SAMPLING SHAD IN SOUTHERN IMPOUNDMENTS

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INTRODUCTION

Management of fishery resources in public waters has been evolving from single-species approaches to those based on trophic relationships within the ecosystem. Forage fish management strategies initiated in the 1950's moved fisheries science from consideration of single-species predator management to consideration of both predator and prey. The development of bioenergetics models over the past 15 years has greatly enhanced our understanding of these relationships and has shown great promise in addressing routine fisheries management questions. The utility of these models is constrained, in part, by the accuracy of the field data used to develop and test them.

Gizzard shad and threadfin shad are the primary prey species in southern reservoirs. Unfortunately, reliability of methods for sampling shad populations currently lags behind our need to better understand predator-prey dynamics. Little research has been aimed at evaluating the efficiency of sampling gears. Hayne et al. (1967) and Aggus et al. (1980) evaluated the use of rotenone to sample coves. Johnson et al. (1988) compared density estimates from a Tucker trawl, seine, and shoreline rotenone quadrats. Michaletz (in press) compared catch data for gizzard shad collected by electrofishing and gill netting. Midwater trawls, first used for sampling shad in the mid-1960's (Houser and Dunn 1967), provided more precise estimates of shad abundance in a North Carolina reservoir than those obtained with cove rotenone sampling (Siler et al. 1986). Hydroacoustic technology is being developed to quantify pelagic fish populations; however, hydroacoustic sampling protocol for estimating shad abundance and size structure is unavailable.

The paucity of published information on shad sampling methodologies prompted us to design a study to determine the relative effectiveness of several sampling techniques for estimating abundance and size distribution of gizzard shad and threadfin shad populations. Six sampling methods, including hydroacoustics, electrofishing, gill nets, rotenone, seines, and midwater trawls, were used concurrently to obtain data from three sites on Lake Texoma, Oklahoma-Texas, in August, 1991 (Figure 1). Shad were collected to compare density estimates, precision, and length-frequency distributions among gear types. Sampling characteristics of individual gears also were evaluated to define sample-size requirements, interpret spatial patterns of shad abundance, and recommend gear and sampling improvements.

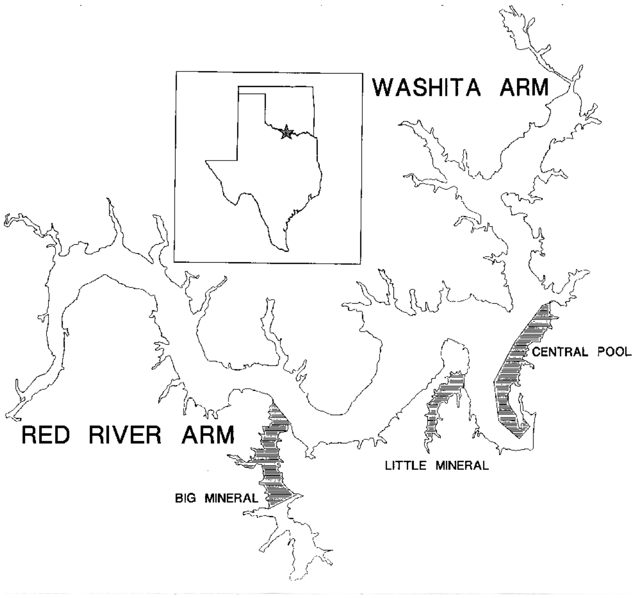

Figure 1. Map of study sites used in the shad sampling evaluation on Lake Texoma, Oklahoma-Texas, 1991.

This booklet is intended to provide fisheries researchers and managers with some general guidelines in developing a shad sampling protocol suited to their specific needs. Gear-specific results will be presented and recommendations as to sample design will be made. A detailed description of the methods and results of this study can be found in a series of eight manuscripts published in the North American Journal of Fisheries Management, Volume 15(4).

HYDROACOUSTICS

Hydroacoustic techniques have proven reliable in sampling pelagic fish communities in marine environments and in the Great Lakes. Advantages of hydroacoustics over more conventional gears, i.e. trawls, include analysis of small scale variation in horizontal and vertical distribution due to the continuous nature of data recording and the large sampling volume relative to other sampling methods. The objectives of this study were to compare abundance and distribution estimates of pelagic fish relative to several hydroacoustic frequencies, to examine among-and within-transect variation in shad distribution, and to make recommendations concerning sampling designs to incorporate density differences noted for shad in other large reservoirs.

Sampling was conducted using a single vessel equipped with four dual-beam acoustic units (38, 120, 200, and 430 kHz). Samples were collected during the day and night in each study site. Each sample consisted of 20 500-m transects. Due to surface interference, the hydroacoustic equipment sampled the water column from approximately 2 m to 1 m above the bottom.

More than 95% of all fish captured by trawls in the three study sites were threadfin shad and were most likely the predominant pelagic fish species sampled by hydroacoustics. Density estimates (number/m^3) varied among frequencies, sites, and between day and night samples. Density estimates from the 120 and 200 kHz transducers were similar. The wavelength of the 38 kHz system made it unsuitable for sampling age-0 pelagic fish and the 420 kHz system may overestimate fish density in productive reservoirs where plankton and *Chaoborus* densities are high. Shad density estimates with the associated coefficient of variation using the 120 and 200 kHz transducers are shown in Table 1.

Shad densities were found to be highest in Big Mineral, followed by Little Mineral, and the Central Pool. Night density estimates were higher than daylight estimates at all sites. Within-transect variation was lower at night than during the day.

Table 1. Mean densities (number/1000 m^3 and number/hectare) of shad sp. and coefficients of variation (in parentheses) estimated from two hydroacoustic frequencies at three sites on Lake Texoma, Oklahoma-Texas, 1991. Densities without the same letter are significantly different at $P < 0.05$.

