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DISSERTATION

ASSESSMENT OF POST-STOCKING MORTALITY FOR TIGER MUSKIES AND STRATEGIES TO INCREASE SURVIVAL

Submitted by

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In partial fulfillment of the requirements

for the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer, 1999

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY KEITH D. KOUPAL ASSESSMENT OF POST-STOCKING MORTALITY FOR TIGER MUSKIES AND STRATEGIES TO INCREASE SURVIVAL BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

ASSESSMENT OF POST-STOCKING MORTALITY FOR TIGER MUSKIES AND STRATEGIES TO INCREASE SURVIVAL

This research was designed to determine major sources of post-stocking mortality for tiger muskies (Esox lucius X E. masquinongy), a stocking strategy to alleviate post-stocking mortality, and an acceptability index to effectively allocate available juvenile tiger muskies. Fish predation appears to have caused post-stocking mortality of 8-49% during 3 years of experimental pond trials, but results were only significant at the 0.05 level in 1 year. However, the consistency of results implicates fish predators as a major contributor to post-stocking mortality of tiger muskies. Bird scarring was observed on a range of 5-17% of surviving tiger muskies during these same experimental pond trials, which suggests that bird predation may also contribute to post-stocking mortality of tiger muskies. Stocking stress, inability to efficiently capture prey, and insufficient condition to survive overwinter were not found to contribute to post-stocking mortality. Providing tiger muskies with predator training ($p = 0.28$) and pond training ($p = 0.33$) did not significantly reduce post-stocking mortality. Early (125 mm total length) and late-stocked (receiving water was 2-4°C) tiger muskies showed no significant difference ($p = 0.43$) for decreasing post-stocking mortality when compared to normal-stocked (early

October) tiger muskies in 1996. In 1997, an adjusted late (receiving water was 5-9°C) resulted in a decrease in post-stocking mortality when compared to normal stocking under similar conditions with predators ($p = 0.02$) and without predators ($p = 0.10$). The acceptability index is intended to assist in the allocation of limited juvenile tiger muskies. The index consists of five primary attributes which include temperature regime, water clarity, living and non-living cover, escapement potential, and availability of prey. These primary attributes are designed to assess the suitability of a water. The derived suitability rating is combined with an acceptability attribute score to obtain a likelihood for successfully establishing tiger muskies. With present knowledge, reservoirs with values of low-medium or low should not be stocked.

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DEDICATION

For my family, they have been an inspiration. Their love and understanding have allowed me to pursue my graduate education.

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BACKGROUND

Northern pike (Esox lucius) is a non-native species to Colorado (Scott and Crossman 1973), that was originally introduced into two of Colorado's eastern plains reservoirs in 1956 to provide sportfish for anglers (Finnell 1983). These two populations were unable to sustain their numbers through natural recruitment. Northern pike were then introduced to several high elevation reservoirs in an attempt to biologically control sucker (Catostomus spp.) populations. In these settings northern pike were able to naturally recruit (Finnell 1983). Concerns over escapement and lack of management control on naturally recruiting northern pike populations led the Colorado Division of Wildlife (CDOW) to use of sterile hybrid tiger muskie (E. lucius X E. masquinongy) for biologically controlling non-game fish populations (Satterfield et al. 1994).

Tiger muskies offer several management advantages over their parental species: higher thermal tolerance than northern pike (Carlander 1969); sterility (Hesser 1978; Satterfield 1993); initial hybrid vigor (Schrouder 1973; Weithman and Anderson 1976; Bovelhimer et al. 1985); hatchery benefits of better survival, greater disease resistance, conversion to pellets (Hesser 1978); and higher vulnerability to anglers than muskies (E. masquinongy), but less than northern pike (Beyerle 1973; Weithman and Anderson 1976). Tiger muskies have been stocked into 51 eastern Colorado impoundments since 1983, and the CDOW annually stocks approximately 38,000 tiger muskies (Satterfield et al. 1994). Stocking success has varied greatly; sometimes strong year-classes have established while other stockings have resulted in no measurable survival.

This dissertation is separated into three chapters, which address a specific objective and present results of related, but independent research. The objective of the first chapter was to determine which processes account for high mortality of stocked juvenile tiger muskies. Many factors have been implicated in post-stocking mortality: thermal stress during stocking (Mather et al. 1986); previous feeding experience (Wahl and Stein 1989; Szendrey and Wahl 1995) species and size of prey available (Weithman and Anderson 1977; Gillen et al. 1981); stocking size and time (Beyerle 1981; Beyerle 1984; Carline et al. 1986); and predation by largemouth bass (Micropterus salmoides) (Stein et al. 1981; Carline et al. 1986; Wahl and Stein 1989). All of the previous research was conducted in the Midwest, and it was unknown if it could be applied to Colorado waters.

I examined the following hypotheses to determine major factors of post-stocking mortality for tiger muskies: 1) The inability of fish to handle stocking stressors, i.e. water quality changes, temperature changes, and/or handling; 2) The inability of hatchery fish to efficiently capture prey in the wild; 3) The condition of hatchery fish going into winter is unsuited to survival; and 4) The inability of newly stocked fish to escape piscivorous predators. Seven experiments were conducted to provide information about these hypotheses. Each experiment was designed to provide information about a specific hypothesis, but results gave insight into several hypotheses.

The objective of the second chapter was to devise stocking strategies to reduce post-stocking mortality. A common belief is that mortality of young-of-the-year (YOY) tiger muskies occurs before the onset of winter. Hence, stocking strategies were evaluated the following spring after tiger muskies had experienced the initial pulse of mortality plus their first winter. Four specific hypotheses for survival of stocked tiger muskies until the following spring were examined: 1) Exposing tiger muskies to fish predation prior to stocking increases survival (because these fish observe predators and learn to avoid them); 2) Placing tiger muskies in a pond prior to stocking increases survival (by allowing them to learn how to search for appropriate habitat, which decreases their vulnerability when stocked); 3) Stocking tiger muskies earlier in the year at a smaller size increases survival (by placing them with more abundant and appropriate prey sizes which in turn can increase tiger muskie growth and provide a buffer of prey to other predators); and 4) Stocking tiger muskies later in the year (after or near formation of ice cover) increases survival (because these fish will avoid bird predation, are exposed to reduced activity of piscivorous fish, and are larger when stocked).

The cost required to raise tiger muskies in a hatchery is a concern of state fish and wildlife agencies. Many years hatchery production falls short of requested numbers. For these reasons reservoirs with higher likelihood of establishing a fishable population should be stocked. The logic employed in the habitat suitability index model developed by McConnell et al. (1984) for reservoirs under construction was used to develop a stocking method for tiger muskies in Colorado (Chapter 3). The new index is called an acceptability index. The goal of the acceptability index is to assess physical, biological, and operational attributes of the current year to predict an existing waters ability to allow sufficient numbers of stocked tiger muskies to survive and grow until their second fall. The index will help biologists rank a water's ability to support tiger muskies and guide the annual allocation of hatchery fish between water bodies.

CHAPTER I - Causes of Post-Stocking Mortality

INTRODUCTION

Tiger muskies have developed fishable populations in less than 1/3 of the waters stocked in Colorado. The reasons for poor survival of stocked tiger muskies are unknown, however many factors have been implicated in studies elsewhere: thermal stress during stocking (Mather et al. 1986); previous feeding experience (Wahl and Stein 1989; Szendrey and Wahl 1995); species and size of prey available (Weithman and Anderson 1977; Gillen et al. 1981); stocking size and time (Beyerle 1981; Beyerle 1984; Carline et al. 1986); and predation by largemouth bass (Stein et al. 1981; Carline et al. 1986; Wahl and Stein 1989). The history of esocid fishes in the Rocky Mountain region is short, since these species are not native to this region. The results of previous research mentioned for tiger muskie in the Midwestern United States have guided hatchery techniques and stocking strategies in Colorado. These changes included stocking fish later in the year, at a larger size, at night, away from shorelines, and with some previous exposure to prey fish. These strategies have provided success in a few waters; unfortunately consistent survival is below expectations.

To increase management success with this species in Colorado and other western states, factors contributing to post-stocking mortality need to be better understood.

Specific hypotheses for this research were to document post-stocking mortality of tiger muskies related to: 1) The inability of fish to survive stocking stressors; 2) The inability of hatchery fish to efficiently capture prey in the wild; 3) The condition of hatchery fish to survive overwinter; and 4) The inability of stocked tiger muskies to escape piscivorous predators. Seven experiments were conducted to provide information pertaining to these hypotheses (Table 1.1). Individual experiments investigated a specific hypothesis, but results provided insight into multiple hypotheses.

METHODS

The methods for the research conducted during these trials can best be viewed by looking at each individual experiment. However, the hatchery production of fish and analysis of results are consistent for all experiments and presented in overview so they are not repeated in each section. The Pueblo Fish Hatchery received eyed eggs or fry from the Linesville Fish Hatchery in Linesville, Pennsylvania. These fish were raised to fingerling size (50-75 mm) and transported to the Wray Fish Hatchery. The Wray Fish Hatchery was responsible for growing these fish until they were stocked. In 1995, tiger muskie fingerlings were raised on pellets. During the same year, approximately 2,000 fingerlings used in experimental trials were stocked into a 0.1-ha culture pond and fed fathead minnows (Pimephales promelas) 2 weeks before being stocked. Fish that are exposed to only pellet feeding prior to stocking are referred to as "naive", while fish that are exposed to fish prey prior to stocking are referred to as "experienced". At the request

Table 1.1 Overview of experiments utilized to assess the causes of post-stocking mortality and the pond or field trials corresponding with each experiment.

Hypothesis of Concern	Experimental Set-up
Handling stress	Two replications of tank holding times of 0 h, 3 h, 6 h, and 9 h
Prey are available and can be captured	Two pond replications of no prey, adequate size prey, and large prey Two stockings of experienced and naive tiger muskies in two reservoirs
Overwintering	Two pond replications of fish held and not held in cages
Fish predation	In 1995, six and four pond trials with and without predators, respectively In 1996, 12 and 2 pond trials with and without predators, respectively In 1997, six and eight pond trials with and without predators, respectively

of biologists, all tiger muskies were provided fathead minnows within raceways for 2 weeks before being stocked in 1996 and 1997.

Survival of stocked tiger muskies is subject to large variability, which makes it difficult to assess differences between the means of designed experimental treatments. For this reason, an arcsine transformation for proportions (Snedecor and Cochran 1967) was used on survival percentages to reduce variability. This transformation was utilized for determining statistical significance of treatments. Percent survival is reported in non-transformed form to allow a better understanding of results by readers. Differences in survival and tests of assumptions were analyzed by general linear models in SAS (SAS Institute 1982) and significance determined at the 0.05 level. All confidence intervals are determined from non-transformed survival percentages at the 95% level. Other statistical procedures are described in particular method sections.

Handling Stress

The stocking process for tiger muskies in Colorado involves loading fish at Wray Fish Hatchery, driving to the first body of water to be stocked, unloading a portion of the tiger muskies, driving to the next reservoir, and so on until the load has been distributed. This procedure results in some fish being held in hauling tanks for many hours. An experiment was designed to determine the effect holding time has on short-term survival. Tiger muskies raised at the Wray Hatchery were divided into eight lots of 60 fish and randomly designated into two replications of either control, 3-h, 6-h, or 9-h experimental units. All fish were starved 24 h before initiation of this experiment. Each experimental unit was placed into a 37.9-L container filled with 18.9 L of water and supplied with lids and air stones. Control fish were placed into a 37.9-L container, then immediately removed and assigned to a circular tank that contained approximately 400 L of water. The other three experimental units were placed in a vehicle and driven around for their randomly assigned time of either 3 h, 6 h, or 9 h. After completion of the driving time, each unit was placed within its own randomly assigned identical circular tank. Each circular tank was covered with a black plastic sheet to prevent escapement and had water added at a rate of 37.9 L/min (6 exchanges/h). Each unit of fish was fed a normal pellet diet and observed within these confines for 3 d to record mortality.

Experienced versus Naive

Experienced tiger muskies have shown better survival than naive fish (Johnson 1978; Gillen et al. 1981; Szendrey and Wahl 1995). Even though experienced tiger muskies have been stocked in Colorado, a comparison of their success versus naive fish was not done. Evergreen Reservoir and Stearns Reservoir (Table 1.2) were chosen for this experiment because of relatively small numbers of tiger muskies required, 200 and 400, respectively. In 1995, equal numbers of experienced and naive fish were stocked at night from the Wray Fish Hatchery. Naive fish had a left pelvic fin clip and experienced fish a right pelvic fin clip. This mark identified recaptured fish as experienced or naive and maintained similar handling procedures for both lots. McNeil and Crossman (1979) determined that muskies received negligible stress from the removal of one pelvic fin.

Table 1.2 Reservoir descriptors for Evergreen Reservoir and Stearns Reservoir.

Descriptor	Evergreen Reservoir	Stearns Reservoir
Elevation (m)	2155	1606
Surface area (ha)	17	10
Maximum depth (m)	7	3
Primary drainage	Bear Creek	St. Vrain Creek
Fluctuation	minimal <1 m	minimal <1 m
Outlet	spillway overflow	spillway overflow
Year TGM[a] introduced	1989	1988

[a] TGM = tiger muskies

These bodies of water were sampled with 12-mm bar mesh gill nets (30.3-m x 1.2-m) and/or by electrofishing with a 5000-Watt generator approximately 7 d, 14 d, 28 d, and once the next spring to determine relative survival of naive and experienced fish. Annual sampling with 45.7- x 1.8-m multifilament experimental (19-, 25-, 32-, 38-, 51-, and 64-mm bar meshes) gill nets was conducted in April or May in 1996, 1997, and 1998 to follow those stockings. Seine hauls, cloverleaf traps, and standard CDOW trap nets (Powell 1980) were also employed to capture juvenile tiger muskies.

Prey Availability

Tiger muskies prefer prey body lengths to be a certain percentage of their own total length, depending on the body shape of the prey species (Gillen et al. 1981). This preference may make size of prey at time of stocking important. This experiment examined the survival of tiger muskies offered no fish prey, ideal length fish prey, and larger than ideal length fish prey.

Tiger muskies were transported from Wray Fish Hatchery to Colorado State University Foothills Research Campus in early October, where they were held in raceways and fed pellets for 3 d to ensure that mortality within experiments would not be related to handling and transportation stress. Six lots of 15 tiger muskies were individually weighed, measured, marked, and randomly assigned to one of six 0.032-ha ponds. Cold branding was the first attempt at marking tiger muskies and was unsuccessful. The same fish were allowed to rest for 3 d and then given T-bar anchor tags to individually identify them. Four lots of 225 white suckers (C. commersoni) were to be approximately 33-40% and 50-60% of the average total length of tiger muskies in this experiment. Unfortunately available white suckers were approximately 50% and 65% of the average total length of stocked tiger muskies. The four prey lots were randomly assigned into ponds, and after 14 d all six ponds were drained for an early indication of predator and prey interactions. Tiger muskies from each pond were counted, and total lengths (mm) and weights (g) were taken. Prey were counted. Ponds were refilled and existing communities replaced to allow these communities to exist overwinter. Ponds were drained in April; surviving tiger muskies were counted, weighed (g), and measured for total length (mm); and prey were counted.

