An Evaluation of Tiger Muskellunge Introduced into Lake Carl Etling, Oklahoma

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Abstract: Tiger Muskellunge (Muskellunge *Esox masquinongy* x Northern Pike *Esox lucius*) were stocked into Lake Carl Etling in the northwestern tip of Oklahoma's panhandle in Cimarron County. This lake sustained a population of Northern Pike from 1966 – 1976, with natural reproduction maintaining the population until 1986. However, after 1986, periods of drought affecting the lake level and water temperature negatively impacted the Northern Pike population. In 2004, Lake Carl Etling's surface area was reduced to approximately 4 ha by drought, which negatively affected the sportfish populations. Salt Cedar (*Tamarix ramosissima*) and other herbaceous vegetation colonized the dry lakebed before rainfall in the summer of 2013 filled Lake Carl Etling to normal elevation. Nongame fish populations became over abundant and Tiger Muskellunge were stocked as biological control and to potentially create a unique trophy fishery. However, through extensive sampling efforts only 1 adult and 76 juveniles (of the 2,656 individuals stocked) were caught. Tiger Muskellunge recruitment was affected by high turbidity and high water temperatures. A combination of increasing turbidity levels and water temperatures, post-stocking, likely resulted in increases in Tiger Muskellunge metabolism. Relative weights (Wr) decreased monthly after stocking in 2016 and 2017, with no fish observed in sampling efforts after July of 2016. These conditions likely required Tiger Muskellunge to forage more frequently. As an ambush predator that depends on sight to forage, they had little foraging success in turbid water, which ultimately led to starvation and death.

Introduction

Oklahoma lakes typically get too warm to sustain populations of cold-water fishes, but Lake Carl Etling, Cimarron County Oklahoma is an exception. Historically, this lake has sustained a population of Northern Pike (*Esox Lucius*) following an initial introduction of 64,000 25-mm fingerlings and 3,151 76.2 mm advanced fingerlings stocked by ODWC on April 9, 1966. Maintenance stockings averaging 2,148 76.2-mm pike continued annually until 1976, however past that year, stocking was discontinued. Limited recruitment was observed during annual electrofishing surveys conducted by ODWC until 1986 (Stahl 1986), however no individuals were found during annual surveys thereafter. It was hypothesized that reduced water elevations lead to increased water temperature during periods of drought surpassed the Northern Pike thermal maxima of 27.8 ºC (Casselman 1978). Other reports of Northern Pike die-off have been documented in lakes following several very warm days where water temperatures ranged from 32° C at the surface to 24° C in the lower epilimnion (Inskip 1982).

In 2004, the surface area of Lake Carl Etling was reduced to approximately 4 ha as a result of prolonged drought, which negatively affected the sportfish populations. Salt Cedar (*Tamarix ramosissima*) and other herbaceous vegetation colonized the dry lakebed before rainfall in the summer of 2013 filled Lake Carl Etling to normal elevation. Consequently, the inundated Salt Cedar created nursey habitat for the remaining fish community. This resulted in increased densities of nongame species (not commonly pursued or consumed by anglers), such as Common Carp (*Cyprinus carpio*), Gizzard Shad (*Dorosoma cepedianum*), and Green Sunfish (*Lepomis cyanellus*).

In an attempt to reduce the abundance of nongame species via biological control, ODWC attempted to establish a population of Tiger Muskellunge (Muskellunge *Esox masquinongy* x Northern Pike *Esox lucius*) in Lake Carl Etling. Tiger muskellunge are highly piscivorous and have been stocked throughout the United States to successfully control populations of fish species (e.g. White Sucker, *Catostomus commersonii*, and Black Crappie *Pomoxis nigromaculatus*, Siler and Beyerle 1986; Yellow Perch, *Perca flavescens*, Monroe 2013; Brook Trout, *Salvelinus fontinalis*, Koeing et al. 2015; etc.). Biological control offers some advantages over other methods, including reduced labor, no chemical pesticides, little specialized equipment, and a low cost/benefit ratio when the action is effective (Hoddle 2002, Koenig et al. 2015). In addition, Tiger Muskellunge are sterile F_1 hybrids (they do not reproduce), which allow managers to control population size or even stop stocking if they later do not want this species present in the lake.

