Environ Biol Fish (2007) 79:11–25
DOI 10.1007/s10641-006-9089-1

ORIGINAL PAPER

The New River, Virginia, muskellunge fishery: population dynamics, harvest regulation modeling, and angler attitudes

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Received: 7 September 2005 / Accepted: 20 June 2006 / Published online: 25 July 2006

Abstract Although muskellunge, *Esox masquinongy*, fisheries in northern US states and Canadian provinces are increasingly being managed by introduction of restrictive harvest regulations (e.g. 1370-mm (54″) minimum length limits), many southern US muskellunge fisheries continue to be managed with comparatively liberal regulations (e.g. 762-mm (30″) minimum length limits) that are implemented statewide. We studied the population dynamics of the New River, Virginia, muskellunge fishery and used predictive modeling to determine whether restrictive harvest regulations also might prove beneficial for this southern latitude fishery. A creel survey was also conducted to learn more about angler attitudes to the New River muskellunge fishery. Muskellunge grew quickly, with fish reaching harvestable lengths (762 mm, 30″) in 2–3 years. Muskellunge fishing pressure, harvest rates, and voluntary release rates were low compared with reports for more northern areas. Most anglers, irrespective of how often they fished for muskellunge, defined ‘‘trophy’’ muskellunge to be approximately 1050–1100 mm (41–43″) in length. Although angler support for restrictive harvest regulations was low, abundance of memorable-length (≥1070 mm, 42″) muskellunge was predicted to increase under all evaluated length limits. Muskellunge yield would remain static at 914-mm (36″) and 1016-mm (40″) length limits, because of the rapid growth of fish, but yield would decline dramatically with a 1143-mm (45″) length limit, because male muskellunge rarely exceeded 1100 mm (43″). Because of rapid growth and low release rates, implementation of higher length limits (e.g. 965–1067 mm, 38–42″) may indeed prove beneficial for augmenting ‘‘trophy’’ muskellunge production on the New River. Angler support for higher minimum length limits might be increased by educating anglers about the rapid growth rates of muskellunge and the expected size structure changes that will result from a length-limit increase. Size structure changes resulting from an increase in the minimum length limit may be difficult to detect because of potential increases in fishing pressure or reduced

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fish growth as a result of competition for food resources. Long-term monitoring of muskellunge growth and angling pressure may therefore be needed to ensure that new regulations are indeed benefitting the fishery.

Keywords *Esox masquinongy* · Dynamic pool model · Creel survey · Minimum length limit · Exploitation · Voluntary release angling

Introduction

Although anglers often associate muskellunge, *Esox masquinongy*, with water bodies in northern US states and Canadian provinces, muskellunge fisheries do exist in southern US regions (e.g. North Carolina, Tennessee, Virginia, and West Virginia). Whereas many northern muskellunge fisheries are managed with harvest regulations tailored specifically for an individual system based on factors such as stock abundance, harvest rate, and growth rate (Simonson and Hewett 1999, OMNR 2005[1]), southern US muskellunge fisheries continue to be managed primarily with statewide limits that are substantially less restrictive than the regulations enforced in some northern water bodies. For example, all muskellunge fisheries in Virginia and North Carolina are managed with 762-mm (30″) minimum length (this and all lengths reported herein are total length measurements) and two-fish per day creel limits (NCWRC 2005[2], VDGIF 2005[3]). In comparison, length limits enforced in places such as Wisconsin and Ontario can be as high as 1270 and 1371 mm (50 and 54″) (Simonson and Hewett 1999, OMNR 2005[1]). Considering that most muskellunge fisheries are managed as "trophy" fisheries (Hanson et al. 1986), this difference in management approaches raises a question regarding the appropriateness of statewide, liberal harvest regulations in southern regions.

Although liberal harvest regulations can be beneficial for increasing production of "trophy" fish by reducing fish densities and preventing competition for food resources (Simonson and Hewett 1999), the paucity of information about muskellunge biology and ecology in southern systems probably is one of the major reasons why southern-latitude muskellunge fisheries are managed with statewide limits. Low length and high creel limits were once common for muskellunge fisheries even in northern areas, but regulations have become more restrictive as interest in muskellunge sportfishing has increased and the impact of overharvest has become more evident (Crossman 1986; Graff 1986). Because little research addressing muskellunge fisheries has been conducted in southern regions, biologists may have lacked data regarding muskellunge growth and mortality rates. Without such information, predicting the impact and justifying alternative harvest regulations for southern muskellunge would indeed prove difficult.

The purpose of our research was to determine whether the New River, Virginia, muskellunge fishery would benefit from implementation of a minimum length limit that differed from the current statewide limit. Very little is known about muskellunge in the New River, because fish are not frequently collected by Virginia Department of Game and Inland Fisheries (VDGIF) personnel during regular fish sampling. The fishery is managed for the production of "trophy" fish and is stocked annually with fingerling (~100 mm, 4″) fish. In recent years, some anglers have become concerned that Virginia's statewide harvest regulations do not afford sufficient protection for fish and that overharvest may be limiting "trophy" fish production. Specific objectives for this research were to estimate important population dynamic rate functions for the New River muskellunge fishery, to predict the effect that alternative harvest regulations would have on the fishery, and to measure angler attitude to the fishery.

[1] Ontario Ministry of Natural Resources. 2005. 2005 Fishing Regulations Survey. OMNR web site address: http://www.mnr.gov.on.ca/MNR/pubs/pubmenu.html#fish

[2] North Carolina Wildlife Resources Commission. 2005. North Carolina Inland Fishing, Hunting and Trapping Regulations Digest. NCWRC web site address: http://216.27.49.98/pg02_Regs/Regs_Digest.pdf

[3] Virginia Department of Game and Inland Fisheries. 2005. Freshwater Fishing in Virginia. VDGIF web site address: http://www.dgif.state.va.us/fishing/regulations/2005_fishing_regulations.pdf

Materials and methods

Study area

The New River originates in northwest North Carolina and flows northward through southwest Virginia and into West Virginia (Fig. 1). The New River merges with the Gauley River in West Virginia to form the Kanawha River, which is a tributary of the Ohio River. Naturalized expansion of muskellunge into the New River was possibly prevented by Kanawha Falls, a waterfall located several kilometers below the confluence of the New and Gauley rivers (Jenkins and Burkhead 1993). Stocking of the New River with muskellunge by VDGIF began in the early 1960s.

The Virginia portion of the New River is 245 kilometers (152 miles) long and the river is impounded by five dams—the Buck, Byllesby, Claytor, Fields, and Fries dams (Fig. 1). Muskellunge are currently stocked in two sections of the river, from the North Carolina-Virginia border to Fries Dam (upper section) and from Claytor Dam to the Virginia-West Virginia border (lower section). Approximately 5,000 fingerling muskellunge are annually stocked in these river sections in early to mid-summer.

