Hiwassee Reservoir Walleye Survey (2000-2003)

Final Report

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Abstract.—Blueback herring *Alosa aestivalis* recently invaded Hiwassee Reservoir, raising concerns because invasions of a similar species, alewife *A. pseudoharengus*, in Tennessee reservoirs have been associated with failures in walleye reproduction. The goal of this study is to characterize the walleye population in Hiwassee Reservoir. Specific objectives are to estimate walleye 1) length distribution, 2) relative weight, 3) age distribution, 4) mortality, 5) recruitment, and 6) growth. We collected a total of 675 walleye *Sander vitreus* from Hiwassee Reservoir in annual fall gill net surveys from 2000-2003. Walleye densities have declined in the reservoir over the four survey years. Relative weight increased over the four years for survey data. Characteristic of the species, Hiwassee Reservoir walleye have sex specific mortality and growth rates which had stayed consistent as walleye densities have declined. Female walleye have an instantaneous mortality rate of 0.36 (standard error = 0.055) and male walleye have an instantaneous mortality rate of 0.56 (0.077). Walleye recruitment has declined following the blueback herring invasion. From 1998 to 2002, walleye recruitment declined 59% annually. Growth of both sexes was initially faster than standard growth equations but maximum total length is average.

The North Carolina Wildlife Resources Commission (NCWRC) routinely surveys sport fish populations to inventory fishery resources and angling opportunities on inland waters. Historically, most fish sampling in Hiwassee Reservoir occurred during two time periods. Initially, between 1957 and 1965, the NCWRC conducted a statewide fisheries research survey and sampled Hiwassee Reservoir with a variety of gears including experimental gill nets, trammel nets, and rotenone (Tebo 1961; Messer 1966). More recently, in 1981 and 1982, Davies (1982) sampled Hiwassee Reservoir with floating gill nets, rotenone, and boat electrofishing. These surveys used rotenone sampling to produce standing crop estimates. Rotenone is no longer used by the NCWRC and its use in other states and academia is becoming increasingly rare; therefore, we needed a new survey to act as a benchmark for future investigations and facilitate comparisons with current research in other locales.

A new stock assessment is also needed because there has been a recent change in the forage fish community. Blueback herring *Alosa aestivalis* invaded Hiwassee Reservoir. They were first observed upstream in Chatuge Reservoir in 1996 where they were likely introduced by hybrid-striped bass *Morone saxatilis* x *M. chrysops* anglers. Blueback herring emigrated downstream of Chatuge Dam and were first collected from Hiwassee Reservoir in January 1998. Attempts to stock threadfin shad in Hiwassee Reservoir have been unsuccessful because of winter kills

The blueback herring invasion in Hiwassee Reservoir is a concern because river herring *Alosa spp.* introductions have caused declines in walleye *Sander vitreus* populations in the southeastern United States. Failures in walleye reproduction have been associated with the introduction and invasion of alewife *A. pseudoharengus* in several Tennessee reservoirs including Watuga, Dale Hollow, Center Hill, Norris, and South Holston (Irwin-Larrimore 1989, Schultz 1992, Vandergoot and Bettoli 2001). Walleye reproduction declined within four years of the introductions in Watuga (Vandergoot and Bettoli 2001) and Dale Hollow (Schultz 1992) reservoirs. The recent blueback herring introduction into Lake Burton, Georgia has coincided with decreased abundance of black crappie *Pomoxis nigromaculatus*, largemouth bass *Micropterus salmoides*, and white bass *Morone chrysops* (Rabern 2000). Although the mechanism by which river herring reduce sport fish recruitment is unknown, several possibilities have been suggested including larval fish predation (Irwin-Larrimore 1989), egg predation (Wheeler et al., in review), and induced nutrient deficiencies (Vandergoot et al. 2001). Similar to interactions between threadfin shad and game fish communities (DeVries et al. 1991), another potential mechanism is complex food chain interactions caused by competition between blueback herring and game fish for prey items.

The goal of this study is to characterize the walleye population in Hiwassee Reservoir. Specific objectives are to estimate walleye 1) length distribution, 2) relative weight, 3) age distribution, 4) mortality, 5) recruitment, and 6) growth.

Methods

Hiwassee Reservoir is a 4,318 ha hydropower impoundment operated by Tennessee Valley Authority (TVA). It was impounded in 1940 and is 35.7 km long and has 265.2 km of shoreline (TVA 2003). This reservoir was classified as oligotrophic in a recent basinwide assessment report (NCDENR 2000).

The physical habitat, water chemistry, and productivity of reservoirs generally change along a longitudinal gradient (Siler et al. 1986). Therefore, we investigated Hiwassee Reservoir in two longitudinal strata. Annually, beginning in 2000, bottom set, experimental gill nets were fished at three sites in both strata (Figure 1). The upper stratum gillnets were fished for three consecutive nights and the lower stratum gillnets were fished for two consecutive nights. All gillnets were 2.4 x 76.3 m and consisted of equal sized panels of 25-, 32-, 38-, 44-, and 51-mm bar mesh. We increased sampling effort in 2003 by adding an additional site in the upper and lower strata (Figure 1), and fishing all nets for three consecutive nights. The walleye collected from the extra sampling effort were considered in estimates that did not require consistent effort such as relative weight, relative stock density, and mean length at age but ignored catch per unit effort (CPUE), mortality rates, and recruitment estimates.

