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Diet, growth and bioenergetics of Northern Pike (Esox lucius Linnaeus, 1758) in Box Canyon Reservoir, Pend Oreille River, Washington

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DIET, GROWTH AND BIOENERGETICS OF NORTHERN PIKE (*Esox lucius* Linnaeus, 1758) IN BOX CANYON RESERVOIR, PEND OREILLE RIVER, WASHINGTON.

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Abstract

The objectives of this study were to describe the growth of northern pike, describe the food habits of northern pike and using bioenergetics modeling assess the mass and total numbers of each species of forage fish the northern pike population consumed in Box Canyon Reservoir, Pend Orielle River, Washington. Northern pike (n=328) were collected by boat electrofishing, fyke netting, angling and gillnetting in 2009 and 2010. All northern pike were sacrificed to obtain stomach contents. Stomach contents were examined in the laboratory and identified to the appropriate level; amphibians and mammals to species, insect prey (aquatic/terrestrial) to family and prey fish to species. Using standard regression equations from Hansel et al. (1988) and those developed for the EWU bone reference collection the length of ingested prey items at time of ingestion were estimated. A standard set of regression equations were then used to convert the estimated length of forage fish to estimate their weight at time of ingestion.

Cliethra and scales were used to age and back-calculate growth of 130 northern pike in Box Canyon Reservoir collected in 2009. The mean length of each age cohort at time of capture was: age 0+ (n=2, 268 mm ±12), age1+ (n=7, 281mm ± 34), age 2+ (n=18, 367 mm ±58), age3+ (n=16, 445 mm ±57), age 4+ (n=17, 634 mm ±70), age 5+ (n=40, 695 mm ±64), age 6+ (n=15, 780 mm ±60), age 7+ (n=10, 868 mm ±38), age 8+ (n=4, 978 mm ±56) and age 9+ (n=1, 1110 mm). Total length at annulus formation back calculated from scales were: age 1 (210 mm TL), age 2 (293 mm TL), age 3 (390 mm TL), age 4 (501 mm TL), age 5 (603 mm TL), age 6 (701 mm TL), age 7(803 mm TL), age 8 (934 mm TL) and age 9 (1059 mm TL). Mean relative weights for Box Canyon northern pike was

slightly below the national average for age 0 to age 3 (95 ±17) and at or above the national average for age 4 to age 9 (110 ±14). Fulton type condition index ranged from 0.27 to 1.00, with the national range of 0.47 to 0.69 (Carlander 1969).

The total population size was estimated at 5435 (±616, C=0.137) northern pike in Box Canyon Reservoir. It was estimated that 293 (5.3%) of pike ranged in length from 220 mm to 295 mm, 627 (11.5%) of pike ranged in length from 296 mm to 380 mm, 710 (13.0%) of pike ranged in length from 381 mm to 485 mm, 334 (6.1%) of pike ranged in length from 486 mm to 585 mm, 1337 (24.6%) of pike ranged in length from 586 mm to 695 mm, 1212 (22.3%) of pike ranged in length from 696 mm to 800 mm, 668 (12.3%) of pike ranged in length from 801 mm to 900 mm, 167 (3.0%) of pike ranged in size from 901 mm to 1005 mm, 84 (1.5%) of pike ranged in length from 1006 mm to 1110 mm.

Quantitative description of food habits included the total number, frequency of occurrence, percent composition by number, total weight, percent composition by weight and relative importance index for prey items consumed by northern pike in Box Canyon Reservoir. When comparing the food habits of reach two and reach three there was no difference in the percent composition by number (p value 0.253) and percent composition by weight (p value 0.688). There was a difference in the frequency of occurrence (p value 0.026) this was attributed to the consumption of trout and brown bullhead in reach two. Identifiable prey organisms included 12 species of fish, bull frogs and one mountain vole. Prey fish comprising the diet of northern pike in order of relative importance were:

1) Yellow Perch (*Perca flavens)* occurred in 44.8% of stomachs and comprised 50.9% by number, 25.1% by weight and 39.4% by relative importance of prey items in the diet.
2) Pumpkinseed (*Lepomis gibbosus)* occurred in 30.3% of stomachs and comprised 26.6% by number, 10.9% by weight and 22.1% by relative importance of prey items in the diet.
3) Peamouth (*Mylocheilus caurinus)* occurred in 9.8% of stomachs and comprised 6.9% by number, 19.3% by weight and 11.7% by relative importance of prey items in the diet.
4) Largescale sucker (*Catostomus macrocheilus)* occurred in 4.4% of stomachs and comprised 4.4% by number, 25.5% by weight and 11.2% by relative importance of prey items in the diet.
5) Bass (*Micropertus spp,)* occurred in 6.0% of stomachs and comprised 3.7% by number, 1.6% by weight and 3.7% by relative importance of prey items in the diet.
6) Northern pikeminnow (*Ptychocheilus oregonensis)* occurred in 2.4% of stomachs and comprised 1.4% by number, 4.1% by weight and 2.6% by relative importance of prey items in the diet.
7) Mountain whitefish (*Prosopium williamsoni)* occurred in 2.0% of stomachs and comprised 1.3% by number, 4.2% by weight and 2.4% by relative importance of prey items in the diet.

8) Tench (*Tinca tinca)* occurred in 1.7% of stomachs and comprised 1.2% by number, 3.7% by weight and 2.1% by relative importance of prey items in the diet.

9) Northern pike (*Esox lucius)* occurred in 1.3% of stomachs and comprised 0.81% by number, 4.0% by weight and 2.0% by relative importance of prey items in the diet.

10) Brown bullhead (*Ameiurus nebulosus)* occurred in 0.9% of stomachs and comprised 0.5% by number, 0.4% by weight and 0.6% by relative importance of prey items in the diet.

11) Eastern brook trout (*Salvelinus fontinalis)* occurred in 0.5% of stomachs and comprised 0.3% by number, 0.2% by weight and 0.3% by relative importance of prey items in the diet.

12) Brown trout (*Salmo trutta)* occurred in 0.2% of stomachs and comprised 0.13% by number, 0.2% by weight and 0.2% by relative importance of prey items in the diet.

Wisconsin Bioenergetics Model 3.0 estimated that northern pike consumed 7,940 Kg of fish flesh or 163,060 prey fish between May 2010 and October 2010. It was estimated that 296 mm to 380 mm pike consumed 49.9 Kg of fish flesh or 26,199 prey fish, 380 mm to 485 pike consumed 52.0 Kg of fish flesh or 29,275 prey fish, 486 mm to 585mm pike consumed 30.3 Kg of fish flesh or 12,195 prey fish, 586 mm to 695 mm pike consumed 184.6 Kg of fish flesh or 43,346 prey fish, 696 mm to 800 mm pike consumed 166.4 Kg of fish flesh or 34,051 prey fish, 801 mm to 900 mm pike consumed 153.3 Kg or

14,668 prey fish, 901 mm to 1005 mm pike consumed 58.5 Kg of fish flesh or 803 prey fish and 1006 mm to 1110 mm pike were not modeled due to the small sample size.

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Introduction

Construction of Grand Coulee Dam blocked anadromous fish from spawning and rearing habitat in the Upper Columbia River System. This area contained healthy, native, self-sustaining populations of resident fish, wildlife, and anadromous fish. The native fish assemblage consisted of resident salmonids, anadromous salmonids, catostomids and cyprinids that were well adapted to the pristine river conditions (Scholz et al. 1985, Bennet and Liter 1991, Ashe and Scholz 1992). In addition to the blockage and loss of habitat the dams created vast changes to the ecosystem. Free-flowing rivers with rapids and gravel bars for spawning and egg incubation have been replaced with a series of reservoirs and impoundments. These severe habitat alterations have created habitat conditions that are more suitable to non-native species. This change in habitat allowed non-native species to out compete many native species (Bennett and Liter 1991, Ashe and Scholz 1992).

Prior to the construction of Albeni falls and Box Canyon Dams the Pend Oreille river was primarily a cold water fishery and supported native cyprinids, catostomids, cottids, and salmonids (Barber et al. 1989, Ashe and Scholz 1992). The completion of the construction of Box Canyon Dam in 1955 and the subsequent filling of the reservoir led to the development of numerous shallow sloughs at the confluences of the tributaries providing habitat for warm and cool-water species such as largemouth bass (*Micropterus salmoides*), pumpkinseed (*Lepomis gibbosus*), yellow perch (*Perca flavescens*) (Bennett and Liter 1991, Ashe and Scholz 1992) and northern pike.

Adult northern pike are voracious predators that will feed on many types of prey including small rodents, water fowl, invertebrates, but prefer soft-rayed, fusiform fishes.

Northern pike can exhibit a considerable amount of dietary plasticity in regard to the variety of prey consumed but northern pike manage to survive mainly through piscivory for the majority of their lives (Craig 2008). Specific prey such as the soft-rayed fusiform members of the Catostomidae, Clupeidae, Cyprinidae, and Salmonidae families are often the preferred prey of northern pike (Mauck and Coble 1973, Wahl and Stein 1988).

Northern pike (*Esox lucius*) are an important sport and commercial fish throughout their natural range. Northern pike have a circumpolar distribution and can be found in northern Europe, Asia, and North America. In the United States northern pike's native range is Eastern New York, the Ohio River Valley, Missouri, Eastern Nebraska and Northeastern Montana. Northern pike have been legally and illegally introduced to water bodies outside of their native range as a sports fish and by fisheries professionals to rehabilitate stunted fish populations (Carlander 1969, Margenua et al. 2008). It is common for introduced northern pike populations to cause a collapse of the forage base within a short period of time of being introduced. This can lead to decreased angling opportunities for other fish and a decreased growth rate of the northern pike population (McMahon and Bennett 1996, Fuller et al. 1999).

The recent introduction of northern pike into Box Canyon Reservoir has led the Kalispel Tribe's Natural Resources Department and the Washington Department of Fish and Game to investigate the diet and bioenergetics of the northern pike population of Box Canyon Reservoir to determine the effect they are having on the forage fish and native fish populations. The overall goals of this research were to describe the food habits of northern pike in Box Canyon Reservoir by comparing the frequency of occurrence, percent composition by weight and percent composition by number of prey species in their diets, describe the growth achieved by northern pike and using bioenergetics modeling assess how much of each species of forage fish the pike population were consuming.

Natural History

Northern pike have a wide native distribution in North America that ranges from Alaska south through Canada, extending west of the Rocky Mountains through Nebraska to Missouri, with a southern boundary lying northeast of the west side of the Appalachian Mountains and north of the Ohio River (Bennett and Rich 1990, Carlander 1969; Figure 1).

In the Coeur d' Alene Basin northern pike were first introduced in the 1970's. In 1992 the northern pike population was experiencing exceptional growth rates at 31% above the national average (mean length of 1,100 mm at age 7) and within ten years their growth rate had slowed to below the national average with a mean length of 639 mm at age 7 in 2002 (Rich 1992, Scott 2002).

Environmental temperatures play significant roles in the distribution and habitat use of northern pike populations. Northern pike can tolerate a wide range of environmental conditions but are primarily a cool-water fish that are best adapted to shallow (< 12 m), productive, mesotrophic to eutrophic environments (Casselman and Lewis 1996). Northern pike begin to spawn shortly after ice-out, though the initiation is dependent on ambient water temperature (Clark 1950, Frost and Kipling 1967). Spawning begins when water temperatures are between 8^{o}-12^{o} C and take place in shallow flooded areas with depths less than 50 cm (Casselman and Lewis 1996, Clark 1950). Spawning dates vary from February to June depending on the geographical

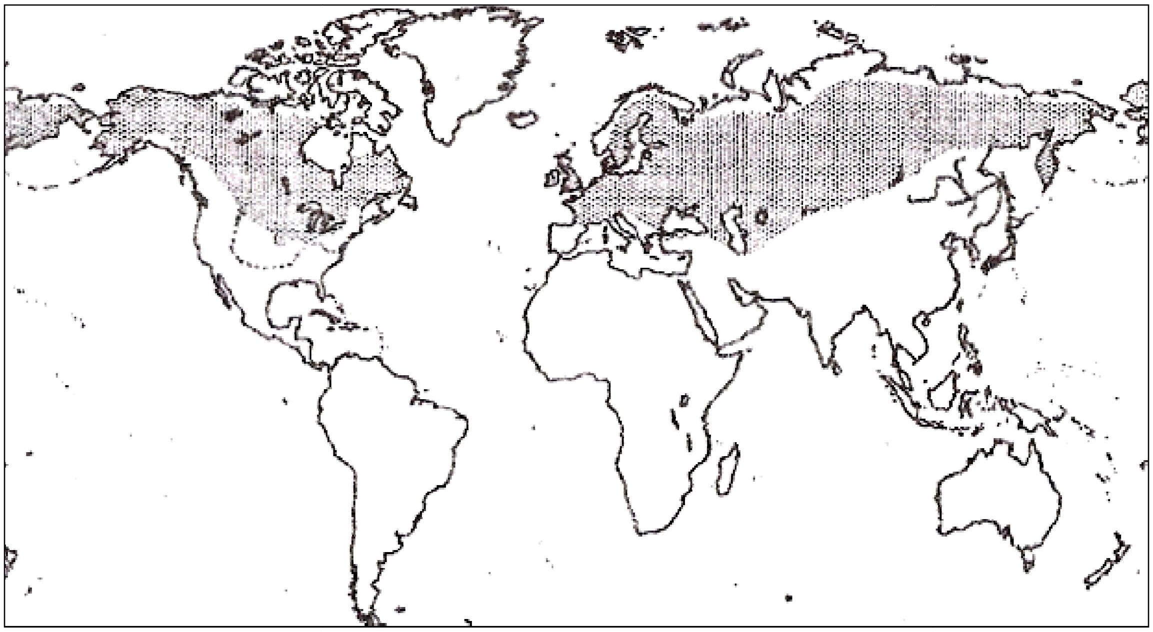

Figure 1. Geographical distribution of northern pike, limited to the cold temperate regions which are circumpolar in the Northern Hemisphere (Image courtesy of Ratt 1988).

location of the population. Northern latitude populations characteristically spawn from May to June while more southern populations spawn earlier, from February to March (Billard 1996).

Northern pike become sexually mature at different times, males can mature by 1 year old whereas females take at least 2 years, the rate at which is dependent on how fast they grow (Kipling and Frost 1967). Mecozzi (1989) reported that female northern pike in Wisconsin matured by age 3 (20-22in.) and males by age 2 (16-18in.). Once sexually mature the female gonad takes approximately 6 months to develop viable eggs and occurs during the fall and winter and can comprises up to 15% of the mass of the female (Carlander 1969). Frost and Kipling (1967) found that the number of eggs produced was proportional to the weight of the female, but there is a wide range in the number of eggs from fish of similar size, a 6.8 kg pike can produce anywhere from 186,000 to 226,000 eggs. Although this is a large number of eggs northern pike fry can experience heavy predation in the first year of life; losses of 99% of the total hatch are not uncommon (Mecozzi 1989).

Upon the arrival at the spawning grounds northern pike form groups consisting of one female with one to three males. To increase the rate of fertilization the males swim adjacent to or slightly behind the female. The female broadcasts 5 to 60 eggs onto flooded vegetation such as grasses and sedges, while the males simultaneously release their milt, this will be repeated until the female has released all her eggs (Clark 1950, Casselman and Lewis 1996, Mecozzi 1989).

Northern pike eggs will hatch 6 to 26 days post spawn when water temperature ranges from 6°C to 14°C (Frost and Kipling 1967, Inskip 1982). Once hatched, northern pike larvae will attach themselves to submerged vegetation for 6 to 10 days post hatch (Frost and Kipling 1967, Inskip 1982). As the developing larvae detach they will remain hidden in the vegetation while feeding on zooplankton and other invertebrates prior to full yolk sac absorption, (Frost and Kipling 1967, Clark 1950). Upon reaching 35mm in length northern pike fry begin to consume fish fry as part of their diet and by the time they reach 65mm their diet is comprised mainly of fish flesh (Carlander 1969).

As northern pike grow and mature their need for varying habitat becomes apparent. Fry will stay in the safe cover of dense macrophyte beds to feed on the many species of invertebrates that are found there (Mecozzi 1989, Frost 1954, Frost and Kipling 1967). As northern pike grow they move into deeper water and use habitat that is comprised of mixed vegetation and woody debris; this is presumed to help reduce predation and aid in camouflage (Casselman and Lewis 1996). All ages of northern pike are sit and wait predators and adults will wait under the cover of vegetation for prey to swim past in open water.

Over the last few decades northern pike have been introduced to Washington and Idaho waters. Rich (1992) and Scott (2002) surveyed the diets of northern pike in the Coeur d' Alene lake system and found that salmonids (79%) and yellow perch (15%) made up the majority of their diet by weight. Bean et al. (2007) analyzed the diets of northern pike in Box Canyon Reservoir and found that peamouth (24.7%), pumpkinseed (20.2%), mountain whitefish (18.3%), northern pikeminnow (12.2%) and yellow perch (8.8%) constituted the majority of their diet by weight.

Bioenergetics

Bioenergetics models are based on a balanced energy equation in which the total amount of energy consumed is equal to the total amount of energy expended through respiration, activity metabolism, food digestion and assimilation, together with waste losses and somatic and gonadal growth (Webber et al. 1998, Headrick 1985, Armstrong and Hawkins 2008). Environmental factors such as water temperature and dissolved oxygen influence the rate of prey consumption and metabolism, which directly affects the overall growth of an animal (Kitchell et al. 1977). The general balanced bioenergetics equation is as follows:

$$C = (R_S + R_A + SDA) + (F + U) + (G_S + G_R)$$

Where:

C = the specific consumption rate,
R_S = specific (standard) rate of metabolism,
R_A = rate of metabolism due to activity,
SDA = specific dynamic action value
F = the specific rate of egestion or fecal loss,
U = the specific rate of excretion of nitrogenous waste,
G_S = the growth rate of somatic tissue, and
G_R = the accumulation rate of reproductive tissue (gonads).