ODWC began stocking Tiger Muskellunge in Lake Carl Etling in the fall 2014 and continued for four years. It was hypothesized by ODWC that the stocked Tiger Muskellunge would primarily forage on over abundant nongame species, which would have two positive impacts on the lake. First, a reduction in the nongame species could potentially free up resources for other sport-fish species to utilize. Secondly, Tiger Muskellunge grow rapidly and may create a unique trophy fishery. However, during the course of this evaluation, only one adult fish was captured, suggesting recruitment failure of the stocked fish. Due to the lack of recruitment, this study focuses on food habits and environmental factors that affected juvenile Tiger Muskellunge to attempt to ascertain why stocking efforts in Lake Carl Etling failed.

Methods

Study Area

South Carrizo Creek, a tributary of the Cimarron River, was impounded in 1958 to form Lake Carl Etling. It is in the northwestern tip of Oklahoma's panhandle (Cimarron County), which is encompassed by the diverse Mesa de Maya/ Black Mesa ecoregion. Lake Carl Etling is 159 surface acres at normal pool elevation, with 8 kilometers of shoreline (Figure 1). It is a hyper-eutrophic lake with a mean depth of 1 meter and maximum depth of 5.5 meters. The lake is managed by the ODWC, and is surrounded by Black Mesa State Park, which is managed by Oklahoma Department of Tourism and Recreation. This area provides recreational opportunities such as fishing, camping, hiking, and wildlife viewing. The lake has historically been a popular Largemouth Bass (*Micropterus salmoides*) and Walleye (*Sander vitreus*) fishery. Prey species include Gizzard Shad, Bluegill (*Lepomis macrochirus*), Green Sunfish (*Lepomis cyanellus*), and Redear Sunfish (*Lepomis microlophus*). White Suckers, Plains Killifish (*Fundulus zebrinus*), Black Bullheads (*Ameiurus melas*), and Common Carp. White Suckers are introduced during trout stocking and are not seen past the summer months. In

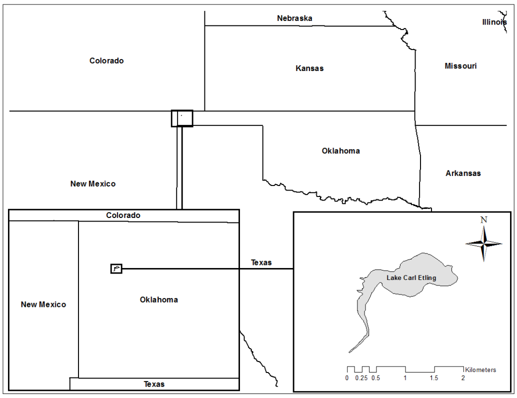

Figure 1. Study site, where Tiger Muskellunge stockings occurred in Oklahoma. Lake Carl Etling is a 64.3 ha impoundment found within the Black Mesa State Park in Cimarron County located in the far northwestern tip of Oklahoma. Lake Carl Etling was built in 1958, impounding South Carrizo Creek, a tributary of the Cimarron River.

addition, ODWC stocks Lake Carl Etling with Channel Catfish (*Ictalurus punctatus*) in the summer and during wintertime trout are stocked for additional winter angling opportunities.

Stocking

Stocking of Tiger Muskellunge in Lake Carl Etling occurred yearly at varying rates, depending on hatchery production (Table 1). Tiger Muskellunge were obtained from both Speas Fish Hatchery in Casper, Wyoming and Wray Fish Hatchery in Wray, Colorado. Tiger Muskellunge stocked in 2014 and 2015 had a mean total length < 250 mm. To reduce predation on stocked Tiger Muskellunge in 2016 and 2017, fish were transported to the Byron State Fish Hatchery in Burlington, Oklahoma and allowed to grow out until mean length exceeded 250 mm. Fish were stocked haphazardly throughout the lake in 2014, 2015, and 2016. In 2017, fish were stocked at the boat ramp in the upper portion of the lake.

