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Bycatch of the Lake Pontchartrain Basin inshore shrimp fishery and its effect on two sea catfish species: the gafftopsail catfish (Bagre marinus) and the hardhead catfish (Ariopsis felis)

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Dedication

This manuscript is dedicated to my grandfather, Lawrence Bres Eustis, as well as my close friends who have seen me through these past years. A patriarch, gardener, and naturalist who has ever encouraged my studies of and efforts towards the conservation of wildlife in Louisiana, my Granddaddy remains an inspiration and a model for my investigations into the natural world.

Darin Acosta, Jane Gruning, Eric Martinez, Stephanie Powell, and Becca Link are the people who have shared and spurred the curiosities and concerns about the future of New Orleans, and of Louisiana as a whole, that led me to write this document.

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Abstract

In Lake Pontchartrain Basin, commercial fishing in estuarine habitats impacts many non-target species collected as bycatch. I investigated the bycatch assemblages collected by commercial vessels and compared these to assemblages collected by typical fishery-independent methods. I compared assemblages using analysis of similarity (ANOSIM) and determined important species by weight and abundance using similarity percentages analyses (SIMPER). I also examined differences in size-class distributions by gear type using density kernel plots and Mann-Whitney U tests. The two gear types collected significantly different assemblages (ANOSIM R = 0.522, p = 0.001) and gear type explained more composition differences than other factors such as month, daytime, or location. Fishery-independent gear underestimated the importance of many species. Although fishery-independent data are invaluable for monitoring assemblage dynamics, fishery-independent gear collects different assemblages than commercial gear. Larger fishes of important species were caught less often in bycatch, but completely absent from fishery-independent gear.

Keywords: fishery, shrimp, bycatch, assemblage, gear type, Lake Pontchartrain

Introduction

The incidental take of non-target fishes by the shrimping industry, or “bycatch,” has long been recognized as a potential threat to the health of Louisiana’s fisheries. Worldwide the highest rates of discarding have been attributed to shrimp trawl fisheries, (Alverson et al., 1994; Bergmann et al., 2002a). The impacts of repeatedly dragging trawl nets, in particular, over water bottoms both in the continental shelf and the deep ocean are among the most severe ecological impacts upon marine ecosystems (Engel and Kvitek, 1998). Any particular area of the shelf can repeatedly dragged many times a year, reducing the structure of bethic habitats as clear-cutting destroys forests (Watling and Norse, 1998). Here I focus only on shrimping’s impact to the fish assemblages in southeastern Louisiana.

The first local attempt to describe the problem was Gordon Gunter’s “Studies of the destruction of marine fish by shrimp trawlers in Louisiana,” written at the dawn of the motorized shrimp fishery in Louisiana (Gunter, 1936). The author lamented the destruction but gave up hope of studying the problem, much less solving it (Gunter, 1936). Despite concerns generated by Louisiana conservationists, the shrimping industry continued to grow into the 1950s and beyond, even after catches had reached a plateau (Anonymous, 2007). Later, in the 1980s, bycatch of endangered sea turtles became a hot-button issue among national environmental groups. These concerns led to federal regulation of fishing gears and mandatory gear changes such as turtle excluder devices (TEDs) and bycatch reduction devices (BRDs). Shrimpers in Texas and Louisiana famously blockaded shipping channels to protest the national TED regulation, which they saw as unnecessary for their region, which was sparsely populated by sea turtles compared to the Atlantic and Florida coasts where the TEDs were invented (Margavio et al. 1996). Since these conflicts, shrimpers have been using wing nets, usually reserved for shallow-water shrimping, more often (Anonymous, 2007). Beyond the fact that no TED is required in the bag end of wing nets, this change will predictably alter which nekton species are impacted most by bycatch mortality.

Chesney et al. (2000) explained the need for directed research on the effects that these anthropogenic changes have on Louisiana's fisheries. In particular, they emphasized the necessity for research on the ecosystem impacts of bycatch in order to find ways to reduce these impacts or channel them in constructive ways. Since 1972, Louisiana's fisheries have proven resilient to the chronic disturbance industrial-scale shrimping imposes—but that resilience does not exclude changes in the assemblage of fishes:

> "Bycatch mortality probably has a significant structuring effect on nekton populations and community structure, but it may not have a significant impact on total system secondary productivity because bycatch is generally consumed within the system…This redistribution of the benthic food chain undoubtedly affects community structure in heavily trawled ecosystems." (Chesney et al., 2000).

The best available data, sampled directly from commercial vessels, comes from a 1993 Louisiana Department of Wildlife and Fisheries (LDWF) technical report on bycatch in the shrimp fishery. A major finding of this report distinguished the gear types (wing net and trawl) in their average fish: shrimp (F: S) ratios (Adkins, 1993). Although the averages reported in Chesney et al., (2000) convey the idea that the amount of bycatch is very regular, the ratio varies markedly per catch (Adkins, 1993) Although annual statistics of the shrimp fishery show F:S of 4:1 or 9:1, 56% of individual tows (n=104) in the Adkins report yielded F:S ratios below 1.5:1, with an overall geometric mean of 1.24:1 (Adkins, 1993).

Such variability suggests that science could benefit the industry and conservation alike by determining which shrimping methods avoid the relatively few trips that result in the vast majority of the bycatch. Because the industry is diverse and the natural variability of bycatch is great, monitoring studies that explore and explain this variability are needed. Monitoring studies are a standard practice for determining bycatch (Diamond, 2003; Brewer et al., 2006; Holst and Revill, 2009). To conduct a representative monitoring study, two questions should be addressed: 1. where and when should sampling occur? and 2. how much sampling is enough? Knowing how variable the differences in assemblages and F:S ratio are between different kinds of hauls would allow us to place Louisiana's current monitoring efforts in context as well as inform managers how to design new monitoring programs appropriately. Similarly, comparing commercial hauls to scientific hauls may allow us to predict which species are regularly missing from the smaller scientific nets. By studying the variability of commercial fish catches, we can determine how to improve our monitoring programs to prioritize highly variable aspects. For example, if catches differ widely over the year, monitoring cannot take place during a single season. We can also judge whether it is reasonable to expect that we can predict whether these missing species show up in bycatch.

The fact that over half of individual catches have a low F:S ratio has inspired researchers to survey bycatches on commercial vessels in the hope of finding environmental or geographical causes of high F:S ratios (Diamond, 2003). These researchers are motivated to discover ways of improving the general ratio. For example, Gunter (1936) claimed that the destruction of fishes was worse from late spring into the fall while Adkins (1993) wrote that ratios of offshore catches were larger than those inshore. Shrimpers' hypotheses vary considerably, but they commonly report that, "It's different every day." How bycatch and F: S ratios differ among areas, days, or boats on the same day will influence future scientific monitoring efforts. Changes in the geography of shrimping activity may also influence the annual F:S ratio, should there be significant differences between F:S ratios offshore and inshore. But if the behavior of the fishery were changed to reduce bycatch without altering its catches of shrimp, the objections to “wild” shrimp fisheries as wasteful would lessen in comparison to objections raised to industrial shrimp aquaculture, with its attendant mangrove deforestation, chemical pollution, and negative public health effects (Barraclough and Finger-Stich, 1996; Lewis et al., 2003). How such objections would be weighted is the topic of ecological economics and outside the scope of this study.

To inform this debate, I gathered data to understand how bycatch generated by the shrimping industry negatively impacts the fish assemblages of the Lake Pontchartrain Basin. My first objective was to compare the bycatch of the inshore fishery to the shrimp fishery of Louisiana as a whole. To accomplish this I compared F:S ratios from commercial gears to statewide data, collected both inshore and offshore in past studies. While it is common to see arithmetic means of these ratios published as the “average” ratio of pounds of fish to pounds of shrimp caught (Adkins, 1993; Diamond, 2003), I calculated the arithmetic mean alongside the geometric mean and the median, because these metrics are respectively mathematically correct (Douglas, 2004), and more representative of the ratio “on average.”

My second objective was to compare the bycatch assemblage by gear type and to discern species differences between fishery-dependent and fishery-independent gears, and between two types of commercial gears. To accomplish this, I conducted an ANOSIM of catches among the three gear types (Clarke and Warwick, 2001).

My third objective was to assess the temporal variability in bycatch compostion so that future fishery independent or fishery dependent sampling efforts can be designed to capture the most information with the least effort (Borges et al., 2004). By comparing the similarity or length-frequency of catches from month to month, agencies can determine how often to sample from commercial or scientific vessels. I also compared the length-frequency of size classes of important species between hauls on a single trip to compare the length-frequency of catches from haul to haul on a single trip.

Materials and Methods

Study Location

All collections were made within the inshore area of the Lake Pontchartrain Basin, which includes LDWF Zone 1, from the Pearl River to the Mississippi Birdfoot Delta, and particularly the passes at the Rigolets and in the Mississippi River Gulf Outlet (MRGO; Figure 1.1). This area contains Lake Borgne, Lake Pontchartrain, and Lake Maurepas. From June to October 2007 and 2008, I periodically collected data aboard commercial shrimping vessels (Diamond, 2003). I solicited shrimpers at docks during and between the brown and white shrimp (*Farfantepenaeus aztecus* and *Litopenaeus setiferus*) seasons. I made eight day-long trips on local shrimp vessels and later conducted my own fishery-independent sampling in the same regions for comparative purposes (Barret et al. 1978; Figure 1.1). Every location I sampled was related to a local maximum in tidal amplitude, because shrimpers seek areas of strong tidal flow to maximize their collection efforts.

Sampling Methods and Data Analyses

F:S ratios were compared using simple scatterplots. The F:S ratios of 104 samples from the statewide shrimp fishery were reported by Adkins (1993). The ratios of the samples collected from the inshore Lake Pontchartrain Basin shrimp fishery (section 12.1 by Adkins' schema) could be compared using histograms, because the data are summarized by gear type.

It should be noted that current fishery-independent monitoring samples by LDWF do not take tide into account and thus may not be comparable to the efforts of shrimpers. With this in mind, I compared data taken from commercial vessels with those by fishery-independent vessels by re-sampling these same areas with a standard "scientific" 4.9 m otter trawl as operated by

LDWF (Barret et al. 1978) during active tidal periods in order to see what differences exist between these “commercial” samples and “scientific” monitoring samples. I refer to these commercial samples as “trawl” or “wing net” samples depending on what gear was deployed during each fishing trip.

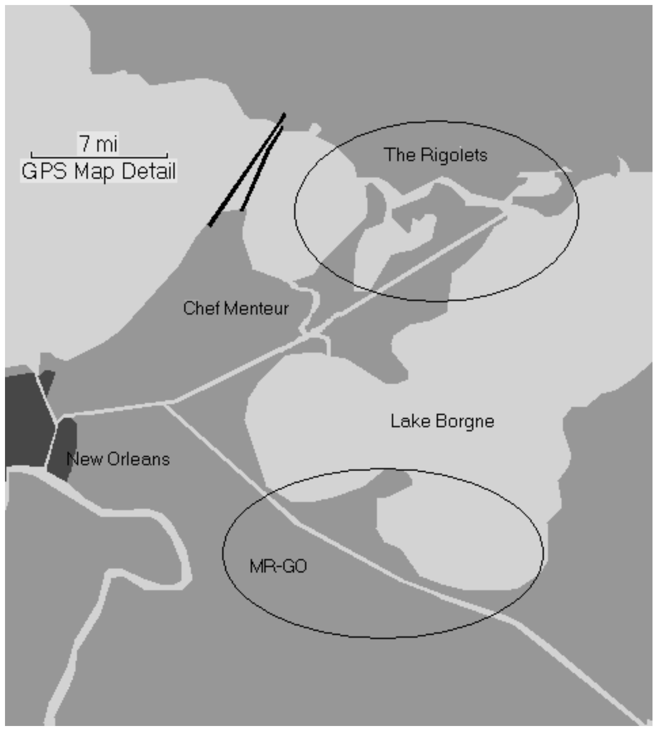

Figure 1.1 Passes sampled during sampling efforts on commercial vessels.

Modifying (Bergmann et al 2002a), I recorded location, tow duration, gear used, and estimated total weight per tow. A GPS unit (Garmin GPS 76) was used to determine location during the entire time period of most commercial samples; location and time were recorded when the nets were lowered and taken up. Commercial vessels generally dragged or pushed nets at 2 knots or less. Typically nets were lowered and then raised after about an hour. At this point, the catch was dumped unto a section of the deck for the purpose of sorting the shrimp from the fishes, using common plastic baskets (Figure 1.2). I separated the fishes from the shrimp, then weighed baskets of catch before placing the fishes on ice in ice chests for later processing in the laboratory. If I ran out of room in the ice chests, I weighed the bycatch after it was separated, before throwing it overboard. From these unsaved samples, I have kept voucher specimens of species previously uncaught on that day. Other species, such as cownose rays (*Rhinoptera bonasus)* were unwelcome onboard commercial vessels and were often thrown overboard immediately. For these, I estimated size and weight based upon previous fishery-independent data collected by the Nekton Research Laboratory (NRL) at the University of New Orleans. Because some boats keep blue crabs (*Callinectes sapidus*) for sale, I weighed these after each tow, before they were thrown on ice. Every time the nets were lifted, the following water quality data are collected with a handheld YSI 85 multi-meter: temperature (^{o}C), salinity (PSU), dissolved oxygen (mg/L), percent dissolved oxygen, and conductivity (mS/cm).

Figure 1.2. The separation and weighing process for a small catch. This captain kindly allowed me room.

To compare fish assemblages caught with different gear, I returned to the same area within two weeks, but in a smaller vessel, fishing with a 4.9 m (16') "test" otter trawl (Barret et al. 1978), referred to here as the "scientific" trawl. I followed the standard scientific protocol and fished the net in a zigzag fashion for 10 minutes at 2 knots, three times over the area sampled previously by the commercial shrimper. Shrimp were separated from fishes and the whole sample weighed and placed on ice in an ice chest with the fishes. For each 10-minute sample, the same water quality data were taken with a handheld YSI 85 multi-meter.

To process assemblage collections, fishes were returned to the laboratory on ice or frozen for later processing. According to LDWF protocol, samples were separated by species, and smallest and largest standard lengths (SL) recorded. Up to fifty total lengths (TL) for each fish species, from individuals randomly selected from the sample, were recorded. Samples were weighed by species. This is the standard procedure for processing LDWF ‘trawl’ samples. The largest and smallest fish from each species were selected to ensure the 50 lengths randomly sampled captured the range.

I used an analysis of similarity (ANOSIM) to compare assemblages by gear type, location, month, as well as day versus night (Clarke and Warwick 2001). This non-parametric multivariate approach tests for significant differences in the species compositions of different samples. Given that the gear types sample different parts of the water column, at different times of day, and that shrimpers fishing with wing nets fish at more similar tidal periods than trawlers, it is expected that the type of gear used will affect the fish assemblage caught. From previous fishery-independent studies in the Lake Pontchartrain Basin (Schieble et al. 2002), time of day (day versus night) affects the catch rate of certain species, due to changes in the effectiveness of the gear as well as behavioral differences among species. In cases of significant assemblage differences, I conducted the SIMPER (similarity percentages) routine to calculate both average similarity and dissimilarity among groups (Clarke and Warwick, 2001). This routine determines which species are the major drivers of the observed assemblage changes.

The paired commercial and scientific samples were compared using ANOSIM to determine significant differences between the two basic gear types: 3 m versus 10 m trawl nets. To conduct an ANOSIM of the effect of gear type on assemblages caught, I transformed the abundance and weight data matrices with a fourth root transformation (Bergmann et al., 2002a). I used this more severe transformation over the square root transformation due to both the differences in sampling effort between commercial and scientific methods, as well as the low sample size.

I used the SIMPER analysis to determine which species were the most significant drivers of the differences among gear types. Scientific samples were also compared to regular monitoring samples taken monthly in similar areas, to determine whether sampling during the tides used by shrimpers had a significant effect in separating the assemblages.

Because the different gear employ nets of different sizes, I expected the lengths of the species caught to be different among the three gear types. Lengths sampled randomly from each sample were not expected to be normally distributed, given that there may be different size classes within a single sample. Each commercial haul lasts approximately an hour's time between the lowering and lifting of nets. Each scientific haul lasts ten minutes. Samples from each haul were weighed by species and an SL range taken. Fifty TLs were taken randomly among the individuals of each species to represent the lengths of that each species each hour.

When individual total lengths of these important species are plotted, the lengths are often bimodal and do not follow a normal distribution. Therefore, detecting differences among gear types requires a non-parametric test. I assessed this by constructing density plots and using a Mann–Whitney U test, a non-parametric test for assessing whether two independent samples of observations come from the same distribution (Holst and Reville, 2008). I examined differences among gear types for four of these important species.

Samples taken during the same trip were compared to determine the basic differences in assemblages caught at the smallest time scale. Throughout a single day or night, shrimpers collect the same species in a haul. I tested whether or not the catch is composed of the same size classes to determine whether or not a sample from one hour-long tow is representative of size classes caught the entire trip. The same density plots and Mann-Whitney U tests were used to display and test for differences in the lengths of one species, white trout, *C. arenarius*, among hours.