With the development of Wisconsin Fish Bioenergetics 3.0 program the modeling of the energetic requirements and potential impacts of a given fish species on the forage base can be easily estimated (Hanson et al. 1997). The program is designed to have known parameter values of the species of interest for each component of the bioenergetics equation input into the program. Once the established value fields have been input, the model can be used to forecast specific consumption values or growth rates for an individual, a cohort, or a population.

Consumption

With predator-prey relationships being an important component in ecosystems, it is the energy requirements of predators that are modeled using prey consumption (Kitchell et al. 1977). Values used for consumption parameters for the northern pike bioenergetics model were based on values from Bean (2010), Bevelhimer (1985) and the Fish Bioenergetics 3.0 software (Hanson et al. 1997). The formulas necessary for the consumption parameters follows:

$$C = C_{MAX}((P)f(T))$$

And

$$C_{MAX} = CA(W^{CB})$$

Where:

C = the specific consumption rate ($g\ g^{-1}\ d^{-1}$),
C_{MAX} = maximum specific feeding rate ($g\ g^{-1}\ d^{-1}$),
P = the proportion of maximum consumption,
$f(T)$ = the temperature dependence function,
T = the water temperature (ºC),
W = fish mass (g),
CA = intercept constant of the allometric mass function (intercept constant)
CB = slope constant of the allometric mass function (weight-dependent constant).

Temperature

Temperature is a vital piece of data for bioenergetic modeling and affects the rate of digestion and metabolism. Pike have been documented to survive in temperatures down to 0.1 °C with an upper limit approaching 30 °C (Bevelhimer et al. 1985, Jacobsen 1992). While northern pike have demonstrated their adaptability to varying environments, optimal growth occurs in temperatures ranging from 19-25 °C. The temperature dependence function for warm-water fish species as described by Hanson et al. (1997) is:

$$F(T) = V^X(e^{(X(1-V))})$$

Where:

$$V = (CTM - T) / (CTM - CTO)$$
$$X = (Z^2 \bullet (1 + (1 + 40 / Y)^{0.5})^2) / 400$$
$$Z = LN (CQ) \bullet (CTM - CTO)$$
$$Y = LN (CQ) \bullet (CTM - CTO + 2)$$

The sub-equations above exist as components of the temperature dependence function. Within these sub-equations, CA is the intercept of the mass dependent function for a 1 g fish at the optimal/preferred laboratory (CTO) water temperature, CTM is the maximum water temperature above which consumption ceases, and CQ approximates Q_{10} (Winberg 1956). The temperature coefficient Q_{10} accounts for the rate of change as a result of adjusting the temperature by 10 °C. A value between 2 and 3 is standard for most fish species (Beamish 1964; Fry 1971). The equation for calculating Q_{10} is as follows:

$$Q_{10} = \frac{C_{(T-10^{o})}}{C_{T^{o}}}$$

Where:

$C_{(T + 10°)}$ = the specific rate of consumption in g g^{-1} d^{-1} within a 10 degree(C) difference of $C_{(T°)}$ and at a given temperature

$C_{(T°)}$ = the specific rate of consumption (g g^{-1} d^{-1}).

Metabolism

Caloric intake, activity level, mass and environmental temperature all influence a fish's metabolic rate. Metabolic rates (standard, active and specific dynamic action) are generally determined by lab experiments by placing acclimated fish into a respirometer and altering the temperature (Chipps et al. 2000, Schoenebeck et al. 2008, Bean 2010). Energy used for metabolism accounts for a significant proportion of the overall energy budget of fish. Standard metabolism (R_S) values of northern pike have been estimated at a variety of temperatures, mass of fish and population locations. A review of standard metabolic rates of northern pike was conducted by Armstrong and Hawkins (2008). In this review it was evident that standard metabolic rates of pike are influenced by multiple factors. Among the studies reviewed, there was a twofold to fourfold deviation in standard metabolic rates when mass and temperature were accounted for (Armstrong and Hawkins 2008).

The dependence of a fish's metabolism on mass and temperature requires that standard metabolism be calculated as a function of mass that is then modified with a temperature dependent function and activity factor (Hanson et al. 1997). The total cost of metabolism is estimated by summing the cost of respiration with costs due to the assimilation of energy (specific dynamic action). The equations used to describe metabolism are as follows:

$$R_S = RA \times W^{RB} \times f(T) \times ACT$$

Where:

R_S = the mass-specific (standard) rate of respiration or metabolism ($g\ O_2 \bullet g^{-1} \bullet d^{-1}$)
W = mass (g) of a fish
RA = the intercept constant of the allometric mass function which is the specific weight of O_2 ($g\ O_2\ g^{-1}\ d^{-1}$) consumed for a 1 g fish at optimum temperature for respiration (º C) and zero swim speed.
RB = the scaling constant of the allometric mass function for standard metabolism
f(T) = a temperature dependence function with T as the temperature of the water (ºC)
ACT = an activity multiplier.

Activity multiplier

The activity multiplier takes in to account the dependence of metabolism on the multiple activity levels of northern pike such as sit and wait, burst speed and daily movement. Since the temperature dependence function has a fixed relationship between temperature and activity it can be adjusted to accommodate the activity of the fish (Kitchell et al. 1977; Hanson et al. 1997). The activity dependent respiration equations described by Hanson et al. (1997) are:

$$F(T) = V^{X}(e^{(X(1-V))})$$

Where:

$$V = (RTM-T) / (RTM-RTO)$$
$$X = (Z^2 \bullet (1+40/Y)^{0.5})^2)/400$$
$$Z = LN(RQ) \bullet (RTM-RTO)$$
$$Y = LN(RQ) \bullet (RTM-RTO+2)$$

And

RQ = the temperature dependence coefficient which approximates Q_{10} or the rate which the function increases over relatively low water temperatures ($^oC^{-1}$),

RTO = optimum temperature for respiration (^oC),

RTM = the maximum or lethal water temperature (^oC)

RA = the intercept constant of the allometric mass function which is the specific weight of O_2 (g O_2 g^{-1} d^{-1}) consumed for a 1 g fish at optimum temperature for respiration (^oC) and zero swim speed

RB = the scaling constant of the allometric mass function for standard metabolism

ACT = a constant multiplied by resting metabolism which accounts for activity above a resting state (Winberg 1956).

Bean (2010) used tracking data gathered by the Kalispel Natural Resources Department to develop the activity multiplier of 1.849 for Box Canyon Reservoir northern pike, which is the number I used.

Specific Dynamic Action

Specific dynamic action is considered a component of overall metabolism and is the proportion of energy utilized in the digestion of food. To calculate the constant proportion of assimilated energy lost to specific dynamic action (*S*), egestion (*F*) must be subtracted from consumption (*C*) as described by the following equation (Hanson et al. 1997):

$$S = SDA(C - F)$$

Where:

S = the proportion of assimilated or digested energy lost to specific dynamic action (SDA),
C = the specific consumption rate (g g^{-1} d^{-1})
F = the specific egestion rate (g g^{-1} d^{-1})

According to Hanson et al. (1997), SDA typically ranges from 0.15 to 0.2. Bevelhimer et al. (1985) and Bean (2010) used an SDA value of 0.14, which was an averaged value suggested for all fishes and used by most researchers.

Egestion and Excretion

Waste loss is generally assumed to have a constant proportion to consumption and varies with temperature (Jacobson 1992, Bevelhimer et al. 1985, Hanson et al. 1997, Bean 2010). Fecal waste loss through egestion (*F*), estimated in grams of waste per gram of fish per day, was assumed to be a constant proportion of consumption (Kitchell et al. 1977) and was calculated as follows:

$$F = FA(C)$$

Where:

F = the egestion of fecal waste (g g^{-1} d^{-1}),
FA = a constant proportion of consumption, and
C = the specific consumption rate (g•g^{-1}•d^{-1})

Bevelhimer et al. (1985) and Bean (2010) used an *FA* value of 0.2, as an averaged value for a variety of fishes and is used widely used by researchers. Nitrogenous waste loss as excretion (*U*), which is assumed to be a constant proportion of consumption (*C*) estimated in grams of waste per gram of fish per day (Kitchell et al. 1977) was estimated as follows:

$$U = UA(C - F)$$

Where:

U = the excretion of nitrogenous waste or urine ($g\ g^{-1}\ d^{-1}$),
UA = is a constant proportion of assimilated energy (consumption),
C = the specific consumption rate ($g\ g^{-1}\ d^{-1}$)
F = the value for fecal waste ($g\ g^{-1}\ d^{-1}$)

Bevelhimer et al. (1985) and Jacobson (1992) used 0.079 as the UA value as it is an average of variety of fishes and no other data were available for esocids at the time. Bean (2010) used 0.2 to maintain consistency with prior studies.

Box Canyon Northern Pike

Northern pike were first collected in a fisheries survey of Box Canyon Reservoir in 2004 (Bean et al. 2007, Ashe and Scholz 1992, Barber et al. 1989). Northern pike in the Pend Oreille River likely originated from the Clark Fork River, Montana where they were established through illegal introductions (Fuller et al. 1999). Since being introduced they have expanded their range to include the Clark Fork and Pend Oreille Rivers. It has been hypothesized that northern pike get washed downstream during high flow events. Anglers have reported catching northern pike in Box Canyon Reservoir prior to being reported in a fisheries survey in 2004. The Kalispel Tribe Natural Resources Department observed northern pike spawning in slough habitats in the upper section of Box Canyon Reservoir between Newport and Cusick, WA in 2004, 2005 and 2006 (Bean et al. 2007). Box Canyon Reservoir varies in habitat type, some of which are better suited to northern pike, with the recent population growth of northern pike have had to expand their range to include these less suited habitat types.

Nine age classes ranging from 0+ to 8+ years old have been documented in Box Canyon Reservoir (Bean et al. 2007). A population estimate conducted by Kalispel Natural Resources Department in 2006 estimated the population of adult northern pike (in excess of 300 mm in total length, ± 95 % CI) in Box Canyon Reservoir to be 665 (595 – 765) individuals (Bean et al. 2007). All of the 123 northern pike collected in the 2006 study were captured between Ashenfelder Bay located near Newport, Washington and Tacoma Slough located north of Cusick, Washington. Even though the northern pike population of Box Canyon Reservoir was small in 2006 it was believed that the population would experience exponential growth for the next 10-20 years until the northern pike population reaches the carrying capacity of the reservoir (Bean et al. 2007). In the present study, to quantify the impact of predation by northern pike on forage fish populations of Box Canyon Reservoir; I had the following specific objectives:

1. Determine age, length and weight of northern pike in Box Canyon Reservoir.
2. Determine the number, size (length and weight) and percent composition of prey species in the diets of northern pike by stomach removal.
3. Mark and recapture northern pike to generate a population estimate.
4. Determine growth of northern pike using scales and cliethra to back-calculate growth.

5. Use bioenergetics modeling for northern pike to determine total grams of prey species consumed and convert data into total number of each prey species consumed for the period between May 2010 and October 2010.
6. Determine if northern pike have different food habits between reaches.

Materials and Methods

Study area

Box Canyon Reservoir was created in 1955 with the completion of Box Canyon Dam which is a run-of-the-river hydropower plant and is operated by the Pend Oreille Public Utility District. Box Canyon Reservoir extends 89.6 km from Box Canyon Dam at RKM 53.3 to Albeni Falls Dam at RKM 145 in Bonner County, Idaho. Box Canyon Reservoir has a surface area of 3,582 ha with average depths ranging from 3 m to13 m. The Pend Orielle River has a mean summer flow of 7,000 cfs with mean spring flows of 80,000 cfs (Figure 2). Box Canyon Reservoir can be broken into three different habitat types; from Box Canyon dam (RKM 53.3) to Riverbend (RKM 88.5) it is a deep, slow moving reach, from Riverbend to Delkena (RKM 128.8) the reservoir is wider and slow flowing and from Delkena to Albeni Falls Dam (RKM 145) it is riverine in habitat.

For this study Box Canyon Reservoir was divided into four reaches; reach 1 extended from Box Canyon Dam to Riverbend, reach 2 extended from Riverbend to Delkena, reach 3 extended from Delkena to Albeni Falls Dam and reach 4 included all the sloughs and bays found throughout the reservoir (Figure 3). Sloughs include Tacoma creek, Old Dyke, Calispell creek, Cee Cee Ah creek, Miltner slough, Baja slough, Cusick/Gardner slough, Campbell's slough, Tiger slough, No Name slough, Pow Wow slough, Everett Island, Ashenfelder bay and Davis slough. Transects were located and numbered every 400 meters along the reservoir and slough shorelines. Sampling locations were then selected by randomly selecting sites. Reach 1 was excluded from the sampling area due to the low abundance of northern pike and lack of habitat for northern pike in the reach.

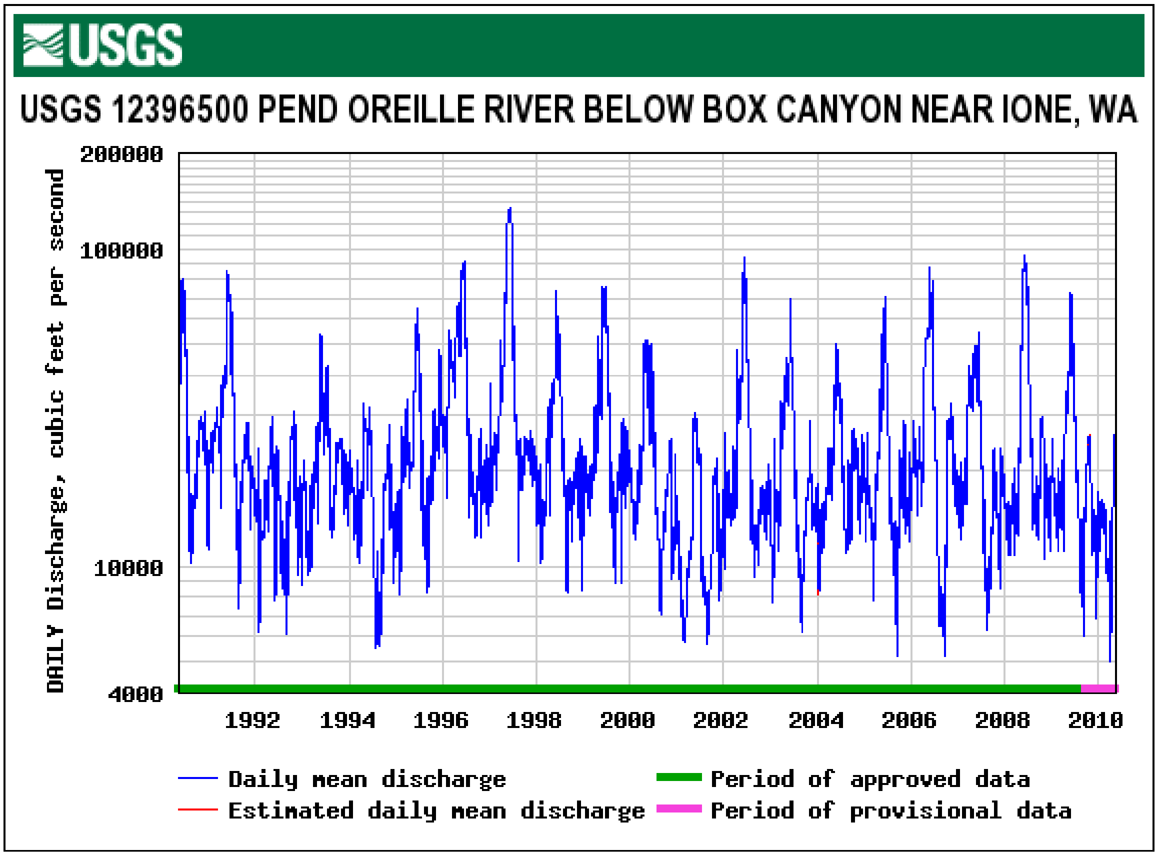

Figure 2. Daily discharge (cfs) of Pend Oreille River below Box Canyon Dam, 1990 to 2010.

