Food Habits of River Otters (*Lontra canadensis*) in the Red River of the
North drainage of Eastern North Dakota

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By
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SYNOPSIS

The nearctic river otter (*Lontra canadensis*) is an opportunistic aquatic predator, reported to capture prey in proportion to the prey's availability, and inversely with the prey's swimming ability. The diet is diverse, but because river otters are largely restricted to aquatic habitats, they are limited to aquatic and semi-aquatic prey. Most previous dietary analyses have shown fish to be the primary prey item. When available, crayfish are usually the second most frequently occurring prey item, but in a few studies they have occurred most frequently. Despite many previous food studies on the river otter, formal studies on the size of their fish prey are rare. However, other studies have previously made inferences about prey size, indicating that fish prey ranges from 2-80 cm, and that most fish consumed are probably 10-30 cm in length.

The food habits of river otters in the Red River of the North drainage of eastern North Dakota were evaluated using scat analysis. A total of 665 river otter scats were collected between 26 July 2006 and 26 November 2007. Scats were primarily collected from study areas on the Red River of the North, Forest, and Turtle Rivers, and secondarily from the Tongue River. Overall, fish and crayfish were the primary prey items, occurring in 75.8% and 57.6% of scats, respectively. Other prey included insects, amphibians, birds, mammals, and freshwater mussels. Fish of Cyprinidae (carp and minnows) were the most frequently occurring fish family in the diet (55.9%). Other relatively common fish families in the diet included Ictaluridae (17.0%, frequency of occurrence), Catostomidae (11.4%), and Centrarchidae (10.1%).

The fish prey of river otters in eastern North Dakota ranged from 3.5 to 71.0 cm total length, averaging 20.7 cm (SE = 0.5, $n = 671$). Northern pike (*Esox lucius*) ($\bar{x}$ =

36.3 cm, SE = 2.2, $n = 35$) and darters (*Etheostoma* spp. or *Percina* spp.) ($\bar{x}$ = 6.0 cm, SE = 0.2, $n = 17$) were the largest and smallest fish prey of river otters, respectively. The fish size category with the highest relative frequency (36.5%) and frequency of occurrence (30.5%) was fish 10.1-20 cm total length. The majority of other fish consumed were ≤10 cm (24.5% relative frequency), 20.1–30 cm (13.1%), 30.1–40 cm (13.7%), or 40.1-50 cm (8.2%). Large fish (>50 cm) comprised a small portion of the diet (2.7%).

Size estimation of fish prey requires the use of hard anatomical structures deposited in river otter scats. Also, a relationship between the size of the structure and fish length must exist for size estimation to be possible. The body-scale relationship of 22 species and 6 multi-species groups of fish from the Red River of the North tributaries of eastern North Dakota was assessed. In most cases (42 of 44), there was a positive relationship between fish length and scale size for single species models. Usually, models built using lateral line scales were better than those using non-lateral line scales. Including >1 variable in a model yielded little improvement over single species models. Generally, scale length and height were the best measurements for prey size estimation. Multi-species models also had significant positive relationships between scale size and fish length, but were generally less precise than single species models. Scales were determined to be the structure based suited for size estimation because of their abundance in scats, the existence of identification keys to the family level, the strength of the relationships between scale size and fish length, and the noninvasive method of establishing predictive relationships.

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CHAPTER 1

Introduction

NATURAL HISTORY

The nearctic river otter (*Lontra canadensis*) is one of 13 otter species worldwide, and belongs to order Carnivora, family Mustelidae, and subfamily Lutrinae (Van Zyll de Jong 1987, Lariviere and Walton 1998). The river otter is semi-aquatic and occurs in palustrine, lacustrine, riverine, and coastal marine habitats (Tarasoff 1972, Melquist and Dronkert 1987, Newman and Griffin 1994, Melquist *et. al* 2003). River otters have a streamlined body, with a long tapered tail making up 35-40% of their length (Melquist and Dronkert 1987, Lariviere and Walton 1998, Melquist et al. 2003). Their legs are short and powerful, with the hind legs longer than the front, causing a hump-backed gait (Melquist and Dronkert 1987, Melquist et. al 2003). River otters have five-toed feet that are fully webbed (Lariviere and Walton 1998, Melquist et al. 2003). At maturity river otters are 5-15 kg (11-33 lbs), and 90-130 cm (35-51 in) in total length, with males being longer and heavier than females (Hall and Kelson 1959, Stephenson 1977, Hall 1981, Melquist and Hornocker 1983, Melquist and Dronkert 1987, Melquist et al. 2003).

River otters have large, mostly linear home ranges of 31-249 km in riverine systems, with variation between genders, age classes, and seasons (Melquist and Hornocker 1983, Route and Peterson 1988, Reid et al. 1994*b*, Blundell et al. 2001). River otters usually do not dig their own dens, instead using rock formations, undercut banks, dens built by other animals, and other structures (Liers 1951, Melquist and Hornocker 1983, Serfass and Rymon 1985, Anderson and Woolf 1987*b*). River otters are more social than most mustelids, often living in social groups (Melquist and Hornocker 1983,

Beckel 1990, Blundell et al. 2002, Blundell et al. 2004). The most common social groups are females with their young (family group) and groups of adult males, but sibling and mixed sex groups also occur (Melquist and Hornocker 1983, Shannon 1991, Reid et al. 1994*b*, Rock et al. 1994, Blundell et al. 2002).

Reproduction usually occurs annually with the breeding season lasting from late winter to early spring (Liers 1951, Hamilton and Eadie 1964, Melquist and Hornocker 1983). Males begin producing sperm at about 2 years of age, but may not become successful breeders until later in life (Liers 1951, Hamilton and Eadie 1964, Melquist et al. 2003). Female river otters usually become sexually mature at 2 years of age, but breeding earlier has been observed (Liers 1951, Hamilton and Eadie 1964, Chilelli et al. 1996). River otters have delayed implantation, during which the embryo doesn't immediately attach to the uterus (Hamilton and Eadie 1964, Melquist et al. 2003). Litters of 1-6 pups (usually 2 or 3) are born from mid-January to mid-May, but most typically from late February to April (Liers 1951, Hamilton and Eadie 1964, Tabor and Wight 1977, Melquist and Hornocker 1983, Docktor et al. 1987, Melquist et al. 2003). Young are weaned at about five months of age, and become separated from the female before the next breeding season (Liers 1960, Melquist and Hornocker 1983).

River otters use auditory, olfactory, tactile, and visual signals to communicate (Melquist and Hornocker 1983, Melquist and Dronkert 1987, Lariviere and Walton 1998, Reed-Smith 2001). However, olfactory signals through scent-marking are probably the most important mode of communication (Melquist and Hornocker 1983, Rostain et al. 2004). Areas where river otters scent-mark are known as latrine sites, and are often used repeatedly, making them good sites for scat collection (Mowbray et al. 1979, Melquist

and Hornocker 1983). Latrines often are several meters from the water's edge on high ground (Swimley et al. 1998). Frequently, latrines are located near prominent features of the landscape including rock formations, points of land, mouths of streams, beaver activity, backwater sloughs, fallen logs, vertical banks, and areas with higher fish densities than random sites (Greer 1955, Melquist and Hornocker 1983, Newman and Griffin 1994, Swimley et al. 1998, Ben-David et al. 2005).

STATUS AND DISTRIBUTION

Into the 1800's river otters occurred in all major waterways of North America except in the Arctic of northern Canada and desert regions of the southwestern United States (Park 1971, Melquist et al. 2003). However, by the early 1900's unregulated trapping, water pollution, and other habitat degradation had caused the river otter to decline in abundance throughout a large portion of their historic range, particularly in the central portion of the U.S. (Park 1971, Melquist et al. 2003). Consequently, complete extirpation occurred in at least 6 states, and river otters became rare in many others (Jenkins 1983, Raesly 2001, Melquist et al. 2003). However, reintroduction programs, improved aquatic conservation, and increased protection, including listing in appendix II of CITES, has enabled river otters to recolonize portions of their historic range (Melquist and Hornocker 1983, Raesly 2001, Reed-Smith 2001, Melquist et al. 2003). Currently, the only state in the continental U.S. where river otters do not occur is New Mexico, but there is recent evidence that they may occur there as well (Raesly 2001, Melquist et al. 2003, Polechla et al. 2004).

In North Dakota river otters occurred on most streams and were relatively common into the 1890's (Bailey 1926, Adams 1961). They were still present in the 1920's along the major waterways and some of the major lakes, but had become rare by the 1960's (Bailey 1926, Adams 1961). Since 1964, and particularly in recent years, reports of river otters have been increasing, with most coming from the Red River of the North and its tributaries, and Lake Sakakawea in the Missouri river drainage (Hagen et al. 2005). Currently, river otters are among North Dakota's 100 species of conservation priority, and are listed at a moderate level of conservation concern (Hagen et al. 2005).

FOOD HABITS

The river otter is an opportunistic aquatic predator reported to capture prey in proportion to the prey's availability, and inversely with the prey's swimming ability (Ryder 1955, Melquist and Hornocker 1983). The diet is diverse, but because river otters are largely restricted to aquatic habitats, they are mostly limited to aquatic and semi-aquatic prey. Most dietary analyses have shown fish to be the primary prey (e.g., Greer 1955, Sheldon and Toll 1964, Melquist and Hornocker 1983, Serfass et al. 1990). When available crayfish are usually the second most frequently occurring prey item, but in a few studies have occurred most frequently in the river otter's diet (Grenfell 1974, Griess 1987, Lizotte and Kennedy 1997, Noordhuis 2002). Amphibians generally occur at relatively low frequencies, but Dubec et al. 1991 demonstrated frogs to be the most frequently occurring prey item during summer. Other organisms eaten by river otters include salamanders, birds, mammals, insects and other invertebrates, and reptiles, all of which usually make up a small portion of the diet.

The diversity of the river otter's prey varies seasonally, and is usually greatest in spring and summer when all major categories of prey (e.g., fish, crayfish, amphibians) are most likely to be consumed (Greer 1955, Toweill 1974, Melquist and Hornocker 1983, Serfass et al. 1990, Noordhuis 2002, Giordano 2005). Seasonal variation in food habits results from varying availability of prey items. For example, during spawning fish become more vulnerable to river otters because of high concentrations in relatively small areas, and can be preyed upon heavily as a result (Greer 1955, Toweill 1974, Melquist and Hornocker 1983, Larsen 1984, Reid et al. 1994*a*).

There are 2 methods of determining the food habits of river otters. The most frequently used method is scat analysis. Scats are collected in the field, and later prey remains in the scats are isolated and identified (e.g., Greer 1955, Sheldon and Toll 1964, Melquist and Hornocker 1983, Serfass et al. 1990). The less common method is the use of digestive tracts (e.g., Lagler and Ostenson 1942, Ryder 1955, Knudsen and Hale 1968, Toweill 1974). River otter carcasses are collected, usually from trappers that have captured them, and the contents of the digestive tract is removed and subsequently analyzed. The analysis of scats has several advantages over analyzing digestive tracts. Scats for instance are available year round, whereas digestive tracts are only available from carcasses collected during the trapping season, or from road kills. Therefore, in areas where there is not an open trapping season, such as in North Dakota, the availability of digestive tracts is extremely limited. Even when there are trapping seasons, relatively few digestive tracts are typically available for analysis in comparison to the number of scats that can be obtained along riparian areas occupied by river otters.

Frequency of occurrence is the most commonly used method for tabulating food habits of river otters. Frequency of occurrence is calculated by tabulating the number of samples a specific food item appears in, and dividing by the total number of samples. Relative frequency is occasionally used, and is determined by identifying the number of samples a food item appears in, and dividing by the total number of prey detections. For example, if within a sample of 100 scats, 90 scats contained prey item A, and 20 scats contained item B, the frequency of occurrence would be 90% (90/100) and 20% (20/100), for items A and B, respectively. The relative frequency would be 81.8% (90/110) and 18.2% (20/110), for items A and B, respectively. Both of the frequency tabulations provide results that are close to the actual diet, and are the quickest and easiest methods for determining food habits (Erlinge 1968, Jacobsen and Hansen 1996). However, the techniques count the presence of an item as a single occurrence, regardless of how many individuals actually are in the sample, and thereby, may not depict the number of individuals consumed. Similarly, both large and small prey items are weighted equally, so the importance of large items is underestimated, and small items overestimated (Carss and Parkinson 1996).

In addition to frequency of occurrence, other methods for tabulating food habits were evaluated in a captive study of the European otter (*Lutra lutra*) by Jacobsen and Hansen (1996). These included: frequency of occurrence multiplied by the weight of the scat, score-bulk estimate (the proportion of prey items is estimated and given a score of 1-10, and then multiplied by the weight of the scat), range-bulk estimate (proportion of the prey item is estimated as a percentage of the scat), and area counting (spreading out the scat on a grid and counting the number of areas that an item occurs in) (Jacobsen and

Hansen 1996). All methods had a significant correlation with the actual diet, except area counting. Several of the methods were more correlated with the actual diet than frequency of occurrence, but were more difficult and time consuming to perform (Jacobsen and Hansen 1996). Also, the non-frequency methods assume that the researcher can accurately identify all prey remains in a scat. Such approaches may be acceptable for determining food habits on a coarse scale (i.e., fish, crayfish, amphibian, etc.), but becomes problematic when attempting to accurately depict the proportion of fish families (or species) that are consumed because many fish remains (e.g., ribs, vertebrae) may be difficult to identify.

SIZE ESTIMATION OF FISH PREY

Several studies have previously made inferences about the size of the fish prey of river otters. These indicate that fish prey ranges from 2-80 cm, and that most fish consumed are probably 10-30 cm in length (Lagler and Ostenson 1942, Greer 1955, Ryder 1955, Hamilton 1961, Toweill 1974, Melquist and Hornocker 1983, Stenson et al. 1984, Tumlison and Karnes 1987, Beckel 1990, Noordhuis 2002, Giordano 2005). However, most studies that have estimated fish size have not disclosed their methods, or did not use previously established predictive relationships relating a structure occurring in the prey remains and fish length. Also, inferences have largely been restricted to 1 or a few species (occasionally only a few individuals), and estimated either the size range of fish prey or the most frequently appearing prey size in the diet, and did not evaluate the frequency of particular length categories in the diet.

The size of the fish prey of the European otter has been studied more thoroughly than that of river otters. Wise (1980) established linear regression models for vertebral length on fish fork length (distance between the snout and the fork of the tail) for 5 species, and estimated the length of the fish prey of the European otter based upon these models. Most other studies (i.e., Adrian and Delibes 1987, Carss et al. 1990, Kemenes and Nechay 1990) have either followed Wise (1980) directly, or used a modification of his methods. Scales also have been used to estimate the size of prey of the European otter (i.e., Kozena et al. 1992). However, fish size was estimated by using the mean scale size of fish in 10 mm size classes for constructing predictive relationships, and used only the largest scales of each species within a scat to estimate prey size (Kozena et al. 1992). Other structures that have been suggested for use in estimating the size of fish prey for otters and other piscivores include: cleithra (Hansel et al. 1988, Copp and Kovac 2003), jaw bones (dentary, premaxillary, maxilla) (Hansel et al. 1988, Prenda and Granado-Lorencio 1992, Copp and Kovac 2003, Hajkova et al. 2003), pectoral spines (Noordhuis 2002), pharyngeal teeth (Hamilton 1961, Prenda and Granado-Lorencio 1992), opercula (Hansel et al. 1988, Copp and Kovac 2003), and otoliths (Dellinger and Trillmich 1999, Granadeiro and Silva 2000, Ross et al. 2005). However, many fish lack ≥ 1 of these structures, but most possess scales.

The use of scales instead of vertebrae or other structures for predicting the size of fish prey has several advantages. A particular advantage is the ability to collect scales without lethally sampling fish. Scales can easily be removed from fish that are captured alive, and subsequently the fish can be released. In the case of vertebrae, otoliths, and other bony structures fish must be sacrificed for predictive relationships to be established.

Therefore, using scales is less complicated and more time efficient than developing models from other anatomical structures, because other structures would typically be obtained by sacrificing and subsequently dissecting fish. A limitation of using many of the potential structures is that river otters may not consume the heads or vertebrae of larger fish, as observed in captive studies of other otter species (Erlinge 1968, Rowe-Rowe 1977*a*). If otters in natural systems are similarly not consuming the heads of larger fish, it may cause an underestimation of the size of fish prey. Difficulty in identification, and the potential for breakage or other degradation in passage through the digestive system are also disadvantages of using vertebrae or other bones in size estimation (Carss and Nelson 1998). However, keys for identifying scales to the family level are available (i.e., Daniels 1996).

A further complication of using vertebrae is that the size of vertebrae within a fish differs among regions along the vertebral column (Wise 1980). Therefore, specific vertebrae may be required for size estimation, but determining the region of origin of vertebrae is complicated and time consuming. Scales also vary by shape and size over the body of an individual fish, which has resulted in criticism of their use for size estimation (Phillips 1948, Joeris 1956, Scarnecchia 1979, Wise 1980, Daniels 1996, Miranda and Escala 2007, Roberts et al. 2007). However, lateral line scales are easily distinguished from other scales by a pore or line on the scale (Daniels 1996, Roberts et al. 2007). Constructing regression models using dimensions of lateral line scales, therefore may reduce the amount of variation in the model and thereby, provide a more precise estimate of the size of fish prey.

Body-Scale Relationship

The hard anatomical structures of fish (e.g., scales, vertebrae, otoliths) grow throughout the life of the fish (Lagler 1956, Daniels 1996). Therefore, a positive relationship exists between fish length and scale size, which is known as the body-scale relationship (Lagler 1956, Daniels 1996). The body-scale relationship has been used in fisheries biology in growth studies to back-calculate the length of fish at earlier ages, and potentially can be used to predict the length of fish prey of piscivores (Lagler 1956, Whitney and Carlander 1956, Francis 1990, Giordano 2005, Miranda and Escala 2007). The body-scale relationship is usually reported as being linear, but some authors have used curvilinear, cubic, quadratic, or logarithmic relationships (Lagler 1956, Hile 1970, Carlander 1982, Francis 1990). The relationship can vary between species, populations of the same species, and by the location on the fish of the scales that are used in assessing the relationship (Lagler 1956, Whitney and Carlander 1956, Hile 1970, Francis 1990, Pierce et al. 1996). The relationship also can be influenced by temperature, fish density, parasitism, and other environmental factors (Lagler 1956, Whitney and Carlander 1956, Hile 1970, Carlander 1982, Francis 1990, Pierce et al. 1996, Poulet et al. 2005, Miranda and Escala 2007).

OBJECTIVES

The main goal of this study was to document the food habits of a newly colonizing population of river otters in the Red River of the North and its tributaries in eastern North Dakota. In doing so, one of my objectives was to evaluate the frequency of occurrence of prey items overall and whether there is variation between study areas. I

also wanted to compare the frequency of occurrence of prey items among seasons, to assess the seasonality of the diet.

Body-scale relationships of fish from the Red River tributaries of eastern North Dakota will be assessed to determine whether the relationships can be used to estimate the size of fish prey of river otters and other piscivores. The body-scale relationships established using only lateral line scales will be compared with the relationships for non-lateral line body scales to determine which scale type produces a better predictive relationship, thereby providing a more precise method for fish size estimation. Using these relationships, the size of the fish prey of river otters will be estimated, and compared among rivers and seasons to assess differences between study areas, and the seasonality of prey size.

CHAPTER 2

Food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota.

ABSTRACT

The food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota was evaluated using scat analysis. A total of 665 river otter scats were collected between 26 July 2006 and 26 November 2007, mostly from the Red River of the North, Forest, and Turtle Rivers, and secondarily from the Tongue River. Overall, fish and crayfish were the primary prey items, occurring in 75.8% and 57.6% of scats, respectively. Other prey included insects, amphibians, birds, mammals, and freshwater mussels. Fish of Cyprinidae (carp and minnows) were the most frequently occurring fish family in the diet of river otters, occurring in 55.9% of scats. Other relatively common fish families in the diet included Ictaluridae (17.0%, frequency of occurrence), Catostomidae (11.4%), and Centrarchidae (10.1%). The fish prey of river otters in eastern North Dakota ranged from 3.5 to 71.0 cm total length, averaging 20.7 cm (SE = 0.5, n = 671). Northern pike (*Esox lucius*) ($\bar{x}$ = 36.3 cm, SE = 2.2, n = 35) and darters (*Etheostoma* spp. or *Percina* spp.) ($\bar{x}$ = 6.0 cm, SE = 0.2, n = 17) were the largest and smallest fish prey, respectively. The size category with the highest relative frequency (36.5%) and frequency of occurrence (30.5%) was 10.1-20 cm total length. The majority of other fish consumed were ≤10 cm (24.5% relative frequency), 20.1–30 cm (13.1%), 30.1–40 cm (13.7%), or 40.1-50 cm (8.2%). Fish (>50 cm) comprised a small portion of the diet (2.7%).

INTRODUCTION

The nearctic river otter (*Lontra canadensis*) is an opportunistic aquatic predator reported to capture prey in proportion to the prey's availability, and inversely with the prey's swimming ability (Ryder 1955). The diet is diverse, but because river otters are largely restricted to aquatic habitats, they feed primarily on aquatic and semi-aquatic prey. Most dietary analyses have shown fish to be the primary prey (e.g., Greer 1955, Sheldon and Toll 1964, Melquist and Hornocker 1983, Serfass et al. 1990). When available, crayfish are usually the second most important prey item, and in a few studies have occurred most frequently in the diet (Grenfell 1974, Griess 1987, Noordhuis 2002). Other organisms occasionally eaten by river otters include amphibians, insects and other invertebrates, birds, mammals, and reptiles.

Centrarchidae (sunfish and basses), Catostomidae (suckers), Cyprinidae (carp and minnows), and Ictaluridae (bullhead catfishes) are usually among the most frequently occurring fish families detected in river otter diet studies. However, centrarchids have had the highest frequency of occurrence in the majority of studies (Greer 1955, Sheldon and Toll 1964, Field 1970, Lauhachinda and Hill 1977, Cooley 1983, Anderson and Woolf 1987*a*, McDonald 1989, Serfass et al. 1990, Lizotte and Kennedy 1997, Noordhuis 2002, Skyer 2006). In fewer studies, cyprinids (Wilson 1954, Hamilton 1961, Griess 1987) and catostomids (Knudsen and Hale 1968 (in one study area), Manning 1990, Reid et al. 1994*a*, Giordano 2005) have also been the most frequently occurring fish family. Rarely, other families such as Fundulidae (killifishes) (Chabreck et al. 1982, Dubec et al. 1991), Gasterosteidae (sticklebacks) (Gilbert and Nancekivell 1982), and

Umbridae (mudminnows) (Knudsen and Hale 1968) have occurred most frequently in the diet, but are reported rarely in other studies.

