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[Article]

Seasonal Estimates of Fish Biomass and Length Distributions Using Acoustics and Traditional Nets to Identify Estuarine Habitat Preferences in Barataria Bay, Louisiana

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Abstract.—We conducted hydroacoustic, gill-net, and push trawl surveys to quantify changes in habitat-specific fish size and biomass in shallow (<2-m) estuarine waters of Barataria Bay, Louisiana, in order to evaluate essential fish habitat. Surveys were conducted monthly between June 2003 and May 2004 among regions located along a north–south salinity gradient. The fish length distributions derived from the gill-net and push trawl catches showed moderate concordance with the measured target strength distributions, indicating that our integrated approach more effectively characterized the fish community than using only a single gear type would have. Acoustic estimates showed that biomass was highest during fall (mean ± SE; 2.30 ± 0.27 g/m^3) and next highest in spring (1.49 ± 0.20 g/m^3), with relatively low biomass during summer (0.70 ± 0.14 g/m^3) and winter (0.86 ± 0.14 g/m^3); pelagic fish biomass from nets was low during winter (53.9 ± 14.9 grams per unit effort [gpue]) but relatively high in fall (846.1 ± 207.2 gpue), spring (774.3 ± 175.5 gpue), and summer (620.3 ± 140.7 gpue). Oyster habitat supported a greater biomass of pelagic fish (acoustic survey: 1.54 ± 0.15 g/m^3; gill-net survey: 467.3 ± 81.0 gpue) than soft-bottom habitat (acoustic: 0.94 ± 0.11 g/m^3; gill-net: 315.2 ± 54.8 gpue). Among regions, the greatest biomass of pelagic fish was observed at polyhaline stations (acoustic: 1.78 ± 0.19 g/m^3; gill-net: 654.3 ± 136.5 gpue), followed by mesohaline (acoustic: 1.18 ± 0.15 g/m^3; gill-net: 378.5 ± 79.1 gpue) and oligohaline stations (acoustic: 0.82 ± 0.12 g/m^3; gill-net: 228.3 ± 50.2 gpue). Gill-net biomass was linearly related to the acoustic biomass estimates of small pelagic fish. The complementary, multigear approach proved to be useful in evaluating habitat use and may be particularly helpful in identifying and monitoring ecosystem reference points to evaluate change and in standardizing ecosystem-based assessment approaches.

Links between estuarine ecosystems and fishery production have been inferred by many studies (Boesch and Turner 1984; Houde and Rutherford 1993; Mitsch and Gosselink 1993). In particular, estuarine systems have been shown to serve as nursery habitat for many transient and resident fishes, including important commercial and recreational species (Rozas and Minello 1998; Dahlgren et al. 2006). The importance of estuaries to fish was acknowledged by Congress through the Sustainable Fisheries Act of 1996 and its recent reauthorization (2006), which defined essential fish habitat (EFH) as the waters and substrates necessary for spawning, breeding, feeding, or growth to maturity (Benaka 1999). Because

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estuarine habitats are highly variable and complex, the dependence of fish on specific habitat types is not well understood (Able 1999; Minello 1999). Effective management and protection of estuarine ecosystems is difficult without sound scientific knowledge of the functional dependence of all life history stages of fish on available habitat.

Estuarine ecosystems in Louisiana are being degraded, primarily owing to the loss of coastal wetlands. Approximately 24 mi^2 (62 km^2) of wetlands and marshes are disappearing each year (Barras et al. 2003); these losses account for about 90% of the land lost in the contiguous United States (Field et al. 1991; Dahl 2000) and are due largely to anthropogenic alterations to the coastal landscape (Barras et al. 2003). In 2006, marine recreational and commercial fisheries in Louisiana accounted for US$2.3 billion in retail sales, 36,700 jobs, $598 million in salaries and wages, and $146 million in federal income tax revenue (LDWF 2006), highlighting their economic importance in addition to their ecological importance; estuaries are particularly important given the proportion of the harvest comprised of estuarine-dependent species (75–85%; NOAA 2009). Barataria Bay currently accounts for approximately 60% of the wetland loss in Louisiana and is expected to account for about 80% by 2050 (Barras et al. 2003). Coastal alterations have led to heightened awareness of the importance of estuarine habitats to fish and their forage base in coastal Louisiana.

Aside from marshes, two habitats dominate the estuaries in Louisiana: soft-bottom (mud–sand) and subtidal oyster reef–shell (the latter commonly created by the eastern oyster *Crassostrea virginica*); soft-bottom habitats are predominant in Barataria Bay (Y. Allen, Louisiana State University, personal communication). Few studies have focused on differences in the abundance of fish among these habitats (Coen et al. 1999; Harding and Mann 2001; Lehnert and Allen 2002), particularly in Louisiana (Plunket and LaPeyre 2005). In addition to discrete habitats, seasonal and spatial variation in environmental conditions (Rakocinski et al. 1992; Rozas and Zimmerman 2000; Granados-Dieseldorff and Baltz 2008) and reproductive behavior (Subrahmanyam and Coultas 1980) can influence the spatial distribution of fish biomass. Moreover, biases in the fishing gears used to collect samples can affect the observed trends in catch (Hayes et al. 1996; Hubert 1996; Jackson and Harvey 1997).

Hydroacoustic sampling is widely accepted as a method for enhancing fisheries assessments and is gaining momentum as a survey technique in shallow-water environments (Krumme and Saint-Paul 2003; Boswell et al. 2007). Most studies utilize acoustics to provide complementary estimates of fish abundance and density while relying on direct biological sampling to gain information on the composition of the fish community (Yule 2000; Mackinson et al. 2004; Simmonds and MacLennan 2005). Attempts have been made to standardize acoustic data to net catches and to use selectivity indices from nets to partition acoustic data (Hansson and Rudstam 1995; Bethke et al. 1999; McQuinn et al. 2005). Little effort has been made to integrate acoustic and net data in shallow waters.

To evaluate the habitat use of fish in shallow-water (<2-m) estuarine habitats, particularly the soft-bottom and oyster reef ones in Barataria Bay, we conducted hydroacoustic, gill-net, and push trawl surveys. Specifically, we examined seasonal differences across a salinity gradient in Barataria Bay to address habitat-specific differences in the relative abundance and biomass of estuarine fish.

Methods

Study area.—Barataria Bay, located in southeastern Louisiana (Figure 1), is characterized as an estuarine–wetland system that is bordered by the natural levees of the Mississippi River to the east and the Bayou LaFourche distributary to the west. Barataria Bay is one of the largest estuaries in the northern Gulf of Mexico, with an area of approximately 4,100 km^2, but it has an average depth of only 2.3 m (Conner and Day 1987). We examined the two predominant subtidal habitats: oyster reef and soft bottom. Three regions were established along a north–south salinity gradient adjacent to the Barataria Bay Navigation Channel. The regions were Fisherman's Point (FP; salinity = 4.48 ± 1.08 practical salinity units [psu; mean ± SD]), Manila Village (MV; 11.46 ± 1.43 psu), and Grand Terre Island (GT; 19.66 ± 1.45 psu) (Figure 1). Salinities were measured with a handheld multiparameter instrument (YSI Model 85; Yellow Springs Instruments, Yellow Springs, Ohio). Each sampling station was characterized by the presence of adjacent oyster and soft-bottom substrates identified from side-scan sonar mosaics (Allen et al. 2005; Boswell et al. 2007); depth was measured with a sounding pole. The GT region did not contain significant oyster habitat, so a high-salinity oyster habitat station was established at nearby Queen Bess Island (QB; salinity = 20.05 ± 1.58 psu). Samples were collected within each of the regions, although the exact locations varied owing to weather conditions.