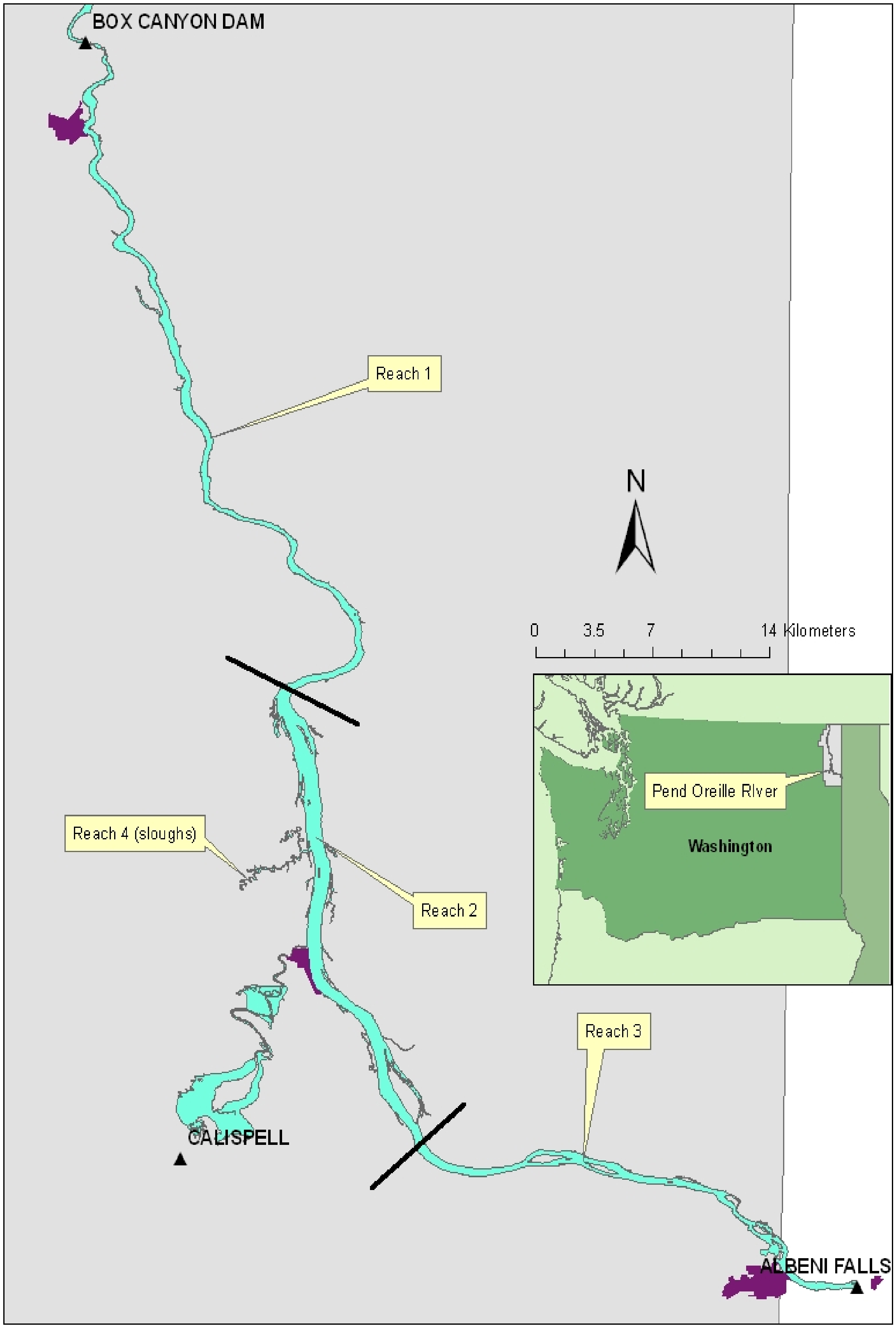

Figure 3. Locations of reachs and reach breaks for Box Canyon Reservoir used in this study.

Field Methods

Electrofishing, Gill netting and Fyke netting

Collection methods of northern pike included boat electrofishing, fyke netting, gill netting and angling. Spring sampling of northern pike diet habits and growth occurred from 18 May to 10 June, 2009, fall sampling occurred from 05 October to 20 October, 2009 and spring 2010 sampling from 03 May to 07 May. Seasonal stomach samples were collected from May through October 2010. Electrofishing surveys began at dusk and continued until 0200 hours. Gill and fyke nets were set at 1600 hours and were fished for 16 to 20 hours. In 2009 a total of 62 electrofishing, 33 gill net and 15 fyke net locations were sampled. Fyke nets were restricted to sloughs due to high flow velocity in the river.

Electrofishing occurred in shallow water (< 2.5m) adjacent to the shoreline while attempting to net every stunned fish (Bonar et al. 2000). Standardized 600-second electrofishing passes was conducted using a Smith-Root electrofishing boat using pulsed DC current (30-120 pulses per second) with low voltage (50-500) and the range adjusted to induce taxis (3 to 5 amps). Experimental gill nets (45.7 meters [m] x 2.4 m) consisting of variable size (13, 19, 25, and 51 millimeter [mm] stretched) monofilament mesh were set perpendicular to the shoreline with the smallest mesh end attached to shore and large-mesh end anchored offshore. Fyke nets were constructed of a main trap (4.7 m long and 1.2 m in diameter with five fiberglass hoops), a single 30.3 m lead, and two 15.2 m wings. Fyke nets were set perpendicular to the shoreline with the lead attached to shore and wings extended at approximately 70^{o} angles from main trap. To maximize efficiency of each gear type sampling was conducted at night when fish are most numerous and active along shorelines.

Population estimate

In the spring of 2010 the Kalispel Natural Resources Department, Washington Department of Fish and Wildlife and Eastern Washington University conducted a northern pike population survey of the Box Canyon Reservoir. The marking period took place between 19 April and 30 April using electrofishing and fyke netting as the mode of capture. Recapture took place between 03 May and 07 May using gill nets as the mode of capture. All northern pike collected during the recapture event were sacrificed to collect data on diet, age, growth and fecundity. The population estimate was calculated using Petersen estimator with Chapman modification (Ricker 1975, Barber et al. 1988).

$$N = \frac{(M+1)(C+1)}{R+1}$$

Where:

N = population estimate
M = number of marked fish
C = total number of fish caught during recapture
R = number of recaptured fish

In order to calculate the 95% confidence interval associated with the population estimate the standard error was calculated using the square root of the variance. The equation used to calculate the standard error was:

$$SE = \sqrt{\frac{N^2(C-R)}{(C+1)(R+2)}}$$

Where

SE = standard error
N = population estimate
C = total number of fish caught on second sample
R = number of recaptured fish on second sample

The 95% confidence interval was then calculated by adding and subtracting 1.96 standard errors to the population estimate.

Population estimate assumptions

The mark-recapture events were designed to meet the assumptions of the Peterson Model (Scalon and Roach 2000). The assumptions are:

1) The population is closed; there is no change in the number or composition of northern pike during the study period. This includes births (recruitment), deaths (mortality), emigration and immigration.
    a) The experimental gill nets used for recapture of marked fish are designed to catch northern pike over 350 mm and the length of time between the mark and recapture events was three weeks so no recruitment to the population was expected during this time.
    b) Natural and angling mortality was expected to be minimal due to the short time period between the mark and recapture periods.
    c) Fish passage upstream of the study area is blocked by Albeni falls dam, No anglers reported catching marked pike downstream of the study area between the mark and recapture period.
2) That all northern pike have the same probability of being captured during the marking period or the same probability of being captured during the recapture period or that marked and unmarked northern pike had become completely mixed between the mark and recapture events (equal catchability). There are two cause of bias, first is heterogeneity; animals may vary in capture probability according to age, sex, social status and other

factors which may vary over the population (Pollock 1981). To reduce this bias both mark and recapture sites were randomly selected and included both river and slough sites. The second concern is trap response; animals may become "trap shy" or "trap happy" depending on the type of trapping method used which affects the probability of capture (Pollock 1981). To reduce the probability of a behavioral response by northern pike to being captured we changed sampling gear from marking (electrofishing and Fyke net) to recapture (Gill net) events.

3) Northern pike do not lose their mark between the mark and recapture events. Northern pike over 350 mm were marked with an individually numbered Floy tag (Floy Tag, Inc. Seattle, WA; Model FD-94, T-shaped anchor). All tags had the inscription –Kalispel Tribe- with unique identification number and telephone number. A second mark consisted of a hole-punch in the right pelvic fin (Scheirer and Coble 1991). We expected tags to be lost and from careful examination of where the standardized placement of tag insertion was, recent wounds from tag loss were determined. Previous tagging studies have found that northern pike have high T-bar tag retention rates. Gurtin et al.(1991) tagged 170 northern pike in three small South Dakota lakes, and found that 92% retained their tags. This tag loss was found to be high when compared to other tag retention studies. Pierce and Tomcko (1993) did a similar study in Minnesota and found that the tag retention for northern pike was 98.8%.

4) All marked northern pike were reported when recapture during the recapture event. This assumption was met by careful examination of the pelvic fins for fin clip and by recording the Floy tag number along with date and location of capture.
5) Tagged northern pike have the same mortality rate as unmarked fish. This assumption will not be tested due to cost and time constraints and the use of previous studies showing that mortality is low for marked fish will be refrenced. Pierce and Tomcko (1993) reviewed previous studies showing that mortality from the handling and tagging for northern pike is 2.4% (trap netting) and 9.1% (gill netting and angling) the wide range in mortality could be due to the method of capture.

Mark and recapture

The capture method used for the marking period was boat electrofishing using the standard methods described previously. Northern pike less than 350 mm were not recruited into the gear used for the recapture and were not represented in the population estimate. Northern pike over 350 mm were marked with an individually numbered Floy tag (Floy Tag, Inc. Seattle, WA; Model FD-94, T-shaped anchor). Orange Floy tags were inserted on the dorsal musculature so that the T-bar anchor became lodged through the dorsal pterygiophores near the anterior edge of the dorsal fin at an approximate 45^{o} angle posterior of the body (Pierce and Tomcko 1993, Scheirer and Coble 1991, Gurten et al. 1999).

The recapture took place the week following the marking period. A different mode of capture was employed (gillnetting) to reduce the chance that previously electrofished northern pike learned to avoid the electrofishing boat. To help reduce the amount of by-catch size selective gear was used. The experimental gill nets were 45.7m X 2.4 m and consisted of variable size monofilament mesh 19mm, 25mm, and 51mm stretched. Gill nets were set three times for 24 hours each time for a total of three days.

Age and Growth

All Northern pike were measured (TL in mm), and weighed to the nearest gram (Bonar et al. 2000). Cliethra were removed by grasping the fish behind the head lifting the branchiostegal and opercular flaps to expose the cleithrum. A knife was inserted between the posterior edge of the cleithrum and the muscle and connective tissue to separate the medial surface of the cleithrum from the underlying soft tissue. The knife was then moved along the inner surface towards the dorsal and posterior and towards the ventral and anterior to remove the bone. It is important during this procedure to avoid tearing or breaking the anterior tip and anterior growing edge (Mann 2004). The cleithrum was placed in a plastic bag, labeled and frozen. In the lab excess flesh was removed by placing cliethra in hot water for 10 to 30 seconds, depending on amount of flesh to be removed. The cliethra were then stored in envelopes for later analysis. Scales were collected from above the lateral line and below the dorsal fin. Using the tip of the knife approximately 6 to 10 scales were removed from the body and placed in a scale sample envelope (Mann 2004).

Diet

Stomachs were checked in the field for undigested prey items, stomachs containing prey items were removed by cutting anterior of the esophagus and posterior of the pyloric sphincter. The stomach and associated intestine were preserved in a jar filled with 10% formalin solution or frozen for later lab analysis.

Laboratory Procedures

Diet

Stomach contents were examined using a Nikon SMZ-10 stereo zoom dissecting microscope with fiber optics ring illumination and adjustable illumination system. Content of stomachs were classified to the appropriate taxonomic level; insect prey (aquatic) were identified to family using Pennak's Freshwater Invertebrates of North America, 3rd edition and prey fish were identified to lowest taxonomic level possible. For those prey fish that were partially digested the recovered bones were compared to those in the EWU fish bone reference collection and diagnostic bone key by Hansel et al. (1988). The EWU reference collection has most of the potential prey species found in Box Canyon Reservoir. Prey fish identified by bones were estimated by counting diagnostic bones from one side of the body, the highest counts were used to estimate the number of that prey species eaten. Recovered diagnostic bones, such as cliethra, dentaries or opercales were measured and prey fish's length was back calculated (Bowen 1996, Hansel et al. 1988). Standard equations from Hansel et al. (1988) and those developed for the EWU bone reference collection were used for calculating length of the prey fish at the time of ingestion (Table 1).

All diagnostic bones were measured to the nearest 0.01mm using a General 152mm digital caliper. Cliethra were measured diagonally from the posterodorsal tip to the anteroventral tip. Dentaries were measured from the synaphysis to the point the ventral edge of the dorsal limb met the dorsal edge of the ventral limb. Opercles were

Table 1, Diagnostic bone regression equations for prey fish consumed by northern pike in Box Canyon Reservoir (y = a + bx). Data from Scott 2002, except Peamouth (Hansel et al. 1988).

Species	Diagnostic Bone	Measurment	Equation	R^2
Yellow Perch	Cleithrum	TL:CL	y=11.87+6.46x	0.96
Northern Pikeminnow	Cleithrum	TL:CL	y=33.42+7.82x	0.98
Tench	Cleithrum	TL:CL	y=10.47+6.38x	0.98
Largemouth bass	Cleithrum	TL:CL	y=16.26+5.39X	0.97
Pumpkinseed	Cleithrum	TL:CL	y=12.16+4.20x	0.99
Brown bullhead	Cleithrum	TL:CL	y=0.36+5.897x	0.99
Largescale sucker	Cleithrum	TL:CL	y=11.18+9.68x	0.93
Oncorhynchus sp	Cleithrum	TL:CL	y=18.13+8.4713x	0.98
Mountain whitefish	Cleithrum	TL:CL	y=-18.41+12.288x	0.99
Peamouth	Cleithrum	TL:CL	Y=-9.55+8.71X	0.99
Yellow Perch	Dentary	TL:DM	y=17.9+21.17x	0.99
Northern Pikeminnow	Dentary	TL:DM	y=51.59+11.36x	0.96
Tench	Dentary	TL:DM	y=2.93+18.64x	0.98
Largemouth bass	Dentary	TL:DM	y=25.69+12.88x	0.97
Pumpkinseed	Dentary	TL:DM	y=-34.49+33.4x	0.91
Largescale sucker	Dentary	TL:DM	y=-38.81+60.425x	0.76
Oncorhynchus sp	Dentary	TL:DM	y=43.69+9.8657x	0.92
Brown bullhead	Dentary	TL:DM	y=15.13+9.4881x	0.97
Mountain whitefish	Dentary	TL:DM	y=-46.53+23.991x	0.96
Yellow Perch	Opercle	TL:OM	y=17.38+11.33x	0.99
Northern Pikeminnow	Opercle	TL:OM	y=24.9+13.52x	0.97
Tench	Opercle	TL:OM	y=21.03+8.86x	0.98
Largemouth bass	Opercle	TL:OM	y=18.0+9.69x	0.99
Pumpkinseed	Opercle	TL:OM	y=9.16+8.44x	0.93
Brown bullhead	Opercle	TL:OM	y=0.036+14.717x	0.99
Largescale sucker	Opercle	TL:OM	y=10.55+13.173x	0.95
Oncorhynchus sp	Opercle	TL:OM	y=31.20+12.595x	0.95
Mountain whitefish	Opercle	TL:OM	y=-1.88+15.8x	0.98
Peamouth	Opercle	TL:OM	Y=-2.77+13.29X	0.99
Yellow Perch	Preopercle	TL:POM	y=6.1+9.25x	0.99
Northern Pikeminnow	Preopercle	TL:POM	y=32.19+10.94x	0.99
Tench	Preopercle	TL:POM	y=15.15+8.62x	0.99
Largemouth bass	Preopercle	TL:POM	y=7.38+7.37x	0.99
Pumpkinseed	Preopercle	TL:POM	y=10.32+6.16x	0.95
Northern Pikeminnow	Pharyngeal arch	TL:PL	y=35.38+12.51x	0.96
Tench	Pharyngeal arch	TL:PL	y=20.0+11.65x	0.98
Largescale sucker	Pharyngeal arch	TL:PL	y=-62.16+18.964x	0.96
Peamouth	Pharyngeal arch	TL:PL	Y=-1.84+14.70X	0.98

measured from the anterodorsal edge above the fulcrum to the anteroventral point of the primary ray. Pharyngeal arches were measured from the dorsal tip to the ventral tip. The preopercles were measured diagonally from the posterodorsal tip to the anteroventral tip. Length of each individual prey item at the time of ingestion was calculated by substituting length of diagnostic bone for x in the regression equation

$$y = a + bx$$

Where:

y = total length of prey at time of ingestion
x = diagnostic bone measurement
a, b = constants determined for specific diagnostic bones

Regression equations from literature were used to determine weight of prey items at time of ingestion. Weight of each individual prey item was calculated from its estimated length from the regression equation (Table 2):

$$Wt = aL^b$$

Where:

Wt =Weight (g)
L = estimated length of prey at time of ingestion
a,b = Constants from the length:weight equations

The data obtained from the previous equations provide information on the length and wet weight of forage fish of northern pike in Box Canyon Reservoir. For each month in the study period the average estimated wet weight (± SD) or the average estimated length (±SD) was summed for each type of prey species and divided by the number of pike stomachs that contained food items. Data were then divided by the number of months in the study to provide an annual monthly average which removes bias for differing number of northern pike diets analyzed each month (Bowen 1996). Quantitative description of diet includes the frequency of occurrence, percent

Table 2. Equations that relate length to weight for prey fish of northern pike in Box Canyon Reservoir, ($Wt = aL^{b}$). *data from Scott 2002, and Divens and Osborne 2007, [1]developed from length/weight data obtained from 2009 and 2010 northern pike survey.

common Name	length:weight regression
Yellow Perch*	$-0.000000006(x^{3.018})$
Northern Pikeminnow*	$-0.00000007(x^{3.4131})$
Tench	$2.7881(x^{-4.3188})$
Largemouth bass*	$-0.4(x^{2.618})$
Pumpkinseed*	$-0.00005(x^{2.795})$
Brown Bullhead*	$-0.005(x^{2.482})$
Largescale sucker*	$-0.000000006(x^{3.0068})$
Northern Pike[1]	$3.28994(x^{-5.9774})$
Oncorhynchus sp*	$-0.0005(x^{2.7002})$
Mountain Whitefish*	$-0.0006(x^{3.153})$
Peamouth	$3.1699(x^{-5.4967})$

composition by number and percent composition by weight for all prey items (Bowen 1996, Hyslop 1980, Beaudoin et al. 1999).

