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Tiger Muskellunge Growth, Condition, Diet, and Effect on Target Prey Species in Two Eastern Washington Lakes: Progress Report 2001 – 2006

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Progress Report 2001 – 2006

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Abstract

Tiger muskellunge *Esox masquinongy x E. lucius* growth, condition, and diet, as well as the effect of stocking on forage populations, was studied in two eastern Washington lakes from 2001 to 2006. Curlew Lake (373 ha), located in Ferry County, was stocked with tiger muskellunge in 1998 to reduce an overabundant Northern Pikeminnow *Ptychocheilus oregonensis* population and to create a unique trophy fishery. Historically, Curlew Lake had provided good fishing opportunity for stocked Rainbow Trout *Oncorhynchus mykiss*, as well as naturally reproducing Largemouth Bass *Micropterus salmoides* and Smallmouth Bass *M. dolomieu*. The quality of trout fishing, however, had declined throughout the 1990's, commensurate with anecdotal observations of increased numbers of Northern Pikeminnow in the sport catch. Silver Lake (197 ha), located in Spokane County, was stocked with tiger muskellunge in 2002 with similar management goals of reducing an overabundant Tench *Tinca tinca* population and to create a unique trophy fishery. Historically, Silver Lake had been managed as a put-grow-and-take Rainbow and Brown Trout *Salmo trutta* fishery, which relied on periodic rotenone rehabilitation to keep competing species in check. Prior to the introduction of tiger muskellunge, rotenone treatment had been abandoned as a management option for the lake even though the fish community had become dominated by naturally reproducing Tench and a variety of centrarchid species. To monitor changes in species relative abundance, each lake was sampled annually in the spring and fall with standardized boat electrofishing, gill netting and fyke netting surveys. Additionally, each lake was sampled by boat electrofishing monthly, from spring through fall, to collect tiger muskellunge diet samples gastric lavage. Tiger muskellunge growth and condition were greater in Curlew Lake than in Silver Lake. Rainbow Trout and Northern Pikeminnow were the most important prey species in Curlew Lake, while Largemouth Bass were a distant third. In Silver Lake, compressiform centrarchids were the most important prey, followed closely by Rainbow Trout. Largemouth Bass and Tench were only somewhat important. Diet varied seasonally, with Rainbow Trout being the most important prey during spring months in both lakes. Average consumed prey length was larger in Curlew Lake, where preferred-type prey (soft-rayed and fusiform) predominated. Average prey length in Silver Lake (dominated by compressiform, spiny-rayed prey) was smaller, which may account for slower tiger muskellunge growth in that community. The relative abundance of Northern Pikeminnow in Curlew Lake

significantly declined over the duration of the study. The high proportion of Northern Pikeminnow observed in the tiger muskellunge diet analysis seems to indicate that the reduction can be attributed to the added presence of tiger muskellunge to the community. Considering this, the biological control goal of this tiger muskellunge introduction has been successful. Continued biannual monitoring of the fish community to assess Northern Pikeminnow abundance should provide the necessary data to refine future Tiger Muskellunge stocking rates in Curlew Lake. At Silver Lake, the impact of tiger muskellunge predation on Tench is less clear. This may be attributed to gape-limitation of the majority of tiger muskellunge inhabiting the lake to date, which had not yet grown to a size capable of consuming the average sized Tench (300-400 mm TL) in the lake. To date, Tench appear to be of minimal importance in the diet of tiger muskellunge, and their relative abundance within the fish community only appeared to decline in the last survey conducted. Continued monitoring of the Silver Lake fish community, as well as tiger muskellunge diet sampling, would likely provide a better understanding of the results of this particular introduction by allowing additional time for the tiger muskellunge population to more fully develop, both in abundance and individual fish growth.

Acknowledgements

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Introduction

Tiger muskellunge (F_1 hybrids of female Muskellunge *Esox masquinongy* and male Northern Pike *E. lucius*) have been widely stocked in waters throughout the United States to provide increased sportfishing opportunity (Gillen et al. 1981; Tomcko et al. 1984; Storck and Newman 1992), as well as in attempts to improve size structure of forage populations through predation (Weithman and Anderson 1977; Goddard and Redmond 1978; Storck and Newman 1992). Additionally, tiger muskellunge are functionally sterile (Black and Williamson 1946), thus allowing fisheries managers to utilize their appeal to anglers and role as an apex predator without the concerns of uncontrolled expansion through natural reproduction. Tiger muskellunge were first introduced into Washington State in 1988 for similar reasons (Tipping 2001). Since that time, the Washington Department of Fish and Wildlife (WDFW) has studied the diet of tiger muskellunge, as well as the response of fish communities into which this apex predator has been stocked. This report presents results of data collected from 1998 through 2006 in Curlew Lake (Ferry County) and Silver Lake (Spokane County) in eastern Washington.

The rapid growth of tiger muskellunge during the first year of life is well-documented (Weithman and Anderson 1977; Wahl and Stein 1991). However, little growth information is available for tiger muskellunge beyond the first year of life, and the available information pertains to growth of tiger muskellunge in centarchid or Gizzard Shad *Dorosoma cepedianum*-dominated reservoirs of the Midwestern region of the United States. Storck and Newman (1992) reported relatively slow growth for tiger muskellunge in an Illinois centrarchid-dominated impoundment when compared to growth observed by Goddard and Redmond (1978) in a Missouri reservoir where the primary prey-base was Gizzard Shad. No growth information has been available for tiger muskellunge in waters west of the Continental Divide, where fish assemblages (and consequently, prey bases), as well as productivity are often different than those of waters in the Midwest.

Likewise, little diet information for adult tiger muskellunge is available, especially west of the Continental Divide. Bozek et al. (1999) conducted a detailed study of Muskellunge *Esox masquinongy* diet in Wisconsin, and Diana (1979) examined diets of Northern Pike *Esox lucius* in Alberta, Canada. Much, however, has been published about prey preference of tiger muskellunge in laboratory and pond experiments (Gillen et al. 1981; Tomcko et al. 1984; Engstrom-Heg et al. 1986; Wahl and Stein 1988). It is clear from these experiments that tiger muskellunge, similar to other esocids, tend to prefer prey fish that are soft-rayed, fusiform, and about one third of their own length. However, a comprehensive study of adult tiger muskellunge diet in the wild is lacking. Wahl and Stein (1993) examined diets of Northern Pike, Muskellunge, and tiger muskellunge through age-3 in an Ohio reservoir, but the sample size for tiger muskellunge beyond age-1 was small. More diet information for adult tiger muskellunge is required for effective management of this predator and its prey species.

Information about the effect of tiger muskellunge on forage species populations is also noticeably sparse in the literature. Storck and Newman (1992) found that tiger muskellunge had no effect on the size structure or density of a Bluegill *Lepomis macrochirus* population in an Illinois reservoir. However, Siler and Beyerle (1986) reported severe declines in Black Crappie *Pomoxis nigromaculatus* and White Sucker *Catostomus commersoni* concurrent with an abnormally high population density (0.34 fish per hectare) of large (≥ 762 mm) Muskellunge in Iron Lake, Michigan. Therefore, it seems likely that if tiger muskellunge were stocked at a sufficient density, they could shape populations of prey fish, and this seems particularly likely for soft-rayed, fusiform prey.

Today, there are typically three management goals that biologists hope to achieve through stocking tiger muskellunge in Washington: (1) to increase sportfishing opportunity, (2) utilization of a forage base unavailable to smaller predators, and (3) reduction of undesirable fishes (“target forage species”). Target forage species are defined as potential prey fish species that are too numerous or too large to be consumed by other species of predatory fish and undesirable to anglers. Since 1988, tiger muskellunge have been stocked into 12 Washington waters, and in each of these, a target forage species was identified before stocking. The objectives of this study were to: (1) determine growth and condition of tiger muskellunge in two waters with differing fish assemblages, (2) characterize diet of tiger muskellunge in these two waters, and (3) determine if any changes in the fish community or prey species population could be attributed to the presence of tiger muskellunge.

Study Area

Curlew Lake is located in Ferry County, 7.7 km northeast of Republic, Washington. Its surface area is 373 ha, with a maximum depth of 40 m and a mean depth of 13 m. The drainage area is 168 km^2, and its elevation is 711 m above mean sea level (msl) (Wolcott 1973). It is a natural lake, but a three-foot dam was built in 1926 to stabilize water levels. Tiger muskellunge were first introduced into Curlew Lake in 1998, with an initial plant of 400 fish, and it has received maintenance stockings (with a goal of 1.2 tiger muskellunge per surface hectare) each year since; however, stocking rates have varied due to availability of stock-sized tiger muskellunge in some years (Table 1). Washington Department of Fish and Wildlife (WDFW) also regularly stocks 180,000 to 200,000 Rainbow Trout *Oncorhynchus mykiss* into the lake on a yearly basis to support a put-grow-and-take fishery. Naturally reproducing species in the fish community include Chiselmouth *Acrocheilus alutaceus*, Peamouth *Mylocheilus caurinus*, Northern Pikeminnow *Ptychocheilus oregonensis*, Bridgelip Sucker *Catostomus columbianus*, Largescale Sucker *C. macrocheilus*, Largemouth Bass *Micropterus salmoides*, and Smallmouth Bass *M. dolomieu*.

Silver Lake is located in Spokane County, 1.8 km east of the town of Medical Lake, Washington. Its surface area is 197 ha with a maximum depth of 24 m and a mean depth of 9 m. Drainage area is 49 km^2, and its elevation is 714 ft above msl (Wolcott 1973). Tiger muskellunge were introduced into Silver Lake in 2002, with an initial plant of 1,000 fish. It has received maintenance stockings each year since (with a goal of 1.2 tiger muskellunge per surface hectare). However, similar to Curlew Lake, stocking rates have varied due to an inconsistent supply of tiger muskellunge in some years (Table 1). WDFW regularly stocks Rainbow Trout and Brown Trout *Salmo trutta* into the lake to support seasonal fisheries. The remainder of the fish community of Silver Lake is composed of naturally reproducing Tench *Tinca tinca*, Goldfish *Carassius auratus*, Brown Bullhead *Ameiurus nebulosus*, Black Crappie, Bluegill, Largemouth Bass, Smallmouth Bass, Pumpkinseed Sunfish *L. gibbosus*, and Yellow Perch *Perca flavescens*. Although not reproducing in the lake, Walleye *Sander vitreum* have been sampled occasionally and are thought to be the result of illegal stocking.

Table 1. Tiger muskellunge stocking rates by year for Curlew and Silver lakes.

