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Age Structure and Mortality of Walleyes in Kansas Reservoirs: Use of Mortality Caps to Establish Realistic Management Objectives

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Abstract.—Age structure, total annual mortality, and mortality caps (maximum mortality thresholds established by managers) were investigated for walleye *Sander vitreus* (formerly *Stizostedion vitreum*) populations sampled from eight Kansas reservoirs during 1991–1999. We assessed age structure by examining the relative frequency of different ages in the population; total annual mortality of age-2 and older walleyes was estimated by use of a weighted catch curve. To evaluate the utility of mortality caps, we modeled threshold values of mortality by varying growth rates and management objectives. Estimated mortality thresholds were then compared with observed growth and mortality rates. The maximum age of walleyes varied from 5 to 11 years across reservoirs. Age structure was dominated (≥72%) by walleyes age 3 and younger in all reservoirs, corresponding to ages that were not yet vulnerable to harvest. Total annual mortality rates varied from 40.7% to 59.5% across reservoirs and averaged 51.1% overall (SE = 2.3). Analysis of mortality caps indicated that a management objective of 500 mm for the mean length of walleyes harvested by anglers was realistic for all reservoirs with a 457-mm minimum length limit but not for those with a 381-mm minimum length limit. For a 500-mm mean length objective to be realized for reservoirs with a 381-mm length limit, managers must either reduce mortality rates (e.g., through restrictive harvest regulations) or increase growth of walleyes. When the assumed objective was to maintain the mean length of harvested walleyes at current levels, the observed annual mortality rates were below the mortality cap for all reservoirs except one. Mortality caps also provided insight on management objectives expressed in terms of proportional stock density (PSD). Results indicated that a PSD objective of 20–40 was realistic for most reservoirs. This study provides important walleye mortality information that can be used for monitoring or for inclusion into population models; these results can also be combined with those of other studies to investigate large-scale differences in walleye mortality. Our analysis illustrates the utility of mortality caps for monitoring walleye populations and for establishing realistic management goals.

Growth, recruitment, and mortality are the three primary factors regulating fish populations (Ricker 1975; Beverton 1987; Colvin 1991; Maceina et al. 1998). Although growth and recruitment are important for understanding population dynamics, knowledge of mortality rates is critical for management. In exploited populations, mortality of fishes occurs as natural and fishing mortality. Nat-

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ural mortality results from factors such as predation (Brandt et al. 1987), disease (Post 1987), or starvation (Chick and Van Den Avyle 1999), whereas fishing mortality results from the direct (harvest) or indirect (hooking or handling mortality) effects of commercial harvest or recreational angling (Ricker 1975; Van Den Avyle and Hayward 1999). Thus, changes in mortality rates may reflect alterations in biological interactions, the physical environment, or exploitation rates, and knowledge of these changes is important for evaluating management activities (e.g., prey or habitat management, harvest regulations).

Despite their importance, mortality rates are not commonly monitored by management agencies. In addition, maximum mortality limits are rarely included in the management of freshwater fisheries, even though mortality reference points are frequently used to monitor and assess fisheries in marine systems (Miranda 2002). Due to the effects of mortality on fish population dynamics, Miranda (2002) suggested that managers of freshwater fish populations should identify mortality caps, defined as the thresholds of mortality above which management objectives are not met. Mortality caps can be useful to management agencies because they not only indicate which management objectives are realistic, but also serve to alert managers when mortality rates are near the threshold. When mortality rates approach or exceed the mortality cap, actions to reduce mortality or re-evaluate management objectives are warranted.

The walleye *Sander vitreus* (formerly *Stizostedion vitreum*) is one of the most popular sport fish in Kansas, and its popularity among anglers has continued to increase over the last decade (Burlingame 1998). Consequently, management of walleye fisheries is a priority for many reservoirs throughout Kansas and the Great Plains. Although we have recently begun to understand walleye recruitment and growth in Kansas reservoirs (Willis and Stephen 1987; Quist et al. 2002, 2003a, 2003b), little is known about how mortality rates vary among reservoirs or how they compare with mortality rates of other walleye populations throughout North America. Therefore, our objectives were to describe the age structure and total annual mortality of walleyes and to evaluate the utility of mortality caps for managing walleye populations in Kansas reservoirs.

Methods

Study area.—Walleyes were sampled from eight Kansas reservoirs (Cedar Bluff, Cheney, Glen Elder, Kirwin, Lovewell, Marion, Webster, and Wilson reservoirs) during 1991–1999. A detailed description of the study reservoirs is provided by Quist et al. (2003a, 2003b). The study reservoirs are large (mean surface area ± SE; 2,649.4 ± 498.7 ha), shallow (depth: 6.2 ± 0.5 m), and turbid, and thermal stratification is rare due to persistent wind action. Watersheds of the study reservoirs are dominated by mixed-grass prairie pastureland, but row-crop agriculture is also common in some drainages. The reservoirs were constructed during the 1960s and 1970s to provide flood protection, agricultural irrigation, and augmentation of downstream flows for navigation in the Missouri and Mississippi rivers. As such, most of the reservoirs experience water-level fluctuations of several meters per year. In addition to dynamic habitat characteristics, thermal regimes in the reservoirs may be stressful to walleyes because water temperatures commonly exceed 28°C during summer (Quist et al. 2002). White crappies *Pomoxis annularis*, white bass *Morone chrysops*, hybrid striped bass *M. saxatilis* × *M. chrysops*, channel catfish *Ictalurus punctatus*, largemouth bass *Micropterus salmoides*, and walleyes are the dominant sport fishes, and the gizzard shad *Dorosoma cepedianum* is the primary prey species in all reservoirs. The study reservoirs have recreational walleye fisheries and are managed with a minimum length limit of either 381 mm (Glen Elder, Kirwin, Webster, and Wilson reservoirs) or 457 mm (Cedar Bluff, Cheney, Lovewell, and Marion reservoirs).