Data collection

From 1998 to 2003 muskellunge were sampled by angling and by boat electrofishing at sites located primarily in the lower section of the river. The electrofishing unit consisted of two drop-wire boom-mounted anodes and a Type VI-A electrofisher (Smith Root, Vancouver, Washington, USA). Electrofishing was conducted in the fall, winter, and spring months using pulsed-DC output at 4 A and a frequency of 60 Hz. Muskellunge was the only species targeted when sampling. Angling occurred throughout the year.

Lengths of captured fish were measured to the nearest mm and fish were weighed, depending on size, to the nearest 0.001, 0.01, or 0.1 kg. Mus-

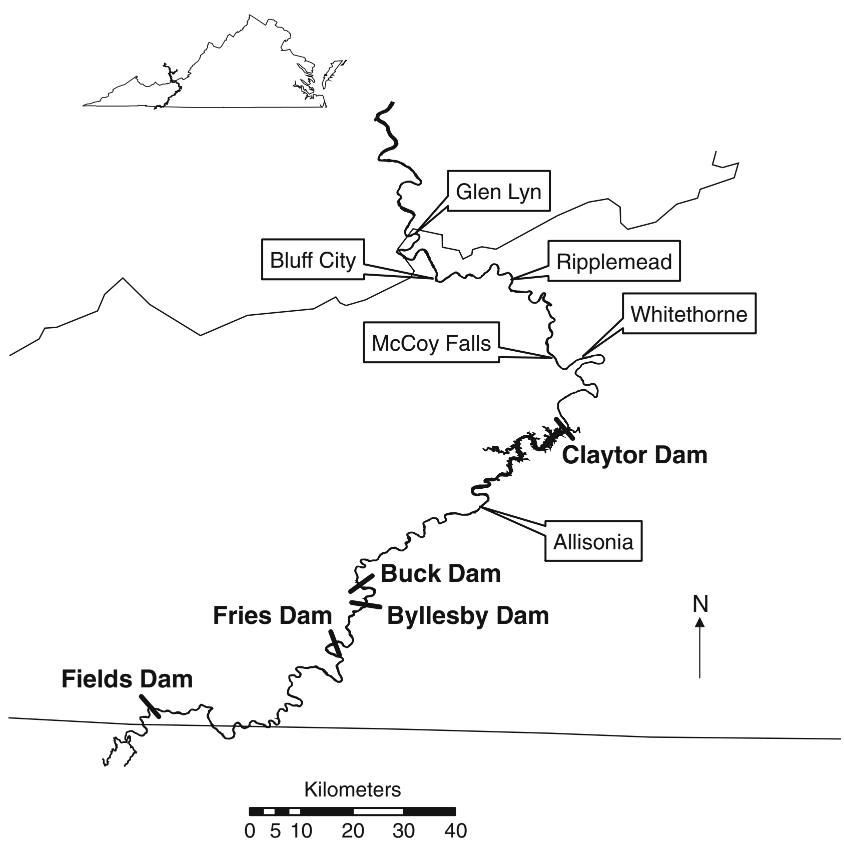

Fig. 1 Map of the New River in southwestern Virginia

kellunge that were captured by electrofishing were sexed using the method of LeBeau and Pageau (1989). A pelvic fin ray from most fish captured in 2000, 2001, 2002, and 2003 was clipped with wire cutters as close to the body as possible and stored in coin envelopes for aging—fin rays were prepared and fish ages were estimated using methods described by Brenden et al. (2006).

Forty-seven muskellunge >600 mm (23″) in length captured below Claytor Dam and at Whitethorne in 2000, 2001, and 2002 were equipped with internal trailing-whip antenna radiotelemetry transmitters (Advanced Telemetry Systems, Isanti, Minnesota, USA) so that more detailed information about sources of fish mortality could be collected. Transmitters listed contact information for VDGIF personnel and a notice that a reward would be given to those who harvested a tagged fish and returned the tag. Weekly attempts to locate telemetered fish were conducted from March 2000 to June 2003. Surveys were typically conducted only in the areas where muskellunge were originally tagged and released, although surveys throughout the entire lower section of the New River, including some West Virginia portions of the river, also were completed to detect whether any fish had moved beyond the areas regularly surveyed.

Angler attitude to the New River muskellunge fishery was measured through a creel survey conducted from 16 March to 8 November 2002 (Copeland 2005). The survey was stratified temporally by season (spring, summer, fall), day type (weekday, weekend/holiday), and river section. The angler intercept method depended on which section of the river was sampled. Region A (Virginia–North Carolina border to Byllesby Reservoir) was sampled by means of a combination of access point and road roving survey, whereby one clerk stayed at individual access sites while another clerk conducted a roadside roving survey. Regions B (Byllesby Reservoir to Allisonia) and C (Claytor Dam to Whitethorne) were sampled with access point surveys. Region D (McCoy Falls to Ripplemead) was sampled with an on-water roving survey. Region E (Bluff City to Glen Lynn) was sampled with a bus-route survey. Survey questions pertaining to the muskellunge fishery that were asked included how many days per year anglers fished exclusively for muskellunge, how many muskellunge had anglers harvested in the past three years, what length of muskellunge did anglers consider a trophy, what length of muskellunge would anglers consider harvesting, whether anglers believed that harvest regulations should be changed, and whether anglers belonged to specialized fishing clubs. Creel clerks also asked about targeted species and catch/harvest for the current fishing trip.

Data analysis

The size structure of the New River muskellunge population was assessed by use of length–frequency histograms and size-structure indices. Length–frequency histograms were constructed for each method of capture to evaluate differences in sampling effectiveness. Proportional stock density (PSD) and relative stock density (RSD) were used to summarize stock size structure. The length classes used to calculate these indices were stock (510–759 mm, 20–30″), quality (760–969 mm, 30–38″), preferred (970–1,069 mm, 38–42″), memorable (1,070–1,269 mm, 42–50″), and trophy (≥1,270 mm, 50″) lengths (Gabelhouse 1984). Lengths and weights of muskellunge were $\log_{10}$-transformed and regressed using least-squares simple linear regression. Differences between regression slopes among years of capture, capture method, and fish sex were tested by use of analysis of covariance (ANCOVA). Growth of male and female muskellunge was described by use of von Bertalanffy growth models, as described in Brenden et al. (2006). Differences between growth of the sexes were tested with sum-of-squares reduction *F* tests (Quinn and Deriso 1999).