Frequency of occurrence for a specific prey item in the diet of northern pike was estimated by counting the number of northern pike stomachs that contained at least one of that particular prey item and dividing by the total number of stomachs analyzed. The numerical percentage for a specific prey item in the diet of northern pike was calculated by summing the number of that particular prey item in all of the stomachs and dividing it by the total number of prey items found in all northern pike stomachs analyzed. Weight percentage for a specific prey item in the diet of northern pike was calculated by summing the wet weight (g) of that particular prey item in all of the stomachs and dividing it by the total weight of prey items found in all northern pike stomachs analyzed.

From a bioenergetics perspective all three quantitative diet descriptors are biased if used separately to determine the relative importance of a prey item for a fish's metabolic requirements (Bowen 1996). For example percent composition by number may over emphasize the importance of small prey items that are abundant in the diet but do not contribute the biomass value of the few larger items. The weight percentage may over estimate the energetic importance of the few larger prey items. Here the smaller prey items may be contributing more to the daily energetic requirements than looking at weight percentages only. For those reasons George and Hadley (1979) proposed the use of a relative importance index:

$$Ri_a = \frac{100Ai_a}{\sum_{a=1}^{n} Ai_a}$$

Where:

Ri = relative importance for prey item a
Ai = Absolute Importance Index for prey item a:
(%frequency of occurrence + %total number + % by weight)
n = number of different prey items

Values for this index range from 0% to 100% and sum to exactly 100%. These values were calculated on an annual and bimonthly basis (Appendix 1). The values were also calculated for each size class and the entire population. The frequency of occurrence, percent composition by number, percent composition by weight and relative importance index were calculated for each reach to evaluate if there was a change in food habits.

Age and Growth:

Both length and weight data are critical in management of a fishery. They provide data for estimating growth and the production of a fishery. The rates of physiological and biological factors such as ingestion, digestion and metabolism determine the growth and condition of fish (Anderson and Nuemann 1996). Growth can be attributed to the environmental conditions which will be reflected in the relative weight of a fish at a given length (Doyon 1988). To determine northern pike's physiological state both a relative weight index and Fulton-type condition factor were determined. A relative weight (W_r) index compensates for variation in weight when analyzing a fish's physical condition.

$$W_r = 100\,\frac{W}{W_s}$$

Where:

W = Weight (g)
W_s = Standard weight-length equation for species.

Willis (1989) proposed the following standard weight-length equation for northern pike:

$$\log_{10}W_s = -5.369 + 3.059 \log_{10}L$$

Where:

W_s = weight (g)
L = length (mm)

Relative weight describes the weight of a fish at specific length to the national average weight of the same length fish. For northern pike relative weight below 100 indicates that the fish is using more energy than it is consuming or is living at a sub-optimal temperature. A relative weight score above 100 indicates that there is an abundant supply of forage fish to consume.

The Fulton-type condition factor (K) describes how a fish adds weight per incremental change in length and was calculated with the following equation (Anderson and Neumann 1996):

$$K = \frac{W}{T^3}(10{,}000)$$

Where:

K = Fulton-type condition factor
W = weight (g)
T = total length(mm)

Scale and cliethra:

Scales were read using an Eyecom Model 3000 microfiche reader. Scale images were projected on to the viewing screen and annuli counted and measured (Frost and Kipling 1959). Measurements were made in the anterior field of the scale (Carlander 1969). Distance from the focus to annulus formation were used to back-calculate length using the Frasier-Lee method (Devries and Frie 1996).

Cliethra were viewed using a Nikon SMZ-10 stereo zoom dissecting microscope with fiber optics ring illumination and adjustable illumination system. Measurements of annuli occurred along the medial costa from the origin to the anterior tip of the cliethra (Casselman 1979). It is common for fish to deposit false annuli and the difference between the two is that true annuli can be traced from the anterior tip to the heel where as false annuli do not extend in to the heel (Casselman 1977). Fish length at annulus formation was back-calculated using Frasier-Lee method (Devries and Frie 1996). The scale and cliethra back-calculation formula was:

$$L_i = \frac{L_c - a}{S_c}(S_i + a)$$

Where:

L_i = the calculated length of a fish at age i,
L_c = length of fish at time of capture,
S_i = cleithrum/scale length at annulus i,
S_c = cleithrum/scale length at time of capture
A = scale/cliethra length at formation or Y intercept from the regression of the body length

Data collected from age and growth calculations were used to evaluate growth of northern pike in Box Canyon Reservoir by:

1) Comparing back-calculated total length of northern pike in Box Canyon Reservoir to other back-calculated total lengths of northern pike in systems where growth is known to be below, at or above average.
2) Compare the condition factor (K_{TL}) of northern pike in Box Canyon Reservoir to the national average for northern pike.
3) Comparing the back-calculated weights of northern pike in Box Canyon Reservoir to northern pike in systems where growth is known to be below, at or above average.

Bioenergetics:

Bean (2010) determined the standard or resting (R_S) and active (R_A) metabolic rates of Box Canyon Reservoir northern pike at four temperatures (4, 13, 22, and 28° C), and northern pike used throughout these experiments ranged from 86-2,146 g in mass and 250-718 mm in total length, which more accurately represent the life history of northern pike in Box Canyon Reservoir. Diana (1983) determined parameters for excretion, egestion, and SDA. Since he was unable to obtain a balanced budget with these values, I chose to use the general values from Wisconsin Fish Bioenergetics 3.0, which are consistent with other studies. Bean et al. (2010) used tracking data of northern pike from Box Canyon Reservoir and estimated the relative proportions of time spent at active and routine activity to produce an activity multiplier of 1.849. Estimates of consumption (C) rates (g g^{-1} d^{-1}) are based on a portion of the maximum consumption for an individual fish of a specific mass and temperature required to achieve optimal growth and were determined by Bevelhimer et al. (1985). The computer program (Hanson et al. 1997) with the parameters that were developed by Bean (2010) and Bevelhimer (1985) was used to estimate the total consumption of fish flesh by northern pike from May through October (Table 3).

Temperature is a vital piece of data for bioenergetic modeling. For this study daily average temperatures were compiled from data collected from the Albeni Falls Dam temperature log (Table 4). This enabled me to determine the thermal variation that northern pike experience from May through October. For caloric density of prey Wisconsin Bioenergetics Model 3.0 (Hanson et al. 1997) has energy density values in

Table 3. Northern Pike Bioenergetics Parameters Described from Other Studies. The parameters developed by Bean (2010) and Bevelhimer (1985) will be used for this study. See bioenergetics formulas within the text for definitions.

Parameter	Casselman (1978)	Diana (1982, 1983)	Bevelhimer et al. (1985)	Jacobson (1992)	Bean (2010)
Consumption					
CA	0.322	0.0014	0.2045	0.322	0.2045
CB	0.431	-0.18	-0.18	0.431	-0.18
CQ	3.3	-	0.59	3.3	0.59
CTO	21.9	-	24	21.9	24
CTM	29.4	-	34	29.4	34
Respiration					
RA	-	0.0014	0.00246	0.00478	0.0153
RB	-	-0.18	-0.18	-0.18	-0.3954
RQ	-	0.16	0.055	0.0833	2.29
RTO	-	-	0.1222	0.13	28.5
RTM	-	-	0	-	30
RTL	-	-	0	-	0
RK1	-	-	1	-	1
RK4	-	-	0	-	0
ACT	-	-	1.13	-	1.849
BACT	-	-	0	-	0
SDA	-	0.1042	0.14	0.1042	0.14
Egestion/Excretion					
FA	-	0.13	0.2	0.13	0.2
UA	-	0.08	0.07	0.079	0.07

Table 4. Temperature (°C) profile of Box Canyon Reservoir. Temperatures are listed as daily means. Temperature data collected from Albeni Falls Dam, Idaho from January 01, 2010 to December 31, 2010. Temperature input table assembled for use in the Fish Bioenergetics 3.0 program.

Day	ºC	Day	ºC	Day	ºC	Day	ºC	Day	ºC	Day	ºC	Day	ºC	Day	ºC
1	2.3	47	2.7	93	5.9	139	11.2	185	17.4	231	21.8	277	15.6	323	7.0
2	2.4	48	2.5	94	6.0	140	11.3	186	16.9	232	21.9	278	15.7	324	6.9
3	2.1	49	2.5	95	5.9	141	11.7	187	15.9	233	22.1	279	15.8	325	6.8
4	2.5	50	2.5	96	6.0	142	13.2	188	16.8	234	22.2	280	15.7	326	6.7
5	2.4	51	2.4	97	6.3	143	13.5	189	16.7	235	22.1	281	15.6	327	6.5
6	2.2	52	2.4	98	6.4	144	13.6	190	16.8	236	22.0	282	15.5	328	6.3
7	2.1	53	2.5	99	6.3	145	12.9	191	17.0	237	21.8	283	15.4	329	6.4
8	2.0	54	2.5	100	6.5	146	11.5	192	17.3	238	21.6	284	15.1	330	6.0
9	2.5	55	2.7	101	6.7	147	11.0	193	17.7	239	21.4	285	14.8	331	5.8
10	2.3	56	2.5	102	6.9	148	11.6	194	18.4	240	21.3	286	14.7	332	5.8
11	2.1	57	2.5	103	7.0	149	12.1	195	18.9	241	21.4	287	14.7	333	5.4
12	2.2	58	2.9	104	7.2	150	12.2	196	19.3	242	21.4	288	14.6	334	5.2
13	2.2	59	2.4	105	7.4	151	11.8	197	19.4	243	20.8	289	14.3	335	5.1
14	2.2	60	2.9	106	7.3	152	12.1	198	19.1	244	20.6	290	14.1	336	4.9
15	2.6	61	2.9	107	7.8	153	12.5	199	18.8	245	20.3	291	13.9	337	5.0
16	2.2	62	2.9	108	7.2	154	12.2	200	18.5	246	19.9	292	13.7	338	5.0
17	2.2	63	3.1	109	7.6	155	11.8	201	17.9	247	19.6	293	13.4	339	4.8
18	2.0	64	3.3	110	7.6	156	11.8	202	18.0	248	19.3	294	13.1	340	4.2
19	2.2	65	3.4	111	8.1	157	11.7	203	18.4	249	19.2	295	12.9	341	4.2
20	2.0	66	3.4	112	8.2	158	12.0	204	19.6	250	19.2	296	12.7	342	4.2
21	2.1	67	3.5	113	8.3	159	12.0	205	19.8	251	19.2	297	12.4	343	4.2
22	2.1	68	3.5	114	8.3	160	11.9	206	20.2	252	18.8	298	12.3	344	4.1
23	2.4	69	3.6	115	8.6	161	11.9	207	20.4	253	18.3	299	12.2	345	4.2
24	2.4	70	3.6	116	8.5	162	12.2	208	20.5	254	17.9	300	12.1	346	4.2
25	2.4	71	3.7	117	9.0	163	12.4	209	20.7	255	17.5	301	11.9	347	3.9
26	2.4	72	4.0	118	9.3	164	12.9	210	21.0	256	17.3	302	11.6	348	4.0
27	2.5	73	3.9	119	9.4	165	12.8	211	21.4	257	17.2	303	11.2	349	3.9
28	2.6	74	4.2	120	9.7	166	12.6	212	21.6	258	17.0	304	11.0	350	3.3
29	2.4	75	4.1	121	9.6	167	12.9	213	21.7	259	16.8	305	10.7	351	3.5
30	2.4	76	4.4	122	8.4	168	13.5	214	22.0	260	16.8	306	10.6	352	3.5
31	2.5	77	4.3	123	7.9	169	13.9	215	22.2	261	16.8	307	10.3	353	3.1
32	2.3	78	4.6	124	7.9	170	14.1	216	22.2	262	16.9	308	10.3	354	3.4
33	2.6	79	4.7	125	8.0	171	13.8	217	22.2	263	17.0	309	10.2	355	3.6
34	2.6	80	4.5	126	8.2	172	13.2	218	22.2	264	16.9	310	10.0	356	3.5
35	2.5	81	4.6	127	8.2	173	13.1	219	22.3	265	16.8	311	9.9	357	3.8
36	2.6	82	4.8	128	8.7	174	14.3	220	22.4	266	16.7	312	9.6	358	2.5
37	2.6	83	5.3	129	8.9	175	14.4	221	22.5	267	16.6	313	9.3	359	2.8
38	2.6	84	5.1	130	8.9	176	14.1	222	22.6	268	16.5	314	9.1	360	2.8
39	2.7	85	5.4	131	9.2	177	13.4	223	22.4	269	16.4	315	8.7	361	2.4
40	2.8	86	5.4	132	9.8	178	14.6	224	22.3	270	16.3	316	8.5	362	2.6
41	2.6	87	5.6	133	10.5	179	15.1	225	22.2	271	16.1	317	8.3	363	2.7
42	2.7	88	5.5	134	11.0	180	15.5	226	22.0	272	16.0	318	8.0	364	2.4
43	2.7	89	5.5	135	11.3	181	15.6	227	21.9	273	15.9	319	7.5	365	2.9
44	2.7	90	5.6	136	11.9	182	15.8	228	21.8	274	15.7	320	7.7		
45	2.7	91	5.7	137	12.2	183	16.1	229	21.7	275	15.6	321	7.0		
46	2.6	92	5.8	138	12.7	184	17.1	230	21.8	276	15.5	322	6.6		

joules/ g wet mass. For prey species that were not found there were researched in literature (Table 5).

As part of the bioenergetic model the researcher must develop cohorts to more accurately estimate consumption rates (Hanson et al. 1997). For this study I determined that the best approach would be to separate the northern pike into different size classes; the size classes were determined by the development of an age/length key for Box Canyon Reservoir northern pike. The different size classes will be modeled for 180 days because it is assumed that the rest of the year consumption is near zero due to the cold water temperatures.

Bioenergetics modeling is used to estimate the consumption rate of an individual or a population of fish. The first step in estimating the population consumption rate is to estimate the consumption rate of an average individual within a size class then using the population estimate, extrapolate the mean individual to the entire size class. All size class estimates are then summed to estimate the entire population's consumption. The diet proportions (percent weight) that are needed to estimate the consumption rate of the population were obtained from the 2009/2010 food habits survey.

Electivity index

Strauss (1979) electivity index was used to determine if northern pike were selecting for, against or consuming at the same rate as the environment the different prey species when compared to the relative abundance of the prey in the environment. It is based on a score from 1 to -1, where 0 is no preference, -1 means the fish is avoiding the prey and 1 is they are searching out these prey items. The relative

Table 5. Energy densities (Joules/gram) used for bioenergetic modeling. Prey energy density table was assembled for use in the Fish Bioenergetics 3.0 program.

Species	Energy Density (joules/gram(wet))	Source
Peamouth	5,720	Antolos et al. 2005
Northern pikeminnow	4,650	Antolos et al. 2005
Tench	4,120	Kamler and Stachowiak 1992
Largescale sucker	4,350	Antolos et al. 2005
Pumpkinseed	1,160	Pope et al. 2001
Northern Pike	4,928	Liao et al. 2004
Yellow perch	4,500-5,902	Hanson et al. 1997
Salmonids	5,770	Tabor et al 2004
Mountain whitefish	5,989	Muhlfeld et al. 2008
Rainbow trout	5,727	Cummins and Wuycheck 1971
Bass	4,186	Hanson et al. 1997
Miscellaneous fish	5,439	Hanson et al. 1997
Meadow vole	Unknown	
Yellow perch eggs	Unknown	
Bull frog	Unknown	

abundance of prey items found in the 2009/2010 food habits survey and the relative abundance from the 2009 warmwater fisheries survey conducted by Kalispel Natural Resources Department were used to calculate the electivity index. Box Canyon Reservoir from Delkena to Riverbend has numerous sloughs, reduced velocity, plentiful cover and abundant forage fish. These attributes make reach 2 the preferred habitat for northern pike and is where most of the population resides. To determine if northern pike diet is similar throughout the study area; Frequency of occurrence, percent composition by number and percent composition by weight was compared between reach two and reach three using Analysis of Variance. Reach one did not have a sufficient number of food habit samples to be included in the ANOVA. To help support these findings an electivity index for each prey species consumed was calculated for each reach.

Results

Population Estimate

In the spring of 2010 the Kalispel Natural Resources Department, Washington State Department of Fish and Wildlife and Eastern Washington University conducted a population estimate of northern pike between Pioneer Park and River Bend. A total of 288 pike were marked from 19 April to 30 April. The following week of 03 May to 07 May a total of 741 pike were collect with 37 recaptures. The estimated population size of pike from Pioneer Park to River Bend of northern pike greater than 350 mm was 5,486 (S.E. 855), with a 95% confidence interval of 4870 to 6102 pike.

Age and Growth

A total of 130 scales were collected from northern pike ranging from 222 mm to 1110 mm total length for estimating age and growth in 2009. Bean et al. (2007) estimated that northern pike form scales at 30.5 mm in length for Box Canyon Reservoir. This intercept parameter was used in the Frasier-Lee equation to back-calculate length at age. Back-calculated total lengths at time of annulus formation were calculated for each cohort (Table 6). The mean back-calculated total length at annulus formation was age 1+ (206 mm), age 2+ (288 mm), age 3+ (382mm), age 4+ (497 mm), age 5+ (599 mm), age 6+ (697 mm), age 7+ (799) age 8+ (930 mm) and age 9+ (1054 mm) total length. The mean estimated annual gain in length was age 1+ (206 mm), age 2+ (82 mm), age 3+ (94 mm), age 4+ (115 mm), age 5+ (102 mm), age 6+ (98 mm), age 7+ (102 mm) age 8+ (131 mm) and age 9+ (124 mm).

A total of 111 cliethra were collected from northern pike ranging from 222 mm

Table 6. Back-calculated length at scale annulus formation for 130 northern pike from Box Canyon Reservoir collected in 2009.