Acoustic data collection.—Acoustic estimates of fish biomass and size distributions were derived using a BioSonics DT-X digital echo sounder equipped with two BioSonics 420-kHz elliptical split-beam transducers (2.4° × 6.2° half-power beam widths). The echo sounder was calibrated following the standard sphere

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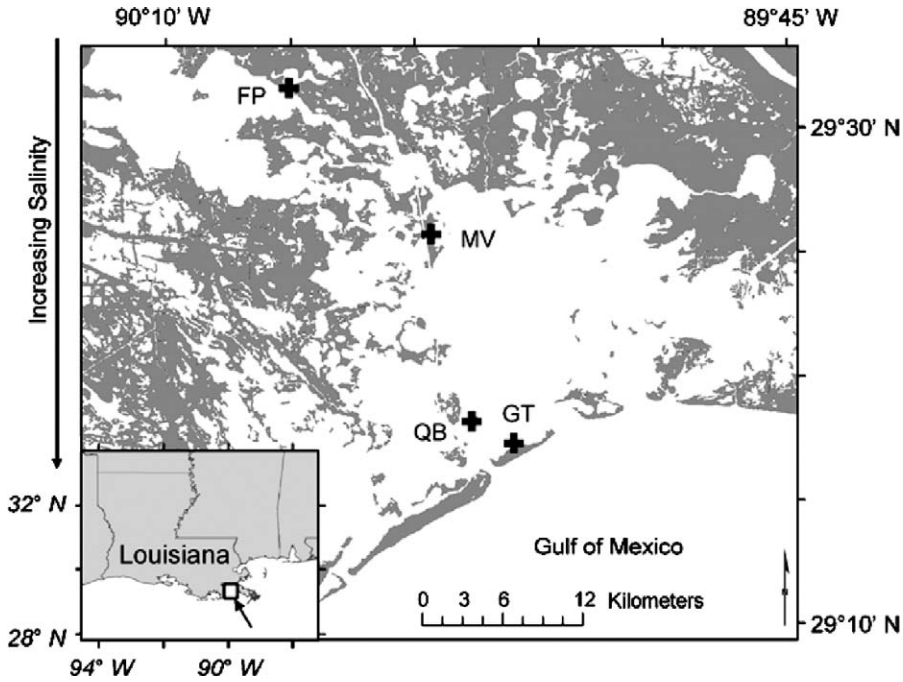


FIGURE 1.—Map of the study regions in Barataria Bay (FP = Fisherman's Point, MV = Manila Village, QB = Queen Bess Island, and GT = Grand Terre Island). The regions are situated along a north–south salinity gradient, and each comprises two stations, one characterized by oyster shell habitat and the other by soft-bottom habitat.

method (Foote et al. 1987). Collection thresholds were set to allow detection of all echoes exceeding −75 dB on the acoustic axis of the beam with a pulse duration of 0.4 ms using the BioSonics Acquisition Program (version 4.1). During each monthly survey, acoustic data were collected for 1 h over each habitat type at each station. For consistency, efforts were made to place the transducers in similar locations and orientations but aimed in opposite directions. Refer to Boswell et al. (2007) for more details on the acoustic methods.

A series of stations within each region were selected to quantify the relative changes in fish biomass and size distribution associated with oyster and soft-bottom habitats. A Global Positioning System unit, interfaced with a personal computer, provided real-time position with respect to previously generated side-scan mosaics (Allen et al. 2005), enabling acoustic data to be collected over discrete habitat types. Monthly surveys were conducted from June 2003 to May 2004 except in November and December 2003, when the weather was inclement; seasons were designated as follows: winter (December–February), spring (March–May), summer (June–August) and fall (September–November). During all surveys, the acoustic equipment was deployed during daylight hours concurrently with both the gillnet and push trawl collections.

Acoustic data processing.—Raw acoustic data were processed in Echoview 3.6 (SonarData Pty Ltd.). Initially, the data were manually edited to exclude unwanted reverberation (entrained air and surface–bottom scatter). Data collected between the near-field range (0.29 m) of the transducer to the onset of reverberation from either the water surface or substrate (range, 20–30 m) were used in the analyses to exclude potential biases from scattering losses (e.g., reverberation and environmental noise) (Guillard 1998; Trevorrow 1998; Boswell et al. 2007). Sound speed and absorption coefficients were applied to account for the effects of temperature and salinity on the acoustic transmissions. The nomenclature for the acoustic variables follows MacLennan et al. (2002).

One limitation of shallow-water acoustic surveys is the susceptibility to bubble-induced noise from entrained air during nonquiescent conditions (Kubecka and Wittingerova 1998; Knudsen and Sægrov 2002). High levels of noise were frequently detected in the acoustic record. Consequently, a novel series of processing algorithms was developed to enhance the acoustic signals of the biological targets relative to the background noise by selecting data that consistently exceeded the background levels (Figure 2). The

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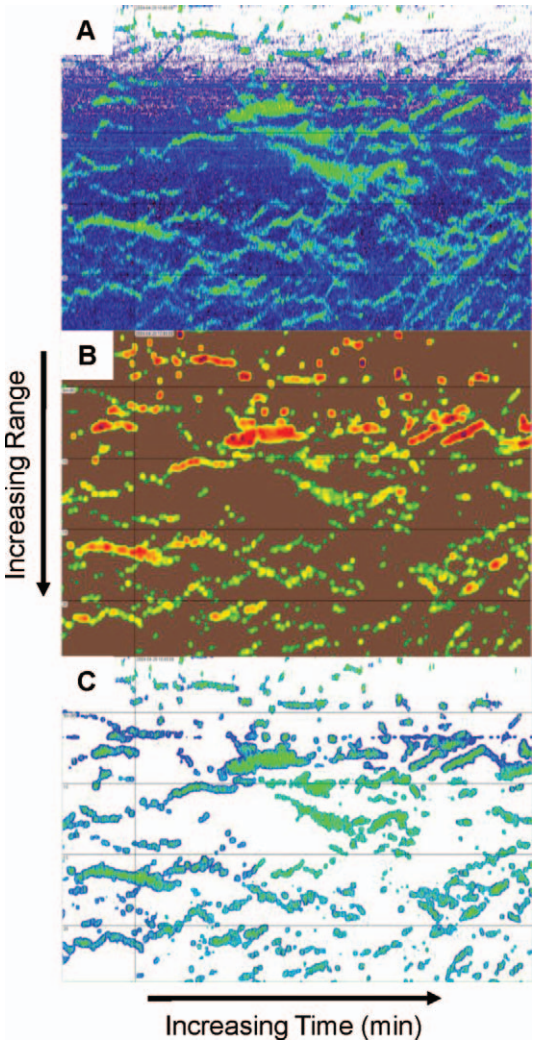


FIGURE 2.—Analytical filters developed in Echoview to remove background noise from the survey data. Panel **(A)** presents the raw volume backscattering (S_v) data; panel **(B)** presents the raw data minus the resampled S_v data; and panel **(C)** presents an echogram of data that consistently exceed background data. Echointegration was conducted on the final echogram.

method described by Boswell et al. (2007) is completely dependent on appropriate analysis threshold settings. In contrast, the revised filtering method proposed in this study is not dependent on data thresholds (aside from the initial collection threshold), as thresholds were not implemented until the echo integration analyses. By eliminating the need to rely directly on analytical thresholds, this method can be readily incorporated into analyses at multiple scales and applied in a variety of aquatic ecosystems.

Given that the mean volume backscattering strength (S_v [dB]) is considered an acoustic approximation of fish biomass within a given volume of water (Simmonds and MacLennan 2005), it was necessary to filter the measured scattering attributed to sources of noise. Raw S_v data were resampled at 400 pings in the horizontal dimension (time) and at 5-m range intervals. The resulting values corresponded to a "noise" echogram consisting of a temporally and spatially smoothed measure of S_v defining the boundary between background noise and the biological signal. In a parallel process, a 7×7 matrix median filter was applied to the raw S_v data, by which each sample in the matrix was replaced with the median value from each data point and its 48 direct neighbors. This enhanced the areas of significant backscatter signal and diminished the areas of low backscatter signal, effectively removing the effects of intersample variation on all scales smaller than the expected scale of the biological backscatter. Samples in the noise echogram were subtracted in the linear domain from the median-filtered samples. A 7×7 convolution matrix filter with coefficient $(i, j) = 1$ for all i and j was applied to the results of the subtraction operation to further smooth and equally weight the values samples. The spatial and temporal coordinates of each remaining sample after application of the convolution filter were used to extract data from the raw S_v echogram. Thus, only the raw S_v data corresponding in time and space to samples in the final convolution filter were used for echo integration analysis. Data were echo integrated over 5-min intervals with a threshold of −70 dB. Estimates of the volume backscattering coefficient (s_v), the arithmetic form of S_v, where

$$S_v = 10 \cdot \log_{10}(s_v), \tag{1}$$

were derived following standard echo integration techniques (Simmonds and MacLennan 2005). Integration results were analyzed in SAS (version 9.1.3).