Two separate methods were used to estimate muskellunge mortality. First, pooled catch-at-age data were used to construct catch curves for the New River muskellunge stock. On the basis of the appearance of the plot of $\log_e$ catch against fish age (Results section), we elected to fit two catch-curve regressions to the data. The first catch-curve regression was fit to the $\log_e$ catch values of age-1 to age-4 fish and the second catch-curve regression was fit to the $\log_e$ catch values of age-4 and older fish. On the basis of estimated fish growth and the 762-mm (30″) minimum length limit that was in effect, the first catch-curve regression primarily estimated natural mortality whereas the second catch-curve regression incorporated both fishing and natural mortality.

The telemetry method of Hightower et al. (2001) was the other approach used to estimate muskellunge mortality. This method estimates mortality on the basis of the number of telemetered fish located during each tracking event relative to the number of at-large telemetered fish during previous time periods. Although telemetered muskellunge were relocated weekly, we used a monthly time-step for estimating mortality. A fish was considered located in a particular month if it was located at least once during that month, unless it was discovered that the fish had been harvested or died from natural causes. Fish that were repeatedly found at the same location were assumed to have died from natural causes (although the possibility of hooking mortality cannot be discounted). Only those fish that were confirmed to be alive at least four months after transmitter implantation were included in the analysis to prevent surgery-related mortality from biasing the estimates. The temporal scale of the mortality analysis was reduced by scaling all fish relocation data to a common time span that began in November and lasted until the May nineteen months later. Thus, fish that were equipped with transmitters during the same month of different years were considered to have been released at the same time. The fate of fish after the 19-month time frame was ignored. Mortality rates were estimated using several different models in which mortality remained constant or varied quarterly or monthly (Hightower et al. 2001). Akaike's information criteria corrected for small sample sizes (AIC_c) and Akaike weights were constructed for the candidate models. Model-average estimates of fishing and natural mortality were computed from the mortality estimates and Akaike weights for the candidate models (Hightower et al. 2001).

Creel survey results were summarized according to the number of angling parties interviewed (as opposed to the total number of anglers), because angling parties formed the sampling unit for the survey questions. Angler subgroups were classified according to how often anglers fished for muskellunge. Response differences to individual questions among angler subgroups were tested using multi-response permutation procedures (Mielke and Berry 2001). The multi-response permutation procedure (MRPP) is a distance-based analytical method for testing differences among groups that uses randomization theory to determine the probabilities of test statistics (Cade & Richards 2005[4]). One of the main advantages of using MRPP as a statistical testing method is it makes few distributional assumption about the data. Detection of overall significant differences among angler subgroups were followed by Bonferroni-corrected pairwise MRPP comparisons between subgroups. The MRPP tests were conducted with Blossom (Cade and Richards 2005[4]) and *P*-values for the tests were obtained by using a Pearson Type-III approximation to the permutation distribution (Cade and Richards 2005[4]). All statistical tests were conducted with a Type-I error rate of 0.05. The Bonferroni-corrected error rate for pairwise comparisons of angler subgroup responses was 0.0083.

The effect of alternative length limits on the New River muskellunge fishery was assessed by use of a dynamic pool model as implemented in the Fishery Analyses and Simulation Tools software package (Slipke and Maceina 2000). Evaluated regulations were 914-mm (36″), 1016-mm (40″), and 1143-mm (45″) minimum length limits. Because of different fish-growth rates, responses of male and female muskellunge were modeled separately, but the results were combined for final evaluation. We assumed an initial population size of 2,000 fish per sex and that recruitment to the population occurred at age 1. Harvest regulations were modeled with conditional annual fishing and natural mortality rates ranging from 5 to 30%. The effects of alternative harvest regulations were evaluated on the basis of the change (%) in population abundance of memorable-length (≥1070 mm, ≥42″) muskellunge, the change (%)

[4] Cade, B. S. & J. D. Richards. 2005. User Manual for BLOSSOM Statistical Software. U.S. Geological Survey Fort Collins Science Center web site address: http://www.fort.usgs.gov/products/publications/21536/21536.pdf

in the total number of fish harvested, and the change (%) in yield-per-recruit (kg ha^{-1} year^{-1}).

Results

Population dynamics

From 1998 to 2003, 523 muskellunge were collected from the New River, 236 by electrofishing and 285 by angling. Two other fish were found dead in the river. A total of 445 muskellunge were seen, but not necessarily captured, when electrofishing. The median electrofishing catch rate for all sampled sites was 1.36 fish per electrofishing hour. Of the captured muskellunge for which sex was identified, the male-to-female ratio was approximately equal (female 49%; male 51%).

Lengths of captured muskellunge ranged from 358 to 1270 mm (14–50″). Comparison between sampling methods suggested that angling captured larger fish more effectively than electrofishing (Fig. 2). This different sampling effectiveness in turn affected size structure estimates. Muskellunge PSD, RSD-P, and RSD-M for fish captured by electrofishing equaled 64, 25, and 5, respectively. Muskellunge PSD, RSD-P, and RSD-M for fish captured by angling equaled 100, 45, and 17. Muskellunge PSD, RSD-P, and RSD-M combined across both sampling methods equaled 87, 38, and 12, respectively.

Significant differences in $\log_{10}$-transformed length–weight relationships by method (ANCOVA: F=2.36, df=1,511, P=0.125) and year (ANCOVA: F=0.90, df=1,503, P=0.482) of capture were not detected. There was, however, a significant difference between the slopes of the length–weight relationships for the different sexes (ANCOVA: F=4.73, df=1,142, P=0.0312). The $\log_{10}$-transformed length–weight relationships for females and males were:

$$\log_{10} W_{\mathrm{f}} = -6.496 + 3.459 \cdot \log_{10} L_{\mathrm{f}}$$

and

$$\log_{10} W_{\mathrm{m}} = -5.991 + 3.280 \cdot \log_{10} L_{\mathrm{m}},$$

where W_{f} and W_{m} are female and male weights (g), and L_{f} and L_{m} are female and male lengths (mm), respectively. Estimated von Bertalanffy growth equations for female and male muskellunge were:

$$L_{\mathrm{f}}(t) \; = \; 1,300 \cdot \left[1 - \exp^{-0.3169 \cdot (t+0.2743)}\right]$$

