strength of our current results, though, is that through the meta-analytical approach, we have shown that the problems with demersal habitats in Lake Pontchartrain appear to be region-specific. Whereas our previous research identified problems with these assemblages, we could not discern if the stressors affecting the fishes in Lake Pontchartrain were related solely to local habitat perturbations such as shell dredging (Francis and Poirrier, 1998) and a local "dead zone" (Abadie and Poirrier, 2000; Lopez, 2005; Poirrier, 1978) or other anthropogenic influences outside of the estuary such as overharvesting or increased bycatch mortality from shrimp trawling (Diamond, Cowell, and Crowder, 2000). Because demersal fish assemblages in the other three estuarine regions appear unaffected, we have a better understanding that whatever is impacting Lake Pontchartrain's demersal fishes is not also affecting the same species in nearby regions. Corrective management efforts need to be focused at specific habitats within this estuarine region.

Our analyses also show that the estuarine regions both upstream (*i.e.,* Lake Maurepas) and downstream (*i.e.,* Biloxi Marshes and Chandeleur Islands) of Lake Pontchartrain have relatively healthy demersal fish assemblages and may serve as population sources for fishes recolonizing the affected habitats. Combined with the cessation of shell dredging in the 1990s (Francis and Poirrier, 1998) and the proposed closing of the Mississippi River Gulf Outlet (which has been linked to a local "dead zone"), these results provide encouraging evidence that demersal habitats and communities in this estuarine region could recover in the future given the relative health of the surrounding estuarine regions. In Lake Maurepas, some collections with reduced taxonomic distinctness occurred more in the southwestern portion of the lake. Because of an extensive levee system, this area no longer receives freshwater inputs from the nearby Mississippi River and is currently experiencing extensive wetlands loss as cypress swamps decline from unnaturally high salinity levels and a lack of flowing water.

Barataria Basin appeared the least affected in regard to demersal fish assemblages. The relative lack of environmental disturbance in this region is likely a reflection of the reduced urbanization as compared with the other three estuarine regions, all of which are in the Pontchartrain Basin (Figure 1). However, it should be noted that the Barataria Basin is currently experiencing significant wetland loss along with the development of its remaining barrier islands (Day *et al.,* 2007; Lindstedt, 2005). For example, in our analyses many of the Barataria collections with reduced taxonomic distinctness were from barrier island areas and tended to occur in more recent surveys. This indicates a recent decline in assemblage health in those areas that are less influenced by natural inputs of freshwater. Future management efforts should be aware of these findings, especially in relation to proposed river diversion projects.

While the demersal habitats of the Barataria Basin appeared relatively healthy, the pelagic fish assemblages of this region exhibited significantly reduced phylogenetic diversity. Pelagic assemblages in the other three estuarine regions showed no signs of a similar impact. This result agrees with previous analyses of long-term Lake Pontchartrain gill net data that indicated that changes in pelagic fish assemblages over a half-century followed natural fluctuations in salinity associated with wet and dry periods (O'Connell, Cashner, and Schieble, 2004). This is typical of healthy estuarine habitats where fish assemblages respond accord-

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ingly to changes in natural environmental cues such as salinity and temperature (Hastings, Turner, and Thomas, 1987; Matern, Moyle, and Pierce, 2002; Wagner, 1999). This appears not to be the case for fishes occurring in pelagic habitats of Barataria Basin, where a significant number of reduced Δ+ values were recorded. In these reduced Δ+ collections, drum species (*i.e.,* Family Sciaenidae) dominated the assemblages but nonsciaenid species were less likely to be present. Further analysis of these gill net data revealed that for all Barataria collections with reduced Δ+, the absence of any one species or group did not contribute to the significant lack of diversity. That is, localized extirpations did not drive these results. Barataria gill net collections with reduced Δ+ were missing 24 families of fishes found in the remaining samples from Barataria Basin and the other three estuarine regions. Because of geographic differences among estuarine regions, it is not expected that all regions share exactly the same species. Therefore, when a species is found to be missing from samples, its natural distribution should be examined to determine if its absence is expected. We found that several of the species and taxa missing from the impacted Barataria gill net collections are vulnerable, endangered, or threatened such as the families Acipenseridae (Paruka, 2005), Polyodontidae (Grady, 2004), Myliobatidae (Barker, 2005), and the genus *Alosa* (Huntsman, 1996). Other taxa declining or potentially declining include the families Trichiuridae (Chesney, Baltz, and Thomas, 2000), Paralichthyidae (Chesney, Baltz, and Thomas, 2000), Megalopidae (Blandon *et al.,* 2003), and the genus *Rhizoprionodon* (Marquez-Farias and Castillo-Geniz, 1998). Further, some of these missing taxa are susceptible to increased direct or indirect fishing pressure (Barker, 2005; Grady, 2004; Marquez-Farias and Castillo-Geniz, 1998; Stevens, 2004). Although some of these taxa may not commonly be found in Barataria (*e.g.,* Acipenseridae), many are shared among the four regions. The loss or decline of these species or others in Barataria Basin is causing the lower phylogenetic diversity seen in this system. Urbanization is less of a problem in the Barataria Basin than the other three regions, implying that other factors such as overharvesting, bycatch mortality, or accelerated wetlands loss are affecting fishes in these habitats. For example, analyses of spotted sea trout (*Cynoscion nebulosus*) collected from across coastal Louisiana show that the diet of this recreationally important species is different in Barataria Basin than in other regions such as Lake Pontchartrain and the Chandeleur Islands (Turner and O'Connell, 2008).

