North American Journal of Fisheries Management 38:1085–1090, 2018
© 2018 American Fisheries Society
ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10211

MANAGEMENT BRIEF

An Indirect Method for Estimating Size-Specific Exploitation

Kristopher A. Bodine* **and J. Warren Schlechte**
Texas Parks and Wildlife Department, Heart of the Hills Fisheries Science Center, 5103 Junction Highway, Mountain Home, Texas 78058, USA

Daniel E. Shoup
Department of Natural Resources Ecology and Management, Oklahoma State University, 008C Ag Hall, Stillwater, Oklahoma 74078, USA

Abstract
Estimating size-specific exploitation (SSU) is critical to assessing population responses to length-based regulations because harvest rates often vary by fish size. Failing to incorporate SSU into assessments could result in regulations that unnecessarily restrict harvest or put the stock at risk of overharvest. Unfortunately, managers rarely estimate SSU because it is difficult and expensive to do this in traditional tag–return studies. We describe how a change-in-ratio estimator (CIRE) that incorporates commonly collected fisheries management data such as creel length frequency, population length frequency, and total exploitation can provide a potentially cost-effective method for estimating absolute SSU. Absolute SSU will allow biologists to determine the size of fish being harvested, the magnitude of harvest for each fish size, and what sizes need to be regulated. We also demonstrate how the CIRE can be used to estimate relative SSU, which can be calculated even when total exploitation data are unavailable. Much like catch per unit effort, relative SSU is useful for monitoring relative changes across time, among fish sizes, or across waterbodies. We believe that the broad applicability and versatility of a CIRE makes it a useful alternative for estimating SSU.

Exploitation (i.e., the fishing mortality rate) is one of a few fundamental rates governing fish populations (Slipke and Maceina 2000), and its estimation is often critical to successful management. Fishing mortality can influence population metrics such as size structure, abundance, and recruitment (Schultz 2004), sometimes resulting in the need for harvest limits on certain sizes of fish. Typically, exploitation is estimated at the population level (yielding one overall rate); however, harvest often varies by fish size and is influenced by fish behavior, angling gear selectivity, and angler behavior (Serns and Kempinger 1981; Gabelhouse and Willis 1986; Miranda and Dorr 2000; Schultz 2004). Developing and implementing management plans without knowledge of size-specific exploitation (SSU) rates could result in regulations that are either too restrictive or too liberal. Thus, fisheries managers should recognize the importance of incorporating SSU into assessment models.

Commonly, SSU is directly estimated through tag–return studies (Miranda et al. 2002). However, tagging studies are not always practical, especially for fisheries managers who manage numerous water bodies with very limited budgets and manpower. Annual assessments of routine fisheries data (e.g., catch rates, size structure, and age and growth) can require considerable resources, and the remaining resources may not cover the costs of conducting additional, specialized tagging studies. Also, tagging studies often require the use of monetary rewards to improve tag return rates (Pollock et al. 2001). Funds to meet these additional costs may not be available, especially if SSU estimates are needed on multiple water bodies. As a result, SSU is often ignored in freshwater fisheries assessments.

Use of a change-in-ratio estimator (CIRE; Hartley and Ross 1954; Goodman and Hartley 1958; Cochran 1977; Pollock and Hoenig 1995) may provide a suitable alternative when tagging studies are not practical. Change-in-ratio estimators have been broadly applied in wildlife management to quantify changes in population density,

---

*Corresponding author: kris.bodine@tpwd.texas.gov
Received February 22, 2018; accepted June 28, 2018

survival, and productivity (e.g., Hanson 1963; Paulik and Robson 1969; Conner et al. 1986; Pollock and Hoenig 1995; Bordage et al. 1998; Hebblewhite et al. 2003). The use of CIREs in fisheries has mostly been limited to marine fisheries (e.g., Chen et al. 1998; Frusher et al. 1998; Claytor and Allard 2003), but variations of CIREs have been used in freshwater environments to measure the exploitation and abundance of some fish populations. Typically, CIREs measure the change in the proportion of a population metric from two discrete components of the population before and after removal (e.g., at the beginning and end of the season; Pollock and Hoenig 1995; Frusher et al. 1998). Here, we describe a unique variation of a CIRE that does not rely on "before" and "after" measurements to estimate SSU. Rather, our CIRE uses common and synchronously collected creel length frequency, population length frequency, and total exploitation to estimate absolute SSU (i.e., the total number of fish of a particular size that are harvested annually). Even when missing data prevent the estimation of absolute SSUs, CIREs can be used to estimate relative SSUs, i.e., increases or decreases within or among samples. Our goal in this process is to demonstrate an SSU estimation method that uses preexisting data and eliminates the need to conduct additional tagging studies.