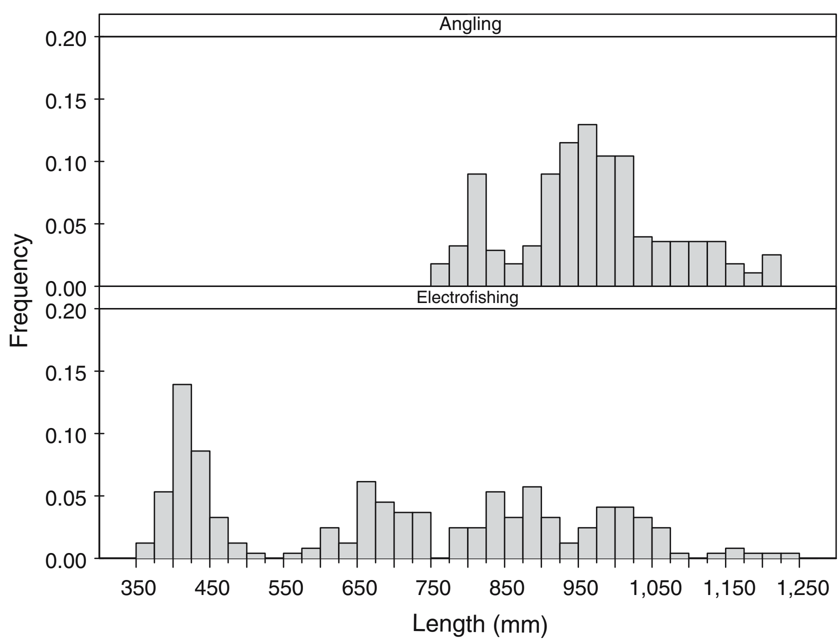

Fig. 2 Length–frequency histograms for muskellunge captured by angling and electrofishing in the New River, Virginia

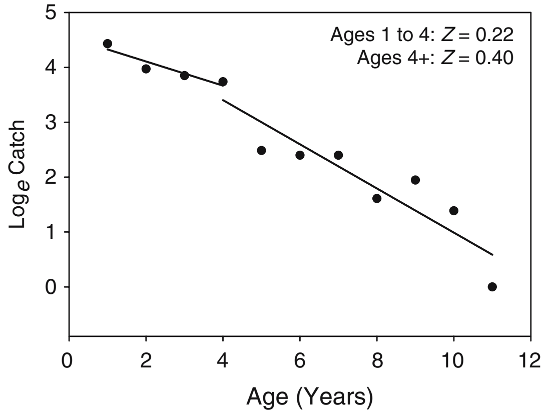

Fig. 3 Relationship between $\log_e$ catch and age data and the catch-curve regression fits for ages 1–4 and ages 4+ fish. On the basis of the scatterplot of $\log_e$ catch against age, it was assumed that fish were recruited to the sampling gear at age 1

and

$$L_m(t) = 1,100 \cdot \left[1 - \exp^{-0.4263\cdot(t+0.1536)}\right],$$

where $L_f(t)$ and $L_m(t)$ are predicted lengths at age (t) for females and males, respectively (Brenden et al. 2006). Significant differences were detected among the parameter estimates of the sex-specific growth equations (F test: $F = 75.98$, df=2,173, $P < 0.0001$).

Total instantaneous mortality estimates from catch-curve regressions equaled 0.22 for age-1 to age-4 fish and 0.40 for age-4 and older fish (Fig. 3). Assuming that total mortality of age-1 to age-4 fish consisted primarily of natural mortality and that this rate remained constant for older fish, instantaneous natural and fishing mortality for muskellunge were estimated to be 0.22 and 0.18, respectively. The telemetry method of Hightower et al. (2001) yielded model-average instantaneous natural and fishing mortality to be 0.05 and 0.15, respectively. Averaging the mortality from the two methods yielded instantaneous natural and fishing mortality estimates of 0.135 and 0.165, respectively. Conditional annual fishing (cf) and natural (cm) mortality were estimated to be 15.2 and 12.6%, respectively. The annual exploitation rate for New River muskellunge was estimated to be 14.2%.

Angler attitudes

Seven-hundred-and-seventy angling parties (hereafter referred to as anglers) were interviewed during the New River creel survey. Twelve percent (n=91) of the interviews were repeat interviews, meaning that those interviewed had been previously interviewed at least once before. When conducting a repeat interview, clerks only asked questions relating to the current angling trip (e.g. targeted species, number of fish caught) and did not repeat questions about angler opinion. Muskellunge was identified as the targeted species by 2.2% (n=17) of anglers. Thirty-five percent (n=6) of those targeting muskellunge had caught a muskellunge during that particular fishing trip (total number caught=6), with one fish approximately 1200 mm (47″) long having been harvested. In comparison, only one percent (n=7) of anglers that were not targeting muskellunge had caught a muskellunge during that particular fishing trip (total number caught=8), with one fish approximately 920 mm (36″) long having been harvested.

Interviewed anglers fished for muskellunge an average of 4 days per year. For the purpose of differentiating angler attitudes, angler subgroups were defined as follows:

- non-muskellunge anglers—those who fished 0 days per year for muskellunge;
- occasional muskellunge anglers—those who fished 1–5 days per year;
- moderately-dedicated muskellunge anglers—those who fished 6–25 days per year; and
- dedicated muskellunge anglers—those who fished >25 days per year.

More than 80% (n=555) of those interviewed were classified as non-muskellunge anglers. Of those anglers who fished at least once a year for muskellunge, 50% (n=61) were occasional, 30% (n=37) were moderately dedicated, and 20% (n=25) were dedicated muskellunge anglers. Only one interviewed angler belonged to a muskellunge fishing club. That angler was a member of a West Virginia Muskies Inc. Chapter and fished frequently enough to be regarded as a dedicated muskellunge angler.

No significant differences in opinion of the length of muskellunge considered a ''trophy'' were found among the angler subgroups (Table 1; MRPP: δ=0.261, P=0.322). Most anglers defined ''trophy'' muskellunge lengths to be approximately 1050–1100 mm (41 to 43''). Seventy-four percent of anglers (n=302) with an opinion about ''trophy'' lengths of muskellunge believed that a ''trophy'' muskellunge was at least 1016 mm (40″) and 11% (n=22) believed that a ''trophy'' muskellunge was at least 1270 mm (50″) (Fig. 4).

Significant differences were found among the angler subgroups about the length of muskellunge they would consider harvesting (Table 1; MRPP: δ=15.58, $P < 0.0001$). Approximately 35% of non-muskellunge anglers indicated they would consider harvesting a muskellunge approximately 800 mm (31″) in length whereas most dedicated muskellunge anglers indicated they would only consider harvesting a muskellunge 1200 mm (47″) or larger (Fig. 4). In terms of differences between angler subgroups, non-muskellunge anglers identified minimum harvestable lengths that were significantly smaller than lengths identified by occasional (MRPP: δ=4.676, P=0.005), moderately-dedicated (MRPP: δ=4.343, P=0.006), and dedicated (MRPP: δ=22.882, $P < 0.0001$) muskellunge anglers. Dedicated muskellunge anglers identified minimum harvestable lengths that were larger than lengths identified by occasional (MRPP: δ=6.314, P=0.001) and moderately-dedicated MRPP: δ=6.019, P=0.001) muskellunge anglers. None of the other differences between angler subgroups was significant (P>0.0083).

