North American Journal of Fisheries Management

ISSN: 0275-5947 (Print) 1548-8675 (Online) Journal homepage: http://www.tandfonline.com/loi/ujfm20

Establishing Size-Based Mortality Caps

L. E. Miranda

North American Journal of Fisheries Management 22:433–440, 2002

Establishing Size-Based Mortality Caps

L. E. MIRANDA*

*Mississippi Cooperative Fish and Wildlife Research Unit,
Post Office Box 9691, Mississippi State, Mississippi 39762, USA*

Abstract.—Mortality limits are seldom identified as management objectives in freshwater fisheries. I present two simple models for establishing approximate mortality caps that reflect threshold objectives about fish mean size or size structure. The deterministic caps would take the form of intervals to account for uncertainties caused by measurement error, model assumption violations, and environmental fluctuations. The intervals represent danger zones that trigger intensified monitoring and reductions in harvest. Monitoring the status of the population relative to a mortality cap would require frequent estimates of fish size and less frequent estimates of mortality. The methods can be used with data obtained from angler harvest surveys and routine population sampling.

During routine monitoring, freshwater fishery managers regularly collect information about the size and age composition of fish populations (Ney 1999). Age structure information is then used to estimate mortality with catch-curve models such as those described by Ricker (1975) and Quinn and Deriso (1999). These estimates of mortality are rough indexes because model assumptions are often violated. Mortality estimates are then used to evaluate the effect of external variables (e.g., Michaletz 1998; Sitar et al. 1999) or management actions (e.g., Slipke et al. 1998; Hale et al. 1999) or to feed into population models that predict yield, population characteristics, or the outcome of length or bag limits (e.g., Beamesderfer and North 1995; Maceina et al. 1998; Miranda and Allen 2000).

Nevertheless, mortality limits are seldom identified as objectives in managing freshwater fisheries. A review of *Inland Fisheries Management in North America* (Kohler and Hubert 1999) revealed that limit values for mortality are never specified, although methods for estimating and controlling mortality are introduced. This is in contrast to marine fisheries, where a large body of literature has emerged in recent years to address mortality reference points (Caddy 1998).

I develop two simple models for establishing approximate mortality caps that reflect threshold size objectives for a fishery. Model 1 uses mean size (e.g., length, weight) and model 2 uses length ratios, but both models assume that size of fish in a population is a function of growth and mortality. Thus, populations with large fish are likely to have low mortality, fast growth, or both. When growth is factored out of this relation, there is an inverse relationship between size and mortality such that excessive mortality produces severe reductions in size. Given this connection, and because fish size is a prominent factor in recreational fishery programs, managers should identify mortality caps above which size objectives for the fishery will not be reached. Mortality values nearing the cap should serve as a warning sign to step up monitoring, and values exceeding the cap should trigger management action or reevaluation of size objectives.

Model 1: Mortality Caps Based on Mean Size

Relation between Mortality, Growth, and Mean Size

Beverton and Holt (1956) defined a model of the mean length (L_{mean}) of fish in a fishery that harvested fish above a minimum length (L_x, and corresponding age, t_x) above which all fish were equally vulnerable to capture:

$$L_{\text{mean}} = \frac{F\displaystyle\int_{t_x}^{t_\infty} N_t L_t \, dt}{F\displaystyle\int_{t_x}^{t_\infty} N_t \, dt}, \qquad (1)$$

where

$$N_t = N_0 e^{-(M)t_x} e^{-(F+M)(t-t_x)}, \qquad (2)$$

and L_t is length at time t, N_0 is the total number of fish at the beginning of time t, and F and M are instantaneous annual fishing and natural mortalities, respectively. In equation (2), $N_0 e^{-(M)t_x}$ represents recruitment to the fishery. Substituting the

* E-mail: smiranda@cfr.msstate.edu

Received April 3, 2001; accepted August 16, 2001

von Bertalanffy growth equation (Ricker 1975) for L_t in equation (1),

$$L_t = L_\infty [1 - e^{-K(t-t_0)}], \tag{3}$$

and equation (2) for N_t and integrating from t_x to t_∞ results in

$$L_{\text{mean}} = L_\infty \left[1 - \frac{F + M}{F + M + K} e^{-K(t_x - t_0)}\right]. \tag{4}$$

