Predatory Impact of Muskellunge on New River, Virginia, Smallmouth Bass

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Abstract: Stomachs of 171 muskellunge *(Esox masquinongy)* ranging in length from 358 to 1270 mm were examined to evaluate fish diet and to estimate through bioenergetics modeling the predatory impact of muskellunge on smallmouth bass *(Micropterus dolomieu)* in the New River, Virginia. Fifty-five percent of muskellunge stomachs examined contained food. Ninety percent of muskellunge stomachs that contained food contained fewer than six items. Muskellunge exhibited an ontogenetic shift in diet at approximately 800 to 900 mm, changing from a diet consisting primarily of cyprinids to one consisting primarily of catostomids. Smallmouth bass comprised a relatively minor (4% by wet weight) component of muskellunge diet overall, although consumption of smallmouth bass did increase with muskellunge length. At an initial abundance of 100 age-1 fish, muskellunge were estimated to consume 0.18 $kg \cdot ha^{-1} \cdot yr^{-1}$ of smallmouth bass. In contrast, muskellunge would consume 0.63, 0.31, and 0.43 $kg \cdot ha^{-1} \cdot yr^{-1}$ of catostomids, cyprinids, and lepomids. Given that muskellunge currently are stocked in the New River as fingerlings (≈100 mm), post-stocking survival of muskellunge is probably low (<10%), thus muskellunge predation likely has little overall impact on New River smallmouth bass stocks. In systems where muskellunge stocking is controversial because of possible predatory impacts on other aquatic species, formulating stocking rates based on acceptable losses to muskellunge predation may help to prevent or resolve stakeholder conflicts.

Key words: muskellunge, diet, New River, bioenergetics, predation.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 58:12–22

Although typically regarded as a northern-latitude species, muskellunge *(Esox masquinongy)* have been stocked in waterbodies in many southern U.S. states (e.g., Alabama, Georgia, North Carolina, Tennessee, Texas, Virginia, West Virginia; USGS 2003). While some stakeholders support muskellunge stocking because of the sport-

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fishing opportunities it provides, other stakeholders view muskellunge stocking less favorably. *Esox* spp. are piscivorous throughout much of their lives and often are regarded as highly voracious predators capable of negatively impacting other members of aquatic communities (Crossman 1986, Moyle 2002). Eradication programs have even been implemented to protect native aquatic species in some areas where esocids have been introduced (Moyle 2002). As a result of these disparate views, conflicts may arise between stakeholders whenever muskellunge stocking is conducted or considered, with some stakeholders promoting and other stakeholders discouraging stocking.

The New River, Virginia, stocking of muskellunge by the Virginia Department of Game and Inland Fisheries (VDGIF) has upset some anglers who believe that smallmouth bass *(Micropterus dolomieu)* fishing quality has declined since the muskellunge stocking began in 1963. Many of these anglers attribute the perceived decline to muskellunge exclusively targeting smallmouth bass when foraging (J. Williams, VDGIF, pers. commun.). Because very little is known about diet of muskellunge in southern warmwater rivers, it is difficult to address angler concerns regarding predation on smallmouth bass. Muskellunge are known to consume limited amounts of smallmouth bass in northern latitude systems, however (Deutsch 1986, Bozek et al. 1999). Stocked muskellunge populations also may have a greater potential to negatively impact smallmouth bass stocks due to the possible establishment of unnaturally high densities. The controversy concerning muskellunge stocking also is complicated by the New River being Virginia's top trophy-producing muskellunge fishery (J. Williams, VDGIF, pers. commun.), thus discontinuing stocking may not be viable without reliable evidence indicating that muskellunge are negatively impacting smallmouth bass stocks. The purpose of this research was to characterize muskellunge diet in the New River and to estimate through bioenergetics modeling the potential predatory impact on smallmouth bass stocks.

