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[Management Brief]

Predicting Walleye Total Length from Head and Mandible Measurements

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Abstract.—To supplement harvest information on walleye *Sander vitreus* collected in Lake Erie creel surveys, we assessed whether walleye size structure and growth could be estimated by using total lengths (TL) predicted from measurements of head length (HL) and mandible length (ML). Regression models were developed by using measurements taken from 124 tournament-caught walleyes sampled in late May 2003. In most cases, HL and ML explained more than 90% of the variation in TL ($r^2 > 0.90$); however, residuals (absolute values) were frequently 10 mm or more. Despite estimation errors, the length-frequency distributions predicted from HL and ML models were not significantly different from observed distributions. Tests of the models with an additional 72 walleyes collected in June 2003 produced similar results. Predicted mean lengths at age for June walleyes ages 2–4 did not differ significantly from mean lengths at age estimated from observed TL. Use of an HL model developed for Minnesota walleyes yielded results similar to those of the Lake Erie models, suggesting that development of population-specific models may not be necessary. Given the accuracy and ease of measurement, we suggest that HL be used to predict walleye TL rather than ML; however, prediction errors indicate that age–length keys constructed by using TL predicted from HL should be validated before use.

Fisheries biologists routinely use creel surveys to quantify fishing effort and harvest (Malvestuto 1996). Estimating the size and age structure of harvested fish is frequently an additional component in many assessments of recreational harvest (Carl et al. 1991; Parsons et al. 1991; Beard and Kampa 1999). Size and age structure of harvested fish are used to monitor fishery trends (Beard and Kampa 1999; Colvin 1991) and to develop models for assessing potential management strategies (Haddon 2001). Creel surveys are time-consuming and expensive, and clerks are often required to interview anglers at multiple sites during individual sampling periods (Fabrizio et al. 1991; Parsons et al. 1991); therefore, successful creel survey implementation often requires optimizing the time a clerk spends at individual sampling sites to obtain interviews and conduct instantaneous angler counts. Because of these logistic constraints, lengths and aging structures may be collected from few numbers of fish for use in estimating size structure and harvest at age (Parsons et al. 1991). Parsons et al. (1991) developed a cost-effective, resort-based head collection program for walleyes *Sander vitreus* in three Minnesota lakes; with this method, sample sizes for estimating harvest at age and stocking contribution increased sevenfold. Ages for walleyes collected at resorts were estimated from opercules; total lengths (TL) were estimated by a linear regression model incorporating head length (HL) as a predictor variable.

We evaluated an approach similar to that of Parsons et al. (1991) for estimating walleye TL from anatomical measurements that might be used to supplement data collected in annual creel surveys conducted along the portion of Ohio bordering Lake Erie. Samples of walleyes measured during Lake Erie creel surveys are often low as a result of time constraints placed on creel personnel. Additionally, because of the ease of removal (Isermann et al. 2003) and efforts to minimize visible damage to harvested fish, scales have historically been used to estimate ages of harvested walleyes. Numerous studies have demonstrated that age estimates derived from scales lack accuracy and precision in comparison with estimates derived by using other aging structures, namely, sagittal otoliths (Erickson 1983; Heidinger and Clodfelter 1987; Hining et al. 2000; Kocovsky and Carline 2000; Hoxmeier et al. 2001), especially for older

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fish. Based on ages estimated from otoliths collected in other survey gears, walleyes in Lake Erie can reach ages of 22 (Ohio Department of Natural Resources, unpublished data), precluding the use of scales in estimating harvest at age. The aforementioned problems make estimating size structure and harvest at age difficult in some cases, a problem similar to that described by Parsons et al. (1991). Walleye heads are readily available from fish-cleaning houses along Lake Erie that process fish for recreational anglers, offering an ideal opportunity to collect otoliths for age estimation. Additional information regarding the size structure and growth of harvested fish could also be obtained if anatomical measurements such as HL could be used to predict walleye TL.