Walleye sampling and mortality estimation.—Walleyes were sampled from each reservoir during late October to early November by use of gill-net compliments (one gill-net compliment equals four separate monofilament gill nets, each 30.5-m long × 1.8-m deep with either 2.5, 3.8, 6.4, or 10.2-cm bar-measure mesh). Total length (mm) was measured from all fish, and scales and otoliths were removed from five fish per 1-cm length-group. The period of scale and otolith collection varied from 2 to 7 years (Table 1). Scales were pressed onto 1.0-mm-thick acetate slides, and ages were estimated with a microfiche projector. Otoliths were used to corroborate scale age and to estimate age when scales were difficult to read. Scales and otoliths from a subsample of 1,239 fish were examined by two readers, who agreed on 96% of the age estimates. An age–length key was used to estimate the age structure of the walleye population for each reservoir and collection year (DeVries and Frie 1996). Age-frequency distributions were constructed by combining years for each reservoir to

TABLE 1.—Maximum theoretical length (L_{inf}, mm), growth coefficient (K), and theoretical time at which length equals zero (t_0) from von Bertalanffy growth models for walleyes sampled in eight Kansas reservoirs. Growth models were developed for each year that age and growth data were collected and for all years combined for each reservoir. The coefficient of determination (R^2) and P-value indicate model fit.

Reservoir and year	L_{inf}	K	t_0	R^2	P
Cedar Bluff					
1992	605	0.45	−0.26	0.99	0.0003
1993	862	0.20	−0.56	0.99	0.0001
1995	655	0.47	0.06	0.99	0.0001
1996	735	0.33	−0.26	0.99	0.0001
All years	779	0.26	−0.46	0.99	0.0001
Cheney					
1995	750	0.25	−0.63	0.99	0.0001
1996	680	0.29	−0.66	0.99	0.0001
All years	681	0.31	−0.52	0.99	0.0001
Glen Elder					
1991	686	0.37	−0.20	0.99	0.0001
1992	1038	0.16	−0.62	0.99	0.0001
1993	699	0.29	−0.48	0.99	0.0001
1995	649	0.44	−0.13	0.99	0.0001
1996	828	0.24	−0.63	0.99	0.0001
1998	661	0.38	−0.34	0.99	0.0001
1999	721	0.29	−0.48	0.99	0.0001
All years	712	0.32	−0.37	0.99	0.0001
Kirwin					
1996	646	0.41	−0.29	0.97	0.01
1998	800	0.29	−0.52	0.99	0.0008
All years	817	0.24	−0.55	0.99	0.0003
Lovewell					
1991	754	0.23	−0.98	0.97	0.0001
1992	622	0.37	−0.55	0.98	0.0001
1993	642	0.39	−0.29	0.99	0.0001
1995	800	0.22	−0.97	0.99	0.0001
1996	654	0.35	−0.58	0.99	0.0001
All years	726	0.26	−0.83	0.98	0.0001
Marion					
1995	800	0.21	−0.94	0.98	0.0001
1996	620	0.46	−0.25	0.99	0.0001
1998	748	0.26	−0.69	0.98	0.0001
All years	705	0.30	−0.59	0.99	0.0001
Webster					
1995	722	0.30	−0.71	0.99	0.0001
1996	690	0.43	−0.19	0.99	0.0001
All years	705	0.36	−0.49	0.99	0.0001
Wilson					
1995	651	0.45	−0.14	0.99	0.0001
1996	714	0.32	−0.45	0.99	0.0001
All years	711	0.33	−0.43	0.99	0.0001

reduce the influence of variable recruitment (Ricker 1975).

Total annual mortality (A) was estimated by use of a weighted catch-curve regression (Slipke and Maceina 2000). Weighted regression decreases the influence of rare and older fish when computing the slope of the regression equation and provides a less-biased estimate of mortality than unweighted regression techniques (Freund and Littell 1991; Slipke and Maceina 2000). Catch curves were based on age structure data pooled across collection years for each reservoir (Ricker 1975). Total mortality for each collection year was also estimated, but differences between annual estimates and pooled estimates were generally less than 5% for all reservoirs. Because age-0 and age-1 walleyes were not fully recruited to the sampling gear, catch-curve analysis was limited to age-2 and older walleyes.

Mortality caps.—Mortality caps for walleye populations were estimated according to the techniques described by Miranda (2002). The first technique (model 1 of Miranda [2002]) relies on growth parameter estimates from the von Bertalanffy growth model and allows for the incorporation of different management objectives and harvest regulations. Mortality caps for model 1 were estimated as:

$$Z = K \times [(L_{inf} - L_{mean}) \times (L_{mean} - L_x)^{-1}],$$

where Z is the instantaneous total annual mortality rate, K is the growth coefficient from the von Bertalanffy growth function, L_{inf} represents the theoretical maximum length from the von Bertalanffy growth function, L_{mean} denotes the management objective for the average length of harvested fish, and L_x is minimum length at which fish are vulnerable to capture or harvest (e.g., the minimum length limit). Estimates of Z were transformed into A by the equation $A = 1 - e^{-Z}$ (Ricker 1975). Mortality caps were estimated for each reservoir by use of annual and overall estimates of L_{inf} and K (Table 1; Quist et al. 2003a). Because length objectives (L_{mean}) have not been established for Kansas walleye populations, we used length objectives of 500, 550, and 600 mm to estimate mortality caps. In addition, we estimated mortality caps assuming that the management objective was maintenance of the current mean length of harvested walleyes (i.e., the status quo). The mean length of harvested walleyes in each reservoir was obtained from the most recent year of creel data (1998–2002) collected by the Kansas Department of Wildlife and Parks. The minimum length of walleyes available for harvest (L_x) was set at either 381 or 457 mm to reflect the current harvest regulation for each reservoir. We also used a 457-mm minimum length limit to estimate mortality caps for populations currently managed with a 381-mm length limit to investigate how management objectives might change with more-restrictive harvest regulations. Empirical total annual mortality rates were then plotted against mortality cap estimates to determine whether management objectives were realistic.