Results

Over two years, I collected 63 vertebrate and one squid species (brief squid, *Lolliguncula brevis*) representing 29,480 specimens. These were collected during 21 trips on commercial vessels and 35 scientific sampling efforts (Table 1.1). In addition to these, I was present for the bycatch of one *Malaclemys terrapin*, a diamondback terrapin that was immediately released upon its removal from the net. All collections were made in the natural and artificial passes that connect Lake Pontchartrain to Lake Borgne and the Gulf of Mexico (Fig. 1.1). Samples collected in the MRGO were from trawling vessels, whereas both commercial gear types were used in the Rigolets. Fewer samples were taken in the later months of the *L. setiferus* season, due to the arrival of hurricanes Gustav and Ike in the fall of 2008. Due to the irregular nature of sampling from commercial vessels, sampling the same area with scientific gear did not always occur. One species, the sharksucker (*Echeneis naucrates*), was collected only once. I also collected specimens of the shrimp eel (*Ophichthus gomesi*) although this species was not found in historical fish surveys of the region (Thompson and Verret *in* Stone, 1980; O'Connell et al., 2004). Both of these species were collected by commercial wing net samples fished at night.

F:S ratios

From 7 commercial and 13 scientific field efforts (trips) for which F:S ratios were recorded in the field, there were 5 individual commercial trawl hauls, 19 individual commercial wing net hauls, and 26 individual scientific otter trawl hauls. 'Hauls' are defined as the catch from the entire time a cod end is released into the water until the time it is pulled up. Of the 26 scientific hauls, 8 caught no shrimp and are excluded from this analysis. Generally, commercial nets were down and actively fishing for approximately an hour, except for an initial part of the trip as the captain "tested" the waters for shrimp. Scientific hauls were ten minutes each. Due to limited storage space on deck, not all hauls that were weighed were sampled for assemblage data and, due to periodic equipment failure, not all assemblage samples were weighed in the field.

As previously stated, geometric mean was calculated alongside arithmetic mean and median, in order to represent the differences between the types of "average."

For the commercial gear samples, F:S of the 19 wing net samples was consistently lower than F:S of the 5 trawl samples (Figure 1.3). Summarized by gear type, the scientific trawl had a total ratio of 1.3, the commercial trawl 2.0, and the wing net a ratio of 0.5. For the scientific trawl (n = 18), the mean F:S was 9.85, the geometric mean 2.85, and the median 4.28. For the commercial trawl (n = 5), the mean F:S was 1.95, the geometric mean 1.33, and the median 2.05. For the wing net hauls (n = 19), the mean F:S was 0.69, the geometric mean 0.51, and the median 0.48.

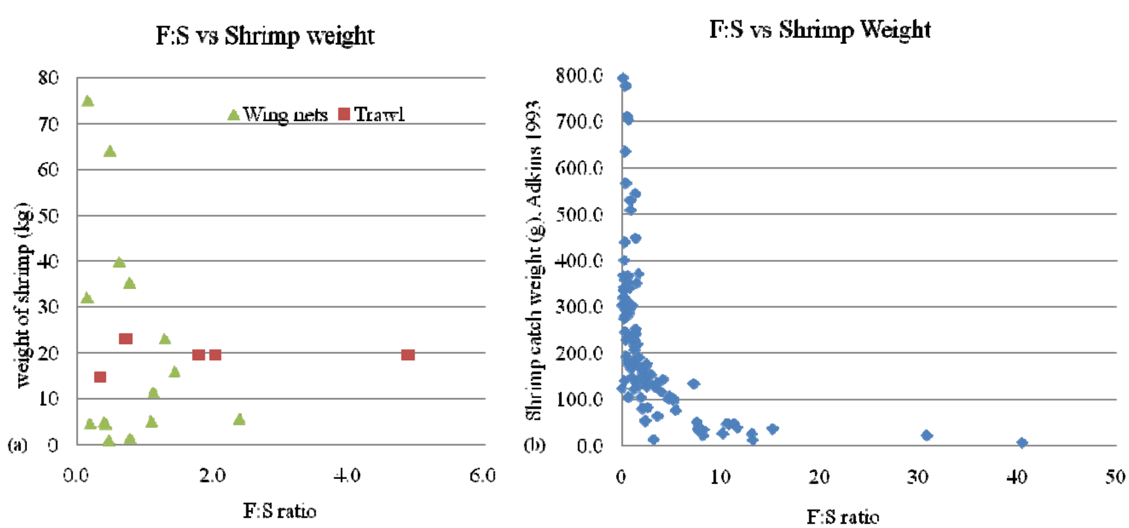

Figure 1.3 F:S versus shrimp weight for commerical hauls (~1 hour each) for this study and Adkins (1993). (a) Ratios from this study. Squares represent ratios from commerical trawl nets and triangles represent wing nets. (b) Ratios from Adkins (1993). Diamonds represent both trawl (n = 71) and wing nets (n = 34), for a total of 104 samples.

Because Adkins' (1993) F:S data are summarized in his report, I could not tell which catches were from wing nets and which from a commercial trawl. The total number of these ratios for the mixed gear types (wing net (n=34) and trawl (n=71)) was 104. The mean F:S was 3.21, the geometric mean 1.24, and the median 1.29. To compare my own data to Adkins' report, I combined the ratios from both commercial gear types in my study, for a total of 24. The mean F:S for mixed commercial gear (wing net (n=19) and trawl (n=5)) was 0.95, the geometric mean 0.62, and the median 0.56. These numbers are lower than those of the statewide study, although the summarized nature of Adkins' (1993) data makes them difficult to compare.

Catch composition differences between commercial and scientific gear

I collected 53 species and 21,641 specimens from 8 field efforts (trips) and 29 sampling efforts (hauls) on commercial vessels (Table 1.2). Specimens of the two penaeid shrimp species targeted by the commercial shrimpers (brown, *F. aztecus* and white, *L.setiferus*) typically occurred in the fish assemblage samples despite our best efforts to sort them out. Most but not all captains retained the specimens of *C. sapidus* for sale at the dock or for personal consumption. Other invertebrates, including isopods (Isopoda), mud crabs (*Rithropanopeus harrisii*), grass shrimp (*Palaemontes* sp)., and mantis shrimp (Stomatopoda), were present but have been excluded from this analysis because their weight and number were markedly small in catches, although they may be quite abundant in the area.

Because *C. sapidus* was retained on most of the commercial vessels, sampling *C. sapidus* in the field was irregular. That species has consequently been excluded from the following data analysis, although it played a large role in the bycatch. With the exclusion of cownose rays (*Rhinoptera bonasus*), fishes that occurred in one third or more of the hauls comprised 92% of the weight and 99% of individuals in all hauls. The three most abundant species were Atlantic croaker (*Micropogonius undulatus*), bay anchovy (*Anchoa mitchilli*), and white trout (*Cynoscion arenarius*), comprising 73% of the total number of fishes. The three heaviest species were *M. undulatus*, *C. arenarius*, and gulf menhaden (*Brevoortia patronus*), comprising 62% of the total weight.

Table 1.1. Descriptions of 23 field efforts (trips) for the current bycatch survey, 2007-2008. Included are temperature (^oC), salinity (ppt), the number of the pair (one scientific effort for every commercial effort), the month of the effort, whether it took place in the day or night, the approximate location, the number of species, the number of individual fish, and the total Weight of the fishescollected, in kilograms.

Trip	Temp°C	PPT	Pair	GearType	Month	Day/Night	Location	S	N	Wgt	d	J'	H'(log_e)
1	26.0	12.8	1	Trawl	June	Day	Mouth of Rigolets	15	791	80.71	2.10	0.76	2.05
2	28.9	7.1	1	Sci. trawl	June	Day	Mouth of Rigolets	17	1598	16.70	2.17	0.46	1.30
3	28.0	10.8	2	Wing nets	June	Night	Back of Rigolets	28	3844	103.86	3.27	0.46	1.54
4	29.1	7.0	2	Sci. Trawl	June	Night	Back of Rigolets	13	165	2.36	2.35	0.57	1.46
5	29.0	7.2	2	Sci. Trawl	June	Night	Back of Rigolets	15	130	1.25	2.88	0.69	1.86
6	27.0	17.0	3	Trawl	Aug	Day	MRGO	19	3334	71.90	2.22	0.46	1.36
7	32.0	13.3	5	Wing nets	Aug	Night	Rigolets	19	480	3.55	2.92	0.65	1.92
8	31.7	13.3	5	Wing nets	Aug	Night	Rigolets	21	967	11.39	2.91	0.62	1.89
10	27.4	15.9	5	Sci. trawl	Sep	Night	Rigolets	22	249	6.38	3.81	0.82	2.52
11	27.4	15.9	5	Sci. trawl	Sep	Night	Rigolets	8	22	0.50	2.27	0.92	1.91
12	30.0	15.9	6	Trawl	Oct	Day	MRGO	23	864	16.83	3.25	0.57	1.79
13	29.7	2.4	8	Sci. trawl	Jun	Day	Mouth of Rigolets	11	266	1.71	1.79	0.64	1.53
15	29.4	4.1	8	Wing nets	Jul	Night	Rigolets	25	8886	103.07	2.64	0.43	1.39
16	30.2	6.6	7	Sci. trawl	Jul	Day	Mouth of Rigolets	7	3478	4.11	0.74	0.05	0.09
17	29.1	5.3	9	Wing nets	Jul	Night	MRGO	15	2653	21.45	1.78	0.44	1.20
18	29.8	21.1	10	Sci. trawl	Jul	Day	MRGO	12	122	1.92	2.29	0.78	1.93
19	29.5	22.3	10	Sci. trawl	Jul	Day	MRGO	17	101	2.17	3.47	0.79	2.23
20	28.6	24.1	11	Sci. trawl	Jul	Day	MRGO	11	700	2.19	1.53	0.20	0.49
21	29.9	18.3	12	Sci. trawl	Jul	Day	MRGO	7	28	na	1.80	0.79	1.53
22	30.0	18.6	12	Sci. trawl	Jul	Day	MRGO	9	60	na	1.95	0.68	1.50
23	29.8	8.9	13	Sci. trawl	Aug	Day	MRGO	7	148	na	1.20	0.43	0.83

Table 1.2. Species caught in commercial hauls, that occurred in more than 33% of hauls. These 16 species are

92% of the weight and 99% of individual specimens. Three species, *C. nebulosus*, *B. marinus*, and *A. felis*, are noticeably larger on average (Mean Weight -grams). “t” signifies “trace” percent of the total weight, below 1 percent.

Commerical Vessels. Species with ·33.3% Occurrence

Species*	Weight (g)	N	Min SL	Max SL	Mean Wgt (g)	% Weight	% Occur.
Cynoscion arenarius	66888.3	3960	44	245	16.9	0.17	1.00
Anchoa mitchilli	9205.3	5091	18	74	1.8	0.02	0.97
Micropogonius undulatus	127312.0	6822	58	203	18.7	0.32	0.93
Dorosoma petenense	3911.8	198	61	152	19.8	0.01	0.90
Brevoortia patronus	51351.0	2747	32	190	18.7	0.13	0.86
Leiostomus xanthurus	24501.4	636	66	184	38.5	0.06	0.76
Sphoeroides parvus	504.4	204	14	70	2.5	t	0.66
Trichiurus lepturus	14699.2	347	113	615	42.4	0.04	0.62
Peprilus alepidotus	553.1	108	20	112	5.1	t	0.59
Anchoa hepsetus	162.1	54	29	110	3.0	t	0.52
Bagre marinus	37739.5	290	71	519	130.1	0.09	0.48
Trinectes maculatus	1684.8	149	51	81	11.3	0.00	0.41
Ariopsis felis	15398.8	103	82	296	149.5	0.04	0.38
Harengula jaguana	3839.2	452	50	90	8.5	0.01	0.38
Bairdiella chrysoura	2532.2	143	40	134	17.7	0.01	0.38
Cynoscion nebulosus	5021.5	28	154	340	179.3	0.01	0.34
	0.92	0.99	14	615	17.1		n=29

Table 1.3. Species from scientific hauls that occurred more than 25% of each haul. These 12 species comprise 90% of the weight and 98% of individuals caught by the smaller (16’ / 4.9 m) otter trawl net. Note that *Brevoortia patronus*, which makes up 13% of the weight and is caught 83% of the time in commercial hauls, does not make this list. The marine catfish species *B. marinus* and *A. felis*

have the largest average weight. “t” signifies “trace” percent of the total weight, below 1 percent.

Scientific Trawl, species of ·.025 % Occurrence

Species	Weight (g)	N	Min SL	Max SL	Mean Wgt (g)	% Weight	% Occr.
Cynoscion arenarius	2101.6	482	13	144	4.36	0.06	1.00
Micropogonius undulatus	7773.4	528	36	158	14.72	0.21	0.90
Anchoa mitchilli	4244.5	5255	13	71	0.81	0.12	0.83
Ariopsis felis	14986.9	254	46	288	59.00	0.41	0.80
Leiostomus xanthurus	684.1	38	76	159	18.00	0.02	0.50
Bairdiella chrysoura	735.4	100	23	135	7.35	0.02	0.43
Citharichthys spilopterus	206.9	27	70	100	7.66	0.01	0.33
Anchoa hepsetus	108.1	46	37	75	2.35	t	0.33
Sphoeroides parvus	174.4	47	16	80	3.71	0.00	0.30
Bagre marinus	2174.4	37	60	465	58.77	0.06	0.27
Synodus foetens	398.9	12	38	217	33.25	0.01	0.27
Trinectes maculatus	76.6	11	35	66	6.96	t	0.27
	0.9	0.98	13	465	0.95		n=30

Using the 4.9 m “scientific” trawl, I collected 6,993 specimens representing 32 fish species and one squid species (*L. brevis*) from 13 trips and 30 hauls (Table 1.3). Each trip consisted of multiple hauls. Again, invertebrates such as *C. sapidus* and *R. harrisii* have been omitted from the analysis. Fishes that occurred in one quarter or more of the samples comprised 90% of the weight and 97.8% of individuals in all samples (Table 1.3). The three most abundant species were *A.mitchilli*, *M. undulatus*, and *C. arenarius*, comprising 89.6% of the total number of fishes. The three heaviest species were hardhead catfish (*A. felis*), *M. undulatus*, and *A. mitchilli*, comprising 74.6% of the total weight of fishes.

The most dominant species by weight and by number in all hauls was *M. undulatus* while *C. arenarius* was collected in 100% of commercial and scientific hauls. The dominant species that showed the most change among sampling types were Gulf menhaden, *B. patronus*, and gafftopsail catfish, *B. marinus* (by weight), and *A. mitchilli* (by abundance). The gafftopsail catfish, *B. marinus,* was almost exclusively caught in commercial trawl hauls. Gulf menhaden, *B. patronus,* was almost exclusively captured by commercial wing net hauls. Bay anchovy, *A. mitchilli*, was almost exclusively captured in wing net and scientific hauls.

ANOSIM Results

For the ANOSIM, I separated hauls into those caught in wing nets, those caught in larger (>10 m) commercial trawls, and those caught in smaller (4.9 m) scientific trawls. Gear type was the factor that explained most of the variance among hauls (Table 1.4, a and b). The global test found significant differences ($R = 0.522$. $p < 0.05$), and all pairwise differences were significant ($p < 0.05$). Differences between samples grouped by location were globally significant (ANOSIM, $R=0.247$, $p=0.014$), although location differences explained less dissimilarity than gear type differences (Table 1.4a). Among the four locations, only pairwise differences between locations in the different passes (Rigolets and MRGO) were significant (Table 1.4c). Differences between samples taken during the day and those taken at night were significant (ANOSIM, R = 0.211, p = 0.015), but since all commercial trawl trips took place in the day, and all wing net trips took place at night, these differences are confounded with gear type. Differences between months were not significant (ANOSIM, R = 0.154, p = 0.083). The lowest stress two-dimensional representation of the dissimilarity matrix (stress = 0.16) exhibits a clear grouping of haul assemblages by gear type (Figure 1.4, Figure 1.5). Other factors did not separate the hauls as well.

Table 1.4. (a) Global one-way ANOSIMs for 4th root transformed abundance data from the four different scenarios. Most differences are significant at $p < 0.05$. (b) Global and Pairwise ANOSIM for the same data by the three gear types. All differences are significant at the $p < 0.05$ level. (c) Table 1.6. Global and Pairwise ANOSIM for the same data by four locations. Only differences between the passes are significant at the $p < 0.05$ level.

(a) Global tests	R	p	(b) Pairwise Tests –Gear		R	p	(c) Pairwise Tests – Location		R	p
Gear	0.522	**0.001**	Trawl	Wing nets	0.0621	**0.018**	back Rigolets	Rigolets	-0.056	0.571
Location	0.247	**0.014**	Trawl	Sci. trawl	0.467	**0.002**	mouth Rigolets	back Rigolets	-0.056	0.486
Day and Night	0.211	**0.015**	Sci. trawl	Wing nets	0.0606	**0.001**	mouth Rigolets	Rigolets	0.198	0.133
Months	0.154	0.083					back Rigolets	MRGO	0.28	0.085
			Global		0.522	**0.001**	mouth Rigolets	MRGO	0.296	**0.036**
							Rigolets	MRGO	0.409	**0.013**
							Global		0.247	**0.014**

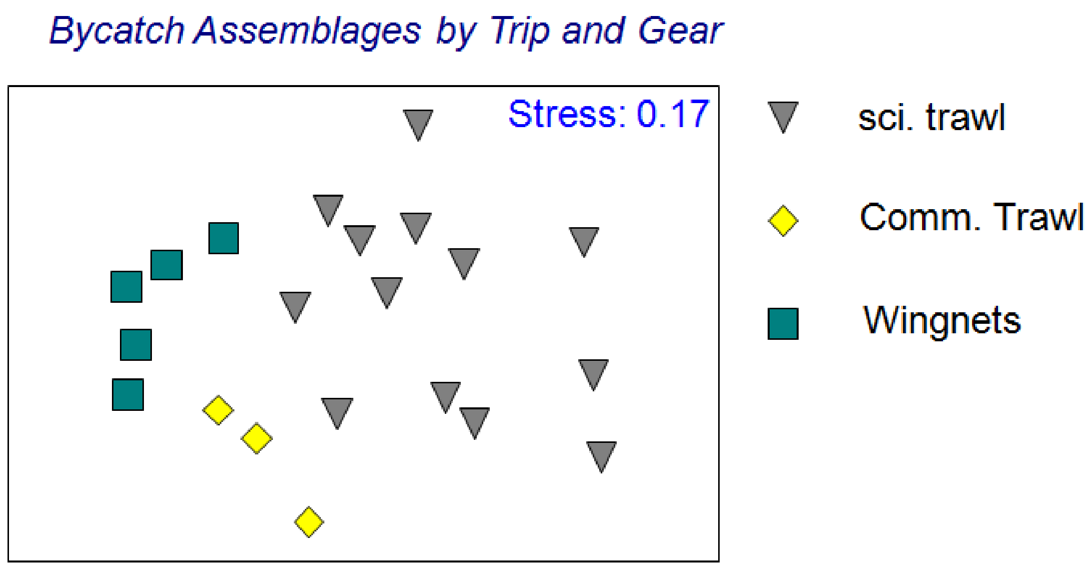

Figure 1.4. MDS plot of 4th root-transformed abundance data by trip for 21 trips. Assemblages group by gear type more strongly than by time or location, or time of day. MDS for 4th root-transformed weight data was similar.