EQUATIONS

Traditional Exploitation Estimation via Tagging

Total or size-specific exploitation is typically estimated directly by tagging a known number of harvestable fish and estimating the total number harvested via tag returns. The traditional equation (Ricker 1958) for estimating total exploitation (μ_T) is

$$\mu_t = \frac{R}{T}, \tag{1}$$

where R is the number of tagged fish harvested and T is the total number of tagged fish at large. To incorporate fish size into the exploitation estimate, equation (1) can also be expressed as

$$\mu T = \sum\left(\frac{R_i}{\sum T_i}\right), \tag{2}$$

where R_i is the number of tagged fish harvested for size-group i and T_i is the total number of tagged fish at large for size-group i. However, because abundance varies among size-groups, size-specific exploitation (μ_i) is estimated using only the tagged fish within size-group i and is expressed as (Miranda and Bettoli 2007; Bodine et al. 2016)

$$\mu_i = \frac{R_i}{T_i}. \tag{3}$$

Absolute SSU Estimation via CIRE

This indirect approach to estimating SSU eliminates the need to estimate the total number of fish removed from the population (Paulik and Robson 1969), instead using the ratio of the percentage of fish in a specific size-group that were observed in the creel to that of fish in the same size-group observed in a population survey. The logic behind this approach is quite simple. In cases in which no size selectivity is present and sampling is unbiased, we should see the same fraction of fish of a specific size in both the creel and the population survey. Differences in these fractions are evidence of size-selective harvest. The calculations are similar to the direct estimation method, by which the number of fish harvested (i.e., the number in the creel) of a specific size-group is divided by the number of that size available to be caught (i.e., the number counted in the population survey). However, the CIRE method differs from the direct method in two important ways: (1) all size-specific creel and population survey data are scaled by their totals (i.e., expressed as proportions) before analysis and (2) the quotient (i.e., the resulting proportion from the ratio of creel to population data) is then multiplied by the total exploitation rate. The resulting equation is

$$\text{Absolute SSU} = \mu_i = \left(\frac{(C_i/C_T)}{(P_i/P_T)}\right)\mu_T, \tag{4}$$

where C_i is the number of fish in size-group i in the creel, C_T is the total number of fish (all sizes combined) in the creel, P_i is the number of fish in size-group i in the population survey, and P_T is the total number of fish in the population survey.

The goal of this process is to scale the total exploitation rate for a given size-group based on whether the size-group is more or less harvested than average; therefore, to estimate SSU, total exploitation must be multiplied by the quotient to describe the proportion of total mortality accounted for by the given size-group. Although the need to estimate μ_T would seem to contraindicate use of this indirect method (since μ_T is typically estimated through tagging studies), μ_T can be estimated indirectly by subtracting an estimate of instantaneous natural mortality (M) from instantaneous total mortality (Z) to estimate instantaneous fishing mortality (F) and then converting F to μ_T (Allen and Hightower 2010). Catch-curve analysis using available age data can be used to provide an estimate of the total mortality rate (Van Den Avyle 1993). Natural mortality can be estimated using a number of different theoretically or empirically based formulas (Slipke and Maceina 2000; Brodziak et al. 2011). For example, M could be estimated as $1.5 \cdot K$, where K is the von Bertalanffy growth coefficient (Jensen 1996). Alternatively, M could be estimated based on the expected longevity of the species in an unfished state (in which 1% of fish live to maximum age; Quinn and Deriso 1999; Slipke and Maceina 2000).

To demonstrate how SSU estimation works, we first show that when we combine all size-groups into a single equation, the result will always produce an estimate that matches the total exploitation rate. To do this, we sum the size-specific ratios from the creel, then divide that by the sum of the size-specific ratios from the population survey. This result is then multiplied by the total exploitation rate, that is,

$$\mu_{\sum i} = \left(\frac{\sum \left({}^{C_i}/_{C_T} \right)}{\sum \left({}^{P_i}/_{P_T} \right)} \right) \mu_T. \tag{5}$$

The resulting quotient is expressed as

$$\mu_{\sum i} = \left(\frac{1}{1} \right) \mu_T \text{ or } \mu_{\sum i} = \mu_T.$$

As expected, when all possible size-groups are included in the equation, the result will always produce an equation in which μ_T is multiplied by 1. Thus, $\mu_{\sum i}$ will always equal μ_T.