All walleye were returned to the lab where they were measured for total length (TL, mm), weighed (g), and sex was determined. Sagittal otoliths were removed in the lab. Otoliths with less than two annuli were aged by viewing the otolith whole. Otoliths with two or more annuli were cut in half along the dorsal-ventral axis and the annuli were counted along the dorsal portion of the anterior half. All ages were determined by the same reader using two 'blind' reads. If the two blind reads disagreed, an author (CSL) determined the age.

Data Analysis

We used gill net catch rates as an index of fish density. Gill net catch rates were quantified by mean CPUE. Since fishing a gill net in the same location for multiple nights does not produce independent replicate samples, a unit of effort was defined as the total number of walleye collected at each site (nights pooled). We used a Repeated Measures Analysis of Variance (RMANOVA) to test if walleye catch rates differed across years for each strata.

The size structure of the walleye population was reported both qualitatively and quantitatively. Qualitatively, a length frequency histogram was constructed to visually assess the length distribution. Quantitatively, relative stock density (RSD) was used to estimate the proportion of quality (RSD-Q) and preferred (RSD-P) sized fish (Gablehouse 1984). No walleye larger than ‘preferred’ size were collected during this survey. Standard errors for the RSD estimates were calculated as

$$\sigma_{\pi} = \sqrt{\frac{\pi\,(1-\pi)}{n}} \qquad (1)$$

where π is the proportion and n is the sample size (Ott 1993).

We used relative weight (W_r) to index fish condition. Relative weight was calculated for all walleye > 150 mm TL using the standard weight (W_s) equation developed by Murphy et al. (1990).

Mortality rates were estimated using a catch curve approach. The instantaneous rate of total mortality (Z) was estimated as the slope of the linear relationship of $\log_e$ (catch) on age. Since we sampled four consecutive years, we were able to estimate Z by following cohorts through time. We used an analysis of covariance (ANCOVA) to test if Z differed among year classes or sexes. Annual mortality rates (A) were calculated from Z using the following relationship from Ricker (1975);

$$A = 1- e^{-Z}. \tag{2}$$

Walleye are fully recruited to our gill nets at age-1; therefore we used total catch at age-1 as an index of year class strength. Because we were interested in the year class strength of year classes that were older than age-1 when we began sampling (*e.g.*, 1998 and earlier year classes), we used the Z and intercept estimates from the catch curve regressions to back calculate the estimated number of age-1 individuals that would have been collected. We used a Taylor series approximation of variance to estimate the variance of our back-calculated year class strength estimates. The general formula;

$$\text{var } \phi(X_1,X_2) = \sum_{j=1}^{2} \text{var } X_j \left(\frac{\partial\phi}{\partial X_j}\right)^2 + 2 \text{ cov } (X_1,X_2) \left(\frac{\partial\phi}{\partial X_1}\right) \left(\frac{\partial\phi}{\partial X_2}\right) \tag{3}$$

is presented as formula 3.3.56 by Sheps and Menken (1973) was solved for the special case of a catch curve regression as;

$$\text{var } (\log_e \text{ catch at age}) = \text{var } (Z) * \text{age}^2 + \text{var (int)} + 2 \text{ cov } (Z, \text{int}) * \text{age}, \tag{4}$$

where age is the age of interest, var (Z) is the variance of the instantaneous mortality estimate, var (int) is the variance of the intercept estimate, and cov (Z, int) is the covariance of the instantaneous mortality estimate and the intercept. Variance estimates were converted to standard errors from which 95% confidence intervals were calculated.

Although we were interested in characterizing the overall growth rate of walleye, cohort specific growth rates (see results) prevented us from fitting von Bertalanffy curves. Instead, we report and plot mean length at age for each age class. We also used standard growth models to compare our walleye growth rates with other walleye populations throughout North America (Quist et al. 2003). The standard growth model for male walleye is

$$L_s = 496 \left(1-e^{-0.419(\text{age}+0.083)}\right) \tag{5}$$

and the standard growth model for female walleye is

$$L_s = 652 \left(1-e^{-0.266(\text{age}+0.346)}\right). \tag{6}$$

Due to the low sample size, the strata were pooled in mortality and growth rate analyses. All analyses were considered statistically significant at a type I error rate (α) of 0.10.

Results

Surface water temperature and secchi depth varied little throughout the four year survey or between the strata (Table 1). Mean surface water temperatures ranged 3.6 °C between the highest mean (22.2 °C; lower stratum in 2002) and lowest mean (18.6 °C; lower stratum in 2001). Mean secchi depth ranged 1.9 m between the highest mean (4.5 m; lower stratum in 2001) and the lowest mean (2.6 m; upper stratum in 2002). Secchi depths averaged 0.8 m deeper and surface water averaged 1.0 °C cooler in the lower stratum than the upper stratum.

