Gill Net Sample Size Requirements for Temperate Basses, Shads, and Catfishes

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Abstract: I estimated variance-mean (s^2–$\bar{x}$) relationships for gill net catches of 8 forage and sportfish species plus a composite group composed of all species combined. These relationships explained 75%–95% of the variation in $\log_e(s^2)$. Predictive equations for $\log_e(s^2)$ were back-transformed to a linear scale, adjusted to correct for transformation bias, and substituted into a standard equation for estimating sample size requirements as a function of the desired level of precision and expected sample mean. Sample size requirements for all species increased with an increase in the desired level of precision or with a decrease in the expected mean. Based on statewide mean catches, all species studied can be sampled with a precision ≤0.3 with a sample size of 25 gill nets and most could be sampled with a precision of ≤0.2 with 50 gill nets; these results represent approximate 95% confidence intervals about estimates of mean catch of $\bar{x} \pm 0.6\bar{x}$ (precision= 0.3) or $\bar{x} \pm 0.4\bar{x}$ (precision = 0.2). Equations for predicting sample size requirement presented in this paper are specific to Texas fisheries and a specific gill net configuration; however, they can be used to provide preliminary estimates of sample size requirements elsewhere.

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Gill nets are among the most widely used gears for sampling fish populations. A survey of North American fishery management agencies found that gill nets were used to sample freshwater fish populations in 42 states and 9 Canadian provinces (Fish. Tech. Standardization Comm. 1992). Despite the wide use of gill nets, analysis and interpretation of catch data are complicated by several factors. First, gill nets are a passive gear; as a result, catches are affected by fish behavior and a variety of environmental conditions such as water temperature, turbidity, and depth (Hubert 1983). Second, catch and size-structure information are subject to gill net size-selectivity (Hamley 1975) that may affect estimates of total abundance and result in over- or underestimates of abundance of different size classes. Third, gill net data are excessively variable and often exhibit a negative binomial distribution (Moyle and Lound 1960, Bagenal 1972), a skewed distribution having a variance greater than the mean (Elliott 1977).

An important step in the design of any sampling program is estimation of the number of samples required to detect the effects or changes of interest (Green 1979). This is especially important in the design of fishery surveys with gill nets because of the excessive variation in catch data. Study results will be of limited usefulness if too few samples are collected, whereas collection of an unnecessarily large number of samples represents a waste of manpower and other resources. Sample size requirements can be determined based on the need to detect an effect of given magnitude or the need to achieve a specified variance or level of precision (Cochran 1977). For fishery surveys, Gunderson (1993) suggests basing sample size requirements on attainable precision.

The relative precision with which fish abundance is measured with gill nets can be estimated as the coefficient of variation of the sample mean ($CV_{\bar{x}} = SE / \bar{x}$). The number of samples, *N*, required to achieve a specified level of precision can be estimated, given some knowledge from previous surveys or published results of the expected sample mean and variance (s^2) or the sample coefficient of variation ($CV = SD / \bar{x}$) for the variables of interest in the following way:

$$N = s^2 \bar{x}^{-2} CV_{\bar{x}}^{-2} \qquad \text{(Equation 1)}$$

(Cochran 1977). For normally-distributed variables, once an estimate of s^2 is obtained, sample size requirements can be estimated for any expected value of because of the independence of s^2 and $\bar{x}$. However, as noted above gill net catches commonly exhibit a negative binomial distribution with $s^2 > \bar{x}$, implying that s^2 increases with any increase in $\bar{x}$.

For non-normal distributions, the relationship between s^2 and $\bar{x}$ can be modelled, after logarithmic transformation of both variables, with linear regression (Downing et al. 1987, Pace et al. 1991, Cyr et al. 1992). Using this approach, Cyr et al. (1992) were able to accurately estimate s^2 for replicate larval fish tows based on $\bar{x}$. This approach has 2 advantages: *N* can be predicted, from equation 1, given knowledge only of $\bar{x}$ because s^2 is a known function of $\bar{x}$ (Cyr et al. 1992); and it allows prediction of *N* for various expected values of $\bar{x}$, even when s^2 and $\bar{x}$ are correlated.