Target strength.—Estimates of target strength (TS [dB]), the acoustic representation of fish length, were derived in Echoview over the same 5-min intervals used for echo integration. Acoustic targets were accepted for processing if they fulfilled single-target criteria and had a measured TS greater than −55 dB (approximately equivalent to a 2.5-cm fish; Frouzova et al. 2005). A single-target algorithm was tuned to accept targets with echo envelopes between 0.6 and 1.7 times the pulse duration with a maximum beam compensation of 12 dB (Boswell et al. 2007). A mean TS value was estimated for each series of single targets that were linked in time and range. We adopted the horizontal-aspect TS to standard fish length (SL [cm]) function

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derived by Frouzova et al. (2005) to calculate TS values from fish collected in nets, namely,

$$\mathrm{TS} = 24.71 \cdot \log_{10}(\mathrm{SL}) - 64.92. \quad (2)$$

Fish biomass calculations.—As described in Boswell et al. (2007), fish biomass (g/m^3) was calculated for the fish community by incorporating an average communitywide length : weight (W [g]) relationship (parameters: $a = 0.0174$ and $b = 2.9628$) based on the size distributions of the most abundant species collected with both trawls and gill nets. We derived a TS-per-unit-weight relationship (TS_w; see Fabi and Sala 2002; Simmonds and MacLennan 2005; Boswell et al. 2007) to incorporate into the biomass calculations, namely,

$$\mathrm{TS}_w = -4.45 \cdot \log_{10}(\mathrm{SL}) - 47.95. \quad (3)$$

Transformation of equation (3) to

$$\sigma_{\mathrm{bsw}} = 10^{\mathrm{TS}_w/10} \quad (4)$$

yielded an equivalent backscattering cross section per unit weight (σ_{bsw}) that was used to scale s_v in order to derive volumetric estimates of the fish biomass in each cell as

$$\text{Fish Biomass}_{\mathrm{cell}} = s_{v,\mathrm{cell}} / \sigma_{\mathrm{bsw,cell}}. \quad (5)$$

Gill-net and push trawl sampling.—Gill nets and push trawls were deployed contemporaneously with the acoustic array to derive the length distributions, relative abundance, and biomass of the fish community. The gill nets were positioned approximately 50 m from the transducers and well separated from the ensonified volume. Acoustics measurements were commenced after the gill nets were set, so that gill-net deployment did not alter the adjacent distribution of fish. The gill nets were fished for 2 h adjacent to the acoustic beam over each habitat type. Fish were collected from the gill nets after 1 h of fishing, then the nets were reset in the same place to obtain another 1-h replicate sample. The gill nets measured 46.5 × 2.48 m and consisted of five randomly arranged panels of monofilament mesh squares (1.27, 1.91, 2.54, 3.18, and 3.81 cm). All fish were iced in the field and later frozen. In the laboratory, all fish were identified to species and weighed (g) and subsamples were measured for standard length (SL; cm). The total weight of each catch was summed across the five panels to obtain a single biomass estimate for each hour fished, expressed as grams per unit effort (gpue). Fish were classified into two groups—small pelagic and nonpelagic—following Boswell et al. (2007) because of the finding that smaller targets disproportionately contribute to acoustic biomass estimates in estuaries (Table 1).

Push trawls were used to capture smaller fish (<7 cm) not effectively sampled by gill nets (Boswell et al. 2007). Three 100-m habitat-specific transects were conducted with a 1-m^2 push trawl (1 cm mesh, 0.5 cm cod end) at approximately 2 m/s. Unlike the gill nets, which were used during each field survey, push trawls were only employed from February to May 2004. The length distributions from the push trawls were combined at each station and habitat type for comparison with the acoustic data. Samples were sorted by species, individuals were measured to SL (cm), and wet weight (g) was recorded. For catches with more than 50 individuals of the same species, subsamples of 50 randomly selected fish were measured and weighed as above. The measured fish lengths from the gill-net and push trawls were converted to TS by means of equation (2) and compared with the TS measurements obtained from the acoustic surveys.

Data analysis.—Differences in acoustic data (biomass and TS) and gill-net and push trawl data (biomass) were analyzed separately in a three-way analysis of variance (ANOVA; Proc GLIMMIX; SAS version 9.1.3) to test for the effects of season (winter, spring, summer, and fall), habitat (oyster and soft bottom), and region (GT–QB, MV, and FP). Seasonal means of biomass and TS represent means derived for the monthly surveys conducted within each season. GLIMMIX, a newly developed statistical procedure, fits generalized linear mixed models to data that are either normal or nonnormally distributed (Schabenberger 2005). A benefit of this procedure is the ability to fit raw data to various distributions while adhering to the assumptions of ANOVA. Using GLIMMIX, biomass data were fit to a negative binomial distribution and TS data to the lognormal distribution. In all ANOVA models, the residuals were tested for normality. Tukey's honestly significant difference post hoc test was used to identify differences in means among interactions and main effects along the same scale as the raw data values. All means and standard errors are reported as least-squares means. The linear dependence of gill-net biomass on acoustic biomass estimates was tested with linear regression techniques (Sokal and Rohlf 1995). The TS frequency distributions were compared by region and habitat with the Kolmogorov–Smirnov (K–S) two-sample test (Sokal and Rohlf 1995) and the median test (Zar 1996). All statistical tests were considered significant at $\alpha = 0.05$.

Results

Target Strength Estimates

Target strength estimates were variable across seasons ($P < 0.05$) and habitats ($P < 0.001$), generally decreasing with increasing salinity, although not

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TABLE 1.—Species collected in gill nets during this study.

Family	Species	Small pelagic
Ariidae	Hardhead catfish *Ariopsis felis*	No
	Gafftopsail catfish *Bagre marinus*	No
Belonidae	Atlantic needlefish *Strongylura marina*	No
Carangidae	Crevalle jack *Caranx hippos*	No
	Leatherjack *Oligoplites saurus*	Yes
	Florida pompano *Trachinotus carolinus*	No
Carcharhinidae	Bull shark *Carcharhinus leucas*	No
Clupeidae	Skipjack herring *Alosa chrysochloris*	Yes
	Gulf menhaden *Brevoortia patronus*	Yes
	Gizzard shad *Dorosoma cepedianun*	Yes
	Threadfin shad *Dorosoma petenense*	Yes
	Scaled sardine *Harengula jaguana*	Yes
	Atlantic thread herring *Opisthonema oglinum*	Yes
Elopidae	Ladyfish *Elops saurus*	No
Engraulidae	Striped anchovy *Anchoa hepsetus*	Yes
Gerreidae	Spotfin mojarra *Eucinostomus argenteus*	Yes
Lepisosteidae	Alligator gar *Atractosteus spatula*	No
	Spotted gar *Lepisosteus oculatus*	No
Mugilidae	Striped mullet *Mugil cephalus*	Yes
	White mullet *Mugil curema*	Yes
Paralichthyidae	Southern flounder *Paralichthys lethostigma*	No
Rachycentridae	Cobia *Rachycentron canadum*	No
Sciaenidae	Silver perch *Bairdiella chrysoura*	Yes
	Sand seatrout *Cynoscion arenarius*	No
	Spotted seatrout *Cynoscion nebulosus*	No
	Spot *Leiostomus xanthurus*	Yes
	Southern kingfish *Menticirrhus americanus*	No
	Atlantic croaker *Micropogonias undulatus*	Yes
	Black drum *Pogonias cromis*	No
	Red drum *Sciaenops ocellatus*	No
Scombridae	Spanish mackerel *Scomberomorus maculatus*	No
Sparidae	Sheepshead *Archosargus probatocephalus*	No
	Pinfish *Lagodon rhomboides*	Yes
Trichiuridae	Atlantic cutlassfish *Trichiurus lepturus*	No
Triglidae	Bighead searobin *Prionotus tribulus*	No

significantly ($P = 0.341$; Table 2; Figure 3). Mean target size was lowest during winter (−44.6 ± 0.75 dB) and peaked during the following fall (−42.2 ± 0.74 dB), the spring and summer sizes being intermediate (−42.3 ± 0.75 dB and −44.1 ± 0.81 dB, respectively). The overall estimates of TS indicate that larger fish were more prevalent over oyster shell habitat (−41.9 ± 0.35 dB; approximately 9.2 cm) than soft-bottom habitat (−44.8 ± 0.34 dB; approximately 6.5 cm) and increased moderately, though not significantly, with increasing salinity from −45.9 ± 0.90 dB at FP to −42.6 ± 0.91 dB at GT–QB. The greatest separation in mean fish sizes was observed at MV between oyster shell (−40.5 ± 0.81 dB) and soft-bottom habitat (−45.5 ± 1.07 dB).

Target Strength Distributions

The measured TS distributions were greatly influenced by fish size, a majority (>75%) of the scattering being attributable to targets less than −45 dB (6.4 cm),

TABLE 2.—Analysis of variance of type III fixed effects on acoustic fish biomass and target strength. Significance was set at $\alpha = 0.05$.