From equation (3), the length of fish at t_x is

$$L_x = L_\infty [1 - e^{-K(t_x - t_0)}], \tag{5}$$

and from equation (5),

$$e^{-K(t_x - t_0)} = \frac{L_\infty - L_x}{L_\infty}. \tag{6}$$

Substituting equation (6) into equation (4) produces

$$L_{\text{mean}} = L_\infty \left[1 - \frac{F + M}{F + M + K} \frac{L_\infty - L_x}{L_\infty}\right], \tag{7}$$

and simplifying equation (7) yields

$$L_{\text{mean}} = L_x + \frac{K}{Z + K}(L_\infty - L_x), \tag{8}$$

where $Z = F + M$. This model assumes that (1) fish grow according to a deterministic von Bertalanffy growth curve (i.e., there is no variation among fish in length at age); (2) all fish larger than L_x are equally vulnerable to the fishing gear and experience constant total mortality risk represented by a negative exponential decay; and (3) recruitment to L_x occurs at a constant uniform rate.

Equation (1) essentially assumes fish have a lifespan in the fishery ranging from t_x to t_∞. If the lifespan is restricted between t_x and the maximum age represented in the catch, t_λ, and corresponding length L_λ, equation (1) may be expressed as

$$L_{\text{mean}} = L_\infty \left[1 - \frac{e^{Kt_0} F \displaystyle\int_{t_x}^{t_\lambda} e^{-(Z+K)t}\, dt}{\displaystyle\int_{t_x}^{t_\lambda} e^{-(Z)t}\, dt}\right]. \tag{9}$$

Integrating equation (9) from t_x to t_λ results in

$$L_{\text{mean}} = \left\{ L_\infty \left[1 - \frac{e^{-Zt_x} - e^{-Zt_\lambda}}{Z} - \frac{e^{Kt_0}[e^{-t_x(Z+K)} - e^{-t_\lambda(Z+K)}]}{Z + K}\right]\right\} \div \left[\frac{e^{-Zt_x} - e^{-Zt_\lambda}}{Z}\right]. \tag{10}$$

Establishing Mortality Caps Based on Mean Size

Equations 8 or 10 can be rearranged to estimate mortality from knowledge of length and K; below I work just with equation (8). Rearranging equation (8) results in

$$Z = K \frac{L_\infty - L_{\text{mean}}}{L_{\text{mean}} - L_x}, \tag{11}$$

and a mortality cap estimated based on the threshold mean length (i.e., smallest mean length acceptable based on the management objective) of fish in the population. Consider, for example, a population of white crappies *Pomoxis annularis* whose growth characteristics are described by a von Bertalanffy model with $K = 0.374$ and $L_\infty = 353$ mm (average growth, Allen and Miranda 1995). A hypothetical fishery for this crappie population is currently regulated by a 200-mm minimum length limit. An objective for this fishery is for fish in the angler's creel to average 250 mm or better. Equation (9) can estimate the maximum level of annual mortality that would still allow the 250-mm mean length objective:

$$Z = 0.374 \frac{353 - 250}{250 - 200} = 0.77,$$

or an interval annual mortality rate A equal to $1 - e^{-0.77}$ or 54%. Therefore, the interval mortality cap to meet the objectives would be roughly 50%; if mortality were higher, whether due to natural causes or to fishing, fewer fish would live to old age (=large size) and mean length would drop below the 250-mm threshold size objective.