The frequency of occurrence of river otter prey varies seasonally, apparently related to changing availability of prey items (Greer 1955, Toweill 1974, Melquist and Hornocker 1983, Serfass et al. 1990, Noordhuis 2002, Giordano 2005). For example, fish apparently are more vulnerable when they congregate for spawning (Greer 1955, Toweill 1974, Melquist and Hornocker 1983, Larsen 1984, Reid et al. 1994*a*). Also, crayfish are more active in warmer water temperatures, probably increasing their vulnerability, which typically results in increased frequency in the diet (Flint 1977, Anderson and Woolf 1987*a*, Tumlison and Karnes 1987, McDonald 1989, Serfass et al. 1990, Lizotte and Kennedy 1997, Noordhuis 2002, Giordano 2005).

Despite many previous food studies on the river otter, formal studies on the size of their fish prey are rare. Previously, other studies have made inferences about prey size, indicating that fish prey ranges from 2-80 cm, and that most fish consumed are probably 10-30 cm in length (Lagler and Ostenson 1942, Greer 1955, Ryder 1955, Hamilton 1961, Toweill 1974, Melquist and Hornocker 1983, Stenson et al. 1984, Tumlison and Karnes 1987, Beckel 1990, Noordhuis 2002, Giordano 2005). However, most of these studies have not disclosed their methods, or did not use previously established predictive relationships relating the size of a structure in the prey remains to the length of the fish consumed. Also, inferences have largely been restricted to 1 or a few species (occasionally only a few individuals), and estimated either the size range of fish prey or the most frequently appearing prey size, but did not evaluate the frequency of particular length classes in the diet.

My main objective for this study was to document the food habits of a newly colonizing population of river otters in the Red River of the North and 3 of its tributaries in eastern North Dakota. In doing so, I wanted to evaluate the frequency of occurrence of prey items overall, and determine if there was variation in the occurrence of prey items among study areas and seasons. Also, the size of the fish prey of river otters was evaluated, and the relative frequency and frequency of occurrence of length categories calculated. The frequency of the length categories was compared among rivers and seasons to assess differences among study areas, and the seasonality of prey size.

STUDY AREA

The Red River of the North forms at the convergence of the Bois de Sioux River and the Ottertail River at Wahpeton, ND and Brackenridge, MN (46°15.84'N, 96° 35.92'W). The river flows north forming the boundary between North Dakota and Minnesota for nearly 640 km before entering Manitoba, Canada (Koel and Peterka 1998). The landscape of the Red River drainage has low relief, and mostly occurs within the former lake bed of Lake Agassiz (Eddy et al. 1972, Stoner et al. 1993). The majority of the Red River valley (80%) is cropland, but pasture also occurs (Stoner et al. 1993). Forested regions mostly are confined to narrow riparian strips (Stoner et al. 1993). Riparian areas consist of strips of grass or trees (Stoner et al. 1993). But, in some areas agricultural fields extend to the river banks (Stoner et al. 1993). The Red River has 10 major tributaries in North Dakota that from north to south include: the Pembina, Tongue, Park, Forest, Turtle, Goose, Elm, Sheyenne, Wild Rice, and Maple Rivers. The tributaries are very similar in physical structure, typically have low gradients, are meandering, and

have high turbidity (Copes and Tubb 1966, Stoner et al. 1993). My study focused on the Forest, Red, and Turtle Rivers, but also included the Tongue River (Appendix I).

The Forest River flows east and northeast through Walsh, Grand Forks, Nelson, and Ramsey counties for about 93 km before emptying into the Red River approximately 50 km north of Grand Forks (Feldmann 1963). The Forest's only major tributaries are its north, middle, and south branches, which converge near Fordville to form the main stem Forest River. There are two distinct regions within the Forest River drainage, with eastern regions being slow moving and turbid with a bottom of silt and clay (Feldmann 1963). The western areas of the river are faster flowing and less turbid, and have a sand and gravel bottom with little aquatic vegetation (Feldmann 1963). The river is used heavily by waterfowl, particularly at Lake Ardoch National Wildlife Refuge, the western border of my study area (Gulf South Research Institute 1980).

The Turtle River is about 72 km long after the junction of the north and south branches near Larimore, and flows through Grand Forks, Nelson, and Walsh counties. The main tributaries of the Turtle River are its north and south branches, the North Marais and South Marais Rivers, and the Saltwater Coulee. The Turtle River flows east and northeast before entering the Red River about 27 km north of Grand Forks. The upper regions of the river have a sand and gravel bottom, with the substrate becoming muddier as the Turtle River approaches the Red River (Cvancara and Harrison 1966).

The Tongue River is about 84 km long flowing through Cavalier and Pembina counties (Copes 1965). The Tongue River flows east and northeast before entering the Pembina River about 6 km southwest of the city of Pembina. Following the convergence, the Pembina River flows east until it empties into the Red River in the city of Pembina.

In spring 2007, permanent study sites were established on the Forest River in Ardoch Township (Walsh County), Red River of the North in Grand Forks, ND, and East Grand Forks, MN, and Turtle River in Turtle River Township (Grand Forks County). A permanent study area was not established on the Tongue River, but latrine sites on it were monitored. These latrines were located in Bathgate Township (Cavalier County).

Cyprinids, ictalurids, and catostomids are the most abundant fishes in the Red River drainage of eastern North Dakota, as documented in fish sampling conducted in the Forest and Turtle River study areas (Appendix III), in a simultaneous study conducted by South Dakota State University (L. Borgstrom and C. A. Hayer, South Dakota State University, personal communication), and other studies (Feldmann 1963, Copes 1965, Kreil and Ryckman 1987, Goldstein et al. 1996, Koel and Peterka 1998). Centrarchids, percids (perches and darters), esocids (northern pike, *Esox lucius*), and gasterosteids (brook stickleback, *Culaea inconstans*) also are relatively common (Feldmann 1963, Copes 1965, Kreil and Ryckman 1987, Goldstein et al. 1996, Koel and Peterka 1998). Relatively rare families in the drainage include Hiodontidae (mooneyes), Moronidae (white bass, *Morone chrysops*), Sciaenidae, (freshwater drum, *Aplodinotus grunniens*), Percopsidae (trout perch, *Percopsis omiscomaycus*), Umbridae (central mudminnow, *Umbra limi*), and Fundulidae (banded killifish, *Fundulus diaphanus*) (Feldmann 1963, Copes 1965, Kreil and Ryckman 1987, Goldstein et al. 1996, Koel and Peterka 1998).

METHODS

I assessed the diet of river otters by analyzing 665 river otter scats collected between 26 July 2006 and 26 November 2007. Initially, scats were collected during sign surveys (surveys along river banks to detect river otter scats, tracks, or other sign) or during checks of latrine sites. Beginning in spring 2007 the permanent study areas were surveyed monthly on foot. But, in summer and fall 2007 several of the known latrine sites in the study areas were checked weekly or biweekly. Scats on the Tongue River were only collected during sporadic checks of latrine sites, and therefore fewer scats were collected than on other rivers. Additionally, 6 scats were collected from the Pembina River, and 1 from the Park River.

Scats were collected in individual bags, which subsequently were labeled with identifying information (i.e., date, site, and river), and frozen until analysis. In preparation for analysis, scats were washed by soaking over night in soapy water, and then rinsed through a 0.125 mm mesh sieve to eliminate small organic material and other debris. After drying, food particles were separated to facilitate identification. Fish remains were identified to species or to as small of an identifiable group as possible using Daniels' (1996) scale identification key, and reference collections of scales and other bony structures. To determine the frequency of occurrence of mammalian prey, hair in scats was compared with river otter and human hair using Spiers (1973). The presence of river otter and human hair was considered to have been ingested during grooming or investigator contamination, respectively, and therefore was not included as part of the diet. Other remains (i.e., amphibian bones) were identified using reference collections.

Some items (small insects and snails) within a scat were considered to have been ingested secondarily (i.e., previously consumed by another organism, which was then consumed by the river otter), and therefore were not recorded as occurring in the diet. Items were identified as being secondarily ingested if they were considered too small for a river otter to purposely forage upon, and the remains of likely predators also occurred within the scat. Also, any plant material was not considered to be part of the diet, as it was either secondarily ingested, incidentally taken by the river otter as it foraged, or was accidently taken by the researcher during scat collection.

The frequency of occurrence of a prey item was determined by tabulating the number of scats the prey occurred in and dividing by the total number of scats. Relative frequency was calculated by tabulating the number of detections of the prey item and dividing by the total number of prey detections. Frequency of occurrence and relative frequency was calculated separately for major prey groups (e.g., fish, crayfish, and amphibians) and fish families. I assessed seasonal variation in the diet of river otters by assigning scats to a season depending on their collection date. Any scats collected from 1 March – 31 May were defined as spring, from 1 June – 31 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. The frequency of occurrence of prey items of major prey groups and fish families were compared across seasons and rivers using chi-square (χ^2) analyses (Minitab Version 14, Minitab Inc., State College, Pennsylvania, USA). In some comparisons winter was excluded because of small sample size. The diversity of prey was evaluated using the Shannon-Wiener diversity index; calculated using software associated with Krebs (2003), and was compared between rivers and seasons.

Size of Fish Prey

The size of the fish prey of river otters was estimated using body-scale relationships (relating fish total length to scale size) established from samples obtained throughout the North Dakota tributaries of the Red River of the North, June – November 2007 (see chapter 3 for methods and results of the body-scale relationship analysis, and a discussion of the technique). Fish scales from river otter scats were measured using the scale measurements included in the best body-scale regressions (refer to chapter 3). Subsequently, the size of fish prey was estimated by inserting the scale measurements of scales sorted from scats into species or group specific models. Lateral line scales were preferred for size estimation, and were always used when present in a scat. When a lateral line scale was not present, a representative non-lateral line scale of the species (or group) was used.

Following Daniels (1996) cyprinids could be identified into 3 groups based on the morphology of their scales. These included carp (*Cyprinus carpio*), dace (*Rhinichthys* and *Phoxinus* spp.), and other cyprinid species. Based on scale length, the "other species" category could be subdivided into large (scale length ≥2.5 mm, hereafter called large non-carp cyprinids) and small individuals (scale length <2.5 mm, hereafter called small cyprinids). The size of dace consumed by river otters was estimated by using a combined model of blacknose dace (*Rhinichthys atratulus*) and longnose dace (*Rhinichthys cataractae*). A combined model using samples from common shiners (*Luxilus cornutus*) and creek chubs (*Semotilus atromaculatus*) was used to estimate the size of large non-carp cyprinids on all rivers except the Forest. The model used on the Forest River also included samples from horneyhead chubs (*Nocomis biguttatus*) and largescale

stonerollers (*Campostoma oligolepis*), because their distribution in North Dakota is limited to the Forest River (Koel and Peterka 1998). The size of small cyprinid prey on the Forest River was estimated using samples from all cyprinids (excluding carp and dace) with scale lengths <2.5 mm. However, the model for small cyprinids used on other rivers did not include scale samples from horneyhead chubs or largescale stonerollers.

The size of crappie (*Pomoxis* spp.) was estimated by using regression models built using black crappie (*Pomoxis nigromaculatus*) scale samples. Occasionally, crappie could not be differentiated from other centrarchids because of a lack of ctenii on the scales. In such cases, a combined regression model composed mostly of black crappie and bluegill (*Lepomis macrochirus*) samples (but also including a few samples from less common species) was applied (Appendix V). For non-crappie centrarchids, models composed of the other centrarchid samples (mostly bluegill) were used to estimate prey size. The size of darters was estimated by using a combined model of blackside darters (*Percina maculata*) and Johnny darters (*Etheostoma nigrum*). White bass and freshwater drum could not reliably be distinguished because of the similarity of their scales. Therefore, they were pooled in the basic diet and prey size analysis, with their size estimated by pooled regression models using samples from both species.

The relative frequency and frequency of occurrence of fish of particular total lengths was evaluated by categorizing fish prey into 6 size classes: ≤10 cm, 10.1–20 cm, 20.1–30 cm, 30.1–40 cm, 40.1–50 cm, and >50 cm. Occasionally, multiple individuals of the same species (or group) could be identified by having non-overlapping 95% prediction intervals of fish length based on the size of scales in the scat. In such cases all individuals were included in calculations for mean prey length and relative frequency, but

were only included in the frequency of occurrence analysis if they were in separate size categories. The relative frequency and frequency of occurrence of size categories was compared among study areas and seasons using χ^2 analyses on Minitab. Mean prey sizes were compared using F-tests through ANOVA using Minitab. In comparisons of fish size relative frequency was the preferred tabulation, because variation in the occurrence of fish (regardless of size) among rivers or seasons would complicate such comparisons. In prey size comparisons among rivers, the Tongue River was excluded due to small sample size. Similarly, small sample sizes occasionally required the omission of 1 or 2 seasons when conducting seasonal comparisons.

RESULTS

Overall Food Habits

Fish and crayfish were the primary foods of river otters in eastern North Dakota, occurring in 75.8% and 57.6% of all scats, respectively (Figure 2.1; Tables 2.1 and 2.2). The frequency of occurrence of fish overall varied between rivers ($\chi^2_3 = 26.15$, P <0.001), as did comparisons for all fish families (Table 2.3). Fish ranged in frequency of occurrence from 29.2% (frequency of occurrence) on the Tongue River to 96.5% on the Red River. The frequency of crayfish in the diet differed among rivers ($\chi^2_3 = 156.60$, $P <$ 0.001), with most frequent occurrence on the Tongue River (96.6%) and the least on the Forest River (34.7%). Insects were relatively common in the diet, occurring in 27.2% of scats, varying from 18.7% on the Turtle River to 32.2% on the Red River ($\chi^2_3 = 9.97$, $P =$ 0.019). The frequencies at which amphibians, birds, and mammals occurred also differed among rivers (7.1%, $\chi^2_3 = 13.86$, $P = 0.003$; 7.1%, $\chi^2_3 = 45.36$, $P < 0.001$; and 5.6%, $\chi^2_3 =$

23.79, $P < 0.001$, for amphibians, birds, and mammals, respectively) (Table 2.3).

Additionally, 1 scat (0.2%) collected from the Forest River contained a freshwater

mussel.

The primary fish family in the diet was Cyprinidae (55.9%) (Figure 2.1; Table

2.1). Carp was the predominant cyprinid species (and fish species overall) preyed on by

river otters, occurring in 48.0% of scats. Other families that were relatively common in

the diet included Ictaluridae (17.0 %), Catostomidae (11.4 %), and Centrarchidae

(10.1%). Percidae (4.8%), Esocidae (4.4%), Sciaenidae or Moronidae (4.1%), and

Hiodontidae (2.1%) occurred rarely (Table 2.1). Despite being present in at least one of

the rivers, Gasterosteidae, Fundulidae, Percopsidae, and Umbridae were not detected in

any river otter scats.

The diet of river otters changed seasonally in eastern North Dakota (Figures 2.6–

2.9; Tables 2.4 and 2.5). Fish was the most important prey item in spring, fall, and winter,

but became less important in summer ($\chi^2_3 = 70.04$, $P < 0.001$) (Table 2.5). The frequency

of occurrence of most fish families varied seasonally, with most being least frequent in

summer (Table 2.5). The season in which each family occurred most frequently varied, as

the relatively common families in the diet tended to occur most frequently in fall or

winter, and rare families most frequently in spring (Table 2.4). In contrast to fish,

crayfish increased in importance in summer when they surpassed fish as the prey item

with the highest frequency of occurrence ($\chi^2_3 = 27.20$, $P < 0.001$) (Table 2.5). Seasonal

differences also were detected in the frequency of occurrence of insects ($\chi^2_3 = 21.72$, $P <$

0.001), amphibians ($\chi^2_3 = 28.64$, $P < 0.001$), and birds ($\chi^2_3 = 10.65$, $P = 0.014$) (Table

2.5). However, a seasonal difference was not detected in the frequency of occurrence of

mammals ($\chi^2_3 = 4.10$, $P = 0.251$) (Table 2.5).

Size of Fish Prey

The fish prey of river otters in the Red River of the North drainage of eastern

North Dakota ranged from 3.5 (a carp) to 71.0 cm (a northern pike), averaging 20.7 cm

(SE = 0.5, $n = 671$) (Table 2.10). Northern pike ($\bar{x} = 36.3$ cm, SE = 2.2, $n = 35$) and

darters (*Etheostoma* spp. or *Percina* spp.) ($\bar{x} = 6.0$ cm, SE = 0.2, $n = 17$) were the largest

and smallest fish prey of river otters, respectively (Table 2.10). The size category with

the highest relative frequency (36.5%) and frequency of occurrence (30.5%) in the diet of

river otters was fish 10.1-20 cm total length (Figure 2.10; Table 2.11). The majority of

other fish consumed were ≤10 cm (24.5% relative frequency), with larger fish (20.1–30

cm (13.1%), 30.1–40 cm (13.7%), 40.1-50 cm (8.2%), and >50 cm 2.7%)) occurring less

frequently (Table 2.1).

The size of fish preyed on by river otters differed among rivers in both relative

frequency and frequency of occurrence, with significant differences for most size

categories (Figure 2.11; Table 2.11). The Red River had the largest mean prey size ($\bar{x} =$

25.5, SE = 0.8, $n = 234$), and was followed by the Forest River ($\bar{x} = 20.2$ cm, SE = 0.8, n

= 262), and Turtle River ($\bar{x} = 14.5$ cm, SE = 0.8, $n = 163$) ($F_{2, 655} = 39.08$, $P < 0.001$)

(Figure 2.11). Fish 10.1–20 cm in total length composed the largest component of the diet

on the Forest and Red Rivers, and occurred in similar proportions on the Turtle River.

However, on the Turtle River fish ≤10 cm comprised the largest proportion of consumed

fish, with fish >20 cm being less frequently consumed than on other rivers (Table 2.11).

The size of fish consumed by river otters changed seasonally, as all but the largest fish (>50 cm) varied in relative frequency and frequency of occurrence (Figures 2.15 and 2.20; Tables 2.12 and 2.18). In summer, most fish (45.6%) consumed were small (≤10 cm). With increasing frequency of fish in the diet in fall and winter, there was a shift towards fish 10.1–20 cm in length. In spring, fish 30.1-40 cm reached their seasonal maximum in relative abundance and were the most abundant size in the diet (25.3%), but 10.1-20 cm (24.7%), and 20.1-30 cm (24.2%) had similar relative frequencies. Furthermore, fish 20.1-30 cm, 40.1-50 cm, and >50 cm reached their seasonal high relative frequency in spring. In contrast, the largest relative frequency of fish ≤10 cm and fish 10.1–20 cm were recorded in summer and winter, respectively. A seasonal low in relative frequency of fish ≤10 cm was recorded in spring, 10.1–20 cm and 20.1–30 cm in summer, 30.1–40 cm in fall, and 40.1-50 cm and >50 cm in winter (Table 2.12). The larger proportion of fish >20 cm in spring, corresponded with the largest mean prey length during that season ($\bar{x}$ = 27.8 cm, SE = 1.0, n = 178) ($F_{3, 667}$ = 25.62, $P < 0.001$) (Table 2.18). The other seasons had similar mean prey lengths ($\bar{x}$ = 18.6 cm, SE = 1.5, n = 90; $\bar{x}$ = 17.8 cm, SE = 0.6, n = 362; and $\bar{x}$ = 21.0 cm, SE = 1.8, n = 41, for summer, fall, and winter, respectively) (Table 2.18).

Forest River

The diet of river otters on the Forest River was largely comprised of fish (83.3% frequency of occurrence) (Figure 2.2; Tables 2.1 and 2.6). However, crayfish (34.7%), insects (29.4%), birds (15.9%), and amphibians (11.0%) were also common in the diet. Mammals (2.0%) and freshwater mussels (0.4%) were rarely preyed upon. Among fish,

cyprinids were the dominant family, occurring in 74.3% of scats, and making up 74.0%

of all fish detections. Catostomids (8.6% frequency of occurrence) and centrarchids

(5.3%) occurred much less frequently than cyprinids (occurring in 8.7 and 14.0 times

fewer scats than cyprinids, respectively), but were the second and third most frequently

occurring fish families (Figure 2.2; Table 2.6).

The frequency of occurrence of fish ($\chi^2_3 = 14.3$, $P = 0.002$) varied among seasons

(Table 2.6). Fish were the most frequent prey item year round, but occurred more often in

winter (100%) and fall (93.4%) than spring (73.8%) and summer (79.6%). Similarly,

cyprinids, centrarchids, and ictalurids varied seasonally, and were most frequent in fall

($\chi^2_3 = 14.1$, $P = 0.003$; $\chi^2_2 = 11.2$, $P = 0.004$, excluding winter; $\chi^2_2 = 13.8$, $P = 0.001$,

excluding winter, for cyprinids, centrarchids, and ictalurids, respectively) (Table 2.6).

On the Forest River the frequency of occurrence of crayfish, birds, and

amphibians varied among seasons ($\chi^2_3 = 10.1$, $P = 0.017$, $\chi^2_3 = 15.1$, $P = 0.002$; $\chi^2_3 = 27.4$,

$P < 0.001$ for birds and amphibians, respectively) (Table 2.6). Crayfish were most

frequent in the diet in summer, and least in winter (Table 2.6). Birds were most common

in spring (31.1%) and much less common in other seasons (Table 2.6). Amphibians were

most frequent in the diet during summer (23.7%) and were not detected in fall or winter

(Table 2.6). No seasonal differences were detected in the frequency of occurrence of

insects ($\chi^2_3 = 1.0$, $P = 0.793$), or mammals ($\chi^2_2 = 7.5$, $P = 0.284$, excluding winter) on the

Forest River.