Age	N	LENGTH AT CAPTURE	1+	2+	3+	4+	5+	6+	7+	8+	9+
0+	2	268 (±12)									
1+	7	281 (±34)	215 (±34)								
2+	16	367 (±59)	215 (±21)	328 (±33)							
3+	17	445 (±57)	199 (±19)	285 (±27)	370 (±31)						
4+	18	634 (±69)	212 (±23)	310 (±40)	444 (±52)	556 (±57)					
5+	40	694 (±64)	198 (±22)	273 (±32)	378 (±44)	489 (±52)	606 (±60)				
6+	15	780 (±59)	202 (±16)	275 (±26)	365 (±41)	475 (±61)	593 (±67)	710 (±71)			
7+	10	868 (±38)	211 (±18)	275 (±31)	363 (±38)	455 (±48)	550 (±51)	657 (±47)	776 (±46)		
8+	4	978 (±55)	217 (±27)	308 (±46)	406 (±75)	501 (±78)	627 (±96)	715 (±73)	832 (±68)	921 (±49)	
9+	1	1110	209	279	380	572	756	832	896	966	1054
GRAND MEAN (mm)	130		206 (±22)	288 (±35)	382 (±51)	497 (±63)	599 (±67)	697 (±71)	799 (±61)	930 (±46)	1054 (+=/-0)
LENGTH GAIN(mm)			206	82	94	115	102	98	102	131	124

Table 7. Back-calculated length of cleithra for 111 northern pike from Box Canyon Reservoir collected in 2009.

AGE	N	LENGTH AT CAPTURE	1+	2+	3+	4+	5+	6+	7+	8+
0+	6	274 (±34)								
1+	10	337 (±35)	253 (±34)							
2+	21	511 (±178)	269 (±61)	400 (±136)						
3+	23	593 (±92)	237 (±42)	350 (±53)	462 (±69)					
4+	24	695 (±77)	246 (±43)	373 (±53)	476 (±51)	570 (±63)				
5+	14	743 (±82)	245 (±36)	346 (±58)	432 (±58)	527 (±66)	617 (±69)			
6+	6	837 (±72)	249 (±22)	335 (±19)	409 (±31)	493 (±30)	582 (±33)	716 (±55)		
7+	4	834 (±72)	254 (±70)	317 (±74)	391 (±87)	494 (±73)	575 (±72)	638 (±61)	716 (±75)	
8+	3	1038 (±84)	274 (49)	384 (±40)	522 (±47)	618 (±70)	698 (±90)	787 (±75)	870 (±72)	940 (±87)
GRAND MEAN (mm)	111		251 (± 46)	365 (±81)	455 (±65)	546 (±70)	612 (±72)	708 (±80)	782 (±107)	940 (±87)
LENGTH GAIN (mm)			251	114	90	91	66	96	74	158

to 1110 mm total length and ranged from for estimating age and growth in 2009. Nine age classes were represented (age 0+ to age 8+). The mean back-calculated total length at annulus formation was age 1+ (251 mm), age 2+ (365 mm), age 3+ (455 mm), age 4+ (546 mm), age 5+ (612 mm), age 6+ (708 mm), age 7+ (782 mm) and age 8+ (940 mm). The mean estimated annual length gain was age 1+ (251 mm), age 2+ (114 mm), age 3+ (90 mm), age 4+ (91 mm), age 5+ (66 mm), age 6+ (96 mm), age 7+ (74 mm) and age 8+ (158 mm) total length (Table 7).

Age/length distribution

Northern pike were stratified into 5 mm length increments to determine the age/length distribution (Table 8). It was estimated that age 0+ (n=2) pike ranged from 220 mm to 275 mm total length, age 1+ (n=7) pike ranged from 220 mm to 315 mm total length, age 2+ (n=16) pike ranged from 300 mm to 565 mm total length, age 3+ (n=17) pike ranged from 385 mm to 570 mm total length, age 4+ (n=18) pike ranged from 385 mm to 780 mm total length, age 5+ (n=40) pike ranged from 590 mm to 895 mm total length, age 6+ (n=15) pike ranged from 700 mm to 895 mm total length, age 7+ (n=10) pike ranged from 820 mm to 965 mm total length, age 8+ (n=4) pike ranged from 940 mm to 1065 mm total length and age 9+ (n=1) pike were 1110 mm total length.

It was estimated that age 0+ pike comprised 1.5% (n=not included in the population estimate) of the population, age 1+ pike comprised 5.3% (n=290) of the population, age 2+pike comprised 13.9% (n=762) of the population, age 3+ pike comprised 12.3% (n=674) of the population, age 4+ pike comprised 13.9% (n=762) of the population, age 5+ pike comprised 29.9% (1640) of the population, age 6+ pike

Table 8. Scale age/length key developed for northern pike in Box Canyon Reservoir 2009.

n		0	1	2	3	4	n		2	3	4	5	6	n		4	5	6	7	8	9
1	220		1				0	510						1	755		1				
1	250		1				0	515						2	760		1	1			
1	255	1					1	520		1				2	765		1	1			
0	260						0	550						0	770						
0	265						1	555		1				1	775		1				
1	270		1				0	560						1	780	1					
1	275	1					1	565	1					1	785			1			
0	280						3	570		1	2			0	790						
0	285						0	575						0	800						
1	290		1				1	580			1			0	805						
1	295		1				0	585						0	810						
0	300						2	590			1	1		0	815						
0	305						0	595						2	820			1	1		
2	310		1	1			0	600						0	825						
1	315		1				2	605			1	1		0	830						
3	320			3			4	610			2	2		2	835			2			
2	325			2			2	615			2			1	840				1		
0	330						4	620			1	3		2	845		1		1		
0	335						0	625						0	850						
1	340			1			2	630			1	1		0	855						
2	345			2			0	635						3	860				3		
1	350			1			2	640				2		1	865				1		
1	370			1			2	645				2		2	870			1	1		
1	375			1			2	650			1	1		1	875		1				
1	380			1			1	655				1		0	880						
1	385				1		1	660				1		0	885						
3	390			2	1		1	665				1		1	890				1		
1	395			1			0	670						1	895			1			
0	400						2	675				2		0	925						
0	405						1	680				1		0	930						
4	410				4		0	685						0	935						
3	415			1	2		3	690			1	2		1	940					1	
1	420				1		1	695				1		1	945					1	
0	425						2	700				1	1	0	950						
1	430				1		1	705			1			0	955						
0	435						1	710			1			0	960						
1	440				1		0	715						1	965				1		
1	445				1		1	720			1			1	970					1	
0	480						3	725				1	2	0	975						
1	485				1		4	730				4		0	1050						
0	490						4	735				2	2	0	1055						
1	495					1	2	740				1	1	1	1060					1	
0	500						2	745				1	1	0	1065						
0	505						1	750				1		1	1110						1

comprised 11.5% (n=630) of the population, age 7+ pike comprised 7.7% (n=422) of the population, age 8+ pike comprised 3.1% (n=170) of the population and age 9+ pike comprised 0.8% (n=44) of the population (Figure 4).

For bioenergetics modeling the length class distribution was class one (220 mm to 295 mm) comprised 5.3% (n=not included in population estimate) of the population, class two (300 mm to 380 mm) comprise 11.5% (n=630) of the population, class three (385 mm to 485 mm) comprised 13.1% (n=718) of the population, class four (490 mm to 585 mm) comprised 6.2% (n=340) of the population, class five (590 mm to 695 mm) comprised 24.6% (n=1349) of the population, Class six (700 mm to 800 mm) comprised 22.3% (n=1223) of the population, class seven (805 mm to 900 mm) comprised 12.2% (n=669) of the population, class eight (905 mm to 1005 mm) comprised 3.1% (n=170) of the population and class nine (1010 mm to 1110 mm) comprised 1.6% (n=87) of the population (Figure 5). These size classes were chosen by the way they grouped themselves in the age/length key.

Relative weight

The relative weight (Wr) of 298 northern pike sampled ranged from 45 to 191 with a mean of 108 (S.D. ± 16). Northern pike less than 400 mm had a Wr range of 55 to 145 with a mean of 95 (S.D. ± 18). The Wr ranged from 45 to 191 for northern pike greater than 400 mm with a mean of 110 (S.D. ±15; Figure 6).

Fulton’s condition index

The Fulton’s condition index (K) of 298 northern pike sampled ranged from 0.27 to 1.00 with a mean of 0.67. Northern pike less than 400 mm had a K range of 0.33 to 0.87

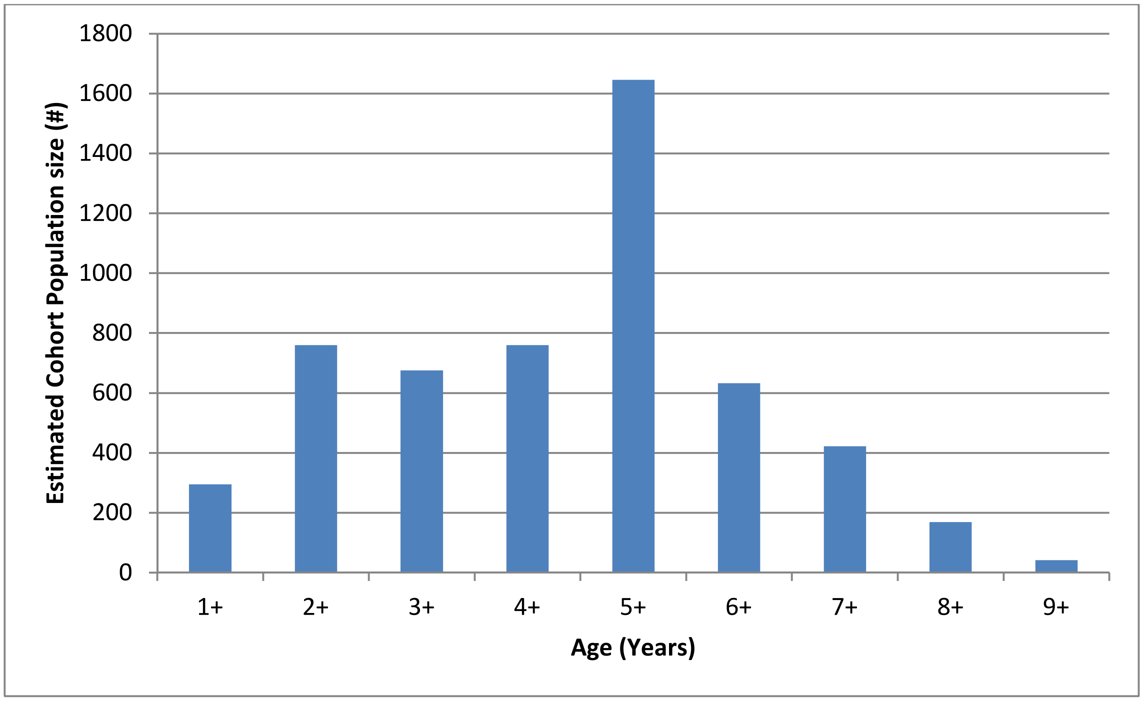

Figure 4. Estimated distribution of northern pike population by age class for Box Canyon Reservoir in 2010. Age 0 not shown because they were not fully recruited into the gear used.

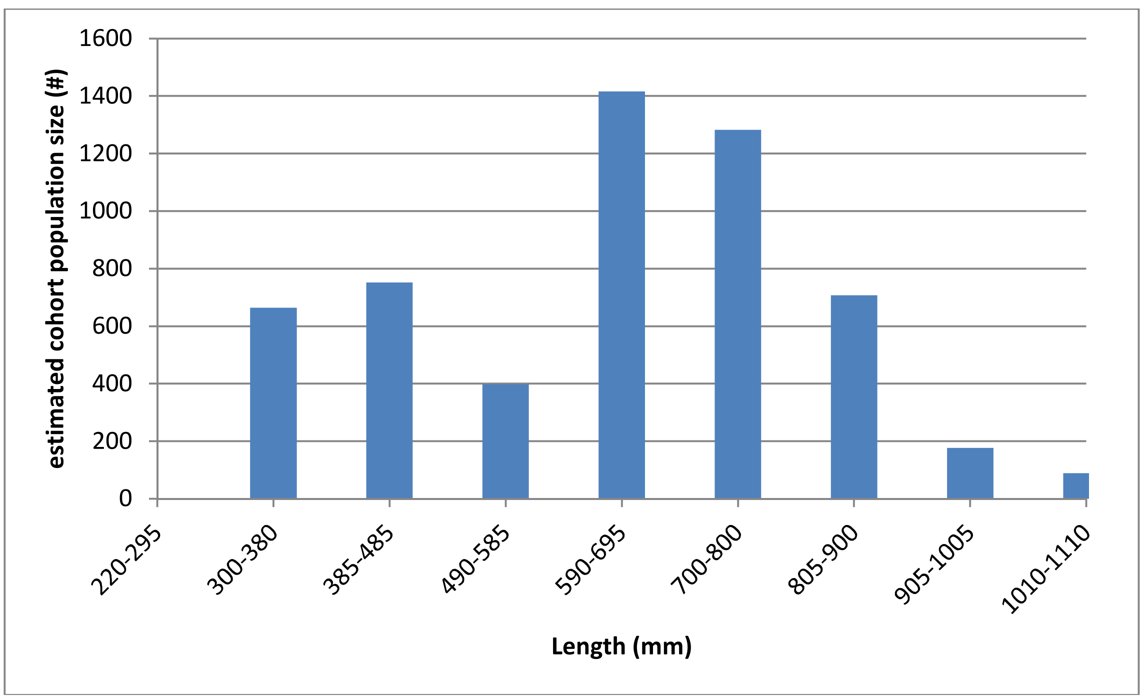

Figure 5. Estimated length distribution of northern pike population for Box Canyon Reservoir 2010. Northern pike less than 300 mm not represented because they were not fully recruited into the gear used.

with a mean of 0.57. Northern pike greater than 400 mm K ranged from 0.27 to 1.00 with a mean of 0.69 (Figure 7).

Diet Analysis

A total of 479 northern pike stomachs were collected for food habit analysis. Northern pike in Box Canyon Reservoir consumed mainly fish for the duration of the sampling period. The food habits of northern pike included 12 fish species, bull frog and meadow vole. There were several invertebrates found in the stomachs which also contained partially digested fish and were assumed to be from these partially digested fish.

A total of 15 different prey items were found in the diet of northern pike in Box Canyon Reservoir. The food habits of northern pike during the sampling period were, in order of relative importance (Table 9):

1) Yellow Perch (*Perca flavens)* occurred in 44.8% of stomachs and comprised 50.9% by number, 25.1% by weight and 40.0% by relative importance of prey items in the diet.
2) Pumpkinseed (*Lepomis gibbosus)* occurred in 30.3% of stomachs and comprised 26.6% by number, 10.9% by weight and 22.1% by relative importance of prey items in the diet.
3) Peamouth (*Mylocheilus caurinus)* occurred in 9.8% of stomachs and comprised 6.9% by number, 19.3% by weight and 11.7% by relative importance of prey items in the diet.

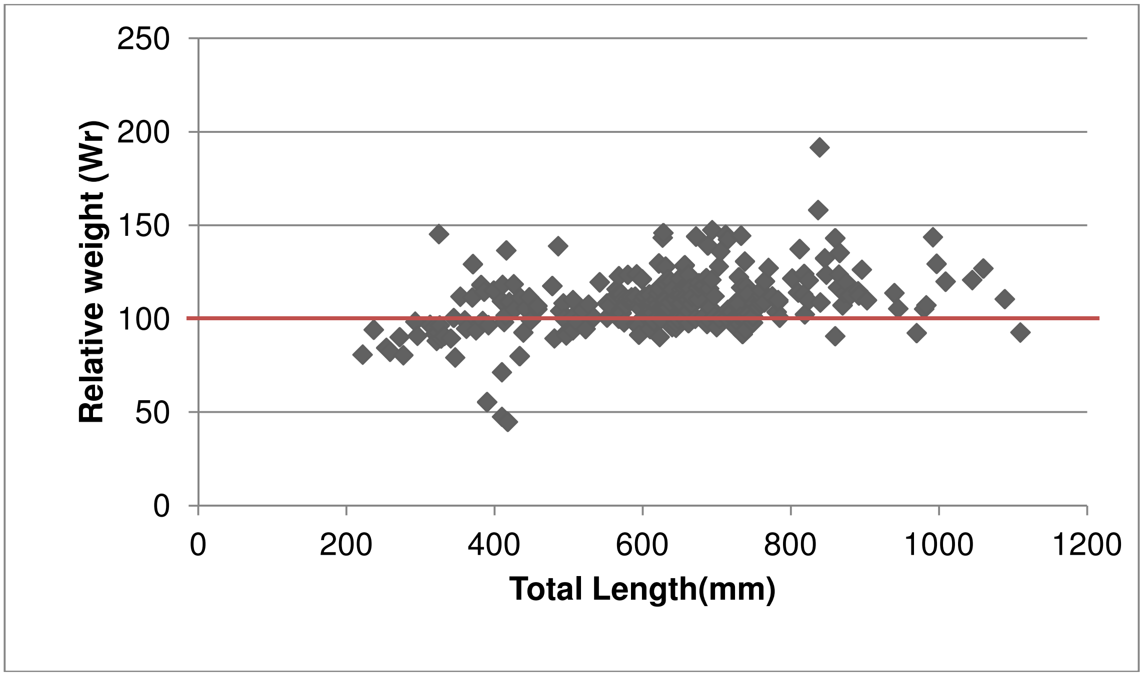

Figure 6. Relative weights for 298 northern pike in Box Canyon Reservoir collected in 2009 and 2010. Score of 100 is ideal for northern pike (Carlander 1969).