We collected 675 walleye during this survey. Catch rates declined in both strata over the four survey years (Table 2). Lower stratum CPUE declined from 35.7 in 2000 to 16.7 in 2003. Upper stratum CPUE declined from 44.3 in 2000 to 14.0 in 2003. This decline was statistically significant ($F_{3,16}$ = 10.24; P = 0.0005) and similar for both strata ($F_{1,16}$ = 0.05; P = 0.8200).

We collected walleye ranging in size from 226 to 447 mm TL (Figure 2). With one exception, all walleye collected were stock size and no fish were memorable or larger. Relative stock densities revealed similar size distributions between the lower and upper strata (Table 2); however, over the four survey years, the size structure of walleye shifted towards larger individuals. Over the four years of the study, RSD-Q increased from 88.0 to 97.4 in the lower stratum and from 70.7 to 98.3 in the upper stratum. Similarly, RSD-P increased from 16.8 to 30.3 in the lower stratum and RSD-P increased from 0.8 to 31.7 in the upper stratum.

Walleye in Hiwassee Reservoir are characterized by a wide age distribution and individuals up to age-10 were represented in our samples. Poor recruitment resulted in mean age increasing throughout the survey from 3.1 in 2000 to 5.7 in 2003 (Figure 3).

Walleye W_r was similar across strata but may have increased slightly across years (Table 2). Lower stratum walleye W_rs ranged from 78.6 in 2000 to 85.8 in 2003. Similarly, upper stratum W_rs ranged from 82.2 in 2000 to 87.5 in 2003.

Individual walleye from year classes prior to 1996 and after 1999 were too rare to be considered in mortality estimates. The ANCOVA detected significant sex specific mortality rates ($F_{1,14}$ = 6.48; P = 0.0233) but no significant differences in mortality rates among year classes ($F_{3,14}$ = 0.22; P = 0.8812). The estimate of instantaneous mortality for male walleye was 0.36 (standard error 0.055) and thus the estimate of annual mortality was 30.4%. The estimate of instantaneous mortality for female walleye was 0.55 (standard error 0.077) and thus the estimate of annual mortality was 42.7%. The linear nature of the catch curves suggests that mortality rates did not change during this survey (Ricker 1975; Figure 4).

The recruitment of walleye to age-1 declined throughout this study. We collected 28 age-1 walleye from the 1999 year class and fewer from each consecutive year class with the exception of the 2001 year class. The Taylor series approximation of variance allowed us to back-calculate recruitment to 1996. Overall, since 1998 (the first blueback herring influenced year class), walleye recruitment has declined 59% each year (Figure 5).

Mean TL at age increased for both male and female walleye throughout this study; however, maximum size appears to have stayed the same for males and possibly decreased for females. The trend is very clear in males, where the average length at age for more recent cohorts is consistently greater than those in previous cohorts (Figure 6). For example, the mean TL of the 1996 cohort at age-7 was 461 mm and this was nearly achieved by the 1999 year class at age-4 (mean TL 458 mm). Females display the same general trend, however with more variation. For females the oldest two cohorts (1996 and 1997) were consistently smaller at the same age than the two more recent cohorts (1998 and 1999). When compared to standard growth curves, it is apparent that although Hiwassee Reservoir walleye do not reach a larger than average maximum size, they reach an average maximum length faster than most North American populations. The fast growth rates are most apparent in the most recent cohorts.

Discussion

The walleye population in Hiwassee Reservoir is characterized by continual change in the wake of the blueback herring invasion. The introduction of blueback herring has coincided with reductions in walleye recruitment and density and increases in walleye growth and relative weight. Reductions in recruitment mirror Tennessee's experience with alewife reducing walleye density. Relative weight and growth rates may be increasing for several reasons. First, blueback herring may be a better forage species for adult walleye than the historical threadfin shad and gizzard shad *Dorosoma cepedianum* assemblage. Second, reduced walleye recruitment may be relaxing density dependant mechanisms that previously limited walleye growth and condition.

Tennessee Wildlife Resources Agency has successfully maintained walleye fisheries following alewife introductions and invasions by stocking fingerlings (Vandergoot and Bettoli 2003). The NCWRC began an experimental stocking of fingerling walleye in Hiwassee Reservoir in 2004. If stocking fingerling walleye stabilizes recruitment, then stocking is a possible management tool. Increasing growth rates as walleye densities decline, suggests that there may be density dependant mechanisms governing growth rates. Thus, growth rates and ultimately the size and quantity of fish in angler creels may be controllable to a degree through stocking rates. These future objectives should be approached through a careful consideration of the values of Hiwassee Reservoir anglers. This is especially important because walleye anglers are often harvest oriented and may prefer to catch many small fish rather than a few large fish.

Natural walleye recruitment is notoriously variable. Although lake spawning segments of the walleye population may exist, it is likely that annual spring spawning in tributary rivers contributes heavily to walleye abundance. Physical conditions in tributary rivers are dynamic in nature. Because walleye deposit their eggs in interstitial spaces in substrate, a great degree of their reproductive success is linked to the variable and unpredictable physical stream environment. Variable recruitment has been blamed for rendering length limits ineffective (Allen and Pine 2000). Because year class strength of many fishes is already determined before the fingerling stage, stocking fingerlings may temporally avoid environmental sources of catastrophic mortality and result in more stable year class strength than found in naturally recruiting populations. If recruitment does stabilize with stocking then carefully setting a length limit should be considered. However, because both walleye density and length limits effect fish growth rates, future management objectives must be accomplished by simultaneously considering both an appropriate stocking density and harvest regulation.