Simulation of Mortality Caps

Mortality caps for crappies *Pomoxis* spp. under various growth patterns and threshold mean length objectives were modeled with equation (11). First, an empirical equation relating K to L_∞ was developed using length-at-age data reported by Hoyer and Canfield (1994), Allen and Miranda (1995), Guy and Willis (1995), Miranda et al. (1997), and McInerny and Cross (1999). The data set included black crappies *P. nigromaculatus* and white crappies representing 57 populations throughout most of their native range expanding over latitudes 28–46°N. The model was fit with linear regression procedures, initially including a dummy variable to identify species and the interaction of the dummy variable and L_∞. This initial model indicated only a marginally significant effect of the dummy variable ($P = 0.09$) and a nonsignificant interaction ($P = 0.53$). Consequently, a single model for

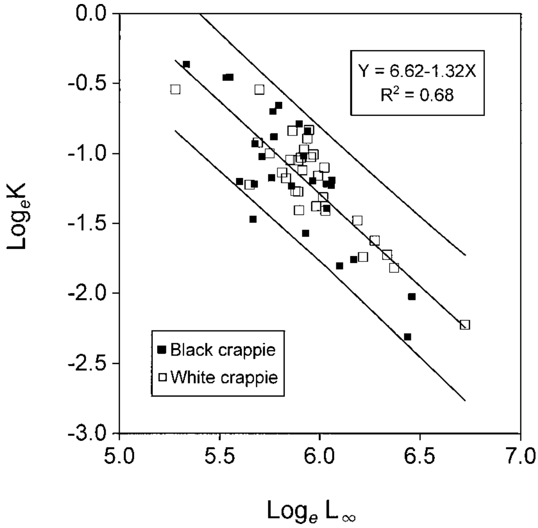

FIGURE 1.—Relationship between K and L_∞ in black and white crappies representing 57 populations throughout most of their native range and expanding over latitudes 28–46°N. Because regression analyses indicated that the models for the two species were only marginally different ($P \leq 0.09$), a single model for the combined species is presented. The lines represent the predicted values and the upper and lower 95% confidence limits.

the combined species was derived (Figure 1). Next, the empirically derived equation was used to replace K in equation (11) as

$$Z = (e^{6.62}L_\infty^{-1.32})\frac{L_\infty - L_{\text{mean}}}{L_{\text{mean}} - L_x}. \tag{12}$$

Then, sequences of L_{mean} and L_∞ values were inserted into equation (12) to generate a range of Z rates for three L_x values (L_x = 150, 200, and 250). Lastly, Z rates were plotted against L_∞ according to L_{mean} and L_x, to illustrate the relation between mortality caps and determinant variables.

The resulting isopleths show the dependency of a mortality cap on the threshold size objective, growth pattern, and L_x (in this example, L_x represents a minimum length limit). The mortality cap