Texas Parks and Wildlife Department (TPWD) uses gill nets to monitor abundance of several forage and sport fishes, including white bass *Morone chrysops*, striped bass *M. saxatilis*, white bass X striped bass hybrids, gizzard shad *Dorosoma cepedianum*, threadfin shad *D. petenense*, blue catfish *Ictalurus furcatus*, channel catfish *I. punctatus*, and flathead catfish *Pylodictus olivaris*. Presently, gill net effort is allocated based on reservoir surface area, but no formal estimate of sample size requirements has been made. In this study I: 1) estimate sample size requirements for temperate basses, shads, and catfishes, as well as a composite group composed of all species combined; and 2) evaluate the precision of gill net samples collected under TPWD's current sampling protocol.

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Methods

In the course of routine population monitoring during 1985 through 1990, TPWD field staff completed a total of 3,410 gill net sets in 202 Texas reservoirs. Gill nets were 61 m long by 2.4 m deep and consisted of 8 equally-sized panels of monofilament meshes arranged in an arithmetic progression with bar measures of 13, 25, 38, 51, 64, 76, 89, and 102 mm. Gill nets were used to survey the entire fish assemblage of each reservoir with particular emphasis on temperate basses and catfishes. Gill nets were fished in all available habitat types: in open waters, nets were set at the surface (11% of all gill net sets), on the lake bottom (22%), or suspended throughout the water column in shallow areas (17%); in inshore areas, nets were set perpendicular to the shore with either the 13-mm mesh (35% of all gill net sets) or the 102-mm mesh (15%) fished toward shore. Gill nets were set in all months of the year, but most were set in January through May.

The number of gill nets set varied among reservoirs in relation to surface area: netting effort on reservoirs <2,025 ha was 5 net nights, effort on reservoirs, ≥2,025 ha and <4,050 ha was 10 net nights, and on reservoirs ≥4,050 ha effort was 15 net nights. For any given reservoir, all samples were collected within a single 3-day period.

I determined the relationship between s^2 and $\bar{x}$ of gill net samples by regressing $\log_e(s^2)$ on $\log_e(\bar{x})$ for each species. Regression equations relating s^2 to $\bar{x}$ were back transformed to a linear scale and corrected for transformation bias (Ricker 1975, Sprugel 1983) to yield means rather than medians of predicted variances. For the $\log_e$ transformation, this correction involves addition of the term MSE/2 (MSE = mean square error of the regression) prior to back transformation. For white bass (Table 1):

$$s^2 = \exp(\ (\text{MSE}/2) + 0.90 + 1.61\bar{x}), \qquad \text{(Equation 2)}$$
$$= \exp(\ (0.413/2) + 0.90 + 1.61\bar{x}), \qquad \text{(Equation 3)}$$
$$= 3.02\bar{x}^{1.61}. \qquad \text{(Equation 4)}$$

I substituted these results into Equation 1 to develop predictive equations for N, the number of gill net samples necessary to achieve a desired level of precision, and evaluated the effects of changes in precision and $\bar{x}$ on N. Again, for white bass:

$$N = s^2\bar{x}^{-2}\text{CV}_{\bar{x}}^{-2}, \qquad \text{(Equation 5)}$$
$$= 3.02\bar{x}^{1.61}\bar{x}^{-2}\text{CV}_{\bar{x}}^{-2}, \qquad \text{(Equation 6)}$$
$$= 3.02\bar{x}^{-0.39}\text{CV}\bar{x}^{-2}, \qquad \text{(Equation 7)}$$

as presented in Table 2. All analyses were performed with SAS (SAS Inst. Inc. 1985).

Results

Regression of $\log_e(s^2)$ on $\log_e(\bar{x})$ was highly significant ($P < 0.0001$) for all species and accounted for 82% to 95% of the variation in $\log_e(s^2)$ (Table 1). Re-

Table 1. Regression statistics for variance-mean relationships to fit the model $\log_e(s^2) = a + b \log_e(\bar{x})$, where s^2 is the sample variance, $\bar{x}$ is mean gill net catch, and a and b are the regression intercept and slope, respectively.