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TABLE 1.—Years, strata, sample dates (nights fished), number of sites, effort (net-nights per site), mean temperature (°C), and mean secchi depth (m) for gillnet sampling on Hiwassee Reservoir. The standard deviations of the estimates are shown in parentheses.

Year	Stratum	Sites (N)	Net - Nights	Sample Dates	Temperature (°C)	Secchi Depth (m)
2000	Lower	3	2	10/9-10/10	18.9 (0.2)	3.4 (0.7)
	Upper	3	3	10/2-10/4	20.9 (0.2)	2.9 (0.3)
2001	Lower	3	2	10/8-10/9	18.6 (0.1)	4.5 (0.8)
	Upper	3	3	10/1-10/4	19.6 (0.1)	3.1 (0.1)
2002	Lower	3	2	10/7-10/8	22.2 (0.1)	2.9 (0.1)
	Upper	3	3	9/30-10/2	21.8 (0.1)	2.6 (0.2)
2003	Lower	4	3	10/6-10/8	19.1 (0.1)	3.9 (0.5)
	Upper	4	3	9/29-10/1	20.5 (0.1)	3.0 (0.3)

TABLE 2.—The number of walleye collected through standardized (N_S) and extra sampling (N_E), mean catch per unit effort, relative stock density for quality and preferred size fish, and mean relative weight (W_r). Standard errors of estimates are shown in parenthesis.

				CPUE	Relative Stock Density		
Year	Strata	N_S	N_E	N_S / site	Quality	Preferred	W_r
2000	Lower	107		35.7 (3.8)	88.8 (3.1)	16.8 (3.6)	78.6 (0.9)
	Upper	133		44.3 (0.9)	70.7 (4.0)	0.8 (0.8)	82.2 (0.4)
2001	Lower	85		28.3 (4.8)	96.4 (2.0)	11.8 (3.5)	84.4 (0.7)
	Upper	107		35.7 (8.8)	93.5 (2.4)	10.3 (2.9)	81.0 (0.5)
2002	Lower	51		17.0 (1.0)	94.1 (3.3)	25.5 (6.2)	84.9 (1.1)
	Upper	55		18.3 (3.8)	100.0 (0.0)	16.4 (5.0)	85.9 (0.8)
2003	Lower	50	26	16.7 (2.9)	97.4 (1.8)	30.3 (5.3)	85.8 (0.9)
	Upper	42	19	14.0 (5.2)	98.3 (1.7)	31.7 (6.1)	87.5 (1.1)