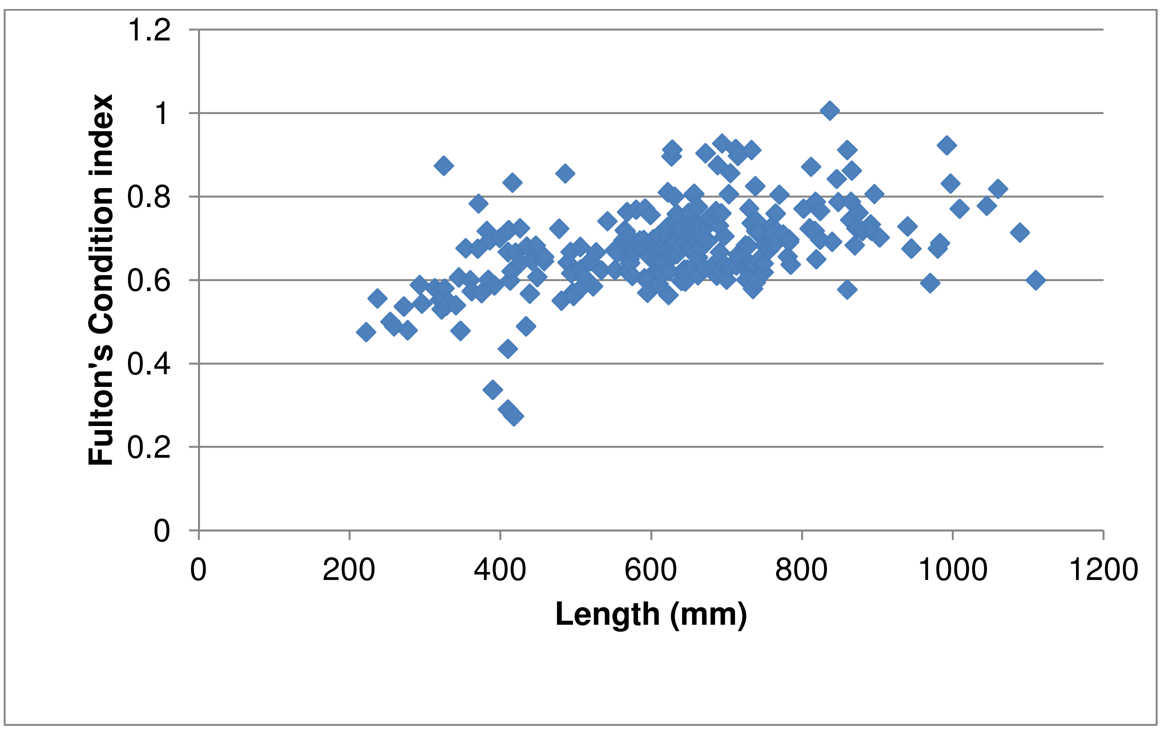

Figure 7. Fulton's condition index for 298 northern pike in Box Canyon Reservoir collected in 2009 and 2010. The average North American northern pike range from 0.47 to 0.69 (Carlander 1969).

Table 9. Mean monthly food habits of northern pike in Box Canyon Reservoir during the sampling period of May and October 2009, May, July, August, September and October 2010.

Species	N (±S.D.)	Composition by Number	Total Weight (g, ±S.D)	Composition by Weight (%)	Frequency Of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	28.1(±19.5)	11.1	599.8 (±1057)	26.8	26.4	21.4
YELLOW PERCH	53.2 (±15.3)	25.7	1390.8 (±3291.6)	50.7	43.5	40.0
TENCH	1.1 (±6.25)	1.9	103.1 (±148.7)	1.1	1.5	1.5
BASS	3.8 (±15)	1.6	85.7 (±0223.9)	3.7	5.6	3.6
LARGESCALE SUCKER	4.7 (±6.9)	28.9	1565.2 (±2975.3)	4.5	4.3	12.6
MOUNTAIN WHITEFISH	1.4 (±8.47)	4.0	214.5 (±242.3)	1.4	1.9	2.4
NORTHERN PIKEMINNOW	1.5 (±3.6)	4.3	231.2 (±396.4)	1.5	2.4	2.7
BULL FROG	1.2 (±4.7)	0.3	18.1 (±19.11)	1.2	1.7	1.1
PEAMOUTH CHUB	7.2 (±5.0)	17.0	920 (±1563.8)	6.9	9.3	11.1
BROWN BULLHEAD	0.71 (±0.17)	0.4	19.4 (±28.0)	0.7	0.9	0.6
BROWN TROUT	0.1 (±0.02)	0.2	12.2 (±12.2)	0.1	0.2	0.2
EASTERN BROOK TROUT	0.3	0.3	14.9	0.3	0.4	0.3
NORTHERN PIKE	0.8 (±2.7)	4.2	228.5 (±73.4)	0.8	1.3	2.1
MEADOW VOLE	0.1	0.1	3.1	0.1	0.2	0.1
EGGS	0.1	0.3	15.0	0.1	0.2	0.2
TOTAL	105		5422.1 ±521.2			100.0

4) Largescale sucker (*Catostomus macrocheilus)* occurred in 4.4% of stomachs and comprised 4.4% by number, 25.5% by weight and 11.2% by relative importance of prey items in the diet.

5) Bass (*Micropertus spp,)* occurred in 6.0% of stomachs and comprised 3.7% by number, 1.6% by weight and 3.7% by relative importance of prey items in the diet.

6) Northern pikeminnow (*Ptychocheilus oregonensis)* occurred in 2.4% of stomachs and comprised 1.4% by number, 4.1% by weight and 2.6% by relative importance of prey items in the diet.

7) Mountain whitefish (*Prosopium williamsoni)* occurred in 2.0% of stomachs and comprised 1.3% by number, 4.2% by weight and 2.4% by relative importance of prey items in the diet.

8) Tench (*Tinca tinca)* occurred in 1.7% of stomachs and comprised 1.2% by number, 3.7% by weight and 2.1% by relative importance of prey items in the diet.

9) Northern pike (*Esox lucius)* occurred in 1.3% of stomachs and comprised 0.8% by number, 4.0% by weight and 2.0% by relative importance of prey items in the diet.

10) Bull Frog (*Rana catesbeiana)* occurred in 1.7% of stomachs and comprised 1.2% by number, 0.3% by weight and 1.1% by relative importance of prey items in the diet.

11) Brown bullhead (*Ameilurus nebulosus)* occurred in 0.8% of stomachs and comprised 0.5% by number, 0.3% by weight and 0.5% by relative

importance of prey items in the diet.

12) Eastern brook trout (*Salvelinus fontinalis)* occurred in 0.4% of stomachs and comprised 0.2% by number, 0.1% by weight and 0.2% by relative importance of prey items in the diet.
13) Yellow perch egg mass occurred in 0.2% of stomachs and comprised 0.1% by number, 0.2% by weight and 0.2% by relative importance of prey items in the diet.
14) Brown trout (*Salmo trutta)* occurred in 0.2% of stomachs and comprised 0.1% by number, 0.16% by weight and 0.17% by relative importance of prey items in the diet.
15) Meadow vole (*Microtus pennsylvanicus*) occurred in 0.2% of stomachs and comprised 0.1% by number, 0.06% by weight and 0.1% by relative importance of prey items in the diet.

Length class food habits

All size classes of northern pike in Box Canyon Reservoir consumed pumpkinseed and largescale sucker. The only size class that did not consume yellow perch was class 8 (1010 mm to 1110 mm). Class 4 (586 mm to 695 mm) was the only class that did not have tench in their food habits. Class 1 (296 mm to 380 mm), class 2 (381 mm to 485 mm) and class 3 (486 mm to 585 mm) northern pike did not have peamouth in their food habits. Class 7(901 mm to 1005 mm) and larger northern pike did not have bass in their food habits. No mountain whitefish or bull frogs were found in the food habits of class 1 and class 2 northern pike. Northern pike minnow were found in the food habits of class 3, class 4, class 5 (696 mm to 800 mm) and class 6 (801 mm to 900 mm) northern pike. No northern pike were found in the food habits of class 1, class 2 and class 3 northern pike (Table 10 thru Table 17).

Food habits of 167 northern pike from River Bend, Washington to Delkena, Washington (Reach 2) and 48 northern pike from Delkena, Washington to Newport, Washington (Reach 3) had their food habits analyzed (Table 18 and Table 19). There were not a sufficient number of stomach samples from reach 1 to be included in the reach food habit study (n=3). There was no difference in percent composition by number (ANOVA, p-value 0.253, F-ratio 1.491), percent composition by weight (ANOVA, p-value 0.688, F-ratio 0.172), relative abundance of the different prey species (ANOVA, p-value 0.982, F-ratio 0.267) or in the index of relative importance (ANOVA, p-value 0.743, F-ratio 0.115). There was a difference in frequency of occurrence between Reach two and Reach three (ANOVA, p-value 0.026, F-ratio 7.082). Since ANOVA will only tell you that there is a difference but not what is different I preformed paired t-test to determine what was different. Northern pike in reach 2 consumed more largescale sucker (paired t-test, p-value 0.471, t-value 0.757), brown bullhead (paired t-test, p-value 0.769, t-value 0.303) brown trout (paired t-test, p-value 0.419, t-value 0.852) and eastern brook trout (paired t-test, p-value 0.514, t-value 0.682) then in Reach 3.

Strauss' electivity index allows researchers to determine if fish are consuming prey at a rate that is similar to that of the environment. It is based on a score from 1 to -1, 0 is no preference, -1 means the fish is avoiding the prey and 1 is they are searching out these prey items. Box Canyon Reservoir northern pike are consuming prey fish at a rate that is similar to the relative abundance of prey fish (Table 20 and Table 21). The only exception to this is in Reach 3 where the northern pike may preferentially seek out

Table 10. Consumption of prey species by northern pike size class 296 mm to 380 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=19).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	7	31.8	77	15.8	36.8	28.1
YELLOW PERCH	7	31.8	56	11.6	31.5	25.0
TENCH	3	13.6	336	69.1	10.5	31.1
BASS	4	18.1	15	3.1	15.7	12.3
LARGESCALE SUCKER	1	4.5	1	0.2	5.2	3.3
TOTAL	22		486		100.0	100.0

Table 11. Food habits of northern pike size class 381 mm to 485 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=31).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	21	41.1	244	27.1	38.7	33.1
YELLOW PERCH	21	41.1	339	37.6	54.8	41.4
TENCH	1	1.9	149	16.5	3.2	6.7
BASS	2	3.9	59	6.5	6.4	5.2
LARGESCALE SUCKER	2	3.9	5	0.5	6.4	3.3
MOUNTAIN WHITEFISH	1	1.9	46	5.1	3.2	3.1
NORTHERN PIKEMINNOW	2	3.9	52	5.7	6.4	5.0
BULLFROG	1	1.9	6	0.6	3.2	1.8
TOTAL	51		900		122.5	100.0

Table 12. Consumption of prey species by northern pike size class 486 mm to 585 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=57).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	33	32.0	788	31.2	45.6	33.5
YELLOW PERCH	61	59.2	1,209	47.8	64.9	53.0
BASS	3	2.9	117	4.6	5.2	3.9
LARGESCALE SUCKER	2	1.9	41	1.6	1.7	1.6
BULLFROG	1	0.9	12	0.4	1.7	0.9
PEAMOUTH CHUB	3	2.9	358	14.1	5.2	6.8
TOTAL	103		2,525		124.5	100.0

Table 13. Consumption of prey species by northern pike size class 586 mm to 695 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=129).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	79	27.5	1,885	16.7	34.8	24.1
YELLOW PERCH	152	52.9	3,976	35.2	61.2	45.5
TENCH	2	0.7	336	2.9	1.5	1.5
BASS	7	2.4	255	2.2	5.4	3.0
LARGESCALE SUCKER	14	4.8	607	5.3	2.3	3.8
MOUNTAIN WHITEFISH	3	1.0	78	0.6	2.3	1.2
NORTHERN PIKEMINNOW	3	1.0	896	7.9	2.3	3.4
BULLFROG	4	1.3	50	0.4	2.3	1.2
PEAMOUTH CHUB	17	5.9	2,711	24.0	10.8	12.4
BROWN BULLHEAD	1	0.3	15	0.1	0.7	0.3
BROWN TROUT	1	0.3	62	0.5	0.7	0.5
EASTERN BROOK TROUT	2	0.7	62	0.5	1.5	0.8
NORTHERN PIKE	2	0.7	345	3.0	1.5	1.6
TOTAL	287		11,278		127.9	100.0

Table 14. Consumption of prey species by northern pike size class 696 mm to 800 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=56).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	34	22.0	786	10.5	35.7	19.6
YELLOW PERCH	90	58.4	2,585	34.6	62.5	44.6
TENCH	1	0.6	200	2.6	1.7	1.4
BASS	2	1.3	70	0.9	5.3	2.1
LARGESCALE SUCKER	1	0.6	217	2.9	1.7	1.5
MOUNTAIN WHITEFISH	2	1.3	217	2.9	1.7	1.7
NORTHERN PIKEMINNOW	1	0.6	45	0.6	1.7	0.8
BULLFROG	2	1.4	23	0.3	3.5	1.4
PEAMOUTH CHUB	18	11.6	2,784	37.3	28.5	22.2
BROWN BULLHEAD	1	0.6	49	0.6	1.7	0.8
NORTHERN PIKE	2	1.3	486	6.5	3.5	3.2
TOTAL	154		7,462		148.2	100.0

Table 15. Consumption of prey species by northern pike size class 801 mm to 900 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=22).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	11	26.8	335	7.8	27.2	19.4
YELLOW PERCH	18	43.9	725	16.9	36.3	30.5
TENCH	1	2.4	235	5.5	4.5	3.9
BASS	1	2.4	69	1.6	4.5	2.7
LARGESCALE SUCKER	3	7.3	1,782	41.7	13.6	19.7
MOUNTAIN WHITEFISH	2	4.8	707	16.5	9.0	9.5
BULLFROG	1	2.4	13	0.3	4.5	2.2
PEAMOUTH CHUB	1	2.4	149	3.4	4.5	3.2
BROWN BULLHEAD	1	2.4	66	1.5	4.5	2.6
NORTHERN PIKE	1	2.4	85	1.9	4.5	2.8
EGGS	1	2.4	105	2.4	4.5	2.9
TOTAL	41		4,271		118.1	100.0

Table16. Consumption of prey species by northern pike size class 901 mm to 1005 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=11).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	1	5.5	20	0.2	9.0	4.4
YELLOW PERCH	8	44.4	494	6.2	54.5	31.2
LARGESCALE SUCKER	6	33.3	6,600	83.4	54.5	50.9
PEAMOUTH CHUB	2	11.1	303	3.8	9.0	7.1
NORTHERN PIKE	1	5.5	491	6.2	9.0	6.2
TOTAL	18		7,908		136.3	100.0

Table 17. Consumption of prey species by northern pike size class 1006 mm to 1100 mm in Box Canyon Reservoir between May 2010 and October 2010 (N=3).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	1	25.0	44	2.8	33.3	18.3
LARGESCALE SUCKER	1	25.0	799	51.0	33.3	32.8
TENCH	1	25.0	199	12.7	33.3	21.3
MOUNTIAN WHITEFISH	1	25.0	522	33.3	33.3	27.5
TOTAL	4		1,564		133.3	100

Table 18. Reach 2, Food habits of northern pike between Delkena Washington and Riverbend Washington, 2009 and 2010 (N=167).

Species	N	Composition by Number (%)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	83	22.9	2057	11.0	34.7	20.7
YELLOW PERCH	232	63.9	6063	32.3	70.1	50.1
TENCH	5	1.4	390	2.1	2.4	1.8
BASS	8	2.2	226	1.2	4.8	2.5
LARGE SCALE SUCKER	6	1.7	5874	31.3	3.6	11.0
MOUNTAIN WHITEFISH	3	0.8	196	1.0	1.8	1.1
NORTHERN PIKEMINNOW	3	0.8	896	4.8	1.8	2.2
BULLFROG	2	0.6	26	0.1	1.2	0.6
PEAMOUTH CHUB	12	3.3	1541	8.2	6.0	5.3
BROWN BULL HEAD	2	0.6	55	0.3	1.2	0.6
BROWN TROUT	1	0.3	86	0.5	0.6	0.4
EASTERN BROOK TROUT	2	0.6	285	1.5	1.2	1.0
NORTHERN PIKE	4	1.1	1070	5.7	2.4	2.8
TOTAL	363	100.0	18765	100.0	131.7	100.0

Table 19. Reach 3, Food habits of northern pike between Newport Washington and Delkena Washington, 2009 and 2010 (N=48).

Species	N	Composition by Number %)	Total Weight (g)	Composition by Weight (%)	Frequency of Occurrence (%)	Relative Importance Index (%)
PUMPKINSEED	14	14.1	274	6.7	22.9	13.5
YELLOW PERCH	65	65.7	1723	42.3	70.8	55.0
TENCH	1	1.0	174	4.3	2.1	2.3
BASS	3	3.0	61	1.5	6.3	3.3
LARGE SCALE SUCKER	9	9.1	554	13.6	10.4	10.2
MOUNTAIN WHITEFISH	3	3.0	457	11.2	4.2	5.7
NORTHERN PIKEMINNOW	1	1.0	22	0.5	2.1	1.1
BULLFROG	0	0.0	0	0.0	0.0	0.0
PEAMOUTH CHUB	2	2.0	451	11.1	4.2	5.3
BROWN BULL HEAD	0	0.0	0	0.0	0.0	0.0
BROWN TROUT	0	0.0	0	0.0	0.0	0.0
EASTERN BROOK TROUT	0	0.0	0	0.0	0.0	0.0
NORTHERN PIKE	1	1.0	355	8.7	2.1	3.6
TOTAL	99	100.0	4071	100.0	125.0	100.0

Table 20. Relative abundance and Strauss electivity values for prey fish found in 2009/2010 Box Canyon Reservoir Reach 2 northern pike diets –vs- the relative abundance in a reservoir wide survey conducted in 2009 by KNRD.