Relative SSU Estimation via CIRE

Relative SSU is estimated similarly to absolute SSU (equation 4), except that μ_T is no longer used in the equation. Relative SSU is expressed as

$$\text{Relative SSU} = \mu_i = \left(\frac{\left({}^{C_i}/_{C_T} \right)}{\left({}^{P_i}/_{P_T} \right)} \right). \tag{6}$$

HYPOTHETICAL EXAMPLES

To demonstrate how these equations would be used to estimate SSU, we created some simplified examples from hypothetical data. For instance, using data from Table 1 along with equation (5) to estimate absolute SSU, we calculate

$$\mu_T = \left(\frac{(100/600 + 300/600 + 200/600)}{(500/1200 + 400/1200 + 300/1200)} \right) 0.25$$
$$= \left(\frac{1}{1} \right) 0.25 = 0.25.$$

To estimate absolute SSU for specific size-groups, we simply extract the size-groups of interest so that μ_T can be scaled accordingly. The size-specific exploitation rate of size-group A (Table 1) would be estimated as

$$\mu_A = \left(\frac{100/600}{500/1200} \right) 0.25 \text{ or } \mu_A = 0.4 \times 0.25 = 10\%.$$

Size-group A constitutes a smaller proportion of the harvest (100/600 = 0.167) than it does of the entire population (500/1,200 = 0.417), such that only 40% as many fish were harvested as would be expected based on their abundance in the population; thus, they only account for 40% of the overall exploitation rate (0.4 × 0.25 = 0.10). Similarly, the size-specific exploitation rate of size-group C (Table 1) would be estimated as

$$\mu_c = \left(\frac{200/600}{300/1200} \right) 0.25 \text{ or } \mu_c = 1.333 \times 0.25 = 33\%.$$

If the target exploitation rate was 25% for a particular management goal, this example illustrates how size-group C would be overexploited by about 33%.

In situations in which total exploitation is unavailable, relative SSU can be used to estimate whether all sizes are being exploited similarly or if anglers are selecting for certain sizes. For example, the relative SSU of size-group A (Table 1) would be expressed as

$$\mu_A = \left(\frac{100/600}{500/1200} \right) \text{ or } \mu_A = 40\%.$$

Similarly, the relative SSY of size-group B would be 150% and that of size-group C would be 133% (Table 1).

TABLE 1. Simulated data from a hypothetical population, along with data from hypothetical creel and population surveys indicating the number of fish harvested (creel) or sampled (population survey) within each size-group.

Size-group	True size of population	Creel	Population survey	Absolute SSU	Relative SSU
A	1,000	100	500	0.100	0.40
B	800	300	400	0.375	1.50
C	600	200	300	0.333	1.33
Total	2,400	600	1,200	0.250	1.00

These estimates are not the actual exploitation rates for the population. Rather, they are relative numbers—much like catch per unit effort, which can be compared among samples to determine relative differences (in this example, for instance, the relative SSU informs us that mortality is almost 4 times as large for group B as it is for group A, even though we do not know the actual mortality rate of either group). In this case, relative SSU can be used to determine whether exploitation is constant across all size-groups. It can also be used as a baseline measurement with which to compare future samples.

The variance and confidence bounds of the CIRE can be estimated in several ways. We recommend using a bootstrapping method (Efron 1981) in which the individual sample units from both data sets (typically day-and time-specific samples for the creel and site-specific samples for the population survey) are independently resampled multiple times (e.g., 1,000 times). Assuming that both the numerator and the denominator are unbiased, this approach will produce an unbiased mean of the ratio estimate and a bias-adjusted variance of the ratio estimate for relative SSU. When estimating the variance associated with an absolute SSU, the variance of the total exploitation rate (μ_T) is needed in addition to the variance of the ratio of the creel and survey data. We recommend using Goodman's (1960) approach to estimating the variance of a product, where the first term is the bootstrap-estimated variance of the ratio and the second term is the variance of the total exploitation rate. This approach will produce an unbiased estimate of the mean of the ratio and a bias-adjusted estimate of the variance of the ratio.