	Number/1000 m^3		Number/hectare	
Site	120 kHz	200 kHz	120 kHz	200 kHz
Central Pool (day)	22(120) a	31(116) a	4709(139)	5261(125)
Central Pool (night)	93(36) b	132(44) b	18946(40)	26121(44)
Little Mineral (day)	66(85) ab	96(98) b	5924(84)	7944(121)
Little Mineral (night)	338(70) c	508(54) d	24772(54)	44719(43)
Big Mineral (day)	146(57) b	265(91) bc	9332(50)	17429(76)
Big Mineral (night)	484(32) d	561(27) d	36742(45)	47224(44)

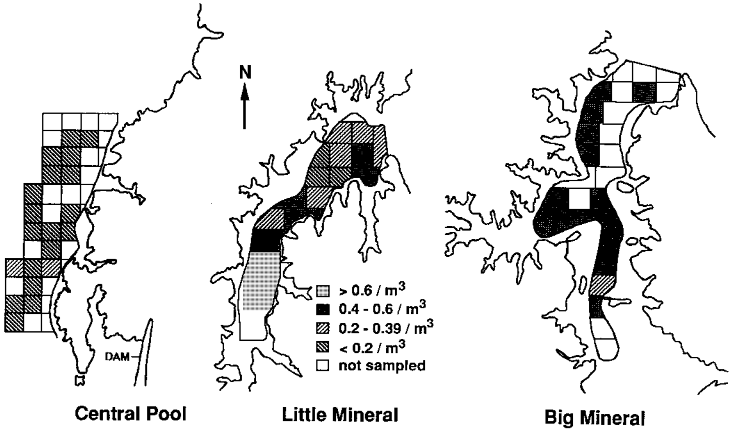

Figure 2. Distribution of density estimates (number/m^3) at night using a 200 kHz transducer from three sites on Lake Texoma, Oklahoma-Texas, 1991.

Shad exhibited a schooling behavior during the day (targets were aggregated into small, dense clumps often separated by tens of meters). At night, targets were aggregated, but the areal size of the aggregation was larger and closer together than during the day, i.e. targets were more dispersed over the sites. As the shad become more dispersed, individual target detection improves thereby improving the accuracy of fish size estimates. In addition, a density gradient rather than a uniform distribution of shad was found in each site. Shad densities varied on a horizontal scale (Figure 2) and with depth (Figure 3).

The median length of hydroacoustic targets was 40 mm at all sites. Although some fish as large as 300 mm were detected, those > 100 mm were only 0.4-7.1% of all targets.

We recommend using a stratified random sampling design and sampling at night using a 120 or 200 kHz transducer. Twenty transects covering approximately 150 m (boat speed of 1.5 m/sec for two minutes) should provide samples with a coefficient of variation of approximately 20%. Due to the nonuniform distribution of shad abundance, the transects selected should include much of the variability in shad density. Ground truthing of the hydroacoustic data is necessary to determine the species composition of the targets. Because of the inability of the hydroacoustic equipment to sample the upper 2 m of the water column, it is necessary to know the relative vertical distribution of the target species either by other sampling gear i.e.

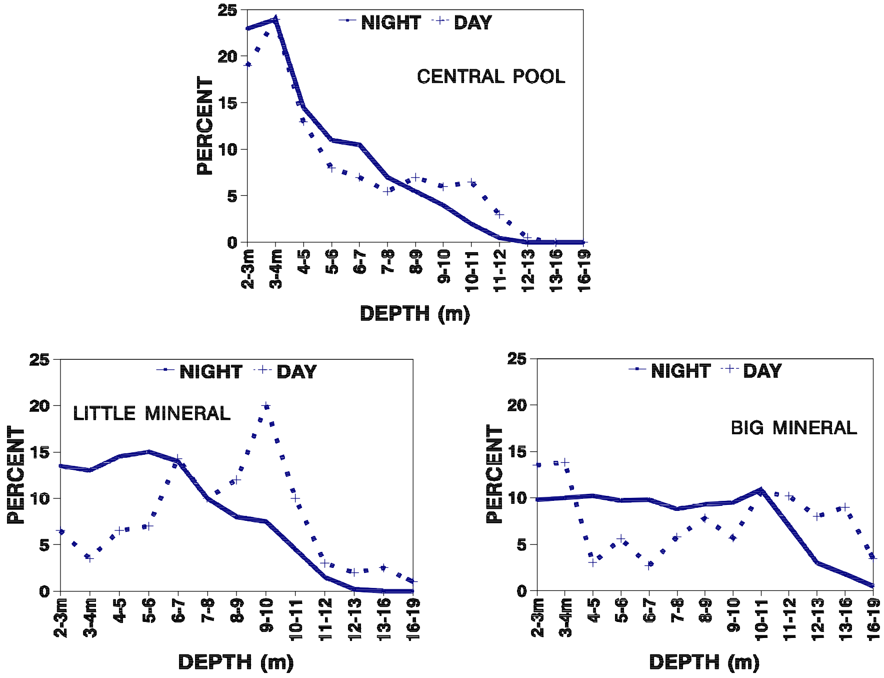

Figure 3. Vertical distribution (2-19 m) of fish for all hydroacoustic frequencies combined at three study sites on Lake Texoma, Oklahoma-Texas, 1991.

trawls or vertical gill nets, or by horizontal-aimed transducers or transducers mounted near the bottom and aimed up.

GILL NETS

Gill nets are used by many management agencies in routine sampling of reservoir fish populations, but these surveys usually are not specifically designed to collect data on shad abundance. The utility of such surveys for detecting environmental impacts or influences of management practices on shad populations could be improved by incorporating knowledge of mesh-size efficiency and sampling variance over a range of shad densities. The objectives of this phase of the study were to define spatial patterns of shad abundance that should be considered when designing gill-net population surveys, determine sampling precision, estimate the power of gill-net sampling for detecting differences in shad abundance, and quantify mesh-size selectivity for gizzard shad and threadfin shad.