Fish 10.1–20 cm had the highest relative frequency of fish with estimated sizes

(39.1%) (Figure 2.12; Table 2.13). In order of relative frequency the other size categories

were ≤10 cm (25.2%), 30.1–40 cm (13.2%), 20.1–30 cm (12.4%), 40.1–50 (6.2%), and

>50 cm (3.9%). Like the overall study, the length of fish prey of river otters on the Forest River changed seasonally, with spring having a larger mean prey size ($\bar{x}$ = 30.8 cm, SE = 1.9, n = 54), than summer ($\bar{x}$ = 19.4 cm, SE = 1.7, n = 77), fall ($\bar{x}$ = 16.1 cm, SE = 1.0, n = 106), and winter ($\bar{x}$ = 17.9 cm, SE = 1.7, n = 21) ($F_{3,254}$ = 17.95, P <0.001). Fish 30.1–40 cm total length were the size most commonly taken by river otters in spring. But, in summer fish ≤10 cm were most common in the diet, and in both fall and winter 10.1-20 cm was the size category most frequently consumed. In spring, fish 20.1–30, 30.1–40, 40.1–50, and >50 cm had their respective highest seasonal relative frequencies in the diet. In contrast, fish ≤10 cm reached their seasonal maximum in relative frequency during summer, as did fish 10.1–20 cm in winter (Table 2.13).

Red River

Fish were the predominant prey item in the diet of river otters on the Red River of the North, occurring in 96.5% of scats (Figure 2.3; Tables 2.1 and 2.7). The fish family with the highest frequency of occurrence was Cyprinidae (58.7%), with carp being the most frequent species consumed (54.2%). Other families that were relatively common in the diet included Centrarchidae (32.2%), Ictaluridae (21.0%), Catostomidae (18.9%), Moronidae or Sciaenidae (17.5%), and Esocidae (10.5%) (Table 2.1). Crayfish (42.7%), insects (32.2%), and mammals (12.7%) also were common prey items of river otters on the Red River. Amphibians (4.2%) and birds (2.1%) were less frequently occurring prey

Seasonal comparisons on the Red River were restricted to comparing spring with fall, because of an inadequate sample size in summer (0 scats) and winter (11 scats). Fish overall, catostomids, cyprinids, and insects occurred more frequently in fall than spring

$(\chi^2_1 = 5.19, P = 0.023; \chi^2_1 = 6.70, P = 0.010; \chi^2_1 = 18.54, P < 0.001; \chi^2_1 = 4.81, P = 0.028$, respectively).Conversely, white bass or freshwater drum occurred much more frequently in spring (32.8%) than fall (6.8%) $(\chi^2_1 = 14.50, P < 0.001)$. The frequency of occurrence of other prey did not differ among seasons (Table 2.7).

Among length categories, fish 10.1-20 cm had the highest relative frequency (33.1%) and frequency of occurrence (42.3%) in the diet of river otters on the Red River (Figure 2.13; Table 2.14). Fish 20.1-30 cm (21.2% relative frequency), 30.1-40 cm (20.8%), and 40.1-50 cm (14.4%) made up relatively large proportions of the diet. Fish ≤10 cm (8.9%), and >50 cm (1.7%) comprised relatively small components of the diet. The size of fish prey did not vary between spring and fall on the Red River in relative frequency or frequency of occurrence (Table 2.14). Also, the mean prey sizes of 25.7 cm (SE = 1.2, n = 99) in spring, 25.7 cm (SE = 1.3, n = 117) in fall, and 24.2 cm (SE =3.0, n = 20) in winter did not differ among seasons ($F_{2, 233}$ = 0.11, P = 0.892).

Tongue River

Crayfish were the dominant prey item on the Tongue River, occurring in 96.6% of scats (Tables 2.1 and 2.8). Insects (31.5%), fish (29.2%), and amphibians (10.1%) also were common prey, but birds (2.2%) and mammals (1.1%) were rare in the diet. The most frequently occurring fish family was Ictaluridae (9.0%), but the occurrence of fish was otherwise infrequent (Figure 2.4; Table 2.1).

Seasonal comparisons of prey items on the Tongue River were restricted to comparing spring and summer because of an inadequate sample size in fall (8 scats) and winter (0 scats). Insects, fish, and amphibians all differed between spring and summer

$(\chi^2_1 = 25.05, P < 0.001; \chi^2_1 = 4.08, P = 0.043; \chi^2_1 = 8.61, P = 0.003;$ for insects, fish, and amphibians, respectively) (Table 2.8). Crayfish occurred frequently in spring (91.4%), but occurred more often in summer (100%) $(\chi^2_1 = 4.08, P = 0.043)$. In contrast, insects and amphibians occurred more frequently in spring (Table 2.8). Fish also were more frequent in the diet during spring $(\chi^2_1 = 4.08, P = 0.043)$ (Table 2.8).

Turtle River

Crayfish and fish were the most prominent prey items in the diet of river otters on the Turtle River, occurring in 79.4% and 71.4 % of scats, respectively (Figure 2.5; Tables 2.1 and 2.9). Other prey included insects (18.7%), mammals (6.0%), amphibians (2.7%), and birds (1.6%). Cyprinid remains occurred in 56.6% of scats, the most of any fish family, and was followed by ictalurids (32.4%), catostomids (14.3%), and percids (8.2%). Centrarchids (2.7%), northern pike (2.2%), and hiodontids (1.6%) occurred infrequently in scats.

The diet of river otters changed seasonally on the Turtle River (Table 2.9). Crayfish varied seasonally $(\chi^2_3 = 23.64, P < 0.001)$, with increasing occurrence in summer (98.1%) (Table 2.9). Correspondingly, there was a decrease in the consumption of fish (which were the most frequent prey item in spring, fall, and winter) in summer, resulting in crayfish surpassing fish as the most frequently occurring prey item. The occurrence of cyprinids, ictalurids, and catostomids also changed seasonally $(\chi^2_2 = 28.81, P < 0.001; \chi^2_2 = 42.79, P < 0.001; \chi^2_2 = 6.66, P = 0.036,$ respectively) (Table 2.9). Cyprinids occurred in similar frequencies in spring (64.3%) and fall (67.0%), but less frequently in summer (30.8%). Ictalurids were much more frequent in fall, and

catostomids had a lower frequency of occurrence in summer than other seasons (Table 2.9).

The frequency of occurrence of other prey, including insects, mammals, and amphibians varied significantly between seasons ($\chi^2_2 = 13.17$, $P = 0.001$; $\chi^2_1 = 5.32$, $P = 0.021$ (excluding spring); $\chi^2_1 = 9.06$, $P = 0.003$ (excluding spring), respectively) (Table 2.9). Insects were common in the diet in spring (28.6%) and fall (24.3%), but rare in summer (1.9%). Mammals only were consumed in fall (9.6%). Amphibians occurred in 7.7% of scats in summer, but none collected during fall.

Fish in the ≤10 cm size category occurred most frequently (46.3% relative frequency) in the diet of river otters on the Turtle River (Figure 2.14; Table 2.15). Most of the remaining fish were 10.1-20 cm (37.2%, relative frequency) (Table 2.15). The size of the fish prey in the diet varied seasonally, with spring having a much larger mean fish length ($\bar{x} = 33.4$ cm, SE = 3.3, $n = 18$) than summer ($\bar{x} = 13.8$ cm, SE = 4.4, $n = 12$), and fall ($\bar{x} = 11.7$ cm, SE = 0.6, $n = 134$) ($F_{2,161} = 51.52$, $P < 0.001$) (Table 2.15). Fish ≤10 cm were the primary size category during summer (58.3% relative frequency) and fall (50.0%), but comprised a much lower proportion of fish consumed in spring (11.1%) ($\chi^2_2 = 10.4$, $P = 0.006$). In contrast, fish 30.1-40 cm in total length were not detected in scats from the Turtle River in summer, and were rare in fall (2.2% relative frequency), but had the largest relative frequency of any size category in spring (33.3%).

Diversity

The Shannon-Wiener diversity index (H') for major prey categories in the diet of river otters in the Red River of the North drainage was 1.996, and was 2.238 for fish families. Diversity varied among rivers, with the Forest River having the highest diversity (2.058), and the Turtle River (1.704) the lowest for major prey categories (Table 2.16). When only considering fish prey, the diversity was highest on the Red River (2.160), and lowest on the Forest River (1.465) (Table 2.16). The diversity of prey changed seasonally, with the diversity for major prey categories being highest in spring, and lowest in winter (Table 2.17). Similarly, the diversity of fish prey was highest in spring, but was lowest in summer (Table 2.17).

DISCUSSION

Food Habits

Fish and crayfish were the primary prey items of river otters in eastern North Dakota, similar to previous studies elsewhere (Lagler and Ostenson 1942, Greer 1955, Hamilton 1961, Sheldon and Toll 1964, Knudsen and Hale 1968, Toweill 1974, Gilbert and Nancekivell 1982, Cooley 1983, Melquist and Hornocker 1983, Anderson and Woolf 1987*a*, Serfass et al. 1990, Reid et al. 1994*a*, Giordano 2005, Crait and Ben-David 2006). In the primary study areas, fish ranged from 71.4% to 96.5%, values typical of most previous studies. However, fish occurred in only 29.2% of scats on the Tongue River, which is the second lowest reported frequency of occurrence (only Grenfell (1974) reported lower). The most important fish families in the diet included Cyprinidae, Ictaluridae, Catostomidae, and Centrarchidae (Table 2.1). Because these fishes are

relatively slow swimmers, and are among the most abundant fishes in North America, they are often the most frequent families reported in the diet of river otters. However, cyprinids have been reported as the most frequently occurring fish family in relatively few studies (i.e., Wilson 1954, Hamilton 1961, Griess 1987) in comparison with centrarchids (i.e., Greer 1955, Sheldon and Toll 1964, Field 1970, Lauhachinda and Hill 1977, Cooley 1983, Anderson and Woolf 1987*a*, McDonald 1989, Serfass et al. 1990, Lizotte and Kennedy 1997, Noordhuis 2002, Skyer 2006). Despite fish being the most frequent prey overall (and on the Forest and Red Rivers), crayfish were the most frequent prey item on the Tongue and Turtle Rivers. Previously, crayfish have been reported as occurring at equal or greater frequencies than fish, but in relatively few studies (Grenfell 1974, Griess 1987, Lizotte and Kennedy 1997, Noordhuis 2002).

River otters are reported to capture prey in proportion to the prey's availability (Ryder 1955). Therefore, the order of frequency of occurrence (and relative frequency), should be similar to the relative abundance in the study area (Ryder 1955). Also, if an area has a higher relative abundance of a particular species than other areas, then it would be expected to have a higher frequency in the diet. In our fish sampling, cyprinids were the most numerous fish, and correspondingly had a much higher frequency of occurrence in the diet than any other family (Table 2.1, Appendix III). Similarly, the second, third, and fourth most abundant fish families in sampling (Ictaluridae, Catostomidae, and Centrarchidae, respectively) occurred in the same order in the overall food study. Furthermore, catostomids, ictalurids, and percids had higher relative abundances on the Turtle River in comparison with the Forest River, and subsequently occurred more frequently in the diet on the Turtle River. In contrast, centrarchids and cyprinids had

higher relative abundances and higher frequencies of occurrence on the Forest River.

Therefore, river otters do appear to capture prey in proportion to their availability in

eastern North Dakota.

There were a few exceptions to the generalization that prey is captured in

proportion to its availability. For instance, despite occurring in approximately the same

proportions as on the Turtle River, catfish were much less frequent in the diet on the

Forest River (Table 2.1, Appendix III). On the Turtle River, white bass were relatively

abundant in fish samples (fourth in relative abundance), but were not detected in any

scats (Table 2.1, Appendix III). However, prior to this study white bass had not been

documented in the Turtle River, and were not captured in the simultaneous study

conducted by South Dakota State University (Feldman 1963, Copes 1965, Kreil and

Ryckman 1987, Goldstein et al. 1996, Koel and Peterka 1998, L. Borgstrom and C. A.

Hayer, South Dakota State University, personal communication). Therefore, our estimate

of the relative abundance of white bass is likely overestimated. Also, on the Turtle River,

percids were fourth in frequency of occurrence, but only 1 individual was captured during

fish sampling (eighth in relative abundance). However, our fish sampling technique may

have excluded darters from being captured, because the fyke nets likely allowed darters

(and other small fish) to move through it without being caught, and minnow traps may

not have attracted them. Therefore, our estimate of the relative abundance of darters, and

hence percids, is likely underestimated. Because of possible overestimation of white

bass/freshwater drum and underestimation of percids in the Turtle River the apparent

disparities between fish sampling and frequency of occurrence of some groups may be an

artifact of non-representative sampling.

Comparing the relative abundance of distinguishable cyprinids to their frequency in the diet reveals another departure from what would be expected based on availability. The majority of consumed cyprinids were carp, which were very abundant in fish sampling (Table 2.1, Appendix III). Non-carp cyprinids also were very numerous, but were consumed less frequently (Table 2.1, Appendix III). Therefore, river otters apparently consume small cyprinids less than what would be expected based on their abundance in the study areas. Although river otters apparently do capture prey roughly in proportion to their availability, the relatively low occurrence of non-carp cyprinids on both rivers, and of catfish on the Forest River, indicates that there are other factors that influence a fishes' occurrence in the diet.

Insects occurred frequently in scats, and previous studies have reported similar frequencies in the diet (Greer 1955, Knudsen and Hale 1968, Cooley 1983, Manning 1990, Reid et al. 1994*a*). However, in some studies insects occurred infrequently or not at all (Field 1970, Anderson and Woolf 1987*a*, Griess 1987, McDonald 1989, Giordano 2005). Most of the differences reported in the literature is likely from regional variation in food habits. However, some of the variation may be attributable to differences in the determination of whether insects were consumed directly by river otters, or indirectly by consuming other prey that had previously consumed them (secondary ingestion). Although some of the insects reported here may have been eaten secondarily, most were probably consumed purposefully based on their size, as only large aquatic insects were included as occurring in the diet.

Birds occurred frequently in the diet on the Forest River, but comprised small portions of the diet on other rivers (Table 2.1). In most previous studies, birds occurred in

<5 % of scats, which was the case on most rivers in this study (Table 2.1). However, river otters inhabiting the Forest River had a relatively high amount of birds in the diet (15.9%). Gilbert and Nancekivell (1982) and Grenfell (1974) also reported birds occurring frequently in the diet (15.5% and 38.0%, respectively). In both studies large populations of waterfowl were noted in the study area, particularly Grenfell's (1974) study which occurred in an over-wintering area for the Pacific flyway. Similarly in North Dakota, waterfowl were prevalent in the Forest River study area, which has previously been reported to be used heavily by waterfowl (Gulf South Research Institute 1980). The majority of detected birds were adults or hatched young, but a few scats contained egg shell fragments, suggesting that river otters will occasionally predate nests. Others (i.e., Footit and Butler 1977, Quinlan 1983) have not documented nest predation, despite reporting predation on nesting birds.

Amphibians frequently have been reported by other studies to have occurred in 10-20% of river otter scats (e.g., Lagler and Ostenson 1942, Greer 1955, Ryder 1955, Knudsen and Hale 1968, Lizotte and Kennedy 1997), but also have been reported to occur less frequently (e.g., Sheldon and Toll 1964, Lauhachinda and Hill 1977, Serfass et al. 1990, Noordhuis 2002, Giordano 2005). Therefore, the frequency of occurrence of amphibians in eastern North Dakota is similar to previous diet studies (Table 2.1). Amphibians were predated more frequently on the Forest and Tongue Rivers than the Red and Turtle Rivers (Table 2.3). Crayfish traps set in the wetlands along the Forest River frequently captured salamanders, and less frequently in traps on the Turtle and Red Rivers, suggesting that populations may be higher in the Forest River study area.

Mammals were more frequent in the diet on rivers with more riparian cover, the Red and Turtle Rivers (Table 2.3). The presence of less disturbed riparian areas, likely provides more habitat for small mammals, and therefore larger populations. With larger populations it is more likely that a river otter would encounter a mammal. River otters on the Red River had a relatively high amount of mammals in the diet (12.7%). Previous studies have also documented mammals occurring in ≥10% of scats (i.e., Field 1970, Cooley 1983, Serfass et al. 1990 in one study area), but they usually occur in <5%. Therefore, the high frequency of mammals on the Red River is unusual, but not unique.

Seasonality of Food Habits

The food habits of river otters in eastern North Dakota changed seasonally (Table 2.5). In summer, fish decreased in occurrence, with a simultaneous increase in the occurrence of crayfish (Table 2.5). Previous studies have shown a similar pattern, including the summer transition from fish to crayfish as the primary prey (Anderson and Woolf 1987*a*, Tumlison and Karnes 1987, McDonald 1989, Serfass et al. 1990, Lizotte and Kennedy 1997, Noordhuis 2002, Giordano 2005). There are several factors likely contributing to the increasing importance of crayfish and declining importance of fish in summer. For instance, fish are probably more difficult to capture in summer, because fish swimming speeds increase as water temperature increases (Erlinge 1968, Wardle 1980). Therefore, fish are less likely to be consumed in summer when water is warm, and more likely to be caught in winter when water temperature (and swimming speed) is low. As a result, in this and previous studies, fish have occurred most frequently in winter, and least often in summer (Sheldon and Toll 1964, Grenfell 1974, Anderson and Woolf 1987*a*,

Serfass et al. 1990, Reid et al. 1994*a*, Giordano 2005). Also, and perhaps a greater contributing factor, crayfish activity and overall availability increases in warmer water temperatures, potentially making them more vulnerable to predation in summer (Flint 1977). Changes in the catchability of fish and crayfish undoubtedly contributed to the switch from fish to crayfish as the most frequently occurring prey item in summer.

Similar to total fish consumption, most fish families varied seasonally in the diet. Cyprinids were the most frequently occurring fish, and spawning aggregations of carp (the dominant species consumed) were observed in spring. Therefore, it was expected that cyprinids would have a higher occurrence in spring, as documented by Melquist and Hornocker (1983), Anderson and Woolf (1987*a*), and Giordano (2005). However, cyprinids (and carp) were most frequent in fall and winter (Table 2.5). In North Dakota, the increase in the frequency of cyprinids coincides with the increase in total fish consumption. Being the most abundant fishes in the study area, cyprinids are more likely to be captured (assuming prey consumption in proportion to availability) than other families. Therefore, as more fish are consumed, the frequency of occurrence of cyprinids would be expected to increase. Yet, despite large spawning aggregations of carp, and a higher occurrence of all fish in spring, the frequency of cyprinids in spring is only slightly higher than the occurrence in summer. In summer, when fish occurred less frequently, cyprinids were the primary target because of their abundance. But, in spring, because many fish become congregated as they spawn, a wider variety of fish species are vulnerable to predation, and as a result, cyprinids aren't consumed as much as might be expected by their abundance and frequency in other seasons (Lee et al. 1980, Koel and Peterka 2003, Werner 2004).

In previous studies, ictalurids have been shown to occur most frequently in spring (Melquist and Hornocker 1983) and fall (Tumlison and Karnes 1987, Giordano 2005). In North Dakota, a similar pattern was observed as ictalurids were more frequent in the diet in fall (31.3%) and spring (12.4%), occurred rarely in summer (3.0%), and were not detected in winter. Ictalurids spawn in late spring and early summer, which could explain the higher occurrence in spring, but not the much higher occurrence in fall (Marzolf 1957, Lee et al. 1980, Blumer 1985, Werner 2004).

Catostomids occurred more frequently in the diet of river otters fall and winter than in other seasons (Table 2.5). Most studies report highest frequencies in winter (Greer 1955, Sheldon and Toll 1964, Tumlison and Karnes 1987, Giordano 2005) or spring (Melquist and Hornocker 1983, Reid et al. 1994*a*). The apparent increase in the frequency of catostomids occurs as total fish occurrence in the diet increases. Because catostomids are relatively abundant and slow swimmers, their occurrence in the diet would be expected to increase during periods of more frequent fish consumption.

Centrarchids have been reported as being most frequently preyed on during winter (Serfass et al. 1990, Giordano 2005), summer (Greer 1955, Tumlison and Karnes 1987), and fall (Sheldon and Toll 1964, Anderson and Woolf 1987*a*). In the Red River study area, where most of the centrarchids were detected, centrarchids occurred most frequently in the diet during spring (39.7%) and winter (36.4%) (Table 2.7). Elsewhere, the frequency of occurrence of centrarchids was highest in winter (27.3% of scats). Although my interpretation is limited because no scats were collected from the Red River in summer, from my research and previous river otter diet studies the seasonality of centrarchid consumption by river otters varies regionally.

Insects were more commonly consumed in spring (33.1%) and fall (32.7%) than in summer (15.6%) and winter (18.2%).Typically, insects have been reported to occur most frequently in the diet during summer (Sheldon and Toll 1964, Knudsen and Hale 1968, Reid et al. 1994*a*), but, have also been most frequent in winter (Melquist and Hornocker 1983, Giordano 2005), spring (Greer 1955), and fall (Anderson and Woolf 1987*a*). Frequency of insects in the diet is likely affected not only by the seasonal abundance of insects, but also of other prey. For example, in North Dakota, crayfish, amphibians, and birds are more available in summer, and therefore river otters take advantage of these seasonally more abundant prey items, consuming insects relatively less frequently. The lower occurrence of insects in winter is probably because insects are less abundant than in other seasons.

Amphibians occurred most frequently in the diet in spring and summer (Table 2.5). Similar to this study, most previous studies have documented higher occurrences in these seasons (Greer 1955, McDonald 1989, Dubec et al. 1991, Serfass et. al 1990, Reid et al. 1994*a*, Giordano 2005). The higher frequency of amphibians in spring and summer coincides with higher activity levels associated with the breeding season.

Birds declined in frequency of occurrence through the year, from spring (11.8%) to winter (0%) (Table 2.5). Most other studies have documented birds occurring most frequently in spring (Greer 1955) or summer (Melquist and Hornocker 1983, Anderson and Woolf 1987*a*, Reid et al. 1994*a*, Serfass *et. al* 1990). Breeding and juvenile aquatic birds were common along the rivers in my study areas in spring and summer. As a result, they are more available as prey, and therefore occurred more frequently in the diet. In

fall, birds migrate from the study areas resulting in a lower frequency of occurrence. By winter few birds remain, and were not detected in any scats.

The frequency of occurrence of mammals did not vary through the year. However, they were slightly more frequent (though not significantly) in fall (7.6%) than other seasons (3.5-4.7%). In the literature no season has been consistently associated with the highest frequency of mammals in the diet. Reid et al. (1994*a*) documented the highest occurrence in winter, Greer (1955) in spring, Melquist and Hornocker (1983) and Giordano (2005) in summer, and Knudsen and Hale (1968) and Grenfell (1974) in fall. Therefore, mammals appear to be predated opportunistically.