Methods

The New River (Fig. 1) originates in northwest North Carolina and flows northward through Virginia into West Virginia, where it merges with the Gauley River to form the Kanawha River. Although it lies within the Ohio River drainage, muskellunge are believed to have been introduced to the New River (Jenkins and Burkhead 1993). Muskellunge were first stocked in 1963 and approximately 5000 fingerling [≈100 mm (this and all lengths reported herein are total lengths)] muskellunge are stocked annually by VDGIF. Two sections of the New River currently are stocked. The upper section (Virginia/North Carolina stateline to Fries Dam) receives 20% of the annual allotment of stocked muskellunge, while the lower section (Claytor Dam to Virginia/West Virginia stateline) receives the remaining allotment (Fig. 1). A middle section (Fries Dam to Claytor Lake) is not stocked because of possible detrimental impacts on the walleye *(Sander vitreus)* fishery (J. Williams, VDGIF, pers. commun.). Combined surface area of the upper and lower sections is approximately 2750 ha.

For this study, muskellunge were collected by boat electrofishing during the

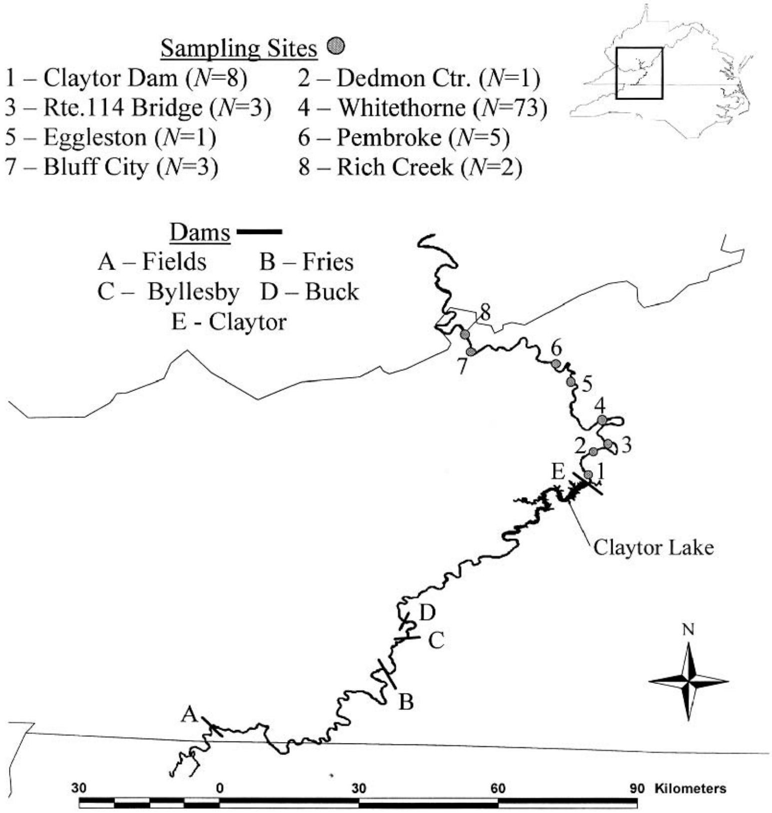

Figure 1. Map of the New River in southwest Virginia showing dam and sampling site locations. Sample sizes are the numbers of muskellunge collected at the sampling site that had contents in their stomachs.

daylight hours from late fall to early summer in 2000, 2001, 2002, and 2003 at eight sites located in the lower section of the river (Fig. 1). Sampling was not conducted in the upper section of the river as shallow water at boat access sites limited sampling effectiveness. Total amount of sampling effort at the eight sites was proportional to the amount of shoreline area that could be sampled at the sites. For example, most sampling (≈70% of total shocking effort) was done at Whitethorne, as this site comprised nearly 60% of the total shoreline area that could be sampled. In addition to the fish collected through electrofishing, two muskellunge stomachs (with contents) were provided by a southwest Virginia taxidermist, the data from which were combined with the data obtained through electrofishing.

Stomach contents of adult muskellunge sampled by electrofishing were collected by gastric lavage, while stomach contents from muskellunge < 500 mm were obtained by dissection. Stomach contents were identified to the lowest taxonomic level possible and weighed (wet weight) to the nearest 0.01 g. Diets of individual fish were characterized by the percentage of weight that each resource category comprised out of all the items consumed.