Sampling

Tiger Muskellunge sampling was conducted monthly starting in July of 2015. Tiger Muskellunge were sampled using electrofishing gear during the day and night. After initial electrofishing samples failed to sample many Tiger Muskellunge, fyke nets (.91 m x 3.05 m; with 12.7 mm mesh, .91 m x 1.83 m rectangular cab, 152.4 mm throat and a 20.12 m lead), mini fyke nets (0.6 m x 6.35 m; with 3.18 mm mesh, 0.6 m x 1.92 m rectangular cab, 60 mm metal throat and a 9.14 m lead), and floating fyke nets (add floats to the cab and hoops to both fyke nets and short lead fyke nets) were also used to increase the number of Tiger Muskellunge captured. Additionally, experimental gill nets (24.4 m long by 1.8 deep and composed of eight, 3-m panels [12.7, 15.875, 19.05, 25.4, 38.1, 50.8, 63.5, and 76.2 mm bar mesh]) were used in May of 2017 to ensure that Tiger Muskellunge were not avoiding electrofishing and trap-net gears. All nets were set haphazardly to avoid the herbaceous and woody vegetation that surrounds the lake. The entire perimeter of the lake was sampled via boat electrofishing during each monthly sample. Temperature and dissolved oxygen (DO) profiles were recorded monthly using a YSI Professional Series 1020 meter. Secchi turbidity measurements were recorded monthly using a turbidity tube as outlined in Myre and Shaw (2006).

After capture, all Tiger Muskellunge were measured (mm), weighed (g), and stomach contents removed by gastric lavage techniques outlined by Fowler and Morris (2008). Stomach contents were place into a zip-lock bag marked with a corresponding number to each individual fish and placed on ice until they could be frozen. In the laboratory, food items were thawed, weighed (g) and volumetric displacement was measured (ml). Food items were categorized into 4 groups: fish, aquatic vegetation, invertebrates, and other prey. Items were identified to species when possible using scientific taxonomic

Table 1. Stocking dates, number, rates, and total length (mm) for Tiger Muskellunge at Lake Carl Etling in Oklahoma.

Date Stocked	*n*	*#/ha*	Mean Total Length (mm)
10/08/2014	166	2.5	206
10/20/2015	805	12.5	193
2/10/2016	205	3.2	236
5/06/2016	1200	18.7	319
2/16/2017	280	4.4	252

keys to identify aquatic invertebrates (Merrit et al. 2008), fish fillets and scales (Oats et al. 1993), clethra guide (Traynor et al. 2010), and dichotomous key (Miller and Robison 2004). Stomach samples were analyzed by percent of empty stomachs, frequency of occurrence (O_i), percent composition by number (N_i), percent composition by volume (V_i), and index of relative importance (IRI) (Bowen 1996, Chipps and Garvey 2007).

Results & Discussion

A total of 2,656 Tiger Muskellunge were stocked from 2014 through 2017 (Table 1). During monthly sampling events, 76 juveniles and 1 adult Tiger Muskellunge were captured from July 2015 through May 2017. Daytime electrofishing captured 95% (73 of 77) of the individuals sampled (Table 2) during 66.83 h of pedal time. Fyke nets and mini fyke nets combined captured the remaining 5% (4 of 77) of Tiger Muskellunge sampled. Gillnets were used in May 2017 to attempt to capture Tiger Muskellunge, however no individuals were caught. A total effort for all gear types combined was 2,442.6 h.