When asked about minimum harvestable lengths at least a few anglers from all subgroups indicated that all muskellunge caught would be voluntarily released (Fig. 4). Although results from the overall test to discover whether angler subgroups differed in the percent of anglers that specified voluntary release of muskellunge would be practiced were significant (MRPP: δ=2.54; P=0.026), none of the pairwise MRPP comparisons between angler subgroups showed differences were significant (P>0.0083). Overall, 40% (n=240) of anglers with opinions about minimum harvestable length of muskellunge specified that voluntary release would always be practiced.

A significant difference in the percent of anglers who had harvested a muskellunge in the past 3 years (calculated from those that had caught a muskellunge in the past 3 years) was found among the angler subgroups (MRPP: δ=2.17; P=0.039). Pairwise comparisons indicated that a higher percentage of muskellunge anglers than non-muskellunge anglers had harvested a muskellunge (MRPP: δ=4.45; P=0.0065). None of the other pairwise comparisons was significant (P>0.0083).

Table 1 Responses of angler subgroups to questions asked during a creel survey conducted on the New River in 2002 regarding the muskellunge fishery. Anglers that had no opinions were excluded from the analysis

Point addressed	Angler Subgroups			
	Non-muskellunge	Occasional	Moderately-Dedicated	Dedicated
Trophy length (mm)	1036	1051	1071	1074
Minimum harvestable length (mm)	858	936	922	1109
Previously harvested a muskellunge (%)[a]	20	22	48	35
Average length of harvested fish (mm)	946	1023	916	995
Support a regulation change (%)	10	28	27	56
Support a creel limit change (%)[b]	83	76	80	79
Support a lower creel limit (%)[c]	31	77	75	82
Support a length limit change (%)[b]	33	76	50	71
Support a higher length limit (%)[d]	32	92	40	80
Suggested length limit (mm)[e]	527	973	550	897

[a] Percentages are calculated out of those anglers who indicated a muskellunge had been caught

[b] Percentages are calculated out of those anglers who believed regulations should be changed

[c] Percentages are calculated out of those anglers who believed creel limit should be changed

[d] Percentages are calculated out of those anglers who believed length limit should be changed

[e] Suggested length limits are weighted averages

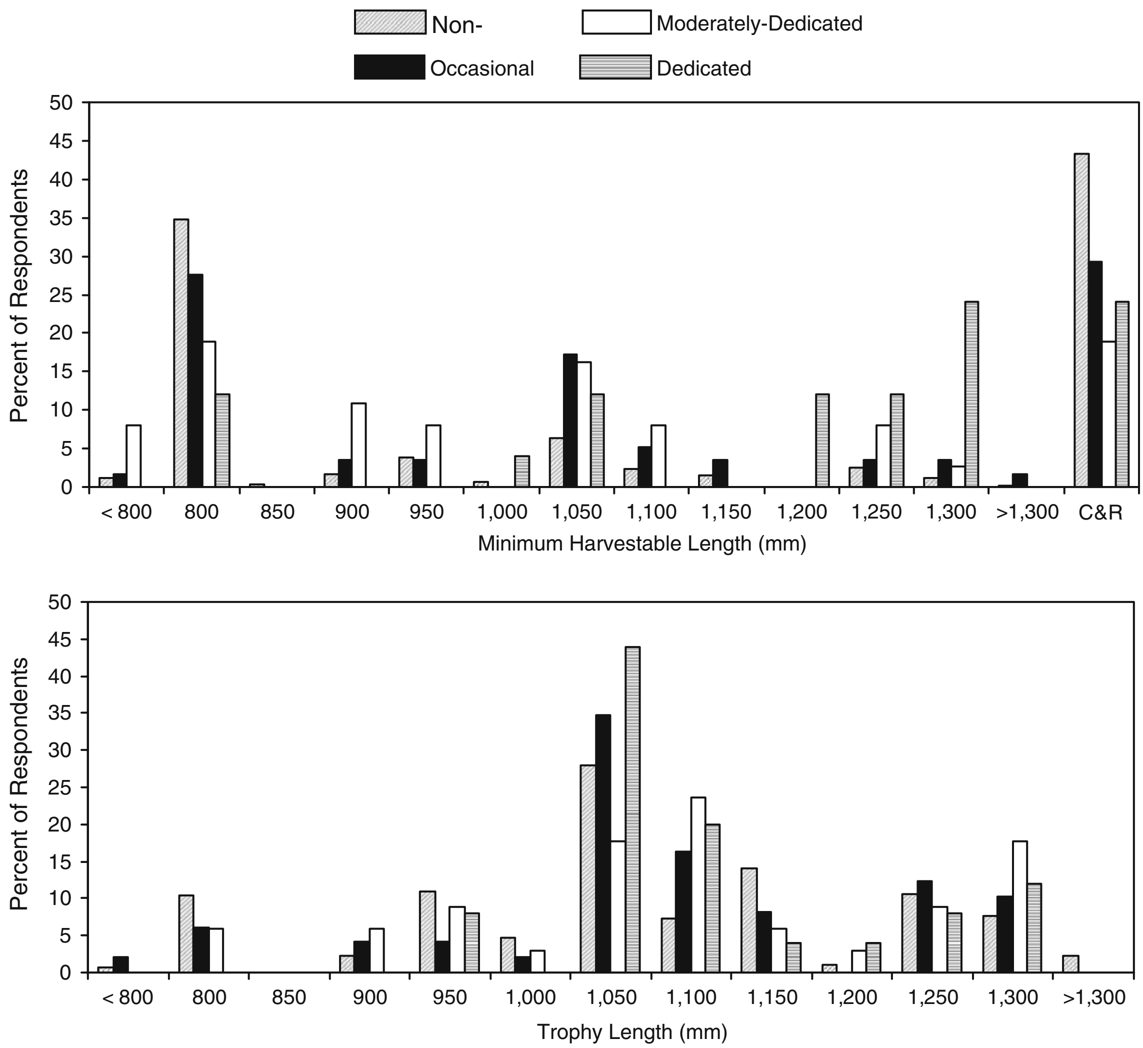

Fig. 4 Lengths of muskellunge regarded as a ''trophy'' (**bottom**) and as the minimum harvestable length (**top**) by non-muskellunge anglers, occasional muskellunge anglers, moderately-dedicated muskellunge anglers, and dedicated muskellunge anglers. The percent of anglers that specified all muskellunge would be released are under the category marked *C&R* (catch and release)