Horizontal gill nets were set at the surface at 20 randomly selected offshore stations in areas ≥ 7 m deep. These nets were 2.4 m tall, 76.5 m long, and included 10 monofilament panels (each of 7.6 m long and hung on a one-half basis) with mesh sizes (bar measure, mm) of 10, 12, 19, 25, 38, 51, 64, 76, 89, and 102. A subset of six offshore stations was randomly selected for sampling with vertical gill nets. These nets included two adjacent 1.8-m wide panels of multifilament netting, one with 12-mm (bar measure webbing) and the other with 19-mm webbing. Vertical nets were fished from the surface to the lake bottom. Vertical and horizontal nets were also set at nearshore sampling stations. Paired-sets were made with the horizontal nets; one on the surface and the other set on the bottom along the 6-8 m depth contours.

Nets were set at dusk and run at dawn (approximately 10-h sets). Data were expressed as number per net-night (CPUE) and were not adjusted for variation in set duration because CPUE was not significantly correlated to set duration.

Spatial heterogeneity of shad abundance was the norm rather than the exception at Lake Texoma. CPUE of both species varied among embayments, between inshore and offshore stations, and between surface and bottom sets within embayments. This agrees with the results seen in the hydroacoustic sampling (Figures 2 and 3). Threadfin shad were collected from a greater range of depths than gizzard shad in vertical gill nets (Figure 4). Gizzard shad were surface-oriented, with greatest abundance in the top meter of the water column at all locations. Few gizzard shad were collected at depths exceeding 6 m. Age-0 shad occurred near the surface with older fish being more evenly distributed over depth. Programs aimed at estimating lake-wide abundance should consider these patterns when selecting sampling designs, stations, and sample sizes.

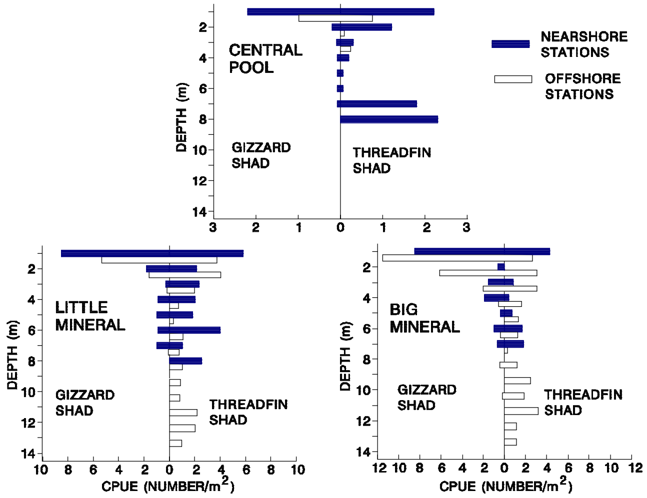

Figure 4. Catch rates (number/m^2 of net) of gizzard shad and threadfin shad in vertical gill nets set at nearshore and offshore stations at three sites on Lake Texoma, Oklahoma-Texas, 1991.

Abundance data from vertical gill nets were less precise than those from horizontal nets. The length frequency within the same mesh sizes of horizontal and vertical nets differed. Sampling with vertical nets is impractical if all sizes of shad are to be sampled. Use of several mesh sizes which is easily done in a single horizontal net requires multiple vertical nets. Sampling with vertical gill nets may be appropriate if a narrow size distribution of shad are being targeted or depth distribution of the sample is important.

Mesh sizes of 10-51 mm would be required to effectively sample the entire length-range of gizzard shad (60-380 mm) and 8-25 mm to sample the length-range of threadfin shad (55-174 mm) encountered at Lake Texoma (Figure 5). Gaps between effective sampling ranges for adjacent mesh sizes in the nets used in this study suggest that several additional meshes were needed to adequately sample all sizes of fish within these ranges. We suggest using horizontal nets of 8, 10, 12, 16, 19, 25, 31, 38, 44, and 51-mm mesh for sampling shad populations where an upper maximum of 400 mm is expected.

Fundamental considerations in the development of a gill-net sampling program include gear configuration, sampling locations, and number of nets used. Net configuration has just been discussed. Due to the surface orientation of age-0 shad and the even distribution of adult shad over depth, horizontal surface sets appear to be the best approach for sampling all sizes of shad. Nearshore and offshore sets should be included in the sampling design with sites chosen randomly. Desirable levels of precision and power for estimating and statistically detecting differences in shad abundance can be achieved with reasonable effort using horizontal gill nets. Based on sample means and variance that we observed in the Lake Texoma sampling, 20 nets should give a coefficient of variation equal to 0.20.

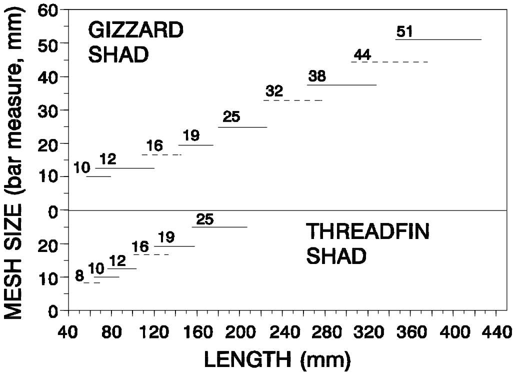

Figure 5. Lengths of gizzard shad and threadfin shad that would be effectively sampled by various gill-net mesh sizes (mm bar measure, labelled above each line). Solid lines indicate ranges for meshes used at Lake Texoma; dashed lines correspond to mesh sizes that should be added to effectively sample all sizes encountered.