Water Body	Year	Number of Tiger Muskie Stocked	Number / ha
Curlew Lake (373 ha)	1998	400	1.1
	1999	100	0.3
	2000	350	0.9
	2001	0	0.0
	2002	336	0.9
	2003	298	0.8
	2004	365	1.0
	2005	600	1.6
	2006	400	1.1
Silver Lake (197 ha)	2002	1000	5.1
	2003	231	1.2
	2004	200	1.0
	2005	400	2.0
	2006	300	1.5

Methods

Fish Sampling – Standardized sampling of the fish community was conducted on Curlew and Silver lakes twice per year (spring and fall) from 2001 – 2006 (Bonar et al. 2000). Fish were captured using boat electrofishing, gill nets, and fyke nets. Species composition and catch per unit effort (CPUE) were calculated according to Bonar et al. (2000). In each survey, 12 to 16 randomly selected shoreline sections (400 m) were electrofished using Smith-Root SR-16s electrofishing boats with 5.0 GPP pulsator units. The units were operated at a pulse rate of 60Hz DC, and at a current of 2-4 amps. Additionally, four to eight randomly selected sections were sampled with experimental gill nets (45.7 m long x 2.4 m deep) constructed of four sinking panels (two each at 7.6 m and 15.2 m long) of variable size (1.3, 1.9, 2.5, and 5.1 cm) stretched mesh. An equivalent number of randomly selected locations were sampled with fyke nets consisting of a main trap (4.7 m long and 1.2 m in diameter), a lead net (30.5 m long x 1.2 m deep), and two wings (7.6 m long x 1.2 m deep). Nets were set in the evening and collected the following morning. All fish collected during netting and electrofishing were identified to species (with the exception of Sculpin *Cottus* spp., which were identified only to genus), measured to the nearest millimeter (mm) total length (TL) and weighed to the nearest gram (g).

Additionally, boat electrofishing was conducted once per month from April through October on both lakes specifically targeting tiger muskellunge for diet evaluation. Captured tiger muskellunge were scanned for a coded wire tag (CWT), implanted prior to stocking, for age and growth determination. Diet items were removed by gastric lavage (Seaburg 1957, Light et al. 1983, Crossman and Hamilton 1978) and regurgitated onto a small-mesh (0.5 mm) sieve. Diet items were preserved in a 10% buffered formalin solution for subsequent analysis.

Growth and condition analysis – Mean length of known-age (ages 1-5, from coded wire tags) tiger muskellunge was used to evaluate growth in both study lakes. Condition of tiger muskellunge was evaluated with the relative weight (W_r) index, calculated as:

$$W_r = \frac{W}{W_s}(100)$$

Where, W is the weight (g) of a fish and W_s is the standard weight of a fish of the same length, calculated with the W_s equation (Murphy and Willis 1991). The equation describing W_s for tiger muskellunge was obtained from Anderson and Neumann (1996).

All statistical analysis was performed with MINITAB software (Ryan and Joiner 2000). A Kolmogorov-Smirnov test ($\alpha = 0.15$) was used to test for normality of Tiger muskellunge W_r values from spring (April – May), summer (June – August), and fall (September – October) in both lakes (Zar 1999). A Kruskal-Wallis test ($\alpha = 0.05$) was used to test for differences in W_r values within each lake, by season. If significant differences were detected, a Kruskal-Wallis non-parametric multiple comparisons test with unequal sample sizes (family $\alpha = 0.20$) was used to determine where the differences occurred (Zar 1999). A Kruskal-Wallis test ($\alpha = 0.05$) was also used to test for differences in W_r values within lakes by tiger muskellunge size class (100 mm length groups). If a significant difference was detected, a Kruskal-Wallis nonparametric multiple comparisons test with unequal sample sizes was used to determine where the differences occurred. A Mann-Whitney test ($\alpha = 0.05$) was then used to test for differences in W_r values between lakes during spring, summer, and fall (Zar 1999).

Diet analysis – In the laboratory, tiger muskellunge diet samples were rinsed with water to remove excess formalin and examined under a dissecting microscope. Stage of digestion was recorded (Table 2), and all prey items were identified to species (Pennak 1978; Hansel et al. 1988; Merritt and Cummins 1996; Wydoski and Whitney 2003), when possible. If diet items were not readily identifiable, key diagnostic bones were used, when present, to identify prey to the lowest possible taxonomic group (e.g., family, genus, or species). Measurements made on these bones were used to calculate original prey lengths (Hansel et al. 1988; Frost 2000; WDFW, unpublished data). Prey weights for each lake were calculated using simple linear regressions of length-weight data from samples collected, for each prey species.

Table 2. Categories of digestive state for tiger muskellunge prey items.

Digestive state of prey	Description
1	Whole fish – intact and identifiable
2	Whole fish – intact but skinless
3	Fish mostly intact and identifiable by shape
4	Skeleton intact with more than 50% of flesh remaining; all bones present
5	Vertebral column and most bones present; some flesh present
6	Vertebral column and some bones present; very little flesh present
7	Only vertebral column present; no flesh or other bones present
8	Any evidence of fish (single bones, scales, flesh, etc.)

Diet analysis included calculation of percent composition of prey by number, frequency of occurrence of each food type (the percentage of fish that ate that food type), percent composition of prey by weight, and relative importance (RI_a) of diet items (George and Hadley 1979). The RI_a is derived from the "absolute importance index" (AI_a) where:

$$AI_a = \text{\% comp by number} + \text{\% occurrence} + \text{\% comp by weight}$$

$$RI_a = 100AI_a / \sum_{a=1}^{n} AI_a$$

The relationship between number of prey items consumed and total length of tiger muskellunge was tested by simple linear regression ($\alpha = 0.05$; Zar 1999). A t-test ($\alpha = 0.05$) was used to test for a difference in the mean number of prey items consumed by tiger muskellunge in the two lakes (Zar 1999).

The ratio of prey TL to tiger muskellunge TL was calculated for fusiform and compressiform prey-fish. Mean ratios of compressiform and fusiform prey TL to tiger muskellunge TL for 100 mm size classes of tiger muskellunge were tested for normality using an Anderson-Darling test ($\alpha = 0.10$) (Ryan and Joiner 2000). Both ratios were normally distributed so a one-way analysis of variance (ANOVA; $\alpha = 0.05$) was used to test for differences in the ratio of prey length to tiger muskellunge length among size classes of tiger muskellunge (Zar 1999). The Tukey's test ($\alpha = 0.05$) was then used to determine which size classes differed (Zar 1999). Tiger muskellunge gape limitation for compressiform and fusiform prey was estimated using simple linear regression ($\alpha = 0.05$) by analyzing TL of the largest prey items (those with the largest ratio of prey TL to tiger muskellunge TL) vs. tiger muskellunge TL.

Stable isotope sampling – In September 2006, flesh samples from six tiger muskellunge (size range 923-1042 mm), nine Rainbow Trout (size range 226–318 mm), 11 Northern Pikeminnow (size range 198–443 mm), and 15 Largemouth Bass (size range 120–255 mm) were collected using sterile 5 mm biopsy punches from Curlew Lake. Flesh samples were stored in plastic vials, placed on ice, and then transported to the WDFW Region 1 Laboratory where they were frozen. Frozen samples were sent to Utah State University where they were dried for at least 48 hours at 65°C (Jardine et al. 2005), ground to a fine powder with a mortar and pestle, and packed in 8 x 5 mm tin capsules. Samples were then shipped to the UC Davis Stable Isotope Facility where the carbon (C) and nitrogen (N) isotope composition was measured. Results were reported in delta (δ) parts per thousand (‰) differences from isotopic standards:

$$\delta\,^{15}\mathrm{N} \text{ or } \delta\,^{13}\mathrm{C} = \{(R_{standard} / R_{sample}) / R_{standard}\}\ (1000)$$

Where R_{sample} was ^{13}C / ^{12}C or ^{15}N / ^{14}N of the organism and $R_{standard}$ was the international standard for C (Pee Dee belmnite; Craig 1957) or atmospheric nitrogen (air; Mariotti 1983). IsoSource, a computer program developed to perform calculations on stable isotope data (http://www.epa.gov/wed/pages/models.htm; Phillips and Gregg (2003), was used to determine mean percentage, based on C and N ratios, of adult tiger muskellunge diet composed of Rainbow Trout, Northern Pikeminnow, and Largemouth Bass.

Target prey population monitoring – Target forage species (Northern Pikeminnow in Curlew Lake and Tench in Silver Lake) CPUE, from standardized littoral samples collected in the fall, was monitored following tiger muskellunge introduction to detect fish community responses that might be attributable to tiger muskellunge predation. Fall electrofishing data from standardized survey techniques (Bonar et al. 2000) was used exclusively to detect CPUE changes due to its relatively low variability (when compared to data collected from gill nets and fyke nets) for the species of interest. An Anderson-Darling test ($\alpha = 0.10$) was used to determine if target forage CPUE data were normally distributed (Ryan and Joiner 2000). If data were not normally distributed a Kruskal-Wallis test ($\alpha = 0.05$) was used to test for differences in CPUE between years of sampling (Zar 1999). If a significant difference in CPUE between years of sampling was detected, a Kruskal-Wallis nonparametric multiple comparisons test with unequal sample sizes ($\alpha = 0.20$) was used to determine in which years CPUE differed (Zar 1999).

To assess changes in length frequencies of target prey populations, a one-way ANOVA ($\alpha = 0.05$) was used to test for differences in target prey lengths among years of sampling (Zar 1999). A Tukey's test ($\alpha = 0.05$) was then used to determine during which years differences were significant (Zar 1999).

Results

Growth and condition – Mean length at age for tiger muskellunge in Curlew Lake was generally greater than those in Silver Lake (Figure 1). Prior to stocking, tiger muskellunge are raised for one year at the WDFW Ringold-Meseburg hatchery, attaining an average TL of 301 mm. In Curlew Lake, tiger muskellunge reached an average of 428 mm by fall of age 1, 734 mm by fall of age 2, 833 mm by fall of age 3, 909 mm by fall of age 4, and 1032 mm by fall of age 5. Those in Silver Lake reached an average of 435 mm, 644 mm, 748 mm, 786 mm, and 918 mm by fall of ages 1-5, respectively. Low sample size accounts for broad confidence intervals associated with some estimates.

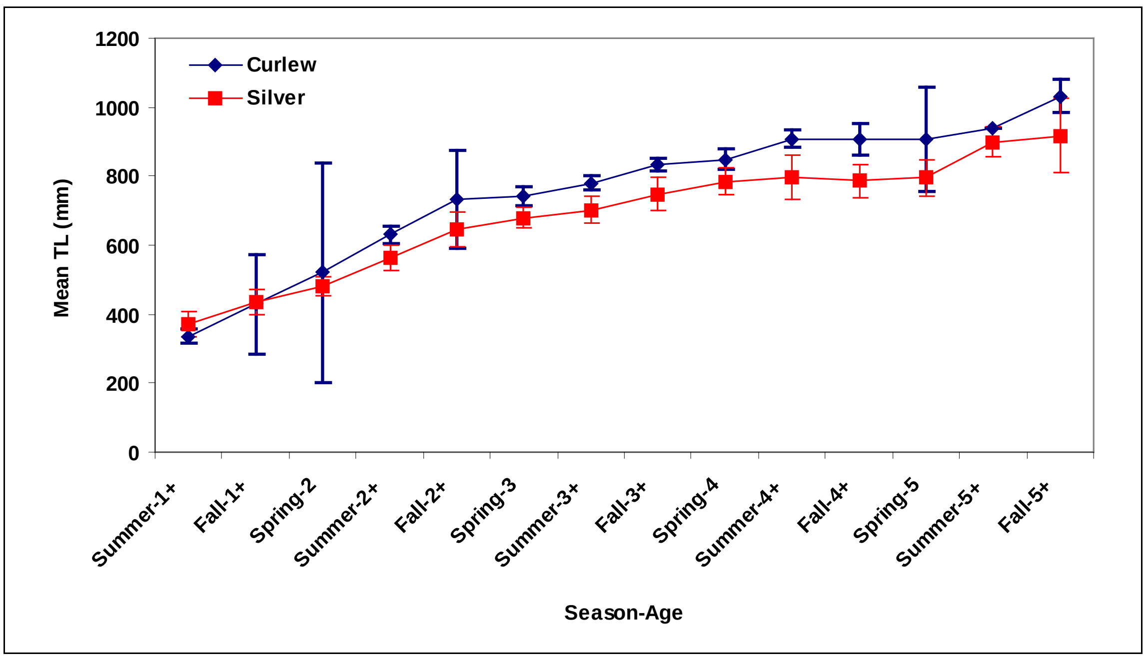

Figure 1. Mean tiger muskellunge length at age in Curlew and Silver lakes with 95% confidence intervals, captured between 2001 and 2006.