	Acoustic biomass		Target strength	
Source	*F*	*P*	*F*	*P*
Season	$F_{3, 298} = 13.12$	<0.001	$F_{3, 298} = 2.74$	0.043
Region	$F_{2, 298} = 10.37$	<0.001	$F_{2, 298} = 1.08$	0.341
Habitat	$F_{1, 298} = 12.43$	<0.001	$F_{1, 298} = 12.87$	<0.001
Station × habitat	$F_{2, 298} = 2.30$	0.1024	$F_{2, 298} = 4.76$	0.009
Season × region	$F_{6, 298} = 6.34$	<0.001	$F_{6, 298} = 2.09$	0.055
Season × habitat	$F_{3, 298} = 3.58$	0.0144	$F_{3, 298} = 1.83$	<0.143
Season × region × habitat	$F_{6, 298} = 9.01$	<0.001	$F_{6, 298} = 3.75$	<0.001

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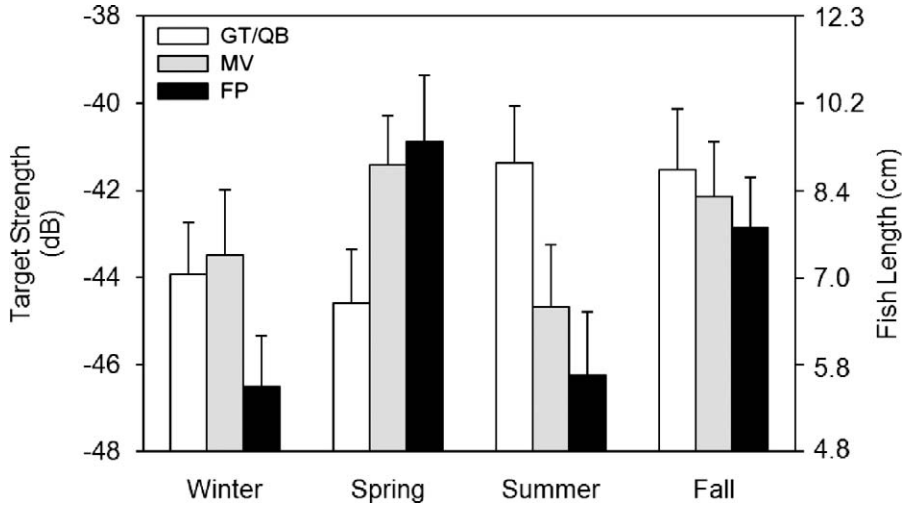


FIGURE 3.—Seasonal target strength and length estimates by region. Lengths were calculated from equation (2); the error bars represent standard errors.

which indicates that more than 95% of the fish sampled were smaller than 15 cm (−36 dB; Figure 4). Differences in TS distributions were not observed between habitat types (K–S test: $P = 0.999$; median test: $P = 0.483$). However, significant differences were observed when comparing TS distributions among regions, GT–QB having a greater proportion of smaller fish than FP (K–S test: $P = 0.038$; median test: $P < 0.005$) and MV not differing significantly from the other two regions.

The fish length distributions obtained from net sampling and converted to TS following Frouzova et al. (2005) showed moderate concordance with the measured TS distributions (Figure 5). Although the peaks in length frequency often did not overlap between the gill-net and push trawl distributions, when the two gear types were available they extended the

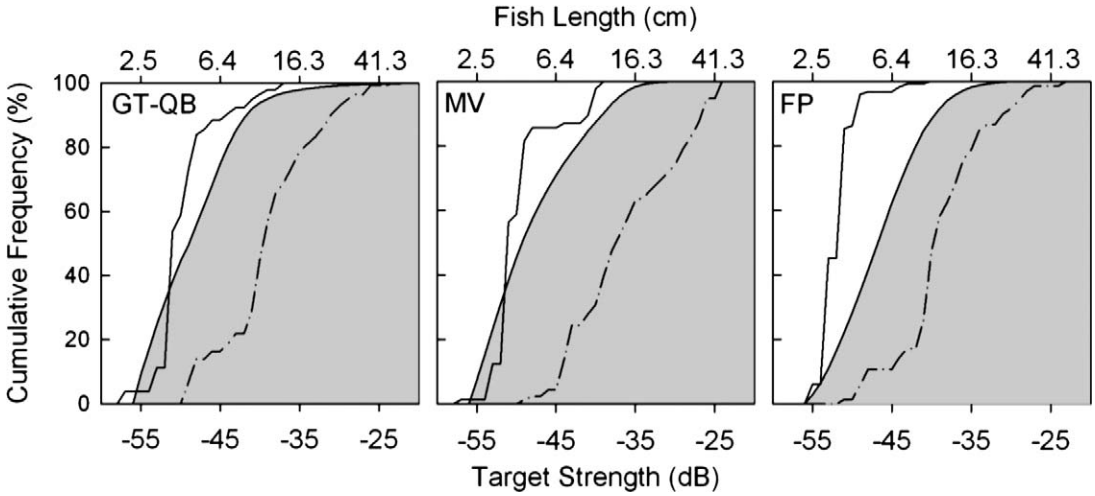


FIGURE 4.—Cumulative target strength frequency distributions by region. The shaded area represents the measured distribution derived from acoustic data, the solid line the distribution estimated from push trawl catch data, and the dashed line the distribution estimated from gill-net catch data.

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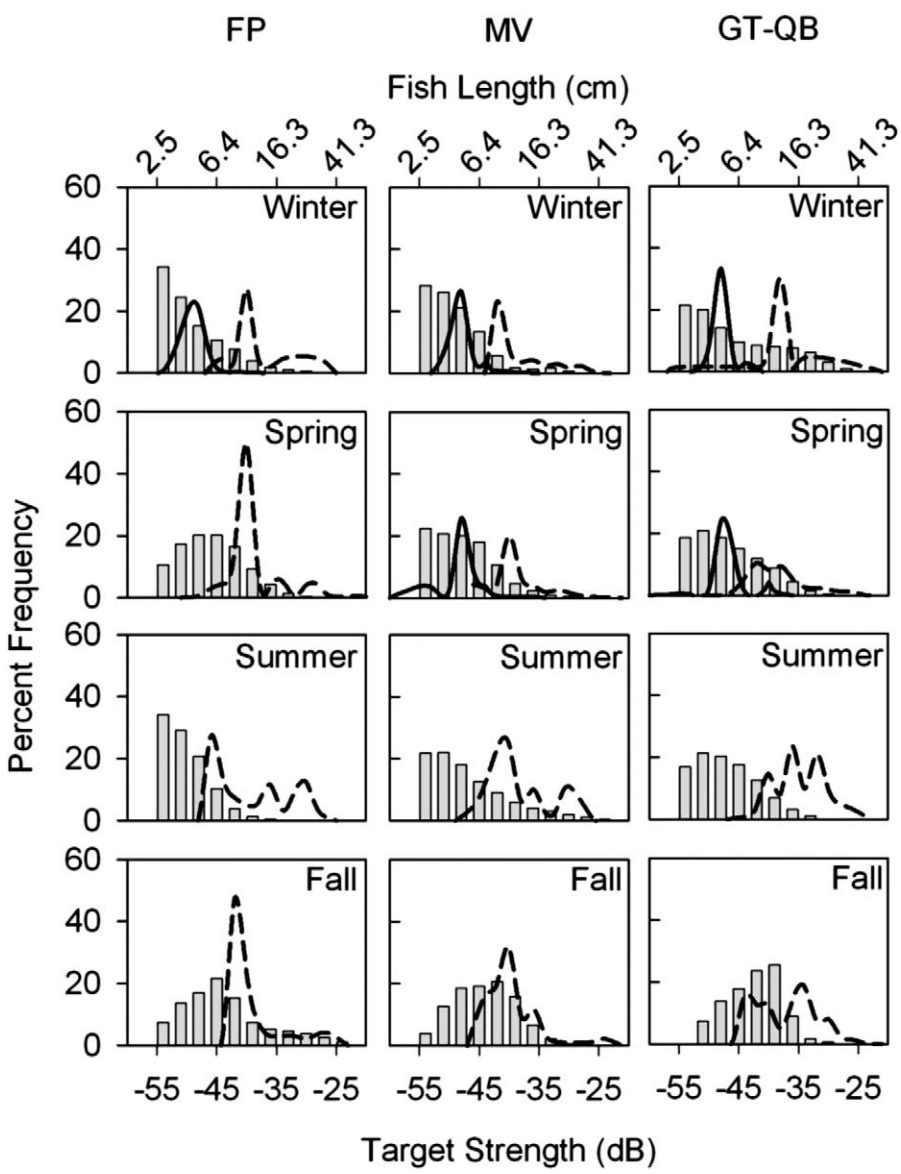


FIGURE 5.—Target strength frequency distributions by region and season. The bars represent measured distributions derived from acoustic data, the solid lines distributions estimated from push trawl catch data, and the dashed lines distributions estimated from gill-net catch data. Push trawls were only conducted in winter and spring (only winter for FP).

range of a majority of the measured target strength distributions.