The percentage of anglers who believed muskellunge harvest regulations should be changed was significantly different among the angler subgroups (MRPP: δ=20.21; $P<0.0001$). A lower percentage of non-muskellunge anglers believed regulations needed to be changed than occasional (MRPP: δ=9.71; P=0.00012), moderately-dedicated (MRPP: δ=5.22; P=0.004), or dedicated muskellunge (MRPP: δ=30.17; $P<0.0001$) anglers. Of the anglers that thought harvest regulations for muskellunge should be changed, 86% (n=85) believed the creel limit should be changed and 56% (n=55) believed the size limit should be changed. Of those anglers who believed the creel limit should be changed, the percentage that wanted a lower creel limit was significantly different among the angler subgroups (MRPP: δ=5.67; P=0.0005). A lower percentage of non-muskellunge anglers believed a lower creel limit should be implemented than occasional (MRPP: δ=5.43; P=0.003) and dedicated (MRPP: δ=5.90; P=0.002) muskellunge anglers.

Of the anglers interviewed who thought the size limit for muskellunge should be changed, the percentage that believed a higher minimum length limit should be implemented was significantly different among the angler subgroups (MRPP: δ=4.56; P=0.002). A lower percentage of non-muskellunge anglers than occasional muskellunge anglers believed a higher minimum length limit should be implemented (MRPP: δ=7.40; P=0.0006). None of the other differences among the angler subgroups was significant (P>0.0083). Of the anglers who believed a higher minimum length limit should be implemented, the mean length specified (irrespective of angler subgroup) was 988 mm (39″) and ranged from 863 to 1219 mm (34–48″). The weighted-average size limits proposed by the angler subgroups, which were found by multiplying the percentages of anglers that wanted lower and higher size limits by the mean size limits they specified, ranged from 527 to 973 mm (21–38″) (Table 1).

Alternative length-limit evaluations

Alternative length-limit modeling indicated that increasing the minimum length limit to 914 mm (36″) would increase the population abundance of memorable-length (≥1070 mm, ≥42″) muskellunge by approximately 25%, on the basis of current mortality estimates (Fig. 5). For other mortality levels, the expected abundance increase could be between 5 and 50%. Total number of harvested fish would be expected to decline by approximately 20% on the basis of current mortality estimates, although as a much as a 40% decrease could be expected with lower natural and higher fishing mortality estimates (Fig. 5). If the minimum length was 914 mm (36″), yield of muskellunge would actually increase, albeit only slightly, on the basis of current mortality estimates (Fig. 5). The increase in yield if the minimum length limit were 914-mm (36″) would be expected to be even larger in a low natural mortality and high fishing mortality scenario (Fig. 5).

With a 1016-mm (40″) minimum length limit, the population abundance of memorable-length (≥1070 mm, ≥42″) muskellunge was predicted to increase by 50% at current mortality (Fig. 5). Expected abundance increases could be as high as 130% with low natural mortality and high fishing mortality, but also as low as 10% with low fishing mortality. On the basis of current mortality estimates, harvest of muskellunge would decline by 40% if the minimum length limit was 1016-mm (40″) (Fig. 5). Yield would be expected to decline by approximately 0.25 kg ha^{-1} year^{-1} (0.22 lbs acre^{-1} year^{-1}) per recruit, on the basis of current mortality estimates, but could also increase by as much as 1.25 kg ha^{-1} year^{-1} (1.12 lbs acre^{-1} year^{-1}) per recruit given a higher estimate of fishing mortality (Fig. 5).

An increase in the minimum-length limit to 1143 mm (45″) was predicted to nearly double the population abundance of memorable-length (≥1070 mm, ≥42″) muskellunge on the basis of current mortality estimates, although the total number of harvested fish was also predicted to decline by as much as 80% (Fig. 5). Unlike the other size limits that were considered, yield under a 1143-mm (45″) minimum length limit was predicted to decline, irrespective of the mortality rates considered in the analysis (Fig. 5). The decline in yield was predicted to be as much as 2.00 kg ha^{-1} year^{-1} (1.78 lbs acre^{-1} year^{-1}) per recruit.

Discussion

New River muskellunge population dynamics

The New River muskellunge fishery was found to consist of fast-growing individuals that become harvestable at young ages under Virginia's current 762-mm (30″) minimum length limit. Nearly all New River muskellunge exceeded 762 mm (30″) by 3 years of age, and fish could exceed 1016 mm (40″) by age 5. This rate of growth is among the fastest reported for any muskellunge population. In northern regions, muskellunge typically do not reach 762 mm (30″) until 4–6 years of age, and fish from some populations may not reach this length until nine to ten years of age (Johnson 1971; Harrison and Hadley 1979; Casselman et al. 1999). In a study of 15 northern Wisconsin lakes, muskellunge took an average of 11.5 years to reach 1016 mm (40″) (Margenau and AveLallemant 2000). Growth of New River muskellunge also was rapid compared with

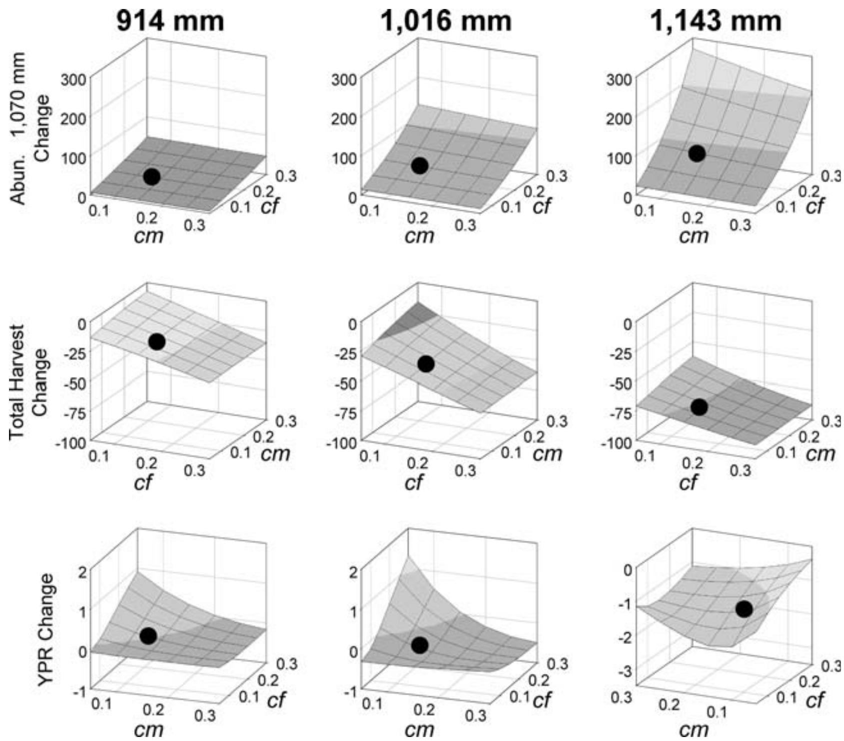

Fig. 5 Predicted changes in population abundance of memorable length (≥1070 mm) fish (% change), total harvest (% change), and yield per recruit (kg ha^{-1} year^{-1} change) for the New River muskellunge fishery on implementation of a 914-mm (36″), 1,016-mm (40″), or 1143-mm (45″) minimum length limit. Changes were predicted with annual conditional natural (*cm*) and fishing (*cf*) mortality ranging from 5–30%. Expected changes on the basis of current mortality estimates (cm=12.6%, cf=15.2%) are indicated by *filled circles*