Species	N	Intercept	Slope	P	r^2	MSE[a]
White bass	215	0.90	1.61	0.0001	0.92	0.413
Stripd bass	66	0.96	1.50	0.0001	0.95	0.303
White X striped bass	122	0.97	1.55	0.0001	0.92	0.519
Gizzard shad	361	0.68	1.54	0.0001	0.82	0.714
Threadfin shad	232	1.32	1.79	0.0001	0.95	0.661
Blue catfish	143	0.67	1.47	0.0001	0.91	0.604
Channel catfish	357	0.30	1.48	0.0001	0.85	0.522
Flathead catfish	239	0.42	1.24	0.0001	0.85	0.274
All species combined	376	-0.88	1.94	0.0001	0.75	1.048

[a] MSE-Mean square error.

gression slopes were significantly greater ($P < 0.05$) than 1.0 for all species indicating that s^2 increases more rapidly than does $\bar{x}$. The $\log_e(s^2)$–$\log_e(\bar{x})$ regression for the composite group was highly significant ($P < 0.0001$) and explained 75% of the variance in $\log_e(s^2)$. The regression slope for the composite group was significantly greater ($P < 0.001$) and the intercept less ($P < 0.001$) than those for the regressions for individual species.

After correction for transformation bias, equations in Table 1 can be used to predict s^2. Substituting predicted values of s^2 into Equation 1 allows estimation of N for any desired level of precision (Table 2). N is inversely proportional to both x and $CV_{\bar{x}}$ (Fig. 1). Holding $\bar{x}$ constant, each doubling of precision (i.e., decreasing $CV_{\bar{x}}$ by half) results in a 4x increase in N; alternatively, for any given level of precision, N increases rapidly as mean catch decreases.

Among species, differences in variance-mean relationships have a large effect on N, especially when desired precision is high (Fig. 2). Assuming $\bar{x} = 7.0$, the

Table 2. Equations for estimating gill net sample size requirements based on expected mean catch rates ($\bar{x}$) and desired level of precision ($CV_{\bar{x}}$).

Species	Predictive equation
White bass	$N = 3.02\,\bar{x}^{-0.39}\,CV_{\bar{x}}^{-2}$
Striped bass	$N = 3.04\,\bar{x}^{-0.50}\,CV_{\bar{x}}^{-2}$
White X striped bass	$N = 3.42\,\bar{x}^{-0.45}\,CV_{\bar{x}}^{-2}$
Gizzard shad	$N = 2.82\,\bar{x}^{-0.46}\,CV_{\bar{x}}^{-2}$
Threadfin shad	$N = 5.21\,\bar{x}^{-0.21}\,CV_{\bar{x}}^{-2}$
Blue catfish	$N = 2.64\,\bar{x}^{-0.53}\,CV_{\bar{x}}^{-2}$
Channel catfish	$N = 1.75\,\bar{x}^{-0.51}\,CV_{x}^{-2}$
Flathead catfish	$N = 1.75\,\bar{x}^{-0.76}\,CV_{\bar{x}}^{-2}$
All species combined	$N = 0.70\,\bar{x}^{-0.06}\,CV_{\bar{x}}^{-2}$

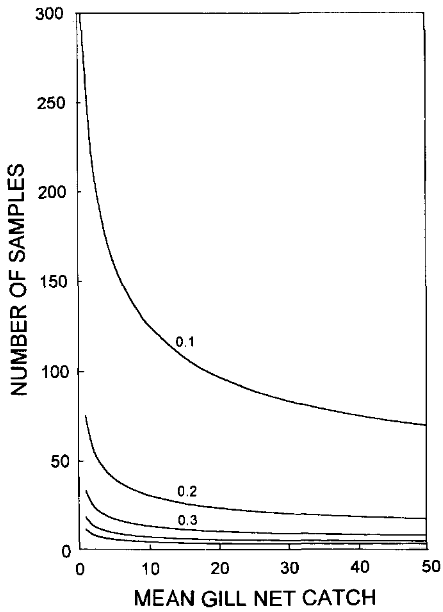

Figure 1. Number of samples required based on different combinations of number per sample and desired precision. Curve labels indicate the level of precision for $CV_{\bar{x}}$ = 0.1, 0.2, and 0.3. The 2 unlabelled (lower) curves are for $CV_{\bar{x}}$ = 0.4 and 0.6, respectively.

number of gill net samples required to achieve a precision of 0.1, for example, ranges from 40 for flathead catfish to 346 for threadfin shad.