Acoustic Biomass Estimates

Mean biomass varied significantly as a function of season, region, and habitat, as did most of the interactions among the main effects (Table 2). Seasonal estimates of biomass were greatest during fall (2.30 ± 0.27 g/m^3), followed by spring (1.49 ± 0.20 g/m^3), with relatively low biomass during summer (0.70 ± 0.14 g/m^3) and winter (0.86 ± 0.14 g/m^3). Oyster habitat supported greater biomass (1.54 ± 0.15 g/m^3; $P < 0.001$) than soft-bottom habitat (0.94 ± 0.11 g/m^3); the greatest biomass was observed at GT–QB (1.78 ± 0.19 g/m^3), followed by MV (1.18 ± 0.15 g/m^3) and FP (0.82 ± 0.12 g/m^3). The interactions among seasonal estimates did not show consistent trends across surveys regions (Figure 6); however, except in

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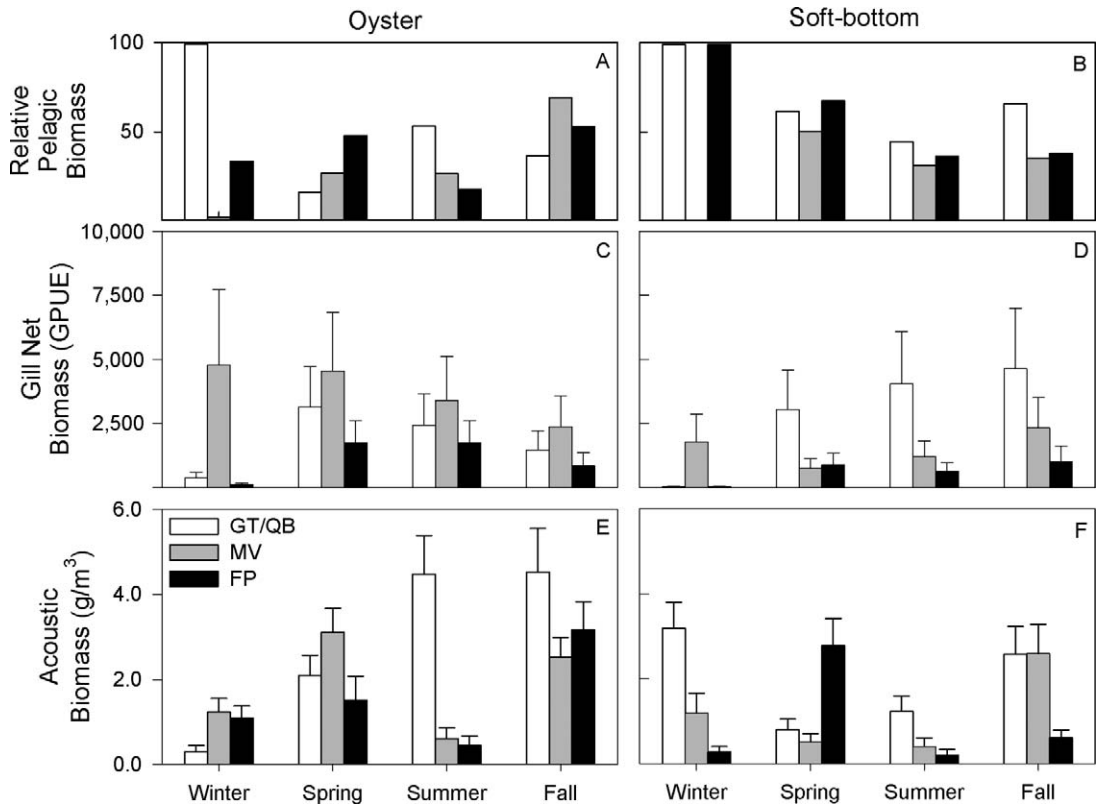


FIGURE 6.—Seasonal plots of fish biomass derived from **(A)–(D)** gill-net and **(E)–(F)** acoustic data, by habitat type and region. Relative biomass (the proportion of total biomass comprised of small pelagic fish) is compared with total fish biomass from gill-net catches (grams per unit effort [gpue]) and acoustic biomass. The error bars represent standard errors.

winter biomass was generally greater over oyster habitat (Figure 7) owing to the high abundance of small-schooling fish (mostly bay anchovy *Anchoa mitchilli* and Gulf menhaden) over soft-bottom habitat.

Gill-Net Collections

Mean fish biomass differed significantly among seasons, stations, and habitats, with some significant interactions (Table 3; Figures 6, 7). Gill-net biomass was lowest during the winter (257.1 ± 65.3 gpue) and relatively high in spring (1,912.5 ± 394.9 gpue), summer (1,873.7 ± 386.9 gpue) and fall (1,771.5 ± 395.1 gpue). Among regions, biomass was greatest at the mesohaline MV (241.7 ± 425.1 gpue) than at both the high-salinity GT–QB (1,246.7 ± 236.9 gpue) and the low-salinity FP (516.6 ± 103.5 gpue) stations. We observed a greater mean biomass over oyster habitats (1,543.5 ± 243.5 gpue) than soft-bottom habitats (827.7 ± 130.8 gpue).

When one extracts the contribution of small pelagic fish from the total biomass estimate (Figures 6, 7), temporal variability in the proportion of pelagic biomass is evident. For example, during the winter the contribution at GT–QB over soft-bottom habitat was 100% and corresponded to a peak in acoustic biomass. The trends among seasons were similar between small pelagic fish and all fish combined. Gill-net biomass was lowest during the winter (53.9 ± 14.9 gpue) and relatively high in fall (846.1 ± 207.2 gpue), spring (774.3 ± 175.5 gpue), and summer (620.3 ± 140.7 gpue). The trend toward greater biomass over oyster habitat was similar for small pelagic fish and all fish combined, although not significant (467.3 ± 81.0 gpue over oyster habitat and 315.2 ± 54.8 gpue over soft-bottom habitat). However, there were differences among regions, the greatest biomass occurring at GT–QB (654.3 ± 136.5 gpue), followed by MV (378.5 ± 79.1 gpue) and FP (228.3 ± 50.2 gpue). The differences in biomass between the two groups of fish were due to the collection of less abundant but larger fish, including

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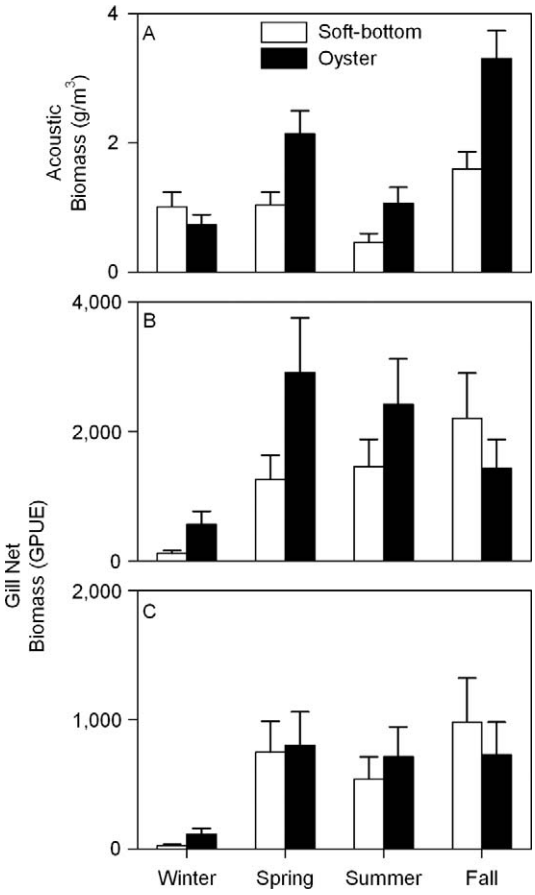


FIGURE 7.—Seasonal fish biomass estimates by habitat type in Barataria Bay illustrating the differences between **(A)** estimates from acoustic data, **(B)** estimates for all fish from gill-net data, and **(C)** estimates for small pelagic fish from gill-net data. The error bars represent standard errors.