An additional experiment was related to this hypothesis and had similar procedures. Four lots of 20 tiger muskies were randomly selected and placed into four separate 0.04-ha ponds. Two of the ponds contained 3.6 kg of fathead minnows and the other 2 ponds had no fish prey. Communities were allowed to exist overwinter and drained the following April. Surviving tiger muskies were counted, weighed (g), and measured for total length (mm). Remaining fathead minnows were batch weighed (kg).

Overwintering

Tiger muskies raised within a hatchery system may be in unsuitable condition to survive overwinter. This experiment was designed to determine their ability to survive overwinter while protected from all predators and receiving minimal amounts of food.

Tiger muskies were transported from Wray Fish Hatchery to Colorado State University Foothills Research Campus. There they were held in raceways and fed fathead minnows for 3 d to ensure mortality within experiments would not be related to handling and transportation stress. Tiger muskies were weighed (g) and measured for total length (mm) and randomly assigned into 8 lots of 10 fish. Each lot of fish was placed in a 1.22-m by 1.22-m by 1.22-m floating cage. Four cages were suspended in each of two 0.04-ha ponds. Mesh sizes on these cages were either 6.3 or 9.5-mm woven mesh. Tiger muskies were fed minimal amounts of fathead minnows throughout the winter and checked periodically for mortality or evidence of cannibalism. Cages were removed when ice cover was gone, and surviving tiger muskies were weighed (g) and measured for total length (mm). Ponds were drained to determine if any lost tiger muskies had escaped the cages. Concurrently two 0.04-ha ponds were stocked with 15 tiger muskies and 3.6 kg of fathead minnows to serve as controls.

Fish Predation

The role of fish predation in post-stocking mortality was assessed in conjunction with stocking strategy trials in 1995, 1996, and 1997. In 1995, fish predation was included as part of a completely random incomplete block of a four by two factorial design. The experiment chose five separate combinations of these four factors and replicated them twice (Table 1.3). Six ponds and four ponds of 20 tiger muskies were stocked into communities with and without predators, respectively. In 1996 and 1997 the emphasis was on time of stocking tiger muskies, but communities with and without predators were included for comparison of this factor. In 1996, 12 ponds were stocked with predators and 2 ponds without predators. In 1997, eight ponds were stocked with

Table 1.3 Experimental design utilized to assess the effect of fish predation.

1995

Number of Ponds in Replication	Exposed to Predators Pre-stocking		Exposed to Pond Pre-stocking		Predator Present in stocking		Prey Present in stocking	
	Yes	No	Yes	No	Yes	No	Yes	No
2	X		X		X		X	
2		X	X		X		X	
2		X		X	X		X	
2		X		X		X	X	
2		X		X		X		X

1996

12		X		X	X		X	
2		X		X		X	X	

1997

8		X		X	X		X	
8		X		X		X	X	

and without predators. All 1996 and 1997 trials utilized randomly selected lots of 15 tiger muskies.

In all years tiger muskies were transported from Wray Fish Hatchery to Colorado State University Foothills Research Campus. There they were held in raceways and fed pellets or fathead minnows for at least 3 d to ensure mortality within experiments would not be related to handling and transportation stress. Three walleyes (Stizostedion vitreum) ($\geq$350 mm total length) served as predators in the exposure and experimental portions of this trial. A prey base of 3.6 kg of fathead minnows was provided to all of these trials except the two replications designated in Table 1.3. All pond trials were drained the following spring after ice-off, and survival of tiger muskies, walleyes, and fathead minnows (by weight) determined. Statistical comparisons were conducted for each year with models that considered the presence of predators and particular stocking strategies conducted during that year. Analysis of these models was performed by general linear models in SAS (SAS Institute 1982) to determine if a difference in mean survival could be detected. In 1995 and 1997 multiple pairwise comparisons were planned and the level of significance adjusted by the Bonferroni method. The p-values for differences between pairs were determined by least square means in SAS (SAS Institute 1982).

RESULTS AND DISCUSSION

Tiger muskies seem resistant to mortality from handling stressors. Simulation of CDOW stocking procedures produced no mortality (Table 1.4). Statistical procedures were not applied to experimental results since survival was 100%. These results are supported by field observations. Individual tiger muskies have been subjected to netting, transportation, branding, tagging, anesthetics, weighing, measuring, and occasionally being dropped, and no mortality from these procedures has been noted. In addition, 14-d results of white sucker experiments, 1996 and 1997 overwinter cage results, and field checks with cages at Stearns Reservoir in 1996 show near 100% tiger muskie survival shortly after stocking. This suggests that handling stressors are not a direct contributor of post-stocking mortality for tiger muskies.

Initial mortality on esocids due to stocking stressors can be as high as 30% (Johnson 1978; Stein et al. 1981). However, both in Wisconsin and Ohio, where these studies were conducted, tiger muskies are stocked in late August or early September into much warmer water. Mather et al. (1986) found juvenile tiger muskies display significant mortality due to dramatic thermal increases but minimal mortality related to handling or to high density confinement. Since standard stocking procedures employed by the CDOW acclimate tiger muskies to similar temperatures, my results would concur with those found by Mather et al. (1986). Current research extends beyond Mather et al. (1986) in that it accounts for length of time in confinement (up to 9 h), which also produced no mortality. Therefore, the hypothesis that post-stocking mortality of tiger muskies occurs due to the inability of fish to survive current stocking stressors is rejected.

Table 1.4 Survival of tiger muskies 3 days later from induced handling stressors.

Transportation Time (h)	Number of Tiger Muskies	Survival (%)
0	60	100
0	60	100
3	60	100
3	60	100
6	60	100
6	60	100
9	60	100
9	60	100

Research comparing naive and experienced tiger muskies failed to produce results. All gear were unsuccessful in capturing juvenile tiger muskies during the initial year of stocking, except one seine haul in Stearns Reservoir which contained three yearlings. Two of these were experienced and one was naive. Continued monitoring of these stockings found one naive and one experienced adult tiger muskie during the spring of 1998 in Evergreen Reservoir. This concurs with current assumptions that tiger muskies become vulnerable to gill nets at approximately age 3. It is believed that both naive and experienced stockings in Evergreen Reservoir and Stearns's Reservoir in 1995 can be considered failures. These stocking failures may have occurred in part because high water years in 1996 and 1997 allowed both reservoirs to overflow, providing easy escapement.

A review of the literature indicates that experienced tiger muskies have displayed better survival than naive fish (Johnson 1978; Gillen et al. 1981; Szendrey and Wahl 1995). But those experiments utilized experienced tiger muskies that were larger than their naive counterparts (i.e. test of size not "experience"). I attempted to account for size variation by selecting a batch of smaller tiger muskies and feeding them on fathead minnows for a short period of time (2 weeks). Experienced tiger muskies averaged 204.6 mm (± 11.7 mm) and 35 g (from batch weight), while naive tiger muskies averaged 195.9 mm (± 8.7 mm) and 29 g (from batch weight). The difference in length is not significant ($p = 0.19$). Lack of success from these stockings precludes any definable results.

The mechanism by which exposing tiger muskies to fathead minnows within the hatchery increases post-stocking survival is likely increased size of stocked tiger muskies and/or experience of prey capture. Gillen et al.(1981) noted that available size of prey widened dramatically as tiger muskies grew from 150 mm to 190 mm. Additionally, increased size of stocked tiger muskies makes them less available as prey. Thus, greater length provides more opportunity to capture prey and less opportunity to become prey. Gillen et al. (1981) observed an increase in efficiency of prey capture between experienced and naive tiger muskies of 1.3 strikes per capture to 2.0 strikes per capture, respectively. However, it is unlikely that capturing prey inefficiently would be a singular cause of mortality. In some of my trials, tiger muskies consumed invertebrates as an alternative to piscivorous prey. The drawback of capturing prey inefficiently, or not at all, would be slower growth making size of tiger muskies being stocked as the overriding factor of higher survival.

Experiments designed to determine if adequate size prey affected survival had poor results. It was difficult to find white suckers small enough to fit the proposed length categories [(33-40%) and (50-60%)], so prey that approximated 50% and 65% of predator length were used for small and large prey categories. However, size of white suckers used in this trial most likely typifies natural sizes found in this geographical region. After 2 weeks all ponds in this experiment were drained, and no mortality of tiger muskies or white suckers was found. No detectable growth had occurred either. These same communities were re-established. In the spring, tiger muskies with no fish prey, smaller white suckers, and larger white suckers produced 0%, 10%, and 13% survival, respectively (Table 1.5). There was no statistical difference ($p = 0.32$) between survival of tiger muskies within these three prey conditions.

Table 1.5 Survival of tiger muskies stocked with two sizes of white suckers.

Prey Used	Prey Survival (%)	TGM[a] survival (%)	Mean TGM[a] survival (%)
None	N/A	0	
None	N/A	0	0
Small	18	0	
Small	21	20	10
Large	15	13	
Large	22	13	13

[a] TGM = tiger muskies

Survival of tiger muskies seems unrelated to consumption of white suckers as prey. Stomachs of surviving tiger muskies were pumped after ponds were drained in the spring. Only invertebrates were found. Furthermore, according to Gillen et al. (1981) the white suckers used in this trial are considered too large for tiger muskies. Confirmation for this assumption can be found from a body depth to total length regression for white suckers ($y = -9.1219 + 0.2083(x)$; $n = 29$; $r^2 = 0.97$), which estimates the body depth of the smaller white suckers as 14 mm and 17 mm for the larger white suckers. Tiger muskies utilized for this experiment had a mean total length of 199 mm with an estimated gape width of 14 mm ($y = -2.4923 + 0.0816(x)$; $n = 28$; $r^2 = 0.59$).

Possible sources of mortality in these six ponds was a general decline overwinter or the presence of piscivorous birds that concentrated their activities around the shallower 0.032-ha ponds. Bird predation is the most likely source of mortality since no carcasses were found and only 22% of white suckers were recovered. Additionally, a confounding factor developed within this experiment that appears to be related to survival. Bottom vegetative cover was between 20-35% for the three ponds with tiger muskie survival, while less than 1% vegetative cover was found in the other ponds. Perhaps this cover inhibited the success of piscivorous birds.

Surviving tiger muskies had invertebrates inside their stomachs and presumably lived solely on invertebrates all winter. The average growth in length was 9 ± 4% of their stocking length (mm) and weight was 31 ± 23% of their stocking weight (g) for surviving tiger muskies. Also, a look at total length of fish stocked showed that of seven remaining tiger muskies two were the smallest stocked in the pond and one was the largest, so it is unlikely that survival was linked to size. Non-size linked survival would be contrary to the conclusion drawn from naive and experienced tiger muskie survival trials. However, in these prey availability trials there were no fish predators, only bird predators. The range in size of stocked tiger muskies does not allow them to outgrow their role as prey to larger fish-eating birds during their first fall. In fact, larger tiger muskies may be more easily detected and captured by bird predators. These results indicate that availability of adequate size prey at the time of stocking does not appear to directly cause mortality, but may restrict growth and be an additive factor in mortality. It is important to note that survival was minimal (<8%) for this experiment.

Mortality due to stocked tiger muskies being in too poor condition to survive through the winter does not appear to account for a major percentage of tiger muskie mortality. The overall survival for the overwinter cage experiments was 98% (Table 1.6). Only 1 mortality was documented while another of the 80 tiger muskies was unaccounted, most likely due to escapement or cannibalism. Concurrently two control ponds displayed 33% and 0% survival during this same time period, which was significantly lower ($p = 0.05$) than overwinter cage survival (Table 1.6). Caged overwintering fish spent most of their time without available prey and also were subjected to being counted approximately monthly, which might have been stressful. High survival under these conditions strongly suggests that overwinter mortality by itself does not inhibit the establishment of tiger muskie populations.

Table 1.6 Overwinter survival displayed by caged and pond-held tiger muskies.

Experimental Unit	Number of Tiger muskies	Cage Survival (Percent)	Cage Mean	Pond Survival (Percent)	Pond Mean
Pond 1 (Cage 1)	10	90		N/A	
Pond 1 (Cage 2)	10	100	95	N/A	N/A
Pond 1 (Cage 3)	10	100		N/A	
Pond 1 (Cage 4)	10	90		N/A	
Pond 2 (Cage 5)	10	100		N/A	
Pond 2 (Cage 6)	10	100	100	N/A	N/A
Pond 2 (Cage 7)	10	100		N/A	
Pond 2 (Cage 8)	10	100		N/A	
Pond 1 (Control)	15	N/A		0	
Pond 2 (Control)	15	N/A	N/A	33	17
Overall Mean			98		17

The underlying question addressed by the assessment of overwinter survival is whether stocked tiger muskies are in good enough condition to survive until prey becomes available. In all three years of pond trials that were stocked in early October, only one pond had carcasses seen on the bottom or floating on the surface. Also, tiger muskies have been able to survive the winter without adequate size prey or without prey. This suggests that physical condition at time of stocking is capable of minimally sustaining stocked tiger muskies.

The presence of walleye appears to decrease first year survival of tiger muskies. The average percent survival increased 30% in 1995 ($p = 0.18$), 8% in 1996 ($p = 0.66$), and 49% in 1997 ($p < 0.01$) when communities had no walleye present (Table 1.7). Data from 1997 displayed a significant difference for percent survival, while data from 1995 indicated a relationship between survival and the presence of walleye. The 1996 data had only two control ponds stocked without walleye of which one had no tiger muskie survival. Tests of assumption were conducted to ensure that year of stocking, individual ponds, or pond types did not bias results. Data for years 1995, 1996, 1997 were not combined because a significant difference in percent survival among years was found ($p < 0.01$). Data for individual ponds ($p = 0.85$) were combined for all years and no significant difference in percent survival was found. Data for both pond sizes (0.04-ha and 0.032-ha) were combined for all years except the 0.032-ha ponds in 1995, which displayed an observed confounding factor of vegetation. A significant difference (p =

Table 1.7 Results for pond trials comparing fish predation.

Stocking Year	Survival (%) When Walleyes Present	95% Confident Interval	Survival (%) When Walleyes Not Present	95% Confident Interval
1995	15	±16	45	±28
1996	9	± 8	17	±32
1997	27	± 7	76	±14

0.39) was not found for these pond sizes. The tests of assumptions above indicate that survival was not affected by individual ponds or pond sizes, but was affected by the year in which stocking occurred.

It was not surprising to observe a high mortality of stocked tiger muskies in these pond situations. The stocking density of walleye represented a population of 75 adults/ha, which is an extremely high population density. However, walleye are a schooling fish, so densities where they are encountered could easily match experimental levels. Minimal amounts of cover were available within these ponds. The confounding factor, observed in the prey availability experiments between survival and percent available cover occurred in situations where walleye were not present. However, it would be a fair assumption to believe that presence of cover would increase survival of tiger muskies exposed to walleye predation. These stocking situations were designed to represent a worst case within the ponds, but these research ponds do shelter stocked tiger muskies from some conditions experienced in reservoirs. Experimental pond situations provide advantages over reservoirs by exposing tiger muskies to: a single fish predator species, stable water levels, and high density of adequate size prey (91 kg/ha) that is forced to interact by small pond size.