→

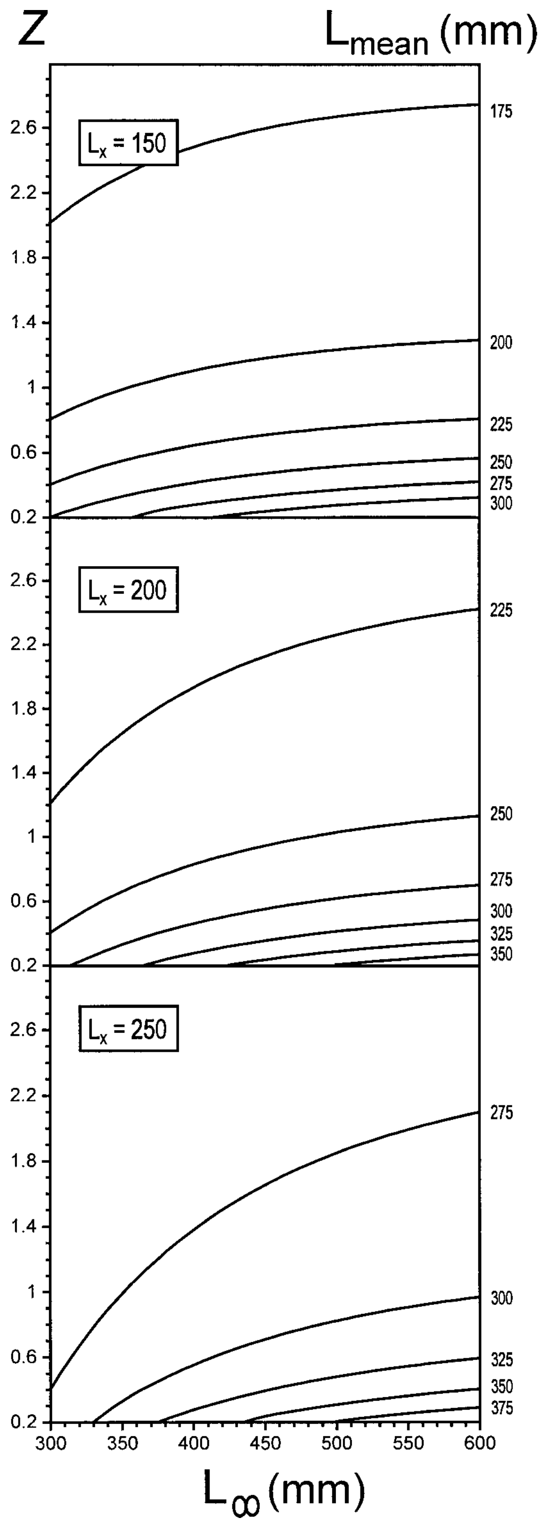

FIGURE 2.—Isopleths for approximating crappie mortality caps (Z) given a growth pattern (L_∞) and a threshold mean length objective (L_{mean}; isopleths). Values were derived with equation (12). The isopleths indicate, for instance, that if the objective is an average fish size of 250 mm or more and L_∞ is 450 mm and L_x (e.g., a minimum length limit) is 200 mm, then instantaneous mortality Z must not exceed about 0.9 (A = 0.59 interval rate).

beyond which a threshold mean length objective is unachievable decreased as the length objective increased (Figure 2). Conversely, for a fixed length objective, the mortality cap increased as L_∞ and L_x increased. For example, if the objective is to maintain crappies that average 275 mm (about 0.3 kg) or better, and L_∞ is about 550 mm, then annual Z must not exceed 2.00 for $L_x = 250$, 0.65 for $L_x = 200$, and 0.40 for $L_x = 150$. However, if L_∞ is about 400 mm, then Z must not exceed 1.40 for $L_x = 250$, 0.45 for $L_x = 200$, and 0.30 for $L_x = 150$.

Although I have used crappies for illustration, mortality caps can be established for any species if K and L_∞ are available. If they are not, rough approximations can be made. Several methods can be used to derive approximations of L_∞. First, dividing the mean length of the three largest fish known from the stock by 0.95 can adequately approximate L_∞ when the stock is not too heavily exploited (Pauly 1984). Second, L_∞ can be estimated from the maximum length of fish observed ($L_{\max}$) with an empirical equation derived by Froese and Binohlan (2000; $L_\infty = 1.045\ L_{\max}^{0.984}$). Third, L_∞ can be estimated through regression of the difference $L_m - L_i$ (L_m = mean length of fish larger than L_i in the length-frequency distribution; L_i = lower limit of ith length interval) as a function of L_i (Wetherall et al. 1987):

$$(L_m - L_i) = a - bL_i, \tag{13}$$

where $L_\infty = -a/b$ and $b = -K/(Z + K)$. Once an estimate of L_∞ is available, values of K may be approximated by rearranging the von Bertalanffy equation. If at least one estimate of length at time t (L_t) is available, and t_0 is assumed to be about zero, then

$$K = \frac{-\log_e(1 - L_t/L_\infty)}{t}. \tag{14}$$

Moreover, empirical data may be used to estimate K from L_∞, as done for crappies in Figure 1. For instance, Beamesderfer and North (1995) published a large data set of K and L_∞ values for largemouth bass *Micropterus salmoides* and smallmouth bass *M. dolomieu* from which empirical models for these species may be derived; data for other species are available throughout the primary literature and agency reports.

Alternative Models

Threshold sizes are often stated in terms of weight. In crappie fisheries, monitoring the mean size of fish harvested by anglers is usually simplified to weighing the composite catch, and dividing by the count. Thus, managers may prefer to express threshold sizes in terms of average weight. Cap mortality values based on threshold average weights are estimated by modifying equation (11) as

$$Z = K\frac{L_\infty - \sqrt[b]{W_{\text{mean}}/a}}{\sqrt[b]{W_{\text{mean}}/a} - L_x}, \tag{15}$$