We expanded on the assessment conducted by Parsons et al. (1991) by incorporating mandible length (ML) as an additional predictor of walleye TL and tested the utility of our models by analyzing data from an independent sample of fish. We also developed models for different size ranges of walleyes in an attempt to improve the accuracy associated with estimates of TL derived from regression equations. To determine whether population-specific models might be necessary for predicting TL from HL, we used the model reported by Parsons et al. (1991) and compared the results with a model developed for Lake Erie walleyes. To evaluate whether HL and ML models could be used to describe walleye size structure and growth, we compared length frequencies and mean lengths at age estimated with TL predicted from HL and ML with observed values.

Methods

Model development.—Measurements of maximum TL (mm), HL (from tip of snout to tip of opercular spine), and ML (anterior to posterior tip of the mandible; Trautman 1981) were obtained from 124 walleyes (316–800 mm TL) caught from the western basin of Lake Erie during a professional walleye tournament held in Port Clinton, Ohio, May 28–31, 2003. Walleyes had been placed in live wells for various periods (1–10 h) and were held overnight in coolers on ice before measurements were recorded. We measured HL and ML to the nearest 0.001 in. with a vernier dial caliper and converted to mm.

Simple linear regressions were used to develop equations for estimating walleye TL from HL and ML. Regression models were constructed by three different methods: (method 1) pooling all the fish in the tournament sample, (method 2) deriving individual equations for walleyes 600 mm long or less and walleyes longer than 600 mm TL; and (method 3) deriving individual equations for walleyes no larger than 500 mm TL, 501–600 mm TL, and at least 600 mm TL. We used visual assessment of residuals to determine whether the assumption of variance homogeneity was valid for each model; Pearson correlations were used to test the hypothesis that residual values increased with walleye TL for each model. The utility of each regression model was assessed in terms of statistical significance ($P < 0.05$), coefficients of determination (r^2), and the percentage of residuals (absolute values) that were at least 10 mm and those that were at least 25 mm. Predicted and observed length-frequency distributions were compared for each model by using nonparametric Kolmogorov–Smirnov two-sample tests (test statistic = D; Daniel 1990).

Model evaluation.—Maximum TL, HL, and ML were measured from an additional 72 walleyes (318–650 mm) obtained from a fish-cleaning service during June 2003; these fish were used to test the validity of models developed with data from the tournament-caught walleyes. Measurements for June walleyes were recorded from fish as they arrived at the cleaning house. Fish had been held in coolers on ice for various amounts of time (2–6 h). Accuracy of TL values predicted from regression models was evaluated on the basis of the percentage of residuals (absolute values) was equal to or greater than 10 mm or 25 mm. Predicted and observed length-frequency distributions were compared with Kolmogorov–Smirnov two-sample tests. Ages were estimated from sagittal otoliths (Heidinger and Clodfelter 1987); mean lengths at age calculated from observed TL and from the TL predicted from HL and ML models were compared for walleyes ages 2–4 ($N = 59$) by analysis of variance (ANOVA; $\alpha = 0.05$). Although older walleyes were collected in the sample, too few individuals ($N < 6$) were collected in the older age groups to warrant comparisons.

Comparison with Minnesota model.—The linear regression equation used by Parsons et al. (1991) to predict walleye TL from HL in Minnesota lakes was TL (mm) = $9.0 + 4.15 \cdot \text{HL}$. The model was formulated based on data for 188 walleyes, which ranged from 187 to 633 mm TL (Parsons et al. 1991; $r^2 = 0.986$, $P < 0.0001$); therefore, we used the Minnesota equation to predict TL only for Lake Erie walleyes collected in June that were within this TL range ($N = 71$). The utility of the Minnesota model was assessed on the basis of the percentage of absolute residual values of at least 10

TABLE 1.—Statistics associated with simple linear regressions using measurements (mm) of head length (HL) and mandible length (ML) as predictors of the total length (TL) of 124 Lake Erie walleyes collected during a tournament held in late May 2003. Models were run using three size classification approaches: (1) pooling all the fish in the tournament sample (method 1), (2) deriving individual equations for walleyes ≤600 mm and walleyes >600 mm TL (method 2), and (3) deriving individual equations for walleyes ≤500 mm TL, 501–600 mm TL, and >600 mm in length (method 3). All models were significant at $P < 0.0001$.