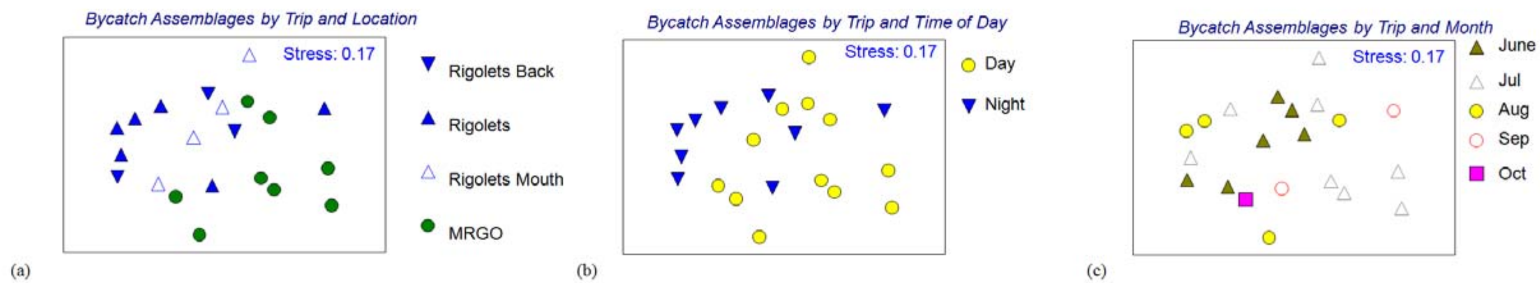

Figure 1.5. MDS plot of 4th root-transformed abundance data by Trip and Gear for 21 trips, by Location(a), Time of Day(b), and Month(c). The MDS plot for 4th root-transformed weight data showed similar groupings

SIMPER Results

SIMPER analysis showed that dissimiliarities between gear types were driven by multiple species, in both analyses by weight and by abundance. That is, in none of the comparisons did just one species drive the observed differences. In only one analysis did a single species, *B. patronus*, drive more than 10% of differences. Below, I describe in detail the five most important species for each of six analyses.

Four species (*B. marinus,* cutlassfish [*Trichiurus lepturus*], white trout (*C. arenarius),* and *M. undulatus,* were collected in larger numbers in the commercial trawl than in the scientific trawl, while *A. mitchilli* were caught in lower numbers (Table 1.5.a). The commercial trawl also captured heavier samples of the first four species, along with spot (*Leiostomus xanthurus*; Table 1.5.b).

Differences between the scientific samples and the wing net samples were driven by an increase in *B. patronus* in the commercial samples, by abundance and by weight. White trout (*C. arenarius*), *M. undulatus*, and threadfin shad (*Dorosoma petenense*) also increased by number and by weight in the wing nets (Table 1.6). In the analysis by abundance, *A. mitchilli* increased in number in wing nets, while *C. nebulosus* was more important in the analysis by weight (Table 1.6.b).

Differences between the two commercial gear types (commercial trawls and wing nets) were driven by similar species. By abundance, more *A. mitchilli* and *B. patronus* were caught in wing nets, while more *B. marinus*, *A felis*, and *M. undulatus* were caught in commercial trawl samples (Table 1.7.a). In the analysis by weight, the increase in *A. mitchilli* and decrease in *M. undulatus* in wing net samples were less important than the increase of *L. xanthurus* and *T. lepturus* (Table 1.7.b).

Table 1.5. SIMPER results for the pairwise comparison of assemblages caught in the commercial trawl and the scientific trawl samples.

Drivers of Dissimilarity by Abundance

Gear Comparison	R-value	p-value	Species	Comm. Trawl	Sci. Trawl	% Contribution
			Bagre marinus	93.67	2.85	7.43
Comm. Trawl			Trichiurus lepturus	73.67	0.15	7.2
vs	0.467	0.002	Cynoscion arenarius	767	37.08	6.99
Sci. Trawl			Micropogonius undulatus	253.33	40.62	5.9
			Anchoa mitchilli	10	404.23	5.49
						33.01

Drivers of Dissimilarity by Weight

Gear Comparison	R-value	p-value	Species	Comm. Trawl	Sci. Trawl	% Contribution
			Cynoscion arenarius	14504.48	210.16	8.75
Comm. Trawl			Bagre marinus	11791.91	217.44	8.56
vs	0.547	0.007	Trichiurus lepturus	3737.4	0.7	7.06
Sci. Trawl			Micropogonius undulatus	7717.99	777.34	6.2
			Leiostomus xanthurus	6194.93	68.41	5.99
						36.56

Table 1.6. SIMPER results for the pairwise comparison of assemblages caught in the scientific trawl and the commercial wing net samples.

Drivers of Dissimilarity by Abundance

Gear Comparison	R-value	p-value	Species	Sci. Trawl	Wing nets	% Contribution
			Brevoortia patronus	0.15	528.8	10.03
Sci. Trawl			Anchoa mitchilli	404.23	1012.2	8.19
vs	0.606	0.001	Micropogonius undulatus	40.62	1212.4	6.9
Wing nets			Dorosoma petenense	0.08	26.6	5.3
			Cynoscion arenarius	37.08	331.8	4.72
						35.14

Drivers of Dissimilarity by Weight

Gear Comparison	R-value	p-value	Species	Sci. Trawl	Wing nets	% Contribution
			Brevoortia patronus	1.51	9436.24	9.66
Sci. Trawl			Micropogonius undulatus	777.34	20831.61	7.09
vs	0.708	0.002	Cynoscion arenarius	210.16	4674.97	5.96
Wing nets			Dorosoma petenense	2.85	444.5	5.32
			Cynoscion nebulosus	0	993.07	5.2
						33.23

Table 1.7. SIMPER results for the pairwise comparison of assemblages caught in the two commercial gear types, the wing net and the commercial trawl samples. Note that this pairwise comparison was not significant by weight.

Drivers of Dissimilarity by Abundance

Gear Comparison	R-value	p-value	Species	Comm. Trawl	Wing nets	% Contribution
			Anchoa mitchilli	10	1012.2	7.26
Comm. Trawl			Brevoortia patronus	34.33	528.8	5.92
vs	0.621	0.018	Bagre marinus	93.67	1.8	5.4
Wing nets			Micropogonius undulatus	253.33	1212.4	4.18
			Ariopsis felis	33.67	0.4	4.15
						26.91

Drivers of Dissimilarity by Weight

Gear Comparison	R-value	p-value	Species	Comm. Trawl	Wingnets	% Contribution
			Bagre marinus	11791.91	472.76	6.96
Comm. Trawl			Ariopsis felis	5054.53	47.04	5.79
vs	0.374	NS	Brevoortia patronus	1389.94	9436.24	5.24
Wing nets			Leiostomus xanthurus	6194.93	1183.31	4.65
			Trichiurus lepturus	3737.4	697.4	4.54
						27.18

Table 1.8 Minimum and Maximum Standard Lengths (mm) for species by gear types.

	Scientific trawl		Trawl		Wing nets	
Species	Min SL (mm)	Max SL (mm)	Min SL (mm)	Max SL (mm)	Min SL (mm)	Max SL (mm)
Anchoa mitchilli	13	71	38	63	18	74
Ariopsis felis	46	288	82	296	134	228
Bagre marinus	60	465	71	519	93	443
Brevoortia patronus	37	**93**	80	171	32	190
Cynoscion arenarius	13	**144**	44	236	45	245
Micropogonius undulatus	36	**158**	58	200	60	203
Trichiurus lepturus	169	**197**	113	615	160	618

Obvious changes in size class between gear types

Among the dominant species collected, there were differences in size classes by gear type (Table 1.8). While there were no obvious differences in the range of sizes (SL) of *A felis* and *B. marinus*, *B. patronus*, *C. arenarius*, and *M. undulatus* (the most commonly caught species) were markedly smaller (by ~50 mm) in the scientific trawl. *Anchoa mitchilli* collected in scientific nets had a slightly (~20 mm) smaller minimum size than those collected with commercial trawl gear. *Trichiurus lepturus* exhibited the largest discrepancy in the maximum size: commercial gears caught fish over 400 mm larger than scientific gear.

Evaluating changes in size class with density kernel plots and U tests

As stated, each commercial haul lasts approximately an hour's time between the lowering and lifting of nets. Each scientific haul lasts ten minutes. Samples from each haul were weighed by species and an SL range taken. Fifty TLs were taken randomly among the individuals of each species to represent the lengths of that each species each hour.

When individual total lengths of these important species are plotted, the lengths are often bimodal and do not follow a normal distribution. Therefore, detecting differences among gear types requires a non-parametric test. I chose the Mann-Whitney U test to examine differences among gear types for four of these important species.

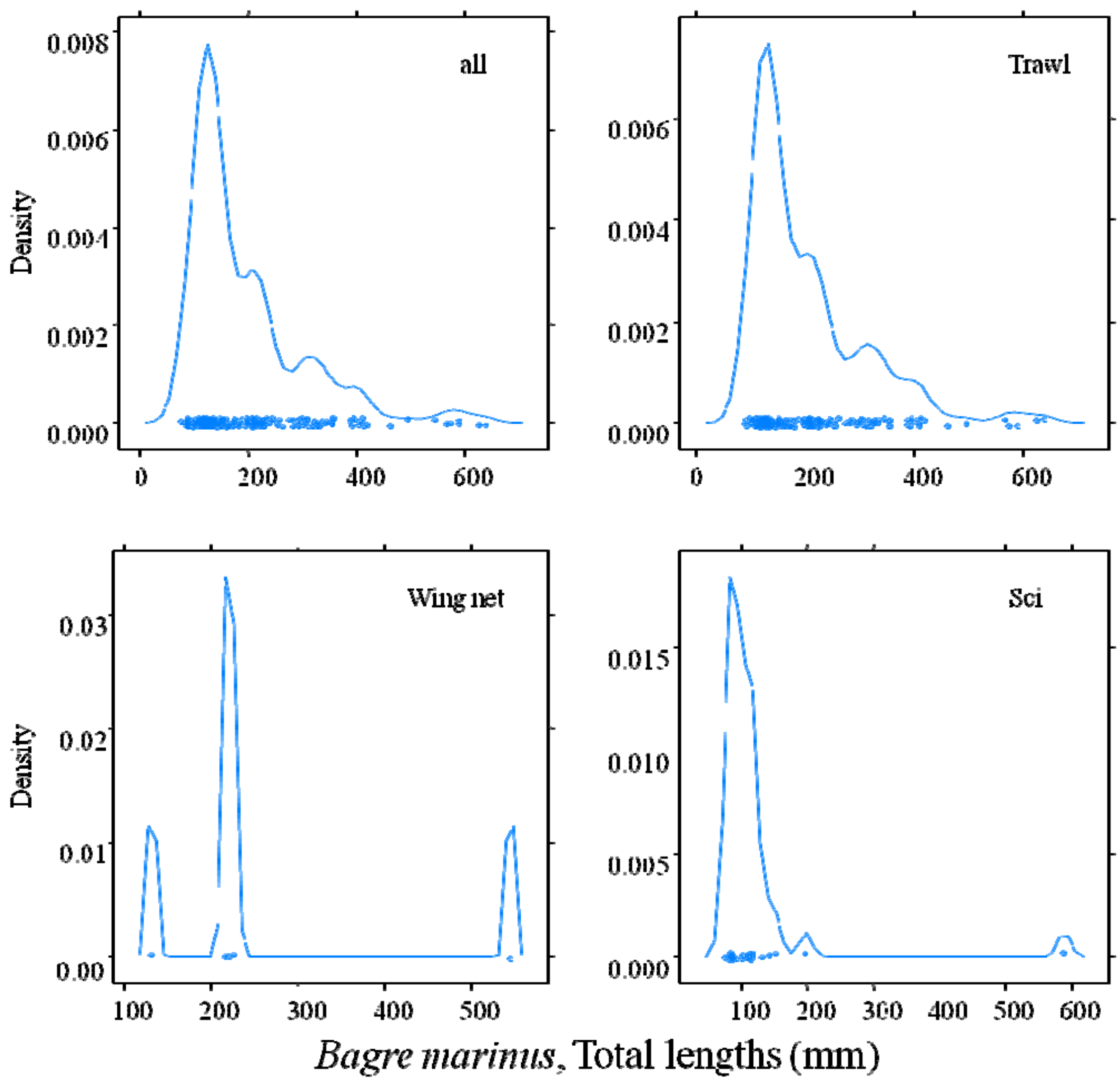

Figure 1.6. Density kernel plots for *B. marinus* TLs, for all gear(a), and by gear, commercial trawl(b), wing net(c), and scientific trawl ("4.9m") (d). There are only a few lengths for the wing net samples. Note the irregular scales of the plots.

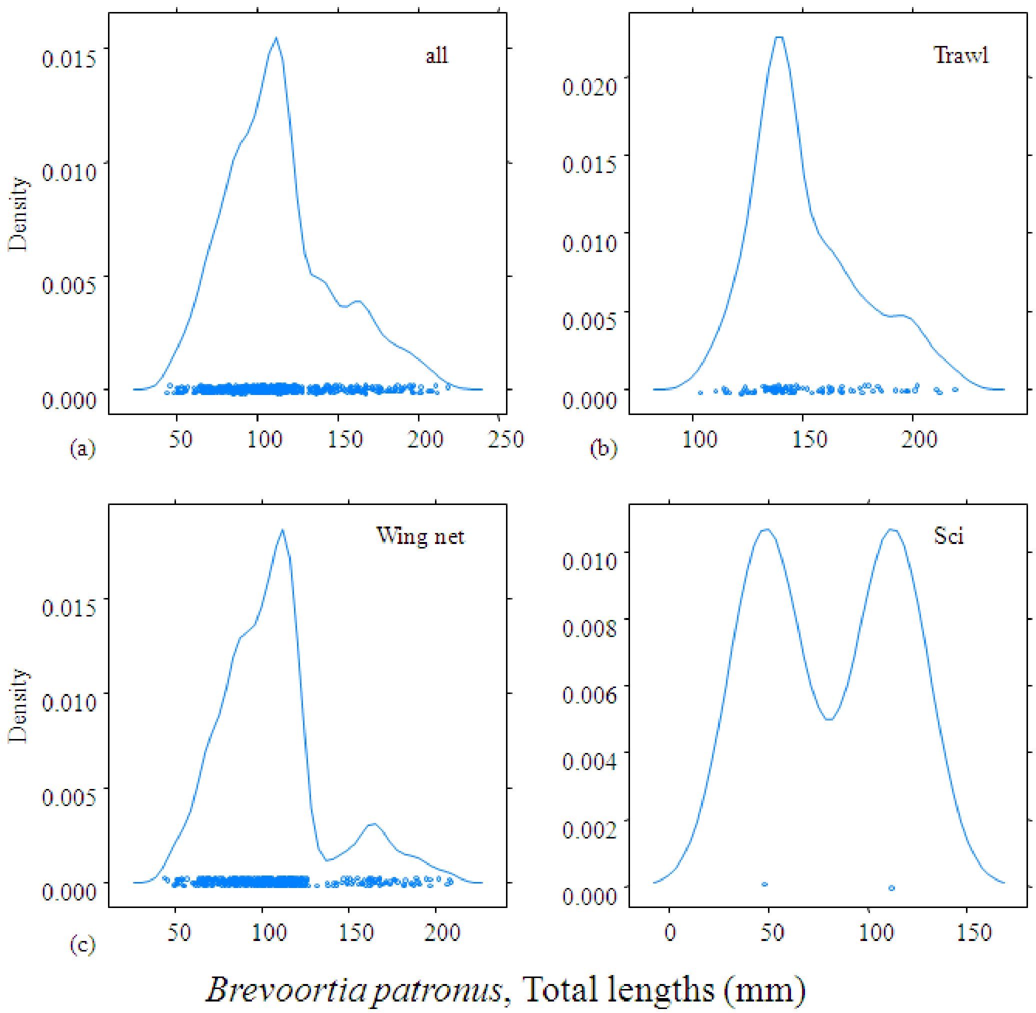

Figure 1.7. Density kernel plots for *B. patronus* TLs, for all gear(a), and by gear, commercial trawl(b), wing net(c), and scientific trawl ("4.9m") (d). There are only two lengths for the scientific trawl samples. Note the irregular scales of the plots.