growth rates from other southern populations. In North Carolina's French Broad River, muskellunge did not attain 762 mm (30″) until 4–5 years of age (Monaghan and Borawa 1988). Likewise in Tennessee, West Virginia, and Kentucky muskellunge did not reach 762 mm (30″) until 5–6 years of age (Parsons 1959; Miles 1978; Axon and Kornman 1986).

An abundance of appropriate-size prey and suitable thermal conditions are two factors probably contributing to the rapid growth of muskellunge in the New River. Fast growth of riverine muskellunge has previously been linked to availability of cyprinids as prey (Harrison and Hadley 1979), and, indeed, New River muskellunge have been found to forage extensively on species such as telescope shiners, *Notropis telescopus*, and white shiners, *Luxilus albeolus*, until approximately 600 mm (24″) in length (Brenden et al. 2005). New River muskellunge also feed primarily on catostomids later in life (Brenden et al. 2005); this also has been correlated with faster growth (Hanson 1986). Water temperature in the New River remains within 20–30°C (68–86°F) throughout much of the summer; this is the temperature range regarded as optimum for muskellunge feeding and growth (Bevelhimer et al. 1985). Further, the water temperature dips below 5°C (41°F), the temperature at which muskellunge feeding stops (Bevelhimer et al. 1985), from early December until early February only. Thus muskellunge in the New River may experience a nearly 10-month feeding and growing season, which may explain the faster growth rates for this stock.

The 14.2% annual exploitation level estimated for New River muskellunge stock was low compared with levels reported elsewhere. Although exploitation ranging from 5.4 to 15% has been reported for muskellunge fisheries in New York (Bimber and Nicholson 1981) and Wisconsin (Hanson 1986), exploitation in excess of 25% has been reported for muskellunge fisheries in West Virginia, Kentucky, and Wisconsin (Miles 1978; Brewer 1980; Axon 1981; Brege 1986; Hanson 1986; Hoff and Serns 1986; Cornelius and Margenau 1999). Exploitation in excess of 25% is believed to be too high for managing a quality muskellunge fishery (Hanson 1986); it thus seems unlikely that overharvest of New River muskellunge fishery is problematic. Suggested regulation changes would therefore be intended primarily to enhance trophy fish production and to prevent overharvest from possibly occurring in the future.

Angler attitudes

The New River angler-attitude survey provided an interesting contrast to surveys conducted in more northern areas. Between 11.8 and 67.3% of anglers fishing on eight northern Wisconsin lakes were found to specifically target muskellunge (Hanson 1986), which is substantially greater than the 2.2% of anglers that were targeting muskellunge on the New River. Between 7.5 and 14.0% of anglers targeted muskellunge on Cave Run Lake, Kentucky (Axon 1981), so percentages of New River anglers targeting muskellunge were more comparable with, albeit still lower than, the percentages for that fishery. New River anglers fished for muskellunge an average of 4 days per year, substantially less than when Wisconsin anglers fished for muskellunge ($\bar{x}$=13 days per year; Margenau and Petchenik 2004).

Lengths of ''trophy'' muskellunge identified by New River anglers were smaller than the lengths identified by Wisconsin anglers. Eighty-nine percent of general anglers surveyed in Wisconsin believed a ''trophy'' muskellunge should be greater than 1016 mm (40″) and 44% believed the fish should be greater than 1270 mm (50″) (Margenau and Petchenik 2004). In comparison, 74% of New River anglers believed that ''trophy'' muskellunge should be greater than 1016 mm (40″) and 11% believed that muskellunge should be greater than 1270 mm (50″). Lengths of ''trophy'' fish identified by muskellunge anglers also differed between Wisconsin and the New River. Ninety-eight percent of anglers in Wisconsin who were members of a muskellunge fishing club believed muskellunge should be greater than 1016 mm (40″) to be a ''trophy'' and 62% believed a fish should be at least 1270 mm (50″) (Margenau and Petchenik 2004). In comparison, 92% of New River anglers that fished most often for muskellunge believed a ''trophy'' muskellunge should be at least 1016 mm (40″), and 13% believed a ''trophy'' muskellunge should be at least 1270 mm (50″).

Although New River anglers that fished less often for muskellunge identified smaller minimum harvestable lengths and were more likely to suggest that higher creel or lower size limits should be enacted than anglers that fished more often for muskellunge, there is little evidence to indicate that harvest by non-muskellunge anglers is negatively affecting the New River muskellunge stock. Although incidental catch of muskellunge on the New River may not necessarily be a rare occurrence, non-muskellunge anglers seem just as likely as muskellunge anglers to release caught fish. Rather, our results indicate that overharvest of New River muskellunge would be more likely to occur because of the greater inclination of all anglers toward harvest of muskellunge. Only 40% of all interviewed anglers indicated that all caught muskellunge would be released, and the estimated release of muskellunge on the basis of the creel survey results was 86%. Release rates for New River muskellunge calculated from Virginia's Angler Recognition program, a program that gives formal recognition to anglers for catching ''trophy'' fish, was estimated to be 46% (J. Williams, unpublished data). In comparison, ninety percent of general anglers in Wisconsin voluntarily released muskellunge, and release rates for muskellunge have been estimated to be as high as 99.9% (Fayram 2003; Margenau and Petchenik 2004).

One factor possibly contributing to a greater tendency for muskellunge harvest in the New River and other southern fisheries is the lack of specialized muskellunge angling clubs (e.g. Muskies Inc.) in southern regions. Such clubs often promote voluntary-release angling both within the club and to the general angling public (Gasbarino 1986; Oehmke et al. 1986). This peer pressure to release muskellunge may be a significant factor shaping angler behavior in locales where the clubs operate. In areas without active clubs there may be less incentive for anglers to release fish. Other factors possibly contributing to higher muskellunge harvest rates include the novelty aspect associated with muskellunge fishing in Virginia or the possibility of regionally different angling release rates.