TRAWLS

A variety of trawls have been used to sample juvenile shad in the pelagic areas of reservoirs. Because of differing trawl designs and sampling methods, comparisons of shad abundance and size structure across studies are difficult because the relative efficiency and precision of these sampling regimes have not been compared. Information on the relative efficiency biases and precision of trawls would enable biologists to more accurately assess past studies, optimize current sampling regimes, and develop sampling regimes for future studies. This phase of the study was intended to evaluate the relative efficiency and precision of four trawls in estimating the abundance and size structure of juvenile gizzard and threadfin shad (> 25 mm). We used the results of the trawl comparisons to make inferences about the effectiveness of each trawl for sampling juvenile shad and about the number of samples that might be required for a moderate level of precision.

A single-mesh 1 x 2 m neuston net (1-mm mesh), a bi-mesh 1 x 2-m (6.4- and 4.8-mm mesh) neuston net, paired 1 m^2 frame trawls (6.4-mm mesh), and a 1.67-m^2 bow-mounted Tucker trawl (6.4-mm mesh) were sampled simultaneously at each of the three sites at Lake Texoma. Twenty hauls were made with each trawl at night at randomly-selected offshore stations within each site.

Gizzard shad and threadfin shad contributed over 99% of the fish collected with the frame and Tucker trawls with threadfin shad being far more abundant than gizzard shad at all three sites. Inland silversides, *Menidia beryllina*, contributed between 11-62% and 88-98% of the catches of the bi-mesh and single-mesh neuston nets, respectively. Densities of both shad species were highest at Big Mineral and lowest at Central Pool. Densities of gizzard shad and threadfin shad estimated from frame and Tucker trawls were similar at all sites and were significantly higher than those estimated from the two neuston nets at all sites for threadfin shad and at the Big Mineral site for gizzard shad.

Precision of the transformed shad density estimates was highest for threadfin shad collected with the frame and Tucker trawls (Table 2). Density estimates were slightly more precise for the frame trawl than the Tucker trawl, possibly because of the greater sample volume or towing distance for the frame trawl. Precision of the gizzard shad density estimates were quite low probably due to the low density estimates.

Most shad collected by the four trawls used in this study ranged from 4-10 cm for gizzard shad and 2-8 cm for threadfin shad. Size distributions for both species were significantly different among trawls at each site. However, the size differences between frame trawl and Tucker trawl samples were small, ranging from 0-0.8 cm.

The poor performance of the neuston nets in this study may be due to those nets being limited to sampling surface waters only. The bi-mesh neuston net performed best at the Big Mineral site, where the fish were distributed closer to the surface. Water clarity was lowest in the Big Mineral site and perhaps also reduced gear avoidance. Performance of these nets may be improved in shallow, turbid systems where shad are concentrated nearer the surface.

Overall, the frame and Tucker trawls were more effective than the neuston nets for sampling juvenile shad in Lake Texoma. Assuming catch data similar to what we observed on Lake Texoma, a moderate level of precision (CV=20%) can be achieved using 20 hauls. This amount of effort can be achieved in one night's sampling which seems to be a reasonable amount of effort for a management agency to expend. Due to the non-uniform distribution of shad described earlier, these stations need to be randomly selected and include both nearshore and offshore areas available given the sampling limitations of the gear used.

Table 2. Mean densities (number/1000 m^3) of threadfin and gizzard shad and coefficients of variation (in parentheses) estimated for trawls at three sites on Lake Texoma, Oklahoma-Texas, 1991. Densities without the same letters within a site are significantly different at $P \leq 0.05$ based on $\log_e$ (X+1) transformed data.

	Single-mesh	Bi-mesh		
Site	Neuston	Neuston	Frame	Tucker
		Threadfin Shad		
Central Pool	0.6(1.64)a	5.5(0.46)b	53.8(0.06)c	44.9(0.14)c
Little Mineral	1.1(1.06)a	5.9(0.34)b	194.4(0.14)c	119.1(0.19)c
Big Mineral	9.5(0.47)a	145.6(0.12)b	532.9(0.10)c	605.1(0.18)c
		Gizzard Shad		
Central Pool	0a	0.1(2.44)b	0a	0a
Little Mineral	0a	0.1(2.30)b	1.2(0.34)c	0.5(1.83)bc
Big Mineral	0a	2.6(0.95)b	21.2(0.22)c	10.6(0.54)c

ELECTROFISHING

Electrofishing is a popular technique used by management agencies for collection of littoral fish, often including gizzard shad and threadfin shad. Critical evaluation of electrofishing techniques and the data that they provide for estimating shad population characteristics are lacking. The standard technique for electrofishing is for two dippers collecting fish at the bow while a third person operates the boat. An alternative method involves the use of a net mounted at the bow to passively collect fish as they are shocked. This is potentially useful for collecting species that reach high densities (such as gizzard shad and threadfin shad), making it difficult for active netters to collect all fish that are shocked. In this phase of the study, estimates of abundance and size distribution for gizzard shad and threadfin shad collected with passive and active electrofishing gears were compared.

All electrofishing boats were equipped with Smith-Root GPP 5.0 electrofishers, with 5000 watt generators. Three boats were used for electrofishing with dip netters (two dippers and one operator/boat) and one boat with the push net (one push net observer and one operator). The push net consisted of a 1.8 x 0.3 frame m (6-mm mesh netting) mounted to the booms at the bow of the boat. Twenty shoreline transects were randomly selected and sampled with dip netters and 10 transects were sampled with the push net in each of two study sites. The Big Mineral site was not sampled due to equipment malfunctions. All samples were collected at night with each transect consisting of one 15-minute unit of effort.