Due to the popularity of size structure indices for evaluating fish populations, Miranda (2002) provided an additional technique (model 2) for estimating mortality caps based on proportional stock density (PSD). Proportional stock density is defined as the number of fish of quality length (380 mm for walleyes) or larger divided by the number of fish of stock length (250 mm for walleyes) or larger, multiplied by 100 (Anderson and Neumann 1996). Because several Kansas walleye populations are managed under PSD objectives, we also estimated mortality caps with model 2:

$$Z = -(\log_e \text{PSD} \times (t_q - t_s)^{-1}),$$

where PSD is the minimum acceptable PSD (i.e., PSD objective, input to the model as a proportion), t_q is the number of years required for fish to reach quality length, and t_s is the number of years required for fish to reach stock length. Estimates of Z were transformed into A as mentioned previously (Ricker 1975). For each reservoir, we used the von Bertalanffy parameter estimates in Table 1 to estimate t_q and t_s for each year and for all years combined. We used PSD objectives of 20, 40, 50, 60, and 80 to estimate mortality caps for each reservoir. The current PSD objective for Cheney, Kirwin, Marion, and Webster reservoirs was 40; Wilson Reservoir had a PSD objective of 50. Proportional stock density objectives were not specified for Cedar Bluff, Glen Elder, or Lovewell reservoirs. Empirical estimates of total annual mortality were compared to mortality cap estimates for each population.

A large portion of our study requires interpretation of mortality caps, and although Miranda (2002) provided an excellent description of appropriate interpretation methods, a brief example is warranted. Figure 1 represents hypothetical mortality cap estimates based on model 1 (Figure 1A) and model 2 (Figure 1B). If, for instance, the mean length objective (L_{mean}) is 550 mm or higher and L_{inf} is 750 mm, then total annual mortality must not exceed 43% (Figure 1A). If the observed total annual mortality rate is 50% (and L_{inf} = 750 mm), a length objective of 550 or 600 mm is probably unrealistic because observed mortality exceeds the mortality cap. In order to satisfy a length objective of 550 mm or greater, managers could either increase growth rates or reduce total annual mortality. Conversely, a length objective of 500 mm would be realistic given current growth and mortality rates. Similarly, if a fish requires 1.5 years to grow from stock to quality length and the PSD objective set by managers is 40, total annual mortality must not exceed 46% (Figure 1B). If total annual mortality is 50%, a PSD of 20 would be the only realistic management objective. As with model 1, managers would have to reduce total annual mortality or increase walleye growth (i.e., reduce $t_q - t_s$) to satisfy a PSD objective of 40.

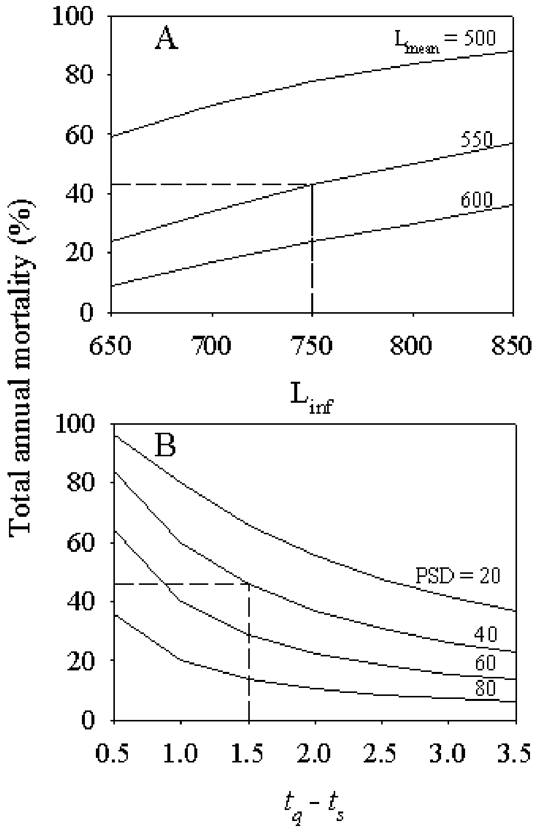

FIGURE 1.—Theoretical models illustrating the interpretation of mortality cap estimates based on (A) mean length objectives (L_{mean}) and (B) proportional stock density objectives (PSD). Isopleths in panel A represent mortality cap estimates for three mean length objectives at different growth rates (theoretical maximum length L_{inf}). Isopleths in panel B represent mortality cap estimates for four PSD objectives at different growth rates (the number of years to reach quality length minus the number of years to reach stock length [$t_q - t_s$]). The dashed line corresponds to the growth rate and mortality cap discussed in the text.

In addition to providing information on realistic management expectations, mortality caps in both models can serve as a warning to managers. When total annual mortality approaches or exceeds the mortality cap, managers either should increase population monitoring efforts and identify the necessary management actions or should change the management objectives.

Results

We sampled a total of 4,726 walleyes and estimated ages for 2,072 walleyes (Figure 2). Although maximum age varied from 5 to 11 years, age structure was skewed towards age-3 and younger walleyes in all reservoirs. For example, age-3 and younger fish made up over 70% of the walleye population in Lovewell (74.9%) and Marion (72.4%) reservoirs, and over 80% of the population in Cedar Bluff (85.4%), Cheney (92.0%), Glen Elder (87.6%), Kirwin (93.5%), Webster (81.9%), and Wilson (83.3%) reservoirs. Consequently, total annual mortality of age-2 and older walleyes was relatively high across reservoirs (mean ± SE; 51.1% ± 2.3%) and varied from 40.7% in Webster Reservoir to 59.5% in Kirwin Reservoir (Figure 3). Although it appears that age-2 walleyes were not adequately sampled in Cheney and Lovewell reservoirs, we did not exclude them from the analysis because the mean walleye length at age 2 in those reservoirs (418 mm at Cheney, 433 mm at Lovewell) equaled or exceeded those of the other reservoir populations (390–455 mm).

Observed rates of total annual mortality in populations managed with a 475-mm minimum length limit were less than the estimated mortality caps for the current mean length objective and the 500-mm length objective (Figure 4). A length objective of 550 or 600 mm was unrealistic given the current growth and mortality rates in all reservoirs. We were unable to estimate a mortality cap for the observed mean length of harvested walleyes in Lovewell Reservoir because the mean harvest length (421.8 ± 10.4 mm) was less than the minimum length limit.