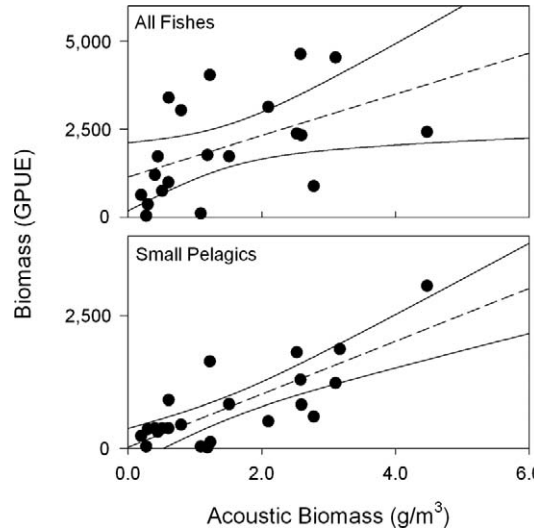


FIGURE 8.—Regressions of biomass estimates derived from gill-net data on those derived from acoustic data for all fish and small pelagic fish across seasons, sites, and habitats. The regressions (dashed lines) explained 28% (all fish, $P = 0.028$) and 62% (pelagic fish, $P = 0.005$) of the variation between the two sets of estimates; the solid lines represent the 95% confidence intervals.

sheepshead, hardhead catfish, and black drum, over oyster habitat (Tables 4, 5).

In addition to the general trends in biomass estimates between acoustic and gill-net data (Figures 6, 7), we found a positive linear relationship between the biomass estimates from gill nets and acoustics (Figure 8). The relationship was much better for small pelagic biomass ($r^2 = 0.62$; $P = 0.005$) than for all fish biomass ($r^2 = 0.24$; $P = 0.028$).

Push Trawl Collections

The results from the push trawl collections were largely inconclusive given the high degree of variability (mean CV [100 • SD/mean] = 150) in catch across all main effects (Table 3), although some trends in mean biomass were consistent across both the acoustic and gill-net data. Bay anchovy consistently dominated the push trawl catches in most regions, whereas the gill-net

TABLE 3.—Analysis of variance of type III fixed effects on fish biomass estimates from gill-net and push trawls. All tests were significant at the 0.05 level.

	Gill net					
	All fish		Small pelagic fish		Push trawl	
Source	*F*	*P*	*F*	*P*	*F*	*P*
Season	$F_{3, 104} = 16.42$	<0.001	$F_{3, 104} = 24.15$	<0.001	$F_{3, 32} = 0.02$	0.885
Region	$F_{2, 104} = 14.26$	<0.001	$F_{2, 104} = 6.05$	0.003	$F_{2, 32} = 0.19$	0.830
Habitat	$F_{1, 104} = 7.79$	0.006	$F_{1, 104} = 2.57$	0.116	$F_{1, 32} = 0.06$	0.806
Station × habitat	$F_{2, 104} = 0.88$	0.419	$F_{2, 104} = 2.75$	0.068	$F_{2, 32} = 1.05$	0.312
Season × region	$F_{6, 104} = 5.93$	<0.001	$F_{6, 104} = 0.75$	0.609	$F_{6, 32} = 0.72$	<0.404
Season × habitat	$F_{3, 104} = 3.16$	0.028	$F_{3, 104} = 2.18$	0.095	$F_{3, 32} = 0.00$	0.999
Season × region × habitat	$F_{6, 104} = 1.13$	0.348	$F_{6, 104} = 1.39$	0.226		

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TABLE 4.—Percent species abundance in gill-net and push trawl catches by region. Only the four most prevalent species are shown for each gear type. Regions are as follows: FP = Fisherman's Point, MV = Manila Village, and GT–QB = Grand Terre–Queen Bess islands (see Figure 1).

	Gill net			Push trawl		
Region	Species	Count	Percent	Species	Count	Percent
FP	Gulf menhaden	290	66.1	Bay anchovy	200	85.8
	Hardhead catfish	36	8.2	Gulf menhaden	27	11.6
	Ladyfish	30	6.8	Rough silverside *Membras martinica*	2	0.9
	Atlantic croaker	20	4.6	Atlantic croaker	2	0.9
	Total	439			233	
MV	Gulf menhaden	388	49.5	Bay anchovy	409	79.6
	Atlantic thread herring	60	7.7	Sand seatrout	44	8.6
	Spot	58	7.4	Rough silverside	16	3.1
	Spotted seatrout	41	5.2	Least puffer *Sphoeriodes parvus*	24	4.7
	Total	784			514	
GT–QB	Gulf menhaden	294	35.6	Bay anchovy	204	86.8
	Atlantic croaker	84	10.2	Blue crab *Callinectes sapidus*	1	0.5
	Spot	83	10.1	Penaeid shrimp *Farfantepenaeus* spp.	1	0.5
	Sand seatrout	67	8.1	Rough silverside	27	11.5
	Total	826			235	

catches were dominated by Gulf menhaden in all regions (Tables 4, 5). The combined data from both gear types reflected consistently higher proportional abundances of bay anchovy (>65%) and Gulf menhaden (>25%) than for all of the other species captured.

Discussion

Biases are undoubtedly associated with each of the collection methods. Traditional sampling techniques such as gill nets and push trawls are influenced by the size, movement, and behavior of fish (Hubert and O'Shea 1992; Hayes et al. 1996; Hubert 1996). Multiple fishing gears were chosen to provide a more complete description of habitat use in Barataria Bay than could have been achieved using only one type of gear. We included the acoustic techniques in an effort to assess the feasibility of comparing biomass indices across multiple gear types and to acquire high-resolution information on the size and biomass of the fish associated with estuarine habitats. We adopted a stationary sampling design because previous work in shallow environments had suggested that there were strong biases in mobile acoustic surveys stemming from avoidance (Kubecka and Wittingerova 1998; Knudsen and Sægrov 2002; Krumme and Saint-Paul 2003).

The TS distributions derived from the gill-net and push trawl data often exceeded the measured TS values. Further, the cumulative frequency distributions indicated that a majority of the scattering was due to fish with low TSs (i.e., smaller targets). At least three factors may have contributed to these discrepancies: (1) proportionally, larger fish are less likely to be detected in the acoustic volume than smaller fish; (2) the ability

TABLE 5.—Percent species abundance of gill-net and push trawl catches by habitat type. Only the four most prevalent species are shown for each gear type.

	Gill net			Push trawl		
Habitat	Species	Count	Percent	Species	Count	Percent
Soft bottom	Gulf menhaden	504	47.9	Bay anchovy	454	83.6
	Spot	102	9.7	Sand seatrout	19	3.5
	Sand seatrout	78	7.4	Rough silverside	28	5.2
	Atlantic croaker	65	6.2	Least puffer	13	2.4
	Total	1052			543	
Oyster	Hardhead catfish	60	6.3	Bay anchovy	409	81.8
	Silver perch	66	7.0	Gulf menhaden	44	5.2
	Gulf menhaden	450	47.6	Sand seatrout	16	5.7
	Atlantic thread herring	63	6.7	Rough silverside	24	3.9
	Total	946			439	

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to ensonify benthic-associated fish (generally the larger fish captured in gill nets, such as black drum, red drum, and hardhead catfish) is reduced by the conical shape of the beam and the difficulty of surveying along the sediment–water interface (Trevorrow 1998); and (3) the lack of orientation-specific TS–SL equations limits our ability to estimate fish length when tracking fish moving in directions other than perpendicular to the beam axis. Despite this, fish biomass estimates derived from acoustic data are useful as an index of the changes in relative biomass (Yule 2000; Boswell et al. 2007). Following Boswell et al. (2007), we recognize that the calculation of biomass is inherently biased because S_v is a measure of all of the scattering within a volume of water—not that specific to individual fish or size ranges—and is dependent on TS, which can vary with orientation and fish condition (Ona 1990; Simmonds and MacLennan 2005). The conversion of TS into an appropriate estimate of SL relies on the proper scaling between TS and SL. The TS–SL relationship in Frouzova et al. (2005) was derived from fish of similar morphologies at all horizontal aspects and at a lower frequency (120 kHz). This probably contributed to the conservative length distributions obtained in this study. While our gill nets were effective at sampling medium-size to larger fish (because of the mesh sizes employed), they were only moderately effective at capturing smaller individuals, which we believe accounted for a significant fraction (>75%) of the observed acoustic scattering. These results provide compelling evidence of the greater effectiveness of using multiple gear types to sample the nekton community, particularly for smaller, more pelagic fish, further supporting the premise that the results of single-gear surveys (including hydroacoustic gears) give misleading results (Jackson and Harvey 1997; Wells et al. 2008).