where W_{mean} represents the threshold mean weight of fish in the catch and a and b are parameters of the $W = aL^b$ model for the population. Assuming a weight–length relation of the form $W = 10^{-5.642}\ L^{3.332}$ (Anderson and Neumann 1996) and a threshold mean weight of 340 g, an approximate annual cap Z for the population would be

$$Z = 0.374\frac{353 - \sqrt[3.332]{340/10^{-5.642}}}{\sqrt[3.332]{340/10^{-5.642}} - 200} = 0.31,$$

or an interval annual mortality rate A equal to $1 - e^{-0.31}$ or 27%. Such a cap on mortality may be difficult to maintain, considering the high natural mortality levels normally associated with crappie populations (Allen et al. 1998). This quick approximation suggests that such a mortality cap and threshold mean weight are unrealistic for this population unless there is a way to accelerate growth rate.

A model similar to equation (11), but not applied here, was derived by Hoenig et al. (1983). Their estimator is based on the median length L_{median} above L_x:

$$Z = \frac{K \log_e 2}{y_{\text{median}} - y_x}, \tag{16}$$

where $y_{\text{median}} = -\log_e(1 - L_{\text{median}}/L_\infty)$, and $y_x = -\log_e(1 - L_x/L_\infty)$. The authors indicated the estimate based on the median length is more robust than one based on mean length, because median length is less sensitive to variability in growth and year-class strength. Equation (16) can estimate mortality caps, but would require the manager to think about threshold length in terms of a median rather than a mean.

Model 2: Mortality Caps Based on Size Ratios

Relation between Mortality, Growth, and Proportional Stock Density

Freshwater fishery managers often rely on size ratios to evaluate fish populations. A commonly applied ratio is the proportional stock density

(PSD) developed by Anderson (1976), and computed as the number of quality size fish N_Q divided by the number of stock size fish N_S. Definitions for stock and quality sizes vary according to species and are given by Anderson and Neumann (1996). In a steady-state population, N_t is given by:

$$N_t = \int_t^{t_\infty} N_0 e^{-Zt}\, dt = \frac{N_0}{Z} e^{-Zt}. \qquad (17)$$

Thus,

$$N_Q = \frac{N_0}{Z} e^{-Zt_Q},$$

$$N_S = \frac{N_0}{Z} e^{-Zt_S}, \quad \text{and}$$

$$\text{PSD} = \frac{\frac{N_0}{Z} e^{-Zt_Q}}{\frac{N_0}{Z} e^{-Zt_S}}, \qquad (18)$$

which simplifies to

$$\text{PSD} = e^{-Z(t_Q - t_S)}, \qquad (19)$$

where t_S is the number of years it takes fish to grow to stock size and t_Q is the number of years to reach quality size.

Establishing Mortality Caps Based on Proportional Stock Density

Equation (19) can be rearranged to estimate mortality from knowledge of $t_Q - t_S$ as

$$Z = -\frac{\log_e \text{PSD}}{t_Q - t_S}, \qquad (20)$$

and an instantaneous mortality cap estimated based on the minimum acceptable PSD. Consider, for example, a population of black bass *Micropterus* sp. whose growth characteristics allow fish to reach t_S (i.e., age at which bass is 200 mm; Anderson and Neumann 1996) in 2 years and t_Q (i.e., 300 mm) in 3.5 years. If the threshold PSD for managing this fishery were 0.4, the instantaneous annual mortality cap on the population would be 0.61 (A = 0.46 annual interval rate). However, if the time it takes the average fish to grow between stock and quality sizes could be reduced from 1.5 to 1.2 years, the mortality cap could be raised to 0.76 (A = 0.54 interval rate) while still remaining above the threshold PSD. The relation between PSD, growth, and mortality is further illustrated in Figure 3. This approach can be modified for use with other size structure indices (i.e., relative stock density indices) described by Anderson and Neumann (1996), simply by substituting in equation (20).