With the exception of Webster Reservoir, all reservoirs currently managed with a 381-mm minimum length limit had observed rates of total annual mortality that were above the estimated mortality caps associated with length objectives of 500 mm or greater (Figure 4). Based on the current mean lengths of harvested walleyes and their associated mortality caps, a potential problem existed only in Glen Elder Reservoir because total annual mortality exceeded the mortality cap. Mortality caps with a 457-mm minimum length limit were also estimated for those populations currently managed with a 381-mm length limit. Based on the 457-mm length limit, a 500-mm length objective was realistic for all reservoirs and a 550-mm length objective was realistic for Webster Reservoir. In Glen Elder Reservoir, observed total annual mortality and the estimated mortality cap associated with the current mean length of harvested walleyes were nearly equal, suggesting that even with a 457-mm length limit, total annual mortality was near the mortality cap. Because observed mean lengths of harvested walleyes in Kirwin, Webster, and Wilson reservoirs were less than 457 mm, their associated mortality caps are not provided in Figure 4.

Total annual mortality was less than the estimated mortality caps for a PSD objective of 20 in all reservoirs (Figure 5). Current PSD objectives were only available for Cheney, Marion, Kirwin, Webster, and Wilson reservoirs. Observed total annual mortality rates were less than the mortality caps for PSD objectives in Cheney, Marion, and Webster reservoirs. In contrast, total annual mortality was higher than the mortality caps estimated for PSD objectives in Kirwin and Wilson reservoirs. The only reservoir for which a PSD objective of 60 might be realistic was Webster Reservoir. In all reservoirs, mortality estimates exceeded mortality caps associated with a PSD objective of 80.

Discussion

The application and interpretation of mortality caps is dependent on several assumptions: (1) population mortality is constant over time, (2) growth is constant and is adequately defined by the von Bertalanffy growth model, (3) recruitment is constant or varies randomly, (4) recruitment into the smallest length used in the analysis (i.e., L_x in model 1; stock and quality lengths in model 2) is constant throughout the year, (5) only lengths fully recruited to the gear are monitored, and (6) the sampling gear adequately represents the age and length structures of the population (Miranda 2002). Although a given population is unlikely to conform to all of these assumptions, we have attempted to account for major violations in our analysis.

Total annual mortality rates were calculated for each collection year in a preliminary analysis. Although mortality estimates varied among years, annual mortality estimates in all reservoirs were within 5% of the mortality estimates pooled across

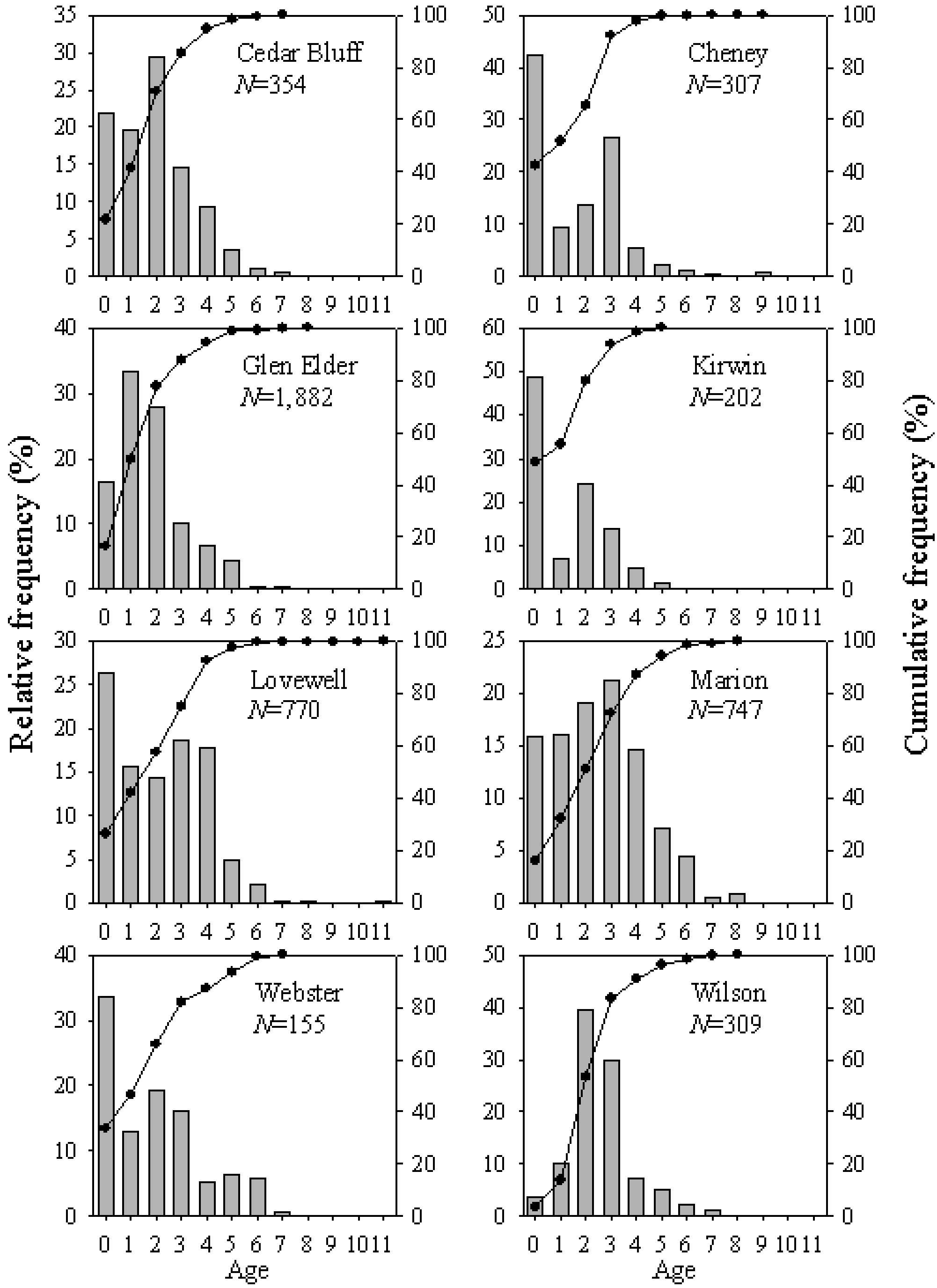

FIGURE 2.—Relative age frequency (bars) and sample size (*N*) of walleyes sampled from eight Kansas reservoirs during 1991–1999. The solid lines represent the cumulative age frequency for each reservoir.