Results of carbon stable isotopes indicate that sources of organic matter appear to be different between *C. nebulosus* from the Chandeleur Islands and the other locations. Further, nitrogen stable isotope results indicate that *C. nebulosus* in Barataria Bay are feeding at a lower trophic level than fish from the other locations (Turner and O'Connell, 2008). This difference in diet may explain why Barataria spotted sea trout are reported to be smaller than other sea trout in Louisiana and may be a result of prey habitat loss. However, increased recreational fishing pressure in this region could result in overfishing of larger individuals, and the diets of the remaining smaller individuals may be reflecting that of younger fish.

The health of nearshore fish assemblages in all regions may be a reflection of the physiological resilience of those species that dominate these assemblages. Many of these small resident species (*i.e.,* those who remain in the estuary throughout their life) are tolerant to environmental extremes of both salinity and temperatures. Fishes in the families Cyprinodontidae, Fundulidae, and Poeciliidae are recognized for their hardiness and are found in nearshore habitats of all four estuarine regions we studied (Appendix). Throughout southeastern Louisiana, though, there has been significant loss of these habitats over time (Day *et al.,* 2007). While vegetated nearshore and other shallow habitats are being eroded, there is a temporary increase in "edge" habitat as they break up into smaller areas (Chesney, Baltz, and Thomas, 2000). It is likely that in these habitats tolerant resident species along with other less-related estuarine dependent species are currently benefiting from the temporary increase in edge and shallow, low energy habitats. These habitats benefit not only resident species associated with vegetation but also juveniles of estuarine dependent species that use shallow nonvegetated habitats. The advantage of temporarily increased edge may be conferring benefits to these nearshore fishes, allowing them to thrive even under the influence of other environmental stressors.

Taxonomic distinctness has been successfully used to study marine groundfishes and nematodes (Hall and Greenstreet, 1998; Rogers, Clarke, and Reynolds, 1999; Warwick and Clarke, 1998), coral reef fishes (Graham *et al.,* 2006), mollusks (Terlizzi *et al.,* 2005), and other macrobenthos organisms (Arvanitidis *et al.,* 2005; Gilkinson *et al.,* 2005; Miranda *et al.,* 2005; Mouillot *et al.,* 2005a; Raut *et al.,* 2005). In other analyses, though, the interpretation of results was often confounded by environmental variability (Bhat and Magurran, 2006; Yim *et al.,* 2006), seasonal differences (Lekve *et al.,* 2005; Reiss and Kroncke, 2005), and differences in taxon response to impacts (Arvanitidis *et al.,* 2005; Mouillot *et al.,* 2005b). Also, unexpected increases in diversity near disturbance have been noted (Somerfield *et al.,* 2006). In light of the variable success in utilizing these measures and because we did not address all factors that may have affected our results (*e.g.,* seasonal differences), it is important to interpret our results correctly so that we have a better understanding of impacts in coastal southeastern Louisiana habitats. The differences in phylogenetic diversity (*i.e.,* health) among fish assemblages of the four regions agree with the degree of generally recognized environmental impact. That is, it should be expected that the more disturbed demersal habitats in Lake Pontchartrain are less healthy than the other regions. It appears that taxonomic distinctness is more of an indication of health in the regions rather than variation in taxonomic distinctness, which rarely was reduced in any region. Given that other studies in Lake Pontchartrain produced similar findings (O'Connell, Cashner, and Schieble, 2004), it is likely that this measure of phylogenetic diversity is accurately reflecting the environmental impacts in these areas. However, that some of the "relatedness" in the affected samples in both regions was due to a preponder-