Size of Fish Prey

The fish prey of river otters in eastern North Dakota ranged from 3.5 to 71.0 cm total length, with most being ≤30 cm, similar to other studies that have made inferences on prey size of river otters (Lagler and Ostenson 1942, Greer 1955, Ryder 1955, Hamilton 1961, Toweill 1974, Melquist et al. 1981, Melquist and Hornocker 1983, Stenson et al. 1984, Griess 1987, Tumlison and Karnes 1987, Beckel 1990, Dolloff 1993, Noordhuis 2002, Giordano 2005), and other otter species (Erlinge 1968, Rowe-Rowe 1977*b*, Jenkins et al. 1979, Conroy and Jenkins 1986, Kruuk and Moorhouse 1990, Kruuk et al. 1993, Ebensperger and Botto-Mahan 1997, Taastrom and Jacobsen 1999). To my knowledge, the largest fish documented in this study, a 71.0 cm northern pike is among the largest fish reported to have been predated by otters, with only Toweill (1974) and Lauhachinda and Hill (1977) having reported a larger estimated length of an individual fish.

The most frequent fish size category consumed by river otters was 10.1–20 cm total length (36.5% relative frequency). Giordano (2005) also documented fish 10.1-20 cm as the most common size consumed, with a nearly identical relative frequency (36.4%). Similarly, fish 30.1-40 cm, 40.1–50 cm, and >50 cm occurred in similar proportions in this study (13.7%, 8.3%, and 2.7% respectively) as in Giordano's (2005) (17.4%, 7.2%, and 2.0%, respectively). However, the relative frequency of fish ≤10 cm, and 20.1–30 cm differed between studies. Here, fish ≤10 cm and 20.1-30 cm were the second (24.4%) and third (14.3%) most abundant fish sizes in the diet, respectively. However, Giordano (2005) reported fish 20.1–30 cm as the second most abundant (26.8%), and fish ≤10 cm as only fourth in relative frequency (10.3%).

If river otters capture fish in proportion to their availability, then the relative frequency in the diet should be similar to the relative abundance in the fish population. Fish 10.1-20 cm did occur in similar proportions in the diet as in fish sampling (Table 2.11, Appendix IV). But, fish ≤10 cm were much less common in the diet than what would be expected based on their abundance (Table 2.11, Appendix IV). In contrast, fish 20.1-30, 30.1-40, 40.1-50, and >50 cm occurred more often in the diet than in sampling (Table 2.11, Appendix IV). There are several possible explanations for the differences, all of which probably contribute to the observed differences between relative frequency and relative abundance of fish lengths. One explanation is that fish sampling was not representative of the fish communities within the area inhabited by the river otters included in the study. This was certainly the case for species abundance, as some of the most abundant and widely distributed species (i.e., common shiner, creek chub, blackside darter, and Johnny darter; from Feldmann 1963, Copes 1965, Kreil and Ryckman 1987,

Goldstein et al. 1996, Koel and Peterka 1998, C. A. Hayer and L. Borgstrom, South Dakota State University, personal communication) were not captured during our sampling (Appendix III). Also, fish >50 cm were not captured during sampling, but were known to occur in the study areas because of observation of spawning congregations, and presence of carcasses on river banks. This disparity indicates that our sampling was not representative of the relative abundance of fish sizes available, as large fish were likely underestimated. Another plausible explanation for differences between the diet and abundance in the study areas is river otter selection for larger fish. Large prey provides additional nutritive value over smaller prey. Therefore, river otters could actively seek out larger fish, thereby capturing small fish less frequently than would be expected by their abundance. Similarly, the selection of larger fish has been observed in captive studies of European otters (Erlinge 1968, Topping and Kruuk 1996).

Another explanation of the differences between the relative abundance and relative frequency of prey sizes is the differential catchability of fish of different lengths. Larger fish swim at faster speeds than smaller individuals of the same species, making them more difficult to capture (Rowe-Rowe 1977*a*, Videler 1993). This presumption would suggest that small fish would be eaten more frequently (and large fish less frequently) than expected based on their abundance. However, because of their size, small fish (i.e., small cyprinids, darters, and small individuals of large species) are probably more difficult for river otters to detect than larger fish. Also, once pursued, there are probably more hiding spaces available to them (relative to larger fish) to find refuge from predation. As a result, small fish could be more difficult to capture than what is suggested by their swimming ability. Similarly, in a captive study of European otters,

Erlinge (1968) noted that otters captured fish ≤10 cm with difficulty, and Adrian and Delibes (1987) reported wild European otters capturing small fish less than expected based on their abundance. As a result of differential catchability, I suspect the smallest (≤10 cm) and largest (>50 cm) fish probably have lower probabilities of being captured than those of intermediate sizes.

A limitation of using scales to estimate prey size is another possible explanation for differences between relative abundance and relative frequency of prey sizes. Using scales it is difficult to distinguish between multiple individuals of the same species, because 95% prediction intervals of fish size based on the size of scales sorted from scats are several centimeters wide. Therefore, multiple individuals of the same species could only be differentiated for species that attain large sizes (e.g. carp). Within one particular scat, only 1 small cyprinid individual could be identified using scales. However, the remains of at least 25 individuals were present in the scat, based upon the number of pharyngeal teeth the scat contained. Therefore, the relative frequency of fish ≤10 cm is likely underestimated, leading to an overestimation of mean prey sizes.

Seasonality of Prey Size

In spring, river otters consumed larger fish than in other seasons, as evidenced by a larger mean prey size, and by higher relative frequencies of fish 20.1-30, 30.1-40, 40.1-50, and >50 cm than other seasons (Figures 2.15-2.19; Tables 2.12 and 2.18). Previous studies on the diet of river otters and European otters have shown that prey sizes are largest in spring or winter (Erlinge 1968, Carss et al. 1990, Kozena et al. 1992, Dolloff 1993, Giordano 2005). Large spawning aggregations of carp were observed in the study

areas in spring, a period when many of the other species also were spawning (Lee et al. 1980, Koel and Peterka 2003, Werner 2004). During spawning, large fish are more vulnerable to predation because of having high concentrations in relatively small areas. Therefore, large fish can be consumed frequently if river otters discover the spawning grounds. As a result, fish >20 cm (more adult fish) were taken more often than in other seasons.

In addition to spawning, another factor potentially contributing to size differences between spring and other seasons is fish swimming speed. Swimming speed is known to increase with water temperature (Wardle 1980). Therefore, in spring when the water is relatively cool, large fish are slower, and thus easier to capture than in summer when water is warmer. Accordingly, the size of the fast swimming northern pike in the diet of river otters was on average smaller in summer than in other seasons (Appendix II). But, this reasoning also suggests that fall and winter should have larger prey sizes than summer. But, this was not the case, as summer, fall, and winter had similar mean prey sizes, and fish 40.1-50 cm, and >50 cm were at their seasonal low relative frequency in winter (Figure 2.15). However, in winter fish ≤10 cm had a lower relative frequency, and fish 10.1-20, 20.1-30, and 30.1-40 cm had higher relative frequencies than summer and fall. This suggests that there may be a shift towards larger fish in winter, but the relatively low sample size in that season prevented a difference from being detected.

Diversity

For major prey items, the Forest River had the highest diversity, followed in order by the Red, Tongue, and Turtle Rivers (Table 2.16). The higher diversity of major prey

items at the Forest River resulted from greater occurrences of birds and amphibians, and

frequencies of fish, crayfish, and insects, being similar to the occurrences on other rivers.

Additionally, the only freshwater mussel documented was from the Forest River. The

prey on the Red River had the second highest diversity, largely because of a relatively

high occurrence of mammals in the river otter's diet at the site. The Turtle River had the

lowest diversity because the diet was dominated by fish and crayfish.

The Red River had the highest diversity of fish prey in the diet, followed by the

Tongue, Turtle, and Forest Rivers (Table 2.16). The higher diversity of fish prey on the

Red River probably can be attributed to the Red River possessing a more diverse fish

fauna. Koel and Peterka (1998) reviewed fisheries literature and surveys from the Red

River drainage and determined that the Red River has a higher species richness (44

species) than the Forest (31), Tongue (20), and Turtle (27) Rivers. With more species

available to them, river otters are more likely to consume a wider variety of fish prey,

resulting in a higher diversity in the diet on the Red River. The Forest River, despite

having the second highest species richness, had the lowest fish prey diversity. But, some

species such as largescale stonerollers and horneyhead chubs only occur in the clearer,

faster flowing regions of the Forest River, which occur west of my study area (Koel and

Peterka 1998). Therefore, if the river otters included in the study did not regularly visit

areas west of our study area, then the effective fish diversity available to them is lower

than what was reported by Koel and Peterka (1998).

Seasonally, spring had the highest diversity of major prey groups and fish families

(Table 2.17). In spring, fish are highly concentrated because of spawning, crayfish and

amphibians begin to increase in activity, and breeding birds migrate into the area. As a

result, all of the major prey groups are abundant, leading to a more diverse diet. The decrease in diversity from spring to summer is the result of increasing activity of crayfish. As crayfish become more active they are preyed upon more heavily, with a corresponding decrease in the occurrence of fish and other prey (Table 2.5). In fall and winter, the activity of crayfish and amphibians decreases, and birds migrate out of the area. Therefore, fish were predated more frequently, and the diversity of major prey categories declined.

Similarly, the diversity of fish prey is highest in spring, when many fish in the study area are spawning (Lee et al. 1980, Koel and Peterka 2003, Werner 2004). Spawning concentrates fish into relatively small areas, so if these areas are discovered even rare species can be preyed upon heavily. This likely explains higher occurrences of rare (i.e., hiodontids, percids, and white bass/freshwater drum) fish in spring than other seasons (Lee et al. 1980, Werner 2004). Diversity of fish prey is lowest in summer, as total fish consumption is also at its seasonal low. Because fish are consumed less in summer than the rest of the year, and fish are apparently captured in proportion to their availability, rare species are consumed less often, contributing to a lower diversity detected during that period.

The only other study to directly measure prey diversity was Giordano (2005), which reported a lower diversity of major prey items than in this study (H' = 1.37 and 2.00, for Giordano (2005) and this study, respectively). This study had a higher frequency of occurrence of crayfish, amphibians, birds, and freshwater mussels. But, Giordano (2005) reported more diverse fish prey (H' = 2.49 and 2.24, for Giordano (2005) and this study, respectively). The difference in the diversity of fish prey results from the river

otters in Giordano's (2005) having a more even diet than the river otters in this study.

Here, 1 family (Cyprinidae) had a much higher frequency of occurrence than all others.

In contrast, Giordano (2005) did not have a dominant family in the diet, as the 3 most

frequent families (Catostomidae, Cyprinidae, and Centrarchidae) had similar frequencies

of occurrence.

Figure 2.1. Food habits of river otters (*Lontra canadensis*) in the Red River of the North

drainage of eastern North Dakota, by frequency of occurrence in scats ($n = 665$) collected

July 2006 -November 2007. A. Major food groups. B. Fish families.

A.
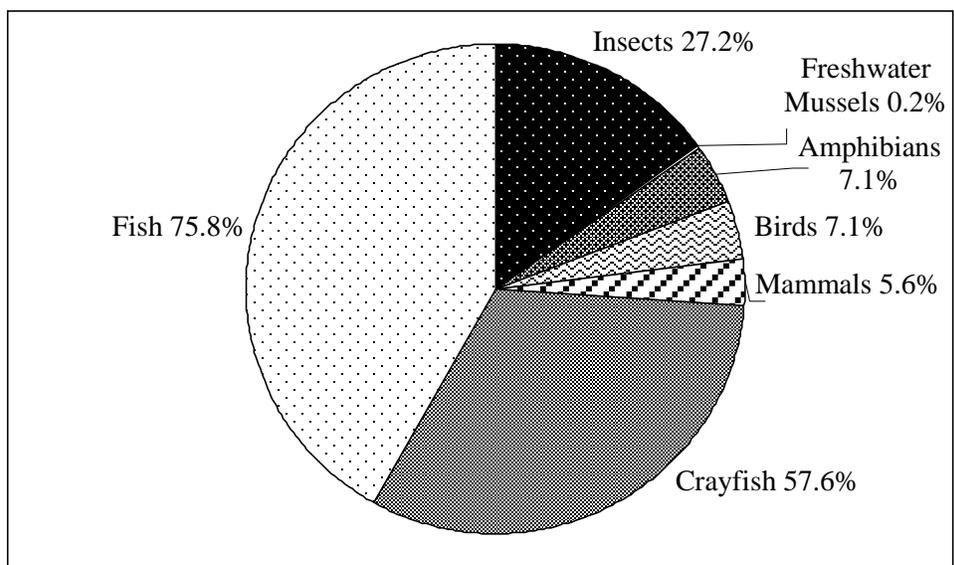
B.

Figure 2.2. Food habits of river otters (*Lontra canadensis*) in the Forest River of eastern

North Dakota by frequency of occurrence in scats ($n = 245$) collected October 2006 –

November 2007. A. Major food groups. B. Fish families.

A.

Insects 29.4%

Freshwater Mussels 0.4%

Amphibians 11.0%

Birds 15.9%

Mammals 2.0%

Crayfish 34.7%

Fish 83.3%

B.

Catostomidae 8.6%

Centrarchidae 5.3%

Esocidae 3.7%

Hiodontidae 0.8%

Ictaluridae 4.5%

Percidae 2.4%

Moronidae/ Sciaenidae 0.8%

Cyprinidae 74.3%
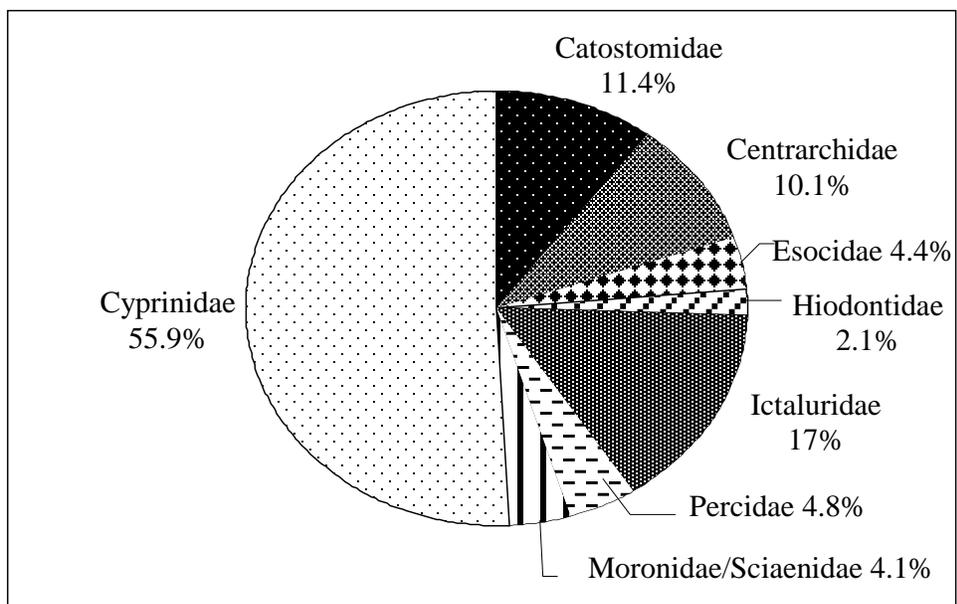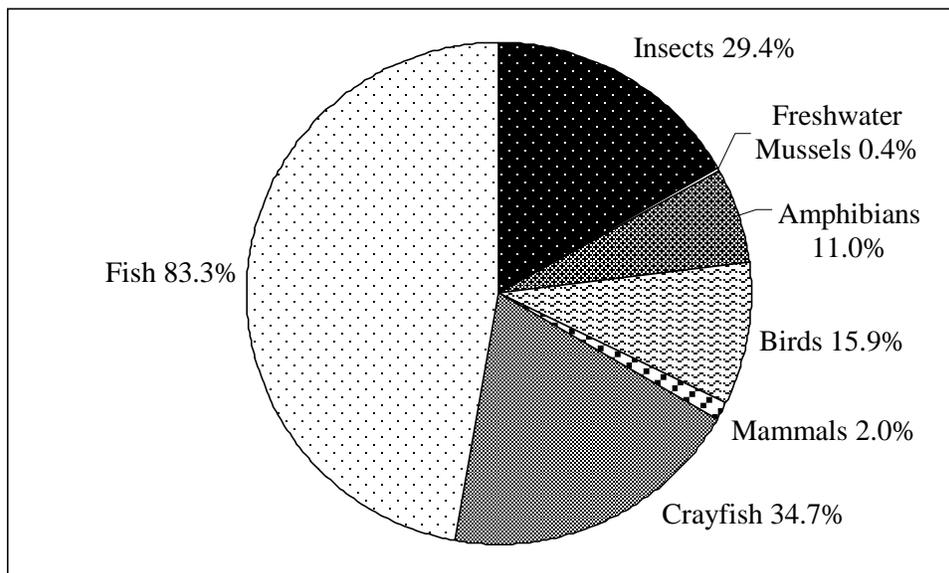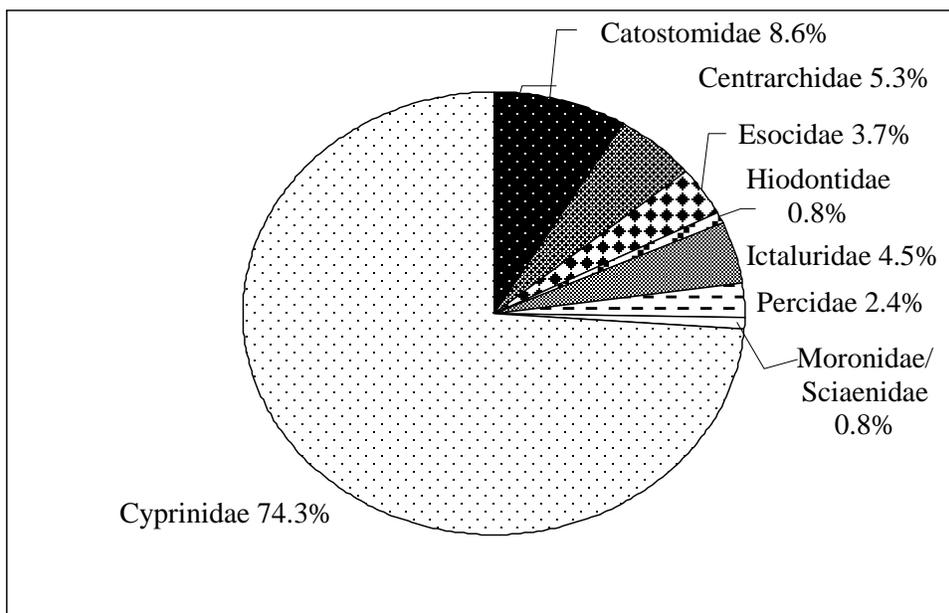
Figure 2.3. Food habits of river otters (*Lontra canadensis*) in the Red River of the North,

North Dakota and Minnesota, by frequency of occurrence in scats ($n = 142$) collected

October 2006 – November 2007. A. Major food groups. B. Fish families.