Fish predation on stocked tiger muskies does account for a significant portion of their mortality. Results from this study concur with Stein et al. (1981) who found 26% and 45% mortality caused by largemouth bass on stocked tiger muskies in two Ohio lakes before the onset of winter. Increased mortality of 30%, 8%, and 49% was observed in 1995, 1996, and 1997, respectively in this study with walleye present (Table 1.7). The overall mortality for tiger muskies stocked in early October was routinely >85% during these trials. Assuming that fish predation accounts for a maximum of 49% of mortality, this still leaves 36% of the mortality unexplained. It is apparent that high first year winter mortality of early October stocked tiger muskies persists without the presence of walleye.

The combined results from these experiments have eliminated handling stressors, availability of prey, and inability to overwinter as major sources of mortality on stocked tiger muskies. Piscivorous predation has been determined to be a major source of mortality on stocked tiger muskies. However, fish predation alone does not account for all of the mortality that has been observed. Other possible sources of mortality include; cannibalism, disease, escapement, and bird predation.

If cannibalism were a major source of mortality, the overwinter cage experiments should have produced this activity. Tiger muskies were kept at high densities within cages overwinter and fed limited amounts of prey. Tiger muskies in this experiment displayed 98% survival (Table 1.6). Although cannibalism is occasionally observed in raceway settings, it is a rare event. It is unlikely that cannibalism would account for a significant portion of mortality on stocked tiger muskies.

The occurrence of disease is not a likely source of mortality on stocked tiger muskies. Tiger muskies are raised within a hatchery for their first 6 months and have shown little susceptibility to disease through this age. It is possible they become exposed after they are stocked, however, fish that die from disease should display erratic behavior or carcasses should be observed, and during this research these things were not observed.

Stocked tiger muskies have been seen escaping from reservoirs, and this may represent a major source of tiger muskie loss from reservoir populations. However, the ponds utilized for these experiments did not provide significant avenues of escapement. Water would skim over the top of standpipes, but most standpipes had screens placed over them. Standpipes that lost these screens would still not allow much of an opportunity to escape. Also, escaped tiger muskies would have been sent to a downstream trout fishing business that would have noticed the introduction of these fish. It is unlikely in these controlled experiments that escapement accounted for a major proportion of tiger muskie loss.

By process of elimination, bird predation must account for the remaining mortality. Bird predation has not been documented for tiger muskies, but I believe it to be a major contributor to post-stocking mortality. Sightings of great blue herons (Ardea herodias) and their tracks in study ponds and marks (scarring) in 1995, 1996, and 1997 on 17%, 17%, and 5%, respectively of surviving tiger muskies raises the contention of serious loss to bird predation. Marks occurred on both sides of surviving tiger muskie bodies, and the marks are consistent with scarring that would be expected from fish that have escaped bird predation. It can only be assumed that if 17% of surviving tiger muskies escaped bird predation, a substantial percentage of mortalities failed to escape bird predation.

I surmise that fish and bird predation account for the majority of stocked tiger muskie mortality (Table 1.8). Fish predation appears to be linked to the size of stocked tiger muskies. Tiger muskies stocked at a larger size are more likely to avoid fish

Table 1.8 Summation of results for each experimental trial utilized to determine causes of post-stocking mortality.

Experimental Trial	Directly Causes Post-stocking Mortality
Handling Stress	No
Experienced versus Naive	Inconclusive
Prey Availability	No
Overwinter Survival	No
Fish Predation	Yes
Bird Predation	Deduced Effect

predation and are capable of eating larger prey, which consequently increases their growth. Bird predation does not appear to be size linked, as piscivorous birds from this region seem to handle all sizes of stocked tiger muskies.

Chapter II - Strategies to Alleviate Post-Stocking Mortality

INTRODUCTION

Many researchers have attempted to increase the survival of stocked esocids. A common belief is that mortality of YOY tiger muskies occurs before the onset of winter. Hanson and Margenau (1992) reported that movement of newly stocked muskies was greatest during the 17 days when they were searching for suitable habitat. Increased movement would presumably elevate the amount of encounters with potential predators as well as create more stress than having a suitable habitat selected. Predation by largemouth bass has accounted for 26 and 45% mortality on tiger muskies in two Ohio lakes before the onset of winter (Stein et al. 1981). Also, initial stocking mortality approached 30% for tiger muskies when the temperature increase at stocking exceeded 9.5 °C, suggesting that thermal shock can be an important cause of post-stocking mortality (Carline et al. 1986).

Numerous stocking strategies to reduce initial mortality and to assist in establishing a year-class have been attempted. Stocking esocids at night away from shoreline habitat is believed to separate stocked fish from potential predators and give them time to adjust to their environment. This stocking strategy is still practiced in Colorado, but in Ohio was found to produce similar survival to daytime stocking (Stein et al. 1981). Other stocking strategies have found survival: to increase with size of tiger muskies stocked (Stein et al. 1981; Carline et al. 1986); to increase when tiger muskies are stocked earlier at a smaller size (Beyerle 1981; Beyerle 1984; Berg and Hepworth 1997); is greater for tiger muskies reared on live food than on pellets (Johnson 1978); and is greater when fish predator densities are low and suitable prey are abundant (Stein et al. 1981). No specific stocking strategy seems to be able to accommodate all situations.

Considering less than 1/3 of reservoirs stocked with tiger muskies in Colorado have developed fishable populations, a study was designed to develop strategies to increase success in establishing populations in the State. The specific objective of this research was to devise appropriate stocking strategies to compensate for known sources of post-stocking mortality. Four hypotheses were examined: 1) Exposing tiger muskies to fish predation prior to stocking increases survival (because these fish observe predators and learn to avoid them); 2) Placing tiger muskies in a pond prior to stocking increases survival (by allowing them to learn how to search for appropriate habitat, which decreases their movement and hence vulnerability when stocked); 3) Stocking tiger muskies earlier in the year at a smaller size increases survival (by placing them with more abundant and appropriate prey sizes); and 4) Stocking tiger muskies later in the year (after or near formation of ice cover) increases survival (because these fish avoid bird predation, are exposed to reduced fish predation, and are larger when stocked). A summary of stocking strategies being tested and their corresponding pond replications can be found in Table 2.1.

Table 2.1 Stocking strategies being tested and their corresponding pond replications.

Stocking Strategy	Pond Replications
predator exposure	two ponds
pond exposure	two ponds
early stocking	four ponds
late stocking	four ponds
adjusted late stocking	four ponds with predators six ponds without predators

METHODS

The methods for the research conducted during these trials can best be viewed by looking at each individual experiment. However, the production of fish within years and analysis of results are consistent for all experiments and presented in overview so they are not repeated in each section. The Pueblo Fish Hatchery received eyed eggs or fry from the Linesville Fish Hatchery in Linesville, Pennsylvania. These fish were raised to fingerling size (50-75 mm) and transported to the Wray Fish Hatchery. The Wray Fish Hatchery was responsible for these fish until they were stocked. In 1995, tiger muskie fingerlings were "naive". At the request of biologists, tiger muskies were provided fathead minnows for 2 weeks before being stocked in 1996 and 1997.

Survival of stocked tiger muskies is subject to large variability, which makes it difficult to assess differences between the means of designed experimental trials. To reduce the variability between observed survival percentages an arcsine transformation for proportions (Snedecor and Cochran 1967) was used. This transformation was utilized for determining statistical significance of treatments. Percent survival is reported in non-transformed form to allow a better understanding of results by readers. Transformed survival proportions were analyzed by general linear models in SAS (SAS Institute 1982) and significance determined at the 0.05 level. Confidence intervals at the 95% level were produced with non-transformed survival proportions.

Predator Exposure and Pond Exposure

Stocked tiger muskies raised by traditional CDOW cultural techniques have never been exposed to predation by large fish. This naivety may make them vulnerable as prey to large piscivores in reservoirs. Also, allowing tiger muskies to swim in ponds prior to stocking may decrease the amount of time it takes them to begin searching for and finding suitable territories when they are stocked. In 1995, exposing tiger muskies to predators and ponds prior to stocking was incorporated into a fraction of a factorial design with four factors, each at two levels. The experiment had five separate combinations of these four factors that were replicated twice (see 1995 treatments in Table 1.3). Loss of data from one pond complicated analysis of this experiment. A statistical comparison was conducted with a model that included all four factors to allow the use of available data. Analysis of this model was performed using general linear models procedure in SAS (SAS Institute 1982) to determine if any difference in mean survival could be detected for the four factors. The remaining three pairwise comparisons were conducted, and the level of significance adjusted by the Bonferroni method. The p-values for differences between pairs were determined by least square means in SAS (SAS Institute 1982).

Tiger muskies were transported from Wray Fish Hatchery to Colorado State University Foothills Research Campus. There they were held in raceways and fed pellets for 3 d to ensure mortality within experiments was not related to handling and transportation stress. Walleyes (≥350 mm total length) served as predators in the exposure and experimental portions of this trial where they were included. Predator exposure consisted of three walleyes placed into a 0.04-ha pond with 100 tiger muskies. Pond exposure consisted of 100 tiger muskies placed in a 0.04-ha pond with no fish predators. Both exposure periods lasted 1 week. Forty of the remaining tiger muskies from the predation exposure pond were divided into lots of 20 fish and stocked into two randomly selected 0.04-ha ponds with three walleyes and 3.6 kg of fathead minnows. Similarly, two lots of 20 tiger muskies from the pond exposure pond were stocked into two randomly selected 0.04-ha ponds with three walleyes and 3.6 kg of fathead minnows. Two lots of 20 raceway (no pond experience) tiger muskies were placed with three walleyes and 3.6 kg of fathead minnows in identical 0.04-ha ponds. An additional two 0.04-ha ponds had 20 raceway tiger muskies placed in them with 3.6 kg of fathead minnows (see 1995 treatments in Table 1.3). All ponds were drained after ice-off, and survival of tiger muskies, walleyes, and fathead minnows (by weight) was determined.

Normal versus Early and Late Stocking

In July, October, and December of 1996, tiger muskies were taken from the Wray Fish Hatchery. These fish were transported to Colorado State University Foothills Research Campus, held for a minimum of 3 d, and stocked into either 0.04-ha or 0.032-ha ponds. Stockings that occurred in July, October, and December are called early, normal, and late stockings, respectively. Tiger muskies were randomly assigned into lots of 15 fish and placed into ponds. Four of the 0.032-ha ponds and 10 of the 0.04-ha ponds were utilized for four replications of early, normal, and late stocking times with predators and for two replications of normal stocking without predators (Table 2.2). Existing communities in research ponds consisted of 3.6 kg of fathead minnows and either three

Table 2.2 Experimental design for comparison of stocking time in 1996.

Time	Replications	Walleye	Prey Present
Early	4	Yes	Yes
Normal	4	Yes	Yes
Normal	2	No	Yes
Late	4	Yes	Yes

walleyes (≥350 mm total length) or no walleyes. Total length measurements (mm) were taken for each tiger muskie and walleye. Weight (g) was taken for each tiger muskie and batch weight (kg) for each set of three walleyes in a community. Early-stocked tiger muskies were 100-150 mm in total length. Normal-stocked tiger muskies ranged from 160-220 mm in total length. Late-stocked tiger muskies were larger (185-250 mm total length) at time of stocking. Ponds were drained after ice-out in March 1997. Survival and number of carcasses found on the pond bottom were recorded for tiger muskies and walleyes (when present) from each pond. Weight (g) and total length (mm) was recorded for each surviving tiger muskie and batch weight (kg) for surviving walleyes and fathead minnows was noted.

Normal versus Adjusted Late Stocking

Results from 1996 indicated that late stocking may have occurred too late in the year with near freezing water temperatures. For this reason in a repeat experiment, the late stocking time was moved forward (pond water temperatures 5-9°C) and called the adjusted late stocking. Experiments starting in 1997 focused on comparing: 1) bi-weekly survival of normal and adjusted late-stocked tiger muskies with predators and prey in the same communities; 2) survival of normal and adjusted late-stocked tiger muskies in protective cages with limited food; 3) survival of adjusted late-stocked tiger muskies with and without predators and normal-stocked tiger muskies without predators in communities having prey present (Table 2.3). For all 1997 stockings, tiger muskies were

Table 2.3 Experimental design for comparison of normal and adjusted late stocking strategies.

Pond Trials

Time	Number of Ponds	Prey Present	Fin Clip	Walleye	Drained
Normal	2	Yes	RP[a]	Yes	Periodically
Adjusted late[b]	(above)	Yes	LP[c]		
Normal	4	Yes		No	Ice-off
Normal	2	Yes		Yes	Ice-off
Adjusted late	4	Yes		Yes	Ice-off
Adjusted late	4	Yes		No	Ice-off

[a] Right pelvic fin was partially clipped
[b] Additional tiger muskies stocked into the same ponds 4 weeks later.
[c] Left pelvic fin was partially clipped

Cage Trials

Time	Number of Ponds	Prey Present	Number of Cages	Checked
Normal	1	Minimal	4	Periodically
Adjusted late	1	Minimal	4	Periodically

transported from Wray Fish Hatchery in October and used for normal stocking trials after 3 d or fed fathead minnows and held for adjusted late stocking trials. Total lengths (mm) were taken for 20 random tiger muskies used for normal stockings and adjusted late stockings and for each walleye, as well as batch weights (kg) for walleyes. Normal-stocked tiger muskies ranged between 160-210 mm (total length) when stocked, while adjusted late-stocked tiger muskies were between 165-225 mm (total length) at time of stocking.

The first set of experiments concentrated on bi-weekly survival of normal and adjusted late-stocked tiger muskies. Two lots of 15 tiger muskies were randomly selected, anesthetized with MS-222, and given a partial right pelvic fin clip. These fish were allowed to rest for 3 d to determine if any mortality was due to handling and marking procedures. Each lot of 15 marked tiger muskies was stocked in 0.032-ha ponds to represent normal stocking. Communities in these ponds consisted of three walleyes ($\geq$350 mm total length) and 3.6 kg of fathead minnows. These ponds were drained every 2 weeks. The number of surviving tiger muskies was recorded and the community re-established. Four weeks into this trial 15 randomly selected tiger muskies were introduced into each pond to represent an adjusted late stocking. Tiger muskies in the adjusted late stocking were previously anesthetized with MS-222, given a partial left pelvic fin clip, and allowed to rest for 3 d to ensure no mortality occurred due to handling and marking procedures. These ponds continued to be drained every 2 weeks and re-established until the onset of ice-cover. Survival of normal and adjusted late-stocked tiger muskies was recorded. Both ponds were allowed to rest during ice-cover, and final survival was determined at ice-off for each treatment stocking time.

To assess overwinter survival of normal and adjusted late-stocked tiger muskies, four lots of 10 normal-stocked tiger muskies were placed in individual 1.22-m by 1.22-m by 1.22-m cages in a single 0.04-ha pond. Four lots of 10 adjusted late-stocked tiger muskies were also placed in similar cages in a 0.04-ha pond. Mesh size on these cages was either 6.3- or 9.5-mm woven mesh. All fish and ponds were randomly selected. Tiger muskies were fed minimal amounts of fathead minnows throughout the winter. Every 2-3 weeks lids and ice were removed from the cages, and tiger muskies were counted to check for mortality or evidence of cannibalism.