CPUE (fish/h) varied widely among transects, ranging from 0 to over 3,200 for threadfin shad and from 0 to over 1,600 for gizzard shad (Figure 6). For both species, CPUE was higher in the Central Pool than in Little Mineral. CPUE did not differ between gears for threadfin shad or small gizzard shad ($\leq$ 150 mm), but for large gizzard shad (> 150 mm) it was higher for dip netters than for the push net. The decreased catch of large gizzard shad by the push net may be due to gear avoidance by larger shad or by selection of larger fish by the dip netters.

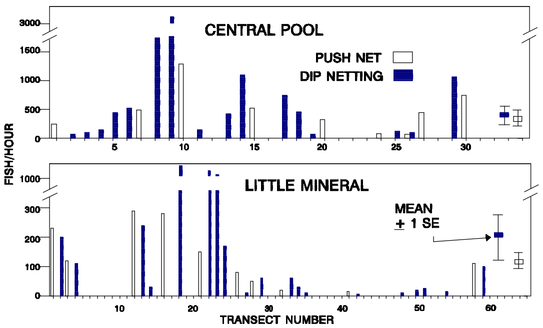

Figure 6. Catch-per-unit-effort (fish/h) of threadfin shad collected with electrofishing gear using two dip netters (DIP NETTING, filled bars and symbols) or a push net (PUSH NET, open bars and symbols) from two sites on Lake Texoma, Oklahoma-Texas, 1991.

The CV for CPUE of gizzard shad was greater for the push net than for dip netters, whereas the opposite was true for threadfin shad. The number of replicate samples required to achieve a CV=20% of the abundance estimate for gizzard shad was 0.5 - 3.0 times greater for the push net than for dip netters. However, 3.0 - 6.0 more samples would be required for dip netting relative to the push net for estimating CPUE for threadfin shad. Reasonable estimates of gizzard shad abundance (CV=20%) can be achieved with 15-20 transects, however effort needed to obtain reasonably precise abundance estimates for threadfin shad would not be practical.

Though the push net provides some advantages relative to personnel, the use of the push net is limited to systems relatively free of obstructions (i.e. logs, rocks, stumps). The push net relies on continual forward motion to keep fish in the net, consequently periodic backing of the boat to avoid such obstacles allows escapement of fish captured by the net.

ROTENONE

One cove in each study site, Central Pool (0.65 hectares), Little Mineral (0.44 hectares), and Big Mineral (0.73 hectares), was treated with one mg/l of rotenone. Fish were collected on two consecutive days and processed by standard methods (Surber 1960). Shad were sorted by species into inch groups and individually measured to convert the data to mm on the first day. On day 2, shad were sorted into inch groups and counted. The count for each inch group was allocated to 10-mm groups in proportion to the distribution observed on day 1.

Density estimates (number/hectare) varied by species and sites (Figure 7). The density estimates of both shad species combined was highest in Central Pool. Gizzard shad density was similar in Central Pool and Big Mineral. The density estimate of gizzard shad in Little Mineral was twice that found at the other two sites. Threadfin shad densities were similar in Little Mineral and Big Mineral with densities in Central Pool being twice those in the other two sites.

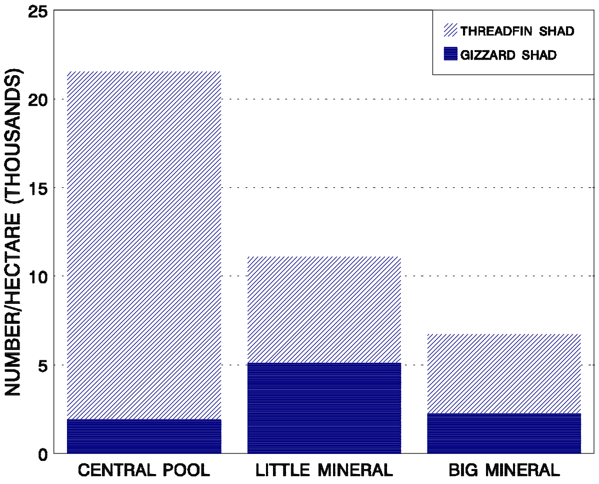

Figure 7. Estimate of gizzard shad and threadfin shad density (number/hectare) from cove rotenone samples from three sites on Lake Texoma, Oklahoma-Texas, 1991.

Length-frequency distributions differed by site for both species (Kolmogorov-Smirnov; P<0.05). However, the length distributions of gizzard shad were similar in Little Mineral and Big Mineral (Figure 8). Age-0 gizzard shad were underrepresented in the Central Pool sample. Perhaps the high densities of threadfin shad in the Central Pool cove displaced the age-0 gizzard shad. Length frequency of age-0 threadfin shad was similar among sites with the dominant mode ranging from 6-8 cm. Age-1 threadfin shad were represented in only the Central Pool sample. Data collected by other gears in this study indicated a great deal of heterogeneity of shad abundance both within and among sites. Because only one sample was collected per site, the precision of the standing crop estimates can not be calculated. Replicate samples within each site would need to be collected to obtain reliable standing crop estimates. Labor and public relations limitations make such an effort unfeasible.

SEINE

Daylight seine samples were collected using a 15.4 m x 1.8 m bag seine with a 6-mm mesh. One quadrant haul was made at each of 10 randomly selected sites in each study area. All fish collected were counted and sorted into cm size classes.

Gizzard shad and threadfin shad contributed over 98% of the fish collected in the seine samples. No differences in CPUE (number/haul) were detected among sites using raw data (Figure 9). Differences were detected when log-transformed data were used. CPUE of gizzard shad was higher in Big Mineral than in Little Mineral and Central Pool. No difference was found between Little Mineral and Central Pool. CPUE of threadfin shad was higher in Big Mineral than in Central Pool. No other among site differences in CPUE were detected for threadfin shad.