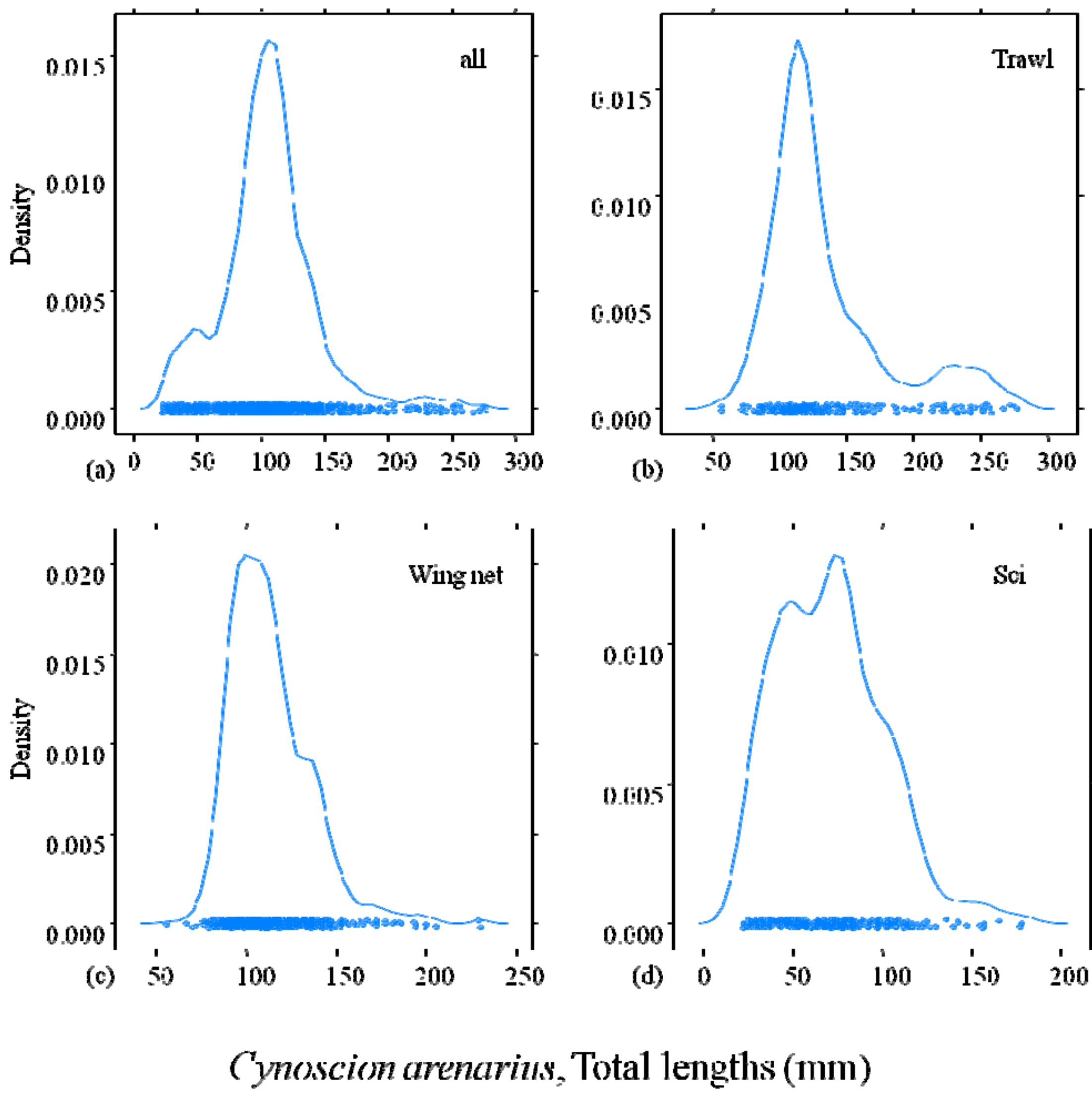

Figure 1.8. Density kernel plots for *C. arenarius* TLs, for all gear(a), and by gear, commercial trawl(b), wing net(c), and scientific trawl ("4.9m") (d). Note the irregular scales of the plots.

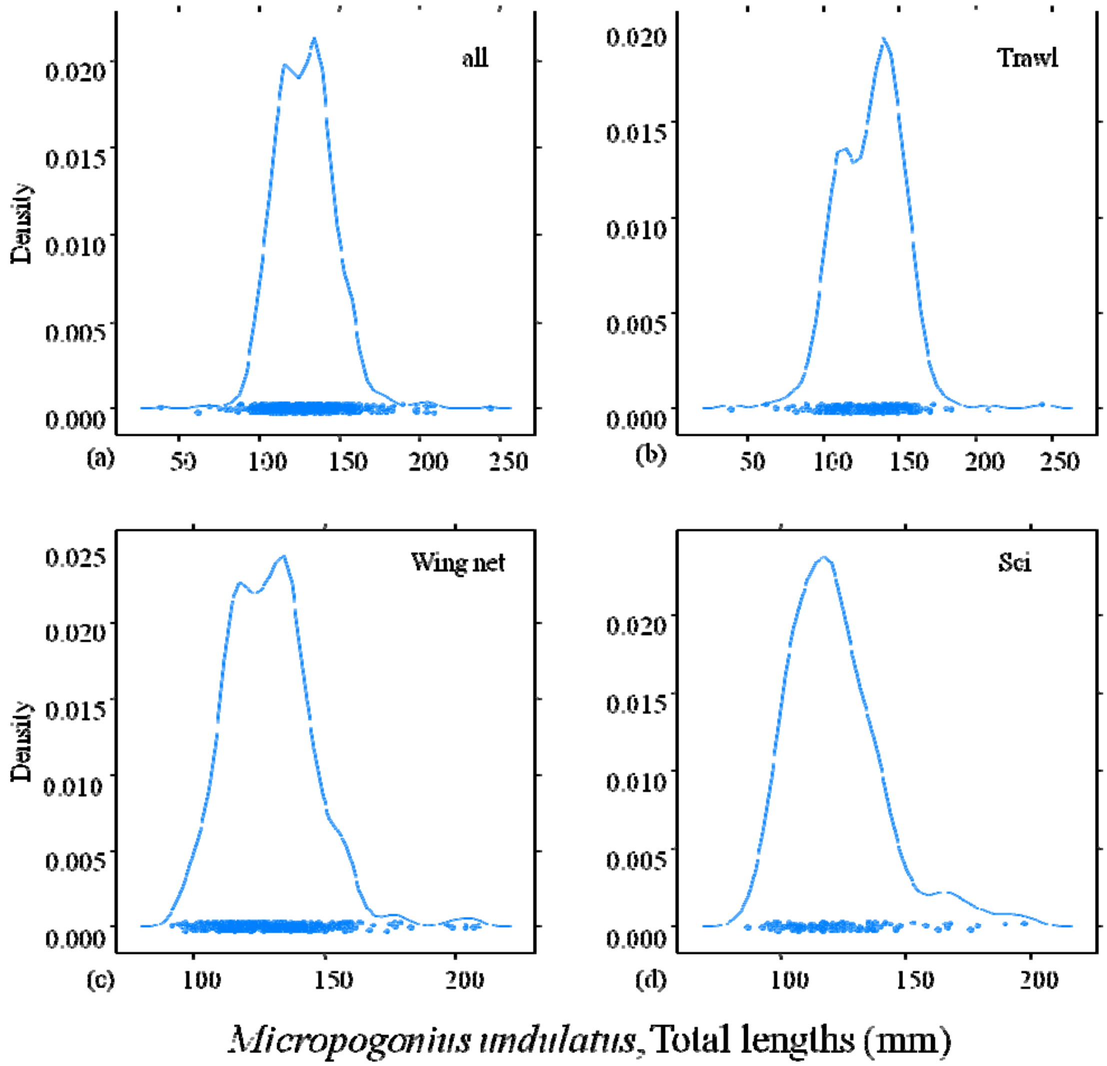

Figure 1.9. Density kernel plots for *M. undulatus* TLs, for all gear(a), and by gear, commercial trawl(b), wing net(c), and scientific trawl ("4.9m") (d). Note the irregular scales of the plots.

Table 1.9 Results of Mann-Whitney U tests, assessing whether the TLs sampled from different gear ("Sci.," "Trawl,", and "Wing net") are from the same distribution.

		B. marinus		*B. patronus*		*C. arenarius*		*M. undulatus*	
		W	p	W	p	W	p	W	p
Sci.	Trawl	8.5	**0.00**	331.5	0.38	35615.0	**0.00**	32809.5	**0.00**
Sci.	Wing net	957.5	**0.00**	2	**0.02**	9384.5	**0.00**	17493.0	**0.00**
Trawl	Wing net	374.5	0.14	47004	**0.00**	138013.5	**0.00**	119902.5	0.11

Density kernel plots are a way to represent probability density functions of random variables that do not follow a normal distribution (Rosenblatt, 1956; Parzen, 1962). These plots for *B. marinus*, *B. patronus*, *C. arenarius*, and *M. undulatus* show that there were fewer specimens of the larger sizes collected in the smaller scientific nets. The distribution of lengths in the catch varied enough that, with enough samples, small differences were significant in many cases (Mann-Whitney U test, $p < 0.05$).

Although the size range of specimens collected is the same among gear types, there were significant differences between *B. marinus* collected by scientific versus commercial gear (Table 1.11; Figure 1.6). The scientific trawl caught young of year (YOY) and an occasional larger specimen, while the commercial trawl collected all size classes, from the young of year to sizes near the maximum recorded for this species. The number of collections from commercial wing nets was small enough to fall within the larger ranges.

For *B. patronus*, there were limited numbers caught in scientific nets, a unimodal distribution in the commercial trawl, and a bimodal distribution in the wing net samples (Table 1.11, Figure 1.7). Wing net samples showed two size classes, with a break at about 170 mm. Although sample size was limited, size differences were not significant ($p < 0.05$) between the commercial and scientific trawl. Fish caught in wing net samples were significantly larger ($p < 0.05$) than fish in commercial trawl samples, however.

Throughout all hauls, *C. arenarius* appeared most often, but the lengths of the fish were significantly different among all groups (Table 1.11, Figure 1.8). The scientific trawl collected many smaller individuals (< 100 mm) that the commercial gears did not collect. The commercial trawl also collected larger individuals (> 200 mm) than the wing nets.

Among the four species analyzed, *M. undulatus* had the most consistent, unimodal distribution, from 100 mm to 150 mm, but differences between the scientific trawl and the commercial gear types were still significant. Even though there was no significant difference ($p = 0.11$) between the two commercial gear types, the commercial trawl collected larger individuals than the wing nets (Table 1.11, Figure 1.9).

Changes in size class within a commercial trip

Each commercial haul lasts approximately an hour's time between the lowering and lifting of nets. Samples from each haul were weighed by species and an SL range taken for each species. Fifty TLs were taken randomly among the individuals of each species to represent the lengths of that each species each hour. Two trips, 001 and 008, were chosen to represent their gear type, trawl and wing net, respectively. *Cynoscion arenarius* was chosen as a model species because of its ubiquity, but also because it showed significant differences in TL among gear type.

When the density kernel plots are examined, the most difference, if any, between hauls on the same trip are between the numbers of the larger size classes (Figure 1.10). Overall, there seems to be little difference between one hour or the next, or between the sample from one hour and the aggregate of samples for all hours (2 hours total for trip 001, 4 hours total for trip 008). This visual analysis is confirmed by Mann-Whitney U tests. Although there may be fewer specimens in the larger size classes, no difference was significant ($p < 0.05$, Table 1.12).

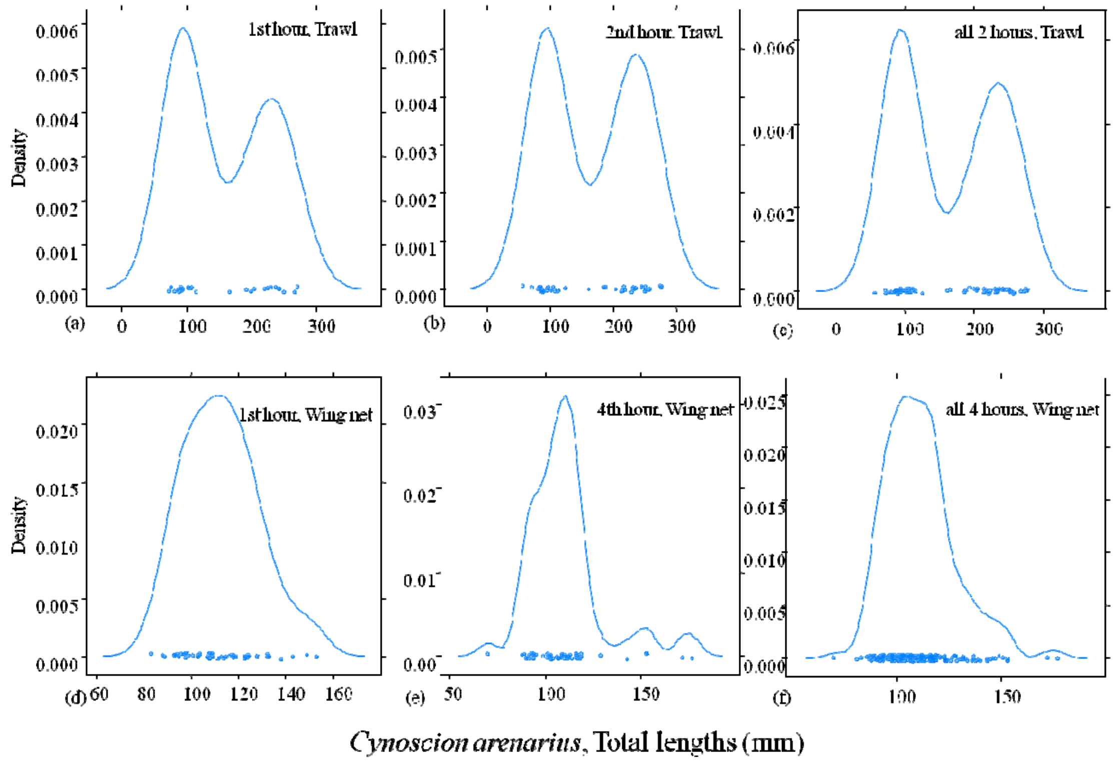

Figure 1.10 Density kernel plots of TL distribution for two consecutive hours (a,b) and both combined (c) in a commercial trawl and wing net (d,e and f). Note the differences in scale for each chart.

Table 1.10 Results of Mann-Whitney U tests, assessing whether the TLs sampled from different hours are from the same distribution. No differences are significant ($p < 0.05$).

		C. arenarius	
Trawl		W	p
1st Hour	**2nd Hour**	504.0	0.65
1st Hour	**2 Hours**	868.5	0.77
2nd Hour	**2 Hours**	1376.0	0.82
Wing net			
1st Hour	**4th Hour**	1094.5	0.82
1st Hour	**4 Hours**	5197.0	0.37
4th Hour	**4 Hours**	4746.5	0.30

Discussion

Gear type drives the changes in species caught in inshore bycatch more than any other factor—which is pertinent to (re)interpreting previous analyses of bycatch based upon fishery independent work, as well as predicting the impact on the system as fishery practices change. Previous work, based on fisheries-independent shrimp population monitoring with a scientific otter trawl, related changes in CPuE of shrimp to changes in bycatch species (Baltz and Chesney, 1995). Although this previous study found a low correlation of shrimp CPuE with *B. patronus*, this study has shown that *B. patronus* is underrepresented in the gear used in that study. Other species like *M. undulatus*, *C. arenarius*, and *D. petenense* were also found to be more important in commercial hauls than scientific hauls. The importance of these species should be further emphasized.

Because gear type is so important, F:S ratios from this study and the summarized Adkins (1993) data are incomparable. Although F:S ratios are lower in this study, and expected to be lower inshore than over all state waters, my result could be attributed to the higher proportion of wing net hauls in my combined commercial data. Because bycatch is generally lower in wing net hauls, the higher proportion of wing nets in my combined data could explain the lower F:S ratios. The F:S ratios in this study also do not include weights of *C. sapidus*, a significant part of bycatch in Louisiana waters (Adkins, 1993; Baltz and Chesney, 1995), although this bycatch species is often brought to market in Lake Pontchartrain, rather than discarded. The exclusion of this species could also lower the F:S ratios enough to confound a statistical analysis of the present data.

In general, I found the geometric mean of F:S ratios is more informative for analyzing individual trips, although it was often lower than the median F:S and the summarized F:S of each commercial gear type. The arithmetic mean was always the highest of these metrics, due to the extreme right skew of the distribution of the ratios. While this number appears to reflect the annual bycatch ratio caught (Adkins, 1993; Diamond, 2003), and so is still useful, the distribution of the data is such that an arithmetic mean, although technically an “average,” does not represent the typical F:S ratio, or the most common one. If by “average” we understand the “typical” bycatch ratio, the “average F:S ratio” would be better represented by the median ratio or the geometric mean, which is the mathematically appropriate mean for an “average” of a series of ratios (Douglas, 2004).

Implications for fishery monitoring studies

There are many factors that influence the species composition of bycatch (Rochet and Trenkel, 2005), but this study focused primarily on gear type, location, and time of year. Gear type was significant. Between types of commercial licenses, this is due to the differences in the depth of water fished between wing nets (top) and trawl (bottom) (Gido and Matthews, 2000; Bergmann et al., 2002b), but perhaps also to the time of day fished—wing nets are deployed at the falling tide, as larger shrimp rise to the surface of the water to catch the tide out of the estuary. Trawl boats are less limited in times available to be fished; but generally, they tow during the day, as shrimp lay along the bottoms of the lakes and passes. This study confounded time of day and depth of the water column as factors, because these factors are largely integrated as a function of gear types. Between the scientific trawl and commercial gear, the differences are largely a function of size and depth, because this method was deployed during day and during the night to match commercial samples.