Season, region, and habitat were all important determinants of fish biomass in Barataria Bay. The differences in biomass among seasons and regions were probably influenced by physiochemical variables such as temperature and salinity, both of which varied significantly among seasons and regions during this study (MacRae 2006). These results are consistent with those of other studies that have found estuarine assemblage structure to be associated with seasonal movement and migration patterns related to environmental conditions (Rakocinski et al. 1992; Rozas and Zimmerman 2000; Granados-Dieseldorff and Baltz 2008). Additionally, catches of species such as Gulf menhaden (a species that dominated our biomass estimates) are known to vary seasonally, primarily because they migrate offshore during late fall to overwinter and reproduce (Patillo et al. 1997). Given that seasonal physiochemical conditions and spatial gradients are known to affect the distribution of fish in shallow-water estuaries (Peterson and Ross 1991; Gelwick et al. 2001; Akin et al. 2003), it was not surprising that we found seasonal and regional variations in biomass along the salinity gradient in Barataria Bay.

In general, our biomass estimates were higher over oyster habitats than soft-bottom habitats, although the trends were not consistent among all region × habitat interactions. The literature suggests that oyster reef communities of fish and macroinvertebrates are often highly diverse and include many species that are never or only rarely found in adjacent soft-bottom habitats (see Coen et al. 1999). Although an association between fish and oyster habitat has been demonstrated (Coen et al. 1999; Lenihan et al. 2001; Lehnert and Allen 2002), the relative value of such habitat to fish is uncertain. Given the presumed ecosystem function of oyster reefs and their importance to fish (as areas for feeding, reproduction, and recruitment, as well as refugia; Coen et al. 1999; Harding and Mann 2001; Lehnert and Allen 2002), it is not surprising that the overall fish biomass estimates were generally higher at oyster habitat. The greater fish biomass associated with oyster habitat may be attributed to its complex three-dimensional substrate, which can be utilized for settlement and feeding, as well as refugia (Coen et al. 1999; Coen and Luckenbach 2000; Mann 2000;Peterson et al. 2003).

Greater fish biomass was observed over oyster habitat in the mesohaline region (MV) than at GT–QB and FP. It may be that the live, seeded and harvested, high-density production reefs at MV offer more complex and favorable habitat to fish than the low-relief, less dense reefs at GT–QB and FP. However, in their study of European estuaries using a semiquantitative habitat utilization index that compared fish use over all life stages among nine discrete habitat types, Elliott and Hemmingway (2002) found that soft-bottom substrates were more than six times more important as biogenic habitat for estuarine fishes. In fact, soft-bottom habitats were found to be the most important of all the habitats compared, in part because of their relative abundance in estuaries. If total biomass is the metric of concern, the Barataria Bay data would produce results much like those reported in Elliott and Hemmingway (2002).

Inspection of the echograms from the acoustic surveys, the compositional data from the gill-net and push trawl collections, and the observed differences among biomass suggests that small pelagic fish are dominant in abundance but not necessarily in biomass. This was the case when a few large species such as

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sheepshead, hardhead catfish, or black drum accounted for most of the biomass while Gulf menhaden were the most numerous. Many small-bodied schooling species were present (e.g., bay anchovy, Gulf menhaden, rough silverside, Atlantic croaker, and spot; Rakocinski et al. 1992; Rozas and Minello 1998; Rozas and Zimmerman 2000; Granados-Dieseldorff and Baltz 2008) and probably contributed to the scattering we observed, particularly given their abundance in the gill-net and push trawl collections and the occurrence of smaller targets in the length distributions. These results suggest that there are similar trends in biomass in the acoustic and gill-net data and support the utility of a multiple-gear approach .

Acoustics should be viewed as a tool for making a rapid and noninvasive assessment of the temporal and spatial changes in the distribution of fish biomass (McClatchie and Dunford 2003; Boswell et al. 2007) and may serve to provide the information required for the designation of EFH. Research suggests that estuarine habitats are mosaics of discrete habitats utilized by various mobile species (Lindberg et al. 1990; McCoy and Bell 1991; Lehnert and Allen 2002); given the complexity of the interactions along seasonal, physical, and environmental gradients, efforts to identify or isolate essential habitats may be misdirected. Hubert and O'Shea (1992) suggested that habitat selection is driven by the resources available and the immediate needs of an individual, so that the mere selection of a particular habitat does not mean that it is essential. Therefore, it may be more prudent to focus on understanding habitat function within a multi–fish species life history context. For example, efforts to determine EFH could be expanded to include ecosystem benefits in addition to those for individual species.

To make effective use of the concept of EFH, a universal standard must be developed, and acoustics could be useful in establishing baseline biomass data for comparisons within and between estuarine systems. Clearly, there is a need for further developing acoustics as a tool for estimating fish distributions in estuarine waters, particularly since it is well known that estuaries play a critical role as nursery habitat and serve as refugia for many fish species (Boesch and Turner 1984; Minello 1999; Zimmerman et al. 2000; Dahlgren et al. 2006). Through proper development and use, acoustics could be useful for quantifying estuarine flux and assessing the production potential of habitats thought to be necessary for optimal fish survival and growth. Acoustics will complement sampling efforts in evaluating habitat importance and could be useful in identifying and monitoring ecosystem reference points and standardizing the methods of ecosystem-based management.

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References

Able, K. 1999. Measures of juvenile fish habitat quality: examples from a national estuarine research reserve. Pages 134–147 *in* L. Benaka, editor. Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Symposium 22, Bethesda, Maryland.

Akin, S., K. O. Winemiller, and F. P. Gelwick. 2003. Seasonal and spatial variations in fish and macrocrustacean assemblage structure in Mad Island Marsh estuary, Texas. Estuarine Coastal and Shelf Science 57:269–282.

Allen, Y. C., C. A. Wilson, H. R. Roberts, and J. Supan. 2005. High-resolution mapping and classification of oyster habitats in nearshore Louisiana using sidescan sonar. Estuaries 28:435–446.

Barras, J. A., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnson, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayada. 2003. Historical and projected coastal Louisiana land changes: 1978–2050. U.S. Geological Survey, Open File Report 03-334, New Orleans, Louisiana.

Benaka, L., editor. 1999. Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Symposium 22, Bethesda, Maryland.

Bethke, E., F. Arrhenius, M. Cardinale, and N. Hakansson. 1999. Comparison of the selectivity of three pelagic sampling trawls in a hydroacoustic survey. Fisheries Research 44:15–23.

Boesch, D. F., and R. E. Turner. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. Estuaries 7:460–468.

Boswell, K. M., M. P. Wilson, and C. A. Wilson. 2007. Hydroacoustics as a tool for assessing fish biomass and size distribution associated with discrete shallow-water estuarine habitats in Louisiana. Estuaries and Coasts 30:607–617.

Coen, L. D., M. W. Luckenbach, and D. L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. Pages 438–454 *in* L. Benaka, editor. Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Symposium 22, Bethesda, Maryland.

Coen, L. D., and M. W. Luckenbach. 2000. Developing success criteria and goals for evaluating oyster reef restoration: ecological function or resource exploitation? Ecological Engineering 15:323–343.

Conner, W. H., and J. W. Day. 1987. Description of the basin. Pages 1–7 *in* W. H. Conner and J. W. Day, editors. The

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ecology of Barataria basin, Louisiana. U.S. Fish and Wildlife Service Biological Report 85 (7.13).

Dahl, T. E. 2000. Status and trends of wetlands in the conterminous United States, 1986 to 1997. U.S. Fish and Wildlife Service, Washington, D.C.

Dahlgren, C. P., G. T. Kellison, A. J. Adams, B. M. Gillanders, M. S. Kendall, C. A. Layman, J. A. Ley, I. Nagelkerken, and J. E. Serafy. 2006. Marine nurseries and effective juvenile habitats: concepts and applications. Marine Ecology Progress Series 312:291–295.

Elliott, M., and K. L. Hemmingway, editors. 2002. Fishes in estuaries. Wiley–Blackwell, New York.