Tiger muskellunge in Curlew Lake exhibited greater condition than those in Silver Lake during spring, summer, and fall (Table 3). In Curlew Lake, there were no differences between W_r values among seasons (Kruskal-Wallis test, $H = 5.43$, $df = 2$, $p = 0.066$; adjusted for ties), but there were differences in W_r values among seasons in Silver Lake (Kruskal-Wallis test, $H = 35.23$, $df = 2$, $p < 0.0001$). Spring and summer W_r values were not significantly different.

However, fall W_r values were lower than those in spring (Kruskal-Wallis multiple comparisons test, Z = 5.19, $p < 0.0001$) and summer (Kruskal-Wallis multiple comparisons test, Z = 5.07, $p < 0.0001$).

Table 3. Results of Mann-Whitney Test for comparison of tiger muskellunge W_r from Curlew and Silver lakes, during three seasons, in 2001-2006.

	Median W_r					
	Curlew	**Silver**	**W**	**Point estimate**	**95% CI**	**Significance**
Spring	96.2	89.1	3564	8.63	4.873, 12.607	p < 0.0001
Summer	94.3	88.8	15783	6.60	3.168, 9.846	p < 0.0002
Fall	91.3	78.5	9023	14.14	10.887, 17.331	p < 0.0001

In Curlew Lake, there were no differences in condition by size class of tiger muskellunge (100 mm length classes) during spring (Kruskal-Wallis test, H = 8.44, df = 7, p = 0.295), but there were significant differences in W_r values by size class in summer (Kruskal-Wallis test, H = 55.79, df = 8, $p < 0.0001$, adjusted for ties) (Figure 2) and fall (Kruskal-Wallis test, H = 28.37, df = 8, $p < 0.0001$) (Figure 3). In general, tiger muskellunge condition increased with length of fish in both summer and fall. In summer, W_r values for tiger muskellunge 300 - 499 mm TL were lower than those of tiger muskellunge ≥ 600 mm TL (Figure 2), and in fall, W_r values for tiger muskellunge 300 - 499 mm TL were lower than those for tiger muskellunge ≥ 700 mm TL, with the exception of those fish in the 1000 mm TL size class.

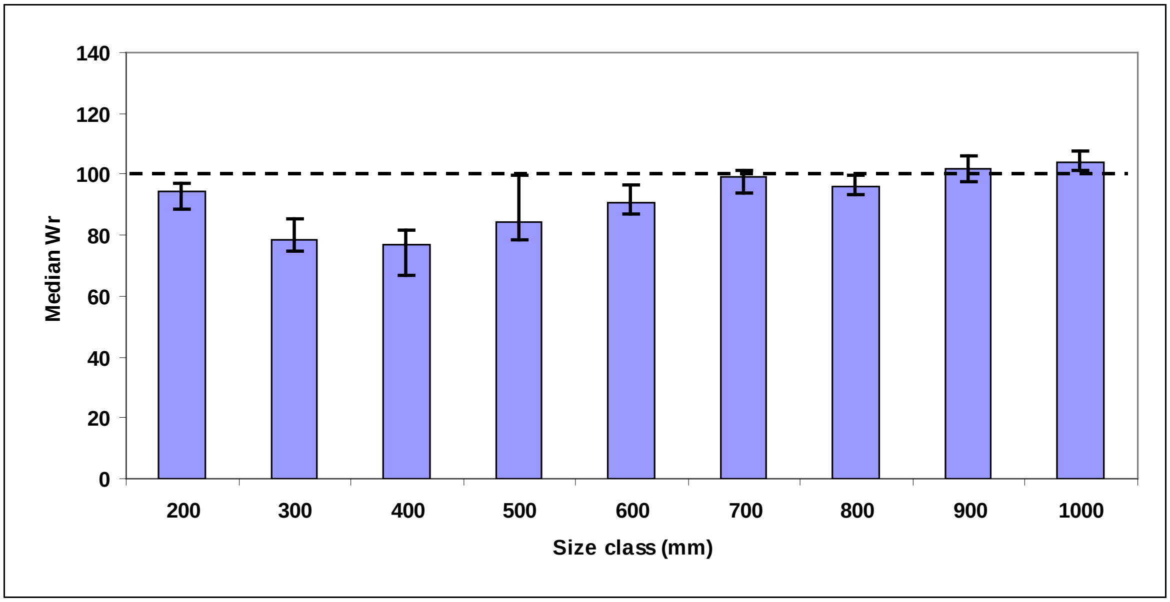

Figure 2. Summer median W_r values of tiger muskellunge by size class (100 mm TL groups) in Curlew Lake (Ferry County) for years 2001 - 2006. Family α = 0.20.

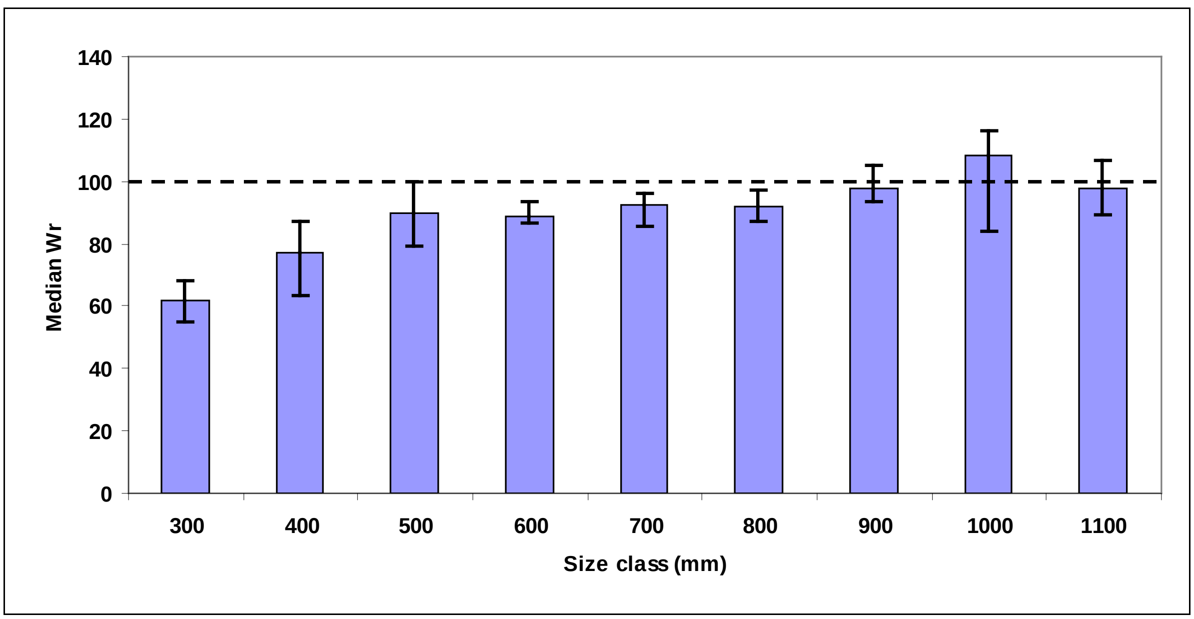

Figure 3. Fall median W_r values of tiger muskellunge by size class (100 mm TL groups) in Curlew Lake (Ferry County) for years 2001 - 2006. Family α = 0.20.

In Silver Lake, there were no differences in tiger muskellunge condition by size class in spring (Kruskal-Wallis test, H = 1.90, df = 5, p = 0.863) or fall (Kruskal-Wallis test, H = 5.62, df = 6, p = 0.467), but there were differences among size classes in summer (Kruskal-Wallis test, H = 27.92, df = 7, p < 0.0001) (Figure 4). Tiger muskellunge W_r values were low for small fish (300 - 499 mm), and increased significantly for mid-size fish (500 - 799 mm). However, tiger muskellunge ≥ 900 mm had significantly lower W_r values than those ranging from 500 – 799 mm.

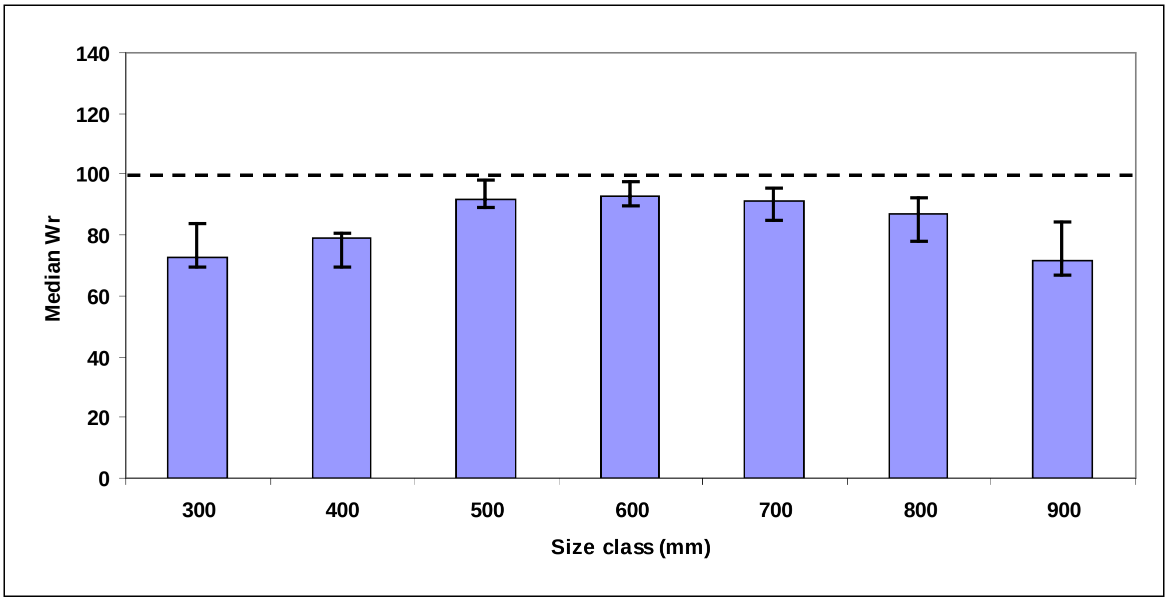

Figure 4. Summer W_r values of tiger muskellunge by size class (100 mm TL groups) in Silver Lake (Spokane County) for years 2001 - 2006. Family $\alpha = 0.20$.