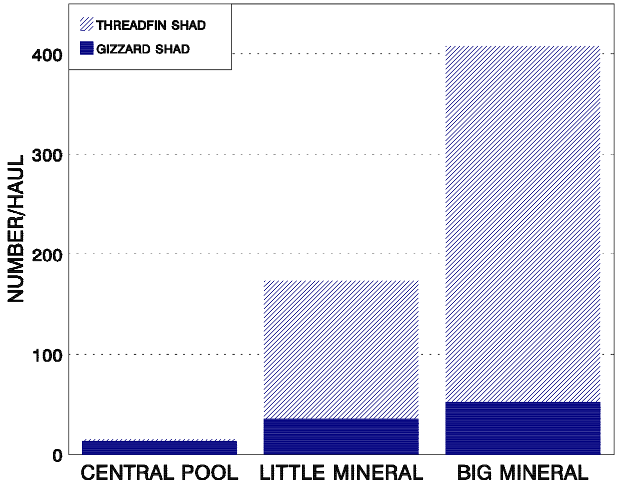

Figure 8. CPUE (number/haul) of gizzard shad and threadfin shad collected by seine from three sites on Lake Texoma, Oklahoma-Texas, 1991.

The precision of the seine CPUE data was poor. Based on the means and variance of the data collected in this study, 25-180 and 109-250 hauls would be required to give CV's=0.20 for gizzard and threadfin shad, respectively.

The length distribution of both species was significantly different among sites. However, the seines appeared to adequately represent the length distribution of age-0 gizzard shad and threadfin shad.

AMONG GEAR COMPARISONS

This study was designed to serve as a guide for researchers and/or managers initiating a shad sampling program and perhaps refining procedures already in use by those of us sampling shad. When selecting a sampling program tailored to meet a stated objective, attention needs to be given to: 1) the quality of the catch data-how precise are the abundance estimates?; 2) the size selectivity of the gear(s) chosen; and 3) what labor and equipment costs are associated with the sampling design.

Before discussing the among gear differences we found in this study, we must hedge what follows by pointing out that some of the variation among gears may be confounded by location effects. Due to the spatial heterogeneity of shad distributions that we have already discussed, differences between nearshore and offshore patterns could reflect gear selectivity or nearshore-offshore differences in shad populations. Trawls and hydroacoustics were used offshore, and electrofishing, seine, and rotenone could only be used nearshore. Gill nets were used in nearshore and offshore areas at each site. Comparisons of CPUE of threadfin shad did not differ between offshore and nearshore sets, whereas gizzard shad CPUE usually differed but in no predictable pattern.

As previously discussed, the shad data collected from surface-set horizontal gill nets were of better quality than bottom-set horizontal gill nets or vertical gill nets. Data from the Tucker trawls and frame trawls were similar. To limit the number of among-gear comparisons, we will use data from only horizontal gill nets, standard electrofishing (no push net), and frame trawls in the discussion that follows.

Size Distribution

The size distribution of shad differed among all gears at all sites. Even though these differences were statistically significant, the biological differences in the length frequencies among some of the gears may be slight.

Species combined

The median length of the hydroacoustic targets was 30-40 mm at all sites, and although some fish as large as 300 mm were detected, those >100 mm were only 0.2-1.4% of all targets. This is generally similar to results for the frame trawl but differs substantially from gill nets. The frame trawl caught few fish >100 mm (<0.1%), and median length was 40-50 mm for all species combined. Offshore gill nets, however, caught many fish exceeding 100 mm (6.4-13.1%), with some as long as 480 mm. Gill nets were not effective in sampling the small fish that dominated the hydroacoustic and trawl samples. The shortest fish collected in gill nets (60 mm) were larger than 71-83% of the hydroacoustic targets. Similar results were obtained when hydroacoustic and rotenone results were compared. Few fish shorter than 50 mm were sampled with rotenone.

Threadfin shad

Most variation of threadfin shad length frequency was related to the presence or absence of age-1 fish and to the sizes of age-0 fish collected. Age-1 fish, which measured 130-180 mm, were principally collected in gill nets, with greatest occurrence in bottom-set nets at nearshore locations in the Central Pool and Little Mineral sites. Electrofishing collected a relatively large number of age-1 fish only at Little Mineral. For age-0 threadfin shad, relationships among gears were relatively consistent among sites. Modal length was 40-50 mm for the trawl, 40-60 mm for the seine, 60-70 mm for rotenone, and 70-80 mm for gill nets and electrofishing. Most age-0 fish from gill nets came from two adjacent 10-mm groups, suggesting pronounced mesh-size selectivity. The other gears had broader size distributions for age-0 shad.

Hydroacoustic length data matched those from the trawl samples reasonably well for threadfin shad. Median length was equal (40 mm) between gears at Central Pool and Little Mineral. At Big Mineral, however, median length increased to 50 mm in trawl samples and decreased to 30 mm in hydroacoustics. Hydroacoustic length distributions tended to be somewhat broader than those of trawling; there was a relatively higher representation of 20-30 mm fish and a more skewed distribution toward longer fish.

Gizzard shad

Age-1 and older gizzard shad showed similar length frequencies when collected with rotenone, seines, and electrofishing; a wide distribution from 150-300 mm, and a single mode between 200 mm and 250 mm. Gill-net samples, however, typically had a bimodal length distribution, with peak frequencies at about 200 mm and 300 mm. Gill nets collected few fish 230-270 mm; this corresponded to shad sizes inefficiently sampled in the meshes used. The gill net was the only gear that regularly collected shad > 300 mm in length. Few age-1 gizzard shad were collected by trawling. The length frequency of age-0 gizzard shad differed among gears, but relationships among gears differed by site. At Central Pool, median length was 100 mm in offshore gill nets, nearshore gill nets, and rotenone, whereas it was 50-80 mm for electrofishing and seines. No age-0 gizzard shad were collected by trawling at this site. At Little Mineral, modal length was 90-100 mm in all gears except the trawl, which collected relatively smaller fish (median=70 mm). At Big Mineral, the median was 90-100 mm in trawls and gill nets and 110 mm in electrofishing, seine, and rotenone samples. In comparison with other gears, gill nets produced the least variable length-frequency data for age-0 gizzard shad, with most fish at lengths of 90-100 mm, regardless of sampling location or site. Other gears provided more evenly distributed length data within sites and revealed variation among sites that was not indicated by gill nets. For example, median length in seine samples ranged from 60 mm at Central Pool to 110 mm at Big Mineral, Similarly, median length ranged from 80 mm to 110 mm in electrofishing and from 70 mm to 90 mm in trawling.