The final experiment was designed to compare survival of adjusted late-stocked tiger muskies with and without predators to normal-stocked tiger muskies without predators. All tiger muskies and ponds were randomly selected. Four lots of 15 normal-stocked tiger muskies were placed into ponds with an existing prey base of 3.6 kg of fathead minnows. Eight lots of 15 adjusted late-stocked tiger muskies were also placed into ponds. Half of these ponds had an existing community of three adult walleyes (≥350 mm total length) and 3.6 kg of fathead minnows, while the other half had just 3.6 kg of fathead minnows. All four lots of each experimental unit were placed into three 0.04-ha ponds and one 0.032-ha pond. All ponds were drained the following spring after ice-off. Survival was recorded for tiger muskies and walleyes. Individual total lengths (mm) and weights (g) were recorded for surviving tiger muskies and batch weight (g) for surviving walleyes and fathead minnows was noted.

Data for bi-weekly survival of normal and adjusted late-stocked tiger muskies with predators was combined with the data comparing survival of adjusted late-stocked tiger muskies with and without predators to normal-stocked tiger muskies without predators. This combination of results allowed a complete comparison of normal and adjusted late-stocked tiger muskies with and without predators. A general linear model with two levels of stocking time and presence of predators was applied to determine if a difference in means existed between the resulting four treatments. The model provided p-values for the influence on survival of predators and stocking times. Six pairwise comparisons were planned and the level of significance adjusted by the Bonferroni method. The p-values for differences between pairs determined by least square means in SAS (SAS Institute 1982).

RESULTS AND DISCUSSION

Exposing tiger muskies to walleye predation before stocking did not increase survival (Table 2.4). In fact, tiger muskies stocked in ponds but not exposed to predation before stocking displayed 28% better survival than those stocked in ponds and exposed to predation; this difference was not significant ($p = 0.28$). Each pond held all three walleyes and greater than 1 kg of fathead minnows when drained. Theoretically, tiger muskies exposed to predators for a short time would observe predacious activities and learn to avoid predators. Due to unexpected results in the training session, it is not known if learned behavior occurred. The training pond with walleyes present returned

Table 2.4 Results for predator exposure, pond exposure, and predatory stocking experiments.

Observation	Treatment	Survival (Percent)	Treatment Mean	95% Confidence Interval
1	pred. exp., WAE[a], FHM[b]	10		
2	pred. exp., WAE[a], FHM[b]	0	5	±10
3	no pred. exp., WAE[a], FHM[b]	55		
4	no pred. exp., WAE[a], FHM[b]	10	33	±44
5	no pond exp., WAE[a], FHM[b]	15		
6	no pond exp., WAE[a], FHM[b]	0	8	±15
7	no pond exp., FHM[b]	20		
8	no pond exp., FHM[b]	70	45	±49
9	no pond exp.	45		
10	no pond exp.	N/A[c]	45	N/A

[a] three walleyes at least 410 mm in length

[b] 3.6 kg of adult and juvenile fathead minnows

[c] pond drain malfunctioned and fish were lost

97% of the tiger muskies while the control pond without walleyes returned only 43%. Bird predators were observed around the control pond and were presumed to have caused the high mortality. Since, tiger muskies in the control pond were exposed to more predation during the week period, it is possible their subsequent higher overwinter survival was due to a learned avoidance. However, it is believed that no differences in survival existed between tiger muskies exposed and not exposed to predation before stocking, and any differences observed were an artifact of only two replications.

Training fish to avoid predation failed as a possible stocking strategy. For this method of stocking to be considered successful, only minor predation should occur during the training period followed by a higher percentage of overwinter survival. These trials started with 100 tiger muskies, and after a week of exposure 97 and 43 tiger muskies remained in the treatment training pond and control pond, respectively. Multiplying these numbers by the percent survival observed overwinter leaves 5 tiger muskies from the predation training pond and 14 tiger muskies from the pond training pond.

Traditional CDOW stocking procedures keep tiger muskies in raceways until stocked. These fish have never been allowed to acclimate to depth or utilize living and non-living cover. This method of raising tiger muskies may make them more vulnerable when they are stocked. Personal observations of stocked tiger muskies in Colorado find them unresponsive to human and boat activity. Stocked tiger muskies are frequently found near the surface where they were stocked or along the downwind shoreline during the next 48 h. A CDOW biologist reported heavy bird predation on stocked tiger muskies during the first 24 h. The accumulation of observations and reports suggests that survival of tiger muskies may increase if these fish would locate appropriate habitat more quickly after being stocked.

Allowing tiger muskies to spend time in a pond before they are stocked may give them valuable experience in searching and finding suitable habitat. Pond trials that provided tiger muskies the opportunity to swim in a pond prior to stocking displayed a 25% increase in survival over fish that were kept in raceways until stocking (Table 2.4). However, this increase in survival was not significant (p = 0.33). Despite lack of significance, these observed survival percentages taken by themselves suggest that placement in ponds prior to stocking may increase a tiger muskie's chance of surviving through its first winter. However, only 43% of tiger muskies given the opportunity to spend time in a pond prior to stocking survived. Combining the 43% survival of tiger muskies from the pond experience training and subsequent 33% survival of these fish when they were stocked means approximately 14% of these fish survived. A 14% overall survival is close to the 8% survival displayed by tiger muskies stocked with raceway experience only.

Stocking trials started in 1996 provided little distinction between survival of early, normal, and late-stocked tiger muskies (Table 2.5). A statistical model for these 1996 stockings and two ponds that were normal-stocked without predators showed no significant differences based on the presence of predators (p = 0.90) or stocking time (p = 0.43). These calculations included data from a normal-stocked pond that lost one walleye and had another dead walleye carcass when it was drained. This replicate displayed 60%

Table 2.5 Results for early and late stocking strategies into 0.1-ha ponds.

Strategy	Number of ponds used	Survival (%)	95% confidence interval
Early Stocking	4	1.67	± 3
Normal Stocking[a]	4	20.00	± 27
Late Stocking	4	16.67	± 19
Control	2	16.67	± 32

[a] The pond that displayed the highest survival (60%) had lost two of its three walleye predators.

survival of stocked tiger muskies and changed the overall mean for the normal stocking time. It is not known when this pond lost these walleyes, but this pond did display the highest survival of all trials for 1996 stockings, including the two trials without walleye. The statistical model and mean percentages were determined without data from this pond and no significant changes were discovered. All ponds held adequate fathead minnows (at least 1 kg) when they were drained.

Stocking tiger muskies early (July) in the year provides the opportunity to utilize the available prey base before it becomes too large too consume. Access to a natural prey base allows tiger muskies to achieve greater lengths and increase their chance for survival (Carline et al. 1986). The concern of this stocking strategy is that placing juvenile tiger muskies in an unprotected situation at an early time, as well as smaller size, may result in a high percentage of mortality before the advantages of increased size can be obtained. Pond trials from this research gave validity to this concern. Two of the four early stocked ponds were drained in November to observe the amount of mortality that occurred prior to winter. One tiger muskie remained in these two ponds. The community that held this tiger muskie was re-stocked. The three ponds were drained in March and produced only that one tiger muskie for a survival of 2% (Table 2.5).

The surviving early-stocked tiger muskie displayed rapid growth. It was 287 mm total length in November, indicating this fish grew a minimum of 162 mm in 4 months. This fish was more than 35 mm longer than any other fish used in normal and late stockings during this year. This supports the belief that stocking tiger muskies earlier allows increased growth. The length of this fish made it appear to have outgrown its role as prey to the walleyes in the pond, re-confirming the importance of size to survival of stocked tiger muskies. Unfortunately, the rate of survival (2%) is far too low to justify this stocking action. The length of time these fish are vulnerable to fish and bird predation makes it virtually impossible to achieve a high percent survival.

Normal-stocked tiger muskies exhibited 20% survival (Table 2.5), but only 7% survival if the pond that lost two walleyes is removed from calculations. The 7% survival is comparable to an 8% survival demonstrated by similar ponds during 1995 stocking trials (Table 2.4). Normal stocking trials were intended to replicate current CDOW stocking procedures. The resulting low survival percentages are problematic and suggest that a new stocking strategy needs to be developed. Normal tiger muskie stocking occurs in early October. Most natural prey have become too large for 200-mm tiger muskies to consume at this time, and many piscivorous birds are feeding heavily as they prepare for winter migration. Evidence of bird predation can be seen by bird scarring being present on 17% of surviving normal-stocked tiger muskies in 1995 and 1996.

Late-stocked trials started in 1996 demonstrated 17% survival (Table 2.5), which was less than normal stocked trials. A two-fold mechanism theoretically would allow late-stocked tiger muskies to survive better; 1) bird predators would be gone or would be unable to capture tiger muskies because of ice cover and 2) fish predators would have a lower metabolism in colder water and consequently would require less food. Despite the low survival observed for late stocking, it appears that the theories for this method show some validity. None of the surviving tiger muskies displayed scarring that would be consistent with bird predation, but one regurgitated tiger muskie was found which indicates fish predation still occurred. Additionally, carcasses representing 33% of the total tiger muskies stocked were found in these ponds after they were drained. Carcasses were not seen in previous trials and serve as evidence that these fish did not die because of predation. Thermal stress created by late stocking may have caused most of this mortality, despite a careful tempering process to acclimate tiger muskies to the cold temperature. Tiger muskies were held in raceways at approximately 13 °C and were stocked into 3 °C water. This temperature difference of 10 °C exceeds the threshold level of 9.5 °C that was believed to produce a 30% post-stocking mortality for Carline et al. (1986). Also, tiger muskies received from the Wray Fish Hatchery for this late stocking appeared in poor condition; despite adequate lengths and weights, these tiger muskies were lightly colored and failed to adapt to dark raceway backgrounds. Also there was evidence of deformed opercula.

Stocking trials conducted in 1996 showed that early-stocked fish were unlikely to produce a strong year-class. Late-stocked fish also showed low survival, however much of the mortality could be explained. For that reason stocking trials started in 1997 concentrated on changing the late stocking process to account for this explainable mortality. The adjusted late stocking occurred in warmer water temperatures. Adjusted late-stocked tiger muskies were held in raceways that allowed natural daily sunlight before stocking. This holding procedure was different than the previous year when late-stocked tiger muskies were held in a building that did not allow natural light and they appeared to be in poor condition.

The first set of experiments in 1997 involved normal-stocked and adjusted late-stocked tiger muskies within the same pond. These ponds were drained and survival checked every 2 weeks. This experimental design provided insight into when tiger muskies were lost and provided a direct comparison between these stocking strategies. Comparisons of stocking strategies was based on amount of time the fish had been in the water, for example survival 2 weeks after stocking. Results for 2 and 4 weeks after stocking showed a 50% increase in survival for adjusted late-stocked tiger muskies over normal-stocked tiger muskies (Table 2.6). This difference was statistically significant ($p = 0.02$). After ice-off both ponds were drained and adjusted late-stocked tiger muskies displayed a 24% increase in survival, which was not statistically significant ($p = 0.12$). No compensation for difference of time after stocking was made for overwinter survival since ponds were drained once and not re-established. Thus, survival after ice-off compares 17 weeks after stocking for normal-stocked tiger muskies against 13 weeks after stocking for adjusted late-stocked tiger muskies.

Normal-stocked tiger muskies appear to be most vulnerable during their first 2 weeks after stocking. This time period claimed 67% of the tiger muskies from this trial and by the onset of ice cover a total of 73% were lost. Adjusted late-stocked tiger muskies lost only 17% of the tiger muskies from this trial before the onset of ice cover. Most of the early mortality is suspected to be caused by bird predation. Evidence to support this belief is 40% of the surviving normal-stocked tiger muskies displayed bird

Table 2.6 Bi-weekly survival rates for normal and adjusted late-stocked tiger muskies.

Week of Trial	Normal Stock Number Remaining		Adjusted Late Number Remaining		Normal Bi-weekly mean survival	Adjusted Late Bi-weekly mean survival
	Pond 1	Pond 2	Pond 1	Pond 2	(%)	(%)
0	15	15	-	-	-	-
2	6	4	-	-	33	-
4	6	4	15	15	33	-
6	6	3	12	13	30	83
8	5	3	12	13	27	83
17	3	1	6	5	13	37

scarring after 2 weeks and 75% after ice-off. Apparently, tiger muskies that had escaped bird predation had a higher survival during the ice-cover period (i.e. were better at escaping walleye predation). No adjusted late-stocked tiger muskies displayed bird scarring at any time during this trial. It is apparent that adjusted late stocking can be successful in avoiding bird predation.

Despite a statistically significant difference in survival before the onset of ice-cover, this difference was not maintained through the winter months. Normal-stocked tiger muskies exhibited high mortality during the first 2 weeks and before ice-cover while adjusted late-stocked tiger muskies exhibited their greatest mortality after the onset of ice-cover. This makes sense, since more adjusted late-stocked tiger muskies were available for consumption by the high density of predators. A total of 18 tiger muskies were lost during the 9-week period of ice-cover. This translates into each walleye in this trial consuming a tiger muskie once every 3 weeks during ice-cover. Since 74% of the tiger muskies available to walleyes in these ponds prior to ice-cover were adjusted late-stocked. it may be that predation was based on opportunity or availability rather than selection for adjusted late-stocked tiger muskies over normal-stocked tiger muskies by walleyes. This hypothesis is supported by similar survival for normal-stocked (50%) and adjusted late-stocked tiger muskies (44%) during the time period between ice-cover and ice-off.

Recall that 33% of 1996 late-stocked tiger muskies were found as carcasses the following spring. It was speculated that this mortality was caused by a combination of thermal stress and poor conditioned fish due to prior rearing procedures. Trials to test these speculations were not conducted; instead cages were used to closely follow normal-stocked and adjusted late-stocked tiger muskies. Overwinter survival in cages was similar for normal-stocked (95%) and adjusted late-stocked (98%) tiger muskies (Table 2.7). No replication existed in this trial, however, a casual observance of the high survival (and slight difference between treatments) should indicate that normal-stocked and adjusted late-stocked tiger muskies have the ability to survive until the next spring.

One normal-stocked tiger muskie was found as a carcass shortly after stocking and the other was cannibalized in December. It is not known what happened to the missing adjusted late-stocked tiger muskie. These results suggest that thermal stress can be compensated for by adjusted late-stocked tiger muskies. Adjusted late-stocked tiger muskies were placed into cages when water temperatures were 5 °C. This was an 8 °C difference from the holding raceways and below the 9.5 °C threshold difference observed by Carline et al. (1986). The holding procedures for adjusted late-stocked tiger muskies changed during this year and allowed exposure to natural sunlight. It is unknown if this change in holding procedures allowed adjusted late-stocked tiger muskies to be in better condition, but these fish looked healthy and displayed subsequent satisfactory survival. . Also, once again the ability of tiger muskies to survive when they are sheltered from bird and fish predators was strongly demonstrated

The final experiment in 1997 compared survival of adjusted late-stocked tiger muskies with and without predators to normal-stocked tiger muskies without predators. Both ponds from the direct comparison trials (two replicates of normal and adjusted

Table 2.7 Overwinter survival displayed by caged normal and adjusted late-stocked tiger muskies.