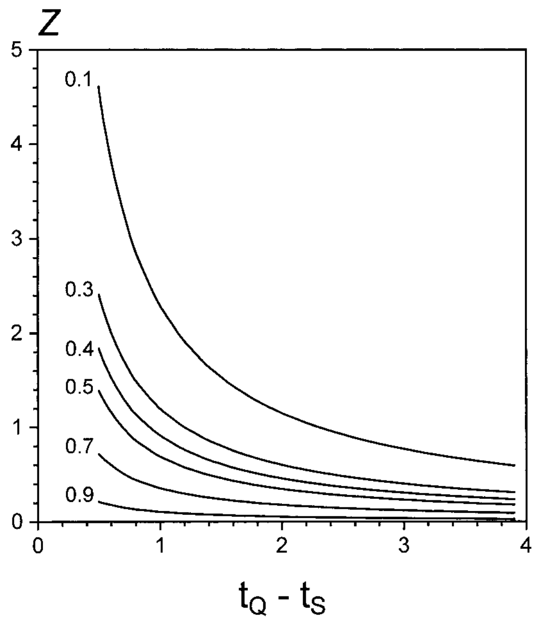

FIGURE 3.—Isopleths for approximating bass mortality caps (Z) given a growth pattern (age at quality length, t_Q, minus age at stock length, t_S) and a threshold proportional stock density (PSD) objective (0.1–0.9 or 10–90%; isopleths). Values were derived with equation (20). The isopleths indicate, for instance, that if the objective is a threshold PSD of 0.4 and fish grow from t_S to t_Q in 1.5 years, then instantaneous mortality Z must not exceed about 0.6 instantaneous rate (A = 0.45 interval rate).

Application and Caveats

Models 1 and 2 can be used to establish mortality caps based on threshold size objectives for the fishery. Once the cap is established, monitoring evaluates the status of the population relative to the threshold. To monitor, mean fish size over L_x in samples is compared on a regular basis with the threshold size objective. On a less frequent basis, mortality estimated from the age composition of the samples is compared with the mortality cap. As the mean fish size in the samples drops near the threshold size, mortality is estimated and compared with the cap with increasing regularity. If the mortality exceeds the cap, management intervention would be required to reduce harvest by at least the difference between the recorded mortality and the cap, and, if possible, to take steps to reduce natural mortality. Methods for controlling mortality include habitat improvement, fish community manipulations, and harvest restrictions, as detailed by Kohler and Hubert (1999).

Monitoring mean size may rely on angler surveys, with L_x representing the minimum length legally available to anglers or the minimum length acceptable by anglers. Alternatively, L_x may be redefined as the smallest fish size adequately sampled by electrofishing, trap-netting, gill netting, or other types of fishing gear. The value of L_x could be redefined as the length at which 50% of the fish entering the gear are retained, the smallest length fully vulnerable to a gear, or any length above these minima.

Assumptions for the application of these procedures include: (1) constant population mortality over time; (2) constant growth, and, in the case of model 1, growth adequately described by the von Bertalanffy model; (3) constant annual recruitment, or at least recruitment that varies in a random fashion; (4) constant recruitment through the year into the smallest length considered for analysis (L_x in model 1, and stock and quality lengths in model 2); (5) only lengths fully recruited to the gear are monitored; and (6) the sampling gear adequately represents the standing age and length distribution.

Catch curves from standing age distributions are commonly used by inland fisheries managers to estimate mortality (Ricker 1975). Because such usage invokes assumptions 1, 2, 3, and 6, one could rationalize that mortality cap estimation as described here should be equally acceptable to managers. Assumption 4 implies that the shapes of the age and length distributions do not vary seasonally. This assumption is violated in populations that exhibit seasonal instead of continuous recruitment, and when gear selectivity changes seasonally (Ralston 1989). Biases associated with violating this assumption hinder comparisons of fish size and mortality in samples with the threshold size objective and mortality cap. Biases can be avoided by taking multiple samples within a year and pooling them before analysis (Ralston 1989), or by limiting analysis to longer and older fish (i.e., avoid low L_x), whose growth in length is slower and whose recruitment into L_x is spread out over the year. Assumption 5 is easily met when a minimum length limit is in effect and infractions are minimal. However, when vulnerability to catch increases over a size range (e.g., when there is no length limit and the angler's size preference varies, or when efficiency of the gear improves with fish size), L_x in model 1 and stock size in model 2 must be established at sizes in which fish are fully recruited to the gear. When the collection gear is selective and underestimates fish size, comparisons with the threshold size and mortality cap result in a bias towards detecting excessive mortality; the reverse is true when the gear overestimates fish size. Methods for estimating and adjusting for selectivity are described by Gulland (1983).