Diet – Of the 277 tiger muskellunge sampled by gastric lavage in Curlew Lake, 39% contained diet items. In contrast, 52% of the 201 tiger muskellunge sampled by gastric lavage in Silver Lake contained diet items. Ninety-three percent of tiger muskellunge in Curlew Lake that contained diet items had a single prey item, and no fish contained more than 2 prey items. In Silver Lake, 29% of tiger muskellunge with diet items contained multiple prey items, and one fish contained up to 11 prey items. There was no relationship between size of tiger muskellunge and number of prey items eaten (p=0.188; Figure 5). However, tiger muskellunge with food in Curlew Lake contained fewer prey items in the stomach than those in Silver Lake (t-test, t = -3.90, df = 113, p < 0.0001).

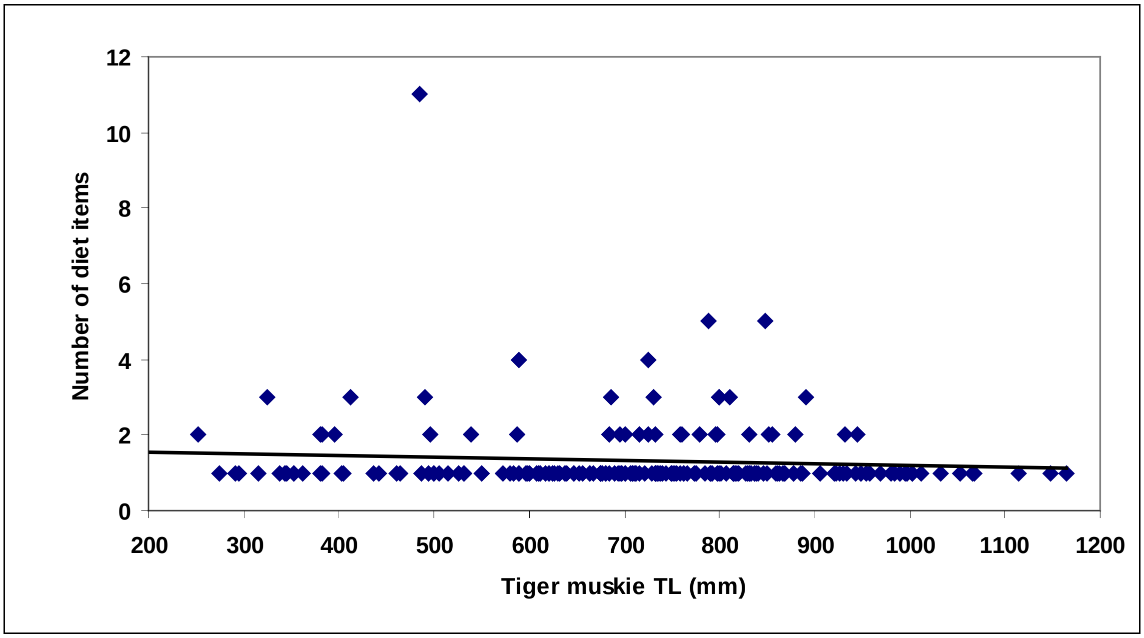

Figure 5. Relationship between tiger muskellunge total length and number of diet items consumed: Number of diet items = -0.0005 (tiger muskellunge TL) + 1.632; r^2 = 0.003; df = 212; P = 0.188. in Curlew and Silver lakes 2001 – 2006.

In Curlew Lake, fish accounted for 90% of prey items (by number), while invertebrates made up 10% of the diet. Similarly, fish accounted for 89% of prey items (by number) in Silver Lake, and the remaining 11% was composed of invertebrates. However, types of invertebrates consumed by tiger muskellunge in the two lakes differed. Most invertebrates (64%) in the diet of Curlew Lake tiger muskellunge were amphipods (order: Amphipoda) and dragonfly or damselfly larvae (order: Odonata) consumed by juvenile tiger muskellunge (<500 mm), while all invertebrates consumed by tiger muskellunge in Silver Lake were found in adults (>500 mm), and 89% of invertebrates consumed were crayfish (order: Decapoda).

Rainbow Trout (RI = 35.8) and Northern Pikeminnow (RI = 29.2) were the most important prey species for tiger muskellunge in Curlew Lake, followed by Largemouth Bass (RI = 11.4) and invertebrates (RI = 6.7) (Table 4). Peamouth and Bridgelip Sucker were of less importance (RI < 5). Unidentified fish and unidentified non-salmonids made up about 7% each of tiger muskellunge diet by number and by weight. In Silver Lake, compressiform centrarchids (*Lepomis* spp. and *Pomoxis* spp., combined RI = 24.8) were most important in tiger muskellunge diet, followed closely by Rainbow Trout (RI = 20.9; Table 5). Largemouth Bass (RI = 11.6), Tench (RI = 10.5), Yellow Perch (RI = 8.2), and invertebrates (RI = 6.5) were somewhat important in tiger muskellunge diet. Brown Trout (RI = 3.2) were of low importance in the diet. Unidentifed non-salmonids made up about 13% of tiger muskellunge diet by number and weight. Unidentified salmonids made up 2% of diet by number and 1% by weight.

Table 4. Relative Importance Index (RI) diet analysis of 107 tiger muskellunge, containing 114 prey items, from Curlew Lake (Ferry County) examined from 2001-2006.

Prey	Percent composition by number	Percent frequency of occurrence	Percent composition by weight	Absolute importance index value (Ai_a)	Relative importance index value (RI)
Rainbow Trout	33.3	34.6	40.9	108.8	35.8
Northern Pikeminnow	25.2	26.2	37.2	88.6	29.2
Largemouth Bass	14.4	15.0	5.4	34.7	11.4
Invertebrates	9.9	10.3	<0.1	20.2	6.7
Peamouth	3.6	3.7	4.0	11.3	3.7
Bridgelip Sucker	0.9	0.9	0.5	2.4	0.8
Unidentified fish	6.3	6.5	6.2	19.0	6.2
Unidentified non-salmonid	6.3	6.5	5.9	19.0	6.2
Total	100	104	100	304	100

Table 5. Relative Importance Index (RI) diet analysis of 104 tiger muskellunge, containing 162 diet items, from Silver Lake (Spokane County) examined from 2002-2006.

Prey	Percent composition by number	Percent frequency of occurrence	Percent composition by weight	Absolute importance index value (Ai_a)	Relative importance index value (RI)
Rainbow Trout	23.5	17.3	26.5	67.2	20.9
Unidentified non-salmonids	11.7	16.3	12.8	40.9	12.7
Largemouth Bass	10.5	14.4	12.6	37.5	11.6
Tench	4.3	6.7	22.8	33.9	10.5
Unidentified *Lepomis* spp.	9.9	15.4	5.3	30.5	9.5
Yellow perch	8.0	11.5	6.7	26.3	8.2
Pumpkinseed	8.6	12.5	4.5	25.7	8.0
Invertebrates	11.1	8.7	1.0	20.8	6.5
Bluegill	5.6	8.7	2.7	17.0	5.3
Brown trout	2.5	3.8	3.9	10.2	3.2
Black Crappie	2.5	3.8	0.1	6.4	2.0
Unidentified salmonids	1.9	2.9	1.1	5.8	1.8
Total	100	122	100	322	100

Importance of prey species in tiger muskellunge diet fluctuated among seasons in Curlew Lake (Figure 6). In spring, Rainbow Trout (RI = 60.6) were the most important prey, and Largemouth Bass (RI = 13.4) were a distant second. However, Northern Pikeminnow (RI = 39.6) were the most important tiger muskellunge prey in summer, followed by Rainbow Trout (RI = 18.5) and invertebrates (RI = 12.1). In fall, both Northern Pikeminnow (RI = 33.0) and Rainbow Trout (RI = 38.6) were important diet items. The RI value for Largemouth Bass ranged between 9.0 and 13.4 for all seasons, indicating that its importance changed little between seasons.

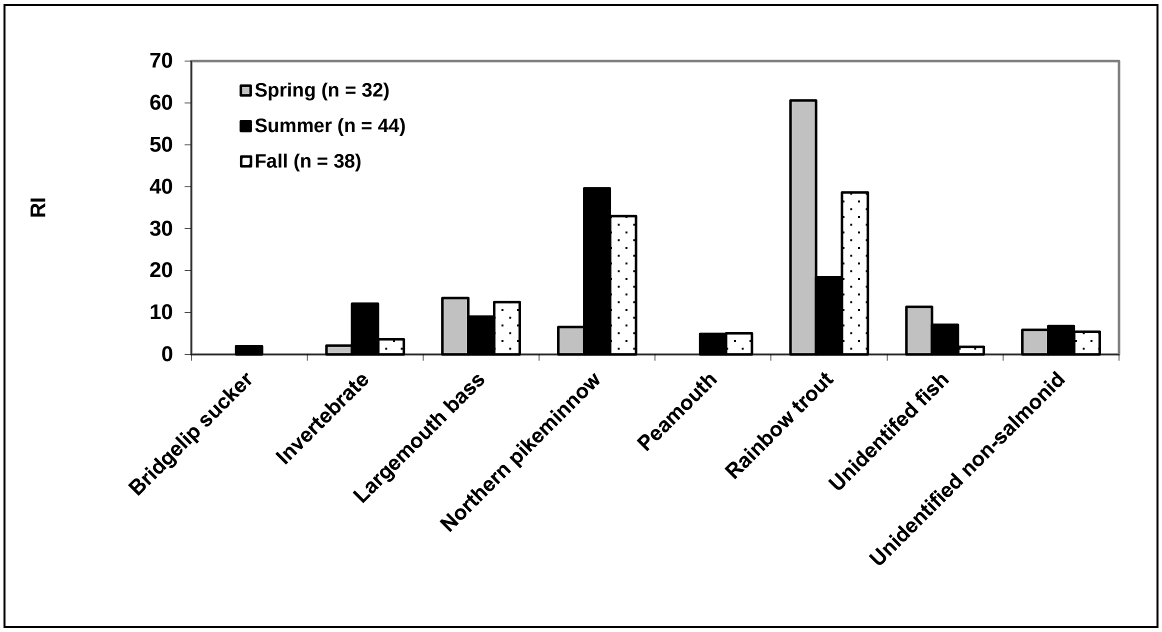

Figure 6. Relative Importance Index (RI) values for tiger muskellunge prey in Curlew Lake (Ferry County) during spring, summer, and fall (2001 – 2006).

In Silver Lake, importance of tiger muskellunge prey species changed by season, as well (Figure 7). In spring, Rainbow Trout (RI = 55.3) was the most important prey species. However, by summer importance of Rainbow Trout decreased substantially (RI = 4.7), and no Rainbow Trout were found in tiger muskellunge diet in fall. Largemouth Bass (RI = 14.4) was the single most important prey species in summer, but compressiform centrarchids (combined RI = 33.6) were also highly important prey species. In fall, Largemouth Bass (RI = 20.3) and compressiform centrarchids (combined RI = 27.2) were, again, important in tiger muskellunge diet. Tench (RI = 18.8) were also important prey items in the fall, whereas they were of little importance in spring and summer (RI = 7.9 and RI = 4.9, respectively).