Cage Trial Number	Normal Stocking Strategy Survival (%)	Adjusted Late Stocking Strategy Survival (%)
1	90	100
2	100	90
3	90	100
4	100	100
Mean Survival (Pond)	95	98

late-stocked ponds with predators) were also included in these results. These ponds were drained four times in the fall, but it is not believed this altered tiger muskie survival, since most tiger muskie mortality occurred during the first 2 weeks and survival for similar treatments was similar. Adjusted late stockings with and without walleye produced 31% (±3) and 87% (±7) survival, respectively, while normal stockings with and without walleye produced 13% (±11) and 63% (±14) survival, respectively (Table 2.8). Bird marks were discovered on 12% of surviving normal stocked tiger muskies and 1% of surviving adjusted late-stocked tiger muskies.

During 1997 stocking trials (Table 2.8), the presence of walleyes decreased survival by 49%, which was a significant difference ($p < 0.01$). The presence of walleyes appeared to override the stocking strategy as both adjusted late ($p < 0.01$) and normal-stocked ($p < 0.01$) tiger muskies displayed significantly lower survival with walleyes. The adjusted late stocking strategy produced better survival in similar situations. When walleyes were not present, an 87% survival was observed for adjusted late-stocked tiger muskies which was not significantly greater than normal-stocked tiger muskies without walleyes (63%) ($p = 0.10$). However, both levels of survival would be considered acceptable. When walleyes were present, survival was significantly greater for the adjusted late stocking strategy ($p = 0.02$). The survival of 31% is not spectacular, but it is a considerable improvement over the current CDOW stocking procedures (13%). Survival with walleyes present is a prominent concern, since walleyes will exist in many Colorado waters where tiger muskies might be stocked.

Table 2.8 Results for normal and adjusted late-stocked strategies with and without walleye.

Stocking Strategy	Number of Ponds Used	Walleyes Present	Mean Survival (%)	95% Confidence Interval
Normal	4	No	63	± 2
Normal	2	Yes	13	±13
Adjusted Late	4	No	87	± 9
Adjusted Late	6	Yes	31	± 5

Adjusted late stocking places tiger muskies into the water approximately 1 month earlier than the original proposed late stocking time. The advantage of reducing or avoiding bird predation appears to be maintained with only one adjusted late-stocked surviving tiger muskie displaying bird scarring. A 56% lower survival for adjusted late-stocked tiger muskies with walleyes compared to without walleyes (Table 2.8) suggests that heavy fish predation still occurs. Tiger muskies from the adjusted late stocking are slightly smaller than late-stocked tiger muskies and slightly larger than normal-stocked tiger muskies. An increase in size at time of stocking provides a better chance for a tiger muskie to avoid fish predation (Stein et al. 1981), but stocking tiger muskies into water temperature changes that exceed 9.5 °C appear to cause post-stocking mortality from thermal stress. The adjusted late stocking strategy attempts to find the stocking time that provides the optimum survival of juvenile tiger muskies based on the absence of bird predators, size of stocked tiger muskies, and difference in water temperatures at time of stocking.

Additionally, the adjusted late stocking provides a field application advantage over late stocking. Late stocking would be conducted late enough in the year that the process of stocking could be difficult. Tempering times for tiger muskies would be lengthy, and ice and snow cover would make access to stocking questionable in some waters. Overall, adjusted late stocking is an improvement over the current CDOW stocking strategy. The adjusted late stocking strategy still exhibits vulnerability to fish predation and thus could be improved by stocking tiger muskies at a larger size. Unfortunately, growing tiger muskies to a larger size before stocking would be quite expensive with current facilities. The adjusted late stocking process should be instituted until further research develops a better alternative. A summation of results for various stocking strategies can be found in Table 2.9.

Table 2.9 Summation of results for stocking strategies utilized to alleviate post-stocking mortality.

Stocking Strategy	Successful in Alleviating Post-stocking Mortality
predator exposure	No
pond exposure	No
early stocking	No
late stocking	No
adjusted late stocking	Yes

CHAPTER III - Acceptability Index for Juvenile Tiger Muskies in Existing Waters

INTRODUCTION

As a top-line predator, very few adult tiger muskies can be supported by typical prey bases. However, the opportunity to catch a few larger fish from a lake each year can greatly increase angler participation and satisfaction (Neuswanger et al. 1994). Unfortunately, it has been difficult to consistently establish a year-class of tiger muskies in many waters. The reproductive strategy of esocids incorporates high fecundity that is offset by high first year mortality. Mimicking large influxes of young-of-the-year with a hatchery product is unrealistic. Management personnel attempt to intercept a mortality curve at the most economically efficient point in order to produce a consistent year-class. A stocking rate of 25/ha at 200 mm length is the target in Colorado. However, many years hatchery production falls short. With limited numbers to stock, only reservoirs with high likelihood of establishing a fishable population should be stocked.

A tool needs to be developed to determine the potential of successfully establishing tiger muskies in a reservoir with the suggested stocking rate of 25/ha. A possible method for predicting stocking success for tiger muskies is a modification of the habitat suitability index model developed by McConnell et al. (1984). McConnell et al. (1984) used logic to obtain a suitability rating for several species in reservoirs under construction. My index deals with existing waters and requires a slight change in logic. The establishment of a fish species in existing waters requires that individuals find a suitable environment and the existing community allows them to persist (conditions are acceptable). A suitability rating is an assigned score that represents expected conditions and the likely response of selected species to those conditions. The suitability rating needs to be combined with an assessment of the bird and fish predator community to determine the potential of a particular species to become established. The combined suitability rating and predator community assessment represents the overall acceptability of a particular water to maintain and develop stocked tiger muskies.

The goal of creating this acceptability index is to assess the physical, biological, and operational attributes of the current year to predict an existing water's ability to allow sufficient numbers of stocked tiger muskies to survive and grow until their second fall, when stocked at a rate of 25/ha. Currently, this stocking rate is employed annually to as many Colorado reservoirs as possible in hope of establishing some adult tiger muskie populations of at least 2.5 fish/ha. The acceptability index will help CDOW biologists rank a water's ability to produce tiger muskies and allocate fish between water bodies.

METHODS

Background

The acceptability index is composed of five primary attributes and an acceptability attribute. Each primary attribute represents an important component of a water's suitability for stocked tiger muskies. A primary attribute can be derived from a single factor or from several factors, which become known as secondary attributes. Each primary and secondary attribute is separated into three levels that would correspond to low, medium, or high. The specific measurements that separate low and medium, as well as, medium and high are called benchmark scores. Each primary attribute is given an attribute score and an overall suitability rating results from the five combined primary attribute scores. The suitability rating describes the suitability of a water for juvenile tiger muskies stocked at a rate of 25/ha and is combined with the acceptability attribute score. The combination of the suitability rating and acceptability attribute score represents the water description for juvenile tiger muskies stocked at a rate of 25/ha (Figure 3.1).

Preliminary Data Collection

Developing an acceptability index required an examination of previous stocking successes and failures to determine reservoir characteristics that have generally led to establishment of tiger muskie populations. Evaluating characteristics of water bodies previously stocked provides an opportunity to determine benchmark scores of certain key attributes that delineate the probability of stocking success.

Waters had to meet certain criteria to be included in this preliminary survey conducted during 1996. All waters that received only one stocking of tiger muskies were rejected, as that was not considered a thorough attempt to establish a population. Also, all reservoirs that had not received at least two stockings of tiger muskies before 1993 were rejected from the survey, since current sampling methods are unable to detect tiger

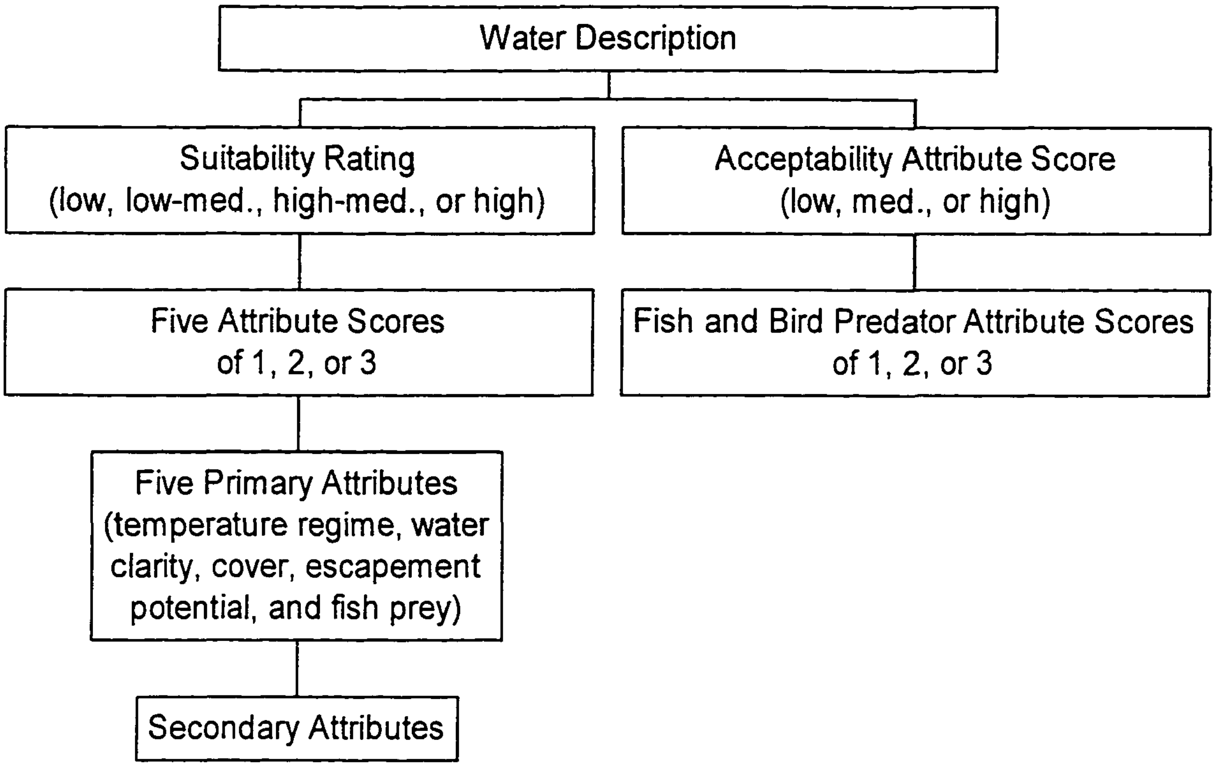

Figure 3.1 Flow chart of organizational terminology utilized in the acceptability index.

muskie populations until they are age 3. The remaining 27 reservoirs were considered suitable for use in developing this index. Each reservoir was given a rating of poor (1), average (2), or above average (3) based on an objective or subjective scale that measures the reservoir's ability to historically produce tiger muskies (Appendix A). Reservoir ratings were compared to information obtained during the preliminary data collection to assist in establishing benchmark scores.

All 27 waters (Appendix B) were visited during a 3-week period starting July 26, 1996. Information about water attributes collected during these visits included: oxygen and temperature depth profiles, Secchi disk reading, pH, phenol alkalinity and total alkalinity, hardness, nitrite, and ammonia. Only oxygen and temperature depth profiles and Secchi disk readings were selected for use in the acceptability index. In addition, a modified Hankin/Reeves method (1988) was utilized to estimate surface, bottom, and shoreline vegetative cover. These vegetative estimates were determined by direct observation, snagging hook, and snorkeling. Vegetative materials are included as part of living and non-living cover in the acceptability index. Information collected during this trip was used as an indicator of likely conditions for all previous stockings of tiger muskies in a reservoir; however, conditions for specific stockings can vary from year to year in a reservoir. Details on how data obtained from preliminary data collection were utilized to assist in setting benchmark scores is explained in the appropriate section in the acceptability index.

Acceptability Index

McConnell et al. (1984) utilized five primary attributes to predict the suitability of a proposed reservoir for certain fish species, including (1) water temperature; (2) silt turbidity; (3) non-living cover; (4) drawdown; and (5) coves. Both the suitability index of McConnell et al. (1984) and the acceptability index are predictive tools. The difference between these tools is that McConnell et al. (1984) predicts if suspected conditions will be favorable for a species while the acceptability index predicts if existing conditions are favorable for the establishment of a specific stocking of a species. To account for this slight difference in objectives and to include certain conditions that have been found to enhance the success of tiger muskies, the five primary attributes were altered for the acceptability index. The first four primary attributes of the acceptability index are similar to those found in McConnell et al. (1984), while the last primary attribute is different. The five primary attributes of the acceptability index are temperature regime, water clarity, seasonal cover, escapement potential, and availability of prey.

The primary attribute of temperature regime assesses several aspects of water conditions. Secondary attributes include maximum mean monthly surface water temperature and depth of thermal stratification during July or August in water that is away from inlets, aerators, or other sources of water movement where depth is at least 80% of the reservoir maximum. Maximum mean monthly surface water temperature is the highest average reading obtained from a water for July or August. Monthly surface water temperatures can be determined from a one-time reading, but a minimum of three is suggested. Depth of thermal stratification is determined from a minimum of three readings that are representative of either July or August. Readings for these secondary attributes are compared to benchmark scores, and an overall attribute score for temperature regime assigned (Figure 3.2). An attribute score of 1 indicates lower temperatures and deeper thermoclines; 3 indicates higher temperatures and shallower thermoclines. An attribute score of 1 represents a better chance for establishing tiger muskies.

The benchmark scores in Figure 3.2 were determined from literature review and assessment of observed temperature and thermocline ranges found during preliminary data collection. Higher water temperatures could be stressful or directly cause mortality as young northern pike did not grow at temperatures above 28°C in the laboratory (Casselman 1978) and temperatures above 32°C can cause death within 2 days (Scott 1964). Observations from the preliminary data collection (Appendix C) show a general trend of warmer waters having less success in establishing tiger muskies. Information from the preliminary data collection does not necessarily reflect maximum mean monthly surface water temperatures, rather a one-time summer reading. The maximum mean monthly surface water temperature benchmark scores were adjusted to accommodate for known literature levels of decreased growth and temperatures of observed success in Colorado. The thermocline offers a cooler refugium and tiger muskies are often found there during the summer (Andrews and Laurion 1982). As thermoclines get closer to the surface, less habitat is available for cover. In addition, many prey species can utilize the hypolimnion and escape tiger muskie predation during the summer. Evidence from

TEMPERATURE REGIME

		Maximum Surface Temperature		
		<24°C	24-28°C	>28°C
Depth of Thermal Stratification	<3m	2	3	3
	3-5m	1	2	3
	>5m	1	1	2

Figure 3.2 - Matrix of the attribute scores for temperature regime.

preliminary data collection (Appendix D) supports the claim of thermocline depth affecting the establishment of tiger muskies. Consequently, benchmark scores were established according to evidence from preliminary data collection.

Water clarity stands by itself as a primary attribute (Figure 3.3). The mean Secchi disk depth for June-September serves as the indicator for water clarity and should be determined from a minimum of three readings that are representative of this time frame. Water clarity can be affected by silt turbidity, planktonic blooms, and dissolved pigments; these clarity variables are not distinguished in my index. Information from preliminary data collection revealed a relationship between water clarity and the successful establishment of tiger muskies in a reservoir (Appendix E). Tiger muskies feed more efficiently in clearer water; this advantage is believed to outweigh the added risk of being detected by predators. Benchmark scores were established from information gained during preliminary data collection. An attribute score of 1 is given to waters with the least clarity, 3 to waters with the most clarity. An attribute score of 3 is the most desirable.