Gill nets were the only passive gear used in this study. Length frequency depends on mesh selectivity plus encounter probability. Small fish have slower swimming speeds and are expected to have reduced probability of encountering the net. Hence, gill nets may under-represent the abundance of small fish.

Abundance Estimates

Most gears revealed generally similar patterns of shad abundance among study sites. Standardized catch rates were usually greatest in Big Mineral embayment and least in the Central Pool. Exceptions were rotenone, which showed highest abundance of threadfin shad in the Central Pool and lowest in Big Mineral, surface-set gill nets at nearshore stations, which showed threadfin shad abundance greatest at Big Mineral and least at Little Mineral, and electrofishing, which showed greatest abundance of both gizzard shad and threadfin shad at the Central Pool.

Correlation coefficients between abundance estimates for hydroacoustics, trawls, and offshore gill nets (offshore samples) were always significant ($P<0.05$) when data from sites were pooled and usually not significant when sites were analyzed separately. Given the among site differences in abundance evident in most samples, apparently correlations among gears were not highly correlated unless a wide range of densities were sampled. At offshore stations, correlation was strongest between trawl and gill-net results for threadfin shad (r=0.80, N=55) and gizzard shad (r=0.58, N=55). Hydroacoustics data produced lower coefficients, r=0.45 (N=58) and r=0.47 (N=53), when compared with data for shad (species combined) in trawls and gill nets, respectively. Coefficients were not significant in comparisons of electrofishing vs seine and surface vs bottom gill nets at nearshore stations.

Because shad sampling programs are often conducted to determine if abundance varies among times and places, questions regarding management effectiveness or environmental impacts may not be answered even if target levels of precision are met. In such cases, it is more important to know the number of samples that should be collected to detect a specified difference between two abundance estimates. Failure to statistically detect a difference may correctly occur when abundance actually is equal or incorrectly occur when abundance differs but the sampling program fails to detect the difference. The probability of detecting a difference in abundance when it actually occurs is termed power. Intuitively, the power of a test of equality of two estimates of abundance increases with sample size and with the magnitude of the true difference between the means. Large differences are easier to detect than small ones, and increased sample size makes detection of true differences more likely.

Levels of significance, power, and precision have not been widely standardized for fisheries investigations. Robson and Regier (1964) estimated sample sizes necessary for Petersen mark-recapture population estimates to achieve three alternative goals for precision. The least-demanding goal was for preliminary surveys, which were expected to produce population estimates within 50% of the true population with 95% certainty. Next was management studies, giving estimates within 25% of the true value, and the most-demanding was research studies, in which estimates were expected to be within 10% of the true value. These goals correspond approximately to CV0=0.25, 0.12, and 0.05, respectively. Hence, achieving CV0=0.2, which we used as a goal throughout our analysis, is intermediate between Robson and Regier's (1964) standards for management and preliminary studies. To achieve the standard for research studies (CV0=0.05), required sample size would be about 16 times that needed for CV0=0.2. Table 3 summarizes CPUE estimates for shad at Lake Texoma and some associated sampling statistics, along with the sample sizes needed to achieve CV0=0.2 (N').

Table 3. Summary of CPUE estimates for shad at Lake Texoma. Column headings are N (actual sample size), 0 (arithmetic mean), SD (standard deviation), CV(coefficient of variation -SD/0), CV$_0$ (coefficient of variation of the mean-SD/0 x sq. root N), N' (sample size needed to get CV$_0$=0.2). Units for CPUE are #/h (electrofishing), #/1000m^3 (trawl and hydroacoustics), #/haul (seine), #/net-night (gill net), #/ha (rotenone).

GEAR	SPECIES	SITE	N	0	SD	CV	CV$_0$	N'
Electro	GIZ	CP	20	336.7	274.7	0.81	0.18	17
(dip net)	GIZ	LM	20	71.1	52.3	0.74	0.16	14
	GIZ	BM	0					
	TFS	CP	20	519.5	796.0	1.53	0.34	59
	TFS	LM	20	221.8	395.0	1.78	0.40	79
	TFS	BM	0					
Trawl	GIZ	CP	20	0.0	-	-	-	-
(frame)	GIZ	LM	20	1.2	1.8	1.53	0.34	59
	GIZ	BM	20	21.2	21.2	1.00	0.22	25
	TFS	CP	20	53.8	14.0	0.26	0.06	2
	TFS	LM	20	194.4	126.6	0.65	0.14	11

Table 3 (Con't).