Predictor variable	Method	TL range	df	Intercept	Slope	r^2
HL	1	316–800	1, 122	18.5	4.1	0.98
HL	2	316–600	1, 58	−3.43	4.3	0.97
		601–800	1, 62	106.1	3.6	0.92
HL	3	316–500	1, 22	−30.5	4.6	0.97
		501–600	1, 34	176.1	2.9	0.74
		601–800	1, 62	106.1	3.6	0.92
ML	1	316–800	1, 122	65.5	8.1	0.97
ML	2	316–600	1, 58	40.5	8.6	0.95
		601–800	1, 62	189.1	6.6	0.90
ML	3	316–500	1, 22	−12.1	9.7	0.96
		501–600	1, 34	262.7	4.9	0.73
		601–800	1, 62	189.1	6.6	0.90

and 25 mm and by comparing predicted and observed length-frequency distributions using Kolmogorov-Smirnov two-sample tests. Mean lengths at age for walleyes ages 2–4 calculated using TL predicted from the Minnesota model were compared with observed mean lengths using ANOVA. To assess differences in accuracy between the Minnesota and Lake Erie HL (method 1) models, we compared the proportion of residuals (absolute values) equal to or greater than 10 mm or 25 mm by using chi-square tests ($\alpha = 0.05$).

TABLE 2.—Percentages of residuals (absolute values) ≥10 mm and ≥25 mm associated with simple linear regressions using measurements (mm) of head length (HL) and mandible length (ML) as predictors of the total length of Lake Erie walleyes ($N = 124$) collected during a tournament held in late May 2003 and an additional sample of walleyes ($N = 72$) collected in June 2003. Walleyes collected in June were used to test models developed from tournament-caught fish. See Table 1 for more information on the models used.

Predictor variable	Method	Residuals ≥10 mm (%)	Residuals ≥25 mm (%)
Tournament walleyes			
HL	1	55	11
HL	2	50	10
HL	3	41	7
ML	1	65	19
ML	2	57	18
ML	3	52	11
June walleyes			
HL	1	43	3
HL	2	38	3
HL	3	32	8
ML	1	54	10
ML	2	44	4
ML	3	46	10

Results

Model Development

No discernible patterns were apparent in the residual plots for 11 of the 12 regression models we formulated. For the ML model using method 2, residual values were positively correlated with walleye TL ($r = 0.29$, df = 60, $P = 0.02$) for walleyes 600 mm long or less, suggesting that the assumption of variance homogeneity may have been violated to some extent. However, this violation did not affect the model in terms of predicting walleye length frequency or mean length at age. All regression models were significant at $\alpha = 0.0001$. Using method 1 (i.e., no length classification), regression models incorporating HL and ML as single-predictor variables yielded r^2 values of 0.90 or more (Table 1). Most regression models for specific length-groups of walleyes (methods 2 and 3) also yielded r^2 values of 0.90 or more. Conversely, HL and ML regressions for walleyes 501–600 mm TL (method 3) yielded lower r^2 values ($r^2 < 0.75$; Table 1). Discussion of residuals herein refers to absolute values. Residual values of 10 mm or more were detected for 41–65% of the fish across all models; 7–19% of residuals were 25 mm or more (Table 2). For all three length-classification methods, the HL models yielded lower percentages of residuals equal to or greater than 10 or 25 mm than did the ML models (Table 2). Development of regression equations using method 3 (i.e., three TL groups) yielded the