Living and non-living cover is the third primary attribute. Appreciable amounts of living and non-living cover have been found in Colorado reservoirs that successfully establish tiger muskies, suggesting that cover is important to the success of this fish. A sagittiform body shape and other physical adaptations predicates that the most efficient strategy for esocids is as a lie-in-wait predator. Performing in this role requires adequate cover or protection to disguise individuals from prey and predators. Secondary attributes for existing living and non-living cover focus on amount present during each of two

WATER CLARITY

Secchi Depth

<1m	1-2m	>2m
1	2	3

Figure 3.3 - Attribute scores assigned to specific Secchi disk readings.

seasons rather than types (Figure 3.4). The two seasons are fall and winter (September 21-March 20) and spring and summer (March 21-September 20). Assessments of living and non-living cover should be performed in October for the fall and winter season and during May for the spring and summer season. Benchmark scores established from preliminary data collection (Appendix F) define attribute categories of none, sparse, and desirable as <10%, 10-25%, and >25%, amounts of cover, respectively. It may be possible to have excessive cover, but this situation has yet to occur in previously stocked Colorado reservoirs.

Developing standards for living and non-living cover and the methods for assigning it an attribute score are essential. Living cover is submerged and emergent aquatic vegetation that could protect stocked tiger muskies. Non-living cover is fallen trees and rocks that could protect stocked tiger muskies. Protection can be offered by cover that displays a minimum two dimension measurement of 5 cm by 25 cm with the third dimension being non-transparent. Accurate assessment of living and non-living cover is expensive and time consuming; for this reason two investigators conducted measurements to estimate this attribute. Measurements were conducted on at least three portions of the reservoir by direct observation, snagging hook, and snorkeling if necessary. Areas measured encompassed different available habitat types. Both investigators individually placed the reservoir in an attribute category for living and non-living cover, and if their estimates were identical, no further measurements were taken. If attribute score estimates differed, cover measurements were performed until estimates concurred. An attribute score of 1 is given to waters with inadequate amounts of cover, 3

LIVING AND NON-LIVING COVER

		Fall/Winter		
		None	Sparse	Desirable
Spring/Summer	None	1	1	2
	Sparse	1	2	3
	Desirable	1	2	3

Figure 3.4 - Matrix of the attribute scores for living and non-living cover.

to waters that display adequate cover. An attribute score of 3 represents the best score for the success of a tiger muskie stocking.

Limited escapement potential is crucial to establishment of tiger muskie populations. Tiger muskies have been reported in waters and irrigation ditches below stocked reservoirs, as well as have been seen leaving reservoirs via spillways. All of this evidence is anecdotal, but the possibility of losing valuable tiger muskies and prey specimens through escapement warrants a primary attribute. Secondary attributes used to determine escapement potential included: depth of water release, probability of a reservoir overflowing the year after stocking, and the anticipated flushing rate the year after stocking (Figure 3.5). The secondary attributes are designed to assess the opportunity tiger muskies would have to leave a body of water based on the amount and frequency of water releases and if tiger muskies are likely to live at the depth of water being released. Evidence to establish benchmark scores is limited for these secondary attributes, so reasonable scores pertaining to the opportunity to escape were set. Information acquired from reservoir operators on past and predicted operating strategies, plus available current and future weather patterns, can be utilized to categorize reservoirs. Attribute scores increase from 1 to 3 as opportunity to escape increases from low to high. An attribute score of 1 is considered the best score for establishing tiger muskies.

The final primary attribute is availability of prey. Juvenile esocids are capable of living primarily on invertebrates (Finnell 1983); however fish prey can provide greater amounts of energy and increase the growth of stocked tiger muskies. Increased growth of juvenile tiger muskies allows them a better chance to avoid bird and fish predation. For

ESCAPEMENT POTENTIAL

		Flushing Rate for Water Year Following Stocking		
		<0.5	0.5-1.0	>1.0
Depth of Water Release	<5m	2	3	3
	5-15m	1	2	3
	>15m	1	1	2

Figure 3.5 - Matrices of the attribute scores for escapement potential.

Probability of Water Overflowing Subsequent Year of Stocking

Flush/ Release Score	<10% of years	10-50% of years	>50% of years
1	1	1	2
2	1	2	3
3	2	3	3

Figure 3.5 (continued) - Matrices of the attribute scores for escapement potential.

these reasons, fish prey is used as the indicator for availability of prey. The secondary attributes for fish prey score are body shape of prey and prey abundance.

Fish prey score is a measure of the type and abundance of fish prey that is available within the community when juvenile tiger muskies are stocked. Fish prey are defined as any member of a fish species that is small enough to be consumed by 200-mm tiger muskies. A linear regression developed from juvenile tiger muskies (170-218 mm total length) provides the estimation that 200-mm tiger muskies can swallow prey with a maximum body depth of approximately14 mm ($y = -2.4923 + 0.0816(x)$; $n = 28$; $r^2 = 0.59$). Varying prey body shapes are grouped by families to distinguish at what total length they would still be vulnerable (Table 3.1). Families were grouped into score categories for primary body shape of prey, based on linear regression of body depth versus total length that was developed from data collected for this research. When data were unavailable, that family's similarity in body shape to families with data available or literature references was used.

Abundance of prey can be determined by sampling. Sampling for prey should include experimental gill nets, electrofishing, and seining. Benchmark scores were established for the following gear based on number of fish prey captured in existing reservoirs during years that displayed high, medium, and low success of tiger muskie stockings (Table 3.2). Experimental gill nets are constructed of monofilament nylon and measure 1.8 m deep and 45.7 m long, with six equal length panels of 19-, 25-, 32-, 38-, 51-, and 64-mm bar meshes. Electrofishing (DC pulse) is often performed with a 5000-W generator and a Coffelt VVP-15 electrofisher. Seining consists of 15.2-m seine hauls

Table 3.1. Maximum length of a family representative to be considered a prey item for a 200-mm tiger muskie.

Family	Body Shape Prey Score	Reason For Score	Maximum Prey Length (mm)
Cyprinidae (carp)	1	linear regression[a]	<50
Clupeidae	1	linear regression[b]	<50
Percichthyidae	1	linear regression[c]	<50
Centrarchidae (non-bass)	1	linear regression[de]	<50
Percidae	2	linear regression[f]	<75
Ictaluridae	2	linear regression[gh]	<75
Catostomidae	2	linear regression[i]	<75
Cyprinidae (non-carp)	2	similar body shape	<75
Centrarchidae (bass)	2	similar body shape	<75
Salmonidae	3	literature reference[j]	<100
Esocidae	3	direct observation	<100

[a] species common carp: $y = 12.5900 + 0.2023(x)$; $n = 10$; $r^2 = 0.74$

[b] species gizzard shad: $y = 1.5372 + 0.2550(x)$; $n = 29$; $r^2 = 0.83$

[c] species palmetto bass: $y = 2.6360 + 0.2236(x)$; $n = 6$; $r^2 = 0.74$

[d] species bluegill: $y = -2.5376 + 0.3926(x)$; $n = 16$; $r^2 = 0.94$

[e] species black crappie: $y = -18.8351 + 0.4651(x)$; $n = 15$; $r^2 = 0.76$

[f] species walleye: $y = -0.8908 + 0.1732(x)$; $n = 14$; $r^2 = 0.97$

[g] species channel catfish: $y = -3.4106 + 0.1877(x)$; $n = 13$; $r^2 = 0.78$

[h] species black bullhead: $y = -0.4458 + 0.1927(x)$; $n = 17$; $r^2 = 0.56$

[i] species white sucker: $y = -9.1219 + 0.2083(x)$; $n = 29$; $r^2 = 0.97$

[j] species kokanee: Finnell (1983)

Table 3.2. Ranking of appropriate sized fish prey abundance (low, medium, high) by various gear capture rates.

Gear	Fish Prey Rank		
	Low	Medium	High
Electrofishing	<20/station[a]	20-40/station	>40/station
Experimental gill nets	<0.5/net-night[b]	0.5-1/net-night	>1/net-night
Seining	<5/haul[c]	5-30/haul	>30/haul

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[a] A station consists of 15 minutes of electrofishing.

[b] A net-night constitutes a gill net actively fishing from evening to morning hours, generally for 12-14 hours total.

[c] A haul consists of a seine being pulled 15 m and than angled to shoreline to collect fish.

with a 7.6-m seine with 7-mm woven mesh. Final determination of fish prey abundance should be based on multiple samples utilizing multiple gears. In the event that multiple measurements give different classification scores, a weighted average score should be used. Since, prey species abundance is highly variable, all measurements used to assign an attribute score should occur within one life span of the major prey fish species. The fish prey abundance attribute score is combined with primary body shape of prey for an overall fish prey attribute score (Figure 3.6). The term primary represents the highest percentage by numbers that fall into category 1, 2, or 3 (see Table 3.1), not necessarily the majority. The attribute score increases from 1 to 3 as abundance and vulnerability of prey body shape increases, thus a score of 3 is considered most desirable.

A five-digit suitability rating is created by combining each primary attribute score, for example 31223. Each of the 243 possible combinations for these five primary attributes is assigned a ranking of low, low-medium, high-medium, or high. (Table 3.3). Also, within this table is a list of limitations that must be remembered when applying the acceptability index, as well as, the set of rules that were used to rate the 243 combinations. The suitability rating reveals the suitability of a water to support tiger muskies, however a water body being suitable does not necessarily guarantee that tiger muskies will be successfully established.

The predominant barrier between suitability and establishment is the presence of predators. The acceptability attribute involves the susceptibility of juvenile tiger muskies to both bird and fish predation. These two types of predation are combined to give an overall acceptability attribute score for predation (Figure 3.7). Bird predation assessment

FISH PREY SCORE

		Abundance of Prey		
		Low	Medium	High
Primary Body Shape of Prey	1	1	1	2
	2	1	2	3
	3	1	2	3

Figure 3.6 - Matrix of the attribute score for fish prey.

Table 3.3. A listing of the acceptability index limitations, rules for suitability ranking, and suitability ratings for all possible reservoir descriptions.

Acceptability Index Limitations

1.) This index is intended for use on Colorado waters only.
2.) This index is intended for use on lentic waters only.
3.) This index is not a guide for stocking rates needed to establish tiger muskies, but rather assumes fish will be stocked at a rate of 25/ha.

Rules for categorizing suitability from five-digit reservoir descriptions. Benchmarks for particular scores can be extracted from the preceding text and appendixes. A general guideline for understanding individual five-digit descriptions is that the best score would be 13313 and the worst score would be 31131. Primary attribute scores are represented by letters (A = temperature regime, B = water clarity, C = living and non-living cover, D = escapement potential, and E = fish prey).

Rules for Low Ranking

1.) If B and E=1, then rank as low
2.) If A and D=3 and E=1, then rank as low
3.) If A=3 and B and C=1, and D≥2 or E=2, then rank as low
4.) If B + E=3 and A and D≥2 and C≤2 unless A, C, and D=2, then rank as low
5.) If A=3 and C and E=1, while D≥2, then rank as low
6.) If C and E=1 and D=3, while A=2 or B=2, then rank as low

Rules for Low-Medium Ranking

If not as above and;
1.) B or E=1, then rank as low-medium
2.) If B and E=2 and A≥2 and C≤2, unless A=2 and C=2 and D≤2, then rank as low-medium
3.) If B and E=2 and A≥2 and D≥2, unless A=2 and D=2 and C≥2, then rank as low-medium
4.) If B and E=2 and C≤2 and D≥2, unless C=2 and D=2 and A≤2, then rank as low-medium
5.) If B + E=5 and A=3 and C=1 and D≥2, then rank as low-medium
6.) If B + E=5 and A and D=3 and C≤2, then rank as low-medium
7.) If B + E=5 and C=1 and D=3 and A≥2, then rank as low-medium

Table 3.3. (continued)

Rules for High-Medium Ranking

If not as above and;
1.) If D=3 unless A=1, B=3, C=3, and E=3, then rank as high-medium
2.) If A=3, then rank as high-medium
3.) If E=2, then rank as high-medium
4.) If B=2 and C=1, then rank as high-medium

Rules for High Ranking

1.) If not as above, then ranking is high

Table 3.3. (continued)

Reservoir description	suitability	Reservoir description	suitability	Reservoir description	suitability
11111	L	12111	LM	13111	LM
11112	LM	12112	HM	13112	HM
11113	LM	12113	HM	13113	H
11121	L	12121	LM	13121	LM
11122	LM	12122	LM	13122	HM
11123	LM	12123	HM	13123	H
11131	L	12131	L	13131	LM
11132	LM	12132	LM	13132	HM
11133	LM	12133	HM	13133	HM
11211	L	12211	LM	13211	LM
11212	LM	12212	HM	13212	HM
11213	LM	12213	H	13213	H
11221	L	12221	LM	13221	LM
11222	LM	12222	HM	13222	HM
11223	LM	12223	H	13223	H
11231	L	12231	LM	13231	LM
11232	LM	12232	LM	13232	HM
11233	LM	12233	HM	13233	HM
11311	L	12311	LM	13311	LM
11312	LM	12312	HM	13312	HM
11313	LM	12313	H	13313	H
11321	L	12321	LM	13321	LM
11322	LM	12322	HM	13322	HM
11323	LM	12323	H	13323	H
11331	L	12331	LM	13331	LM
11332	LM	12332	HM	13332	HM
11333	LM	12333	HM	13333	H

Table 3.3. (continued)

Reservoir description	suitability	Reservoir description	suitability	Reservoir description	suitability
21111	L	22111	LM	23111	LM
21112	LM	22112	LM	23112	HM
21113	LM	22113	HM	23113	H
21121	L	22121	L	23121	LM
21122	L	22122	LM	23122	HM
21123	LM	22123	HM	23123	H
21131	L	22131	L	23131	L
21132	L	22132	LM	23132	LM
21133	LM	22133	LM	23133	HM
21211	L	22211	LM	23211	LM
21212	LM	22212	HM	23212	HM
21213	LM	22213	H	23213	H
21221	L	22221	LM	23221	LM
21222	LM	22222	HM	23222	HM
21223	LM	22223	H	23223	H
21231	L	22231	L	23231	LM
21232	L	22232	LM	23232	HM
21233	LM	22233	HM	23233	HM
21311	L	22311	LM	23311	LM
21312	LM	22312	HM	23312	HM
21313	LM	22313	H	23313	H
21321	L	22321	LM	23321	LM
21322	LM	22322	HM	23322	HM
21323	LM	22323	H	23323	H
21331	L	22331	LM	23331	LM
21332	LM	22332	LM	23332	HM
21333	LM	22333	HM	23333	HM

Table 3.3. (concluded)

Reservoir description	suitability	Reservoir description	suitability	Reservoir description	suitability
31111	L	32111	L	33111	L
31112	L	32112	LM	33112	HM
31113	LM	32113	HM	33113	HM
31121	L	32121	L	33121	L
31122	L	32122	LM	33122	LM
31123	L	32123	LM	33123	HM
31131	L	32131	L	33131	L
31132	L	32132	LM	33132	LM
31133	L	32133	LM	33133	HM
31211	L	32211	LM	33211	LM
31212	LM	32212	LM	33212	HM
31213	LM	32213	HM	33213	HM
31221	L	32221	L	33221	LM
31222	L	32222	LM	33222	HM
31223	LM	32223	HM	33223	HM
31231	L	32231	L	33231	L
31232	L	32232	LM	33232	LM
31233	LM	32233	LM	33233	HM
31311	L	32311	LM	33311	LM
31312	LM	32312	HM	33312	HM
31313	LM	32313	HM	33313	HM
31321	L	32321	LM	33321	LM
31322	LM	32322	LM	33322	HM
31323	LM	32323	HM	33323	HM
31331	L	32331	L	33331	L
31332	LM	32332	LM	33332	HM
31333	LM	32333	HM	33333	HM

PREDATOR INDEX

Bird Predator Abundance for Remaining Open Water Year	Bird Predator Abundance First 2 Weeks		
	<0.5/ha/d	0.5-1/ha/d	>1/ha/d
<0.25/ha/d	1	1	2
0.25-0.5/ha/d	1	2	3
>0.5/ha/d	1	2	3

Figure 3.7 - Matrices of the acceptability attribute scores.