A.
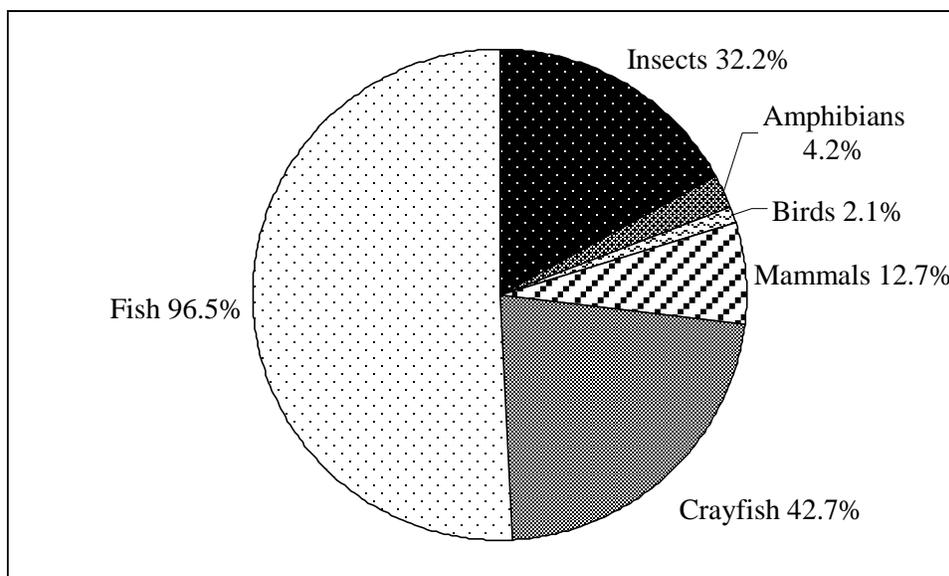
B.
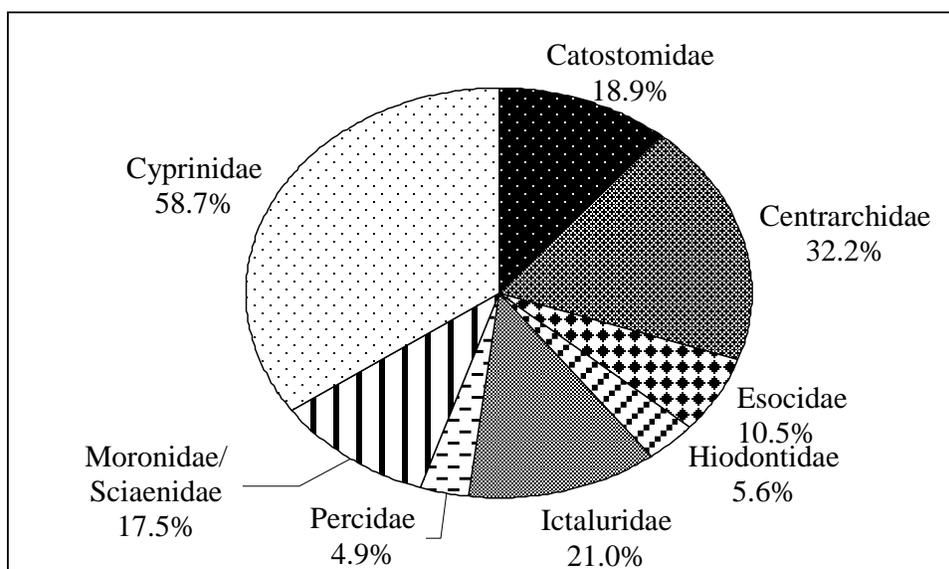
Figure 2.4. Food habits of river otters (*Lontra canadensis*) in the Tongue River of eastern North Dakota by frequency of occurrence in scats ($n = 89$) collected May – October 2007. A. Major food groups. B. Fish families

A.
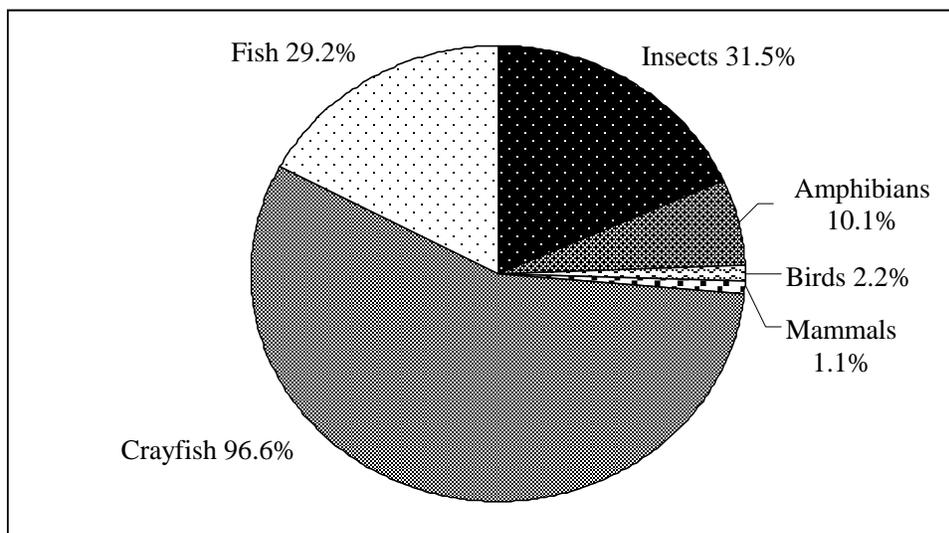
B.
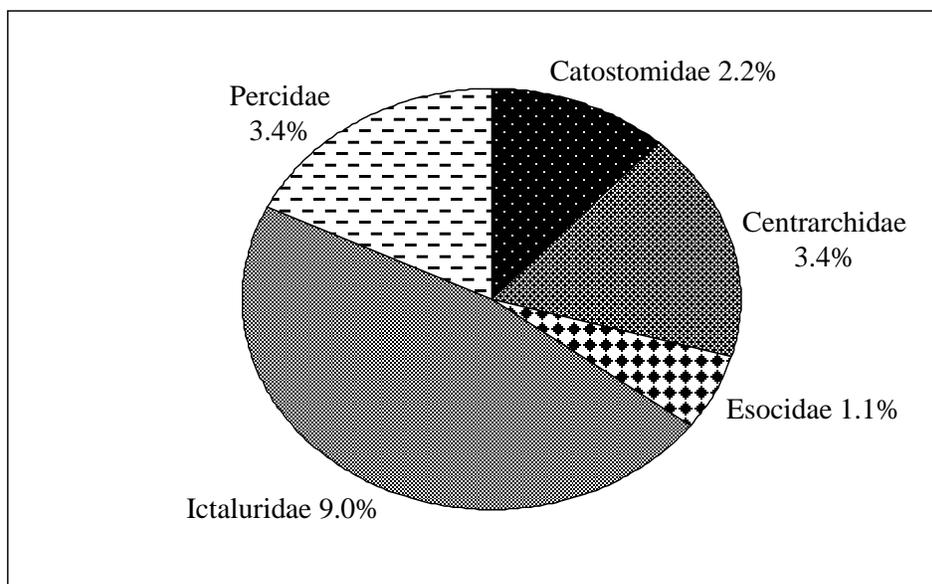
Figure 2.5. Food habits of river otters (*Lontra canadensis*) in the Turtle River of eastern

North Dakota by frequency of occurrence in scats ($n = 182$) collected October 2006 –

November 2007. A. Major food groups. B. Fish families.

A.

Pie chart A showing: Insects 18.7%, Amphibians 2.7%, Birds 1.6%, Mammals 6.0%, Crayfish 79.7%, Fish 71.4%

B.

Pie chart B showing: Catostomidae 14.3%, Centrarchidae 2.7%, Esocidae 2.2%, Hiodontidae 1.6%, Ictaluridae 32.4%, Percidae 8.2%, Cyprinidae 56.6%
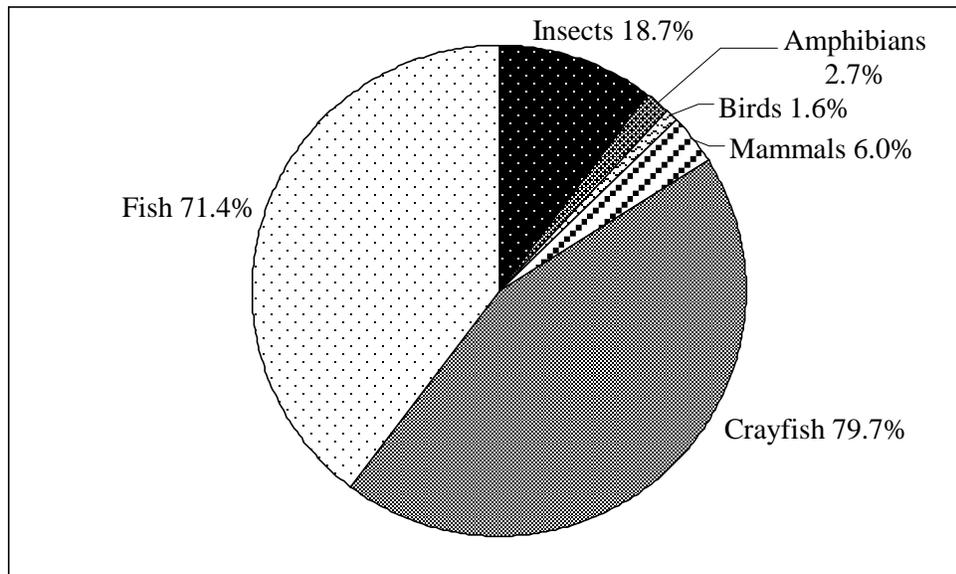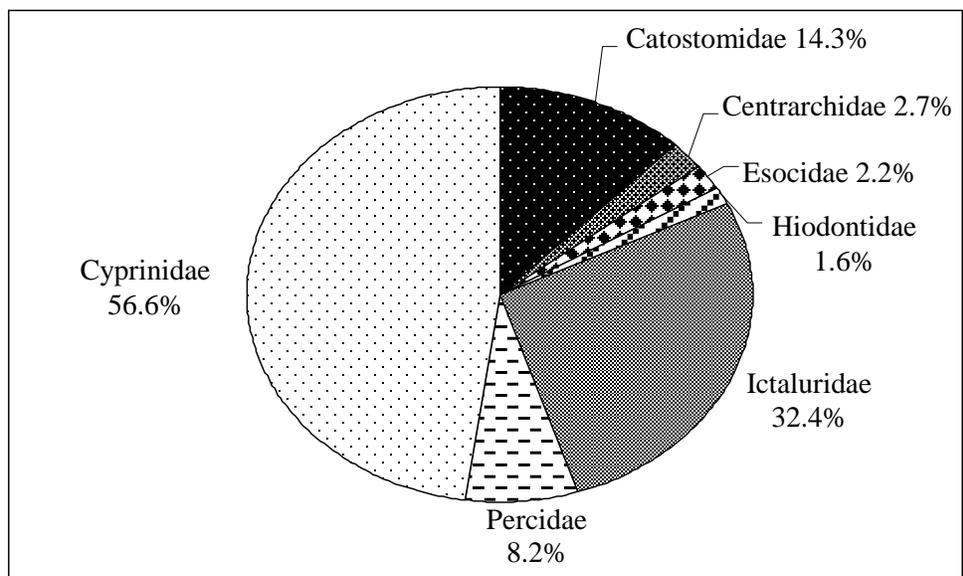
Figure 2.6. Food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota in spring (1 March – 31 May 2007), by frequency of occurrence in scats, $n = 169$. A. Major food groups. B. Fish families.

A.
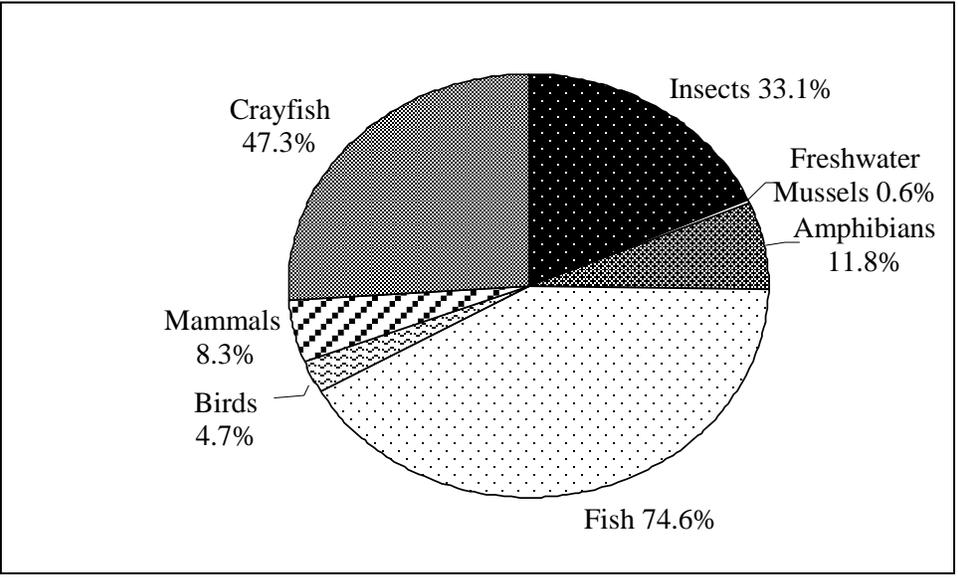
B.
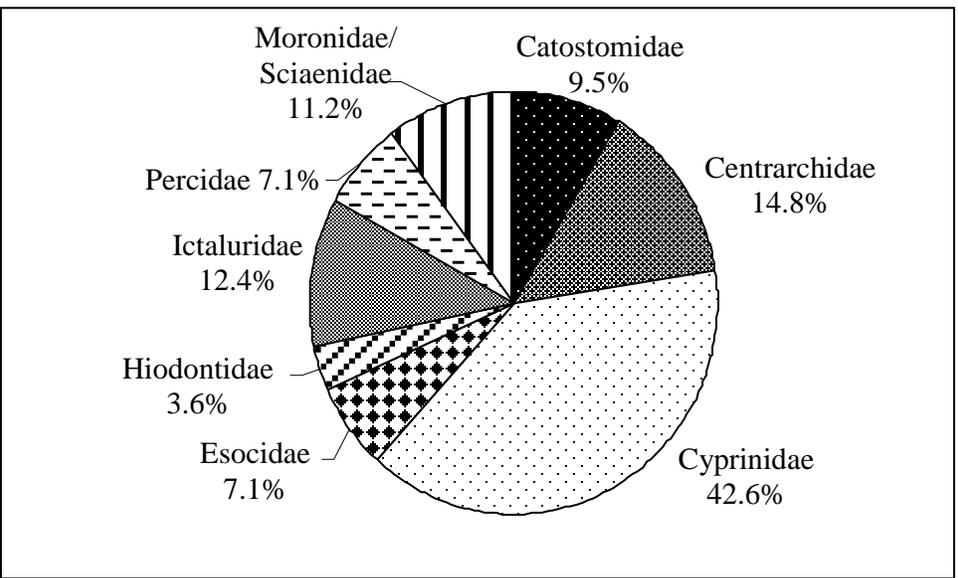
Figure 2.7. Food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota in summer (26 July 2006, and 1 June – 31 August 2007), by frequency of occurrence in scats, n = 199. A. Major food groups. B. Fish families.

A.
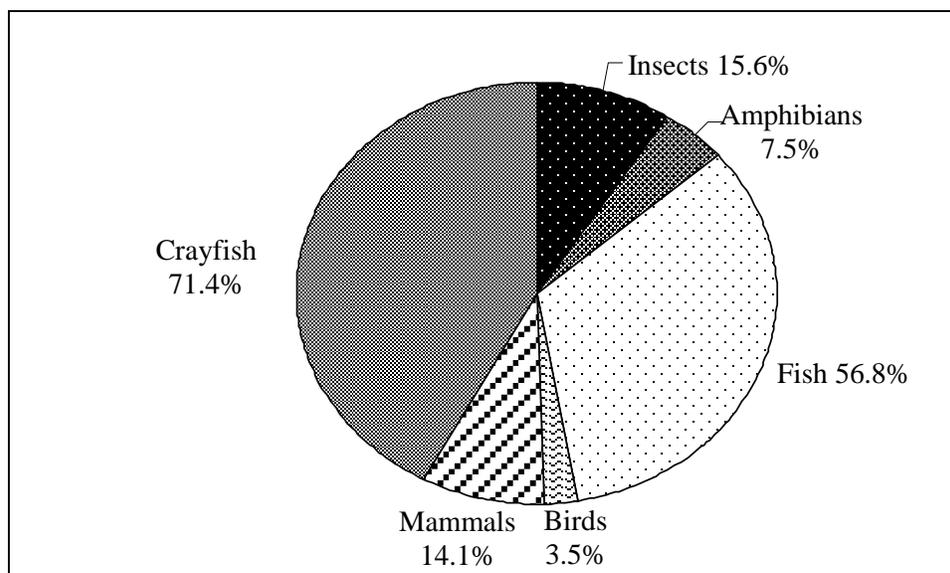
B.
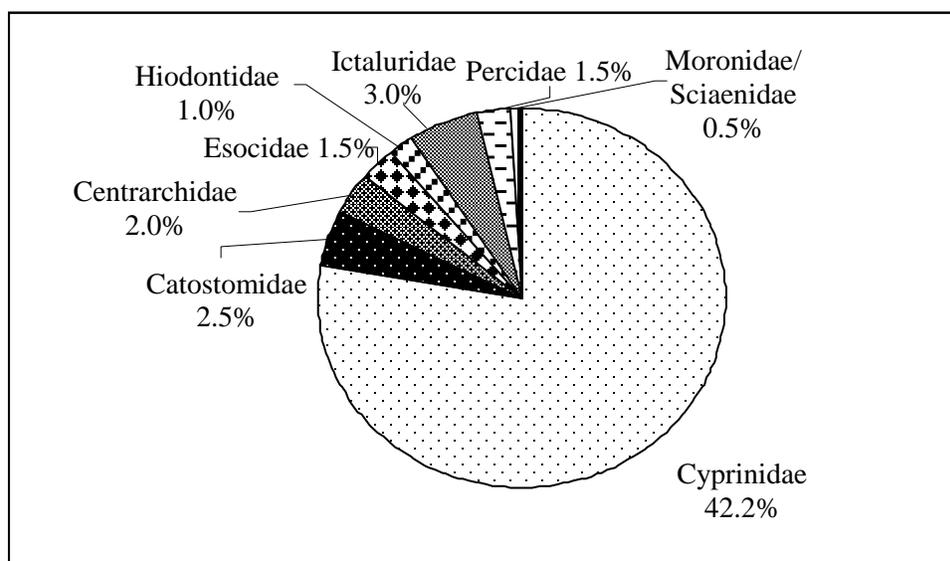
Figure 2.8. Food habits of river otters (*Lontra canadensis*) in the Red River of the North

drainage of eastern North Dakota in fall (1 October – 30 November 2006, and 1

September - 30 November 2007), by frequency of occurrence in scats, $n = 275$. A. Major

food groups. B. Fish families.

A.

Insects
32.7%

Crayfish
55.6%

Amphibians
4.4%

Mammals
1.5%

Birds
7.6%

Fish 88.4%

B.

Percidae
5.8%

Moronidae/
Sciaenidae
1.8%

Ictaluridae
31.3%

Cyprinidae
73.5%

Hiodontidae
2.2%

Esocidae
4.0%

Centrarchidae
11.3%

Catostomidae
18.5%
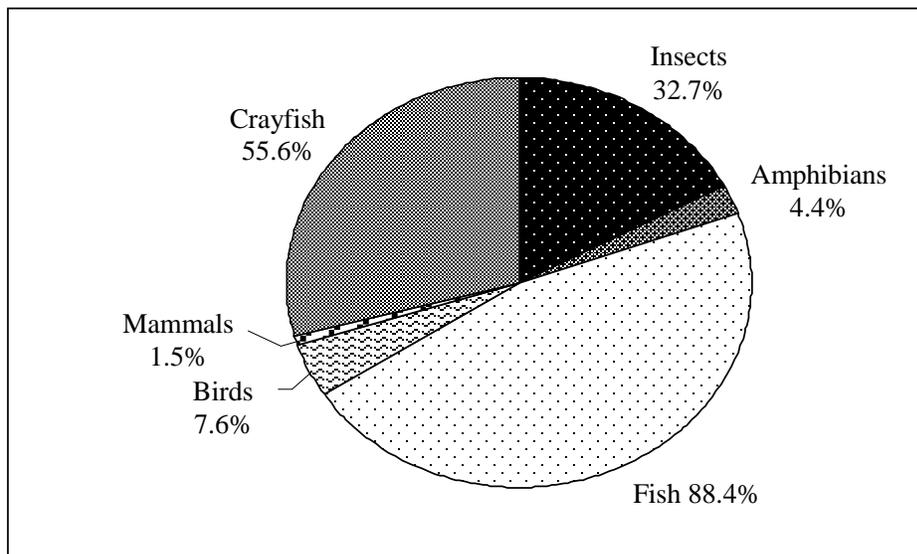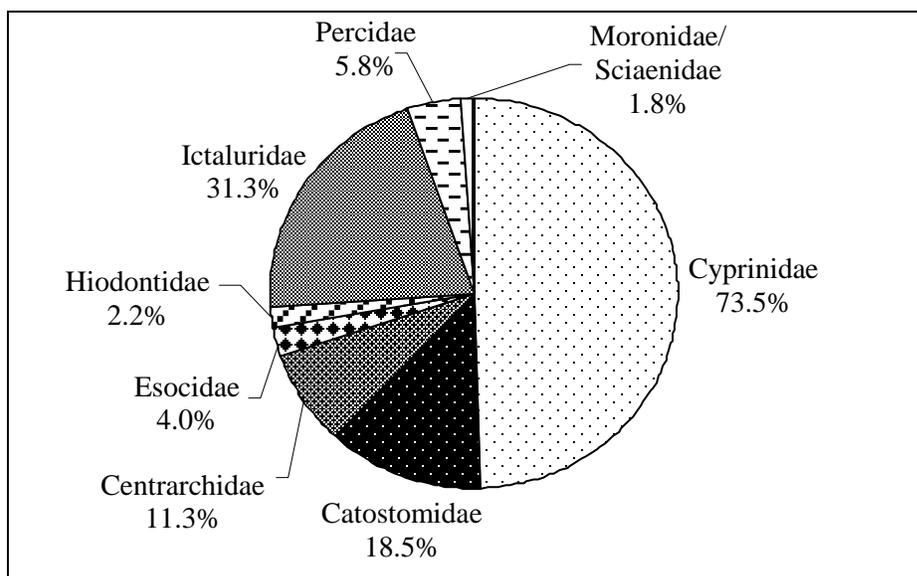
Figure 2.9. Food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota in winter (1 December 2006 – 28 February 2007), by frequency of occurrence in scats, $n = 22$. A. Major food groups. B. Fish families.