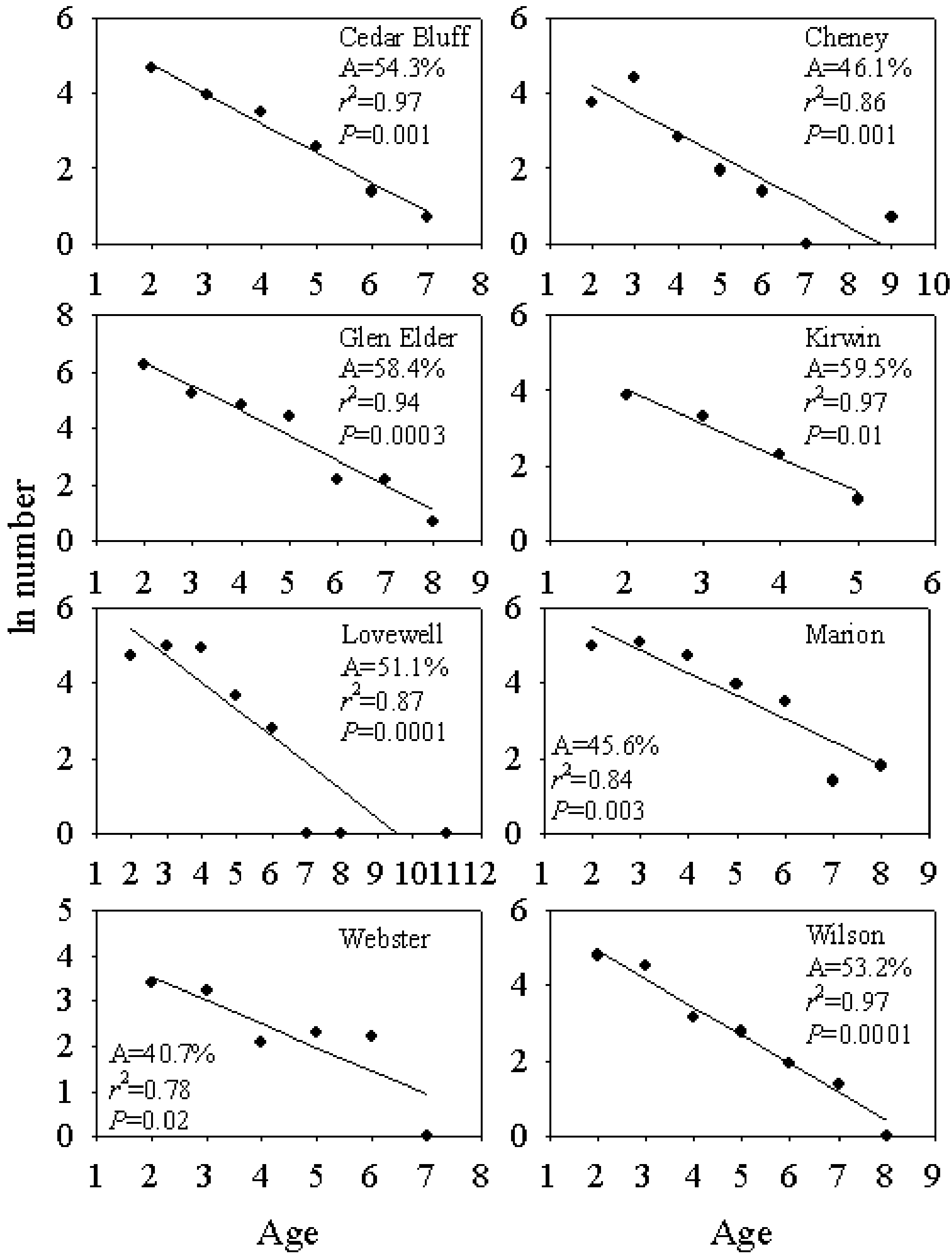

FIGURE 3.—Weighted catch-curve regressions and total annual mortality (*A*) for age-2 and older walleyes sampled from eight Kansas reservoirs during 1991–1999. The natural logarithm of the number of fish at each age was regressed on age to produce the catch curves. The coefficients of determination (r^2) and associated *P*-values are provided as indicators of model fit.

years. Recruitment of walleyes in Kansas reservoirs is also variable, but the patterns appear to be random (Quist et al. 2003b). Nevertheless, we pooled data across years to reduce the influences of variable mortality rates (assumption 1) and variable recruitment (assumption 3; Ricker 1975). The assumptions of constant mortality and recruitment are primarily related to empirical estimates of total annual mortality (i.e., catch-curve analyses). Consequently, high variation in mortality or recruitment may hinder the comparison of observed mortality rates with estimated mortality caps. For situations in which extended time-series data are unavailable, mortality and recruitment are highly variable among years, or recruitment variation is not random, monitoring should occur frequently, particularly when mortality is near the estimated mortality cap.

The models also assume that growth is constant and can be adequately defined by the von Bertalanffy growth model (assumption 2). We found that growth of walleyes was well defined by the von Bertalanffy model, but was variable among years within reservoirs (Quist et al. 2003a). Therefore, we used both the reservoir–year combinations and the overall estimates of L_{inf} and K to estimate mortality caps. Although growth varied among years, variable growth had little influence on our interpretation of mortality caps or management objectives. Assumption 4 specifies constant recruitment into L_x throughout the year (model 1) or constant recruitment into stock and quality lengths (model 2). Growth of walleyes in Kansas reservoirs is not constant but instead varies seasonally, and up to 80% of annual growth occurs during early fall (Quist et al. 2002). However, walleyes become fully recruited during a short time period: all fish in this study were fully recruited to L_x by age 2 (when L_x = 381 mm) or age 3 (when L_x = 457 mm) and were fully recruited to quality length by age 2. Miranda (2002) stated that violation of assumption 4 might hinder comparisons of fish size and mortality with size objectives and mortality caps. Miranda (2002) suggested that managers could meet this assumption by collecting multiple samples within a year and pooling them before analysis or, alternatively, by limiting the analysis to longer fish so that recruitment to L_x or stock and quality lengths is spread out over the year. Although these recommendations may be applicable in many situations, time constraints would likely prevent managers in Kansas from routine, intensive sampling throughout the year. In addition, due to rapid fish growth, walleye populations in Kansas are unlikely to consistently recruit to L_x or to stock and quality lengths.