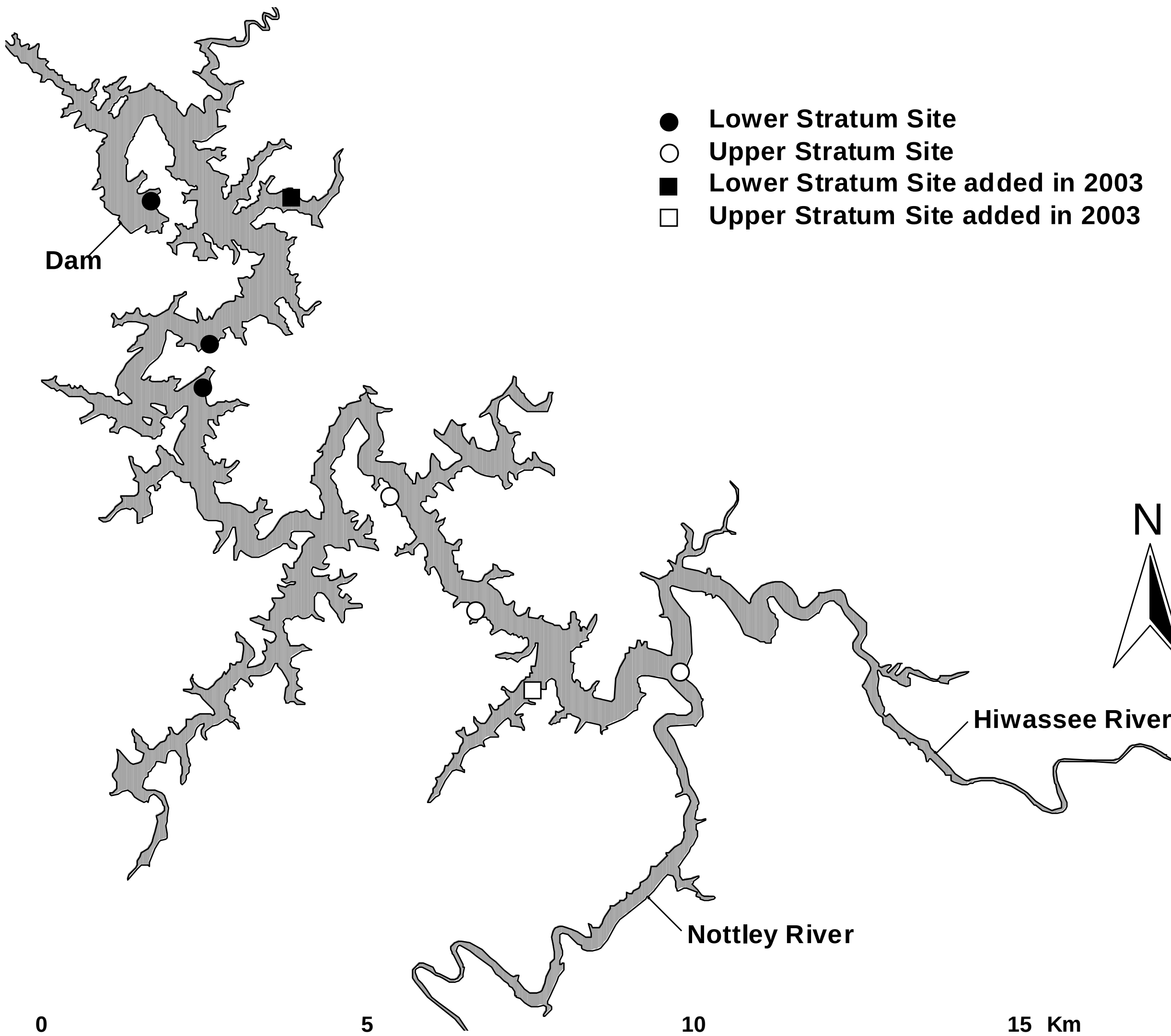

FIGURE 1.–Map of Hiwassee Reservoir showing the eight gill net sites used in this study, 2000-2003.

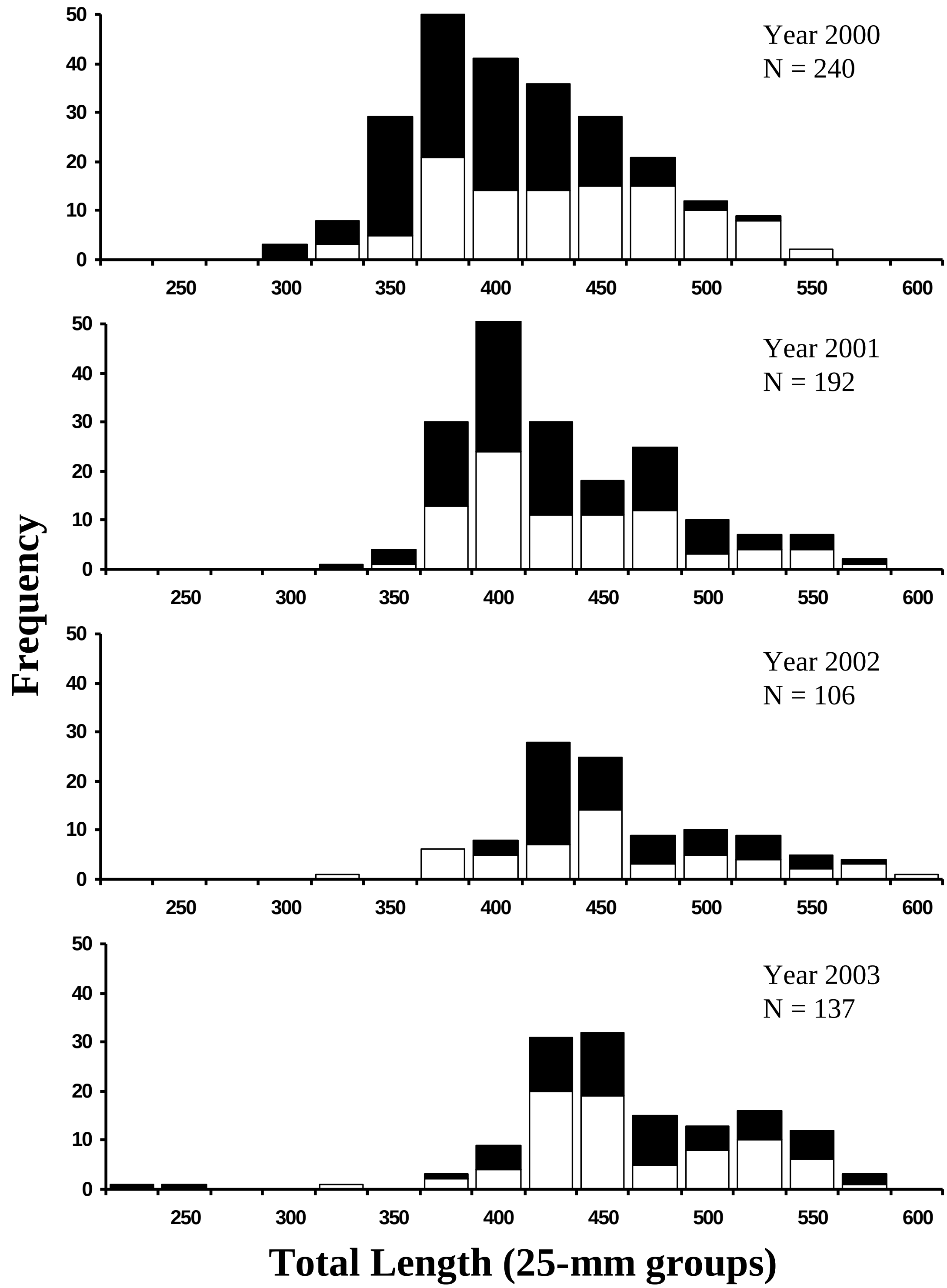

FIGURE 2.−The length frequency distribution of walleye collected during this survey. The frequency of the upper and lower strata fish are shown separately by black and white bars respectively.