Mortality Caps as Danger Zones

The mortality caps derived herein are reference points identified deterministically to represent an upper limit of mortality, in order to achieve the size objectives for the fishery. The cap is intended to prevent overfishing that renders the size distribution of a population undesirable from a fishery perspective. The cap is not a target for management, but instead it helps managers define the upper limits of mortality. If the cap is approached, additional emphasis must be placed on monitoring the fishery, and if the cap is exceeded, Z must be immediately reduced through cuts in harvest that are equal to or larger than the excess Z.

There is considerable uncertainty associated with establishing a mortality cap. The first source of uncertainty is the joint effect that violating some or all of the assumptions identified in the previous section has on estimation of the cap. A second source of uncertainty is the measurement error associated with estimating growth characteristics used in computation of the cap. Such uncertainty is generally reduced when accurate and precise data are available, as well as when data expand a long time series. A third source of uncertainty is fluctuations in environment that directly affect growth. Such fluctuations suggest that the mortality cap must fluctuate, but it is difficult to forecast environmental conditions and their effects on growth.

Given these uncertainties, a prudent step may be to conduct an uncertainty analysis to construct a probability distribution around the mortality cap, rather than using a single deterministic value. Such a distribution may be developed by selecting at random, for example, 1,000 parameter values from the probability distribution of L_∞, and 1,000 from the distribution of K, and inserting them into equation (11) to generate the probability distribution of the mortality cap. Probability distributions of L_∞ and K can be constructed from estimates of measurement error (e.g., Defeo and Seijo 1999). Similarly, the distribution of the mortality cap based on PSD (equation 20) may be constructed by selecting values at random from the probability distributions of t_Q and t_S. The resulting mortality probability distribution is likely to mix estimation error and natural variability, which is pertinent given that management will be applied to naturally stochastic populations occupying unpredictable environments.

Further application of the mortality cap must involve the probability interval. The interval could serve as a danger zone that triggers further and perhaps intensified monitoring that would provide additional mortality estimates, preferably using more than one method. Estimates of mortality made during monitoring also have probability intervals. Conceivably, harvest could be reduced gradually as the upper tail of the probability estimate around observed mortality meets and merges with the lower tail of the probability interval around the mortality cap. Thus, reductions in harvest may be applied in direct proportion to the degree of overlap of these two probability distributions.

Precautionary mortality reference points are now commonly applied in management of marine resources to define exploitation limits that will protect stocks from collapsing (Caddy 1998). However, the mortality reference point proposed here is not precautionary in the sense used in the marine literature. Instead, it simply identifies the maximum level of mortality that will support a certain size objective. Conceivably, mortality caps derived with models 1 and 2 can lead to permanent damage to the stock if the manager sets the cap too high. To make the mortality cap precautionary so that recruitment overfishing may be avoided and stocks will not decline, managers may take two approaches. First, they can use threshold mean length values (i.e., L_{mean} in equation 11) that are equal to or larger than the mean length at which, say, 50% of the population is reproductively mature, ensuring that 50% of the stock would spawn at least once. Additionally, they can establish thresholds on spawner density, biomass, catch, or some other indicator of abundance to use in combination with mortality caps.

Acknowledgments

S. Oppenheimer helped derive equation (20). P. Bettoli, B. Hubbard, L. Morgan, H. Schramm, and R. Smiley provided helpful reviews.

References

Allen, M. S., and L. E. Miranda. 1995. An evaluation of the potential value of harvest restrictions in managing crappie fisheries. North American Journal of Fisheries Management 15:766–772.

Allen, M. S., L. E. Miranda, and R. E. Brock. 1998. Implications of compensatory and additive mortality to the management of selected sportfish populations. Lakes and Reservoirs: Research and Management 3:67–79.

Anderson, R. O. 1976. Management of small warmwater impoundments. Fisheries 1(6):5–7,26–28.