Assumptions 5 and 6 require that the sampling gear adequately samples the population. Gill nets are selective for different lengths of fish, but we believe that the walleye size and age structures were accurately represented by the gear, as suggested by previous research on walleyes in other portions of their distribution (Beamesderfer and Rieman 1988; Isbell and Rawson 1989) and supplemental samples collected in Kansas. For example, walleyes are commonly sampled by electrofishing in Kansas reservoirs during the fall for stocking evaluations and during the spring for egg collection. Based on these samples, we are confident that the mesh sizes used in our study adequately sampled the length and age distributions, except for the smallest walleyes. To account for the bias against small walleyes, we excluded age-0 and age-1 walleyes from the analysis. Gill nets were the most appropriate gear to use in our analysis because they are the primary gear used by managers in Kansas to monitor long-term trends in walleye populations.

Analysis of mortality caps illustrated several trends and provided an illustration of the utility of mortality caps for fisheries management. For example, when the management objective was to provide anglers with walleyes that averaged the current mean harvest length (i.e., the status quo; model 1), the only reservoir of immediate concern was Glen Elder Reservoir because observed total annual mortality was higher than the mortality cap. Although managers in Kansas have not established mean length objectives for any of the walleye populations, several populations are managed with PSD objectives. Based on PSD objectives, total annual mortality only exceeded the mortality caps for Kirwin and Marion reservoirs. Mortality caps serve as a warning, because when total annual mortality rates approach or exceed the mortality caps, monitoring activities should increase and management actions may be necessary. Because total annual mortality rates were close to the mortality caps for management objectives in Glen Elder Reservoir (model 1) and in Cheney, Kirwin, and Wilson reservoirs (model 2), it may be necessary to frequently monitor growth, mortality, and mean length of harvested fish in those reservoirs (Miranda 2002). In order to meet or increase the mean length or PSD objectives, some form of management would be required. Management activities could include reducing fishing mortality through more-restrictive harvest regulations, de-