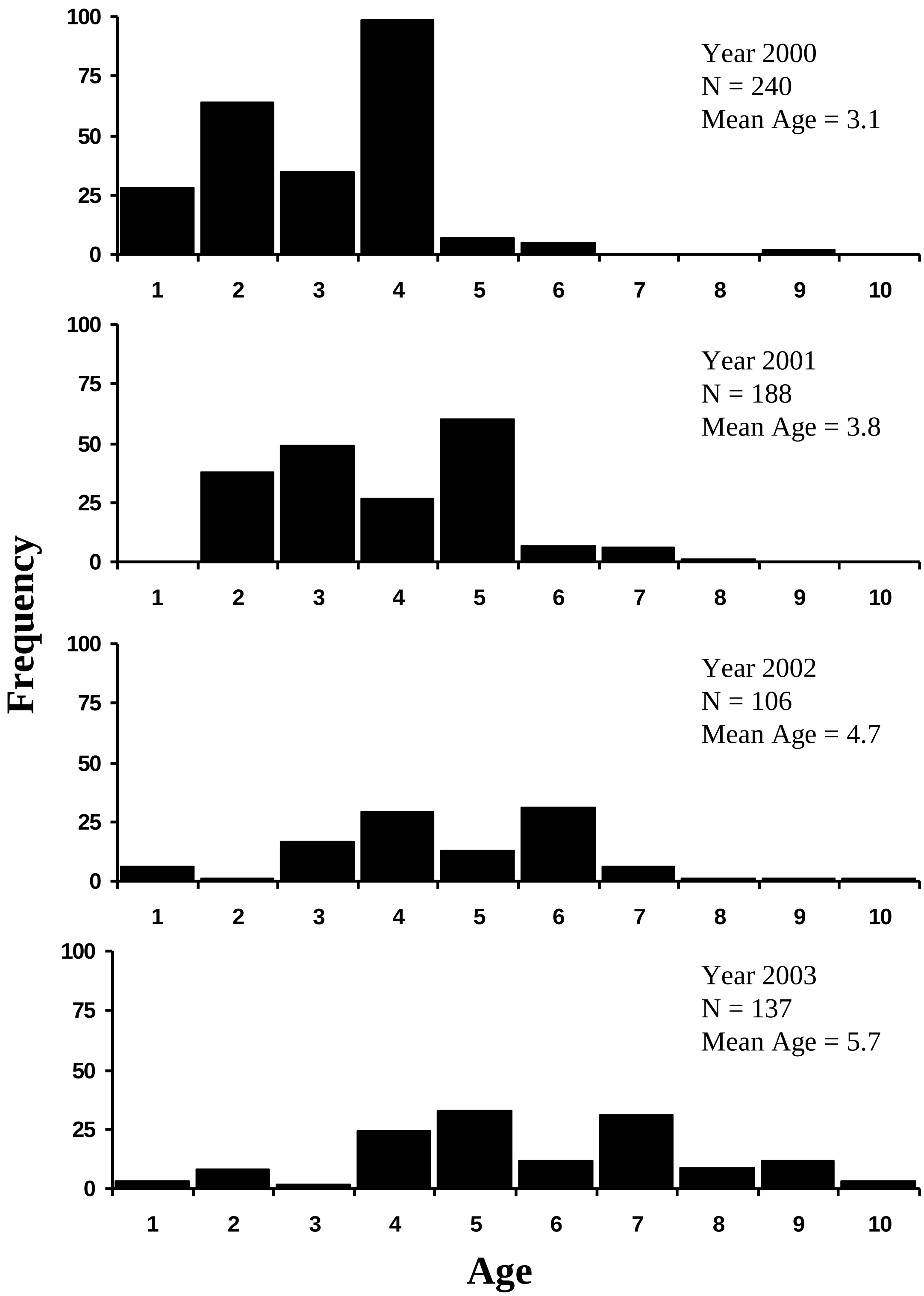

FIGURE 3.−Age-frequency distributions for walleye collected during this survey. Sample effort increased in 2003 (see methods).