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ance of species from the family Sciaenidae raises some questions about the validity of this measure. The four regions are characterized by many Sciaenid species (Appendix). It is not known if the dominance of this family is just a reflection of its natural occurrence in the area or decline of other unrelated species. Many of these drum species themselves could be affected by anthropogenic impacts such as habitat loss or overfishing. Their abundance indicates that this family is still well-represented even if there have been impacts. However, the lack of unrelated species or taxa in these samples (that are either found in unaffected collections or that could increase the phylogenetic diversity) may indicate a decline in taxa that are more affected by disturbance. It is interesting to note that our analyses of more recent Lake Pontchartrain fishery data for a separate project (O'Connell, Cashner, and Schieble, 2006) also found evidence of disturbance in this region. Of further concern is that the effects measured in the more recent data appear in all three habitats (demersal, nearshore, and pelagic).

CONCLUSIONS

Demersal fish assemblages from Lake Pontchartrain and pelagic fish assemblages from the Barataria Basin were more affected than fishes collected in similar habitats in the other regions of southeastern Louisiana. Our measurements of average taxonomic distinctness ($\Delta+$) and variation in taxonomic distinctness ($\Lambda+$) indicated a loss of phylogenetic diversity in these habitats in both of these regions. While this taxonomic approach may not always be able to accurately measure impacts in all situations, the loss of diversity we measured should be interpreted in light of additional knowledge about impacts in the area and results of similar regional research.

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APPENDIX

List of all families and species collected in each of the four estuarine regions by each of the three gear types: trawls (T), seines (S), and gill nets (G).

Family	Species	Barataria Basin	Lake Maurepas	Lake Pontchartrain	Biloxi and Chandeleurs
Carcharhinidae	*Carcharhinus brevipinna*	G			
	Carcharhinus leucas	T,G		S,G	T,G
	Carcharhinus limbatus	G			G
	Negaprion brevirostris				S
	Rhizoprionodon terraenovae	G			T,G
Sphyrnidae	*Sphyrna tiburo*				G
Dasyatidae	*Dasyatis sabina*	T,S,G	G	T,S,G	T,S,G
Rhinopteridae	*Rhinoptera bonasus*	T,G		G	T,G
Acipenseridae	*Acipenser oxyrinchus desotoi*			G	G
Polyodontidae	*Polyodon spathula*		T,G		
Lepisosteidae	*Atractosteus spatula*	T,G	G	T,S,G	
	Lepisosteus oculatus	S,G	G	S,G	S
	Lepisosteus osseus	G	T,G	T,S,G	
Elopidae	*Elops saurus*	S,G	G	T,S,G	T,S,G
Megalopidae	*Megalops atlanticus*	G		G	
Anguillidae	*Anguilla rostrata*		T	S	
Ophichthidae	*Myrophis punctatus*			T,S,G	
	Ophichthus gomesii	T,S			
Engraulidae	*Anchoa hepsetus*	T,S	T	T,S	T,S
	Anchoa lyolepis	T,S			
	Anchoa mitchilli	T,S	T	T,S	T,S
Clupeidae	*Alosa alabamae*		T,G		
	Alosa chrysochloris	T,S,G	T,G	T,S,G	S,G
	Brevoortia patronus	T,S,G	T,G	T,S,G	T,S,G
	Dorosoma cepedianum	T,S,G	T,G	T,S,G	T,S,G
	Dorosoma petenense	T,S,G	T,G	T,S,G	T,S,G
	Harengula jaguana	G		T,S	S
	Opisthonema oglinum	S,G			T,S,G
	Sardinella aurita	G		S	
	Clupeid larvae		T		
Cyprinidae	*Cyprinella venusta*			S	
	Notemigonus crysoleucas			S	
	Opsopoeodus emiliae			S	
Catostomidae	*Carpiodes carpio*		G	G	
	Hypentelium nigricans			S	
	Ictiobus bubalus		T,G		
Ictaluridae	*Ameiurus melas*		G	S	
	Ictalurus furcatus	G	T,G	T,S,G	
	Ictalurus punctatus	S,G	T,G	T,S,G	
	Pylodictis olivaris		T	T	
Ariidae	*Ariopsis felis*	T,S,G	G	T,S,G	T,S,G
	Bagre marinus	T,S,G	T,G	T,S,G	T,G
Synodontidae	*Synodus foetens*	T,S,G		T,S	T,S
Aphredoderidae	*Aphredoderus sayanus*		T	S	
Ophidiidae	*Lepophidium brevibarbe*	T			
	Ophidion holbrookii	T			
Phycidae	*Urophycis floridana*	T,S			T
Batrachoididae	*Opsanus beta*	T,S		T	T,S
	Porichthys plectrodon	T,G		T	
Antennariidae	*Antennarius radiosus*	T			
	Histrio histrio	T			
Mugilidae	*Mugil cephalus*	T,S,G	T,G	T,S,G	S,G
	Mugil curema	S,G		S	S,G
Atherinopsidae	*Membras martinica*	T,S		T,S	S
	Menidia beryllina	T,S	T	T,S	T,S
Belonidae	*Strongylura marina*	S	T,G	T,S	S,G
Hemiramphidae	*Hyporhamphus meeki*	S		T,S	T,S,G
Fundulidae	*Adinia xenica*	S		S	S
	Fundulus chrysotus			T,S	
	Fundulus grandis	T,S		S	S
	Fundulus jenkinsi	S		S	S
	Fundulus pulvereus	S		S	S
	Fundulus similis	T,S		S	S
	Lucania parva	T,S		T,S	S