TABLE 2. Effect of an error in the creel data on size-specific exploitation estimates. This example shows how a 25% error in the creel data leads to a proportional error in the SSU estimate. In Table 1, we used the unbiased creel data below and equation (4) in the text to derive the unbiased estimate of SSU for size-group A (SSU_A) as $[(100/600)/(500/1{,}200)]\cdot 0.25 = 0.10$. With the incorporation of a 25% error, however, the number of fish in the creel increases to 125 and $SSU_A = [(125/600)/(500/1{,}200)]\cdot 0.25 = 0.125$, or 25% more.

Size-group	Unbiased creel (no. of fish)	% error added	Biased creel (no. of fish)	Unbiased survey (no. of fish)
A	100	0.25	125	500
B	300	–0.25	225	400
C	200	0.25	250	300
Total	600		600	1,200

TABLE 3. Effect of an error in the population survey data on size-specific exploitation estimates. This example shows how a 25% error in the population survey data leads to an nonproportional error in the SSU estimate. In Table 1, we used the unbiased population survey data below and equation (4) in the text to derive the unbiased estimate of SSU for size-group A (SSU_A) as $[(100/600)/(500/1{,}200)]\cdot 0.25 = 0.10$. With the incorporation of a 25% error, however, the number of fish in the population survey increases to 625 and $SSU_A = [(100/600)/(625/1{,}200)]\cdot 0.25 = 0.08$, or 20% less.

Size-group	Unbiased creel (no. of fish)	Unbiased survey (no. of fish)	% error added	Biased survey (no. of fish)
A	100	500	0.25	625
B	300	400	–0.25	300
C	200	300	–0.08	275
Total	600	1,200		1,200

EFFECTS OF BIAS

The validity of the CIRE method is based on several assumptions: (1) that both the creel and population survey data are random, representative samples of the true population, (2) that the estimate of μ_T is accurate, and (3) that the population is composed of different size-groups and that fish are accurately classified by size. Violation of these assumptions will affect SSU estimates because the ratio of each size-group will be incorrectly estimated. However, the magnitude of the effects depends on where the errors occur. Errors in creel data will produce a proportional response by which a 1% error in the data will result in a 1% error in the SSU (i.e., the 1% rule). This can be shown by multiplying the estimated SSU by a creel multiplier (CM), where CM = 1 + % error added (Table 2). For example, applying a 25% error to the creel data would result in

$$\text{Biased SSU}(SSU_B) = 10\% \times 1.25 \text{ or } SSU_B = 12.5\%.$$

The biased SSU is thus 25% higher than the unbiased SSU (Table 2). Errors in the population survey data (the denominator of the SSU equation) are similarly proportional; however, they differ from creel errors in that they are inversely proportional and do not adhere to the 1% rule. An error in the population survey is translated into SSU error by multiplying the unbiased SSU by a population survey multiplier (PM), where PM = 1/[1 + % error added] (Table 3). Errors in both the creel and population surveys are translated into the total SSU error by multiplying by both the CM and the PM.

APPLICATION OF THE CIRE APPROACH

Despite the importance of estimating SSU, high costs often prevent biologists from collecting the required data; however, the CIRE method may provide an alternative approach that is more practical in some situations. Because most standard fishery assessment programs do not incorporate specialized tagging studies, the costs of such studies are typically additional to those already encumbered. The CIRE method provides an alternative option for estimating SSU in which biologists can use routinely collected, standard assessment data to estimate SSU. When these data are available, the CIRE method could provide a cost-effective alternative. However, the CIRE may not always be the cheapest and most practical option because it requires synchronous estimation of each parameter. Although all CIRE parameters are routinely collected by most fisheries managers, we were unable to find a population for which all three elements (size-specific creel harvest, size-specific population abundance, and the total exploitation rate) were estimated within the same time period. Thus, to estimate SSU, biologists must consider the trade-offs between conducting a specialized tagging study and ensuring the synchronous collection of all three CIRE data elements.

Even when some CIRE data elements are not readily available, it may be advantageous to collect those data instead of conducting a separate tagging study. Each data element of the CIRE is critically important to effectively assessing and managing a fishery. Age data are also used to estimate growth rates, which is another fundamental dynamic rate needed to manage fish populations (Van Den Avyle 1993; Slipke and Maceina 2000). Creel data also allow assessment of relative harvest rates (e.g., those among seasons, species, anglers, etc.) and daily harvest rates, which are needed to help determine appropriate daily bag limits. When the total exploitation rate is unavailable, the CIRE can still be used to estimate relative SSU, which is useful for monitoring relative changes across time among fish sizes or across water bodies. Relative SSU could also be used to evaluate size-based harvest rates before and after regulation changes (e.g., raising or lowering allowable exploitation). Finally, relative SSU could be used as a litmus test to determine whether an estimate of absolute SSU is necessary. For example, if the relative SSU is constant across fish sizes, estimating the absolute SSU would be unnecessary and μ_T could simply be used for all fish sizes. We believe that the cumulative benefits and flexibility of the CIRE make it a potentially valuable tool for fisheries assessments.