Species	N	Relative Abundance in Environment	Relative Abundance in Diet	Strauss Electivity Index
BROWN BULL HEAD	35	0.0075	0.006	-0.001
BLACK CRAPPIE	239	0.0509	0	-
COTTIDAE SP.	4	0.0009	0	-
CUTTHROAT TROUT	1	0.0002	0	-
BASS	485	0.1042	0.022	-0.082
LONGNOSE SUCCKER	20	0.0043	0	-
LARGESCALE SUCKER	71	0.0151	0.017	0.002
NORTHERN PIKEMINNOW	209	0.0445	0.008	-0.036
PEAMOUTH CHUB	265	0.0565	0.033	-0.023
PUMPKINSEED	1386	0.2953	0.229	-0.066
RAINBOW TROUT	2	0.0004	0	-
TENCH	176	0.0375	0.014	-0.023
WHITEFISH	7	0.0017	0.008	0.006
YELLOW PERCH	1767	0.3765	0.639	0.262
BROWN TROUT	5	0.0011	0.003	0.002
BRIDGELIP SUCKER	8	0.0017	0	-
CHISLEMOUTH SUCKER	6	0.0013	0	-
EASTERNBROOK TROUT	2	0.0004	0.006	0.005
WALLEYE		0.0000	0	-
TOTAL	4693	1.0000	0.985	

Table 21. Relative abundance and Strauss electivity values for prey fish found in 2009/2010 Box Canyon Reservoir Reach 3 northern pike diets –vs- the relative abundance in a reservoir wide survey conducted in 2009 by KNRD.

Species	N	Relative Abundance in Environment	Relative Abundance in Diet	Strauss Electivity Index
BROWN BULL HEAD	14	0.0085	0	-
BLACK CRAPPIE	115	0.0697	0	-
COTTIDAE SP.	4	0.0024	0	-
CUTTHROAT TROUT		0.0000	0	-
BASS	55	0.0407	0.03	-0.011
LONGNOSE SUCCKER	44	0.0267	0	-
LARGESCALE SUCKER	58	0.0352	0.091	0.055
NORTHERN PIKEMINNOW	220	0.1334	0.01	-0.123
PEAMOUTH CHUB	139	0.0843	0.02	-0.064
PUMPKINSEED	520	0.3153	0.141	-0.174
RAINBOW TROUT	1	0.0006	0	-
TENCH	86	0.0522	0.01	-0.042
WHITEFISH		0.0000	0.03	0.030
YELLOW PERCH	320	0.1941	0.657	0.462
BROWN TROUT	16	0.0097	0	-
BRIDGELIP SUCKER	43	0.0261	0	-
CHISLEMOUTH SUCKER		0.0000	0	-
EASTERNBROOK TROUT	1	0.0006	0	-
WALLEYE	1	0.0006	0	-
TOTAL	1649	1.0001	0.989	

yellow perch in Reach 3 (Strauss electivity index of 0.462).

Bioenergetics Analysis

To obtain the mean energy utilized on respiration, SDA, excretion, egestion, and growth in Box Canyon Reservoir northern pike each cohort was modeled for 184 days and the mean value from the nine size classes was estimated. According to the model simulations 42.1% of the total mean energy expended by a Box Canyon Reservoir northern pike is spent on respiration. The second highest proportion of total energy expenditure is fecal egestion (20.0%) with an addition 5.6% lost to nitrogenous wastes (5.6%). Specific dynamic action and associated digestive processes accounted for 15.6% of the total energy lost. The remaining 16.7% of the energy budget was used for somatic and gonadal tissue growth.

The weight percent from the food habits study along with the prey energy density and temperature regime were entered into the Wisconsin Fish Bioenergetics 3.0 program for each size class. The results for each class size estimates were summed to give the overall population consumption estimate. The model estimated that northern pike consumed a total of 7.5 metric tons of forage fish from Box Canyon Reservoir consumed by northern pike from May 2010 to October 2010 (Table 22). To enumerate the weight of prey fish consumed during the modeling period the average prey sizes from the food habits study were used to convert the weight estimate to the number of individuals consumed (Table 23). The estimate of the number of individuals consumed was 5,243 peamouth, 1,829 northern pikeminnow, 2,825 mountain whitefish, 44,897 pumpkinseed, 78,862 yellow perch, 11,750 suckers, 7,177 bass, 571 brown bullhead, 269 eastern brook trout, 2,223 northern pike and 5,241 tench (Table 24).

Table 22. Total estimated mass (mt) of prey items consumed by northern pike from May through October 2010.

	SIZE CLASS								
SPECIES	296-380	381-495	496-585	586=696	696-800	801-900	901-1005	1006-1110	TOTAL
PUMPKINSEED	0.05	0.1	0.1	0.3	0.2	0.1	0.002	0.03	0.8
YELLOW PERCH	0.07	0.2	0.1	0.6	0.6	0.3	0	0	1.8
TENCH	0.3	0.09	0	0.05	0.04	0.09	0	0.1	0.7
BASS	0.01	0.03	0.01	0.03	0.01	0.02	0	0	0.1
LARGESCALE SUCKER	0.005	0.003	0.005	0.1	0.05	0.6	0.5	0.5	1.7
MOUNTAIN WHITEFISH	0	0.03	0	0.01	0.05	0.3	0	0.3	0.7
NORTHERN PIKEMINNOW	0	0.03	0	0.01	0.01	0	0	0	0.05
PEAMOUTH CHUB	0	0	0.04	0.4	0.6	0.05	0.02	0	1.1
BROWN BULLHEAD	0	0	0	0.005	0.01	0.02	0	0	0.03
BROWN TROUT	0	0	0	0.008	0	0	0	0	0.008
EASTERN BROOK TROUT	0	0	0	0.008	0	0	0	0	0.008
NORTHERN PIKE	0	0	0	0.2	0.1	0.03	0.04	0	0.3
TOTAL(mt)	0.4	0.5	0.3	1.7	1.6	1.5	0.5	0.9	7.6

Table 23. Mean estimated mass (g) of individual prey items consumed by northern pike from May and October 2009 and May, July, August, September and October 2010.

	SIZE CLASS							
SPECIES	296-380	381-495	496-585	586-696	696-800	801-900	901-1005	1006-1110
PUMPKINSEED	11	12	24	24	23	30	20	44
YELLOW PERCH	8	16	20	26	29	40	0	0
TENCH	112	149	0	168	200	235	0	199
BASS	4	30	39	36	23	69	0	0
LARGESCALE SUCKER	1	2	20	40	217	594	1,100	799
MOUNTAIN WHITEFISH	0	46	0	26	108	0	0	522
NORTHERN PIKEMINNOW	0	26	0	299	45	0	0	0
PEAMOUTH CHUB	0	0	119	159	154	149	151	0
BROWN BULLHEAD	0	0	0	15	49	0	0	0
BROWN TROUT	0	0	0	62	0	0	0	0
EASTERN BROOK TROUT	0	0	0	31	0	0	0	0
NORTHERN PIKE	0	0	0	173	243	85	491	0

Table 24. Total estimated number of prey consumed by northern pike from May through October 2010.

	Size Class								
SPECIES	296-380	381-495	496-585	586=696	696-800	801-900	901-1005	1006-1110	TOTAL
PUMPKINSEED	4,990	11,978	3,939	11,098	7,673	4,497	93	629	44,897
YELLOW PERCH	9,357	12,270	7,242	23,050	19,864	6,899	0	0	78,682
TENCH	3,119	580	0	297	224	391	0	630	5,241
BASS	3,743	1,146	357	925	651	355	0	0	7,177
LARGESCALE SUCKER	4,990	1,562	288	2,497	223	1,084	474	632	11,750
MOUNTAIN WHITEFISH	0	577	0	448	447	721	0	632	2,825
NORTHERN PIKE MINNOW	0	1,162	0	445	222	0	0	0	1,829
PEAMOUTH CHUB	0	0	369	2,512	4,064	360	157	0	7,462
BROWN BULLHEAD	0	0	0	333	238	0	0	0	571
BROWN TROUT	0	0	0	134	0	0	0	0	134
EASTERN BROOK TROUT	0	0	0	269	0	0	0	0	269
NORTHERN PIKE	0	0	0	1,338	445	361	79	0	2,223
TOTAL	26,199	29,275	12,195	43,346	34,051	14,668	803	2,523	163,060

Discussion

Growth

The oldest northern pike sampled was Age 9 with individuals as large as 9 kg were collected during the study period. Annual growth increase was highest in young-of-year with a mean gain of 206 mm which is similar to other northern pike populations (Diana and Mackay 1979; Table 21). In Box Canyon Reservoir the average weight of age 1 through age 4 northern pike were below average for a typical northern pike in North America (Casselman 1996). Age 5 northern pike begin to exceed the typical northern pike growth rate in North America and are typically twice the North American mean by the time they reach age 8 (Casselman 1996; Table 22). The high growth rate in Box Canyon Reservoir is probably the result of a combination of optimal summer water temperatures of 17^{o}C to 22^{o}C (Casselman 1978) and availability of prey fish at optimum sizes and densities (Beyerle 1978).

Box Canyon Reservoir northern pike in 2009 had a K_{TL} range that was lower than what Bean et al. (2007) reported for Box Canyon Reservoir which ranged from 0.49 to 1.09. The national average as reported by Carlander (1969) for northern pike in North America ranged from 0.47 to 0.69. This study suggests that during the first four years of growth northern pike struggle to consume enough food for rapid growth and as they reach five years of age they are large enough to consume most of the prey items available to them in Box Canyon Reservoir. This size advantage and voracious appetite allows them to achieve a high level of growth that exceeds the national average.

Relative weight (W_r) describes if a fish of a particular length is of a low, normal or high weight when compared to a typical fish of that length. To understand the score of

Table 25. Comparison of back-calculated total lengths of northern pike in Box Canyon Reservoir with back-calculated average total lengths from other populations in North America.

		Total Length (mm) at Age										
Location	**n**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Reference**
Box Canyon Reservoir	130	206	288	382	497	599	697	799	930	1,054		Present Study
Box Canyon Reservoir	133	194	312	401	530	656	764	883	1,012			Bean et al. (2007)
Coeur d' Alene, ID	202	312	604	749	821	920	996	1,110				Rich (1992)
Coeur d' Alene, ID	28	145	234	322	403	520	584	634				Scott (2002)
Northern Wisconsin Lakes	--	216	351	442	503	561	612	668				Snow (1969)
Clear lake, IA	190	307	421	518	617	693	922					Ridenhour (1957)
Oahe Reservoir, SD	557	323	475	605	693	922						Fogle (1963)
Minnesota Lakes	8,198	180	318	442	531	622	711	777	851	909	922	Carlander (1969)
Churchhill Lake, SASK	--	132	216	269	320	394	434	498	546	594	649	Rawson (1957)
Great Slave Lake, NWT	73	114	170	234	302	361	419	472	531	574	617	Miller and Kennedy (1948)
Great Bear Lake, NWT	70	102	163	249	335	414	480	541	599	650	698	Miller and Kennedy (1948)
Lake Erie, PA	130	300	486	607	703	789						Buss and Miller (1961)
Mean 82 N. A. Populations	--	191	339	445	509	594	657	678	721	752	806	Casselman (1996)
Mean		209	337	436	520	619	661	706	741	755.5	738	

Table 26. Comparison of mean calculated weight (g) at each annulus, based on back-calculated TL.

		Total weight (g) at Annulus										
Location	**n**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Reference**
Box Canyon Reservoir	130	43	130	329	782	1,445	2,380	3,730	6,146	9,278		Present Study
Box Canyon Reservoir	133	38	184	409	1,042	2,196	3,637	5,809	8,433			Bean et al. (2007)
Great Slave Lake, NWT	73	28	57	85	170	255	397	567	794	1,049	1,034	Miller and Kennedy (1948)
Great Bear Lake, NWT	70	57	142	198	284	454	652	907	1,276	1,700	2,070	Miller and Kennedy (1948)
Athabasca Lake, AB, SASK	65	28	57	85	198	284	510	624	1,077	1,474	1,843	Miller and Kennedy (1948)
North American (typical)	--	85	369	595	936	1,361	1,900	2,440	3,090	3,910	4,700	Carlander (1969)

the W_r the following guide lines have been established, a score of < 87 is usually interpreted as poor growth, 94 to 104 is usually interpreted as moderate growth and a score > 108 is interpreted as fast growth. The high relative weights of northern pike in Box Canyon Reservoir indicate that they are heavier than the average North American northern pike but have experienced a slowdown in weight gain since 2007. (Bean et al. 2007, Willis 1989). Both the relative weight and condition factor scores for northern pike in this system indicate that their growth is above the national average but has shown a slowdown in the current study. Scott (2002) surveyed the growth of northern pike in the Coeur d' Alene lake system and found that as they exceeded the carrying capacity of the lake system their growth slowed significantly from that reported by Rich (1992).

Northern pike can consume fish that are 25-50% of their total length (Frost 1954, Mann 1976, Gillen et al. 1981, Rich 1992). Once northern pike reach 500 mm their gape is big enough to accommodate most sizes of yellow perch, peamouth, pumpkinseed and mountain whitefish many of which were abundant throughout the reservoir (Bean et al. 2007). The high abundance and size range of the prey base allowed northern pike to forage with little energy expenditure allowing them to allocate more energy to growth of somatic and gonadal tissue growth, resulting in above average growth for larger northern pike.

Diet

Since their introduction into Box Canyon Reservoir they have altered the relative abundance of the fish community. Rich (1992) and Scott (2002) surveyed the diets of northern pike in the Coeur d' Alene lake system and found that yellow perch, salmonids and catostomids made up the majority of their diet. Bean et al. (2007) analyzed the diets of northern pike in Box Canyon Reservoir and found that pumpkinseed, peamouth, yellow perch, northern pikeminnow and mountain whitefish constituted the majority of their diet. In the current study northern pike had shifted their food habits with the majority being comprised of pumpkinseed and yellow perch.

Pike are considered opportunistic predators and very flexible in their food habits (Chapman et al. 1989, Beaudoin et al. 1999). If their preferred food items become unavailable or a preferred prey item becomes available they can quickly adapt to alternate food sources (Mann 1985, Rutz 1999). Wolfert and Miller (1978) found that northern pike in eastern Lake Ontario selected alewife (*Alosa pseudoharenqus*) over perch species. In two Georgia reservoirs northern pike adapted their food habits from yellow perch to recently stocked hatchery rainbow trout (Hottell 1976). In Slapton Ley, England, Roach (*Rutilus rutilus*) were selected over perch (Bergazzi and Kennedy 1980). Yellow perch were selected for over various centarchids in two Minnesota lakes (Seaburg and Moyle 1964). The results of the food habits study suggest that northern pike in Box Canyon Reservoir have adjusted their food habits to take advantage of the abundant supply of yellow perch and pumpkinseed found in the reservoir. The semi-fusiform shape and high abundance of yellow perch in Box Canyon Reservoir make them the most ideal prey item for northern pike. Wahl and Stein (1988) suggested that northern pike prefer soft-rayed, fusiform fish due to the fact that they are easily swallowed when compared to the spiny and/or laterally compressed fish species. This optimal shape decreases the handling time of the prey and allows more energy to be converted to somatic or gonadal tissue growth instead of tissue maintenance.

The food habits of northern pike from age 0+ to age 9+ in this study consisted of 99.4% fish. Many studies have reported that the food habits of northern pike consisted almost exclusively of fish (Lawler 1965, Seaburg and Moyle 1964, Mann 1982, Wolfert and Miller 1978). The data indicated that non-fish organisms were insignificant in the diet of yearling and older northern pike in Box Canyon Reservoir. The only salmonid consumed on a regular basis by northern pike was mountain whitefish. The low frequency of salmonid species in the food habits was probably due to the low relative abundance of salmonids in the reservoir. In a fisheries survey conducted in 2004 the six salmonid species found in Box Canyon Reservoir comprised 0.8% of the relative abundance (Unpublished data, KNRD 2009).

Bean et al. (2007) found that pumpkinseed, peamouth and yellow perch comprised 53.7% (by weight) of the food habits of northern pike. In the current study yellow perch, pumpkinseed and peamouth comprised 83.4% (by weight) of the food habits. In the current study tench and bass have increased in the food habits and this may be due to the increase in northern pike abundance leading to a reduced prey base. In 2007 northern pike were searching out mountain whitefish and avoiding tench where in the current study they were consuming them both at a rate similar to the environment. This may be due to the decrease in Mountain whitefish abundance and the increased abundance of tench within the reservoir (Table 27). In Bean et al (2007) northern pike were searching out mountain whitefish and to a limited extent peamouth. This increased predation may have lead to a rapid decrease in these two fish populations explaining why they are no longer being searched out by northern pike.

From 2004 to 2009 there is a decrease in the catch per unit effort of largemouth

Table 27. Relative abundance of fish species in Box canyon Reservoir in 2004 and 2009 in standardized warmwater survey (KNRD unpublished data).

2004 Spring standardized warmwater survey			2009 Spring standardized warmwater survey	
Species	N	Relative Abundance (%)	N	Relative Abundance (%)
Brown bullhead	278	1.8	300	4.9
Black crappie	862	5.6	107	1.8
Eastern brook trout	5	0.0	2	0.0
Brown trout	42	0.3	49	0.8
Largemouth bass	1,237	8.0	187	3.1
Longnose sucker	82	0.5	13	0.2
Largescale sucker	447	2.9	213	3.5
Mountain whitefish	64	0.4	4	0.1
Northern pike	27	0.2	136	2.2
Northern pikeminnow	1,660	10.7	408	6.7
Peamouth	1,109	7.1	170	2.8
Pumpkinseed	4,317	27.8	1,461	24.1
Rainbow trout	8	0.1	6	0.1
Smallmouth bass	30	0.2	61	1.0
Tench	1,048	6.8	809	13.3
Walleye	1	0.0	1	0.0
Yellow perch	4,255	27.4	2,142	35.3
Total	15,511		6,073	

Table 28. Catch Per Unit Effort (C.P.U.E) for fish species in Box Canyon Reservoir 2004 and 2009 (KNRD unpublished data).