Within one pass, changing location does not significantly change the assemblage caught, but between the two passes, location was significant. This result is relevant to any decision of how to distribute fishery monitoring efforts across the space of the inshore fishery. Limited resources necessitate prioritizing any monitoring effort for capturing a more representative sample of the fishery as a whole. More variation will be captured by spreading efforts among vessels with different gear types in different passes than distributing efforts among vessels with different gear types in different locations within the same pass.

In this study, I was unable to observe significant population differences among bycatch hauls within a single trip. All trips taken were day trips and lasted less than 24 hours. Assemblage differences among hauls on the same trip were also similar (unpublished data). This makes sense, given that captains will often change the duration of the trip based on how many shrimp are "running" in a given night. Captains will not set their nets for long periods unless they hear of good results from their fellows or see plenty of shrimp in "test" hauls. After hauls have begun, captains will cease with long hauls after the number of shrimp drop below a certain number. Given this fishing behavior, the most likely differences will be found between the first and final hauls. This study found no differences. Because captain, shrimp, and fishes all will generally change behavior with the tide, especially during wing net trips, it is likely that hauls within a trip will be similar. This result confirms the basic result of several other studies in European trawl fisheries (Tamsett et al., 1999; Allen et al., 2002; Borges et al., 2004; Borges et al., 2005).

A similar conclusion can be made about the differences between vessels in the same location in the same day (or night) of fishing. Because captains often make decisions based on informal reports from other captains, over radios and at the dock, fishery activity is often aggregated in time and space. During this study, there were nights when captains who generally fished other passes in the region came into the Lake Pontchartrain Basin on word of good fishing. Captains of commercial and recreational vessels often ask the NRL vessel for reports on the location and amount of shrimp and fish caught by the monitoring vessel. There are trips when the monitoring vessel has caught a large amount of marketable shrimp in the scientific net, although there were no captains working the passes.

Future monitoring efforts could take advantage of this conclusion by sampling fewer hauls per trip, saving time and effort at the bench for sampling more trips per gear and more passes or areas. Because wet weight per species is much simpler to measure than number of individuals, future analysis of fish assemblages could be based on wet weight rather than number of individuals to save time on the boat and at the bench.

Effect of gear size on bycatch composition and implications for monitoring

Different gear catch different fishes, but different gear, by the nature of their different sizes, often catch a different size-class distribution of a given species (Howell and Langan, 1987; Rochet and Trenkel, 2005). The different sizes of net and mesh play a role in selecting for size classes for fishes caught (Kulka,1998; Rochet and Trenkel, 2005). It follows that a scientific net, 4.9 m wide–which only opens to 2.5-3.5 m underwater (Thompson and Verret, 1979)—will catch only the smaller and slower individuals of an assemblage. The commercial nets are larger nets: wing nets are generally paired sets ~4 m or more on a side, spread widely on a frame; commercial trawl nets more than 10 m (Adkins, 1993). The smaller mesh is designed to catch smaller fishes, but it does not follow that a larger mesh will allow the smaller fishes to pass in all cases. As the catch gets heavier or the time fished gets longer and the full bag of the shrimp net clogs the mesh, smaller individuals cannot escape the press of flesh amassed in a bag end. Mesh size has been found to influence the amount, diversity, and length composition of bycatch (Rochet and Trenkel, 2005).

The simplest interpretation of metabolic theory would predict fewer individuals of larger size class for a given species in a given place and time (Kaspari, 2004). The larger size classes (150-250 mm) not caught in the scientific trawl are the same ones that are more variable over time in commercial catches. If the goal of a monitoring study is to examine these larger size classes, sub-sampling should be stratified by size class to capture more of the larger individuals. For example, a population model of *B. marinus* may determine that the population's growth is determined by the number of the largest males, since large males can brood more eggs in their mouths. In order to get an accurate evaluation of how shrimping activity affects the population as a whole, scientific trawl methods would be insufficient—not only because this species is underrepresented as bycatch in scientific trawl samples across all size classes, but particularly because the smaller nets are particularly bad for capturing the larger individuals critical to the population analysis.

Although size class distributions are variable, within one trip they remain stable. This is an unstated assumption of several reports on bycatch (Adkins, 1993, Diamond, 2003), which have subsampled bycatch for obvious logistical reasons. Although sampling aboard commercial vessels may still require that an observer ride for the entire trip, the knowledge that the size class distribution of a particular species is generally stable, or varies only at the larger size classes, can allow more effort to be made for collecting other data, like F:S ratios, over the whole course of the trip. For example, Adkins (1993) subsampled haphazardly from a haul during an ongoing trip into a container of uniform volume, then disembarked the vessel. Because this quicker method allows monitoring of multiple trips in a night, over several vessels or passes, it is a more effective way to sample the whole fishery than the methods presented here. Diamond (2003) subsampled hauls randomly, collecting fewer fishes than this study while staying on the vessel for the entire duration (Diamond, 2003). Both of these methods also require much less time at the bench. This study demonstrates that they were correct in subsampling a single haul to characterize a trip, unless they were especially interested in the catches of the larger individuals of a particular species or of larger species caught as bycatch.

For sub-adults of estuarine-dependent species, we expect size class distributions to shift over the months of sampling, as individuals grow over the course of the summer before exiting the colder shallow waters in the winter. This has been observed in sampling data and documented in other monitoring studies (Gido and Matthews, 2000). Time differences vary with season, and may not be relevant because the inshore fishery shuts down for the coldest part of the year, at one seasonal extreme. And although time differences were not observed in this study, such temporal shifts are not necessarily made invisible by the size selectivity of the commercial gear. Future efforts with more repeated samples by gear and by pass could answer this question better than this limited study.

Gear type, time of day, and unique species

The new species not caught by previous NRL sampling or by Thompson and Verret (1979) were collected in wing nets at night. In the 1950s, Dr. Royal Suttkus sampled extensively at night in the Lake Pontchartrain Basin and collected both sharksucker (*Echeneis naucrates*) and Atlantic midshipman (*Porichthys porosissimus*) (Thompson and Verret, 1979). Although bycatch mortality may be important to their individual populations in the Basin, these species are not numerically or ecologically important within the bycatch assemblage. This example, though, demonstrates the importance of gear type in determining which species are caught.

Ultimately, the differences between the gear demonstrate the necessity of monitoring commercial vessels, or at least sampling with commercial gear from scientific vessels, in order to determine ecosystem, assemblage, and population scale impacts of the the bycatch assemblage killed by the shrimping fishery. That assemblage composition and even population of a given species remain consistent within a trip indicates that one or two hauls per trip is sufficient to represent the trip. The fact that location is not significant within one pass indicates that the spatial scale of a monitoring effort can be per pass and the lack of significance in the changes between months indicate that sampling per gear and per pass should take a higher priority over taking multiple samples in a single month. This knowledge will allow a monitoring program to sample the natural variation most effectively.

Predicting ecosystem, assemblage, and population changes with fishery changes

If inshore shrimpers are using wing nets more often than offshore shrimpers, and using wing nets more often over time, the changes in the assemblages caught have ecosystem, community, and population-level implications. At the ecosystem scale, less fish biomass will be caught and killed as bycatch as the shrimp fishery changes to proportionally more wing nets. The assemblage caught, though more diverse, will shift away from the less resilient families of fishes like Ariidae and Sciaenidae, and toward more resilient, lower trophic level families like Engraulidae and Clupeidae (Baltz and Chesney, 1995). Although these populations may be resilient, smaller individuals are more likely to die (Davis, 2002).

At the population level, species caught less will suffer lower mortality due to the lowered catch, but species that benefit from discards, such as gulls, brown pelicans (*Pelicanus occidentalis*; Anderson et al., 1980; Duffy, 1983; Croxall, 1987), dolphins (*Tursiops truncatus;* Fertl and Leatherwood, 1997), bull sharks (*Carcharinus leucas*; Tuma, 1976; Curtis, 2008), blue crabs (Hughes and Seed, 1981, Laughlin, 1982), and marine catfish (Darnell, 1959; Levine in Stone et al., 1980) may find this high quality food less available. These changes will be accelerated by the reduction of all shrimping effort as fewer and fewer boats operate in Louisiana waters (Anonymous, 2008, Figure 1.11).

There is also evidence from European fisheries that nets "pushed" across the top of the water column are less damaging to ecosystems, because they avoid the trawl's damaging of epifauna and infauna on the water bottom, to the point of changing the structure of the benthic community (Hall, 1999; Cryer et al., 2002). A European analogy to wing nets is the Scottish Seine, discussed as a possible "sustainable" fishing method with fewer impacts than "on-bottom" trawl fisheries (Fuller and Cameron, 1998; Arkley, 2008).

Although the inshore of the Lake Pontchartrain Basin is primarily a soft-bottom system, a ban on bottom trawling for shrimp was instituted as part of a campaign to lower human impacts on the Lake and on the common Rangia clams (*Rangia cuneata*) in particular. A larger, more geographically extensive *Rangia* population would circulate more water through the local biosphere more quickly and lower the suspended sediment in the Lake more quickly (Poirrier et al., 2008; Poirrier et al., 2009; Wong et al., 2010).

A reduction in trawling effort has been modeled for the entire Gulf of Mexico by Walters et al., (2006). A "counterintuitive" result of the modeling effort was a reduction (by benthic predators) of vulnerable juvenile populations of red snapper (*Lutjanus campechanus*), *B.*

patronus, and red drum (*Sciaenops ocellatus)*, significant players in the ecosystem and commercially important species.

> The basic cause of these negative impacts is very simple: Ecosim indicates that shrimp trawling has had a very large negative impact on abundances of some benthic predatory fish, particularly the catfishes. When bycatches are reduced, these species increase several-fold in abundance, and cause high predation mortality on a variety of juvenile fish (and older menhaden). We initially dismissed this scenario as obviously too extreme. But on reflection, it warns us that abundances of many species in the current Gulf ecosystem have developed in the face of massive shrimp trawling, and it is quite possible that some species have even benefited from the impacts of that trawling. Catfish are particularly abundant in coastal Florida where inshore trawling has been banned.
>
> (Walters et al., 2006).

Elsewhere, I have confirmed the rising abundance of the more predatory gafftopsail catfish in the inshore waters of the Lake Pontchartrain Basin, coincident with a drop in overall shrimping effort (Figure 1.11), as well as a ban in the Lake itself on commercial trawl gear. My current results on the differences in bycatch composition among three gear types offers a similar explanation. Even though trawling has not been banned inshore (in most areas), the popularity of the wing net gear type, one that does not typically kill catfish species, may have led to the same result. In the following chapter I have described the diet of these catfish (*B. marinus and A. felis*), but only in the inshore areas where *L. campechanus* do not occur. In this study, I found *B. patronus* in catfish stomachs and it is possible that juvenile *S. ocellatus* are part of the unidentifiable fishes. But whether the biomass of the system balances in favor of these catfishes at the expense of our commercially important fishes is a question only imperfect systems models, currently based upon ‘inference chains based upon untested assumptions’ can answer.

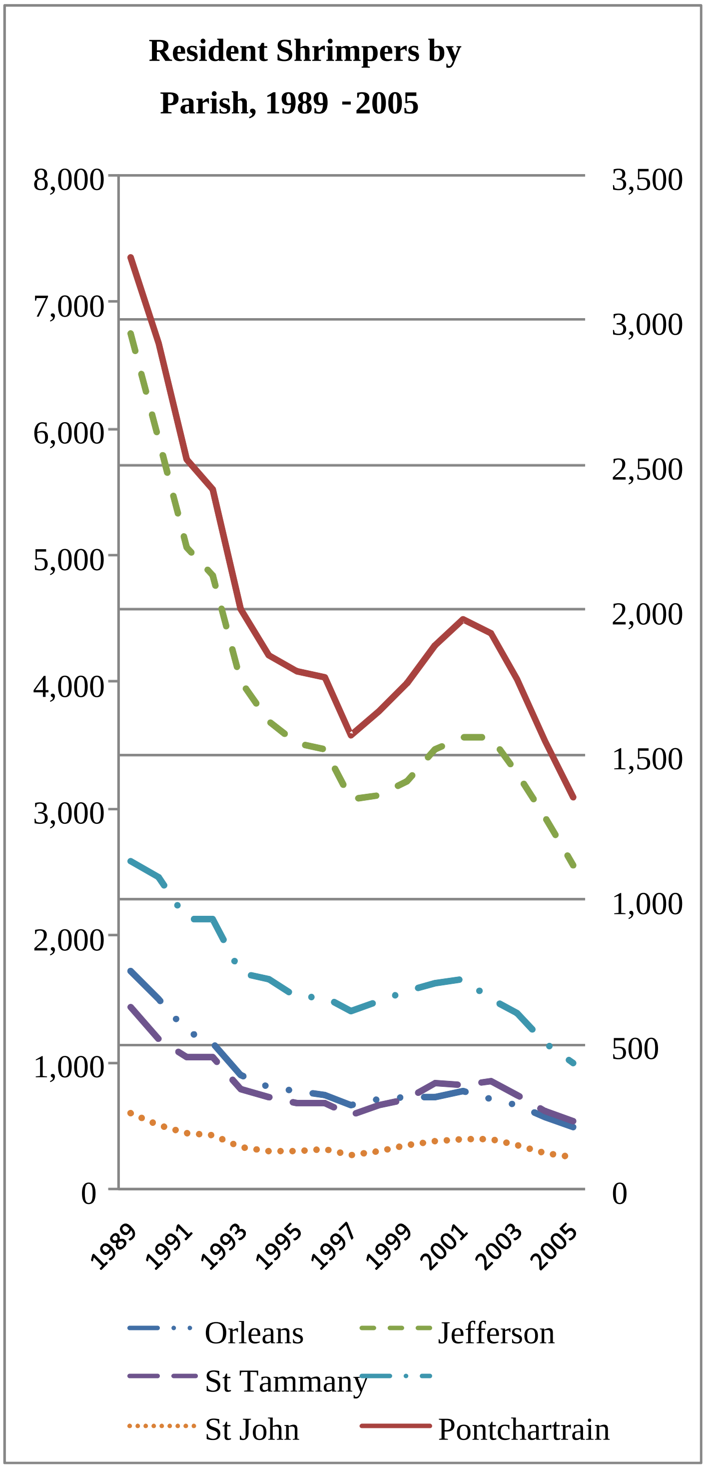

Figure 1.11. (from LDWF website (http://www.wlf.state.la.us/) Number of licenses by year for several parishes around Lake Pontchartrain (right axis), as well as a total for all parishes adjacent to the Lake Pontchartrain Basin (Pontchartrain; left axis)

II. Diet Shifts in Opportunistic Foragers: gafftopsail catfish (*Bagre marinus*) and hardhead catfish (*Ariopsis felis*)

Abstract

In Lake Pontchartrain Basin (LPB), commercial fishing impacts non-target species collected as bycatch. Species such as the gafftopsail (*Bagre marinus*) and hardhead catfishes (*Ariopsis felis*) may consume carcasses discarded from fishing vessels; To test that these catfishes exploit discarded bycatch, I examined gut contents of catfishes collected near shrimping activity during and between the shrimp seasons. I collected catfishes with 250 m gillnets. Specimens were transported on ice to the laboratory, measured; then gut items were identified and weighed. Based on gut contents of 363 *B. marinus* and 138 *A. felis*, I found an increase in occurrence of fishes in catfish diets by area and during the shrimp seasons. Weight of fishes in catfishes' diets also increased significantly during the shrimp seasons (t-test, $p = 0.05$). Graphical analysis of diet categories provides additional evidence for a shift in catfish diet up the trophic scale while shrimpers are fishing the area.

Keywords: Gut Content, diet, marine catfish, *Ariopsis felis, Bagre marinus*, bycatch

Introduction

Estuarine food webs can be markedly altered by shrimping activity, with commercial shrimpers serving as the *de facto* "keystone predator" (Condrey and de Silva, 1998; Chesney et al., 2000; Bozzano and Sarda, 2002). Those species most affected by shrimping can be identified by monitoring bycatches. Fishes and invertebrates living on the water bottom are brought to the surface, largely dead (Davis, 2002). Tertiary predators and larger fishes become the "prey" of the fisherman as bycatch and are discarded to become food for scavengers and detritivores (Andrew and Pepperell, 1992; Fonds and Groenewold, 2000; Bozzano and Sarda, 2002; Bergman et al., 2002; Furness et al., 2007). While fishing can reduce the populations of some organisms, other species killed can be less sensitive, such that any negative effect on their population is outweighed by the benefits they receive from the new source of food, or the fishing gear's killing of their predators (Polis and Strong, 1996; Bergmann et al., 2002b).

Some ecological players benefit from these fishing activities. It is obvious to any observer aboard a day-fishing vessel that the gulls, terns, pelicans, and dolphins that follow working boats in flocks and pods benefit from the large amounts of dead and near-dead fishes discarded from shrimping vessels. Less obvious are the sharks, crabs, and other invertebrate scavengers that benefit from bycatch discards that sink through the water column to the seafloor (Hughes and Seed, 1981; Laughlin, 1982; Rothlisberg et al., 1992; Ramsay et al., 1998). Those species that benefit from discards have been identified in clearer waters with cameras, a method unavailable to researchers working in the turbid waters of the Lake Pontchartrain Basin (Bozzano and Sarda, 2002, Bergmann et al., 2002b).