Similarity in muskellunge diets by length (100-mm length classes), season [late fall and winter combined (before April 1) versus spring and early summer combined (on or after April 1)], and sampling site (Whitethorne versus other sampling sites) were tested independently using a multi-response permutation procedure (MRPP; Mielke and Berry 2001), which is a distribution-free method for testing differences in multivariate data between groups. A MRPP compares observed intra-group average distances in responses to distances calculated after permutation of the observed data (Cade and Richards 2001). Pairwise MRPP comparisons in muskellunge diets between the 100-mm length classes were conducted as a post-hoc testing method in the event of an overall significant difference between the length groups. All permutation procedures were conducted in BLOSSOM (USGS 2004) and *P*-values for the tests were obtained using a Pearson Type III approximation to the permutation distribution (Cade and Richards 2001). The overall tests for diet differences between the length classes, seasons, and sampling sites were evaluated for significance with an $\alpha = 0.05$. The α for the pairwise length class tests equaled 0.015, and was determined using the step-up false discovery rate method (García 2004).

The total amount of prey biomass consumed by age-1 and older muskellunge was estimated using Fish Bioenergetics 3.0 (Hanson et al. 1997). Parameter estimates for respiration, consumption, egestion, and excretion were borrowed from Bevelhimer at al. (1985). Water temperature input was based on a nonparametric regression model that predicted New River water temperature as a function of day of year (Fig. 2). Estimates of New River muskellunge growth rates, length-weight relationships, and mortality rates (Table 1) were used to predict abundance and biomass changes for each age class. Consumption was modeled assuming an initial age-1 muskellunge abundance of 100 fish (50 M:50 F).

Although 16 prey types [bluegill *(Lepomis macrochirus),* central stoneroller *(Campostoma anomalum)*, gizzard shad *(Dorosoma cepedianum),* northern hogsucker *(Hypentelium nigricans),* redbreast sunfish *(Lepomis auritus),* rock bass *(Ambloplites rupestris),* silver shiner *(Notropis photogenis),* smallmouth bass, spottail shiner *(Notropis hudsonius),* telescope shiner *(Notropis telescopus),* white shiner *(Luxilus albeolus),* unknown catostomid species, unknown cyprinid species, unknown fish species, unknown *Lepomis* species, unknown *Luxilus* species, and unknown *Notropis* species] were identified from muskellunge stomachs, we consolidated diet items into seven categories (catostomids, cyprinids, gizzard shad, lepomids, rock bass, smallmouth bass, and partially digested unidentifiable fish). Rather than including unidentifiable items in the bioenergetics model, the amount that muskellunge diets consisted of this category was proportionately allocated to the remaining six categories. Published energy density estimates were available for three of the six categories [lepomids (4.186 $kJ \cdot g^{-1}$: Kitchell et al. 1974), smallmouth bass (4.186 $kJ \cdot g^{-1}$: Shuter and Post 1990), and gizzard shad (5.85 $kJ \cdot g^{-1}$: Adams et al. 1982)]. For

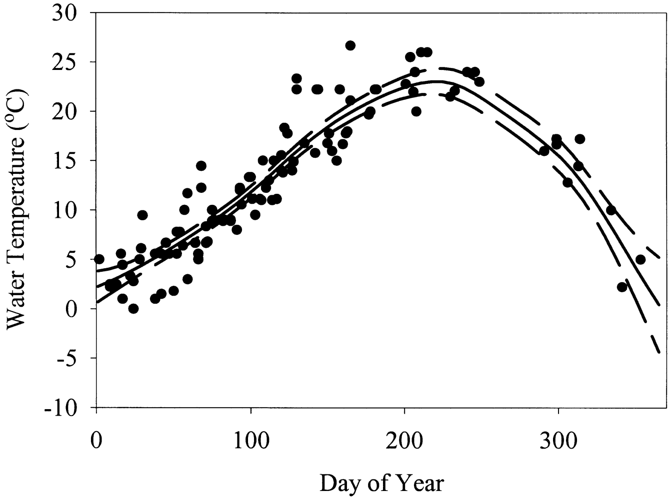

Figure 2. Water temperature (closed circles) in the New River recorded periodically from 2000 to 2004 in relation to day of year. Local linear regression was used to predict water temperature (solid line) along with 95% confidence intervals (dashed lines) as a function of day of year. Predicted daily water temperature from the regression model was used as the temperature input for the bioenergetics model.

the other three categories, we collected several specimens from the New River and we used bomb calorimetry (Parr 1281 Bomb Calorimeter; Parr Instrument Company, Moline, Illinois) to estimate energy content. Average energy density estimates for these diet categories were 5.313 (catostomids), 4.853 (cyprinids), and 4.167 (rock bass) $kJ \cdot g^{-1}$.