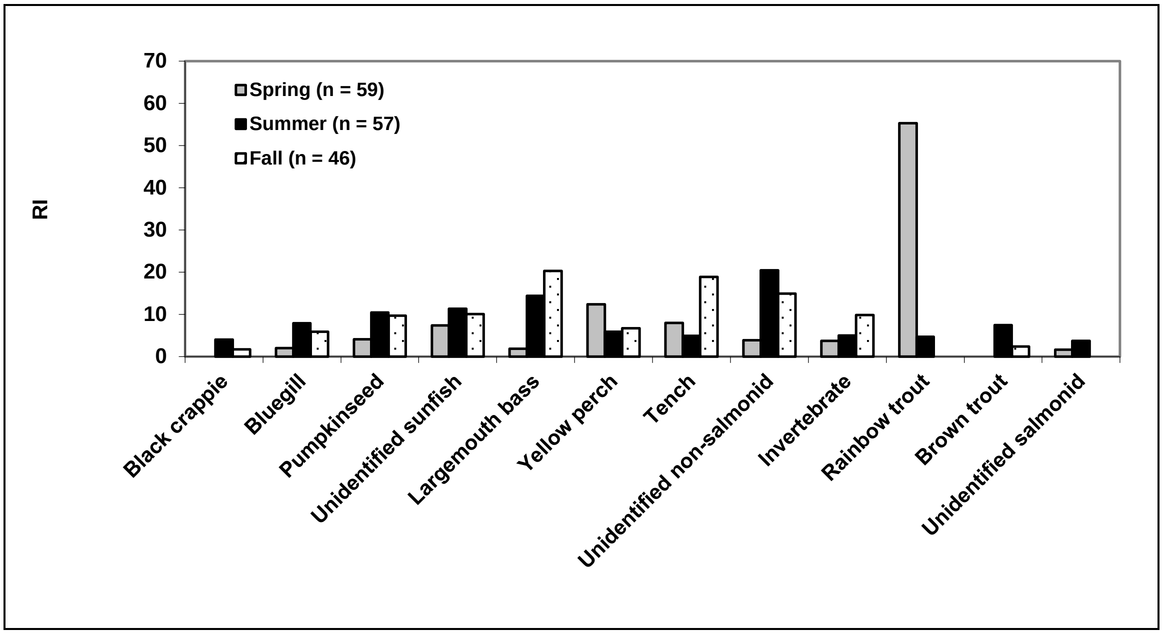

Figure 7. Relative Importance Index (RI) values for tiger muskellunge prey in Silver Lake (Spokane County) in spring, summer, and fall (2002-2006).

Prey fish consumed by tiger muskellunge averaged 24.6% of tiger muskellunge TL and ranged from 4.7 – 53.6% for all (i.e., both lakes) tiger muskellunge diet samples containing fish. The ratio of fusiform prey fish length to tiger muskellunge length averaged 28.0% across 100 mm size classes. There were differences in the ratio of fusiform prey fish length to tiger muskellunge length class (ANOVA, $F = 3.36$, $p = 0.001$), with the ratio being slightly smaller for the 400 mm size class than for the 800 and 900 mm size classes. The ratio of compressiform prey fish length to tiger muskellunge length averaged 16.7% across size classes. There was a difference in ratio of compressiform prey fish length to tiger muskellunge length class, as well (ANOVA, $F = 5.66$, $p = 0.001$). The ratio of prey fish length to tiger muskellunge length differed between the 300 mm and 500 mm size classes. However, ratio of prey length to tiger muskellunge length was consistent among most size classes for fusiform prey and for compressiform prey (Figure 8). Tiger muskellunge gape limitation occurred at approximately 55% of tiger muskellunge total length for fusiform prey (ANOVA, $F = 252.39$, $p < 0.001$) and 19% for compressiform prey (ANOVA, $F = 34.37$, $p < 0.001$; Figure 9).

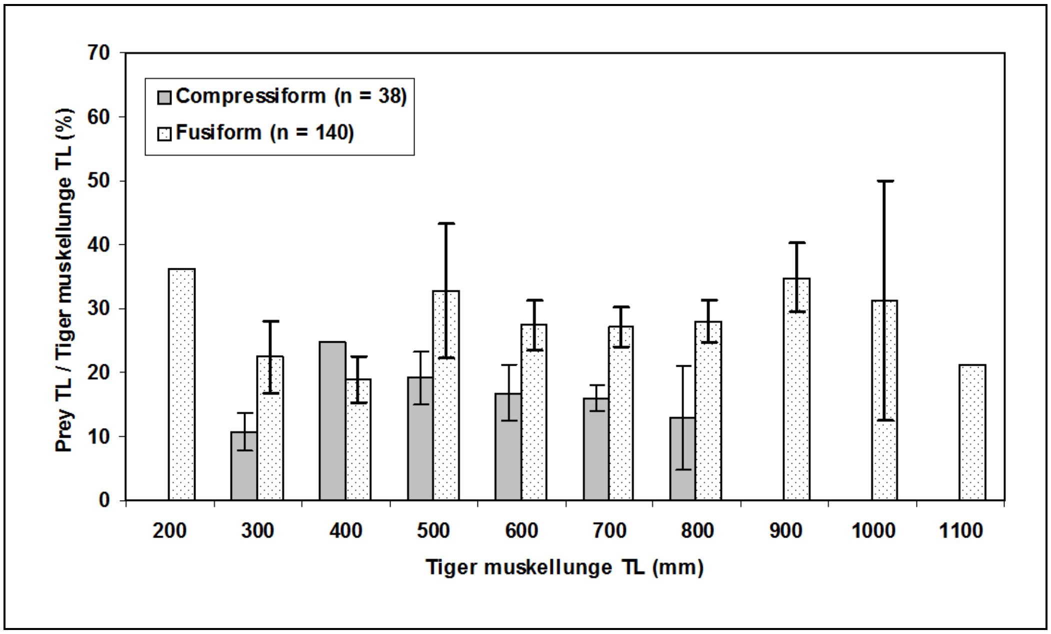

Figure 8. Ratio of prey length to tiger muskellunge length (by 100 mm size class), with 95% confidence intervals, for fusiform and compressiform prey from diet samples collected from Curlew and Silver Lakes from 2001 to 2006.

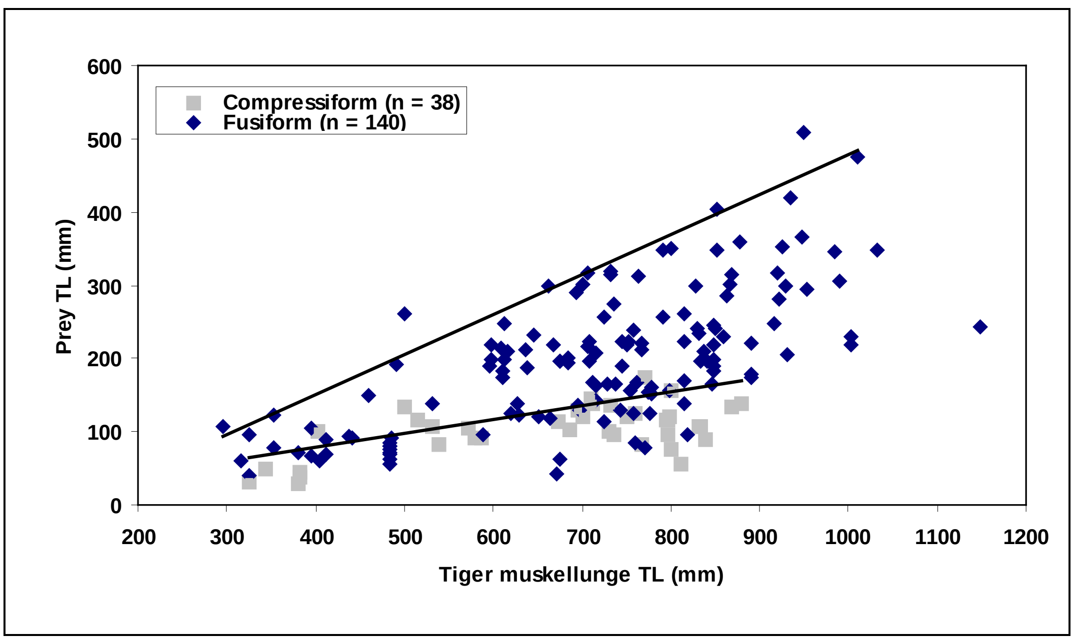

Figure 9. Relationship between prey fish total length and tiger muskellunge total length. The upper line denotes tiger muskellunge gape limitation for fusiform fish: Prey TL = 0.546 (tiger muskellunge TL) – 67.214; r^2 = 0.95; df = 13; p < 0.001; and the lower line denotes tiger muskellunge gape limitation for compressiform fish: Prey TL = 0.187 (tiger muskellunge TL) + 3.903; (r^2 = 0.70; df = 14; p < 0.001).

Stable Isotope Analysis – Proximity of plotted mean values for carbon and nitrogen isotopic signature demonstrated the relationship between adult tiger muskellunge and the three prey species in Curlew Lake (Figure 10). Rainbow Trout and Northern Pikeminnow plotted nearer to adult tiger muskellunge than Largemouth Bass, indicating that these species made up a larger percentage of the diet than Largemouth Bass. The stable isotope analysis indicated that large proportions of adult tiger muskellunge diet are composed of Rainbow Trout (mean = 53%) and Northern Pikeminnow (mean = 47%), followed distantly by Largemouth Bass (mean = 1%) (Figure 11).

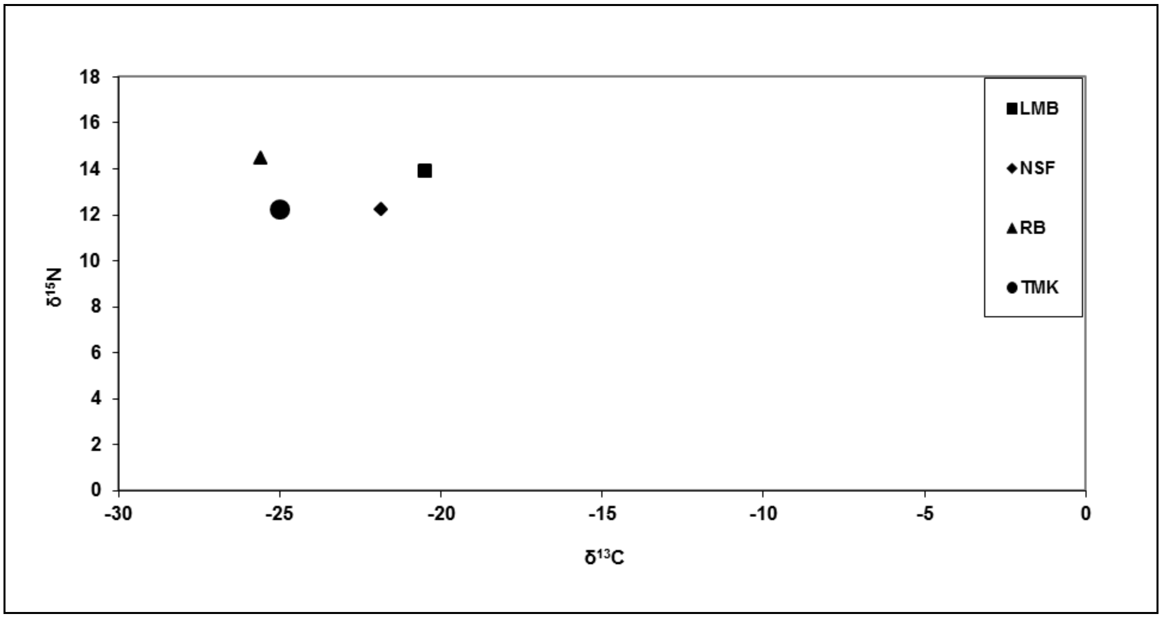

Figure 10. Mean Carbon and Nitrogen isotopic signatures for tiger muskellunge, Rainbow Trout, Northern Pikeminnow, and Largemouth Bass sampled in Curlew Lake (Ferry County) September 2006. The average standard error for measurement was 0.009‰.