Bird species benefit from discards

Discards from trawl fisheries in European waters are utilized by many different seabird species (Bozzano and Sarda 2002). This body of research has shown that individuals of certain species that are confirmed to eat discards may not pass on the benefit at the population level—this is known as the "junk food hypothesis" (JFH, Grémillet et al., 2008). Discards usually do not comprise the majority of bird diets, even if they fulfill a large amount of a population's energy requirements (Catchpole et al., 2006). Discards, at times, can only partially compensate for the larger destruction of forage fish populations by fishing vessels. It has also been valuable for bird researchers to examine which individuals within a population utilize the discards, as there may be differences in the diets of breeding and non-breeding individuals, or sick and hale birds (Votier et al., 2008; Votier et al., 2010). This kind of food source may be more important in winter, when food is scarce, than summer.

More relevant to this study is the fact that scavenging birds are the first wave of scavengers behind fishing vessels and select certain species of discarded catch (Garthe et al., 1996) to the point that those species become unavailable to scavengers farther away from the vessel. In one study of the English *Nephrops* lobster fishery, birds such as the Fulmar (*Fulmarus glacialis),* the Northern gannet (*Morus bassanus),* the Great skua (*Catharacta skua)*, the Common gull (*Larus canus)*, the Lesser black-backed gull (*Larus fuscus)*, the Herring gull (*Larus argentatus),* the Great black-backed gull (*Larus marinus),* and the Black-legged kittiwake (*Rissa tridactyla)* were found to consume up to 57% of individual discarded fishes behind trawling vessels (Catchpole et al., 2006). This rate was considered artificially high for the system in which it was conducted, because the trawling vessels normally discard the bycatch in large dumps, instead of one fish at a time. In the Lake Pontchartrain shrimp fishery, however, discards are usually thrown overboard gradually while shrimp are sorted from fish and crabs. Such a steady release of discards would give Louisiana's scavenging pelican and gulls ample opportunity to take discards.

As I have shown, gear type affects bycatch composition (Chapter 1), but the type of gear fished can also mean a different community of scavengers, if that gear type is associated with a time of day. During the operation of wing net vessels, in the dark of night, no birds were seen following the trail of discards for a meal. And yet, the carcasses were removed by some organism.

Invertebrate scavengers benefit from discards

Another important group of benthic scavengers are the arthropods (Bergmann et al., 2002b). In the *Nephrops* trawl fishery, arthropods have been shown to be important and rapid consumers of discarded fish flesh on the bottom of the sea and are attracted to the passing of the trawl net along the bottom of the sea (Kaiser and Spencer, 1994; Bergmann et al., 2002b). The most important arthopod to the waters of Lake Pontchartrain is the blue crab, *Callinectes sapidus*. a populous and voracious scavenger (West and Williams, 1986). It is common sense that this arthropod scavenger consumes discarded bycatch, because many blue crab fishermen (who are often also shrimp fishermen or at least share a dock) in Lake Pontchartrain use "Pogies," discarded Gulf menhaden (*Brevoortia patronus*) as bait for crab traps (pers. obs.). This large arthopod may also be crucial to further decomposition of the carcasses, as it can easily tear skin that can keep smaller arthropods from consuming the meat (Monaghan and Milner 2008). Invertebrates such as crabs have been shown to attract their own predators to discarded fish by proxy—the arthropod predators can track the population of scavengers to the discards, or may be attracted to the discards themselves, but eat other scavengers because the ‘free meal’ has brought predator and prey together (Bergmann et al., 2002b)

Animal carcasses as a biomass vector

Some systems, such as newly formed streams in Alaska, are dependent upon the movement of fish upriver to cycle nutrients into oligotrophic habitats. Salmon run upstream to spawn and die in streams otherwise depauperate of large sources of biomass. Once the salmon run reaches the headwaters, smaller scavengers are dependent upon larger predators, such as bears, to begin the deconstruction of the carcasses (Monaghan and Milner, 2008). In deepwater systems below the photic zone, scavengers can be specialized to respond quickly to falling carcasses, as this kind of heterotrophic nutrient flux must replace the regular primary production available to shallow water dwellers (Cryer et al., 2002).

Louisiana’s fisheries are second only to Alaska in productivity and the most productive in the northern Gulf of Mexico. The combined bycatch of Louisiana’s fisheries is more than the targeted catches of the other states combined (Chesney et al., 2000). Much of this biomass turnover can be attributed to the shrimp fishery, which can discard two to four pounds of fishes for every pound of shrimp caught annually (Adkins 1993). There are many ways that this large input of dead animals can affect the food web of the LPB. Even without visual methods, or much prior research, we can predict which species are likely to benefit from discarded bycatch and develop sampling methods to accurately assess their diets relative to fishing activity. Such quantitative assessments are important for tracking ecosystem changes over time, as the activity of the shrimp fishery declines.

The importance of marine catfishes in Lake Pontchartrain

In the LPB, two likely benefactors of discards are the gafftopsail catfish (*Bagre marinus*) and the hardhead catfish (*Ariopsis felis*). My own preliminary analysis of fishery-independent data collected by the Nekton Research Laboratory (NRL) from 2000-2008 for the Lake Pontchartrain Basin (LPB) has shown that, in regard to biomass, *B. marinus* and *A. felis* rank among the heaviest species by wet weight (Figure 2.1). These species are caught regularly in strike gillnets, a method whereby a gill net is set, then circled with the vessel to scare fishes into the net. Although they are caught regularly throughout the sampling season and are larger than average fishes, these two species are not taken regularly in the scientific otter trawl that is the normal gear for most fish monitoring studies in these and other waters (Table 2.5). When weight-by-species is summed over all gear types in the 2000-2008 data, *B. marinus* and *A. felis* rank first and fourth heaviest, respectively. So even though they are not caught by the most common method, their abundance and large weight in gill nets is enough to outrank *B. patronus*, the species expected to be the heaviest (Darnell, 1958; Kaspari, 2004). From an ecosystem perspective, they rival other more abundant species like *B. patronus*, bay anchovy (*Anchoa mitchilli*), and Atlantic croaker (*Micropogonius undulatus*), key players in the local fish assemblage. These marine catfishes are also opportunistic feeders whose adult forms are large enough to consume the sizes of fish caught as bycatch and discarded dead from shrimping vessels. Given the ecological importance of these two marine catfish species and their opportunistic feeding behavior (Darnell, 1961; Levine in Stone et al., 1980; USFWS, 1983), I expected that these two catfish species consume a significant portion of fishes discarded as bycatch. Previous studies of gut contents of Lake Pontchartrain fishes have revealed that fishes make up an important component of predator diets (Darnell, 1958; Darnell, 1961; Levine in

Stone et al., 1980). Darnell analyzed the contents of 34 fish species, 17 of which had fishes in tracts above trace amounts (Darnell 1958). Eight species had large amounts of fish in their diet: longnose gar (*Lepisosteus osseus*), crevalle jack (*Caranx hippos*), bull shark (*Carcharinus leucas*), white trout (*Cynoscion arenarius*), southern flounder (*Paralichthys lethostigma*), speckled trout (*Cynoscion nebulosus*), ladyfish (*Elops saurus*), and needlefish (*Strongylura marina*). These species were dependent upon fishes for over 60% of their diet (by volume). A 1980 diet survey reported 20 of 41 with fishes above trace amounts, and seven of 41 species with fish-dependent diets (> 60% fishes by percent occurrence). These seven species are bull shark (*C. leucas*), freshwater drum (*Aplodinotus grunniens*), black drum (*Pogonias cromis*), southern flounder (*P. lethostigma*), red drum (*Sciaenops ocellatus*), speckled trout (*C. nebulosus*), and gafftopsail catfish (*B. marinus*; Levine in Stone et al., 1980).

Table 2.1 The sum of weight (kg) for the four heaviest species in 2000 – 2008 fisheries-independent monitoring data. The gill net is the gear type that captures the large majority of the total weight for these four species.

Sum of Weight (kg), 2000 - spring 2008

Gear Type	*Bagre marinus*	*Brevoortia patronus*	*Ariopsis felis*	*Carcharhinus leucas*
Gillnet	540.5	436.2	235.3	275.2
Seine	0.1	67.9	13.0	0.0
Trawl	7.8	6.4	47.6	4.0
Total	548.4	510.4	295.9	279.2
Gillnet %	98.6%	85.5%	79.5%	98.6%

Table 2.2 Gear Type biases for three different gear types, soak gill nets, strike gill nets, and trot line. Although the hooks on the trot line were average size, this gear caught larger individuals that what appeared in either gill net gear type.

Bagre marinus	Standard Lengths (mm)		
	Soak	Strike	Trotline
Minimum SL	188	223	382
Average SL	335	339	455
Maximum SL	468	452	513
N	95	41	11

Unfortunately these earlier studies failed to include any results of how bycatch discards affect diets or comment on whether their diet data could have been affected by a higher availability of carcasses as food during the shrimp season. In these studies, analysis has been limited to percent volume and percent occurrence of each type of content by species (Darnell, 1958; Darnell, 1961; Levine in Stone et al., 1980; Hyslop, 1980), and occasionally extended to display geographical variance of diets for selected species. In his report on the diet of *M. undulatus*, Levine (1980) showed an increase in percent occurrence of fishes in the diet from west to east (Levine in Stone et al. 1980), but only conducted this kind of analysis for species with a large number of specimens. Any study design looking at changes in percent occurrence over time should also account for some natural spatial variation as well. Because of their importance as abundant and large secondary (or tertiary) consumers in Lake Pontchartrain, examining the marine catfishes' diets can show to what degree the higher availability of fish carcasses affects the biomass of fishes generally throughout the system.

To understand how bycatch impacts the fish assemblages of the LPB, I examined how discarded fishes benefit local populations of *B. marinus and A. felis,* by looking for evidence of discarded fish remains in catfish diets. Marine catfish collected during times of high shrimping activity should have more bycatch-associated prey items in their guts than individuals collected during times from areas with limited shrimping activity. As I was unable to access fishery effort data collected by the Louisiana Department of Wildlife and Fisheries (LDWF), I used the temporal designation of the shrimp seasons as a proxy for fishery effort. Should these effort data become available, the diet data collected should be sufficient for a more rigorous test of this hypothesis. I tested this hypothesis by comparing percent occurrence of non-*Anchoa* fishes in the diets of the marine catfishes during and between the shrimp seasons, by comparing generalized linear models with a logistic regression by the models AICc values.   Anchovies were excluded as "fish" because they were not as common in much of the bycatch in an earlier study, and because the catfishes prey upon them whether or not they are bycatch. The three areas of the LPB sampled were, west to east, Lake Pontchartrain west of the causeway bridge ("WLP"), Lake Pontchartrain east of the causeway bridge ("ELP"), and Lake Borgne, including sections of the MR-GO ("LBN"). These three areas acted as blocks that control for the natural spatial variation of fishes in fish diets in Lake Pontchartrain (Levine in Stone et al., 1980).

Logistic regression using generalized linear models with binomial error structure were constructed to test whether shrimping season is as important a factor as temporal season, area, or species in determining the likelihood of fishes in the catfish guts. Welsh's T-tests were used to determine if, given a catfish had eaten fish, whether or not this fish content was heavier during the shrimp seasons than between.

Lastly, because diet composition as a whole should shift, I examined the diets with multivariate methods to determine which components were driving the shift. Higher-trophic-level items like fishes should appear more important during the shrimp seasons, and lower-trophic-level items like vegetation (algae or vascular plants) should appear less important.

Materials and Methods

Study Location

My study area is Lake Pontchartrain and Lake Borgne, within LDWF Zone 1. To account for spatial variability in marine catfish diets, I divided Lake Pontchartrain and Lake Borgne into three sections, referred to as “WLP, ELP, and LBN” (Figure 2.1). In western Lake Pontchartrain (WLP), west of the Causeway Bridge, no trawling is allowed, although many boats with wingnets still work in Pass Manchac. Eastern Lake Pontchartrain (ELP), the area of lowest shrimping activity, reaches from the western end of the Rigolets and Chef Menteur passes west to the Causeway Bridge. Lake Borgne (LBN) includes these passes and areas east to the Biloxi Marshes. I attempted to obtain a similar number (>30) of each species in each of the three sections, during and between shrimping seasons.

Sampling Methods and Data Analyses

I sampled during the initial brown shrimp (*F. aztecus*) season (May to mid-July), the off season in between (mid-July to mid-August), and the longer white shrimp (*L. setiferus*) season (mid-August to December in both 2007 and 2008). The marine catfish migrate out of the Lake as the temperature decreases below 20^{o}C (Muncy and Wingo 1983), so no samples could be taken after October each year. I took samples from the trawl and strike gillnet sets that are part of monthly NRL monitoring efforts and recorded which section they occurred within, as well as the distance from known shrimping activity. I also supplemented these samples with “soak” gillnet sets, in order to achieve a more balanced sampling design. Here, “soak” gillnets are gillnets fished as a passive gear set out over an hour or more. Other specimens came from a concurrent bycatch survey from commercial vessels or a preliminary trotline survey, although these were not included in the statistical analysis due to probable gear artifacts (Eustis, unpublished data). A gut content survey of *B. marinus* and *A. felis* was conducted using fishes caught in either gillnet soaks or gillnet strikes (in which the net is circled thrice with a fast boat, driving fishes into the net). Specimens extracted from the net were either kept on ice or frozen until such time as they were weighed and measured and their stomachs extracted. Once the stomachs were opened, gut contents were weighed as a whole, separated into identifiable components, then each separately weighed. After weighing, components were placed into a graduated cylinder partially filled with water to determine their separate and entire volume by water displacement. Special care was taken for fish specimens found in the gut: they were identified, photographed, and lengths measured however possible. As space and resources permitted, voucher specimens were preserved in 10% formaldehyde for future reference.

Anchovies were excluded as "fish" because they were not as common in much of the bycatch in an earlier study, and because the catfishes prey upon them whether or not they are bycatch. The three areas of the LPB sampled were, west to east, Lake Pontchartrain west of the causeway bridge ("WLP"), Lake Pontchartrain east of the causeway bridge ("ELP"), and Lake Borgne, including sections of the MR-GO ("LBN"). These three areas acted as blocks that control for the natural spatial variation of fishes in fish diets in Lake Pontchartrain (Levine in Stone et al., 1980).

These data were used to determine percent occurrence and percent weight of fishes in the guts of the marine catfish, as well as to compare the data of the present study with previous studies (Levine *in* Stone et al., 1980; Darnell, 1961).

Logistic regression, regression with binomial error structure, is appropriate when testing whether or not different sample populations have the same mean ratio of some value. Here, I use logistic regression to determine the significance of the effect of shrimp season on the ratio of occurrence to total tracts sampled, or the percent occurrence (Hyslop 1980). Different models list different effects as factors. Under a multiple working hypothesis paradigm, the importance of any effect of shrimp season is shown by a lower AICc for the models with “season” as a variable. (To clarify, “season” here does not represent a strictly temporal category, related to temperature and other climate cycles, but a factor defined by whether or not the shrimp season was open at the time the marine catfish individuals were captured). The test of whether or not shrimp season is more important an effect than natural temporal variation, is whether that model alone has the lowest AICc. Ultimately, the model with the lowest AICc is the one that is best supported by the data, given the limitations of the data.

The marine catfish should have larger portions of fish by weight in their guts during shrimp season, so I tested this by comparing the average weight of fish in the guts of each species, when the guts did contain fish, with a t-test (Welsh’s t-test, a t-test without assuming similar variance about the means). Should the means be significantly different, then the estimated means give us some idea of the true increase in importance of fishes in catfish diets.

Additionally, multidimensional scaling (MDS) plots using diet data summarized by species, season, and area were examined for changes in the diet as a whole, as well as changes in the relative importance of selected diet items in different places and times. As before, data were 4^{th} root transformed and analyzed in PRIMER-e software (Clarke and Warwick, 2001).

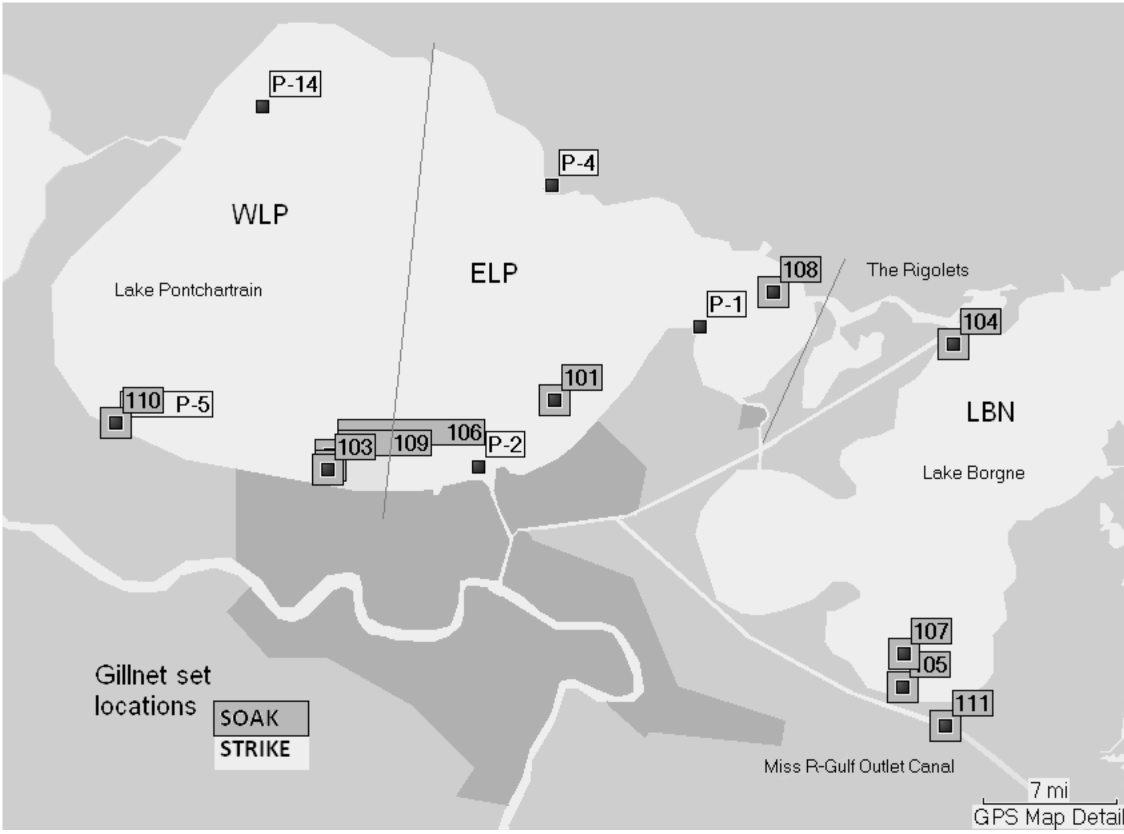

Figure 2.1 Three areas of Lake Pontchartrain Basin (WLP, ELP, LBN),with Soak (dark) and Strike (light) locations for 250 m LDWF gillnets, 2007-2008 (adapted from Garmin).