To evaluate the precision of TPWD gill net samples, I rearranged the equations in Table 2 to predict CV_x as a function of N and $\bar{x}$; for $\bar{x}$, I used the statewide

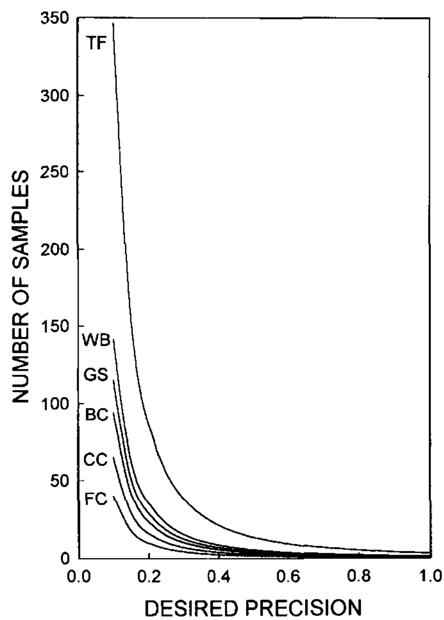

Figure 2. Number of samples required to achieve desired levels of precision, assuming $\bar{x}$ = 7.0 fish per net, for threadfin shad (TF), white bass (WB), striped bass (SB), gizzard shad (GS) blue catfish (BC), channel catfish (CC), and flathead catfish (FC).

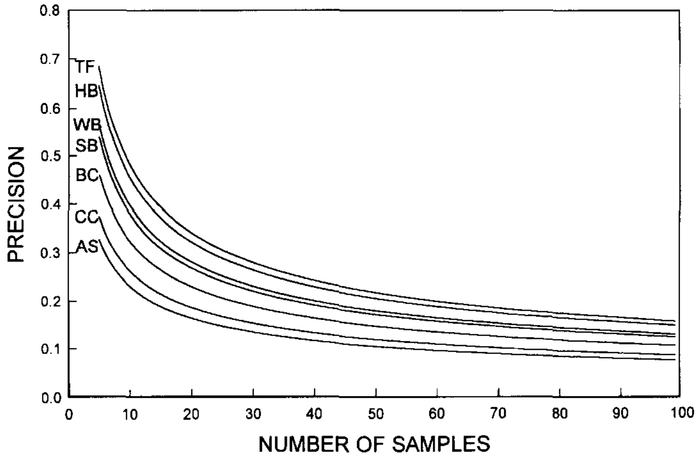

Figure 3. Expected level of precision for various sample sizes, *N*, and Texas statewide mean gill-net catches ($\bar{x}$) for threadfin shad (TF; $\bar{x}$=45.2), white X striped bass hybrids (HB; $\bar{x}$=3.0), white bass (WB; $\bar{x}$=5.2), striped bass (SB; $\bar{x}$=4.4), blue catfish (BC; $\bar{x}$=5.6), channel catfish (CC; $\bar{x}$=6.1); and all species combined (AS; $\bar{x}$=85.5).

mean gill-net catch for each species. For N = 5, expected precision is low (>0.4) for all species except gizzard shad, channel catfish, and the composite group (Fig. 3). For N = 10, precision between 0.2 and 0.3 can be achieved for gizzard shad, channel catfish, and the composite group. For blue catfish and striped bass, a precision of <0.35 and <0.4, respectively, is possible with a sample size of 10, but for other species precision was >0.4. A precision ≤0.4 can be achieved for all species with N = 15, although gizzard shad, channel catfish, blue catfish, and the composite group can be sampled with a precision ≤0.3 with this number of samples. Based on statewide mean gill-net catches, all species can be sampled with a precision ≤0.3 or ≤0.2 with a sample size of 25 or 50 gill nets, respectively.