A.
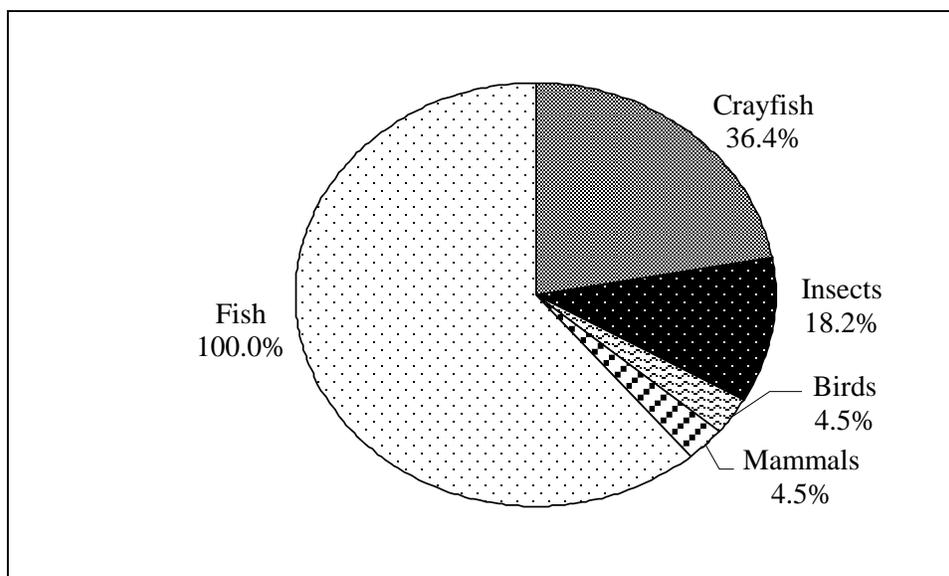
B.
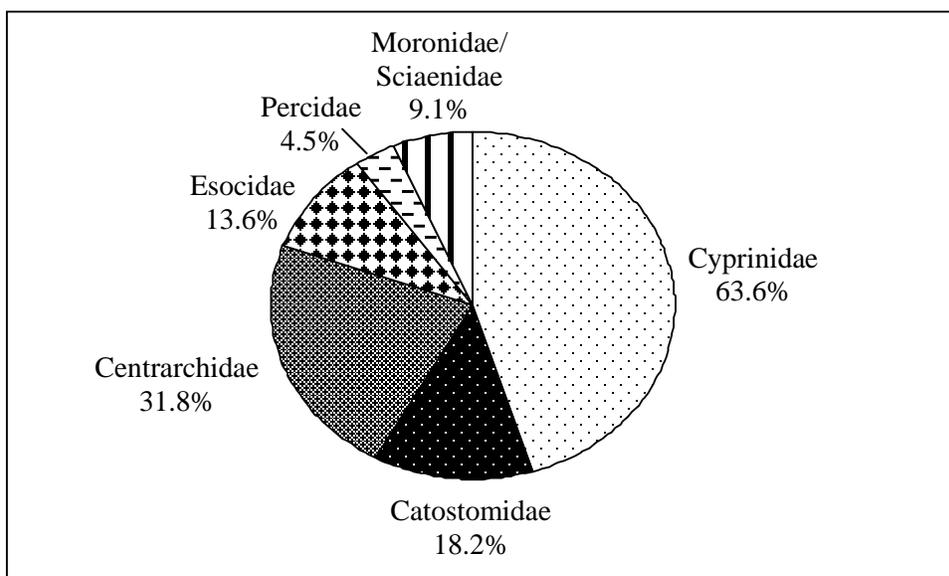
Figure 2.10. Relative frequency of fish size categories (total length in cm) consumed by river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007, $n = 671$.
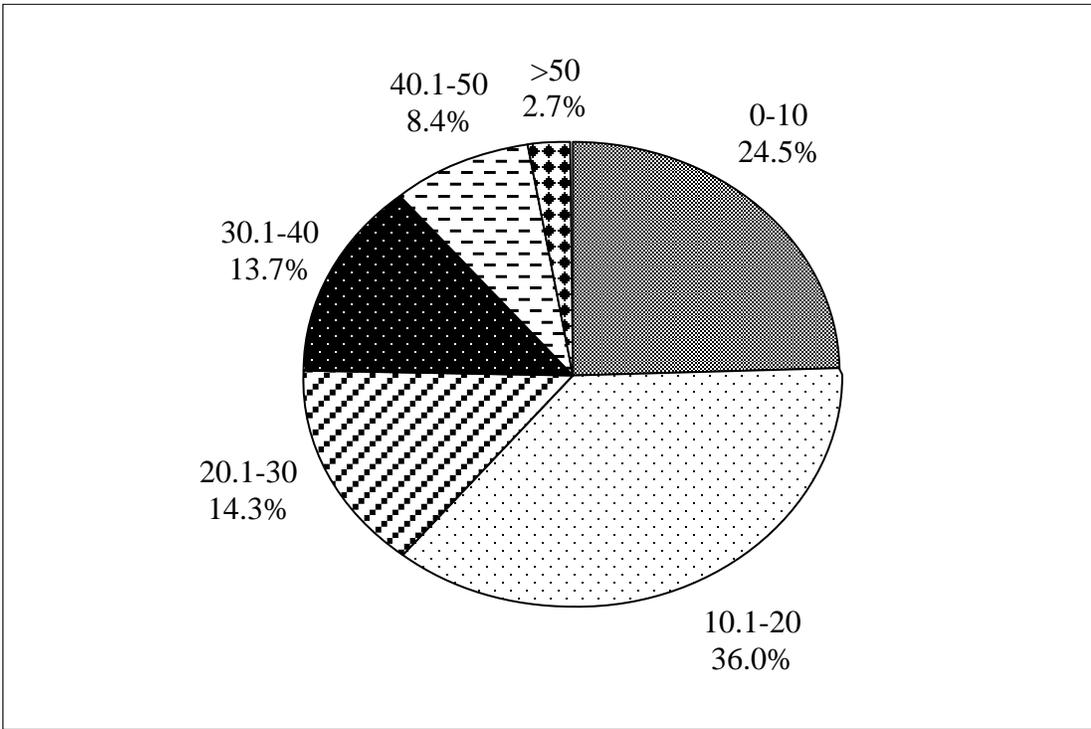
Figure 2.11. Comparison of the size of fish prey of river otters (*Lontra canadensis*) among rivers in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007. The line connects mean prey size.

Size of Fish Prey by River
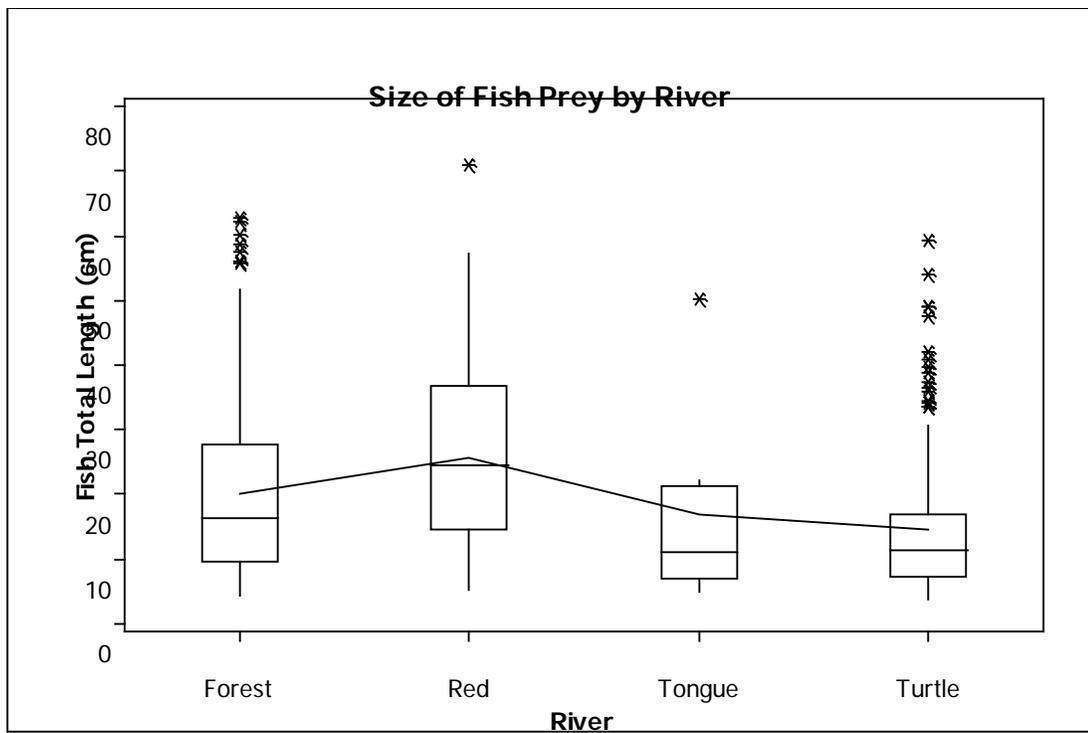
Figure 2.12. Relative frequency of fish size categories (total length in cm) in the diet of

river otters (*Lontra canadensis*) on the Forest River, North Dakota, October 2006 -
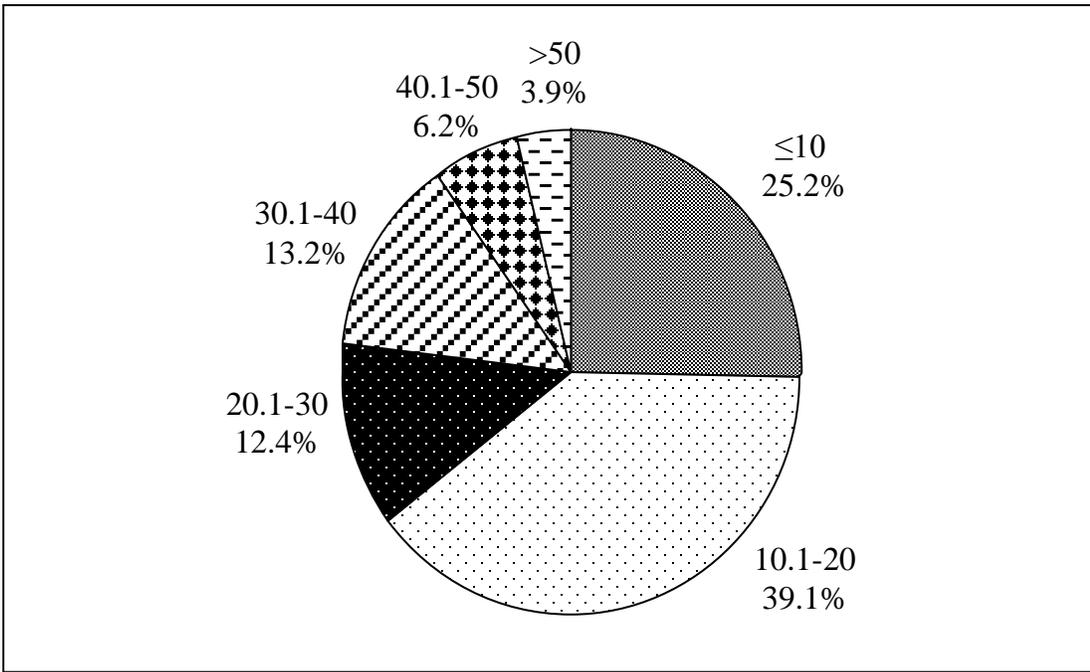
November 2007, *n* = 258.

Figure 2.13. Relative frequency of fish size categories (total length in cm) in the diet of river otters (*Lontra canadensis*) on the Red River of the North, North Dakota and Minnesota, October 2006 – November 2007, $n = 236$.
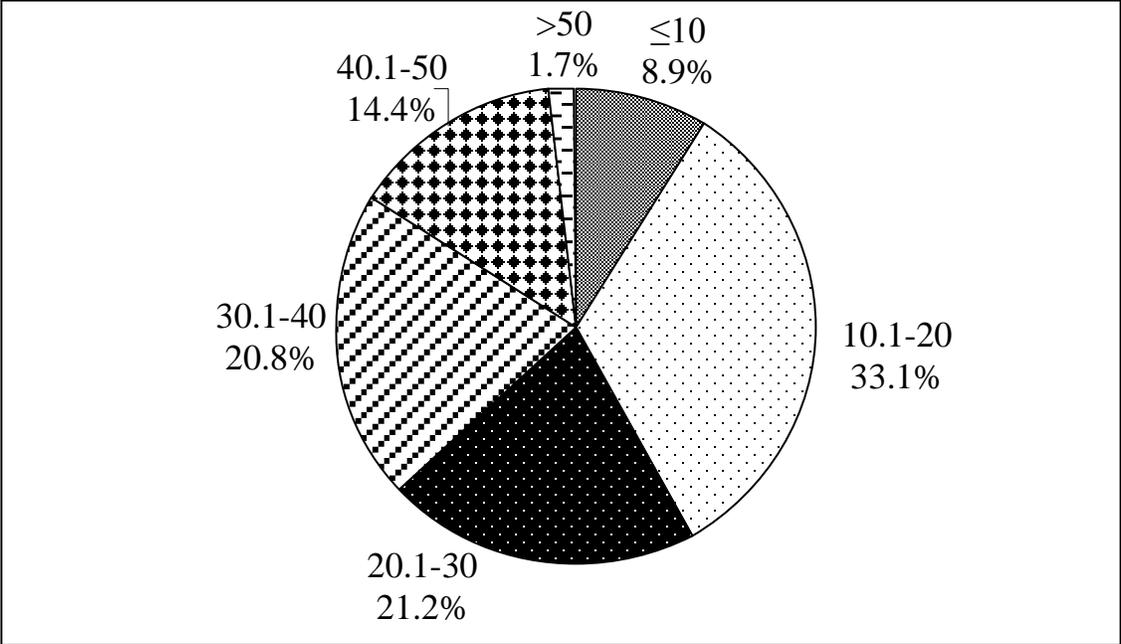
Figure 2.14. Relative frequency of fish size categories (total length in cm) in the diet of river otters (*Lontra canadensis*) on the Turtle River, North Dakota, October 2006 - November 2007, $n = 164$.
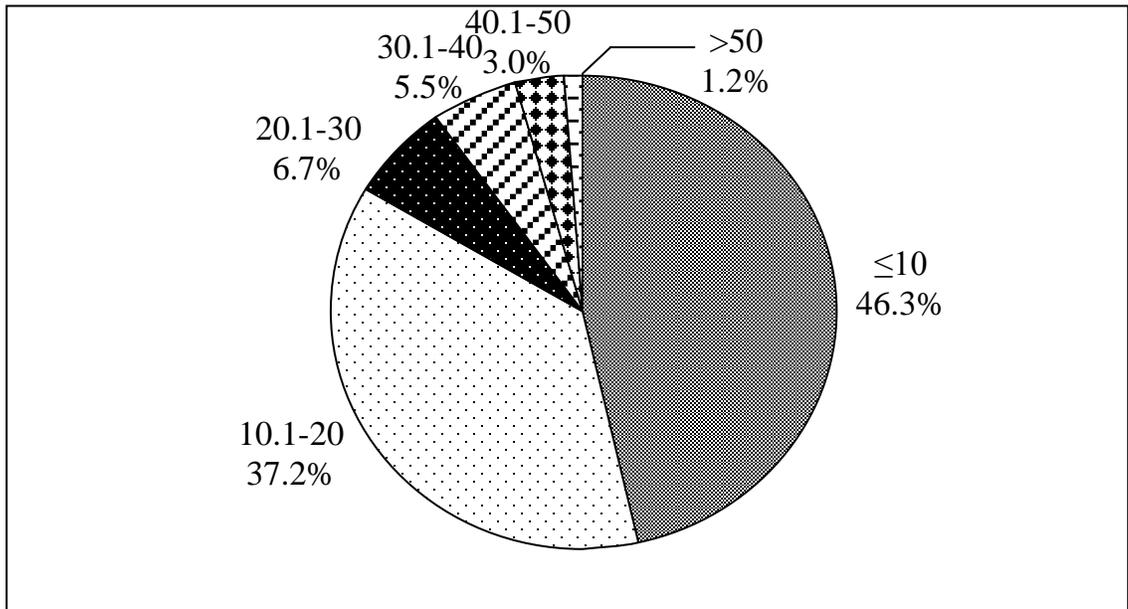
Figure 2.15. Seasonality of the size of fish prey of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. The line connects mean prey size.

Seasonality of Fish Prey Size
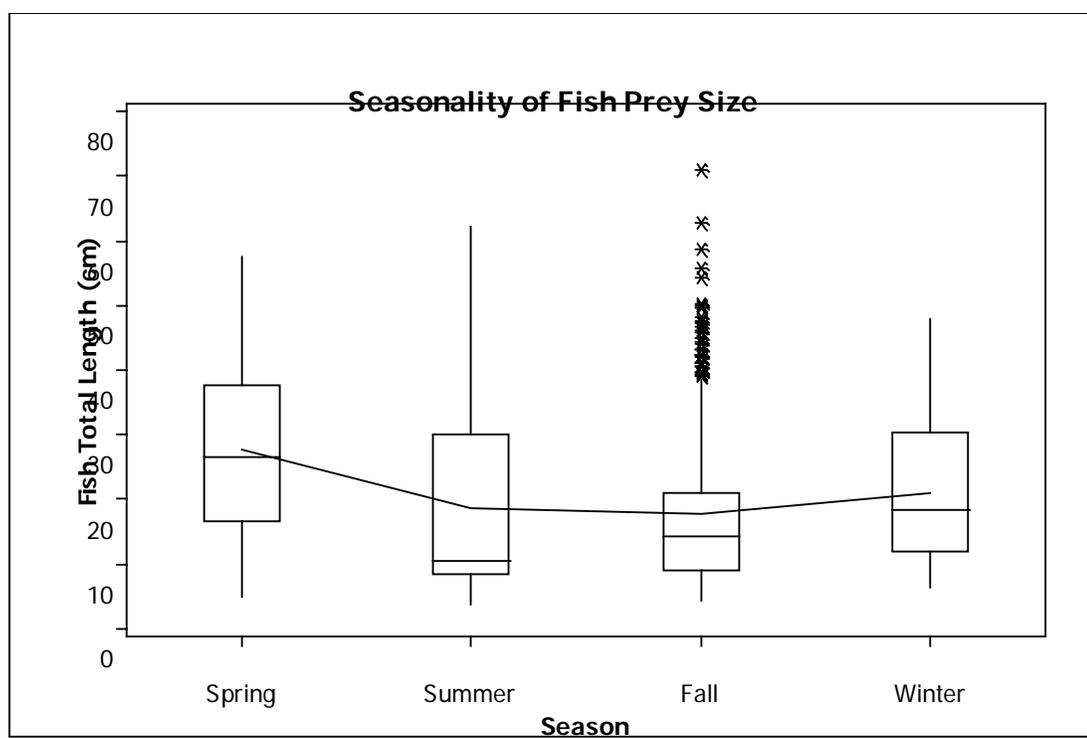
Figure 2.16. Relative frequency of fish size categories (total length in cm) in the diet of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota in spring (1 March – 31 May 2007), $n = 178$.
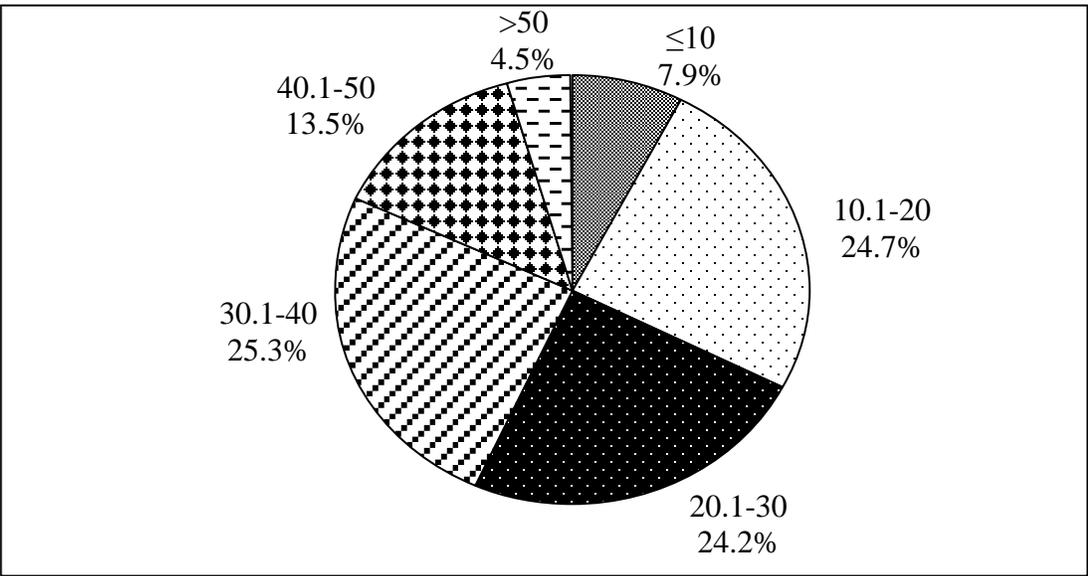
Figure 2.17. Relative frequency of fish size categories (total length in cm) in the diet of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota in summer (26 July 2006, and 1 June – 31 August 2007), $n = 90$.

>50
4.4%

40.1-50
7.8%

30.1-40
12.2%

20.1-30
6.7%

≤10
45.6%

10.1-20
23.3%
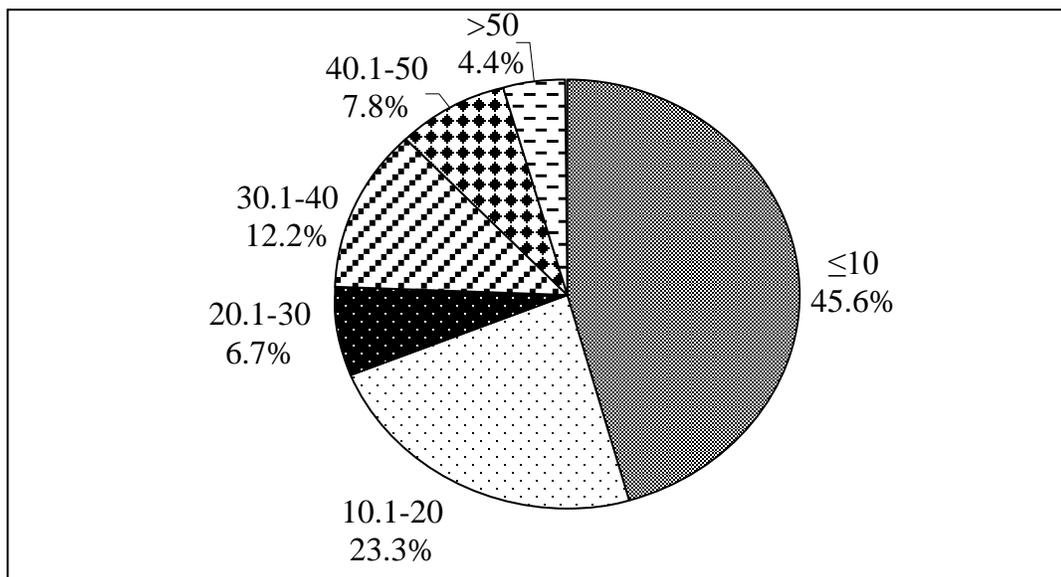
Figure 2.18. Relative frequency of fish size categories (total length in cm) in the diet of

river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North

Dakota in fall (1 September – 30 November, 2006 and 2007), $n = 362$.
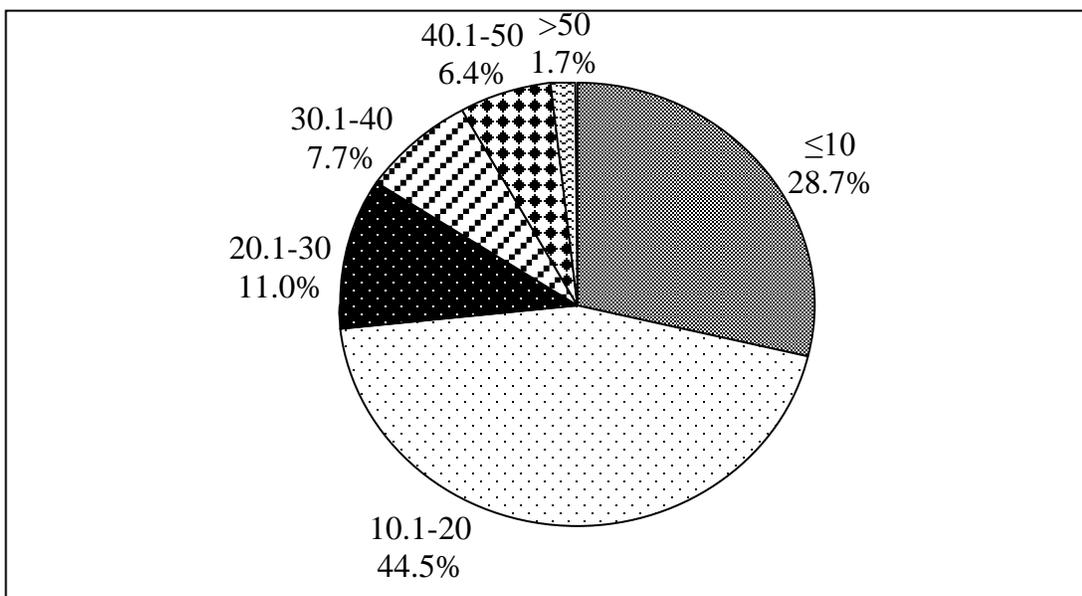
Figure 2.19. Relative frequency of fish size categories (total length in cm) in the diet of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota in winter (1 December 2006 – 28 February 2007), $n = 41$.
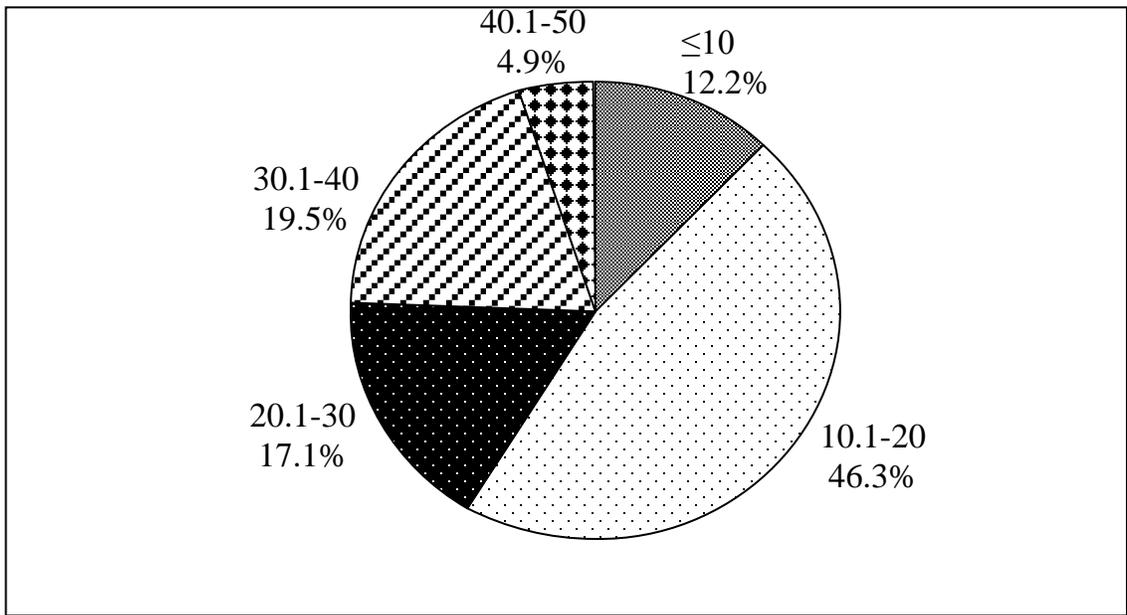
Figure 2.20. Seasonality of mean prey length for four fish groups in the diet of river otters

(*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, July

2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1

June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28

February as winter.