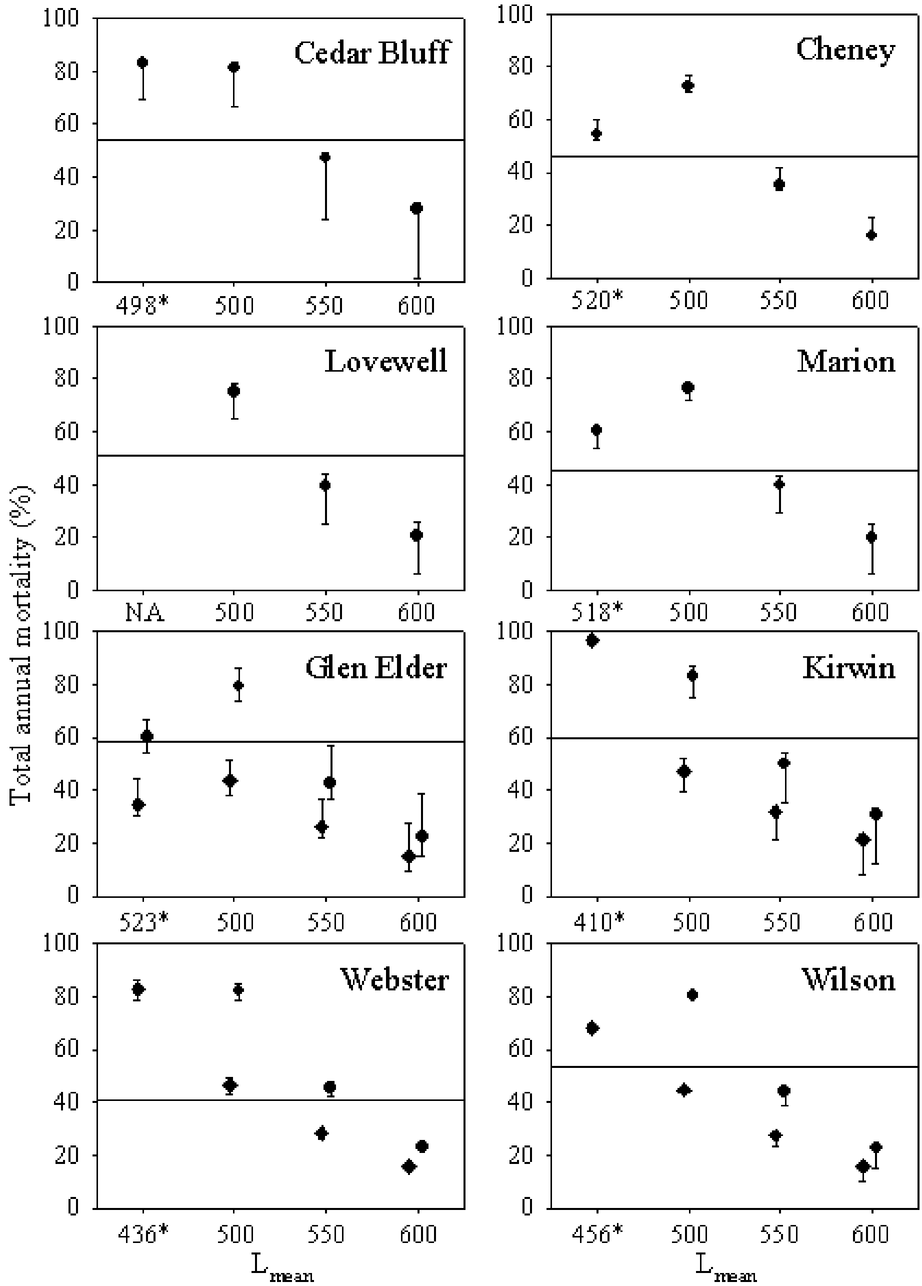

FIGURE 4.—Estimated mortality caps for eight Kansas reservoirs based on model 1 described by Miranda (2002). Overall mortality cap estimates (solid symbols) and year-specific mortality cap estimates (bars indicate maximum and minimum estimates) were calculated based on the theoretical maximum length (L_{inf}) and the growth coefficient (K). Mortality caps were estimated for a mean length objective (L_{mean}) equal to the current mean length of harvested walleyes (asterisks) and for L_{mean} values of 500, 550, and 600 mm. The minimum length available for harvest (L_x) was set at 457 mm for Cedar Bluff, Cheney, Lovewell, and Marion reservoirs to represent current harvest regulations. The mortality cap for the current mean length of harvested walleyes in Lovewell Reservoir was not plotted because the current mean was lower than the minimum length limit. For Glen Elder, Kirwin, Webster, and Wilson reservoirs, mortality caps were estimated based on L_x values of 381 mm (diamonds; current regulations) and 457 mm (circles) (the two estimates at each L_{mean} are offset to prevent overlap and to aid interpretation). The horizontal lines represent empirical estimates of total annual mortality for each reservoir.

creasing natural mortality, or increasing growth rates. Because walleyes in Kansas reservoirs already have high growth rates (Quist et al. 2003a) and the causes of natural mortality are likely beyond the control of managers (e.g., high water temperatures; Quist et al. 2002), reducing fishing mortality or changing the management objectives may be the only realistic options.

In addition to alerting managers when management objectives are not being met, analysis of mortality caps can provide an indication of realistic management expectations. For example, a PSD objective of 20 was realistic for all reservoirs, and a PSD objective of 40 was realistic for several of the study reservoirs. A mean length objective of 600 mm was an unrealistic expectation for any of the study reservoirs given current walleye growth and mortality rates. Thus, analysis of mortality caps can provide an indication of realistic objectives when none have been established, as is the situation for most Kansas walleye populations. Mortality caps can also provide insight into the potential effects of restrictive harvest regulations. For instance, a 500-mm mean length objective for harvested walleyes was not realistic for reservoirs managed with a 381-mm minimum length limit (except Webster Reservoir). However, when L_x was changed to 457 mm, a 500-mm length objective was reasonable for those same reservoirs and a 550-mm length objective was realistic for Webster Reservoir. Although our analysis did not account for potential changes in density, mortality, growth, or size structure due to different harvest regulations, it did indicate potential management expectations. Similar analyses could provide additional support for regulation changes, particularly when used in combination with models designed to assess the effects of different harvest regulations on yield (e.g., Maceina et al. 1998).

We used models 1 and 2 in our analysis of mortality caps. Both models can be used by managers as tools for monitoring fish populations and as indicators of realistic management objectives. The data required for each model (age, growth, and mortality estimates) are similar, but model 1 focuses on mean length objectives, whereas model 2 relies on size structure indices. Therefore, the combined use of the models provides greater insight than either model in isolation and enables managers to establish management objectives and monitor populations with the aid of two separate measures. In addition to our analysis of mortality caps, our study provides important information on the age structure and mortality of walleyes occupying the southern limit of the species' distribution.

Total annual mortality rates observed in this study were within the ranges reported for other systems. For example, total annual mortality was 37% for walleyes in Leech Lake, Minnesota (Schupp 1972), and was 47% for age-3 and older walleyes in Escanaba Lake, Wisconsin (Kempinger and Carline 1977). Total annual mortality of walleyes aged 2–9 varied from 19% to 47% for five populations in Wyoming reservoirs (calculated from data in Marwitz and Hubert [1995]). In Kansas reservoirs, total annual mortality of age-2 and older walleyes varied from 41% to 60% and averaged 51%. These values are relatively high compared to many other populations in North America, possibly due to either high natural mortality or high fishing mortality.

Natural mortality can result from a variety of factors (e.g., predation, disease) and may be especially high in the marginal habitats (e.g., high water temperature; Kocovsky and Carline 2001) characteristic of Kansas reservoirs. Because Kansas is near the southern distributional limit of walleyes, one of the most important factors potentially influencing natural mortality is water temperature. Water temperatures in Kansas reservoirs are above the thermal optimum of walleyes for most of the summer, often approach their upper lethal limit, and may be a primary source of natural mortality in Kansas walleye populations (Quist et al. 2002). Life history characteristics may also explain the skewed age distribution and high mortality rates observed in our study. Beverton (1987) investigated the relationships among growth, mortality, and lifetime egg production of walleyes across North America and found that lifetime egg production per recruit was equal across latitudes. Thus, walleyes from southern latitudes grew faster, matured at an earlier age, and died earlier than the slow-growing fish in northern latitudes. Walleyes grow fast in Kansas reservoirs (Quist et al. 2003a), but males typically mature at age 2 or 3, whereas females mature at age 3 or 4. Therefore, fish would not likely die after their first or second year following sexual maturity, as observed in our study. Furthermore, all reservoirs (except Kirwin Reservoir) contained walleyes age 7 or older, indicating that walleyes in Kansas reservoirs are able to survive to older ages.