Discussion

For a given species, the number of samples required to achieve a desired level of precision is inversely related to the expected sample mean: fewer samples are necessary when a targeted species is abundant than when it is uncommon. Among species, sample size requirements vary as a function of aggregation. Variance-mean relationships suggest that flathead catfish, blue catfish, and channel catfish are the least aggregated species among those included in my study and required the fewest samples to achieve a given level of precision. A greater number of samples is required for the more aggregated, schooling species, including temperate basses, gizzard shad, and especially threadfin shad.

Gill net sample size requirements for several freshwater fishes have been estimated by Bagenal (1972), Craig and Fletcher (1982), and Craig et al. (1986).

These authors developed single estimates of s^2 (and $\bar{x}$) for each species studied and then estimated sample size requirements under various sampling regimes for which expected mean catches did not necessarily equal $\bar{x}$. When s^2 and $\bar{x}$ are correlated, as is the case with gill net catches, the approach taken by Bagenal (1972), Craig and Fletcher (1982), and Craig et al. (1986) will require collection of too many samples when expected catches are less than $\bar{x}$ and too few samples when expected catches are greater than $\bar{x}$. As an example, Craig et al. (1986) reported that at least 6 gill net samples were necessary to achieve a precision of approximately 1.0; in contrast, my results indicate that a precision of 0.33 to 0.68, depending on species, can be achieved with only 5 gill nets. Over-estimation of sample size requirements, in the face of finite resources, led Craig and Fletcher (1982) to conclude that gill nets were of little practical value in assessing changes in stock abundance.

The number of gill net sets (16 to 60, depending on species and based on statewide means) required to achieve relatively high precision, $CV_{\bar{x}} \leq 0.2$, may not be practical except in well-funded research programs. On the other hand, a precision $\geq$0.5 would be useful only in detecting large increases in abundance, as 95% intervals about $\bar{x}$ would include 0.0. All species included in my study can be sampled with an expected level of precision of 0.3 or 0.4 with 25 or 15 gill nets, respectively. These results translate into 95% confidence intervals about estimates of mean catch of $\bar{x} \pm 0.6\bar{x}$ ($CV_{\bar{x}} = 0.3$) and $\bar{x} \pm 0.8\bar{x}$ ($CV_{\bar{x}} = 0.4$) and, in the absence of the usual constraints of time and manpower, probably represent the minimum acceptable level of precision for surveys or monitoring programs conducted with gill nets.

Survey data frequently are collected to monitor and test for changes in fish abundance. In such cases, sample size requirements might more appropriately be based on statistical power (Peterman 1990) than on sampling precision. Sample size estimates based on statistical power are dependent upon the specific hypothesis being tested and varying numbers of samples are required to detect a change from one year to the next, heterogeneity among 3, 4, or more years, or a linear (or other) trend through time. The variance-mean relationships presented in this paper can be used to calculate sample sizes based on statistical power for any desired design.

Because of limited resources, fishery sampling effort is often allocated among water bodies based on surface area or some other measure of waterbody size so that larger waters receive a greater proportion of the total sampling effort. Unless fish abundance is directly related to surface area, such an allocation can result in reduced precision in the estimates of fish abundance in smaller waters and, possibly, greater precision than required in larger waters. Also, smaller waters are more susceptible to overexploitation and other causes of population fluctuations; consequently, allocating fewer samples to these waters may limit the ability of managers to detect population changes until they have become problematic. If fish abundance is not related to surface area, it may be advantageous to allocate sampling effort based on local abundances of targeted species, regardless of surface area. Such an allocation would represent an attempt to control the surveywide (or statewide, etc.) sampling precision at some logistically and statistically acceptable level.

Although my results are specific to Texas reservoirs and the specific gill net configuration described above, the equations in Table 2 can be used to calculate sample size requirements for individual species elsewhere if local s^2–$\bar{x}$ relationships are similar to those indicated in Table 1. As an alternative, the equation in Table 2 for the composite group can be used, in the absence of other information, to provide preliminary estimates of sample size requirements. Sample size estimates obtained from this equation are likely to be quite robust with respect to changes in gill net configuration; however, based on the $\log_e(s^2)$–$\log_e(\bar{x})$ relationship for the composite group, sample size may be slightly underestimated when $\bar{x}$ is low.

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