Table 2.1. Food habits of river otters (*Lontra canadensis*) in four rivers of the Red River of the North drainage of eastern North Dakota, using frequency of occurrence (%) in scats collected July 2006 – November 2007.

Prey Item	River				
	Forest (*n* = 245)	Red (*n* = 142)	Tongue (*n* = 89)	Turtle (*n* = 182)	Total[+] (*n* = 665)
Crayfish	34.7	42.7	96.6	79.7	57.6
Insects	29.4	32.2	31.5	18.7	27.2
Freshwater Mussels	0.4	0.0	0.0	0.0	0.2
Amphibians	11.0	4.2	10.1	2.7	7.1
Birds	15.9	2.1	2.2	1.6	7.1
Mammals	2.0	12.7	1.1	6.0	5.6
Fish	83.3	96.5	29.2	71.4	75.8
Catostomidae (suckers)	8.6	18.9	2.2	14.3	11.4
Catostomus commersoni (white sucker)	4.9	5.6	1.1	7.1	5.1
Moxostoma spp. (redhorses)	2.0	11.3	0.0	4.4	4.4
Ictiobus spp. or *Carpiodes cyprinus*	2.0	0.7	0.0	1.1	1.2
Centrarchidae (sunfish)	5.3	32.2	3.4	2.7	10.1
Pomoxis spp. (crappies)	1.6	5.6	2.2	0.0	2.1
Ambloplites rubestris or *Lepomis* spp.	2.9	20.4	0.0	2.7	6.2
Unknown centrarchids	0.8	11.3	1.1	0.0	2.9
Cyprinidae (minnows)	74.3	58.7	0.0	56.6	55.9
Cyprinus carpio (carp)	65.7	54.2	0.0	42.9	48.0
Rhinichthys spp. (dace)	0.4	0.0	0.0	0.5	0.3
Large non-carp cyprinids*	1.2	0.7	0.0	1.1	1.2
Small cyprinids^	6.5	0.7	0.0	13.7	6.0
Esocidae *Esox lucius* (northern pike)	3.7	10.5	1.1	2.2	4.4
Hiodontidae (mooneyes)	0.8	5.6	0.0	1.6	2.1
Ictaluridae (catfish)	4.5	21.0	9.0	32.4	17.0
Percidae (perches)	2.4	4.9	3.4	8.2	4.8
Etheostoma spp. or *Percina* spp. (darters)	2.0	1.4	2.2	4.9	2.7
Perca flavescens or *Sander* spp.	0.4	4.2	1.1	3.3	2.3
Moronidae/Sciaenidae *Morone chrysops* (white bass) or *Aplodinotus grunniens* (freshwater drum)	0.8	17.5	0.0	0.0	4.1

+ The total also includes 6 scats collected from the Pembina River, and 1 from the Park River.
*Includes non-carp cyprinids with scale lengths ≥2.50 mm.
^Includes cyprinids with scale lengths <2.50 mm, excluding *Cyprinus carpio* and *Rhinichthys* spp.

Table 2.2. Food habits of river otters (*Lontra canadensis*) in four rivers of the Red River of the North drainage of eastern North Dakota, using relative frequency (%) in scats collected July 2006 - November 2007.

Prey Item	River				
	Forest ($n = 245$)	Red ($n = 142$)	Tongue ($n = 89$)	Turtle ($n = 182$)	Total[+] ($n = 665$)
Crayfish	19.6	22.4	56.6	44.2	31.9
Insects	16.6	16.9	18.4	10.4	15.1
Freshwater Mussels	0.2	0.0	0.0	0.0	0.1
Amphibians	6.2	2.2	5.9	1.5	3.9
Birds	9.0	1.1	1.3	0.9	3.9
Mammals	1.2	6.6	0.7	3.4	3.1
Fish	47.1	50.7	17.1	39.6	42.0
Catostomidae (suckers)	8.5	11.2	11.8	12.1	10.4
Centrarchidae (sunfish)	5.3	19.0	17.6	2.3	9.2
Cyprinidae (minnows)	74.0	34.7	0.0	47.9	51.0
Esocidae *Esox lucius* (northern pike)	3.7	6.2	5.9	1.9	4.0
Hiodontidae (mooneyes)	0.8	3.3	0.0	1.4	1.9
Ictaluridae (catfish)	4.5	12.4	47.1	27.4	15.5
Percidae (perch)	2.4	2.9	17.6	7.0	4.4
Moronidae/Sciaenidae *Morone chrysops* (white bass) or *Aplodinotus grunniens* (freshwater drum)	0.8	10.3	0.0	0.0	3.7

+ The total also includes 6 scats collected from the Pembina River, and 1 from the Park River.

Table 2.3. Comparison between study areas of the food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, using frequency of occurrence (%) in scats collected July 2006 – November 2007. **Bold** indicates a significant difference (P <0.05). Comparisons of fish families exclude the Tongue River.

Prey Item	Forest (*n* = 245)	Red (*n* = 142)	Tongue (*n* = 89)	Turtle (*n* = 182)	Total (*n* = 665)	χ^2	P
Crayfish	34.7	42.7	96.6	79.7	57.6	156.6	**<0.001**
Insects	29.4	32.2	31.5	18.7	27.2	10.0	**0.019**
Amphibians	11.0	4.2	10.1	2.7	7.1	13.9	**0.003**
Birds	15.9	2.1	2.2	1.6	7.1	45.4	**<0.001**
Mammals	2.0	12.7	1.1	6.0	5.6	23.8	**<0.001**
Fish	83.3	96.5	29.2	71.4	75.8	149.5	**<0.001**
Catostomidae (suckers)	8.6	18.9	2.2	14.3	11.4	9.1	**0.011**
Centrarchidae (sunfish)	5.3	32.2	3.4	2.7	10.1	85.5	**<0.001**
Cyprinidae (minnows)	74.3	58.7	0.0	56.6	55.9	17.0	**<0.001**
Esocidae *Esox lucius* (northern pike)	3.7	10.5	1.1	2.2	4.4	13.4	**0.001**
Hiodontidae (mooneyes)	0.8	5.6	0.0	1.6	2.1	9.8	**0.007**
Ictaluridae (catfish)	4.5	21.0	9.0	32.4	17.0	57.9	**<0.001**
Percidae (perches)	2.4	4.9	3.4	8.2	4.8	7.5	**0.024**

Moronidae/Sciaenidae
     Morone chrysops (white bass) or
     Aplodinotus grunniens
     (freshwater drum)
	0.8	17.5	0.0	0.0	4.1	69.4	**<0.001**

Table 2.4. Food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, by season using frequency of occurrence (%) in scats collected July 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter.

Prey Item	Spring (*n* = 169)	Summer (*n* = 199)	Fall (*n* = 275)	Winter (*n* = 22)	Total (*n* = 665)
Crayfish	47.3	71.4	55.6	36.4	57.6
Insects	33.1	15.6	32.7	18.2	27.2
Freshwater Mussels	0.6	0.0	0.0	0.0	0.2
Amphibians	8.3	14.1	1.5	4.5	7.1
Birds	11.8	7.5	4.4	0.0	7.1
Mammals	4.7	3.5	7.6	4.5	5.6
Fish	74.6	56.8	88.4	100.0	75.8
Catostomidae (suckers)	9.5	2.5	18.5	18.2	11.4
Catostomus commersoni (white sucker)	6.5	1.5	6.1	4.5	5.1
Moxostoma spp. (redhorses)	1.2	0.5	7.5	9.1	4.4
Ictiobus spp. or *Carpiodes cyprinus*	0.6	0.5	2.4	4.5	1.2
Centrarchidae (sunfish)	14.8	2.0	11.3	31.8	10.1
Pomoxis spp. (crappie)	1.8	0.5	2.1	9.1	2.1
Ambloplites rubestris or *Lepomis* spp.	10.7	1.5	5.9	27.3	6.2
Unknown centrarchids	3.6	0.0	4.3	4.5	2.9
Cyprinidae (carp and minnows)	42.6	42.2	73.5	63.6	55.9
Cyprinus carpio (carp)	36.7	28.6	67.7	59.1	48.0
Rhinichthys spp. (dace)	0.6	0.0	0.3	0.0	0.3
Large non-carp cyprinid*	0.6	0.5	1.6	0.0	1.2
Small cyprinid^	0.0	6.5	8.5	4.5	6.0
Esocidae *Esox lucius* (northern pike)	7.1	1.5	4.0	13.6	4.4
Hiodontidae (mooneyes)	3.6	1.0	2.2	0.0	2.1
Ictaluridae (catfish)	12.4	3.0	31.3	0.0	17.0
Percidae (perches)	7.1	1.5	5.8	4.5	4.8
Etheostoma spp. or *Percina* spp. (darters)	4.1	0.0	3.2	4.5	2.7
Perca flavescens or *Sander* spp.	3.6	1.5	3.2	0.0	2.3
Moronidae/Sciaenidae *Morone chrysops* (white bass) or *Aplodinotus grunniens* (freshwater drum)	11.2	0.5	1.8	9.1	4.1

*Includes non-carp cyprinids with scale lengths ≥2.50 mm.
^Includes cyprinids with scale lengths <2.50 mm, excluding *Cyprinus carpio* and *Rhinichthys* spp.

Table 2.5. Seasonal comparison of food habits of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, using frequency of occurrence (%) in scats collected July 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. * Indicates comparison excluded winter. **Bold** indicates a significant difference (P <0.05).

Prey Item	Spring (*n* = 169)	Summer (*n* = 199)	Fall (*n* = 275)	Winter (*n* = 22)	Total (*n* = 665)	χ^2	*P*
Crayfish	47.3	71.4	55.6	36.4	57.6	27.2	**<0.001**
Insects	33.1	15.6	32.7	18.2	27.2	21.7	**<0.001**
Amphibians	8.3	14.1	1.5	4.5	7.1	28.6	**<0.001**
Birds	11.8	7.5	4.4	0.0	7.1	10.7	**0.014**
Mammals	4.7	3.5	7.6	4.5	5.6	4.1	0.251
Fish	74.6	56.8	88.4	100.0	75.8	70.0	**<0.001**
Catostomidae (suckers)	9.5	2.5	18.5	18.2	11.4	31.0	**<0.001**
Centrarchidae (sunfish)	14.8	2.0	11.3	31.8	10.1	30.4	**<0.001**
Cyprinidae (minnows)	42.6	42.2	73.5	63.6	55.9	62.2	**<0.001**
Esocidae *Esox lucius* (northern pike)	7.1	1.5	4.0	13.6	4.4	7.4	**0.025***
Hiodontidae (mooneyes)	3.6	1.0	2.2	0.0	2.1	2.8	0.249*
Ictaluridae (catfish)	12.4	3.0	31.3	0.0	17.0	74.3	**<0.001**
Percidae (perches)	7.1	1.5	5.8	4.5	4.8	7.3	0.063
Moronidae/Sciaenidae *Morone chrysops* (white bass) or *Aplodinotus grunniens* (freshwater drum)	11.2	0.5	1.8	9.1	4.1	33.7	**<0.001***

Table 2.6. Seasonal comparison of the food habits of river otters (*Lontra canadensis*) on

the Forest River, North Dakota using frequency of occurrence (%) in scats collected

October 2006 – November 2007. Scats collected 1 March – 31 May were considered as

spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1

December – 28 February as winter. * Indicates comparison excluded winter. **Bold**

indicates a significant difference (*P* <0.05).

Prey Item	Spring (*n* = 61)	Summer (*n* = 98)	Fall (*n* = 76)	Winter (*n* = 10)	Total (*n* = 245)	χ^2	*P*
Crayfish	26.2	42.9	35.5	0.0	34.7	10.1	**0.017**
Insects	29.5	27.6	32.9	20.0	29.4	1.0	0.793
Amphibians	6.6	23.5	0.0	0.0	11.0	27.4	**<0.001**
Birds	31.1	12.2	10.5	0.0	15.9	15.1	**0.002**
Mammals	0.0	4.1	1.3	0.0	2.0	2.5	0.284*
Fish	73.8	79.6	93.4	100.0	83.3	14.3	**0.002**
Catostomidae (suckers)	9.8	3.1	10.5	40.0	8.6	4.4	0.112*
Centrarchidae (sunfish)	0.0	2.0	10.5	30.0	5.3	11.2	**0.004***
Cyprinidae (minnows)	63.9	69.4	88.2	80.0	74.3	14.1	**0.003**
Esocidae *Esox lucius* (northern pike)	1.6	3.1	6.6	0.0	3.7	2.5	0.285*
Hiodontidae (mooneyes)	1.6	0.0	1.3	0.0	0.8	-	-
Ictaluridae (catfish)	3.3	0.0	11.8	0.0	4.5	13.8	**0.001***
Percidae (perches)	4.9	1.0	2.6	0.0	2.4	2.3	0.317*
Moronidae/Sciaenidae *Morone chrysops* (white bass) or *Aplodinotus grunniens* (freshwater drum)	0.0	1.0	0.0	10.0	0.8	-	-

Table 2.7. Seasonal comparison of the food habits of river otters (*Lontra canadensis*) on the Red River of the North, North Dakota and Minnesota, using frequency of occurrence (%) in scats collected October 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 September – 30 November as fall, and 1 December – 28 February as winter. **Bold** indicates a significant difference ($P < 0.05$). The statistical comparisons were between only spring and fall.

Prey Item	Spring (*n* =58)	Fall (*n* = 73)	Winter (*n* = 11)	Total (*n* = 142)	χ^2	*P*
Crayfish	44.8	38.4	63.6	42.7	0.6	0.455
Insects	24.1	42.5	9.1	32.2	4.8	**0.028**
Amphibians	1.7	5.5	9.1	4.2	1.2	0.265
Birds	1.7	2.7	0.0	2.1	0.6	0.438
Mammals	13.8	12.3	9.1	12.7	0.1	0.804
Fish	93.1	100.0	100.0	96.5	5.2	**0.023**
Catostomidae (suckers)	10.3	28.8	0.0	18.9	6.7	**0.010**
Centrarchidae (sunfish)	39.7	26.0	36.4	32.2	2.8	0.097
Cyprinidae (minnows)	39.7	76.7	45.5	58.7	18.5	**<0.001**
Esocidae *Esox lucius* (northern pike)	10.3	8.2	27.3	10.5	0.2	0.675
Hiodontidae (mooneyes)	5.2	6.8	0.0	5.6	0.2	0.691
Ictaluridae (catfish)	19.0	24.7	9.1	21.0	0.6	0.436
Percidae (perches)	6.9	2.7	9.1	4.9	1.3	0.258
Moronidae/Sciaenidae *Morone chrysops* (white bass) or *Aplodinotus grunniens* (freshwater drum)	32.8	6.8	9.1	17.5	14.5	**<0.001**

Table 2.8. Seasonal comparison of the food habits of river otters (*Lontra canadensis*) on the Tongue River, North Dakota using frequency of occurrence (%) in scats collected May – October 2007. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, and 1 September – 30 November as fall. **Bold** indicates a significant difference (*P* <0.05). The statistical comparisons were between only spring and summer.

Prey Item	Spring (*n* = 35)	Summer (*n* = 46)	Fall (*n* = 8)	Total (*n* = 89)	χ^2	*P*
Crayfish	91.4	100.0	100.0	96.6	4.1	**0.043**
Insects	57.1	6.5	62.5	31.5	25.1	**<0.001**
Amphibians	22.9	2.2	0.0	10.1	8.6	**0.003**
Birds	0.0	4.3	0.0	2.2	-	-
Mammals	0.0	2.2	0.0	1.1	-	-
Fish	40.0	19.6	37.5	29.2	4.1	**0.043**
Catostomidae (suckers)	2.9	0.0	12.5	2.2	-	-
Centrarchidae (sunfish)	0.0	2.2	25.0	3.4	-	-
Esocidae *Esox lucius* (northern pike)	2.9	0.0	0.0	1.1	-	-
Ictaluridae (catfish)	17.1	4.3	0.0	9.0	3.7	0.056
Percidae (perches)	8.6	0.0	0.0	3.4	4.1	**0.043**

Table 2.9. Seasonal comparison of the food habits of river otters (*Lontra canadensis*) on the Turtle River, North Dakota using frequency of occurrence (%) in scats collected October 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. * Indicates the comparison only included summer and fall. **Bold** indicates a significant difference ($P <0.05$).

Prey Item	Spring ($n = 14$)	Summer ($n = 52$)	Fall ($n = 115$)	Total^ ($n = 182$)	χ^2	*P*
Crayfish	42.9	98.1	75.7	79.7	23.6	**<0.001**
Insects	28.6	1.9	24.3	18.7	13.2	**0.001**
Amphibians	7.1	7.7	0.0	2.7	9.1	**0.003***
Birds	0.0	1.9	1.7	1.6	-	-
Mammals	0.0	0.0	9.6	6.0	5.3	**0.021***
Fish	85.7	44.2	81.7	71.4	26.2	**<0.001**
Catostomidae (suckers)	21.4	3.8	18.3	14.3	6.7	**0.036**
Centrarchidae (sunfish)	14.3	1.9	0.0	2.7	-	-
Cyprinidae (minnows)	64.3	30.8	67.0	56.6	28.8	**<0.001**
Esocidae *Esox lucius* (northern pike)	28.6	0.0	0.0	2.2	-	-
Hiodontidae (mooneyes)	7.1	3.8	0.0	1.6	-	-
Ictaluridae (catfish)	7.1	1.9	49.6	32.4	42.8	**<0.001**
Percidae (perches)	7.1	3.8	10.4	8.2	3.3	0.189

^ Total includes 1 scat from winter.

Table 2.10. The mean and range of the estimated total length (cm) of fish consumed by river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007.

Species	Minimum	Maximum	Mean
Catostomidae			
*Catostomus commersoni (*white sucker*) (n = 36)*	8.7	62.3	31.4
Moxostoma spp. (redhorses) (*n = 29*)	10.6	42.4	18.4
Centrarchidae			
Pomoxis spp. (crappies) (*n = 15*)	5.1	28.7	14.6
Ambloplites rubestris or *Lepomis* spp. (*n = 49*)	4.9	25.6	13.3
Unknown centrarchids (*n = 18*)	6.0	21.2	12.4
Cyprinidae			
Cyprinus carpio (carp) (*n = 377*)	3.5	62.9	21.8
Rhinichthys spp. (dace) (*n = 2*)	7.5	10.7	9.1
Large non-carp cyprinids* (*n = 8*)	12.2	33.7	16.1
Small cyprinids^ (*n = 40*)	4.8	10.7	7.5
Esocidae			
Esox lucius (northern pike) (*n = 35*)	14.9	71.0	36.3
Percidae			
Etheostoma spp. or *Percina* spp. (darters) (*n = 17*)	4.8	8.6	6.0
Perca flavescens or *Sander* spp. (*n = 15*)	10.9	19.7	15.9
Moronidae/Sciaenidae			
Morone chrysops (white bass) or *Aplodinotus grunniens* (freshwater drum) (*n = 30*)	14.7	49.7	29.0

*Includes non-carp cyprinids with scale lengths ≥2.50 mm.
^Includes cyprinids with scale lengths <2.50 mm, excluding *Cyprinus carpio* and *Rhinichthys* spp.

Table 2.11. Comparison among rivers of total length (cm) categories of fish consumed by river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007. A. Using relative frequency. B. Using frequency of occurrence in scats. Comparisons did not include the Tongue River. **Bold** indicates a significant difference ($P <0.05$).