	Fish Predator Abundance		
Bird Predator Score	Low	Medium	High
1	1	1	2
2	1	2	3
3	2	3	3

Figure 3.7 (continued) - Matrices of the acceptability attribute scores.

requires estimating the number of bird predator days during the first 2 weeks after stocking and for the rest of the open water year. A bird predator day was defined as active fishing by a piscivorous bird during any part of the day. An estimation of the number of bird predator days separates bodies of water into low, medium, or high categories. The abundance of these species is determined by on-site visual estimation along with knowledge of the annual presence of piscivorous birds on particular bodies of water. On-site visual counts should be performed by driving a boat around the entire shoreline and counting all piscivorous birds on or above the water and within approximately 100 m of the shore. Scores from both time frames combine to give a single bird predator score. Piscivorous birds in this geographic area include american white pelican (Pelacanus erythroorhynchus), double-crested cormorant (Phalacrocorax auritus), black-crowned night heron (Nycticorax nycticorax), green-backed heron (Butorides striatus), great blue heron, gull species (Larus spp.), golden eagle (Aquila chrysaetos), bald eagle (Haliaeetus leucocephalus), osprey (Pandion haliaetus), and belted kingfisher (Ceryle alcyon).

Fish predation score is a relative measure of the density of fish predators that exist within the community when juvenile tiger muskies are stocked. Fish predators are defined as any member of a piscivorous fish species that is large enough to consume a 200-mm tiger muskie (Table 3.4). Sampling for predators should include gill nets, experimental gill nets, and electrofishing. Gill nets are constructed of multifilament nylon and measure 1.8 m deep and 61.0 m long, with 5.1-cm mesh (bar measure). Each form of sampling carries specific capture numbers for ranking fish predators as high,

Table 3.4. Minimum length of a species to be considered a piscivore on a 200-mm tiger muskie.

Species	Length (mm)
Walleye	350
Saugeye	350
Channel Catfish	350
Largemouth Bass	300
Smallmouth Bass	350
Palmetto Bass	350
White Bass	350
Tiger Muskie	400
Northern Pike	400
Brown Trout	400
Rainbow Trout	400
Cutthroat Trout	400
Lake Trout	400

medium, or low (Table 3.5) based from observed numbers of sampled predators in previously stocked tiger muskie waters. Final categorization of the fish predator score should be based from multiple samples utilizing multiple gears. Multiple measurements allow more confidence in predator assessment. In the event that multiple measurements give different classification scores, a weighted average score should be used. Fish predation score is combined with the bird predator score to give an acceptability attribute score (Figure 3.7). The attribute score increases from 1 to 3 as the abundance of bird and fish predators increases, thus a score of 1 is considered most desirable.

The suitability rating is combined with the acceptability attribute score to give a water description. If the acceptability attribute score is 3, the overall water description decreases one step from the suitability rating. For example, a reservoir with a low-medium suitability rating and acceptability attribute score of 3 would have a low water description for the successful establishment of stocked tiger muskies that year. An annual water description gives an indication of the acceptability of the water and community toward the introduction of tiger muskies that fall. A high description for a water means that tiger muskies stocked at a rate of 25/ha have a very good chance of surviving until the second fall. The chance of surviving until the second fall becomes less as the water description decreases.

RESULTS AND DISCUSSION

Results of this chapter are the amalgamation of the acceptability index portrayed in Table 3.3. Reservoirs currently stocked with tiger muskies naturally fit the

Table 3.5. Ranking of fish predator abundance (low, medium, high) by various gear capture rates.

Gear	Fish Predator Rank		
	Low	Medium	High
Electrofishing	<0.5/station[a]	0.5-1/station	>1/station
Experimental gill nets	<1/net-night[b]	1-2/net-night	>2/net-night
Walleye gill nets	<1.5/net-night	1.5-3/net-night	>3/net-night

[a] A station consists of 15 minutes of electrofishing.

[b] A net-night constitutes a gill net actively fishing from evening to morning hours, generally between 12-14 hours total.

acceptability index well, since they were used to create the acceptability index. Two reservoirs were stocked in 1997 and 1998 to test the acceptability index. An adequate assessment on the success of these newly stocked reservoirs is not complete at this time, since current gill net sampling is most efficient on 3 year and older tiger muskies. Validation provides confidence in the acceptability index and is a necessary step in its development. Without validation the acceptability index stands at face-value as a document of logic and observed past trends.

In lieu of validation, the logic and observed past trends need to be reiterated to lend understanding of how the acceptability index was developed. Each water that met specific requirements in 1996 was included in a preliminary data collection effort. Each of these waters was designated as either poor, average, or above average based on objective or subjective evaluations of their tiger muskie populations (Appendix A). Relationships were observed between the designation of tiger muskie populations and: maximum surface temperature (Appendix C), depth of thermocline (Appendix D), water clarity (Appendix E), and percent vegetative cover (Appendix F).

A review of literature and common sense shows that existing prey and predator communities also play an important role in the establishment of tiger muskies. To establish a relationship between prey and predators and the successful establishment of tiger muskies, past sampling endeavors with various gears were examined for poor, average, and above average waters. This relationship was placed into an associated catch per unit effort for particular gear capturing prey (Table 3.2) and predators (Table 3.5). In addition a standardized size was established for classification as prey or predator.

Maximum length of a species to be considered a prey item was determined by grouping species into families and establishing a body depth to length ratio for a representative of that family and comparing that to the estimated gape width size of 200-mm tiger muskies (Table 3.1). Minimum lengths to be a predator were based on observations and general knowledge of each predator species (Table 3.5).

The last primary characteristic was developed from reports and observations of tiger muskies leaving reservoirs. Escapement limits the establishment of tiger muskie populations, unfortunately this loss has not been quantified. Tiger muskies need water to escape, so a measurement of how much water was being released from reservoirs in areas that tiger muskies inhabited was developed.

It should also be noted that I was intentionally vague in describing acceptability scores of high, high-medium, low-medium, and low. The desired adult tiger muskie population level (2.5 adults/ha) mimics esocid levels obtained in good fisheries in the Midwest. Population estimates in Colorado have yet to be determined. The low numbers of tiger muskies in a reservoir and difficulty in capturing this species makes mark-recapture estimates difficult to do with little confidence in the results. Therefore it would be impractical to determine expected population levels for each acceptability score. The best description to guide the reader in understanding these acceptability ratings is in the state of Colorado a tiger muskie stocked in waters with a high acceptability rating has more favorable conditions present for its survival than the other acceptability ratings. Favorable conditions for survival decrease as a water receives an acceptability rating of high-medium, low-medium, and low, respectively.

The intention of this acceptability index is to provide CDOW biologists with a tool to effectively stock available tiger muskies. For this reason, the acceptability index was constructed in a manner that allowed ease of use for CDOW biologists. Most information needed to use the acceptability index can be determined from standardized sampling. The rest of the information can be obtained with a few phone calls and a couple of short visits during specific times of the year. This process of gathering information must be done annually as reservoirs are dynamic. Particularly dynamic is the primary attribute of fish prey. A caution must be sent to all users of this index that it is only as good as the data that are used to establish the reservoir descriptions.

The acceptability index holds promise as a useful tool for apportioning limited numbers of juvenile tiger muskies. However, it is important to remember the restrictions that are built into the index. The acceptability index is intended for Colorado waters only. The acceptability index is intended for use on lentic waters only. Finally, the acceptability index is not a guide for stocking rates needed to establish tiger muskies, but rather assumes fish will be stocked at a rate of 25/ha. The acceptability index should also be viewed as an evolutionary document that can be changed. It is expected that when more information is gathered or validation procedures are completed, some rules for establishing reservoir descriptions and acceptability ratings may need to be altered.

Summary and Conclusion

Current research was motivated by poor performance of stocked juvenile tiger muskies. A two-fold approach was used to develop stocking methodology for juvenile tiger muskies. The first approach examined causes of post-stocking mortality and evaluated stocking strategies that would alleviate post-stocking mortality. The second approach developed a method to determine waters with current conditions that will be conducive to the existence and persistence of stocked juvenile tiger muskies.

The presence of fish predators was found to be a significant contributor to post-stocking mortality of juvenile tiger muskies. The process of deduction suggests that bird predation is an additional contributor to post-stocking mortality. Stocking stressors, presence of adequate size prey, and overwinter survival were not considered major contributors in these trials. However, any factor that reduces the growth of juvenile tiger muskies can make them vulnerable to fish predators for a longer period of time. Bird predation does not appear to be size related for juvenile tiger muskies as bird predators in this region are large enough to capture even the largest of juvenile tiger muskies.

Stocking strategies were tested for their effectiveness of alleviating causes of post-stocking mortality. The adjusted late stocking method provided a decrease in post-stocking mortality. This strategy stocks tiger muskies in 5-9 °C water, which is after many bird predators have migrated and when fish predators have a lower metabolism. A restriction on adjusted late stocking is to not exceed a 9°C difference in water temperature on the day of stocking. Training tiger muskies to avoid predators or search for appropriate cover more quickly, and stocking tiger muskies earlier or later in the year all failed to decrease post-stocking mortality in pond stocking trials.

The second approach addressed by this research pertained to determining which waters were most capable of accepting juvenile tiger muskies. The acceptability index utilized thermal regime, water clarity, living and non-living cover, escapement potential, and availability of prey to determine the suitability rating for juvenile tiger muskies in a particular body of water. The suitability rating was combined with the assessment of the predator community to give a water description representing the overall acceptability. The acceptability index should be viewed as a tool for effectively stocking juvenile tiger muskies into waters that give them the best chance to persist until the next fall. Tiger muskies that survive until their second fall should have lower mortality due to their increased size.

The appropriate use of the acceptability index is as a selection tool for which waters shall receive tiger muskies when limitations are recognized. The acceptability index was created using data from existing reservoirs, literature references, and logic designed to reflect natural settings. Consequently, the acceptability index is designed for specific situations and has limitations on its use. This index is restricted for use on lentic Colorado waters. The index assumes that tiger muskies will be stocked at a rate of 25/ha. The index also assumes that the data submitted to the index is current for the stocking year and reasonably predicts conditions for the year following stocking.

Research Needs

Recommendations from this research are based from results observed in artificial pond settings. Attempts to obtain information from natural settings were unsuccessful because capture techniques for tiger muskies during their first 3 years of existence failed. Assessing the success or failure of tiger muskie stockings after 3 years becomes difficult, since even for good stockings very few individuals remain. In addition, individuals sampled after 3 years are typically collected by gill nets or electrofishing and display high mortality from capture stress, thus destroying a valuable resource. Research to develop methods of assessing age 1 tiger muskies must be conducted to facilitate the capabilities of biologists to effectively manage this species.

Learning to capture age 1 tiger muskies will allow field validation of the adjusted late stocking strategy. Research needs to be conducted to determine if this stocking strategy reduces post-stocking mortality in natural settings. A true comparison of normal-stocked and adjusted late-stocked tiger muskies within the same reservoir would be the most appropriate test.

The adjusted late stocking strategy shows the most promise for decreasing post-stocking mortality of juvenile tiger muskies with current culture techniques. However, new or enhanced culture methods could increase the success of stocked tiger muskies. An increase in size at similar time of stocking should increase survival of tiger muskies. Developing economical methods of overwintering tiger muskies in hatcheries would allow fewer, larger tiger muskies to be stocked the next spring. Also, developing a feasible method of placing tiger muskies in protective cages until the next spring may allow fewer tiger muskies to be stocked. The hope is that new production techniques will change which methods of stocking are most efficient at producing adult year-classes.

Field validation of the acceptability index also needs to be achieved. This can be done by assigning an acceptability rating to individual waters during a current year and following those stockings to determine if the success of establishing tiger muskies was as predicted. Validation trials have been started, but results are not available at this juncture. Two obstacles in achieving field validation exist. The first is obtaining reliable data in a timely manner to determine if a particular stocking was successful. The second is the difficulty of finding reservoirs with a high or high-medium ranking in this region. Validating only reservoirs with low or low-medium acceptability ratings does not provide a complete look at the usefulness of this index.

Research needs to be conducted to evaluate different stocking rates. This research should be related back to the acceptability index for a stocking guideline to establish desired adult densities. For instance, it would be useful to know if waters with a high acceptability rating might need a stocking rate of only 15/ha to produce a 2.5/ha adult density, whereas a water with a low-medium acceptability rating might establish the same adult density with a stocking rate of 75/ha. The difficulty of establishing these relationships is the inability to accurately assess tiger muskie populations in natural settings. Without development of sampling procedures, management actions must be based from relationships established in artificial settings and long-term monitoring of populations that require speculation on what conditions created the observed success or failure.

Finally, a cost benefit analysis should be performed for tiger muskies in the state of Colorado. Assessing the economic efficiency of a program is a critical evaluation step for public agencies. A list of direct costs is provided in Appendix G. The estimate of \$0.48 per tiger muskie is less than the production cost found elsewhere (\$1.00-\$15.00 per fish) (Esocid Technical Committee 1997; Storck and Newman 1992). The discrepancy in cost can be explained by all of these estimated costs being for either true muskies or tiger muskies raised to a larger size. Also, costs associated with administration, equipment maintenance, and lost opportunity for production are left out of the direct cost estimate provided in Appendix G.

A complete examination of the benefits of tiger muskie fisheries must be conducted. Information concerning the number of tiger muskies caught, number of hours spent angling, the value of direct participation, and existence and bequest values need to be substantiated. No specific methodology has been developed for the benefit analysis of an esocid fishery. One possible method is to assess benefits as the number of fish creeled or caught (Walters et al. 1997; Storck and Newman 1992). However, I believe this grossly underestimates the value of the esocid fishery and a more appropriate method for analysis is based on effort and contingent value. Neuswanger et al. (1994) provides a good example of this valuation method for esocids.

The data provided within this appendix do not provide a complete analysis of the production costs of tiger muskies in the state of Colorado. To go farther would require many assumptions to be made. It is the intent of the author that this partial information not be used to make management decisions, rather promote future investigations.

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Appendices

Appendix A

Reservoir rating to be given to each impoundment that qualified for preliminary data collection. Reservoir ratings are based on either objective or subjective evaluations of a water bodies tiger muskies population.