GEAR	SPECIES	SITE	N	0	SD	CV	CV_0	N'
Hydro	ALL	CP	20	177.4	81.8	0.46	0.10	6
(200 kHz,	ALL	LM	20	518.9	279.0	0.54	0.12	8
night)	ALL	BM	19	699.1	334.0	0.48	0.11	6
	TFS	BM	20	532.9	235.0	0.44	0.10	5
Seine	GIZ	CP	10	13.3	35.7	2.68	0.85	180
	GIZ	LM	10	35.7	76.6	2.13	0.67	114
	GIZ	BM	10	52.5	53.3	1.00	0.32	25
	TFS	CP	10	1.9	6.0	3.16	1.00	250
	TFS	LM	10	138.2	302.0	2.19	0.69	120
	TFS	BM	10	355.8	739.0	2.08	0.66	109
Rotenone	GIZ	ALL	3	526	193.0	0.37	0.21	4
	TFS	ALL	3	1677	1141.0	0.68	0.39	12
Gill Net	GIZ	CP	20	3.8	2.7	0.70	0.16	13
(offshore,	GIZ	LM	15	59.9	14.9	0.25	0.06	2
surface)	GIZ	BM	20	368.7	238.6	0.65	0.15	11
	TFS	CP	20	91.2	56.0	0.61	0.14	10
	TFS	LM	15	527.4	224.9	0.43	0.11	5
	TFS	BM	20	1159	477.4	0.41	0.09	5
Gill Net	GIZ	CP	5	18.8	13.3	0.71	0.32	13
(near-	GIZ	LM	5	27.6	21.5	0.78	0.35	16
shore,	GIZ	BM	5	55.8	23.5	0.42	0.19	5
bottom)	TFS	CP	5	37.8	38.4	1.02	0.46	26
	TFS	LM	5	50.6	41.5	0.82	0.37	17
	TFS	BM	5	216.2	365.8	1.69	0.76	72
Gill Net	GIZ	CP	5	35.4	18.8	0.53	0.24	8
(near-	GIZ	LM	5	128.8	40.1	0.31	0.14	3
shore,	GIZ	BM	5	138.4	42.2	0.30	0.13	3
surface)	TFS	CP	5	188.8	123.9	0.66	0.27	11
	TFS	LM	5	557.4	146.0	0.26	0.11	2
	TFS	BM	5	277.2	91.1	0.33	0.15	3

Sampling effort needed to collect reasonably precise abundance data for gizzard shad and threadfin shad would be practical for management agencies to expend using trawls, hydroacoustics, and/or gill nets (N', Table 3). The precision of the electrofishing and rotenone data for gizzard shad was within the limits that were specified for this study, however, the differences in the among sites patterns of abundance between these gears and the trawl, hydroacoustics, and gill net data tend to make the electrofishing and rotenone data suspect.

The prime concern when establishing sampling protocol should be the quality of the data. However, capital and labor costs can not be ignored. Gill-net costs are readily available from net manufacturers. The cost of a boat, fully equipped to sample with a frame trawl is approximately $42,000. Hydroacoustic costs and expertise needed to operate the equipment have been reduced substantially in recent years, with the price of the needed equipment (excluding boat) being in the $25,000 range. Labor costs, including collecting and processing the data were 2.3 h/sample, 1.6 h/sample, 1.0 h/sample, 1.6 h/sample, 101 h/sample, and 4.4 h/net for electrofishing, trawl, hydroacoustics, seine, rotenone, and gill nets, respectively. Labor costs were based on crew sizes and catch rates that we used and observed on Lake Texoma.

CONCLUSION AND RECOMMENDATIONS

Based on the results of our study, we feel that a sampling program using surface-set gill nets, trawls, and/or hydroacoustics would provide the "best" data on gizzard shad and threadfin shad in southern reservoirs. The trawl and hydroacoustic samples need to be collected at night. The lack of precision of the seine data make effective sample sizes impractical. The same was true for electrofishing data for threadfin shad. Effective sample sizes for gizzard shad using electrofishing were reasonable but the lack of conformity in the abundance patterns relative to the other gears make the data suspect. Rotenone samples are limited to nearshore habitats and given the large amount of spatial variation in shad abundances, expanding the nearshore estimates may not be appropriate to the whole of the reservoir. Labor and public relation costs of rotenone also limit the practicality of this sampling method. We will limit our conclusions and recommendations to gill nets, trawls and hydroacoustics.

1. The heterogeneity in both the horizontal and vertical distribution of gizzard and threadfin shad make randomization of sampling locations highly desirable. Shad abundance patterns varied both within and among sampling locations. Selection of sampling sites should cover the ranges of shad density.

2. The specific objectives of the study should dictate the sampling methods used. Trawls and hydroacoustics are capable of providing biomass estimates. Gill-net data are limited to CPUE trends. The length distributions of the samples differed among gears. Surface-set gill nets sampled the widest range of lengths of the gears used in our study. The effectiveness of the trawls are limited to juvenile shad (< 80 mm). Theoretically, hydroacoustics should sample the entire range of shad lengths (>20 mm). However, shad > 100 mm were underrepresented, relative to the gill-net samples. Hydroacoustic samples need to be ground-truthed with other sampling methods (i.e. trawl or purse seine-used by Duke Power Co.). These gear-specific limitations need to be taken into account when establishing a sampling program.

3. The gizzard shad in Lake Texoma at the time of our sampling (mid-August) were too large to be effectively sampled with the trawls. This was likely the cause of the low gizzard shad CPUE in the trawl data and the correspondingly low precision. Samples would need to be collected earlier in the season for the trawls to be effective in collecting juvenile gizzard shad data. The precision of the threadfin shad trawl data were within the limits set for our study. Ten-15 hauls would be needed to give a CV_0 =0.2, based on the catch statistics of our samples.

4. Ten hydroacoustic transects covering approximately 150 m (boat speed of 1.5 m/sec for two minutes should provide abundance estimates with CV_0=0.2 using either 120 kHz or 200 kHz transducers. The abundance estimates in our study were site specific. If lake-wide abundance and/or biomass estimates are desired the required number of samples will have to be increased to take into account variations in shad density.

5. Twenty net-nights of gill-net effort using surface sets at both nearshore and offshore locations should give abundance estimates with CV_0=0.2. Nets should be configured to contain 8, 10, 12, 16, 19, 25, 31, 38, 44, and 51-mm meshes. It must be kept in mind that these data are relative abundance estimates and as such would be appropriate for trend data and not absolute abundance or biomass estimates.

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