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447–512 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Beamesderfer, R. C. P., and J. A. North. 1995. Growth, natural mortality, and predicted response to fishing for largemouth bass and smallmouth bass populations in North America. North American Journal of Fisheries Management 15:688–704.

Beverton, R. J. H., and S. J. Holt. 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapports et Procès-Verbaux des Réunions, Conseil International pour l'Exploration de la Mer 140:67–83.

Caddy, J. F. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fisheries Technical Paper 379.

Defeo, O., and J. C. Seijo. 1999. Yield-mortality models: a precautionary bioeconomic approach. Fisheries Research 40:7–16.

Froese, R., and C. Binohlan. 2000. Empirical relationships to estimate asymptotic length, length at first maturity, and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Journal of Fish Biology 56:758–773.

Gulland, J. A. 1983. Fish stock assessment. FAO/Wiley, Chichester, UK.

Guy, C. S., and D. W. Willis. 1995. Growth of crappies in South Dakota waters. Journal of Freshwater Ecology 10:151–161.

Hale, R. S., M. E. Lundquist, R. L. Miller, and R. W. Petering. 1999. Evaluation of a 254-mm minimum length limit on crappies in Delaware Reservoir, Ohio. North American Journal of Fisheries Management 19:804–814.

Hoenig, J. M., W. D. Lawing, and N. A. Hoenig. 1983. Using mean age, mean length and median length data to estimate the total mortality rate. International Council for the Exploration of the Sea, ICES-CM-1983/D:23, Copenhagen.

Hoyer, M. V., and D. E. Canfield. 1994. Handbook of common freshwater fish in Florida lakes. University of Florida, Gainesville.

Kohler, C. C., and W. A. Hubert, editors. 1999. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Maceina, M. J., P. W. Bettoli, S. D. Finely, and V. J. DiCenzo. 1998. Analyses of the sauger fishery with simulated effects of a minimum size limit in the Tennessee River of Alabama. North American Journal of Fisheries Management 18:66–75.

McInerny, M. C., and T. K. Cross. 1999. Effects of lake productivity, climate warming, and intraspecific density on growth and growth patterns of black crappie in southern Minnesota lakes. Journal of Freshwater Ecology 14:255–264.

Michaletz, P. H. 1998. Population characteristics of gizzard shad in Missouri reservoirs and their relation to reservoir productivity, mean depth, and sport fish growth. North American Journal of Fisheries Management 18:114–123.

Miranda, L. E., M. Allen, R. Brock, K. Cash, B. S. Dorr, L. C. Isaak, and M. S. Schorr. 1997. Evaluation of regulations restrictive of crappie harvest. Mississippi Department of Wildlife, Fisheries and Parks, Federal Aid in Fish Restoration, Project F-105, Final Report, Jackson.

Miranda, L. E., and M. S. Allen. 2000. Use of length limits to reduce variation in crappie fisheries. North American Journal of Fisheries Management 20: 752–758.

Ney, J. J. 1999. Practical use of biological statistics. Pages 167–192 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Pauly, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. International Center for Living Aquatic Resources Management, ICLARM Studies and Reviews 8, Manila.

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

Ralston, S. 1989. Effect of seasonal recruitment on bias of the Beverton-Holt length-based mortality estimator. Pages 190–197 *in* E. F. Edwards and B. A. Megrey, editors. Mathematical analysis of fish stock dynamics. American Fisheries Society, Symposium 6, Bethesda, Maryland.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Sitar, S. P., J. R. Bence, J. E. Johnson, M. P. Ebener, and W. W. Taylor. 1999. Lake trout mortality and abundance in southern Lake Huron. North American Journal of Fisheries Management 19:881–900.

Slipke, J. W., M. J. Maceina, V. H. Travnichek, and K. C. Weathers. 1998. Effects of a 356-mm minimum length limit on the population characteristics and sport fishery of smallmouth bass in the shoals reach of the Tennessee River, Alabama. North American Journal of Fisheries Management 18:76–84.

Wetherall, J. A., J. J. Polovina, and S. Ralston. 1987. Estimating growth and mortality in steady-state fish stocks from length-frequency data. ICLARM (International Center for Living Aquatic Resources Management), Conference Proceedings 13, Manila.