Most fish were captured as juveniles within 2-3 months post-stocking, and juveniles were not present in monthly surveys after November in 2015 (fish stocked in October), after July in 2016 (fish stocked in February and May), and after May in 2017 (fish stocked in February). After no age-1+ tiger Muskellunge were sampled by late summer 2016, it was hypothesized that the mean total length of fish at stocking was too small (Table 1), and fish were being preyed upon by resident predators (Largemouth Bass, Walleye) shortly after stocking. This resulted in Walleye stocking to be discontinued. Stein et al. (1981) found that 95% of Tiger Muskellunge stocked ≤180 mm were preyed upon within 40 days after stocking and recommended that tiger muskellunge be stocked after they are > 250 mm, TL to reduce predation by Largemouth Bass, Walleye, and other Tiger Muskellunge. Therefore, in 2016 and 2017 fish were held in hatchery ponds at the Bryon State Fish Hatchery and were not stocked until their mean length was ≥250 mm. Despite efforts to grow fish to larger sizes prior to stocking, Tiger Muskellunge still were not observed in samples > 3 months from the time of stocking, suggesting stocking failure.

Table 2. Number of Tiger Muskellunge captured in Lake Carl Etling for each sampling method during 2015-2017.

Year	Method	Number Captured	Net Nights	Effort (hhh:mm)
2015	Electrofishing (Daytime)	8	-	23:10
	Electrofishing (Nighttime)	0	-	13:40
	Fyke Nets	0	55	770:00
	Mini Fyke Nets	0	36	468:00
2016	Electrofishing (Daytime)	54	-	31:10
	Electrofishing (Nighttime)	0	-	14:50
	Fyke Nets	2	42	504:29
	Mini Fyke Nets	2	29	319:22
	Floating Fyke Nets	0	12	168:17
2017	Electrofishing (Daytime)	11	-	12:30
	Gill-nets	0	9	117:08

Following stocking each year, mean relative weight (W_r) of juvenile Tiger Muskellunge decreased each month until they were no longer detected in monthly samples (Figure 2). Relative weight at the time of stocking was 94 – 112 and declined to < 75 in three to four months, with the lowest W_r being 46 in July of 2016 (2 months after the May stocking). Relative weight remained highest for February-stocked fish. All fish stocked in spring had rapid drops in W_r from May to July (Figure 3). During this May to July time period, water temperature increased, which may have caused sub-lethal stress to Tiger Muskellunge, ultimately resulting in stocking failure via delayed mortality.

The likely cause of stocking failure was exposure to high temperatures. In a laboratory experiment, Snow et al. (*in-press*) exposed Tiger Muskellunge to a range of acclimation temperatures and found as acclimation temperature increased, mean lethal thermal maxima response variable temperatures increase as well. Based on these results, Tiger Muskellunge should be able to survive during the hottest part of the year in Lake Carl Etling. However, Snow et al (*in-press*) also found thermal stress responses were 2-3^{o}C lower for starved fish than for fed fish in the 28^{o}C acclimation treatment. There was a span of 20 days in Lake Carl Etling during the summer of

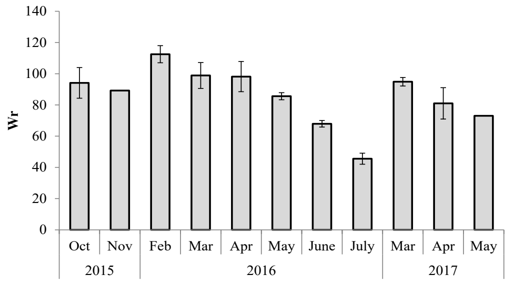

Figure 2. Mean relative weight (Wr) of Tiger Muskellunge (>240 mm TL) collected monthly during 2015-2017 from Lake Carl Etling, Oklahoma. Error bar represent standard error. Months without error bar indicate only 1 individual was captured in that month.

2015 that exceeded the thermal maximum of Tiger Muskellunge if fish were not foraging, that could have resulted in death. Water temperatures were also exceedingly warm during June and July 2016 (29.9 to 33.4^{0}C from the dam to the creek mouth), which would have likely resulted in death of juvenile tiger muskellunge regardless of their foraging return. The mean water temperature on July 6, 2016 was 32.1^{0}C, high enough to exceed the upper thermal limits of a juvenile Tiger Muskellunge, especially if they were not able to forage. Not only did Tiger Muskellunge disappear from monthly samples, but anglers also reported the inability to catch Tiger Muskellunge past July 2016.