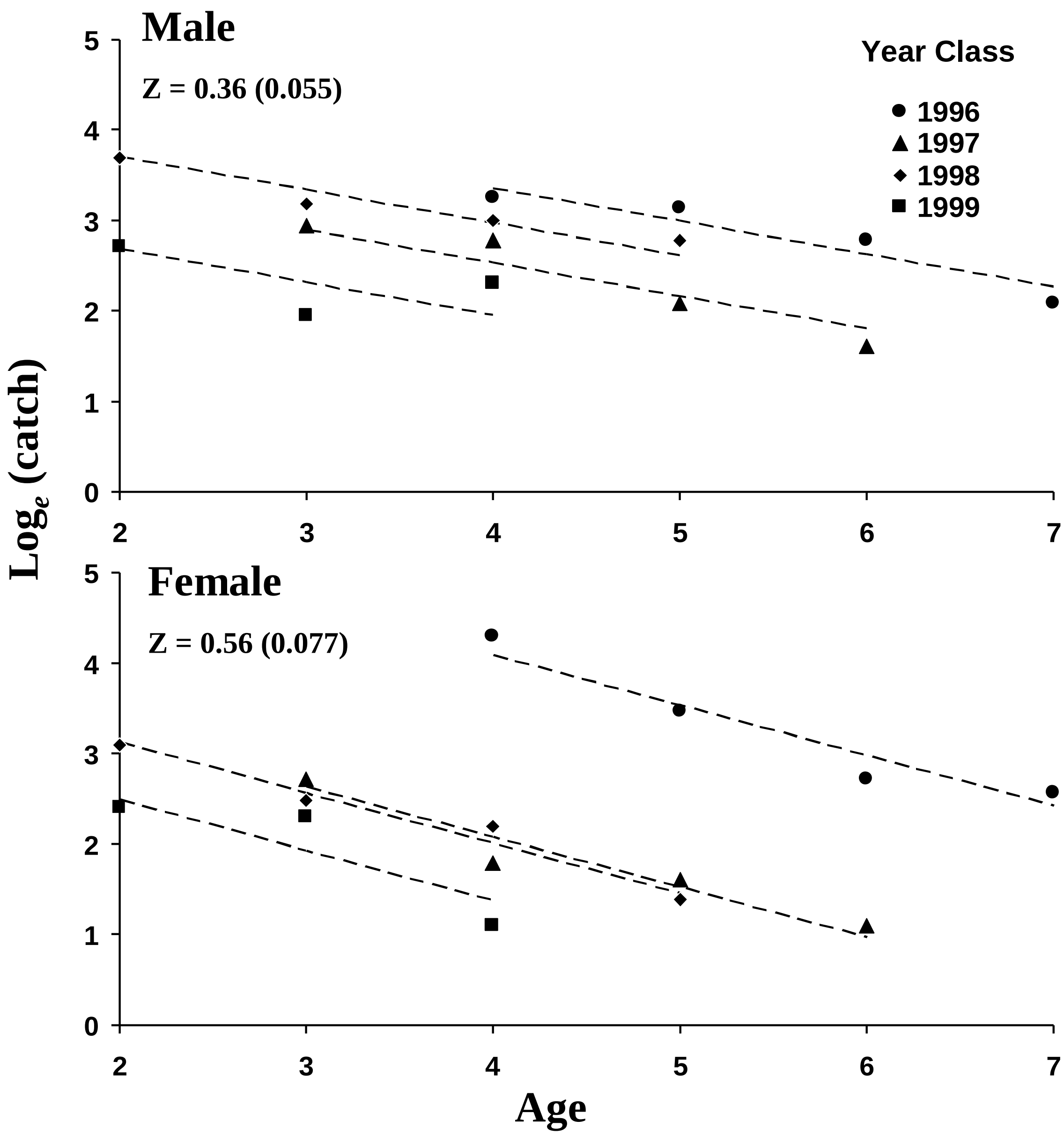

FIGURE 4.−Catch curve regressions and instantaneous mortality rate estimates (Z; and standard errors) for male and female walleye collected during this survey. Walleye could not reliably sexed until age-2.