Results

Stomachs of 171 muskellunge ranging in length from 358 to 1270 mm that were collected by electrofishing were examined for contents. Fifty-six percent (*N* = 96) of fish stomachs (excluding those contributed by the taxidermist) contained a measurable amount of food. Ninety percent of the stomachs that contained food (including the fish stomachs contributed by the taxidermist) contained fewer than 6 items, although as many as 45 items were found in one stomach. The majority (73%) of muskellunge collected with contents in their stomachs were collected from Whitethorne (Fig. 1), which at least partially reflected the greater amount of sampling conducted at this site.

Because of limited sample sizes, muskellunge > 1000 mm were combined into a single length class (1000+ mm). An overall significant difference in muskellunge

Table 1. Parameter estimates of von Bertalanffy growth models (L_∞ = asymptotic length; κ = Brody growth coefficient; t_0 = age at which length is 0), $\log_{10}$ transformed length- weight relationships (β = slope; $\log_{10} \alpha$ = intercept), and conditional mortality rates used to predict changes in abundance of New River muskellunge (Murphy et al. 2003).

	Female	Male
Growth		
L_∞ (mm)	1300	1100
κ	–0.3169	–0.4263
t_0	–0.2743	–0.1536
Length-Weight		
$\log_{10} \alpha$	–6.496	–5.991
β	3.459	3.280
Mortality		
Ages 1 to 3	0.125	0.125
Ages 3+	0.275	0.275

Table 2. Summary of pairwise MRPP comparisons in diets of muskellunge for fish grouped into 100-mm length classes. The top entry is the absolute value of the MRPP test statistic and the bottom value (in parentheses) is the test's *P*-value.

	Length (mm)						
Length (mm)	400	500	600	700	800	900	1000+
300	0.196 (0.480)	0.707 (0.738)	0.259 (0.517)	6.952[a] (0.000)	1.255 (0.111)	2.780[a] (0.014)	5.793[a] (0.000)
400		0.475 (0.592)	1.054 (0.914)	6.993[a] (0.000)	1.494 (0.083)	3.193[a] (0.011)	9.467[a] (0.000)
500			0.526 (0.634)	1.439 (0.088)	0.358 (0.518)	0.028 (0.331)	1.195 (0.119)
600				4.628[a] (0.001)	0.089 (0.397)	0.770 (0.201)	4.314[a] (0.001)
700					3.224[a] (0.010)	4.284[a] (0.001)	4.870[a] (0.002)
800						0.322 (0.319)	2.770 (0.015)
900							0.109 (0.367)

a. Pairwise comparison considered significantly different ($P < 0.015$).

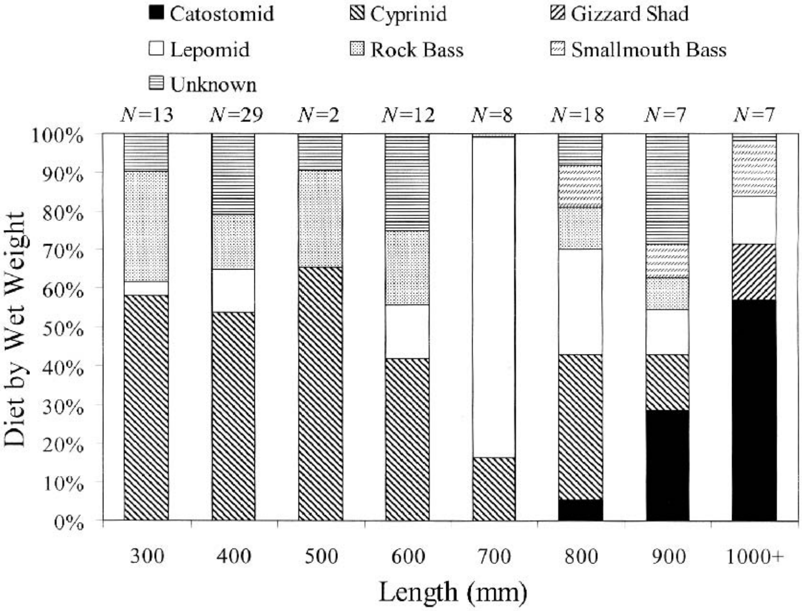

Figure 3. Percent by wet weight that each food category comprised of muskellunge diet by 100-mm length classes.