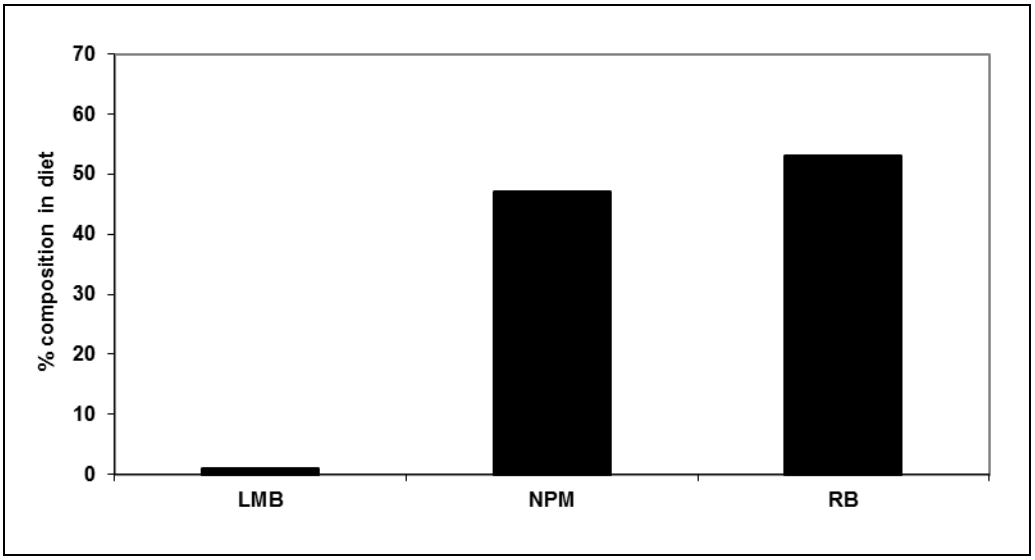

Figure 11. Percent tiger muskellunge diet composition (stable isosope analysis) from Curlew Lake (Ferry County). LMB = Largemouth Bass, NPM = Northern Pikeminnow, and RB = Rainbow Trout.

Target prey populations – Northern Pikeminnow CPUE in Curlew Lake differed by year (Kruskal-Wallis test, $H = 33.50$, $df = 7$, $p < 0.0001$, adjusted for ties). Catch per unit effort was significantly lower in 2006 than in all previous years except for 2001(Figure 12). Mean total length of Northern Pikeminnow differed by year, as well (ANOVA, $F = 22.16$, $df = 1549$, $p < 0.0001$). Mean total length of Northern Pikeminnow was significantly larger in 1998 than in all other years except for 1999 (Figure 13). Mean total length was greater in 1999 than during the years of 2001 – 2004, but did not differ from 2005 or 2006. Northern Pikeminnow TL was smaller in 2001 and 2002 than in all other years.

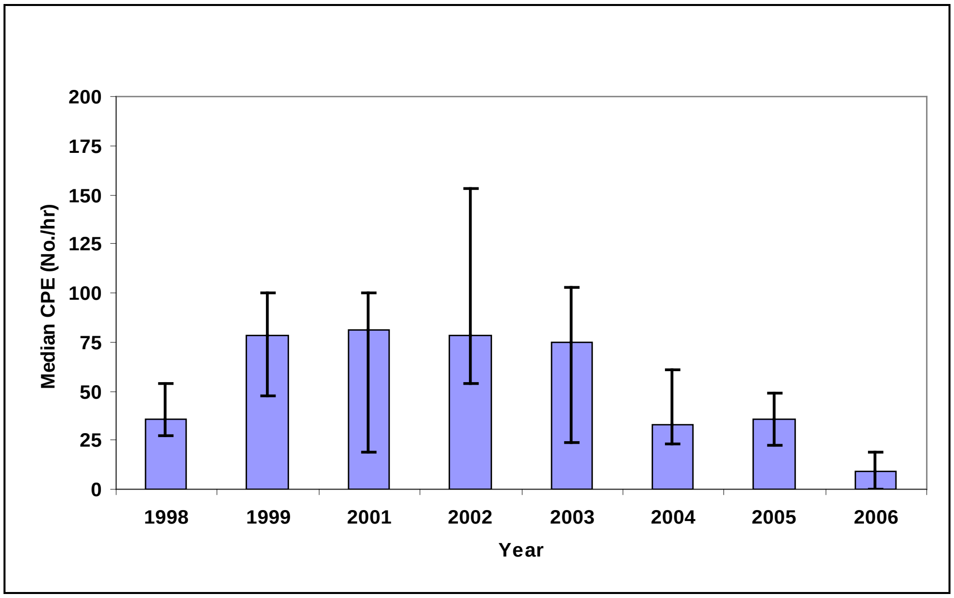

Figure 12. Electrofishing CPUE for Northern Pikeminnow in Curlew Lake (1998 - 2006). Family α = 0.20.

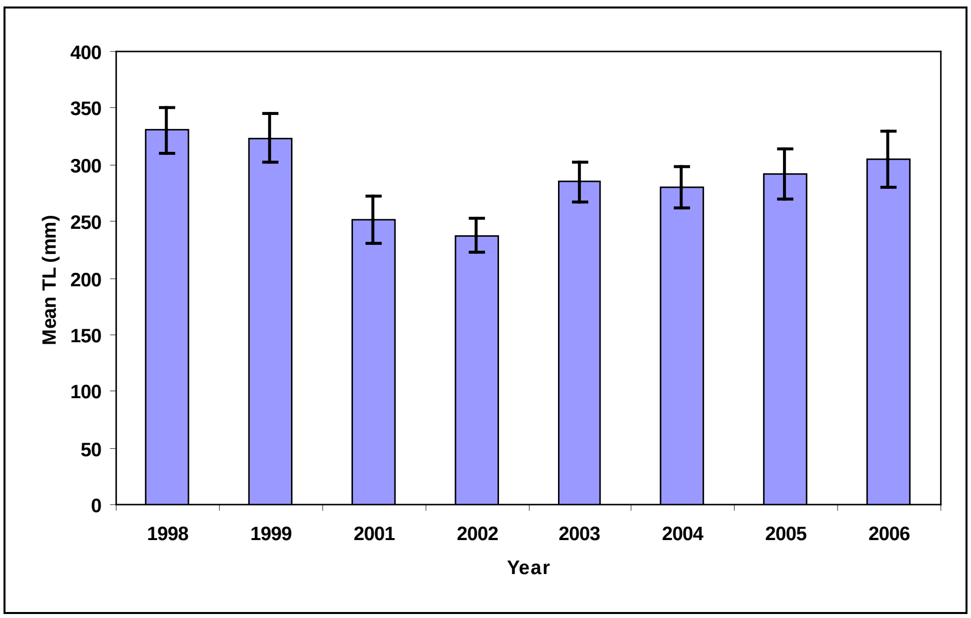

Figure 13. Mean total length of Northern Pikeminnow in Curlew Lake (1998 - 2006). Family α = 0.05.

Tench CPUE in Silver Lake differed by year (Kruskal-Wallis test, H = 17.63, df = 5, p = 0.003; adjusted for ties). Catch per unit effort was lower in 2006 than during 2002-2004 (Figure 14). Mean total length of Tench in Silver Lake differed by year (ANOVA, F = 6.56, df = 640, p < 0.0001). Tench were larger in 2002 and 2006 than in 2001 (Figure 15). Mean total length did not differ during the years of 2002 - 2005. However, Tench mean TL was greater in 2006 than in 2001, 2003, and 2004.

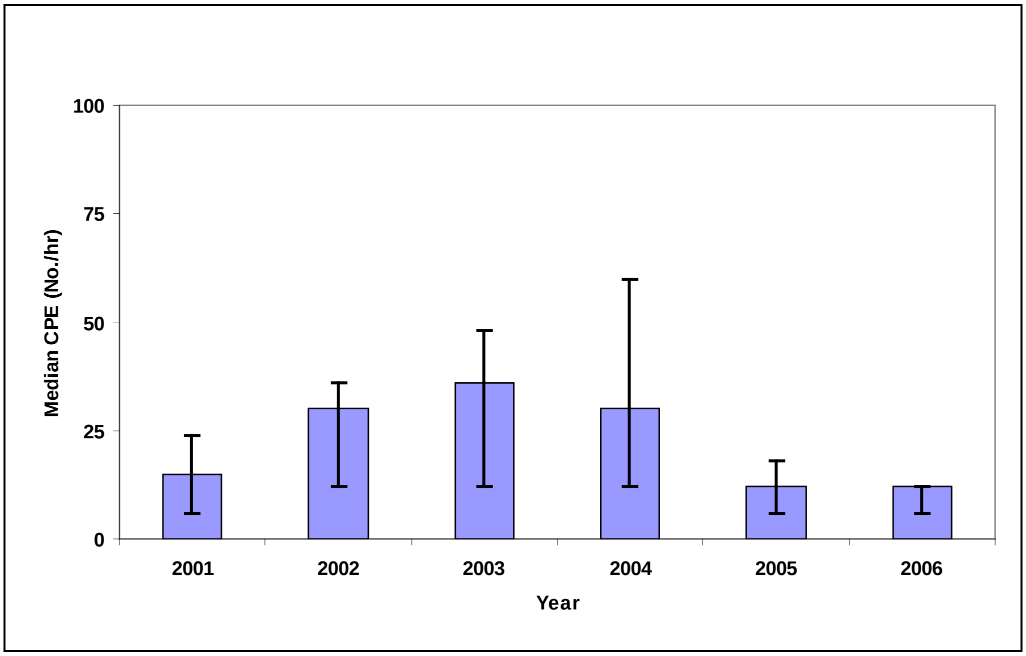

Figure 14. Electrofishing CPUE for Tench in Silver Lake (1998 - 2006). Family α = 0.20.