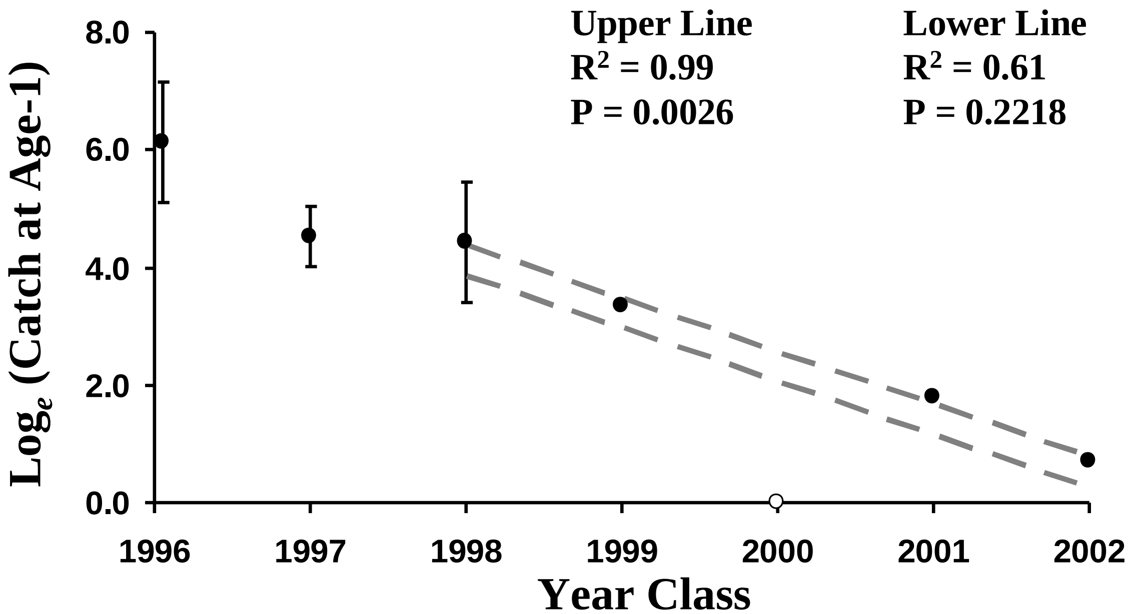

FIGURE 5.− Recruitment of walleye to age-1. The 1999 year class was the first age-1 walleye vulnerable to our sampling. Recruitment of year classes before 1999 were estimated from catch curve regressions and the precision of the estimates are presented with 95% confidence interval error bars. The open circle represents a value that is undefined (*i.e.*, $\log_e$ of zero). The 'upper line' was calculated ignoring the undefined value, whereas the lower line considered the undefined point with a value of zero. The slope and instantaneous rate of decline of both lines was 0.90 and the annual rate of decline is 59%.

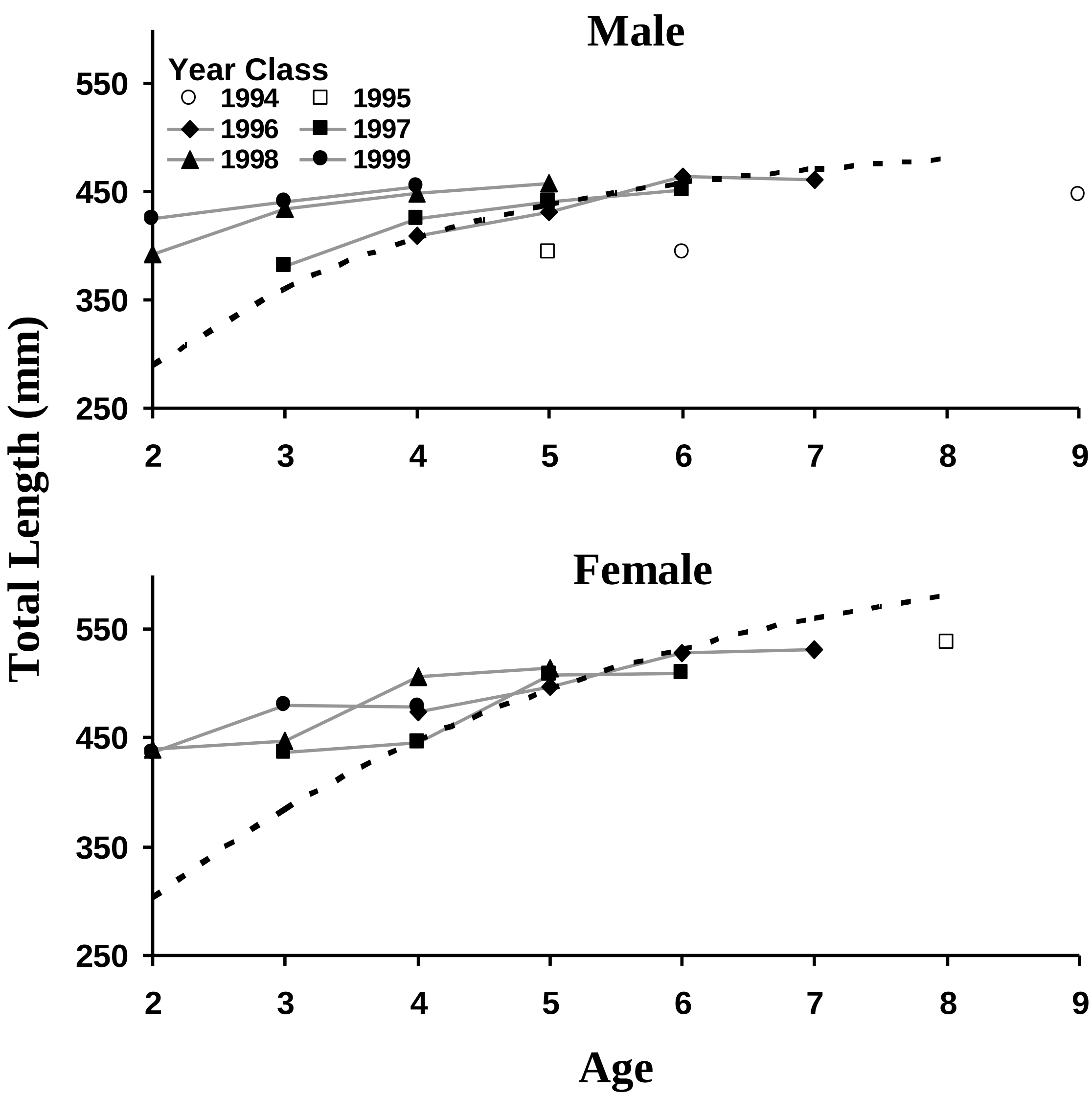

FIGURE 6.−Mean length at age for male and female walleye collected during this survey. Points were only included if the 95% confidence interval was narrower than +/-10% of the mean. Standard growth models are shown by dashed lines.