diets among the 100-mm length classes was found (MRPP: test statistic = 7.48, $P < 0.0001$). Pairwise MRPP comparisons indicated that muskellunge underwent an ontogenetic diet shift at around 800 to 900 mm (Table 2). Diet of muskellunge smaller than 800 mm consisted primarily of cyprinids and, to a lesser extent, rock bass, while muskellunge larger than 900 mm primarily consumed catostomids (Fig. 3). The change in diet was not a distinct shift, as 800- to 899-mm muskellunge had a diet that was similar to that of both smaller and larger length classes (Table 2). Although the heavy reliance of 700- to 799-mm muskellunge on lepomids (Fig. 3) resulted in this length class of fish having a diet that was significantly different from nearly every other length group (Table 2), this may have been an anomalous result due to small sample sizes rather than being indicative of a diet shift at this length. No seasonal difference in diets was detected (MRPP: test statistic = 1.39, $P = 0.09$). Similarly, no difference in diets between the sampling sites was detected (MRPP: test statistic = 0.178, $P = 0.355$).

Overall, smallmouth bass comprised a relatively minor component (4% by weight) of muskellunge diet. No smallmouth bass were identified from prey items consumed by muskellunge smaller than 800 mm (Fig. 3). However, 800-mm and larger muskellunge did consume some smallmouth bass. Smallmouth bass comprised 11% of muskellunge diet by weight for 800-mm and larger fish, which was less than the proportion of muskellunge diet that consisted of either catostomids (22%), cyprinids (24%) or lepomids (20%). The highest percentage that smallmouth bass comprised of muskellunge diet was for ≥ 1000-mm fish (14%; Fig. 3).

Total consumption per initial abundance of 100 age-1 muskellunge was estimated at 1.77 $kg \cdot ha^{-1} \cdot yr^{-1}$. Consumption of smallmouth bass was estimated at 0.18 $kg \cdot ha^{-1} \cdot yr^{-1}$. In comparison, estimated consumption was 0.63 $kg \cdot ha^{-1} \cdot yr^{-1}$ for catostomids, 0.31 $kg \cdot ha^{-1} \cdot yr^{-1}$ for cyprinids, 0.11 $kg \cdot ha^{-1} \cdot yr^{-1}$ for gizzard shad, 0.43 $kg \cdot ha^{-1} \cdot yr^{-1}$ for lepomids, and 0.11 $kg \cdot ha^{-1} \cdot yr^{-1}$ for rock bass. Although larger muskellunge consumed the highest proportion of smallmouth bass per individual, consumption of smallmouth bass in terms of biomass was the highest for age-3 to age-7 muskellunge due to the greater abundance of fish at these age classes. Age-3 to age-7 muskellunge consumed 73% of the total biomass of smallmouth bass.

Discussion

Diet of muskellunge in the New River was similar to that in northern-latitude lakes and rivers (Deutsch 1986, Bozek et al. 1999). In most systems where diet has been studied, cyprinids and catostomids have been two of the primary food resources consumed by different ontogenetic stages of muskellunge. Muskellunge growth rates have been positively correlated with abundance of both of these resources (Harrison and Hadley 1979, Hanson 1986), thus cyprinid and catostomid abundance may provide a useful criterion for evaluating prey availability and the trophy-producing potential of a system. Muskellunge also have been found to heavily consume yellow perch *(Perca flavescens)* and gizzard shad (Wahl and Stein 1988, Wahl and Stein 1993, Bozek et al. 1999), species that also may be useful indicators for evaluating the suitability of muskellunge stocking. As a side note, although common carp *(Cyprinus carpio)* were routinely observed in the same areas that muskellunge were captured, in no instances were muskellunge found to consume this species. Muskellunge also did not prey significantly upon common carp in Wisconsin (Bozek et al. 1999). Therefore, muskellunge may not provide an efficient control for common carp, particularly in those systems where there is an abundance of other food types (e.g., gizzard shad, catostomids).