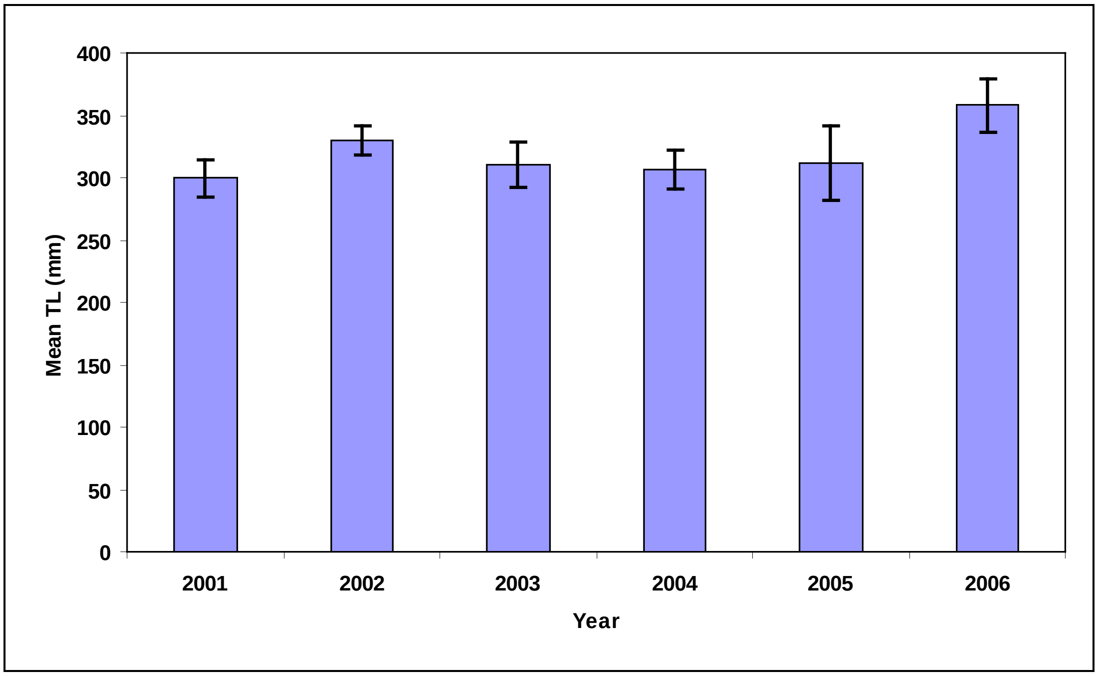

Figure 15. Mean total length of Tench in Silver Lake (2001 - 2006). Family $\alpha = 0.05$.

Length frequency distribution of Northern Pikeminnow at Curlew Lake varied in sampling conducted between 1998 and 2006 (Figure 16). In contrast, Tench length frequency distribution changed little between 2001 and 2006 (Figure 17).

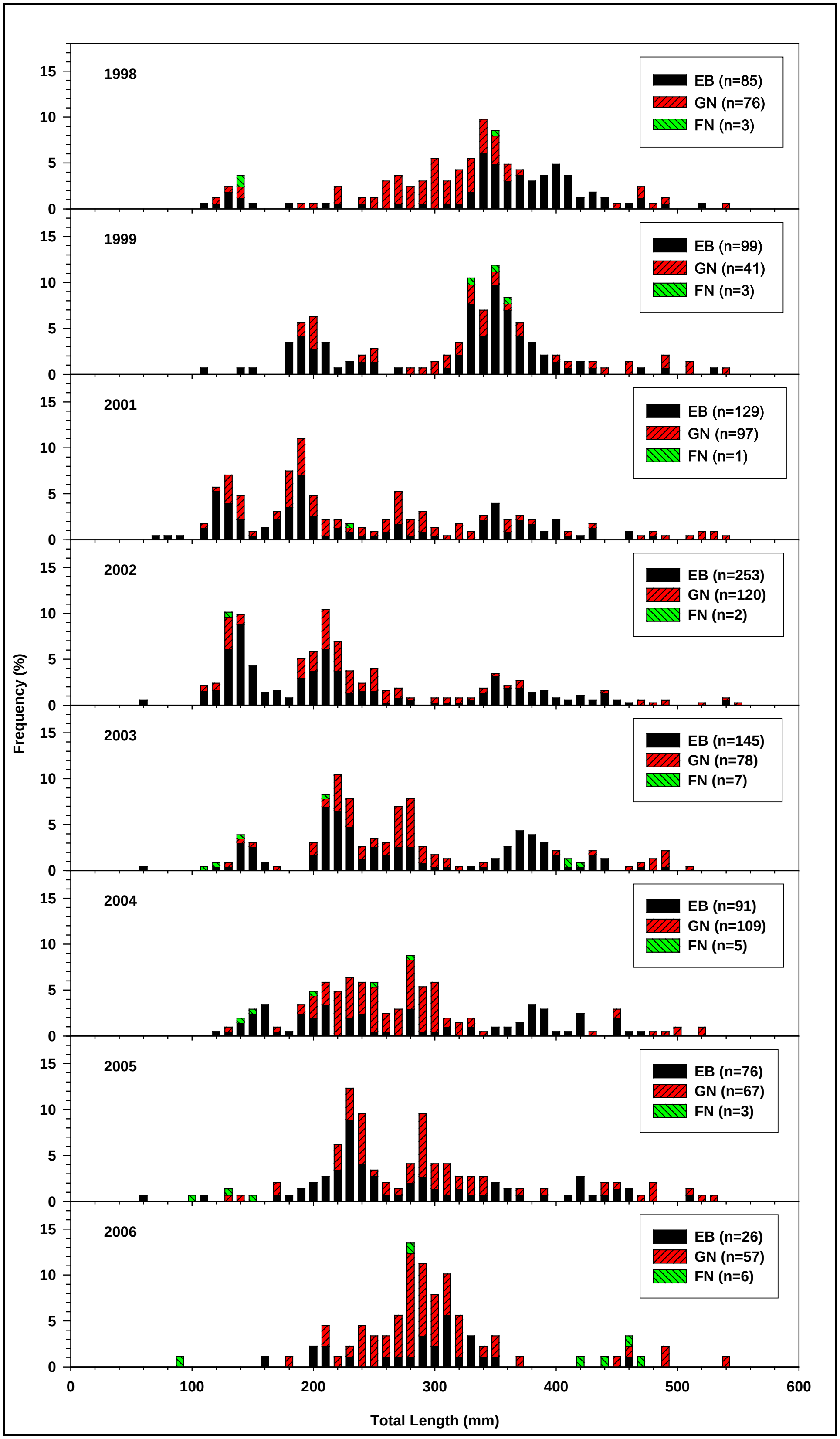

Figure 16. Curlew Lake Northern Pikeminnow length frequency distributions (1998 - 2006). EB = electrofishing, GN = gill netting, and FN = fyke netting.

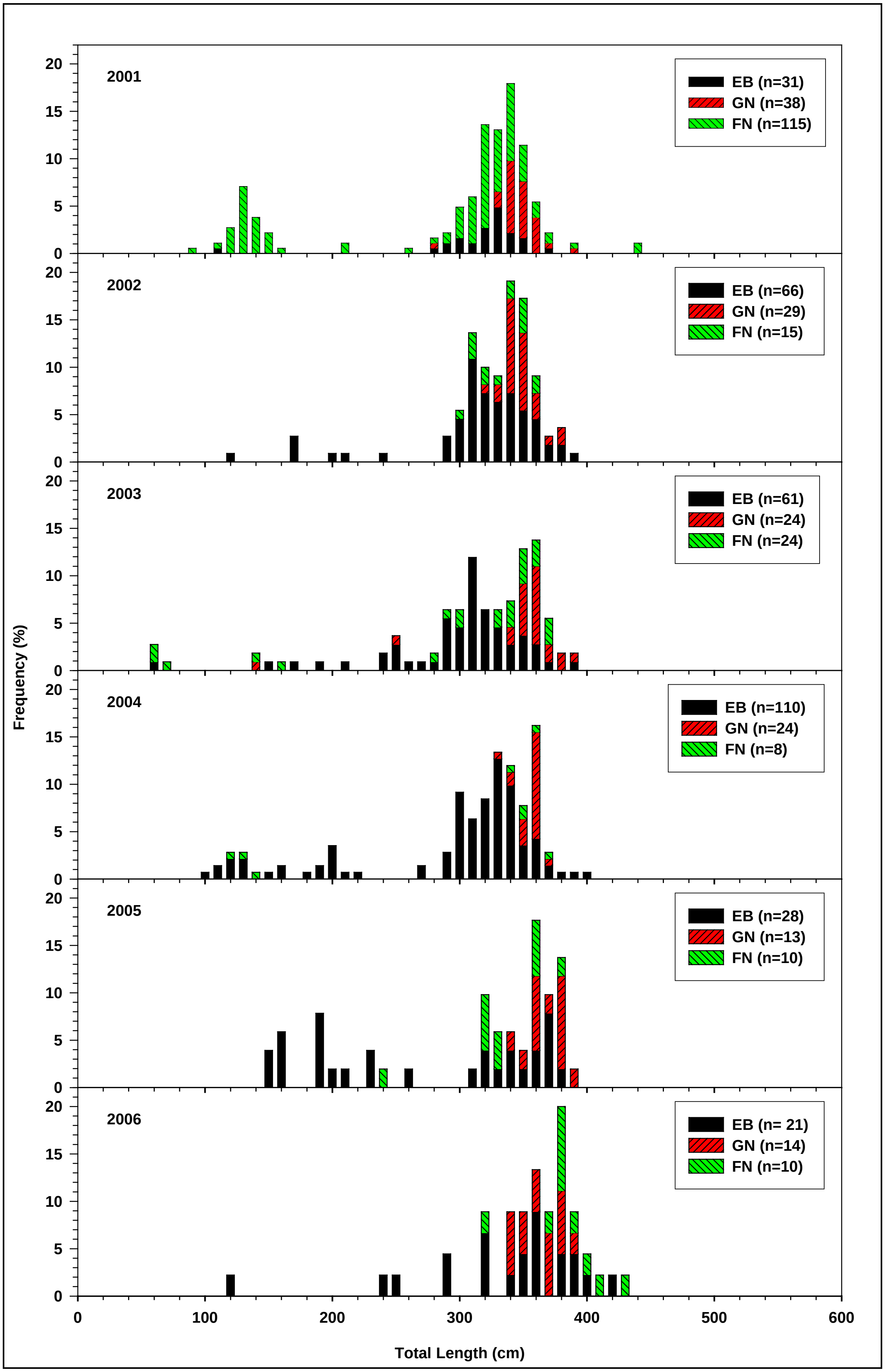

Figure 17. Silver Lake tench length frequency distributions (2001-2006). EB = electrofishing, GN = gill netting, and FN = fyke netting.

Discussion

Tiger muskellunge in Curlew Lake grew more quickly than those in Silver Lake. This is consistent with expectations based on knowledge of the differences in available forage in these lakes. Tiger muskellunge, like other esocids, prefer soft-rayed (Weithman and Anderson 1977; Engstrom-Heg et al. 1986; Wahl and Stein 1988), fusiform prey (Wahl and Stein 1988; Nilsson and Bronmark 2000) about one third their own length (Gillen et al. 1981; Carline et al. 1986; Wahl and Stein 1988). The fish community of Curlew Lake has abundant fusiform prey of the appropriate size for tiger muskellunge, and black bass (Largemouth and Smallmouth Bass) are the only fish species in Curlew Lake that are not soft-rayed. In contrast, the fish communtiy of Silver Lake is dominated by spiny-rayed, compressiform centrarchids, and few potential prey species are soft-rayed (WDFW, unpublished data). Gillen et al. (1981) and Tomcko et al. (1984) suggested that tiger muskellunge growth might be adversely affected when stocked into waters with a centrarchid-dominated forage base. Carline et al. (1986) found that tiger muskellunge grew more quickly in lakes with forage bases composed of Gizzard Shad and cyprinids than in lakes with forage bases composed of only centrarchids. Similarly, Storck and Newman (1992) reported slow growth of tiger muskellunge in an Illinois reservoir dominated by Largemouth Bass and Bluegill.