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APPENDIX

Continued.

Family	Species	Barataria Basin	Lake Maurepas	Lake Pontchartrain	Biloxi and Chandeleurs
Poeciliidae	*Gambusia affinis*	S		S	
	Heterandria formosa			S	
	Poecilia latipinna	S		S	T,S
Cyprinodontidae	*Cyprinodon variegatus*	T,S		S	S
Syngnathidae	*Hippocampus erectus*	T,S			T
	Hippocampus zosterae				S
	Syngnathus floridae				T,S
	Syngnathus louisianae	T,S		T,S	T,S
	Syngnathus scovelli		T	T,S	T,S
Scorpaenidae	*Scorpaena calcarata*	T			
Triglidae	*Prionotus longispinosus*	T			S
	Prionotus rubio	T			
	Prionotus scitulus	T			
	Prionotus tribulus	T,S,G		T	T,G
Moronidae	*Morone chrysops*		G	S	
	Morone mississippiensis		T,G	T,S,G	T
	Morone saxatilis	G	G	S,G	
Serranidae	*Centropristis philadelphica*	T			
	Diplectrum bivittatum	T,S			T
	Diplectrum formosum	T			
	Mycteroperca microlepis	T			
Centrarchidae	*Lepomis cyanellus*	S,G			
	Lepomis gulosus			S	
	Lepomis macrochirus	S	T	T,S	S
	Lepomis megalotis	G	T		
	Lepomis microlophus	S,G		S	
	Lepomis microlophus hybrid		G		
	Lepomis miniatus	S		S	
	Lepomis symmetricus			S	
	Lepomis spp.	S			
	Micropterus punctulatus			S	
	Micropterus salmoides	S,G		S	
	Pomoxis annularis		G		
	Pomoxis nigromaculatus			S	
Pomatomidae	*Pomatomus saltatrix*	T,S,G		G	S,G
Echeneidae	*Echeneis naucrates*			S	T,G
Rachycentridae	*Rachycentron canadum*	T,G			T
Carangidae	*Caranx bartholomaei*	G			
	Caranx crysos	G			G
	Caranx hippos	T,S,G	G	T,S,G	T,S,G
	Chloroscombrus chrysurus	T,S,G		T,S	T,S,G
	Decapterus punctatus	G			
	Hemicaranx amblyrhynchus	T		T	
	Oligoplites saurus	T,S,G		T,S	S,G
	Selene setapinnis	T		T	T
	Selene vomer	T,S,G			T
	Trachinotus carolinus	S,G			S
	Trachinotus falcatus	S,G			
	Trachurus lathami	G			T
Lutjanidae	*Lutjanus campechanus*	T			
	Lutjanus griseus	T,S,G			T,S
	Lutjanus synagris	T			T
Lobotidae	*Lobotes surinamensis*	T			
Gerreidae	*Eucinostomus argenteus*	T,S		S	
	Eucinostomus gula	T,S		T	T,S
	Eucinostomus spp.	S			
Haemulidae	*Orthopristis chrysoptera*	T,G			T,S,G
Sparidae	*Archosargus probatocephalus*	T,S,G	T,G	T,S,G	T,S
	Lagodon rhomboides	T,S,G		T,S,G	T,S,G
Polynemidae	*Polydactylus octonemus*	T,S,G		T,S	

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APPENDIX

Continued.