Fabi, G., and A. Sala. 2002. An assessment of biomass and diel activity of fish at an artificial reef (Adriatic Sea) using a stationary hydroacoustic technique. ICES Journal of Marine Science 59:411–420.

Field, D. W., A. Reyer, P. Genovese, and B. Shearer. 1991. Coastal wetlands of the United States: an accounting of a valuable national resource. National Oceanic and Atmospheric Administration, Rockville, Maryland.

Foote, K.G., H. P. Knudsen, G. Vestnes, D. N. MacLennan, and E. J. Simmonds. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report 144.

Frouzova, J., J. Kubecka, H. Balk, and J. Frouz. 2005. Target strength of some European fish species and its dependence on fish body parameters. Fisheries Research 5: 86–96.

Gelwick, F. P., S. Akin, D. A. Arrington, and K. O. Winemiller. 2001. Fish assemblage structure in relation to environmental variation in a Texas Gulf coastal wetland. Estuaries 24:285–296.

Granados-Dieseldorff, P., and D. M. Baltz. 2008. Habitat use by nekton along a stream-order gradient in a Louisiana estuary. Estuaries and Coasts 31:572–583.

Guillard, J. 1998. Daily migration cycles of fish populations in a tropical estuary (Sine-Saloum, Senegal) using a horizontal-directed split-beam transducer and multibeam sonar. Fisheries Research 35:21–29.

Hansson, S., and L. G. Rudstam. 1995. Gill-net catches as an estimate of fish abundance: a comparison between vertical gill-net catches and hydroacoustic abundances of Baltic Sea herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). Canadian Journal of Fisheries and Aquatic Sciences 52:75–83.

Harding, J. M., and R. Mann. 2001. Diet and habitat use by bluefish, *Pomatomus saltatrix*, in Chesapeake Bay estuary. Environmental Biology of Fishes 60:401–409.

Hayes, D. B., C. P. Ferreri, and W. W. Taylor. 1996. Active-capture techniques. Pages 193–220 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Houde, E. D., and E. S. Rutherford. 1993. Recent trends in estuarine fisheries: predictions of fish production and yield. Estuaries 16:161–176.

Hubert, W. A. 1996. Passive-capture techniques. Pages 157–192 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Hubert, W. A., and D. T. O'Shea. 1992. Use of spatial resources by fishes in Grayrocks Reservoir, Wyoming. Journal of Fresh Water Ecology 7:219–225.

Jackson, D. A., and H. H. Harvey. 1997. Qualitative and quantitative sampling of lake fish communities. Canadian Journal of Fisheries and Aquatic Sciences 54:2807–2813.

Knudsen, F. R., and H. Sægrov. 2002. Benefits from horizontal beaming during acoustic survey: application to three Norwegian lakes. Fisheries Research 56:205–211.

Krumme, U., and U. Saint-Paul. 2003. Observations of fish migration in a macrotidal mangrove channel in northern Brazil using a 200-kHz split-beam sonar. Aquatic Living Resources 16:175–184.

Kubecka, J., and M. Wittingerova. 1998. Horizontal beaming as a crucial component of acoustic fish stock assessment in freshwater reservoirs. Fisheries Research 35:99–106.

Lehnert, R. L., and D. M. Allen. 2002. Nekton use of subtidal oyster shell habitat in a southeastern U.S. estuary. Estuaries 25:1015–1024.

Lenihan, H. S., C. H. Peterson, J. E. Byers, J. H. Grabowski, G. W. Thayer, and D. R. Colby. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. Ecological Applications 11:764–782.

LDWF (Louisiana Department of Wildlife and Fisheries). 2006. 2005–2006 annual report. LDWF, Baton Rouge.

Lindberg, W. J., T. K. Frazer, and G. R. Stanton. 1990. Population effects of refuge dispersion for adult stone crabs (Xanthidae, *Menippe*). Marine Ecology Progress Series 66:239–249.

Mackinson, S., S. Freeman, R. Flatt, and B. Meadows. 2004. Improved acoustic surveys that save time and money: integrating fisheries and ground-discrimination acoustic technologies. Journal of Experimental Marine Biology and Ecology 305:129–140.

MacRae, P. S. D. 2006. A community approach to indentifying essential fish habitat of spotted seatrout, *Cynoscion nebulosus*, in Barataria Bay, Louisiana. Doctoral dissertation. Louisiana State University, Baton Rouge.

Mann, K. H. 2000. Ecology of coastal waters, with implications for management, 2nd edition. Blackwell Scientific Publications, Oxford, UK.

McClatchie, S., and A. Dunford. 2003. Estimated biomass of vertically migrating mesopelagic fish off New Zealand. Deep-Sea Research I 50:1263–1281.

McCoy, E. D., and S. S. Bell. 1991. Habitat structure: the evolution and diversification of a complex topic. Pages 3–27 *in* S. S. Bell, E. D. McCoy, and H. R. Mushinsky, editors. Habitat structure: the physical arrangement of objects in space. Chapman and Hall, London.

MacLennan, D. N., P. G. Fernandes, and J. Dalen. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science 59:365–369.

McQuinn, I. H., Y. Simard, T. W. F. Stroude, J. Beaulieu, and S. J. Walsh. 2005. An adaptive, integrated "acoustic-trawl" survey design for Atlantic cod (*Gadus morhua*) with estimation of the acoustic and trawl dead zones. ICES Journal of Marine Science 62:93–106.

Minello, T. J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. Pages 43–75 *in* L. Benaka, editor. Fish habitat: essential fish habitat and rehabilitation.

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American Fisheries Society, Symposium 22, Bethesda, Maryland.

Mitsch, W. J., and J. G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold: New York.

NOAA (National Oceanic and Atmospheric Administration). 2009. Commercial fishery landings. Available: http://www.st.nmfs.noaa.gov/. (December 2009.)

Ona, E. 1990. Physiological factors causing natural variations in acoustic target strength of fish. Journal of the Marine Biological Association of the UK 70:107–127.

Patillo, M. E., T. E. Czapla, D. M. Nelson, and M. E. Monaco. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, volume 2: species life history summaries. ELR Report 11, NOAA/NOS SEA Division, Silver Spring, Maryland.

Peterson, C. H., J. H. Grabowski, and S. P. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation. Marine Ecology Progress Series 364:249–264.

Peterson, M. S., and S. T. Ross. 1991. Dynamics of littoral fishes and decapods along a coastal river–estuarine gradient. Estuarine, Coastal, and Shelf Science 33:467–483.

Plunket, J., and M. K. LaPeyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. Bulletin of Marine Science 77:155–164.

Rakocinski, C. F., D. M. Baltz, and J. W. Fleeger. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. Marine Ecology Progress Series 80:135–148.

Rozas, L. P., and T. J. Minello. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. Bulletin of Marine Science 63:481–501.

Rozas, L. P., and R. J. Zimmerman. 2000. Small-scale patterns of nekton use among marsh and adjacent shallow nonvegetated areas of the Galveston Bay estuary, Texas, United States. Marine Ecology Progress Series 193:217–239.

Subrahmanyam, C. B., and C. L. Coultas. 1980. Studies on the animal communities in two north Florida salt marshes, part III. Seasonal fluctuations of fish and macroinvertebrates. Bulletin of Marine Science 30:790–818.

Schabenberger, O. 2005. Introducing the GLIMMIX procedure for generalized linear mixed models. SAS Institute, Paper 196-30, Cary, North Carolina.

Simmonds, E. J., and D. N. MacLennan. 2005. Fisheries acoustics: theory and practice, 2nd edition. Blackwell Scientific Publications, Oxford, UK.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research, 3rd edition. Freeman, New York.

Trevorrow, M. V. 1998. Boundary scattering limitations to fish detection in shallow waters. Fisheries Research 35:127–135.

Wells, R. J. D., K. M. Boswell, J. H. Cowan, and W. F. Patterson. 2008. Size selectivity of sampling gears targeting red snapper in the northern Gulf of Mexico. Fisheries Research 89:294–299.

Yule, D. 2000. Comparison of horizontal acoustic and purse-seine estimates of salmonid densities and sizes in eleven Wyoming waters. North American Journal of Fisheries Management 20:759–775.

Zar, J. H. 1996. Biostatistical analysis, 3rd edition. Prentice-Hall, Upper Saddle River, New Jersey.

Zimmerman, R. J., T. J. Minello, and L. P. Rozas. 2000. Salt marsh linkages to productivity of penaeid shrimps and blue crabs in the northern Gulf of Mexico. Pages 293–315 *in* M. P. Weinstein and D. A. Kreeger, editors. Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Dordrecht, Netherlands.

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