Water Rating	Tiger Muskie Population Characteristic
Poor (1)	Objective: Catch per gill net-night in spring sample is <0.5 tiger muskie. Subjective: Water has never produced a solid year class and adult recruitment is minimal at best
Average (2)	Objective: Catch per gill net-night in spring sample is between and including 0.5 and 1.25 tiger muskie. Subjective: Water has produced fair numbers of tiger muskie from more than one year class and a few individuals exhibit growth to large size.
Above Average (3)	Objective: Catch per gill net-night in spring sample is >1.25 tiger muskie. Subjective: Water has produced consistent year classes and numerous individuals exhibit growth to large size.

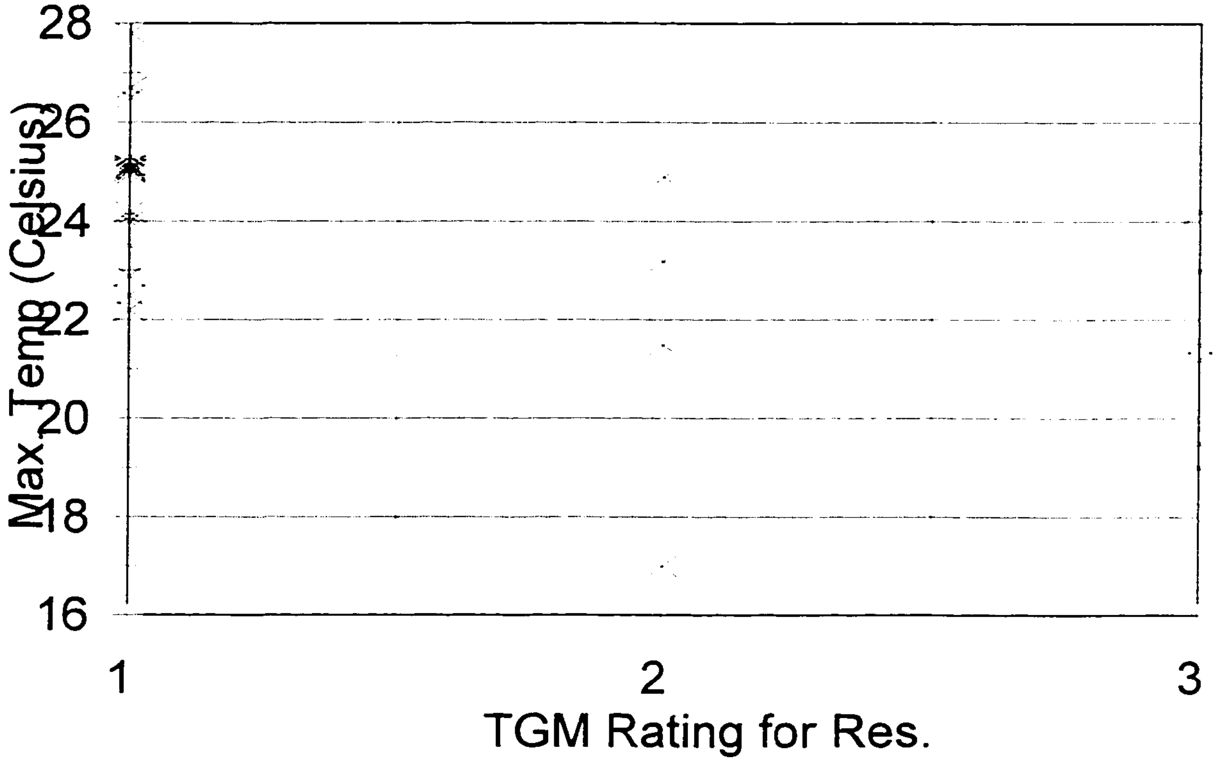
Appendix A- Reservoir rating to be given to each impoundment based on objective and subjective evaluations of a water body's tiger muskie population.

Appendix B

List of Reservoirs

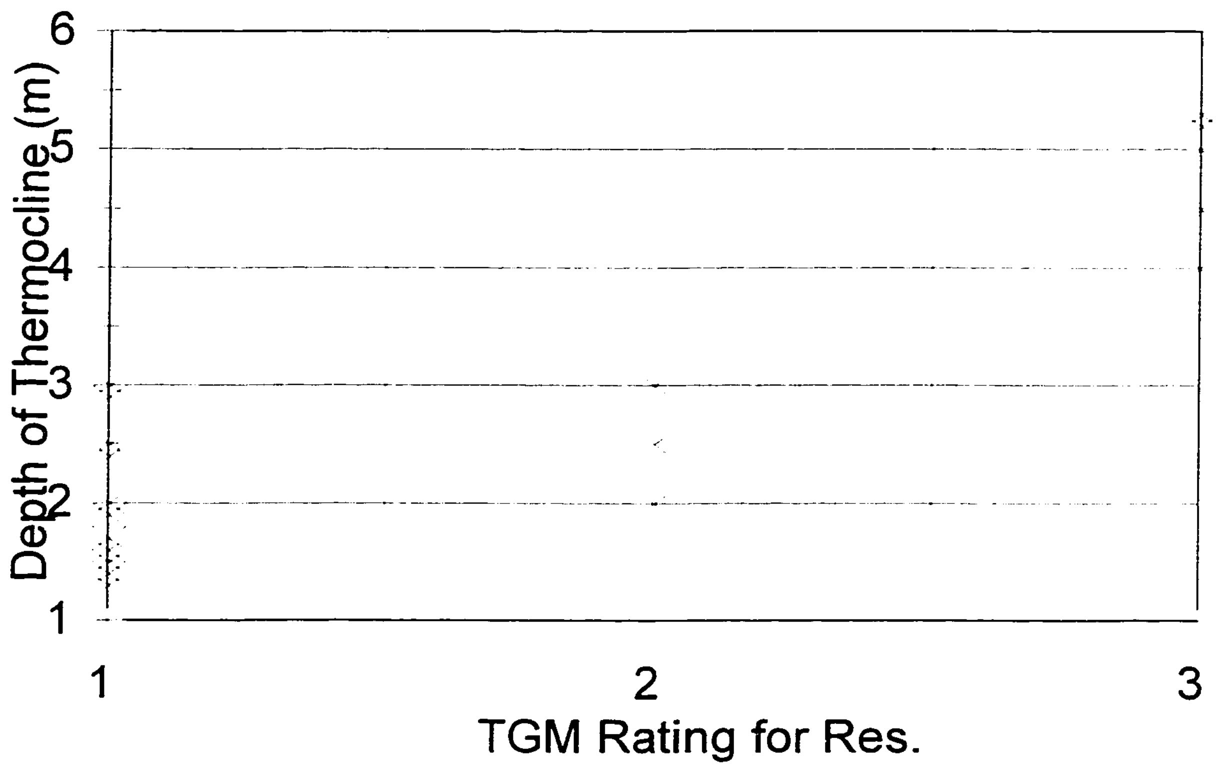
Adobe Creek Reservoir
Arvada Reservoir
Barr Lake
Bear Creek Reservoir
Chatfield Reservoir
Cherry Creek Reservoir
Evergreen Lake
Flagler Reservoir
Gross Reservoir
Holbrook Reservoir
Horseshoe Reservoir
John Martin Reservoir
Lagerman Reservoir
Lon Hagler Reservoir
Lower Big Creek Lake
Meredith Reservoir
Nee Grande Reservoir
Nee Noshe Reservoir
North Sterling Reservoir
Prewitt Reservoir
Prospect Pond #3
Quincy Reservoir
Riverbend Pond #3
Stalker Lake
Stearns Reservoir
Thurston Reservoir
Wellington Reservoir #4

Appendix B - List of reservoirs that were included in the preliminary data collection process conducted in 1996.



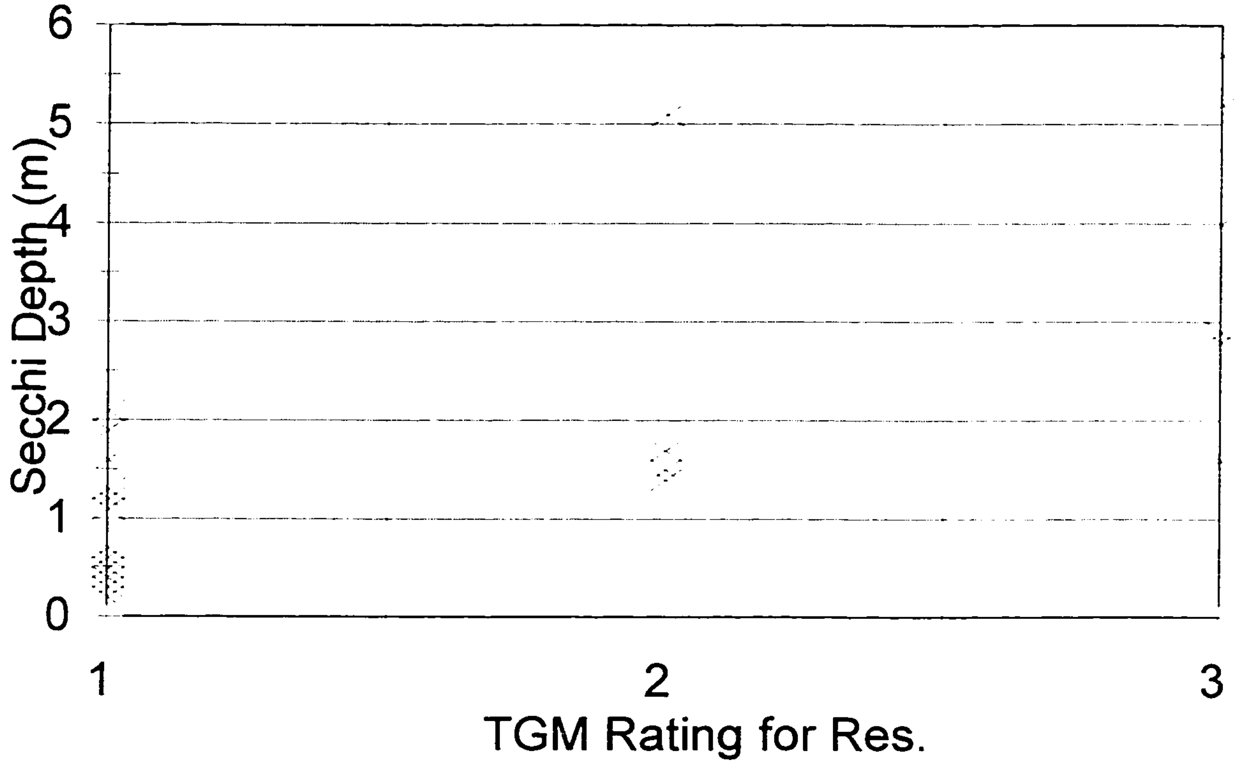
Appendix C - Observed relationship between the historical ability of a reservoir to establish tiger muskies and summer surface temperature recorded in 1996.

Appendix D



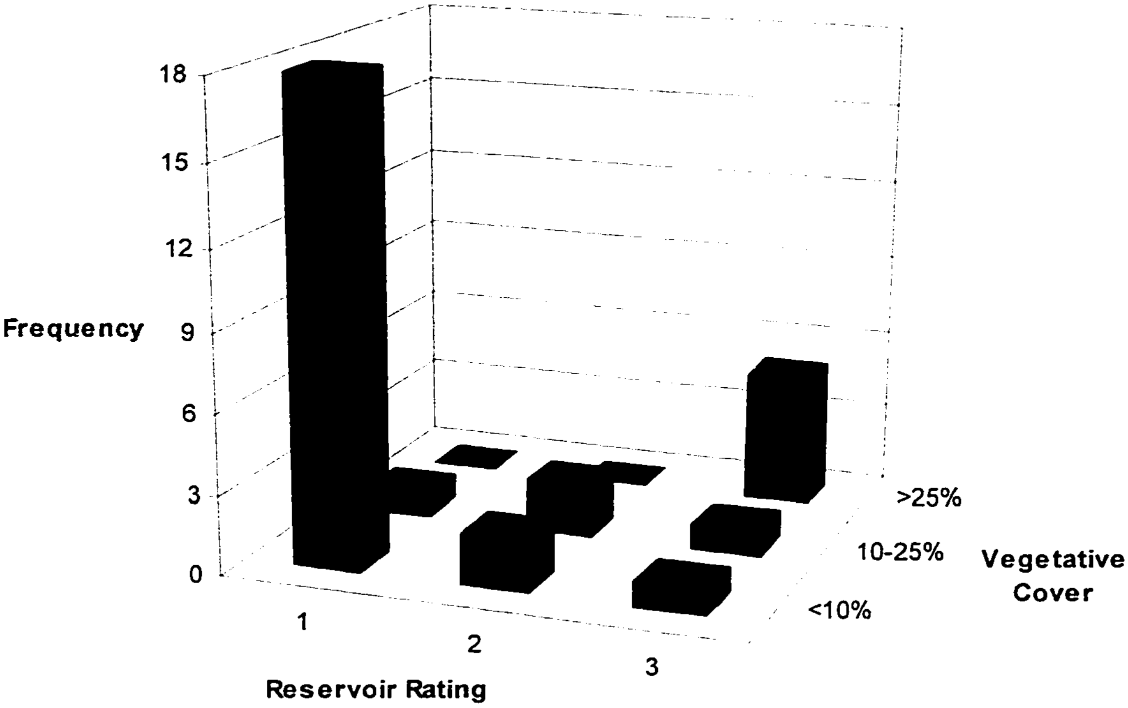
Appendix D - Observed relationship between the historical ability of a reservoir to establish tiger muskies and depth of thermocline recorded in the summer of 1996.

Appendix E



Appendix E - Observed relationship between the historical ability of a reservoir to establish tiger muskies and water clarity as measured by a Secchi disk in the summer of 1996.

Appendix F



Appendix F - Frequency of occurrence for possible combinations of the historical ability of a reservoir to establish tiger muskies and the amount of vegetative cover observed in that reservoir during the summer of 1996.

Appendix G

Source of Cost	Amount of Cost ($)
Pueblo hatchery production[a]	8,195
Wray hatchery production[b]	
Pellet food supplied - 4,024 pounds ($0.25/lb)	1,006
Fathead minnows supplied - 187.5 gallons ($25/gallon)	4,688
Pump cost for tiger muskie tanks (four months) - $300/month	1,200
Labor (feeding, maintenance, stocking) - 385 hours ($17/hr)	6,545
Transportation costs for stocking - 4641 miles ($0.22/mile)	1,021
Total Cost	22,655
Number of Tiger Muskies Produced in 1997	47,000
Cost per Tiger Muskie Produced	≅ 0.48

Estimate of the cost per age 3 tiger muskie with varying post-stocking survival rates

10% Survival	5% Survival	1% Survival
$4.80/fish	$9.60/fish	$48.00/fish

[a] The estimated production cost was provided by Tom Kingsley (CDOW).

[b] The estimate of production needs and specific costs for pelleted food and pump operation were provided by Dave Schnoor (CDOW). Cost of fathead minnows were based from bait dealer wholesale prices in South Dakota. Costs for labor and transportation were based from CDOW rates.

Appendix G - An assessment of the CDOW's production costs for tiger muskies in 1997.