Tiger Muskellunge are an ambush predator, which depend on sight when foraging (Andersen et al. 2008). Lake Carl Etling is highly turbid at times due to suspended solids. High turbidity levels could affect the ability for Tiger Muskellunge to detect prey, which could result in reduction of foraging return and ultimately starvation. In a laboratory study, a secchi depths ≤ 26 cm (increased turbidity levels) reduced the foraging success and selectivity of juvenile Tiger Muskellunge (Snow et al. *in review*). The mean monthly secchi depth at Lake Carl Etling was 23.4 cm from October 2015 through May 2017. Therefore, a combination of increasing turbidity levels and high water temperatures likely resulted in increases in Tiger Muskellunge metabolism making them expend more energy foraging with little success, thus leading to starvation and death.

Out of all Tiger Muskellunge sampled, 76.6% had empty stomachs (no food items present), which may explain the overall poor condition (Figure 3) of juvenile Tiger Muskellunge and supports the plausible scenario that the fish were not able to forage efficiently under the conditions experienced in Lake Carl Etling. The remaining 23.4% of Tiger Muskellunge contained 5 species of fish and 1 species of invertebrate (Table 3). Gizzard shad composed the bulk of the diet, representing 43.8% of the food eaten (V_i) and was the most important diet item (56% IRI). Bluegill represented the second most important species consumed by Tiger Muskellunge at 15.1% (IRI), just ahead of Green Sunfish 7.2% (IRI). Both Gizzard Shad and Common Backswimmer (*Notonecta glauca*) were the most numerically abundant item consumed 25% (N_i), however Common Backswimmers ranked

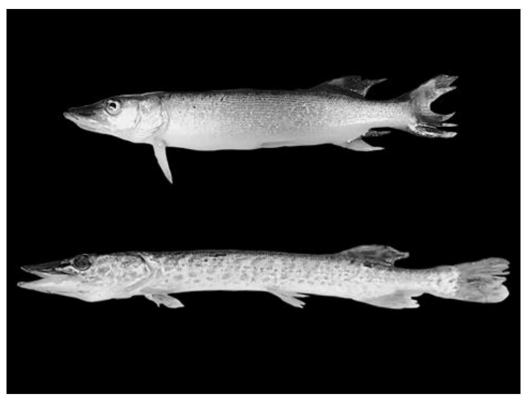

Figure 3. Tiger Muskellunge that were stocked in May 2016 into Lake Carl Etling, Oklahoma. The top photograph is an average size/condition Tiger Muskellunge at time of stocking (284 mm TL, 125 g, and relative weight = 108). The bottom photograph is a Tiger Muskellunge that was captured in Lake Carl Etling during the July 2016 electrofishing survey. This fish shows the effects of high temperature and increased turbidity on condition of juvenile Tiger Muskellunge (337 mm TL,100 g, and relative weight = 49)

Table 3. Percent composition by number (N_i), percent composition by volume (V_i), frequency of occurrence (O_i), and Index of Relative Importance (IRI) of prey items consumed by Tiger Muskellunge in Lake Carl Etling from 2015 - 2017.

Prey	%N_i	%V_i	%O_i	%IRI
Fish:				
Bluegill Sunfish	15	22.2	18.75	15.1
Gizzard Shad	25	43.8	37.5	56.0
Green Sunfish	10	16.4	12.5	7.2
Plains Killifish	5	9.6	6.25	2.0
Invertebrate:				
Common Backswimmer	25	4.8	6.25	4.1
Other:				
Unknown	22.2	3.2	31.25	15.6

4.1% (IRI) in importance because of their small size (Table 3). Unknown diet items occurred in 31.25% (O_i) of diets, but only made up 3.2% by volume (Table 3).