Because we lacked data regarding post-stocking survival of muskellunge, we estimated smallmouth bass loss to muskellunge consumption based on an age-1 muskellunge abundance of 100 individuals and assumed a steady-state population. We thought that estimating smallmouth bass consumption in this manner would be of greater utility to fishery biologists than simply assuming a particular post-stocking survival rate, since survival of muskellunge is known to be heavily influenced by factors such as fish length and predator density (Wahl 1999). By estimating prey consumption for only age-1 and older fish, overall loss of smallmouth bass could be estimated under different stocking scenarios. Because muskellunge currently are stocked in the New River as fingerlings (≈100 mm), post-stocking survival is almost assuredly less than 30%, and is probably less than 10% (Hanson et al. 1986, Serns and Andrews 1986, Szendrey and Wahl 1995, Wahl 1999). At a 30% survival rate and an annual stocking of 5000 muskellunge, total estimated consumption of smallmouth bass in the New River would equal 2.7 $kg \cdot ha^{-1} \cdot yr^{-1}$. At a 10% survival rate, total estimated consumption of smallmouth bass would equal 0.9 $kg \cdot ha^{-1} \cdot yr^{-1}$. Smallmouth bass production, which represents the amount of a population that can be removed without affecting long term population size or biomass (Ney 1990), has been estimated to be as high as 32.1 $kg \cdot ha^{-1} \cdot yr^{-1}$ for certain areas of the New River (Roell and Orth 1993). Thus, it seems doubtful that New River smallmouth bass stocks are seriously impacted by stocked muskellunge with the current stocking protocol, although it might be possible for localized areas with low smallmouth bass production and high muskellunge abundance to be impacted. If VDGIF's stocking program was ever modified so that post-stocking survival of muskellunge increased (e.g., muskellunge were stocked as fall yearlings rather than summer fingerlings), then it might be prudent to reduce muskellunge stocking rates in order to prevent excessive predation. At a 90% survival rate and a stocking rate of 5000 fish, for example, muskellunge would consume nearly 8 $kg \cdot ha^{-1} \cdot yr^{-1}$ of smallmouth bass, which might represent an excessive loss.

The perception of anglers that muskellunge feed heavily on smallmouth bass is undoubtedly caused to some extent by the irritating attempts of muskellunge to "steal" fish off the hooks of unsuspecting anglers. Muskellunge are considered opportunistic foragers (Scott and Crossman 1973) and the movement from a hooked fish may stimulate a feeding response and cause muskellunge to actively pursue hooked fish. Smallmouth bass anglers who happen to witness muskellunge pursuing hooked fish may attribute the attempts to muskellunge normally consuming smallmouth bass, thus resulting in a conflict between smallmouth bass and muskellunge anglers. While angler opinions may be difficult to change, published diet studies, such as this one, should help to refute false beliefs.

Stocking of muskellunge is a relatively common approach used to manage muskellunge populations (Crossman 1986). We encourage those formulating stocking protocols to consider potential predatory impacts on other aquatic species. That is, rather than basing stocking rates on habitat availability, stocking rates could be based on acceptable levels of predation. While our study primarily focused on muskellunge impacts to smallmouth bass, predatory impacts on other aquatic species (including endangered or threatened species) similarly could be evaluated. Such an approach would result in management at a community level, and may help to prevent or resolve stakeholder conflicts.

Acknowledgments

Funding for this project was provided by the Virginia Department of Game and Inland Fisheries (VDGIF) through Federal Aid in Sportfish Restoration Project F-122-R and through a Burd McGinness Fellowship awarded by the Virginia Tech Department of Fisheries and Wildlife Sciences. The authors thank VDGIF district fisheries biologist J. Williams for sampling assistance and D. Parks for contributing fish stomachs. T. Copeland, M. Cyterski, T. Newcomb, and two anonymous reviewers improved this manuscript through comments provided on earlier drafts.

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