Despite the practical uses of the CIRE, biologists should be mindful of potential errors when estimating SSU so that biases can be minimized. Errors in any component of the CIRE will bias the result; however, errors associated with the numerator (errors in creel data) are less problematic than errors in the denominator (errors in population survey data). The numerator is conveniently bounded by the 1% rule, which at most would double the SSU estimate (i.e., a 100% overestimate of the numerator would result in a doubling of the exploitation estimate). As with many ratio estimators, errors in the denominator can have a more profound effect because ratios are more sensitive to change when the values in the denominator are small. Also, errors in the denominator are unbounded and can produce a much larger effect on the result. Because the CIRE is most sensitive to errors in the denominator, we recommend that population survey data be as accurate as possible. Care should be taken to collect a representative sample for each CIRE data element or the analyses should be limited to size ranges that are accurately measured (i.e., those recruited to the gear). The study designs needed for application of the CIRE technique can vary greatly and will depend on specific project objectives; however, when accurate and representative samples for each CIRE element are obtained, the CIRE should reliably estimate SSU with a margin of error that is acceptable in most fisheries applications.

Regardless of its potential biases, the CIRE may be as reliable as many alternative methods. For example, tagging studies are vulnerable to tag loss, tagging mortality, tag recognition, "fishing for tags," and nonreporting of tags; all are potential sources of error that are often ignored or assigned a predetermined value (Pollock et al. 1991). Although models can be employed to account for such errors (Pollock et al. 1991), like the CIRE such techniques are limited by the quality of the input data. It is our opinion that if care is taken to ensure that the data elements are accurate and representative, the CIRE will be as robust as alternative options.

Ratio estimators have been widely used in resource management. Fisheries biologists routinely describe population characteristics with ratio estimators (Anderson and Gutreuter 1983) such as relative weight, the proportional size distribution, and the spawning potential ratio. Terrestrial wildlife managers have also thoroughly demonstrated the use of ratio estimators to quantify metrics such as population density, survival, and productivity (Paulik and Robson 1969; Conner et al. 1986; Bordage et al. 1998; Hebblewhite et al. 2003). Such widespread application of common ratio estimators further demonstrates their reliability and utility for resource managers. Although CIREs have yet to be used to quantify size-specific exploitation rates for fish, we have demonstrated the broad applicability, versatility, and quality of such an approach. We recommend that fisheries professionals consider using this CIRE to estimate SSU and continue developing CIREs to quantitatively describe other fisheries metrics.

ACKNOWLEDGMENTS

Editorial comments provided by Spencer Dumont, Dan Daugherty, and Dave Buckmeier improved this manuscript. Partial funding for this study was provided by the U.S. Fish and Wildlife Service through Federal Aid in Sport Fish Restoration Program grant F-231-R2. There is no conflict of interest declared in this article.

REFERENCES

Allen, M. S., and J. E. Hightower. 2010. Fish population dynamics: mortality, growth, and recruitment. Pages 43–77 *in* W. A. Hubert and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Anderson, R. O., and S. J. Gutreuter. 1983. Length, weight, and associated structural indices. Pages 283–300 *in* L. A. Nielsen, D. L. Johnson, and S. S. Lampton, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Bodine, K. A., J. W. Schlechte, R. A. Ott, D. L. Bennett, and J. D. Norman. 2016. Estimating exploitation and modeling the effects of hand fishing on a Flathead Catfish population in east Texas. North American Journal of Fisheries Management 36:1416–1424.

Bordage, D., N. Plante, A. Bourget, and S. Paradis. 1998. Use of ratio estimators to estimate the size of common eider populations in winter. Journal of Wildlife Management 62:185–192.

Brodziak, J., J. Ianelli, K. Lorenzen, and R. D. Methot Jr., editors. 2011. Estimating natural mortality in stock assessment applications. NOAA Technical Memorandum NMFS-F/SPO-119.