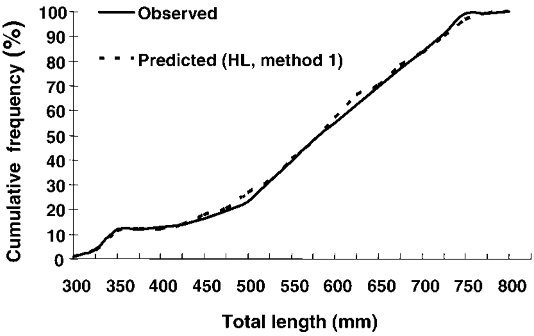

FIGURE 1.—Cumulative frequency distributions of observed total length (TL; solid line) and TL predicted from a regression equation incorporating head length (HL) as a predictor variable (dashed line) for 124 Lake Erie walleyes collected during a tournament held in late May 2003 (method 1). Length-frequency distributions were not significantly different (Kolmogorov–Smirnov test: $D = 0.07$, $P = 0.96$). The predicted TL frequency distributions did not significantly differ from the observed distribution ($P \geq 0.9$) for any regression model incorporating HL or mandible length as a predictor variable (Table 1).

fewest residual values of at least 10 mm or 25 mm compared with methods 1 and 2 for both HL and ML (Table 2). Predicted length-frequency distributions did not significantly differ from observed length frequencies for any model (Kolmogorov–Smirnov tests; $D = 0.04$–0.07, $P \geq 0.9$; i.e., Figure 1).

Model Evaluation

The percentage of absolute residual values 10 mm or more ranged from 32% to 54% across models for walleyes collected in June; the percentage of residuals 25 mm or more ranged from 3% to 10%. Use of HL as a predictor resulted in lower percentages of residuals equal to or greater than 10 mm or 25 mm than ML models (Table 2). For HL models, method 3 yielded the lowest percentage of residuals of 10 mm or more (32%), but the percentage of residuals of 25 mm or more was greater in method 3 (8%) than in method 1 (3%) or method 2 (3%; Table 2). For ML models, the percentage of residuals 10 mm or more was greatest for method 1 (54%; Table 2); these percentages were similar between method 2 (44%) and method 3 (46%). The percentage of residuals 25 mm or more for ML models was lowest (4%) in method 2 and reached similar values for method 1 (10%) and method 3 (10%; Table 2). Length-frequency distributions predicted from HL and ML regressions did not significantly differ from observed distributions ($D = 0.08$–0.17, $P = 0.28$–0.96). For all models, mean lengths at age for walleyes ages 2–4 calculated by using predicted TL were not significantly different from mean lengths at age estimated by using observed TL ($F < 1.48$; df = 5, 112; $P > 0.22$; Table 3).

Comparison with Minnesota Model

Predicted and observed length-frequency distributions did not significantly differ when we used the model provided by Parsons et al. (1991) to predict the TL of Lake Erie walleyes ($D = 0.08$, $P = 0.96$). Mean lengths at age for walleyes ages 2–4 estimated by using TL predicted from the Minnesota model did not significantly differ from mean lengths at age estimated by using observed TL ($F = 0.11$; df = 5, 112; $P = 0.75$; Table 3). The percentage of residual values of at least 10 mm was 32% when using the Minnesota model to predict TL of Lake Erie walleyes; percentage of residuals of at least 25 mm was 1%. After ex-

TABLE 3.—Mean total lengths (TL [mm]) at ages 2–4 and standard deviations (parentheses) for Lake Erie walleyes collected in June ($N = 59$) calculated using observed TLs and TLs predicted from simple linear regression equations incorporating head length (HL) and mandible length (ML) as predictor variables (Table 1). Mean TLs at age calculated from TL values predicted by a TL–HL relationship developed for Minnesota walleyes (Parsons et al. 1991) are also reported. Mean lengths at age calculated using predicted TLs did not significantly differ from the observed values for any model ($F < 1.48$; df = 5, 112; $P > 0.22$).

Predictor variable	Method	Age 2	Age 3	Age 4
None (observed values)		359 (19)	432 (21)	487 (29)
HL	1	368 (21)	439 (25)	491 (31)
HL	2	362 (21)	436 (26)	490 (33)
HL	3	358 (23)	437 (28)	495 (35)
ML	1	375 (20)	439 (26)	489 (34)
ML	2	366 (21)	434 (28)	485 (36)
ML	3	357 (24)	434 (31)	494 (40)
HL[a]		363 (21)	434 (25)	487 (32)

[a] Parsons et al. 1991.

cluding the single June walleye that was outside the TL range observed in Minnesota, the Lake Erie HL model using method 1 yielded 44% of residuals 10 mm or more and 3% of the residuals were equal to or greater than 25 mm. These proportions were not significantly different between Minnesota and Lake Erie models ($\chi^2 < 1$, df = 1, $P > 0.99$).