Lake Carl Etling has experienced drastic changes in temperature regime through time, with resulting changes in species composition. In May 1959, a Rainbow Trout (*Oncorhynchus mykiss*) fishery was created from an initial stocking of 52,800 fingerlings (Houser 1961). This resulted in a year-round trout fishery from 1959 - 1961. However, after 1963, trout could no longer survive year-round in Lake Carl Etling, leading ODWC to create a winter time fishery for trout in 1989 (ODWC unpublished data). Bennett (1979) describes Lake Carl Etling as a highly vegetated, clear water lake (secchi depth of 48 cm) with marginal dissolved oxygen (DO) levels below 6 m and a main pool surface and bottom temperature of 22.5^{0}C and 21.5^{0}C, respectively in August. This is considerably different than main pool mean temperature from 2015-2016 in August of 28.7^{0}C (surface) and 24.6^{0}C (bottom) with anoxic condition below 3.4 m and a mean secchi measurement of 31 cm (high turbidity levels). Furthermore, there is a substantial difference in maximum depth (9.8 m) recorded in 1992 (Stahl 1992) and in 2014 (5.7 m).

We hypothesize that changes in land practices and sedimentation via stream flow or dust storms has affected the natural spring flowing into Lake Carl Etling. Historically, it is likely that flowing springs were used as thermal refuge by cold water species during the summer months in Lake Carl Etling. Koch and Steffense (2013) found that Northern Pike in Kingsman Lake in Southcentral Kansas become vulnerable to anglers when fish congregate on cold water springs during the hottest months of the year. In the early 1980's, ODWC attempted to excavate a natural spring in the bottom of Lake Carl Etling that was thought to be plugged with silt and organic matter. Despite hitting ground water, this attempt was unsuccessful as water flow from the spring was not initiated (John Stahl, Oklahoma Department of Wildlife Conservation, personal communication). Lake Carl Etling is located near the High Plains aquifer, which includes Beaver, Cimarron, Ellis, Harper, Texas and Woodward Counties in Northwestern Oklahoma. Water level in this aquifer has decreased 3.4 m from predevelopment to 2011 (McGuire 2012). The main reason for the reduction of the High Plains aquifer is the increase in the number of large capacity wells (> 100 gal min; < 50 in the 1950's to an estimated 2,400 in 1999) used mostly for agricultural purposes (Luckey and Becker 1999). We speculate that Lake Carl Etling's elevation is higher than the current elevation of the water table of the High Plains aquifer, resulting in a cut off of flow to the natural springs. Furthermore, the main substrate in the area is sand, which allows water to permeate quickly making it difficult for Lake Carl Etling to maintain normal pool level.

Stocking fish at the fringe of its geographic range can be risky as small changes in habitat or annual environmental variation could make the habitat unsuitable for stocking success. For example, Northern Pike stocking efforts were successful in the 1970's in Lake Carl Etling. Because of the success of the Lake Carl Etling introductions, ODWC attempted to create a sport fishery for Northern Pike in Watonga Lake located within Roman Nose State Park, Blain County, Oklahoma. Fish were stocked from 1970 to1976 with no observed recruitment of Northern Pike. A single Northern Pike (838 mm Tl, 2408 g) was captured during an annual gill-net survey in 1980, four years after the last stocking (ODWC unpublished data). No other Northern

Pike were caught in surveys conducted during and after stocking, similar to efforts targeting Tiger Muskellunge in Lake Carl Etling. During the time that stocking was occurring, fertilizer was being added to Watonga Lake each spring to offset poor primary productivity and promote phytoplankton growth. Fertilizing would cause phytoplankton-induced turbidity, which has shown to decrease population densities of Northern Pike (Cassleman and Lewis 1996). Furthermore, Craig and Babaluk (1989) described poor condition of Northern Pike caused by turbid water conditions that affected their ability to forage, leading to decreased prey consumption. Northern Pike have lower lethal thermal maxima than Tiger Muskellunge, which if Northern Pike react similar through periods high temperature and starvation, it could have affected the ability of Northern Pike to recruit in Watonga Lake. These results suggest that it is critical to understand reservoir conditions (i.e. predator abundance, forage availability, water turbidity, water temperature) prior to stocking a new species as this may determine how successful an introduction will be.

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