Results

Gut content was analyzed for 449 *B. marinus* and 149 *A. felis*. Of these samples, 86 *B. marinus* and 11 *A. felis* were excluded due to the fact that they were caught in gear (trotline, long line, or trawl) that could affect the amount of fish in their stomachs. The remaining 363 *B. marinus* and 138 *A. felis* were caught in gillnet soaks or strikes. Compared to Levine (1980), the total percent occurrence was lower for each species (Figure 2.3). For *B. marinus,* percent occurrence of fishes shifted from ~60% in 1980 to ~30%, for *A. felis*, ~40% to ~15%.

Increases in percent occurrence

I summarized occurrence of non-*Anchoa* fishes in catfish guts over all catfish stomachs of a given species examined in a given area and season status (either “on” or “off,” although there are technically four “seasons,” two “on” and two “off”), and standardized the amount of times a non-*Anchoa* fish was found in a stomach by dividing by the number of samples in that division (Fig. 2.2).

For *B. marinus*, the preliminary results show an increase in the percent occurrence of fishes in catfish stomachs in the Lake Borgne area for all time periods, and an increase during the shrimp seasons for all areas. Thus, the probability that a gafftopsail catfish is eating a larger fish is higher during the shrimp seasons, as well as higher toward Lake Borgne and the passes (Figure 2.2). For *A. felis,* there is a similar result, although the low numbers of fish caught in WLP give an impression that there is a great increase in percent occurrence during the shrimp season there.

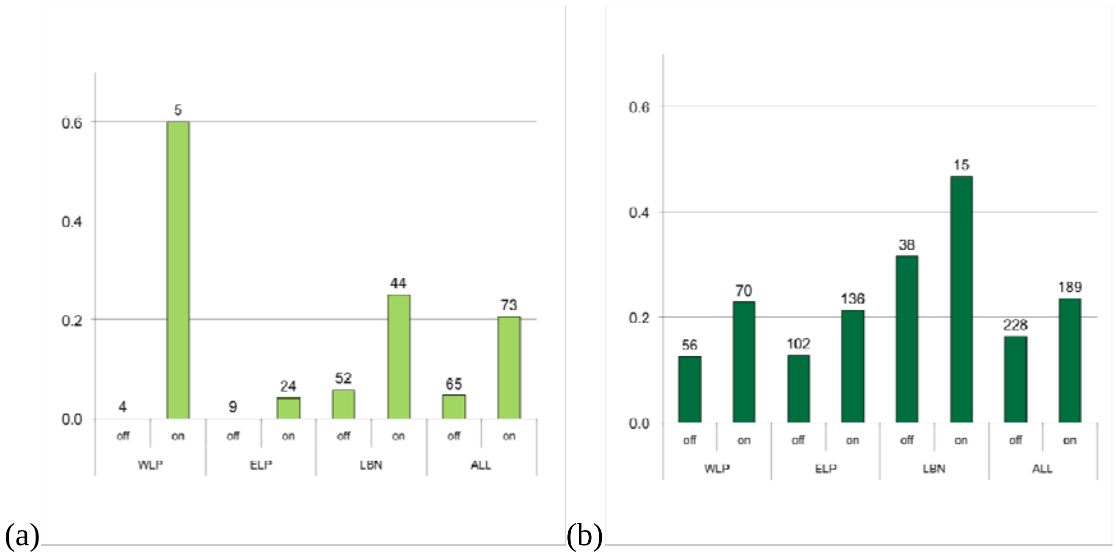

Figure 2.2. Percent Occurrence of non-*Anchoa* fishes in catfish guts for two species, (a) *A. felis* and (b) *B. marinus*, displayed by area and season, with a summary for all areas in the fourth column. The locations are displayed from west to east (upriver to downriver, pass to gulf). The numbers above each bar represent the number of samples.

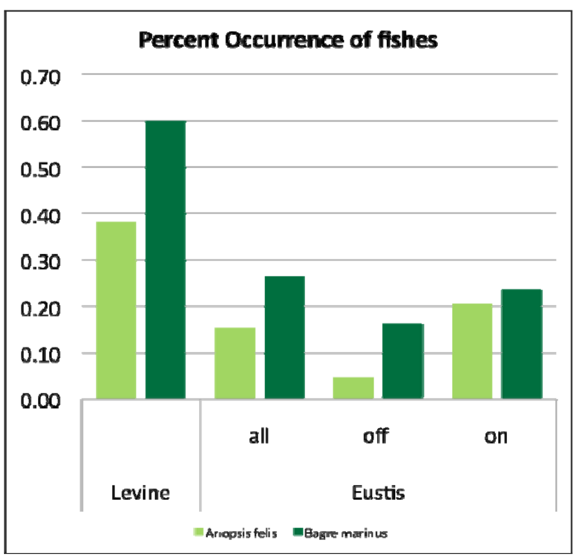

Figure 2.3 Percent occurrence comparison between data adapted from Levine *in* Stone et al. 1980, and the current study. If the data collected in the 19980 study were collected during shrimping and between shrimping seasons, the comparison could be made between “all” of the current data and the Levine data. If the Levine data were collected between shrimping seasons, “off” is the comparable dataset. If all the Levine data were collected during shrimping activity “on” is the comparable dataset. Note the increase in percent occurrence for non-*Anchoa* fishes increases from periods with no shrimping “off” to periods with shrimping “on.”

Analysis of multiple working hypotheses

Model results show that the hypotheses for each species that include Season are better than the null model (y ~ location + error). Coefficient estimates for these models are significantly positive for *B. marinus* and *A. felis* for the model percent occurrence (y) ~ location + season + error ($p < 0.06$; Fig. 2.4). The instance of shrimping increases the chance that a catfish will be eating a fish.

For the multiple working hypothesis analysis, if any one of the models captures 80% of the weight (AICwi), it is considered that the balance of evidence is in favor of the validity of the particular hypothesis represented by that model, over the others (Table 2.1). A model that separates the four seasons ("Sn") captured the most weight (AICwi = 0.86, *B. marinus* and AICwi = 0.93, *A. felis*), indicating that there is temporal change among the four periods of time (two "Off" seasons and two "On" seasons, brown shrimp and white shrimp), as well as an increase of fishes in catfish diets during shrimping activity.

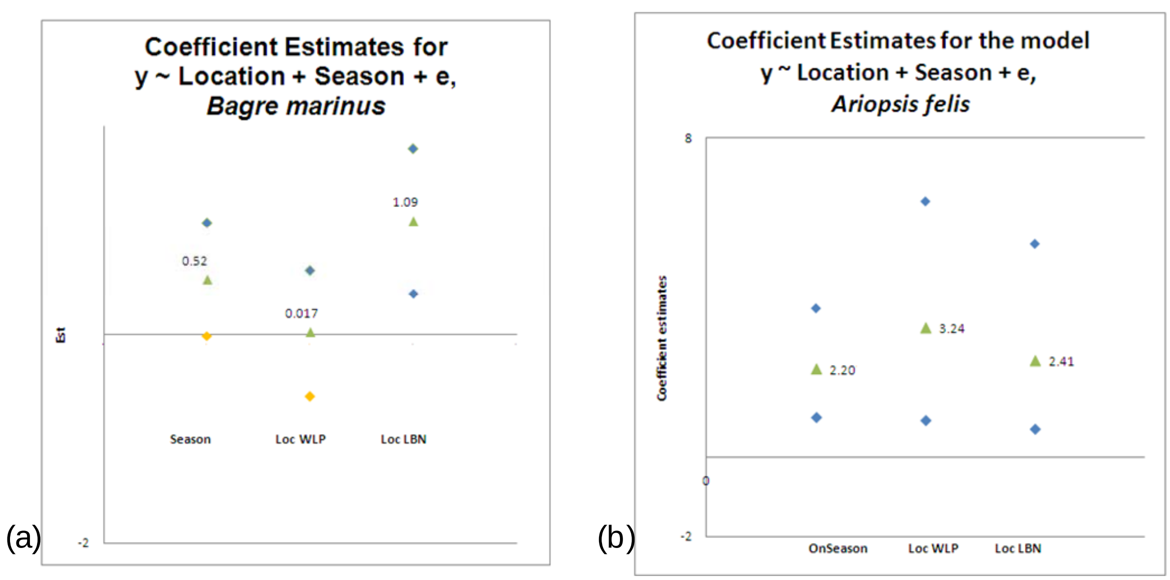

Figure 2.4 Coefficient estimates for locations other than ELP, and Shrimp season effect, for (a) *B. marinus* and (b) *A. felis*

Table 2.3 Model results for three percent occurrence models for non-*Anchoa* fishes in (a) *B. marinus* and (b) *A. felis*, and, 2007-2008.

(a)

model	AIC'c	K	Δi	exp(-0.5*Δi)	AIC'wi
y ~ Location + Sn − e. binomial	136.24	2	0.00	1.00	0.86
y ~ Location + Season + e. binomial	140.97	2	4.72	0.09	0.08
y ~ Location + e. binomial	141.79	1	5.55	0.06	0.05

(b)

model	AIC'c	K	Δi	exp(-0.5*Δi)	AIC'wi
y ~ Sn + Location + e. binomial	44.15	4	0.00	1.00	0.93
y ~ Location + Season +e. binomial	45.45	3	5.13	0.08	0.07
y ~ Location + e. binomial	57.00	2	16.68	0.00	0.00

Preliminary model testing on 2007 *B. marinus* data, during a year without hurricanes to disrupt the effort of shrimpers, had showed that the model with Location and Season alone was selected by the data (AICwi=0.95; Table 2.2), over the model with month of the year as the driver

Table 2.4 Results for three percent occurrence models for non-*Anchoa* fishes in *B. marinus*, 2007-2008.

model	AIC'c	K	Δi	exp(-0.5*Δi)	AIC'wi
y ~ Location + Season +e. binomial	54.03	2	0.00	1.00	0.95
y ~ Location + month + e. binomial	60.96	2	6.93	0.03	0.03
y ~ Location + e. binomial	61.94	1	7.91	0.02	0.02

Increases in percent importance

Model testing confirms the increase in probability of any non-*Anchoa* fish as a diet item in marine catfish diets during the shrimp seasons. In addition, among those marine catfish stomachs that had any fishes, the weight of fishes was heavier during the shrimp seasons.

The weight of fishes as a diet item in *B. marinus* increased in a similar way, but the increase was significant. The mean weight of fishes in catfish stomachs with fishes was 2.89 g between the shrimp seasons and 5.17 g during the shrimp seasons. The mean weight of shrimp in gafftopsail stomachs with shrimp increased from 2.72 g between the seasons to 7.59 g during the shrimp seasons. Although model testing for the occurrence of non-*Anchoa* fishes did not show as important a shift in the probability of large fishes in *B. marinus* stomachs as in *A. felis* stomachs, the increased number of *B. marinus* samples between the seasons allowed for a stronger statistical test (Table 2.3.a).

For *A. felis,* the mean weight of fishes in tracts with fishes was 2.44 g between the shrimp seasons and 4.33 g during the shrimp seasons. The variance during the shrimp seasons was much greater; the number of tracts with fishes between the shrimp seasons was very low (n=4), as we may expect from the percent occurrence results. Because of the low samples of *A. felis* with fishes in their stomachs, a Welsh's T-test did not find this increase in importance by weight to be significant (p = 0.26), even though I expect that this increase is biologically significant (Table 2.3.b). To examine the limits of the sampling method, I also present the change in importance by weight for shrimp in *A. felis* stomachs during and between the shrimp seasons. The mean weight of shrimp in catfish stomachs was 2.43 g between the shrimp seasons and 4.18 g during the shrimp seasons, very similar to the increase in fish during the shrimp seasons. The Welsh's T-test found this increase was also not significant (p = 0.22), although I expect the marine catfish to eat more and heavier shrimp during the shrimp seasons, which are open during the times when Penaeid shrimp are more abundant, more available, and heavier.

Table 2.5 Results of four t-tests comparing the weight of fish or shrimp in (a) *B. marinus* and (b) *A. felis* diets during vs. between Shrimp Seasons
(a)t-Test: Two-Sample Assuming Unequal Variances; *B.marinus* diets during and between Shrimp Seasons

	fish (g); off	fish (g); on	shrimp (g); off	shrimp (g); on
Mean	2.89	5.17	2.72	7.59
Variance	15.9	68.3	7.84	69.15
Observations	51	39	42	38
P(T<=t) one-tail	0.06		0.00	

(b) t-Test: Two-Sample Assuming Unequal Variances; *A.felis* diets during and between Shrimp Seasons

	fish (g); off	fish (g); on	shrimp (g); off	shrimp (g); on
Mean	2.44	4.33	2.43	4.18
Variance	19.04	53.48	13.56	9.89
Observations	4	17	4	11
P(T<=t) one-tail	0.26		0.22	

Multidimensional scaling plots as evidence of diet shift

The third source of evidence of a shift in marine catfish diets up the trophic scale during shrimp seasons is a simple visual analysis of an MDS plot of the differences in relative importance of 16 categories of diet content among the six sectors (WLP, ELP, LBN, during and between seasons ("On" and "Off").

Results for *B. marinus* for these four diet categories (shrimp, fish, gray UOM, and vegetation) were less marked and showed more difference in the effect of shrimp seasons depending on the region (Figure 2.6). There was a less obvious separation among the six diets when the 16 categories were considered. For example, the diet of *B. marinus* caught between the seasons in Lake Borgne was very similar to the diets of *B. marinus* caught during the seasons in Eastern Lake Pontchartrain. The general difference in the six diets was due to both geographic and shrimp season differences, but shrimp season seems to have changed the overall diet of *B. marinus* in the western part of Lake Pontchartrain differently than the other two regions. Shrimp were more important in Lake Borgne than in East Lake Pontchartrain, and more important in ELP than WLP. Shrimp were more important during the shrimp seasons except within Lake Borgne, where there was a slight decrease in the relative importance of shrimp as a diet item. As with *A. felis*, fishes were more important in *B. marinus* diets towards Lake Borgne, and more important during the shrimp seasons. The exception is the western part of Lake Pontchartrain, where there was no apparent change in the relative importance of fishes. There was a more ambiguous result for gray UOM for *B. marinus* than for *A. felis*; it was more important during the shrimp seasons in Lake Borgne, showed no change in ELP, and showed a decrease during the shrimp seasons in WLP. As with *A. felis*, vegetation was less important during the shrimp seasons, only appearing during the shrimp seasons in stomachs from ELP.

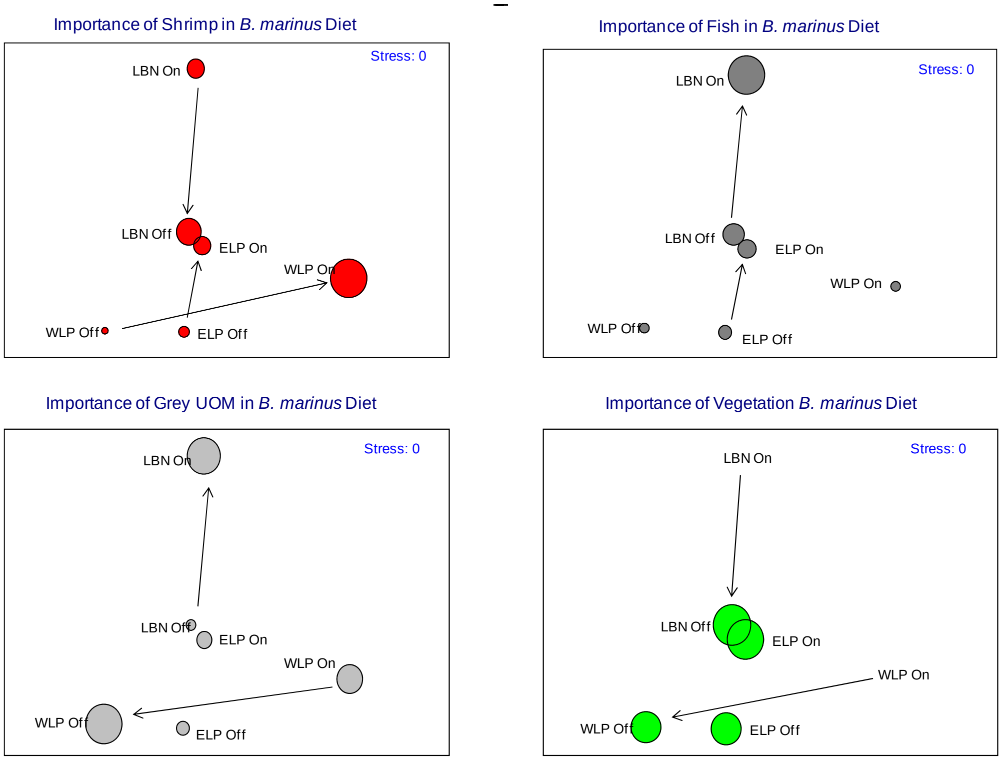

Figure 2.5 MDS Plots of diets by relative weight for six categories of *B. marinus* samples. Bubble sizes are only relative to one another within a single box. Arrows denote the direction of changes in relative importance larger than 3% between diets from the same location. From left to right: Shrimp, Fish, Gray UOM, Vegetation

For *A. felis*, the six sectors separate cleanly along an axis of geographic differences as well as shrimp season differences (Figure 2.5) in all 16 diet categories. Overall, the diets were separated more by geographic differences than by shrimp season differences. When select categories of diet items are examined, the relative importance of shrimp season for each geographic area is revealed. Shrimp are more important in Lake Borgne samples and during the shrimp seasons. Shrimp were not an important diet item in stomachs of *A. felis* from WLP, neither during nor between shrimp seasons. Fishes are more important in samples from Lake Borgne and more important to the diet of *A. felis* caught in Lake Borgne during the shrimp seasons. Contrary to what I have presented in other analyses, fishes are more important between the shrimp seasons in the western part of Lake Pontchartrain. An aggregate category—gray unidentified organic matter ("gray UOM"), which may be fish—was important during the shrimp seasons in all geographic areas. Various vegetation types were important between the shrimp seasons, while discards are not available. This is evidence that the diet of the fish changes during shrimp seasons.