Discussion

Head length and ML proved to be good predictors of TL for Lake Erie walleyes. Except for one length-group of walleyes utilized in method 3, r^2 values were high (>0.90) when HL and ML were used to explain variation in TL of walleyes. Similarly, Parsons et al. (1991) reported a high r^2 when using HL to predict TL of walleyes in Minnesota ($r^2 = 0.986$). Despite high r^2 values, TL predicted from HL and ML often deviated by 10 mm or more from observed TL, but length-frequency distributions and mean lengths at age estimated with the HL and ML models were not significantly different from observed values. Using no length classification (method 1) represented the simplest approach to predict TL and was adequate for describing size structure and mean lengths at age; however, developing models for specific length ranges may reduce prediction errors in some cases. Although developing models for specific TL ranges of walleyes reduced the estimation errors for tournament-caught walleyes in May, trends in error reduction were not consistent when HL and ML models were used to estimate TL of walleyes collected in June.

Some of the estimation error we observed is probably due to variability associated with measuring HL, ML, and TL because the consistency of these measurements could be affected by differences in fish morphology (e.g., some fish may have disproportionately large or small heads) or slight variation in the selection of measurement reference points (e.g., tip of snout, tip of mandible). Estimation error could also be a product of the manner in which walleyes were handled before measurements were taken. Blackwell et al. (2003) demonstrated that holding walleyes in live wells or on ice can result in various extents of fish shrinkage, which could affect relationships between TL and anatomical measurements such as HL and ML. Future studies could be designed to determine what factors influence estimation error when using HL or ML to predict TL.

We recommend that future studies use HL rather than ML as a predictor of walleye TL. Head length models offered better accuracy than ML models and measuring HL was somewhat easier than measuring ML, because HL reference points (tip of snout, tip of opercular spine) were easier to define. Size structure and growth estimates calculated with TL predicted from HL can be used to supplement similar information obtained during Lake Erie creel surveys or in similar situations where data obtained during creel surveys are insufficient to describe walleye age and size structure, as well as growth rates, within a particular fishery. However, using age–length keys (Ricker 1975) constructed with TL predicted from HL models could result in age assignment errors. Age–length keys are frequently developed by subsampling a fixed number of fish within 10–25 mm intervals (Bettoli and Miranda 2001). Based on the observed percentage of absolute residual values that were 10 mm or more, aged fish could easily be placed into incorrect size groups if 10-mm intervals were used for age–length key construction and TL of aged fish were predicted from HL or ML. Similar errors would occur if 25-mm intervals were used but to a lesser extent. Incorrect length classification of aged fish could result in incorrect age distributions within specified length intervals that would be used to assign ages to unaged fish. We believe that in cases where TL is predicted from HL or ML, use of age–length keys should be validated before assigning ages to unaged fish measured in concurrent creel surveys.

Development of population-specific TL-to-HL relationships may not be necessary. The slope (4.15) and intercept (9.0) of the model for Minnesota walleyes were very similar to those of the Lake Erie HL model, method 1 (slope = 4.1, intercept 18.5). Furthermore, the Minnesota model was adequate for estimating length frequency and mean length at age for Lake Erie walleyes. This occurred despite environmental and potential genetic differences (Billington et al. 1992) between walleye populations in western Minnesota and Lake Erie and despite differences in the range of TL used to develop each model. The only difficulty with using the Minnesota model was that it could not be applied to all Lake Erie walleyes because 40% (49 of 124) of fish in our tournament sample exceeded the maximum TL (633 mm) that had been observed in Minnesota (Parsons et al. 1991). Hence, HL models should be developed from a large sample of fish encompassing the expected range of TL in the population.

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