	2004 Mean C.P.U.E. by sampling method (80% CI)			2009 Mean C.P.U.E. by sampling method (80% CI)		
Species	Electrofish Boat (fish/hour)	Gill Net (fish/net set)	Fyke Net (fish/net set)	Electrofish Boat (fish/hour)	Gill Net (fish/net set)	Fyke Net (fish/net set)
Rainbow trout	0.4 (±0.2)	0	0	0.6 (±0.3)	0	0
Mountian whitefish	2.8 (±1.1)	0.1 (±0.1)	0	0.3 (±0.2)	0	0
Brown trout	1.8 (±0.6)	0.1 (±0.1)	0.1 (±0.1)	4.3 (±1.4)	0.2 (±0.1)	0
Northern pike	0.1 (±0.1)	0.5 (±0.4)	0	3.0 (±1.4)	3.5 (±0.9)	0
Peamouth	16.0 (±2.9)	13.3 (±2.3)	0.5 (±0.3)	10.2 (±3.5)	1.9 (±0.7)	0.1 (±0.1)
Northern pikeminnow	59.9 (±10.0)	6.8 (±0.90)	0.4 (±0.2)	31.5 (±8.7)	2.5 (±1.0)	0.1 (±0.1)
Tench	18.55(±2.7)	6.2 (±1.3)	4.8 (±1.5)	46.1 (±9.0)	6.5 (±1.9)	7.9 (±2.4)
Longnose sucker	3.0 (±1.0)	0.3 (±0.1)	0	1.2 (±0.7)	0	0
Largescale sucker	18.1 (±2.9)	1.2 (±0.4)	0.2 (±0.1)	17.2 (±4.2)	0.6 (±0.2)	0.1 (±0.1)
Brown bullhead	4.9 (±1.3)	0.2 (±0.1)	2.6 (±1.1)	9.3 (±2.6)	0.2 (±0.1)	13.1 (±7.5)
Pumpkinseed	162.8 (±18.1)	7.3 (±1.5)	6.9 (±1.7)	47.9 (±9.1)	10.8 (±4.8)	40.7 (±30.0)
Smallmouth bass	1.4 (±0.5)	0.1 (±0.1)	0	4.2 (±1.1)	0.5 (±0.4)	0.1 (±0.1)
Largemouth bass	56.6 (±6.6)	0.6 (±0.2)	0.1 (±0.1)	16.5 (±4.1)	0.5 (±0.2)	0
Black crappie	25.8 (±5.9)	4.4 (±1.2)	1.2 (±0.6)	4.6 (±1.0)	1.8 (±0.7)	0
Yellow perch	154.1 (±21.1)	11.5 (±2.0)	5.6 (±2.4)	174.2 (±30.2)	7.1 (±1.8)	7.2 (±2.9)
walleye	0	0.1 (±0.1)	0	0.1 (±0.1)	0	0
Brook trout	0.2 (±0.1)	0.1 (±0.1)	0.1 (±0.1)	0	0.1 (±0.1)	0

bass, northern pikeminnow, peamouth chub, black crappie and pumpkinseed (Table 28). Unexpectedly yellow perch, brown bullhead and tench have experienced an increase in catch per unit effort since the introduction of northern pike. While the relative abundance comparison between the two surveys shows a similar trend, the 2009 survey had half the number of sites sampled and may not show the true effect that the northern pike are having.

Cannibalism was not present in the small sized pike but increased in the larger pike. In most cases, the occurrence of cannibalism in northern pike is directly related to prey availability and pike density (Craig 1996). As the pike population continues to grow we will expect to see a continued decrease in the catch per unit effort and relative abundance of prey species in Box Canyon Reservoir which will result in a higher frequency of cannibalism. Cannibalism in Box Canyon Reservoir was insignificant (1.3%), similar to systems containing other available prey (Frost 1954, Lawler 1965 and Wolfert and Miller 1978).

Bioenergetics

The most widely used bioenergetics model for northern pike (Bevelhimer et al. 1985) includes a wide range of temperatures (5, 15, 20, 25, and 30 °C) but falls short for the size range used (total lengths = 128-227 mm; weights = 9.5-53.2 g) and does not accurately represent the full size range of northern pike found in Box Canyon Reservoir where they can reach over 8,000 g. Diana (1983) developed a bioenergetics model using a larger size range (5-1,200 g) and used the temperatures 1 and 18 ˚C. While this size range better fits the size of northern pike in Box Canyon Reservoir the temperatures do not; the temperature goes from near 2.0^{o}C to nearly 23^{o}C in Box Canyon Reservoir. The different geographical locations and thermal history of the separate populations of pike might cause them to react differently across a range of temperatures. Standard metabolism accounts for a substantial proportion of consumed energy expenditure and has been shown to vary among many northern pike studies (Armstrong and Hawkins 2008). The principal problem with these discrepancies is the risk of over or under estimating consumption.

When comparing consumption estimates based on metabolic parameters prompted in the Fish Bioenergetics 3.0 software (Bevelhimer et al. 1985) to estimates produced by the parameters developed by Bean (2010), it is evident that Bean's parameters produce a more conservative estimate. Based on Bean's parameters the modeled Box Canyon Reservoir northern pike population had an estimated annual consumption of 7.6 mt or 163,000 prey fish which is approximately half of the estimated 14.1 mt using the preset software parameters. Since there is such a large discrepancy between the two sets of parameters I compared the monthly food habits averages to both models.

For most models the need to adjust the population size for mortality is necessary but since the Box Canyon Reservoir northern pike population was estimated at 534 in 2007 and by 2010 had grown to an estimated size of 5483. I did not include mortality into the model due to the rapid growth rate the population was experiencing where recruitment would be much higher than mortality rate.

Comparing the bioenergetic model estimates using Bean's parameters to those from the diet survey (monthly average) a large discrepancy occurs. When calculating the total number of fish consumed using the 105 fish per month consumed northern pike consume an estimated 575,715 fish per month or 3,454,290 fish for the six months that were modeled. To try and find the reason for the large discrepancy I adjusted the population size to account of northern pike with empty stomachs. There were 886 northern pike sacrificed and 407 had no food items in their stomach which means that an estimated 46% of the population had empty stomachs. This gives an adjusted population estimate of 2961 northern pike that had full stomachs and would have consumed an estimated 310,905 fish per month or 1,865,430 fish for the modeling period. This is over 10 times greater than that estimated by the bioenergetics model of 163,000 prey fish consumed. Ashe and Scholz (1990) estimated the population of fish in Box Canyon Reservoir to be 14.5 million fish with yellow perch making up 8.8 million of that total. Given the high overall population of Box Canyon Reservoir and the above average growth of northern pike it is likely that the monthly food habits average is the more accurate of the two methods used. Why there is such a large discrepancy between the diet monthly average and Bean's bioenergetics parameters is unknown at this time and more work needs to be done to find out where the discrepancy lies.

Management recommendations

Where do managers go from here? The need to educate both anglers and the general public should be priority. They need to let them know what an unmanaged northern pike population can do and what the current population is doing. For example an increased northern pike population will lead to decreased angler opportunity for other game species such as trout and bass that have already been impacted from the introduction northern pike. As the population of northern pike continues to increase the prey base will become depleted reducing the encounter rate and energy that can be allocated for growth resulting in a stunted northern pike population reducing pike angler satisfaction.

Managers should use data from this study and others to develop a sound management plan that will ensure that angling opportunities enjoyed today will be here well into the future. Consideration needs to be given to prevent future downstream movement; this is to protect the already threatened and endangered salmonids that migrate up and down the Columbia River. If managers decide that removal of northern pike from Box Canyon Reservoir is the best course of action, not only do they need to inform the public as to why removal is the best option, they should proceed using sound procedures where the ecological impact is kept to a minimum. Determining when and where pike are spawning will ensure the most effective use of gill nets to remove pike before they are allowed to spawn. All sizes of pike need to be targeted, small pike due to the fact that they consume the highest quantity of prey items and the larger pike because they are the most fecund. To ensure that the management plan is working fisheries biologist will need to continue monitoring the northern pike population with Spring Pike Index Netting and further warmwater fisheries surveys to make certain that the plan is working and to adjust it as necessary.

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Appendix A

Bi-monthly food habits

In 2010 there were 75 stomachs collected for seasonal food habits analysis and were collected from May to October. The percent weight composition was used in the Wisconsin fish Bioenergetics program to estimate the consumption rate of pike.

There were 10 prey items found in the May and June 2010 diet of northern pike in Box Canyon Reservoir. The food habits were, in order of relative importance (Table 20):

1) Pumpkinseed (*Lepomis gibbosus)* occurred in 50.9% of stomachs and comprised 55.1% by number, 16.1% by weight and 37.6% by relative importance of prey items in the diet.
2) Peamouth (*Mylocheilus caurinus)* occurred in 24.5% of stomachs and comprised 15.6% by number, 36.5% by weight and 23.6% by relative importance of prey items in the diet.
3) Yellow Perch (*Perca flavens)* occurred in 26.4% of stomachs and comprised 18.3% by number, 6.3% by weight and 15.7% by relative importance of prey items in the diet.
4) Largescale sucker (*Catostomus macrocheilus)* occurred in 5.6% of stomachs and comprised 2.7% by number, 25.8% by weight and 10.5% by relative importance of prey items in the diet.
5) Mountain whitefish (*Prosopium williamsoni)* occurred in 1.8% of stomachs and comprised 0.9% by number, 7.5% by weight and 3.2% by relative importance of prey items in the diet.

6) Bass (*Micropertus spp,)* occurred in 5.6% of stomachs and comprised 2.7% by number, 1.8% by weight and 3.1% by relative importance of prey items in the diet.

7) Northern pikeminnow (*Ptychocheilus oregonensis)* occurred in 3.7% of stomachs and comprised 1.8% by number, 1.1% by weight and 2.0% by relative importance of prey items in the diet.

8) Tench (*Tinca tinca)* occurred in 1.8% of stomachs and comprised 0.9% by number, 3.4% by weight and 1.9% by relative importance of prey items in the diet.

9) Brown bullhead (*Ameilurus nebulosus)* occurred in 1.8% of stomachs and comprised 0.9% by number0.9% by weight and 1.1% by relative importance of prey items in the diet.

10) Bull Frog (*Rana catesbeiana)* occurred in 1.8% of stomachs and comprised 0.9% by number, 0.1% by weight and 0.9% by relative importance of prey items in the diet.

There were 8 prey items found in the July and August 2010 diet of northern pike in Box Canyon Reservoir. The food habits were, in order of relative importance (Table 21):

1) Pumpkinseed (*Lepomis gibbosus)* occurred in 35.0% of stomachs and comprised 38.1% by number, 30.4% by weight and 34.5% by relative importance of prey items in the diet.

2) Yellow Perch (*Perca flavens)* occurred in 35.0% of stomachs and comprised 33.3% by number, 16.5% by weight and 28.2% by relative importance of prey items in the diet.
3) Northern pikeminnow (*Ptychocheilus oregonensis)* occurred in 5.0% of stomachs and comprised 4.7% by number, 20.2% by weight and 9.9% by relative importance of prey items in the diet.
4) Largescale sucker (*Catostomus macrocheilus)* occurred in 5.0% of stomachs and comprised 4.7% by number, 13.9% by weight and 7.9% by relative importance of prey items in the diet.
5) Tench (*Tinca tinca)* occurred in 5.0% of stomachs and comprised 4.7% by number, 9.5% by weight and 6.4% by relative importance of prey items in the diet.
6) Peamouth (*Mylocheilus caurinus)* occurred in 5.0% of stomachs and comprised 4.7% by number, 5.8% by weight and 5.2% by relative importance of prey items in the diet.
7) Bass (*Micropertus spp,)* occurred in 5.0% of stomachs and comprised 4.7% by number, 2.5% by weight and 4.1% by relative importance of prey items in the diet.
8) Bull Frog (*Rana catesbeiana)* occurred in 5.0% of stomachs and comprised 4.7% by number, 0.9% by weight and 3.5% by relative importance of prey items in the diet.

There were 11 prey items found in the September and October 2010 diet of northern pike in Box Canyon Reservoir. The food habits were, in order of relative importance (Table 20):

1) Yellow Perch (*Perca flavens)* occurred in 32.4% of stomachs and comprised 27.5% by number, 6.3% by weight and 20.2% by relative importance of prey items in the diet.
2) Pumpkinseed (*Lepomis gibbosus)* occurred in 21.6% of stomachs and comprised 21.7% by number16.1% by weight and 18.1% by relative importance of prey items in the diet.
3) Largescale sucker (*Catostomus macrocheilus)* occurred in 8.1% of stomachs and comprised 11.5% by number, 25.7% by weight and 13.9% by relative importance of prey items in the diet.
4) Peamouth (*Mylocheilus caurinus)* occurred in 2.7% of stomachs and comprised 1.4% by number, 36.4% by weight and 12.4% by relative importance of prey items in the diet.
5) Mountain whitefish (*Prosopium williamsoni)* occurred in 10.8% of stomachs and comprised 7.2% by number, 7.5% by weight and 7.8% by relative importance of prey items in the diet.
6) Bass (*Micropertus spp,)* occurred in 13.5% of stomachs and comprised 7.2% by number, 1.8% by weight and 6.9% by relative importance of prey items in the diet.

7) Bull Frog (*Rana catesbeiana)* occurred in 13.5% of stomachs and comprised 8.7% by number, 0.1% by weight and 6.8% by relative importance of prey items in the diet.
8) Tench (*Tinca tinca)* occurred in 10.8% of stomachs and comprised 7.2% by number, 3.4% by weight and 6.5% by relative importance of prey items in the diet.
9) Northern pikeminnow (*Ptychocheilus oregonensis)* occurred in 5.4% of stomachs and comprised 2.9% by number, 1.1% by weight and 2.8% by relative importance of prey items in the diet.
10) Northern pike (*Esox lucius)* occurred in 5.4% of stomachs and comprised 2.9% by number, 0.9% by weight and 2.8% by relative importance of prey items in the diet
11) .Meadow vole (*Microtus pennsylvanicus*) occurred in 2.7% of stomachs and comprised 1.4% by number, 0.3% by weight and 1.3% by relative importance of prey items in the diet.

Table 29. Diet habits for northern pike (n-24) in the months of May and June 2010.

Species	Frequency of Occurrence (%)	Total Weight (g)	Composition by Weight (%)	N	Composition by Number (%)	Relative Importance Index
PUMPKINSEED	50.9	1,114	16.1	60	55.1	37.6
YELLOW PERCH	26.4	436	6.3	20	18.5	15.7
TENCH	1.8	235	3.4	1	0.9	1.9
BASS	5.6	129	1.8	3	2.7	3.1
LARGESCALE SUCKER	5.6	1,782	25.8	3	2.7	10.5
MOUNTAIN WHITEFISH	1.8	522	7.5	1	0.9	3.2
NORTHERN PIKEMINNOW	3.7	76	1.1	2	1.8	2.0
BULLFROG	1.8	13	0.1	1	0.9	0.9
PEAMOUTH CHUB	24.5	2,522	36.5	17	15.6	23.6
BROWN BULLHEAD	1.8	66	0.9	1	0.9	1.1
TOTAL	124.5	6,895		109		100.00

Table 30. Diet composition of northern pike (n=20) in the months of July and August 2010.

Species	Frequency of Occurrence (%)	Total Weight (g)	Composition by Weight (%)	N	Composition by Number (%)	Relative Importance Index
PUMPKINSEED	35.0	475	30.4	8	38.1	34.5
YELLOW PERCH	35.0	257	16.5	7	33.3	28.2
TENCH	5.0	149	9.5	1	4.7	6.4
BASS	5.0	40	2.5	1	4.7	4.1
LARGESCALE SUCKER	5.0	217	13.9	1	4.7	7.9
NORTHERN PIKEMINNOW	5.0	315	20.2	1	4.7	9.9
BULLFROG	5.0	14	0.9	1	4.7	3.5
PEAMOUTH CHUB	5.0	91	5.8	1	4.7	5.2
TOTAL	100.0	1,558		21		100.00

Table 31. Diet composition of northern pike (n=37) in the months of September and October 2010.

Species	Frequency of Occurrence (%)	Total Weight (g)	Composition by Weight (%)	N	Composition by Number (%)	Relative Importance Index
PUMPKINSEED	21.6	1,114	16.1	15	21.7	18.1
YELLOW PERCH	32.4	436	6.3	19	27.5	20.2
TENCH	10.8	235	3.4	5	7.2	6.5
BASS	13.5	129	1.8	5	7.2	6.9
LARGESCALE SUCKER	8.1	1,782	25.7	8	11.5	13.9
MOUNTAIN WHITEFISH	10.8	522	7.5	5	7.2	7.8
NORTHERN PIKEMINNOW	5.4	76	1.1	2	2.9	2.8
BULLFROG	13.5	13	0.1	6	8.7	6.8
PEAMOUTH CHUB	2.7	2,522	36.4	1	1.4	12.4
NORTHERN PIKE	5.4	66	0.9	2	2.9	2.8
MEADOW VOLE	2.7	22	0.3	1	1.4	1.3
TOTAL	127.0	6,917		69		100.0

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