Tiger muskellunge in Curlew Lake exhibited greater condition than those in Silver Lake. There was no overall difference in W_r of tiger muskellunge between seasons in Curlew Lake, and fish were in relatively good condition during spring, summer, and fall, indicating that adequate forage is available during these seasons. In Silver Lake, W_r of Tiger muskellunge was somewhat low during all seasons, and was significantly lower in fall than in spring and summer, indicating that adequate forage may be limited, particularly in the fall.

In Curlew Lake, juvenile tiger muskellunge (300 - 499 mm) were in poorer condition than adults (≥ 500 mm) during summer and fall. Juvenile tiger muskellunge in Silver Lake were also in poorer condition than adults (500 – 799 mm) during summer. Considering that juvenile tiger muskellunge are fed live fish at the hatchery for approximately 3 months prior to release, it's unlikely that poor W_r is the result of a lack of foraging skill. Instead, it could be a result of diet.

Increased W_r for larger tiger muskellunge may indicate that an ontogenetic shift occurs around 500 mm TL. In Curlew Lake, supporting evidence for an ontogenetic shift is strong. Most invertebrates were eaten by juvenile tiger muskellunge in Curlew Lake, and adult tiger muskellunge seldom preyed upon anything but fish. However, lack of preferred prey of an appropriate size for juvenile tiger muskellunge could also contribute to lower W_r values. Few target forage or Rainbow Trout of appropriate size (< 120 mm) for juvenile tiger muskellunge predation were found in either lake using standardized sampling (WDFW, unpublished data).

Relative weight of adult tiger muskellunge (> 500 mm) increased with size of fish in Curlew Lake during summer and fall, and W_r of adult tiger muskellunge in Silver Lake exhibited a similar pattern, during summer, until fish reached about 800 mm TL, at which point it declined. These results are not surprising, as Northern Pikeminnow and Rainbow Trout of appropriate size (150 - 350 mm) for tiger muskellunge predation are abundant in Curlew Lake during all seasons. Conversely, few Tench in Silver Lake are of appropriate size (150 – 300 mm) for predation as most individuals in the population are large (> 300 mm), and it appears that few Rainbow Trout persist into summer.

Tiger muskellunge in Silver Lake contained significantly more prey items than those in Curlew Lake. Although the average size of tiger muskellunge in Curlew Lake is larger than that of Silver Lake, size of tiger muskellunge had no effect on the number of prey items consumed. In both lakes, fish made up the largest part of tiger muskellunge diet, and invertebrates accounted for a small proportion. Tiger muskellunge were capable of consuming fusiform fish that were more than half their own length, but such instances were relatively rare. Prey fish TL averaged 25% of tiger muskellunge TL, which is consistent with other field studies of esocid diet (Carline et al. 1986; Wahl and Stein 1988; Bozek et al. 1999). The ratio of fusiform prey fish TL to tiger muskellunge TL (28%) was greater than the ratio of compressiform prey fish TL to tiger muskellunge TL (17%). Both ratios were slightly lower than predicted for Fathead Minnows *Pimephales promelas* (fusiform) and Bluegill (compressiform) in laboratory experiments, but in pond experiments conducted during the same study, tiger muskellunge selected smaller individuals of both prey types than predicted from the laboratory experiments (Gillen et al. 1981).

Results of both the Relative Importance Index and stable isotope analysis were similar indicating Rainbow Trout and Northern Pikeminnow were the most important prey items in Curlew Lake. Although Largemouth Bass were also extremely abundant in Curlew Lake, their importance in tiger muskellunge diet was relatively low. This result is consistent with the literature, as both Rainbow Trout and Northern Pikeminnow (both soft-rayed) better match the description of a preferred tiger muskellunge prey item than does Largemouth Bass (spiny-rayed). Both Peamouth and Bridgelip Sucker were of low importance in tiger muskellunge diet in Curlew Lake, likely due to their relatively low abundance (WDFW, unpublished data).

In Silver Lake, compressiform centrarchids and Rainbow Trout were, overall, the most important prey items. This too, was likely an artifact of availability. While compressiform centrarchids do not match the description of preferred tiger muskellunge prey, they were extremely abundant in Silver Lake, and few soft-rayed, fusiform fish were available (WDFW, unpublished data). Beyerle and Williams (1968) reported that small Northern Pike (178 – 584 mm TL) would consume small centrarchids (38 – 64 mm TL) when offered as forage in aquaria studies, but selected for minnows and Lake Chubsuckers *Erimyzon sucetta* (fusiform, soft-rayed species) if available. For Silver Lake tiger muskellunge, a majority of which were small (<600 mm TL), propensity to prey upon centrarchids was likely an artifact of their high relative abundance in the lake. There was little change in the length frequency distribution of Tench over the duration of the study. Most Tench in Silver Lake were unavailable to tiger muskellunge as prey because most were too large to be eaten by the relatively small tiger muskellunge. Only in 2006 had tiger muskellunge grown to a size at which gape limitation was likely not an issue, allowing the majority of Tench in the population to be utilized as prey.

In both lakes, importance of tiger muskellunge prey items changed seasonally. In Curlew Lake, Rainbow Trout was the most important prey species in spring. However, by summer, importance of Rainbow Trout declined and Northern Pikeminnow were most important. In fall, both Northern Pikeminnow and Rainbow Trout were important prey items. Since Rainbow Trout appear to be a preferred prey item of tiger muskellunge, it seems likely that there is some habitat partitioning of the two species during summer, and consequently, lesser predation during that time of year. This could be a result of differences in temperature preference. Meade and

Lemm (1986) showed that maximum growth of tiger muskellunge (120 – 130 mm) occurred at 23°C and that growth declined substantially below 20°C. Wydoski and Whitney (2003) reported that Rainbow Trout prefer water temperatures < 21°C, and that in lakes with surface water temperatures above 21°C, they move to deeper, cooler water if oxygen content is sufficient. This appears to be the case in Curlew Lake, as Rainbow Trout were commonly found in littoral electrofishing samples conducted during spring and late fall, when water temperatures were low (< 15°C) but were uncommon in littoral samples conducted in summer, when water temperatures were higher (> 21°C).

In spring, Rainbow Trout were the most important tiger muskellunge prey species in Silver Lake, as well. As in Curlew Lake, the importance of Rainbow Trout declined substantially in Silver Lake tiger muskellunge diet in summer. However, unlike Curlew Lake, Rainbow Trout did not become an important prey item again in the fall. In fact, no Rainbow Trout were observed in the diet of Silver Lake tiger muskellunge during fall, likely indicating that there were few Rainbow Trout present in the lake by that time. This seems likely for two reasons: (1) relatively few "catchable-size" Rainbow Trout are stocked in Silver Lake each spring, and (2) Silver Lake is "predator heavy" with both tiger muskellunge and a sizable population of Largemouth Bass > 350 mm TL. During both summer and fall, compressiform centrarchids and Largemouth Bass were the most important prey items in Silver Lake. This is indicative of a general lack of preferred prey during these two seasons and is likely responsible for the poor W_r of tiger muskellunge > 800 mm TL during summer, as well as the poor W_r of all tiger muskellunge in the population during fall.

Stable isotope sampling was conducted to provide a comparison with the diet data collected through gastric lavage. Although stable isotope analysis is not a substitute for traditional diet analysis (Johnson et al. 2002) it can provide a method for verification of empirical diet data. In this study, stable isotope analysis corroborated the results of data collected through gastric lavage. Including stable isotope analysis in future evaluations of predator diet can be a valuable complement to traditional diet sampling.

Tiger muskellunge appeared to impact target prey populations in both study lakes. Catch per unit effort of Northern Pikeminnow in Curlew Lake was significantly lower in 2006 than all other years except for 2001, when CPUE variability was high. This drop in CPUE is likely the result of reduction of the Northern Pikeminnow population through predation by tiger muskellunge. Mean length of Northern Pikeminnow decreased during the middle of the study period (2001 and 2002). However, unlike CPUE, mean length increased again toward the end of the study period (2003 – 2006). The initial decrease in length can be explained by recruitment of young Northern Pikeminnow to the population following mortality of larger individuals associated with tiger muskellunge predation and old age. The subsequent increase in length may be a compensatory response associated with population reduction and subsequently, lesser intra-specific competition during the latter years of the study. Age and growth data for target prey species, which were not collected during this study, should be included in future research examining predator/prey interactions.

Catch per unit effort of Tench in Silver Lake was significantly lower in 2006 than during the period from 2002 – 2004. Mean length of Tench remained fairly static from 2001 (one year prior to tiger muskellunge introduction) through 2005, but increased in 2006. Since most Tench sampled in all years were 300 – 400 mm TL, the majority of the Tench population was unavailable to tiger muskellunge as prey until 2006 due to gape limitation. By summer of 2006, tiger muskellunge from the first year of stocking in Silver Lake averaged nearly 900 mm TL, and they averaged 918 mm TL by fall of that year. If these fish were selecting for Tench that were approximately one-third of their own length, they would prey on fish averaging around 300 mm TL. The static nature of the largest size classes of Tench in Silver Lake from 2001 – 2004 indicate that there was little change in recruitment or growth during those years (Figure 17). Fifty-one to 74% of captured Tench were 300 – 359 mm TL during that period, and 9 – 23% were ≥ 360 mm TL. However, in both 2005 and 2006, only 27% of the Tench population was between 300 – 359 mm TL and 43% and 56% of the population was ≥ 360 mm TL during those years, respectively. The apparent growth of Tench in the largest size classes may be compensatory, due to a reduction in the number of individuals in the 300 – 350 mm TL range.

Considering the results of this study to date, the primary objectives have largely been met, particularly at Curlew Lake. The growth and condition data collected in these two waters clearly demonstrates that tiger muskellunge stocked into waters containing esocid-preferred prey will exhibit faster growth and higher condition than those stocked into waters where preferred prey species are less available. The results for diet analysis within, and between, each of the study lakes indicates that tiger muskellunge will select for preferred soft-rayed fusiform species over spiny-rayed compressiform species when available. The introduction of tiger muskellunge into Curlew Lake has resulted in successfully reducing the once overabundant Northern Pikeminnow population (i.e., the target forage species). The success of the tiger muskellunge introduction at reducing the Tench population at Silver Lake is less clear, but may be attributable to gape limitation within the majority of the slower growing tiger muskellunge population.

At this point in time, the introduction of tiger muskellunge into Curlew Lake is considered a success, and further diet sample data collection at the lake is likely unwarranted. Managers should consider continued sampling on a more limited scale, perhaps conducting fish community surveys every other year, to monitor the relative abundance of the Northern Pikeminnow population within the lake. This monitoring should provide a gauge by which future tiger muskellunge stocking rates can be adjusted (i.e., adjust annual tiger muskellunge stocking based on Northern Pikeminnow CPUE).

Study results are less conclusive at this point in time for Silver Lake. Considering this, it is recommended that future sampling of both tiger muskellunge diet and the overall fish community be continued to help clarify the results of introducing tiger muskellunge into a fish community comprised predominately of centrarchids and Tench. Continuing data collection at Silver Lake for an additional three to five years should help to further characterize the diet of tiger muskellunge stocked into a mixed species fish community and allow for a better understanding of how well the introduction of tiger muskellunge can meet management objectives in similar fish communities.

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