Although thermal regime and life history characteristics may partially explain high mortality of walleyes in Kansas, angler harvest probably has a large influence on mortality rates. Age structure

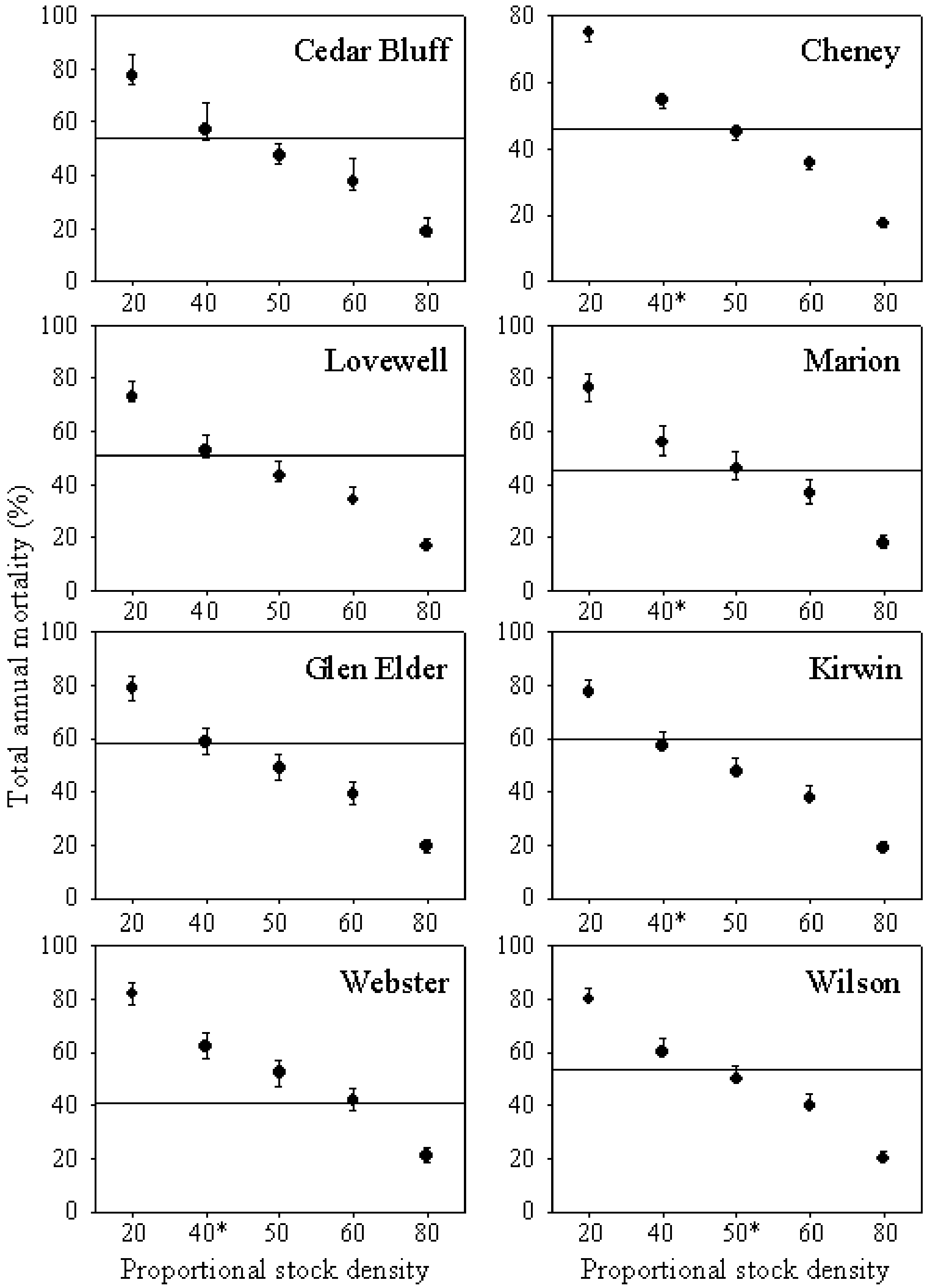

FIGURE 5.—Estimated mortality caps for eight Kansas reservoirs based on model 2 described by Miranda (2002). Overall mortality cap estimates (solid symbols) and year-specific estimates (bars indicate maximum and minimum estimates) were calculated based on the number of years (*t*) required to reach a quality length of 380 mm (t_q) and a stock length of 250 mm (t_s). Mortality caps were estimated based on mean proportional stock density (PSD) objectives of 20, 40, 50, 60, and 80. Asterisks indicate the current PSD management objectives for Cheney, Marion, Kirwin, Webster, and Wilson reservoirs; the remaining reservoirs did not have specified PSD objectives. The horizontal lines represent empirical estimates of total annual mortality for each reservoir.

of walleyes was skewed towards young fish, corresponding to the ages that had not yet become available for harvest. For example, in nearly all reservoirs managed with a 381-mm minimum length limit, a change in age structure was observed at age 2 or 3, when the fish reached harvestable size (Quist et al. 2003a). In reservoirs with a 457-mm minimum length limit, a similar relationship was observed after age 3 or 4, when the walleyes became available for harvest. Maceina et al. (1998) reported similar results for sauger *Sander canadensis* (formerly *Stizostedion canadense*) in tailwaters along the Tennessee River in Alabama, where an age distribution skewed towards young individuals resulted from high exploitation rates. Although walleye exploitation rates are currently unknown for most Kansas reservoirs, recent research has suggested that fishing mortality may be extremely high. For instance, an ongoing study on Glen Elder Reservoir has shown that angler exploitation of walleyes has, on average, exceeded 50% over the past 3 years (2001–2003) and accounts for nearly all of the total annual mortality in the reservoir (J. L. Stephen, unpublished data). All of the reservoirs in our study maintain important recreational walleye fisheries; this fact, coupled with the high total annual mortality rates we observed, leads us to suspect that fishing mortality is also high for other walleye populations in Kansas.

This study provides important information on walleye mortality rates in reservoir systems. This information can be used for monitoring purposes, for incorporation into population models that predict yield and effects of harvest regulations (e.g., Maceina et al. 1998), or for large-scale comparisons among fish populations (e.g., Beverton 1987). Analysis of mortality caps illustrated several trends and provided an example of their utility for fisheries management. In addition to providing an assessment of current conditions, mortality caps allow managers to establish realistic management goals within the context of growth and mortality rates (Miranda 2002). After management goals are identified, mortality caps can provide a tool for managers to monitor populations and identify potential effects of changes in habitat conditions, biotic interactions, or angler exploitation on fish populations. Although our study focused on walleye populations in Kansas reservoirs, similar studies should be conducted for other species and systems to provide further insight into the application of mortality caps.

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