Alternative harvest regulations

At current estimated mortality levels, abundance of memorable-length (≥1070 mm, ≥42″) was predicted to increase by 25, 50, and 100% on implementation of 914-mm (36″), 1016-mm (40″), and 1143-mm (45″) minimum length limits. Although the total number of harvested fish would also decrease if these length limits were implemented, yield per recruit would occasionally increase (914-mm (36″) minimum length limit) or decrease only slightly (1016-mm (40″) minimum length limit). This is primarily because of the rapid growth of muskellunge—addition of fish biomass will offset the decrease in overall catch. A 1143-mm (45″) minimum length limit would result in the largest decrease in yield, because of the inability of male muskellunge to reach these larger lengths. Thus, 1143-mm (45″) would result in a ‘‘female only’’ muskellunge fishery. Although ‘‘female only’’ muskellunge fisheries are not a major concern to fishery biologists in northern-latitudes (Simonson and Hewett 1999), in an introduced southern latitude fishery where anglers, perhaps, view muskellunge fishing as a novelty, the yield of the fishery may need to be a greater concern to biologists.

Although it might seem unequivocal that higher length limits will lead to increases in the abundance of larger fish, this is not always true. Cornelius and Margenau (1999) found that abundance of large muskellunge in Bone Lake, Wisconsin initially remained stable after the lake's size limit was increased from 762 to 864 mm (30–34″). Similarly, Margenau and AveLallemant (2003) did not find the abundance of large muskellunge to have increased with implementation of a 1016-mm (40″) minimum length on seven northern Wisconsin lakes. One factor in particular that can prevent regulation changes from affecting muskellunge size structure is an increase in fishing pressure and harvest rate coincidental with the regulation change (Cornelius and Margenau 1999). Given that all other muskellunge fisheries in Virginia are managed with the statewide 762-mm (30″) minimum length limit, an increase in the New River muskellunge length limit may indeed lead to increased fishing pressure as anglers may be attracted to the fishery because of to the uniqueness of the regulation.

Management implications

Intraspecific or interspecific competition for food resources resulting in slow growth, physiological inability to reach large sizes, and high voluntary release of fish by anglers are a few possible reasons why low minimum length limits can be useful for muskellunge fisheries (Simonson and Hewett 1999). On the basis of our results, however, none of these factors seems applicable to the New River muskellunge fishery. As a result, an increase in the New River minimum length limit to approximately 965–1067 mm (38–42″) may prove beneficial for increasing the production of ‘‘trophy’’ muskellunge, which is the stated management goal for the fishery. Although the increase in abundance of ‘‘trophy’’ muskellunge would be even more substantial with a length limit change to 1143 mm (45″) or greater, such a drastic change in the size limit seems unnecessary given New River angler opinions about ‘‘trophy’’ lengths of muskellunge. Our observation that a small minority of even the most dedicated muskellunge anglers rarely identified ‘‘trophy’’ muskellunge to be greater than 1270 mm (50″) means that few anglers may be supportive of length limits of that order of magnitude. Even winning support for a 965-mm to 1067-mm (38–42″) size limit might prove difficult given the small number of anglers who believed it was necessary to change the minimum length limit. Public support for a length limit change could possibly be increased by publicizing the rapid growth rates of muskellunge and by explaining how higher limits should result in a greater abundance of ‘‘trophy’’ fish.

Negative consequences that could result from a change in the length limit include reduced growth rates of muskellunge as a result of competition for food resources, increased predatory impacts on other New River fish species, and increased fishing pressure on the muskellunge stock (Cornelius and Margenau 1999). To ensure that muskellunge growth is not affected, growth rates of fish, particularly during early life stages, should be monitored subsequent to harvest regulation changes.

If it becomes evident that muskellunge growth rates have been reduced, it may be necessary to return the harvest regulation to the original limits or to reduce stocking densities. In terms of increased predatory effects on other fish species, muskellunge consumption per initial abundance of 100 age-1 muskellunge has been estimated to be 0.63 kg ha^{-1} $year^{-1}$ (0.56 lb $acre^{-1}$ $year^{-1}$) for catostomids, 0.31 kg ha^{-1} $year^{-1}$ (0.28 lb $acre^{-1}$ $year^{-1}$) for cyprinids, 0.18 kg ha^{-1} $year^{-1}$ (0.16 lb $acre^{-1}$ $year^{-1}$) for smallmouth bass, *Micropterus dolomieu*, and 0.43 kg ha^{-1} $year^{-1}$ (0.38 lb $acre^{-1}$ $year^{-1}$) for Lepomis spp. (Brenden et al. 2005). With enactment of a 1067-mm (42″) minimum length limit, consumption of catostomids, cyprinids, smallmouth bass, and Lepomis spp. would increase by 51, 8, 44, and 18%, respectively (T. Brenden, unpublished data). Monitoring of muskellunge growth and the concurrent abundance assessment of these food items should be conducted to ensure that elevated consumption rates do not affect fish stocks. Future creel or angler surveys also should be used to determine whether a concurrent increase in muskellunge fishing pressure occurs as a result of any regulation change.

This research was initiated to determine whether a southern-latitude muskellunge fishery might benefit from more restrictive harvest regulations. Although the results from the study do indicate that the New River would benefit from a higher length limit, it remains to be seen whether these results are typical among other southern latitude muskellunge fisheries. Growth of muskellunge in other populations may not be nearly as fast, nor may fish be able to achieve lengths as large as those from the New River population. The one factor that might remain similar among fisheries is a greater tendency of anglers to harvest muskellunge, given the lack of specialized muskellunge angling clubs in southern regions. Before length limits are changed in other fisheries, biologists should ensure that conditions within the fishery warrant the change. If biologists lack suitable data or resources for assessing these conditions, collaboration with experienced muskellunge anglers may provide a convenient method for collecting the information required.

Acknowledgments Funding for this research was provided by the Acorn Alcinda Foundation and the Virginia Department of Game and Inland Fisheries through Federal Aid in Sportfish Restoration Project F-122-R. The authors thank G. Gardener and A. Scott for their angling collections, S. Malvestuto for his assistance with the creel survey design, S. Arthur, J. Hightower, and J. Hines for their assistance with the telemetry mortality model, and the numerous clerks who interviewed anglers for the creel survey. Reviews by V. Dicenzo, D. Isermann, D. Orth, E. Smith, D. Stauffer, J. Younk, and several anonymous reviewers aided the preparation of this manuscript.

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