Chen, C. L., J. M. Hoenig, E. G. Dawe, C. Brownie, and K. H. Pollock. 1998. New developments in change-in-ratio and index removal methods, with application to snow crab (*Chionoecetes opilio*). Canadian Special Publication of Fisheries and Aquatic Sciences 125:49–61.

Claytor, R., and J. Allard. 2003. Change-in-ratio estimates of lobster exploitation rate using sampling concurrent with fishing. Canadian Journal of Fisheries and Aquatic Sciences 60:1190–1203.

Cochran, W. G. 1977. Sampling techniques, 3rd edition. Wiley, New York.

Conner, C. M., R. A. Lancia, and K. H. Pollock. 1986. Precision of the change-in-ratio technique for deer population management. Journal of Wildlife Management 50:125–129.

Efron, B. 1981. Nonparametric estimates of standard error: the jackknife, the bootstrap, and other methods. Biometrika 68:589–599.

Frusher, S. D., R. B. Kennedy, and I. D. Gibson. 1998. Preliminary estimates of exploitation rates in the Tasmanian rock lobster (*Jasus edwardsii*) fishery using the change-in-ratio and index removal techniques with tag–recapture data. Canadian Special Publication of Fisheries and Aquatic Sciences 125:63–71.

Gabelhouse, D. W. Jr., and D. W. Willis. 1986. Biases and utility of angler catch data for assessing size structure and density of Largemouth Bass. North American Journal of Fisheries Management 6:481–489.

Goodman, L. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708–713.

Goodman, L. A., and H. O. Hartley. 1958. The precision of unbiased ratio-type estimators. Journal of the American Statistical Association 53:491–508.

Hanson, W. R. 1963. Calculation of productivity, survival, and abundance of selected vertebrates from sex and age ratios. Wiley, New York.

Hartley, H. O., and A. Ross. 1954. Unbiased ratio estimators. Nature 174:270.

Hebblewhite, M., P. C. Paquet, D. H. Pletscher, R. B. Lessard, and C. J. Callaghan. 2003. Development and application of a ratio estimator to estimate wolf kill rates and variance in a multiple-prey system. Wildlife Society Bulletin 31:933–946.

Jensen, A. L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53:820–822.

Miranda, L. E., and P. W. Bettoli. 2007. Mortality. Pages 229–278 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Miranda, L. E., R. E. Brock, and B. S. Dorr. 2002. Uncertainty of exploitation estimates made from tag returns. North American Journal of Fisheries Management 22:1358–1363.

Miranda, L. E., and B. S. Dorr. 2000. Size selectivity of crappie angling. North American Journal of Fisheries Management 20:706–710.

Paulik, G. J., and D. S. Robson. 1969. Statistical calculations for change-in-ratio estimators of population parameters. Journal of Wildlife Management 33:1–27.

Pollock, K. H., and J. M. Hoenig. 1995. Change-in-ratio estimators. Pages 109–112 *in* S. Kotz, C. B. Read, and D. L. Banks, editors. Encyclopedia of statistical sciences, update volume. Wiley, New York.

Pollock, K. H., J. M. Hoenig, W. S. Hearn, and B. Calingaert. 2001. Tag reporting rate estimation, 1. An evaluation of the high-reward tagging method. North American Journal of Fisheries Management 21:521–532.

Pollock, K. H., J. M. Hoenig, and C. M. Jones. 1991. Estimation of fishing and natural mortality when a tagging study is combined with a creel survey or port sampling. Pages 423–434 *in* D. Guthrie, J. M. Hoenig, M. Holliday, C. M. Jones, M. J. Mills, S. A. Moberly, K. H. Pollock, and D. R. Talhelm, editors. Creel and angler surveys in fisheries management. American Fisheries Society, Symposium 12, Bethesda, Maryland.

Quinn, T. J. II, and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fisheries Research Board Canada Bulletin 119.

Schultz, R. D. 2004. Size-specific angling return rates of White Bass in Kansas reservoirs. North American Journal of Fisheries Management 24:719–723.

Serns, S. L., and J. J. Kempinger. 1981. Relationship of angler exploitation to the size, age, and sex of Walleyes in Escabana Lake, Wisconsin. Transactions of the American Fisheries Society 110:216–220.

Slipke, J. W., and M. J. Maceina. 2000. Fishery analysis and simulation tools. Auburn University, Auburn, Alabama.

Van Den Avyle, M. J. 1993. Dynamics of exploited fish populations. Pages 105–135 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.