Family	Species	Barataria Basin	Lake Maurepas	Lake Pontchartrain	Biloxi and Chandeleurs
Sciaenidae	*Aplodinotus grunniens*		T,G	T,S,G	
	Bairdiella chrysoura	T,S,G	T	T,S,G	T,S,G
	Cynoscion arenarius	T,S,G	T,G	T,S,G	T,S,G
	Cynoscion nebulosus	T,S,G	T	T,S,G	T,S,G
	Cynoscion nothus	T,S,G			
	Larimus fasciatus	T,S			T
	Leiostomus xanthurus	T,S,G	T,G	T,S,G	T,S,G
	Menticirrhus americanus	T,S,G		T,S,G	T,S,G
	Menticirrhus littoralis	T,S,G			T,G
	Micropogonias undulatus	T,S,G	T,G	T,S,G	T,S,G
	Pogonias cromis	T,S,G	G	T,S,G	S,G
	Sciaenops ocellatus	T,S,G		T,S,G	T,S
	Stellifer lanceolatus	T,S,G		T	T
Elassomatidae	*Elassoma zonatum*			S	
Uranoscopidae	*Astroscopus y-graecum*	T,S			
Blenniidae	*Chasmodes bosquianus*	T,S		S	
	Chasmodes saburrae				T,S
	Hypleurochilus geminatus	T,S			
	Hypsoblennius hentz	T			T
	Hypsoblennius ionthas	T			T
	Blenniidae larvae	T			
Gobiesocidae	*Gobiesox strumosus*	T,S		T,S	T,S
	Gobiesox spp.	T,S			
Eleotridae	*Dormitator maculatus*			S	
	Erotelis smaragdus	T			
Gobiidae	*Bathygobius soporator*				S
	Ctenogobius boleosoma	T,S			S
	Ctenogobius shufeldti	S	T	T,S	
	Evorthodus lyricus	T,S			S
	Gobioides broussonnetii	T,S			T
	Gobionellus oceanicus	T,S		T,S	T,S
	Gobiosoma bosc	T,S	T	T,S	T,S
	Gobiosoma robustum				T,S
	Microgobius gulosus	S	T	T,S	S
	Microgobius thalassinus				T
	Gobiidae larvae	S			
Ephippidae	*Chaetodipterus faber*	T,S,G		T,S	T
Sphyraenidae	*Sphyraena barracuda*				T,S
	Sphyraena guachancho	T,S,G			T,S
Trichiuridae	*Trichiurus lepturus*	T,S		T,G	T
Scombridae	*Scomberomorus cavalla*	S			
	Scomberomorus maculatus	T,S,G		T,G	G
Stromateidae	*Peprilus burti*	T,G		T	T,S,G
	Peprilus paru	T,S,G		T	T
Paralichthyidae	*Ancylopsetta ommata*	T			
	Ancylopsetta quadrocellata	G			
	Citharichthys macrops	T,S			
	Citharichthys spilopterus	T,S	T,G	T,S	T,S
	Etropus crossotus	T,S		T	T,S
	Paralichthys lethostigma	T,S,G	T,G	T,S,G	T,S,G
	Syacium gunteri	T			
Achiridae	*Achirus lineatus*	T,S		T,S	
	Trinectes maculatus	T,S	T	T,S,G	T
Cynoglossidae	*Symphurus civitatium*	T,S			
	Symphurus plagiusa	T,S,G		T,S	T,S
Monacanthidae	*Aluterus scriptus*				T
	Stephanolepis hispidus	T,S			T
Ostraciidae	*Acanthostracion quadricornis*				T
	Lactophrys trigonus				T
Tetraodontidae	*Lagocephalus laevigatus*	T			
	Sphoeroides parvus	T,S		T,S	T,S
Diodontidae	*Chilomycterus schoepfii*	T			T,S

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