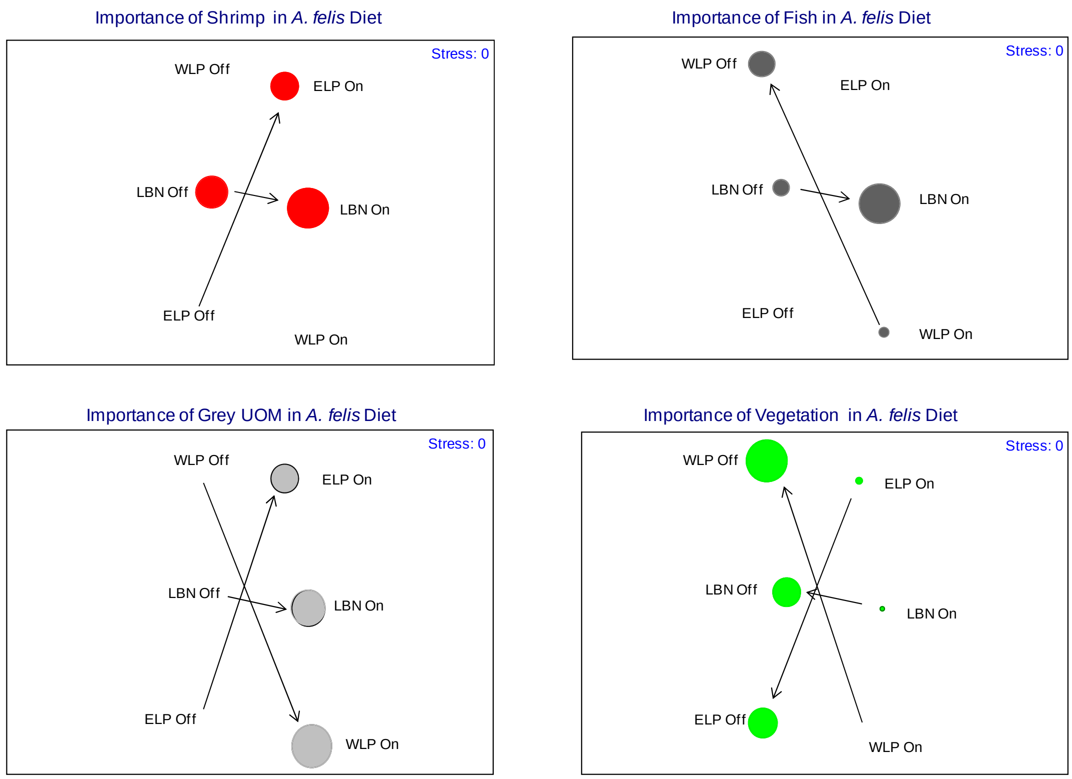

Figure 2.6 MDS Plots of diets by relative weight for six categories of *A. felis* samples. In each figure, the three diets to the right (WLP On, ELP On. LBN On) represent the diet during shrimp season ("On"). Bubble sizes are only relative to one another within a single box. Arrows denote the direction of changes in relative importance larger than 3% between diets from the same location. From left to right: Shrimp, Fish, Gray UOM, Vegetation.

Discussion

Gut content analysis showed that the presence of shrimping and a more Gulfward location increase the chance that marine catfish eat large fishes. Shrimping also changes the importance of fishes in marine catfish diets, as well as the relative importance of different diet items. All three analyses supported a general hypothesis that these marine catfishes are switching their diets to exploit the discards that become available during the shrimp seasons, although the magnitude of the shifts differ between the species and among locations.

Increase in percent occurrence

The logistical regression showed that season and location are significant factors in determining percent occurrence of fishes in *B. marinus* and *A. felis* stomachs, although the natural seasonal differences are confounded with differences caused by shrimping effort by a model that uses a calendar proxy for shrimping effort. The model that treated each shrimp season (Jan-Apr, May-Aug, Aug, Aug-Dec, the “Sn” variable) as having a separate effect on percent occurrence was the one best supported by the data. This separate treatment can be explained either by natural variation in percent occurrence in marine catfish diets, but more likely variation in shrimping effort among the two shrimping seasons. Because the model testing from both years (2007 and 2008) gave a different result than the model testing in 2007 alone, I speculate that hurricanes Gustav and Ike lowered actual shrimping effort during the white shrimp season in the later part of the year. Fewer discards thus lowered the levels of larger fishes in catfish diets, obscuring a more clear result because of the reliance of a calendar proxy for fishery activity. Regardless, shrimp season was not rejected as a significant factor in increasing the occurrence of discard-size fish in catfish stomachs, so I conclude that the marine catfishes are taking advantage of these discards as a high quality food.

Bagre marinus *occurrence model results*

In a comparison of several generalized linear models with binomial error structure, the model that included location and shrimping season outperformed other models (including a model which included month as a random factor with an interaction term) in predicting percent occurrence of non-*Anchoa* fishes in *B. marinus* diets. Should effort data become available, this study design is sufficient to test the importance of shrimping activity against the natural temporal and spatial variation in diet. It is interesting to note that the same model run on 2007 data alone produced results that selected the model with shrimp season over the model with natural temporal variation as a factor. The full model, which includes temporal variability, independent of shrimping season, as a factor in *B. marinus* diet may come to be supported by the data, should true effort data become available. But, even without a control area, the model selection process removes doubt that the shift in diet is due only to background temporal and spatial variability in food availability. This fish eats more non-*Anchoa* fishes during the shrimp season due to the shrimp season.

Ariopsis felis *occurrence model results*

The comparison of models for *A. felis* shows an even split between the importance of shrimp season and temporal variability in the occurrence of fishes in the diet. But the fact that location was ruled out is mainly a result of the fact that the over 60% of *A. felis* samples were taken from the same location: Lake Borgne. This species does not occur as frequently in Lake Pontchartrain as *B. marinus*.

Comparison with data from Darnell (1959) and Levine (1980) showed a decrease in percent occurrence of fishes in diet for both species from 1959 or 1979 to 2007. Although we do not know precisely where and when Darnell (1959) or Levine (1980) obtained their samples, a decrease is consistent with the hypothesis that the availability of shrimp discards drives the increase in percent occurrence, because shrimping activity around the State has declined since its peak in the early 1980s (Figure 2.7).

The importance of fishes in marine catfishes' diets also increased, both as a raw weight measure and by a percentage of the whole diet. This increase was not statistically significant for *A. felis*, in this study, but the low sample size lowered the power of the statistical test to the extent that this test could not even show an increase in the importance of shrimp during the shrimp seasons. As evidence, the increase in shrimp in *A. felis* diet during the shrimp seasons was just as likely as the increase in fish. The *A. felis* likely feeds on more shrimp during the shrimp season, as I have shown with the *B. marinus* diet. The increased weight of fishes in the diet is further evidence that this catfish feed on discards, because the length of the modal bycatch specimen (~150 mm) is larger than the small fishes (anchovies and juveniles, ~60 mm) *B. marinus* is usually assumed to catch (USFWS 1983; Fishbase, 2008).

Multidimensional scaling: a more complete snapshot of diet

Multivariate analysis of several diet items also reveals a general pattern of increased quality of diet during the shrimp season. *Ariopsis felis* has much less vegetation in its diet during than between the shrimp seasons. This is likely due partially to the increase of the importance of shrimp and crabs during these times, but also to the increase in occurrence and importance of fishes in the species' diet. A post-hoc review of the multivariate data showed that gray UOM only occurred during the shrimp seasons. From this, as well as other characteristics (primarily odor—the smell of rotten *B. patronus*), I infer that gray UOM is also fish (probably menhaden), although none of this material was counted as such in the previous statistical analyses. The shifts in *B. marinus* diet are more complicated. In ELP, overall diet differences are the smallest and for individual items there are only small increases. In WLP, there is a large increase in the importance of shrimp and a decrease in the importance of vegetation, with no or only small changes in the importance of fish and gray UOM. In Lake Borgne, there was an unexpected reduction in the importance of shrimp, increases in the importance of fishes and gray UOM, and an expected reduction in the importance of vegetation.

Although *B. marinus* is more of a rover-predator and thus more able to take advantage of changes in availability of higher-quality food, the diet of *A. felis* is more affected by changes availability in food items, over space and time (Levine, S., 1980, Fishbase, 2008). This may reflect a limitation in the study design, if *B. marinus* is shown to travel longer distances in the same amount of time than *A. felis*. Overall, these changes in diet, away from vegetation, and toward higher-quality food, can help explain why these marine catfishes can achieve unexpectedly high stable isotope trophic signals comparable to the higher, tertiary predators (Levine, S., 1980; Williams and Martinez, 2004; Turner, pers. comm., Fishbase, 2008).

Comparison of marine catfishes as scavengers to other systems

Many studies on bycatch have focused on more visible scavengers such as seabirds. These scavengers have been estimated to harvest as much as 57% percent of discards from daytime fisheries. Many of these studies have determined by sight whether or not the scavengers individually benefitted from discards and by more intensive methods which sectors of the population benefitted more than others (Votier et al., 2010).

For example, in Votier et al., (2010) breeding northern gannets (*Morus bassanus*), plunge-divers similar to pelicans, were found to travel farther for a engraulid fish impacted by trawling, because of its higher nutritional value; non-breeding gannets followed trawling vessels and ate the lower quality food. Because their nutritional requirements were different, non-breeding birds were healthy while breeding gannets suffered. What effects this would have on the population as a whole would require population-level modeling and monitoring. Different subpopulations and sizes of marine catfishes may similarly feed on discards in different ways and brooding males do not feed at all.

Although feeding on fishery discards was found to be correlated with a lower body condition among some birds (Grémillet et al., 2008), there is confusion over whether or not a lower body condition is a cause or effect of eating discards. Sick animals, being less able to pursue prey, may prefer their food pre-killed in order to save energy for survival. And thus, discards may be sustaining animals that would otherwise starve. On the other hand, discards can sometimes be less nutritive than the animals' natural food. In this case, eating discards can lead to an animal becoming sick. Given that marine catfishes eat a higher quality and higher volume of food during shrimp seasons, this is not the case for marine catfish in Lake Pontchartrain.

Although birds are a major consumer of discards during the day, there is evidence that they do not feed on discards at night, which is when some trawls and all wing net shrimping occurs in the inshore of the Lake Pontchartrain Basin. Therefore, although more than half of discards can be attributed to birds in some regions (Votier et al., 2010) , the amount may be much lower in Lake Pontchartrain Basin and will change as the ratio of wing net to commercial trawl activity changes.

On the decomposition of discards and carcasses as a nutrient vector

During the previous study of bycatch, although many fishes were caught (and caught while several other boats were operating in the vicinity), only once did a bycatch sample contain a previously killed fish carcass. This fish was identified by the advanced progression of its decomposition in comparison to the other dead fishes in the catch, although it showed no signs of having been bitten or chewed and looked as though it had been crushed to death, just as all the other dead fishes.

In addition to this, these kind of re-caught fish corpses are never caught in re-sampling efforts in the vicinity of shrimp trawls (pers. obs.). One can assume, then, that the carcasses are removed and devoured by some scavenger or decomposed too quickly to be collected by the next trawler's net. Other studies have shown that many invertebrates as well as fishes are attracted to areas having been trawled (Bergmann et al., 2002a). Opportunistic fishes such as gunards (Triglidae), although not normally classified as strict scavengers, were attracted to the path of the trawl and the food it provided, although researchers were not sure whether the fishes were attracted to the discards themselves or the invertebrates feeding on the discards, as a live prey item.

In a freshwater systems, carcasses were eaten by catfishes very quickly, in less than 24 h (Viosca, 1931; Schneider 1998). These freshwater bullheads (*Ameiurus* sp.) were shown to be able to consume increasing percentages of their body weight as the temperature increased. Our marine catfishes are also known to change their behavior with temperature and so their scavenging potential (Schneider, 1998) may change from brown shrimp season to white shrimp season, based on temperature.

Even in oligotrophic, cold water streams, decomposition is rapid (Monaghan and Millner, 2008). Invertebrate and other scavengers could be the beginning of a process that decomposes the discards enough that they cannot be re-captured by the same nets that killed them. Salmon carcasses have been shown to subsidize freshwater streams by relocating large amounts of protein upstream into rocky, oligotrophic systems. These carcasses subsidize the streams to such an extent that the Salmon are viewed as "keystone species" (Monaghan and Millner, 2008). Furthermore, whole carcasses are not fully exploited by smaller detrivores, such as caddisflies (Trichoptera) unless the skin of the dead fish has been broken by a larger scavenger, such as a brown bear (*Ursus arctos*), weasel (*Mustela* sp.), or wolverine (*Gulo gulo*). Similarly, the eastern bottlenose dolphin (*Tursiops truncatus*) may be important to the beginning of the decomposition cycle in the Lake Pontchartrain Basin by breaking larger carcasses discarded as bycatch into smaller pieces. This process has many indirect effects, "enrich[ing] organic biofilms, stimulat[ing] microbial activity, and increas[ing] primary production downstream" (Monaghan and Millner, 2008). Although fishes caught and discarded are not dying further upstream by biological imperative, the inshore shrimp fishery, and especially wing net boats, which "push" into a falling tide, relocates carcasses further upstream in the estuary. This may attract higher marine predators, such as dolphins, further inshore than normal, but also may augment the already active detritivorous activity of shallow estuarine waters.

Although this study was not designed to test this hypothesis, blue crab (*Callinectes sapidus*) may well be the dominant scavenger in Lake Pontchartrain and may benefit the most from discards. Pots-as-traps are a method of learning which species are scavenging from fishery discards (Bergmann et al., 2002a). The blue crab fishery in Lake Pontchartrain utilizes discards of *B. patronus* from shrimping activity, as a primary crab bait. Therefore crab bycatch monitoring can tell us the rate of scavenging by species other than *C. sapidus*, because it is a measure of what is eating discarded *B. patronus*, a major element of shrimp bycatch that has sunk.

Summary

If mortality due to shrimp bycatch has a significant structuring effect on both nekton populations and nekton community structure in the Lake Pontchartrain Basin, that effect will be modulated by the basic type of gear used by the shrimping industry. This study has shown, albeit with a limited data set, that gear type differences change the "assemblage" caught in shrimper's nets more than location or time of year.

The design of future bycatch monitoring research should account for gear type and prioritize it as a factor as much as sampling from boats in different passes and sampling during different times during the year. Gear type and gear size also determines what size of fishes are caught for the dominant bycatch species.

If a redistribution of the estuarine food web affects fish assemblage in ecosystems with a high level of shrimping activity, we can discern a diet shift in some of the many species that could benefit from discards. Although they have not been previously mentioned as benefactors of discards, this study has shown that the marine catfishes, *B. marinus* and *A. felis* have an increased chance of eating higher quality food and do eat higher amounts of higher quality food during the shrimp seasons. These fishes benefit from discards, even as they would benefit from a reduction in use of the commercial trawl in the shrimp industry, the gear type that captures and kills them as bycatch.

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VITA

Scott Eustis was born in New Orleans, Louisiana, on August 24, 1979. He grew up under the oaks of Lakeview, next to the herons of City Park, and swung his first fishing pole into Crane Creek east of Necaise, Mississippi. Adventuring between the neglected New Deal cityscape of New Orleans and recovering Oak and Magnolia lowlands of coastal Mississippi taught him of the dogged resilience of the natural world to the slights of industrial humanity. He graduated from Jesuit New Orleans Summa Cum Laude in May of 1997, after witnessing the many May floods during his high school career. He escaped to study in Athens, Georgia, at the University of Georgia, and discovered the discipline of Ecology while pursuing studies of the English language, all in search of a solution to the problem of a sinking metropolis. After graduating Magna Cum Laude with a double degree, he pursued laboratory, field, and course work in the foothills and mountains of North Georgia, until certain storms struck his home state after his 26th birthday in 2005. Upon returning, he sought to study the estuarine system that housed his family for so many generations, and enrolled at the University of New Orleans to study the Lake Pontchartrain Basin system and New Orleans' reliance upon it.