A.

Total Length (cm)	Forest (n = 258)	Red (n = 236)	Tongue (n = 8)	Turtle (n = 164)	Total[*] (n = 671)	χ^2	P
≤10	25.2	8.9	25.0	46.3	24.4	73.2	**<0.001**
10.1-20	39.1	33.1	50.0	37.2	36.5	2.0	0.363
20.1-30	12.4	21.2	12.5	6.7	14.3	17.8	**<0.001**
30.1-40	13.2	20.8	0.0	5.5	13.9	19.0	**<0.001**
40.1-50	6.2	14.4	0.0	3.0	8.2	18.9	**<0.001**
>50	3.9	1.7	12.5	1.2	2.7	3.8	0.148

* The total also includes 3 fish from the Park River and 2 from the Pembina River

B.

Total Length (cm)	Forest (n = 245)	Red (n = 142)	Tongue (n = 89)	Turtle (n = 182)	Total[+] (n = 665)	χ^2	P
≤10	22.9	14.8	2.2	31.9	20.6	13.0	**0.001**
10.1-20	35.5	42.3	4.5	28.0	30.5	7.2	**0.027**
20.1-30	11.4	32.4	1.1	6.0	13.2	47.8	**<0.001**
30.1-40	13.5	31.0	0.0	4.9	13.1	43.1	**<0.001**
40.1-50	6.1	23.2	0.0	2.2	7.8	47.3	**<0.001**
>50	4.1	2.8	1.1	1.1	2.7	3.4	0.183

+ The total also includes 6 scats collected from the Pembina River, and 1 from the Park River.

Table 2.12. Seasonal comparison of total length (cm) categories of fish consumed by
river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North
Dakota, July 2006 – November 2007. Scats collected 1 March – 31 May were considered
as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1
December – 28 February as winter. A. Using relative frequency. B. Using frequency of
occurrence in scats. * Indicates the comparison excluded winter. **Bold** indicates a
significant difference (*P* <0.05).

A.

Total Length (cm)	Spring (*n* = 178)	Summer (*n* = 90)	Fall (*n* = 362)	Winter (*n* = 41)	Total (*n* = 671)	χ^2	*P*
≤10	7.9	45.6	28.7	12.2	24.4	55.1	**<0.001**
10.1-20	24.7	23.3	44.5	46.3	36.5	29.0	**<0.001**
20.1-30	24.2	6.7	11.0	17.1	14.3	21.8	**<0.001**
30.1-40	25.3	12.2	7.7	19.5	13.7	32.4	**<0.001**
40.1-50	13.5	7.8	6.4	4.9	8.3	8.7	**0.034**
>50	4.5	4.4	1.7	0.0	2.7	5.9	0.117

* The total also includes 3 fish from the Park River and 2 from the Pembina River

B.

Total Length (cm)	Spring (*n* = 169)	Summer (*n* = 199)	Fall (*n* = 275)	Winter (*n* = 22)	Total (*n* = 665)	χ^2	*P*
≤10	8.3	18.1	30.2	22.7	20.6	31.8	**<0.001**
10.1-20	21.3	10.6	48.0	63.6	30.5	95.2	**<0.001**
20.1-30	22.5	3.0	13.8	27.3	13.2	34.6	**<0.001**
30.1-40	24.9	5.0	9.8	31.8	13.1	41.7	**<0.001**
40.1-50	13.0	3.5	8.0	9.1	7.8	11.3	**0.010**
>50	4.7	2.0	2.2	0.0	2.7	3.2	0.205*

+ The total also includes 6 scats collected from the Pembina River, and 1 from the Park River.

Table 2.13. Seasonal comparison of total length categories (cm) of fish consumed by river otters (*Lontra canadensis*) on the Forest River, North Dakota, October 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. A. Using relative frequency. B. Using frequency of occurrence in scats. * Indicates comparison excluded winter. **Bold** indicates a significant difference (*P* <0.05).

A.

Total Length (cm)	Spring (*n* = 54)	Summer (*n* = 77)	Fall (*n* = 106)	Winter (*n* = 21)	Total (*n* = 258)	χ^2	*P*
≤10	9.3	44.2	22.6	9.5	25.2	25.1	**<0.001**
10.1-20	14.8	20.8	60.4	61.9	39.1	49.0	**<0.001**
20.1-30	20.4	7.8	11.3	14.3	12.4	4.9	0.184
30.1-40	33.3	14.3	1.9	14.3	13.2	31.1	**<0.001**
40.1-50	14.8	9.1	0.9	0.0	6.2	14.4	**0.002**
>50	7.4	3.9	2.8	0.0	3.9	1.9	0.390*

B.

Total Length (cm)	Spring (*n* = 61)	Summer (*n* = 98)	Fall (*n* = 76)	Winter (*n* = 10)	Total (*n* = 245)	χ^2	*P*
≤10	6.6	30.6	26.3	20.0	22.9	13.1	**0.004**
10.1-20	11.5	16.3	72.4	90.0	35.5	89.2	**<0.001**
20.1-30	16.4	6.1	13.2	20.0	11.4	5.2	0.160
30.1-40	29.5	10.2	2.6	30.0	13.5	24.4	**<0.001**
40.1-50	11.5	7.1	1.3	0.0	6.1	6.0	0.050*
>50	6.6	3.1	3.9	0.0	4.1	1.2	0.562*

Table 2.14. Seasonal comparison of total length categories (cm) of fish consumed by river otters (*Lontra canadensis*) in the Red River of the North, North Dakota and Minnesota, October 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 September – 30 November as fall, and 1 December – 28 February as winter. A. Using relative frequency. B. Using frequency of occurrence in scats. * Indicates comparison excluded winter. **Bold** indicates a significant difference ($P < 0.05$).

A.

Total Length (cm)	Spring (*n* = 99)	Fall (*n* = 117)	Winter (*n* = 20)	Total (*n* = 236)	χ^2	*P*
≤10	5.1	11.1	15.0	8.9	3.4	0.180
10.1-20	32.3	34.2	30.0	33.1	0.2	0.916
20.1-30	28.3	15.4	20.0	21.2	5.4	0.069
30.1-40	21.2	19.7	25.0	20.8	0.3	0.853
40.1-50	10.1	18.8	10.0	14.4	3.6	0.162
>50	3.0	0.9	0.0	1.7	1.4	0.237*

B.

Total Length (cm)	Spring (*n* = 58)	Fall (*n* = 73)	Winter (*n* = 11)	Total (*n* = 142)	χ^2	*P*
≤10	8.6	17.8	27.3	14.8	3.6	0.162
10.1-20	43.1	41.1	45.5	42.3	0.1	0.950
20.1-30	41.4	24.7	36.4	32.4	4.2	0.122
30.1-40	32.8	30.1	36.4	31.0	0.2	0.895
40.1-50	17.2	28.8	18.2	23.2	2.6	0.276
>50	5.2	1.4	0.0	2.8	1.6	0.209*

Table 2.15. Seasonal comparison of total length categories (cm) of fish consumed by

river otters (*Lontra canadensis*) on the Turtle River, North Dakota, October 2006 –

November 2007. Scats collected 1 March – 31 May were considered as spring, 1 June –

30 August as summer, and 1 September – 30 November as fall. A. Using relative

frequency B. Using frequency of occurrence in scats. * Indicates comparison excluded

spring. ^ Indicates comparison excluded summer. **Bold** indicates a significant difference

(P <0.05).

A.

Total Length (cm)	Spring (n = 18)	Summer (n = 12)	Fall (n = 134)	Total (n = 164)	χ^2	P
≤10	11.1	58.3	50.0	46.3	10.4	**0.006**
10.1-20	11.1	33.3	41.0	37.2	6.2	**0.046**
20.1-30	11.1	0.0	6.7	6.7	0.5	0.499^
30.1-40	33.3	0.0	2.2	5.5	27.5	**<0.001^**
40.1-50	27.8	0.0	0.0	3.0	-	-
>50	5.6	8.3	0.0	1.2	-	-

B.

Total Length (cm)	Spring (n = 14)	Summer (n = 52)	Fall (n = 115)	Total (n = 182)	χ^2	P
≤10	14.3	11.5	43.5	31.9	19.0	**<0.001**
10.1-20	14.3	7.7	39.1	28.0	18.9	**<0.001**
20.1-30	14.3	0.0	7.8	6.0	4.3	**0.038***
30.1-40	42.9	0.0	2.6	4.9	-	-
40.1-50	28.6	0.0	0.0	2.2	-	-
>50	7.1	1.9	0.0	1.1	-	-

Table 2.16. Shannon-Wiener diversity (H') of river otter (*Lontra canadensis*) prey in the Red River of the North drainage in eastern North Dakota, July 2006 – November 2007, by river.

River	Diversity (H')	
	Major Prey Categories	**Fish Prey**
Forest (*n* = 245)	2.058	1.465
Red (*n* = 142)	1.868	2.610
Tongue (*n* = 89)	1.720	1.994
Turtle (*n* = 182)	1.704	1.973
Overall (*n* = 665)	**1.996**	**2.238**

Table 2.17. Shannon-Wiener diversity (H') of river otter (*Lontra canadensis*) prey in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007, by season. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. A. Including all collected scats. B. Including only scats collected on the Forest, Tongue, and Turtle rivers.

A.

	Diversity (H')	
River	**Major Prey Categories**	**Fish Prey**
Spring (*n* = 169)	2.108	2.605
Summer (*n* = 199)	1.986	1.348
Fall (*n* = 275)	1.836	2.124
Winter (*n* = 22)	1.435	2.124
Overall (*n* = 665)	**1.996**	**2.238**

B.

	Diversity (H')	
River	**Major Prey Categories**	**Fish Families**
Spring (*n* = 110)	2.130	1.999
Summer (*n* = 196)	1.974	1.258
Fall (*n* = 199)	1.765	1.887
Winter (*n* = 11)	1.053	1.659
Overall (*n* = 516)	**1.995**	**1.874**

Table 2.18. Seasonal comparison of mean prey sizes (total length in cm) of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. **Bold** indicates a significant difference ($P < 0.05$).

	Spring	Summer	Fall	Winter	Total	*F*	*P*
Catostomidae (suckers)	38.7	44.0	20.9	16.2	25.6	10.2	**<0.001**
Centrarchidae (sunfish)	14.8	12.2	11.7	13.7	13.3	1.8	0.151
Cyprinidae							
Cyprinus carpio (carp)	32.2	19.0	18.4	23.5	21.8	26.7	**<0.001**
Other cyprinids	22.2	8.4	8.5	6.2	8.9	9.8	**<0.001**
Esocidae *Esox lucius* (northern pike)	39.7	31.0	33.4	40.1	36.3	0.8	0.497

Moronidae/Sciaenidae
  Morone chrysops (white bass) or
  Aplodinotus grunniens (freshwater drum)
	27.4	24.2	37.1	24.1	29.0	2.8	0.061

Percidae (perches)	11.3	14.4	9.7	6.9	10.6	0.9	0.451
Total	**27.8**	**18.6**	**17.8**	**21.0**	**20.7**	**25.6**	**<0.001**

CHAPTER 3

The Use of Scales to Estimate the Size of Fish Prey of Nearctic River Otters (*Lontra canadensis*) and other Piscivores

ABSTRACT

Size estimation of the fish prey of nearctic river otters (*Lontra canadensis*) and other piscivores requires the use of hard anatomical structures that are deposited in scats. Also, a relationship must exist between the size of the structure and fish length for size estimation to be possible. The applicability of scales for estimating the size of fish prey was evaluated by conducting a linear regression analysis of scale size and fish length for 22 species and 6 multi-species groups of fish from the Red River of the North tributaries of eastern North Dakota. Analyses included 6 scale measurements, and separate models were constructed for lateral line and non-lateral line (random) scales. Single and multiple regression models were considered, and the best models were determined by maximizing the coefficient of determination (r^2) (for single variable models) or adjusted coefficient of determination (adjusted R^2) (for multi-variable models), and maintaining the simplicity of the model. In most cases (42 of 44) a positive relationship existed between scale size and fish length for single species models. A positive relationship existed for the best single variable model for all 22 species using lateral line scales, and for 20 of 22 species using non-lateral line scales. Typically (for 20 of 22 species), the best lateral line model produced better relationships (higher r^2) than the best non-lateral line models. Scale length on average was the best scale measurement using lateral line and random models, and provided the best fit for the most species using lateral line scales, and second most

species using random scales. Scale height provided the best fit for the most species using random scales, and second most using lateral line scales. Diagonal, posterolateral radius, and posterior radius were also good measurements for some species. Multi-variable models usually had higher adjusted R^2 than single variable models. However, improvements by including >1 variable were small. Positive relationships also existed for body-scale relationships using multiple species, with lateral line scales always producing better models than random scales. Similar to single species models, using ≥1 variable improved multi-species models only slightly. As a result of their abundance in scats, the existence of identification keys to the family level, positive relationships between scale size and fish length, and the noninvasive method of establishing predictive relationships, scales were determined to be the structure best suited for estimation of the size of fish prey of river otters.

INTRODUCTION

The nearctic river otter (*Lontra canadensis*) is an opportunistic aquatic predator reported to capture prey in proportion to the prey's availability, and inversely with the prey's swimming ability (Ryder 1955). The diet is diverse, but because river otters are largely restricted to aquatic habitats, they are limited to aquatic and semi-aquatic prey. Most dietary analyses have shown fish to be the primary prey (e.g., Greer 1955, Sheldon and Toll 1964, Melquist and Hornocker 1983, Serfass et al. 1990, Chapter 2). Despite many previous studies on the diet of river otters, formal studies on the size of their fish prey are rare. Outcomes of these studies indicate that fish prey ranges from 2-80 cm, and that most fish consumed are <30 cm in length (Lagler and Ostenson 1942, Greer 1955,

Ryder 1955, Hamilton 1961, Toweill 1974, Lauhachinda and Hill 1977, Melquist and

Hornocker 1983, Stenson et al. 1984, Griess 1987, Tumlison and Karnes 1987, Beckel

1990, Noordhuis 2002, Giordano 2005, Chapter 2). However, most previous studies did

not provide methodologies, or did not develop and apply previously established

predictive relationships between an anatomical fish structure in the prey remains and fish

length.

The size of the fish prey of the European otter has been studied more thoroughly

than the nearctic river otter. Wise (1980) established linear regression models for

vertebral length on fish fork length (distance between the snout and fork of the tail) for 5

species, and estimated the length of fish prey of the European otter from these models.

Most other studies (e.g., Adrian and Delibes 1987, Carss et al. 1990, Kemenes and

Nechay 1990) have either followed Wise (1980) directly, or used a modification of his

methods. Scales also have been used to estimate the prey size of the European otter (i.e.,

Kozena et al. 1992). However, fish size was estimated by using the mean scale size of

fish in 10-mm size classes for constructing predictive relationships, and used only the

largest scales of each species within a scat to estimate prey size (Kozena et al. 1992).

Other structures that have been suggested for use in estimating the size of the fish prey of

otters and other piscivores include: cleithra (Hansel et al. 1988, Copp and Kovac 2003),

jaw bones (i.e., dentary, premaxillary, maxilla) (Hansel et al. 1988, Prenda and Granado-

Lorencio 1992, Copp and Kovac 2003, Hajkova et al. 2003), pectoral spines (Noordhuis

2002), pharyngeal teeth (Hamilton 1961, Prenda and Granado-Lorencio 1992), opercula

(Hansel et al. 1988, Copp and Kovac 2003), and otoliths (Dellinger and Trillmich 1999,

Granadeiro and Silva 2000, Ross et al. 2005).

Estimating the length of fish using scales or other hard anatomical structures is based on a relationship between the size of the structure and fish length. These positive relationships result from growth of the structure as the fish grows in length (Lagler 1956, Daniels 1996). The relationship between fish length and scale size is known as the body-scale relationship, which has previously been used in fisheries biology in growth studies to back-calculate the length of fish at earlier ages (Lagler 1956, Whitney and Carlander 1956, Francis 1990, Daniels 1996). The body-scale relationship is usually reported as being linear, but some authors have used curvilinear, cubic, quadratic, or logarithmic relationships (Lagler 1956, Hile 1970, Carlander 1982, Francis 1990). The relationship can vary among species, populations of the same species, and by the location on the fish from which the scales are taken (Lagler 1956, Whitney and Carlander 1956, Hile 1970, Francis 1990, Pierce et al. 1996). The relationship also can be influenced by temperature, fish density, parasitism, and other environmental factors (Lagler 1956, Whitney and Carlander 1956, Hile 1970, Carlander 1982, Francis 1990, Pierce et al. 1996, Poulet et al. 2005, Miranda and Escala 2007).

The use of scales instead of vertebrae or other structures for predicting the size of fish prey has several advantages. A particular advantage is the ability to collect scales without lethally sampling fish. Scales can easily be removed from fish that are captured alive, and subsequently the fish can be released. In the case of vertebrae, otoliths, and other bony structures fish must be sacrificed for predictive relationships to be established. Therefore, using scales is less complicated and more time efficient than developing models from other anatomical structures, because other structures would typically be obtained by sacrificing and subsequently dissecting fish. A limitation of using many of

the potential structures is that river otters may not consume the heads or vertebrae of larger fish, as observed in captive studies of other otter species (Erlinge 1968, Rowe-Rowe 1977*a*). If otters in natural systems are similarly not consuming the heads of larger fish, it may cause an underestimation of the size of fish prey. Difficulty in identification, and the potential for breakage or other degradation in passage through the digestive system are also disadvantages of using vertebrae or other bones in size estimation (Carss and Nelson 1998). However, keys for identifying scales to the family level are available (e.g., Daniels 1996).

A further complication of using vertebrae is that the size of vertebrae within a fish differs among regions along the vertebral column (Wise 1980). Therefore, specific vertebrae may be required for size estimation, but determining the region of origin of vertebrae is complicated and time consuming. Scales also vary by shape and size over the body of an individual fish, which has resulted in criticism of their use for size estimation (Phillips 1948, Joeris 1956, Scarnecchia 1979, Wise 1980, Daniels 1996, Miranda and Escala 2007, Roberts et al. 2007). However, lateral line scales are easily distinguished from other scales by a pore or line on the scale (Daniels 1996, Roberts et al. 2007). Constructing regression models using dimensions of lateral line scales, therefore may reduce the amount of variation in the model and thereby, provide a more precise estimate of the size of fish prey.

The objective of my study was to assess the appropriateness of using scales to estimate the size of the fish prey of river otters and other piscivores. In doing so, I evaluated the body-scale relationships of fish from the Red River of the North tributaries of eastern North Dakota. The relationships for lateral line and non-lateral line scales

(hereafter referred to as random scales) were compared to determine which scale type produces the best relationships, thereby providing a more precise method for fish size estimation.

STUDY AREA

The Red River of the North forms at the convergence of the Bois de Sioux River, and the Ottertail River at Wahpeton, ND and Brackenridge, MN (46°15.84'N, 96° 35.92'W). The river flows north forming the boundary between North Dakota and Minnesota for nearly 640 km before entering Manitoba, Canada (Koel and Peterka 1998). The landscape of the Red River drainage has low relief, and mostly occurs within the former lake bed of Lake Agassiz (Eddy et al. 1972, Stoner et al. 1993). The majority (80%) of the Red River valley is cropland, but pasture also occurs, and forested regions are mostly confined to riparian strips (Stoner et al. 1993). Riparian areas consist of strips of grass or trees (Stoner et al. 1993). In some areas agricultural fields extend to the river banks (Stoner et al. 1993). The Red River has 10 major tributaries in North Dakota that from north to south include: the Pembina, Tongue, Park, Forest, Turtle, Goose, Elm, Sheyenne, Wild Rice, and Maple Rivers. The tributaries are similar in appearance, typically having low gradients, having frequent meanders, and high turbidity (Copes and Tubb 1966, Stoner et al. 1993).

METHODS

In summer 2007 I collected scale samples by collaborating with researchers from South Dakota State University during surveys of fish communities in the North Dakota tributaries of the Red River of the North. Sampling was conducted using a backpack electrofishing unit, seine, and cloverleaf and minnow traps. From 28 September to 2 November 2007 I obtained additional scale samples from fish collected using fyke nets and minnow traps from the Forest and Turtle River my river otter diet study areas (Chapter 2, Appendix III). The total length (from snout to the tip of the tail) of each fish was recorded following its capture. Ten equal sized regions were then visually imposed down the length of the fish, and a random lateral line scale was taken from one of the regions. Then, 10 regions were visually imposed along the height of the fish on top of the length regions, thereby forming a 10 x 10 grid over the fish. Thereafter, a random non-lateral line scale was selected from one of the cells within the grid.

After scales were collected 6 measurements (length, height, diagonal, anterior radius, posterior radius, and antero- or posterolateral radius) were taken using calipers accurate to 0.01 mm (Figure 3.1). Each of the scale dimensions measured the distance between scale margins, or from the focus (the point of origin of the scale) to a scale margin. The scale length was measured from the anterior to the posterior margin along the midline. Scale height measured from one lateral margin to the other through the center of the scale. The anterolateral radius measured from the focus to an anterior corner. Instead of an anterolateral radius, a posterolateral radius (from focus to a posterior corner) was measured for cyprinids (except carp, *Cyprinus carpio*). Anterior radii

measured from the focus to the anterior margin along the midline. Similarly, the posterior radius measured from the focus to the posterior margin along the midline.

From fish length and scale measurements I performed a linear regression analysis (SAS Version 8.02, SAS Institute, Cary, North Carolina, USA; Minitab Version 14, Minitab Inc., State College, Pennslvania, USA) to determine if a linear relationship exists between fish length and scale size for each species. The analysis included 22 species that each included ≥10 lateral line and random scale samples, and single and multiple regression models were constructed for both scale types. The best model for each species was determined by maximizing the coefficient of determination (r^2) for single variable models or adjusted coefficient of determination (adjusted R^2) for multi-variable models, while maintaining simplicity of the model. For each species, models were constructed independently for lateral line and random scales, and r^2 values of the scale types were compared. The mean r^2 of the best lateral line and random models (averaging across the 22 species) was compared using a paired t-test.

For species that could not reliably be distinguished by the morphology of their scales, multi-species models were constructed. In such models, all samples collected from each of the species in the group were included in the multi-species model. Therefore, multi-species models included samples from species that were evaluated individually, and from species that lacked adequate sample sizes to be analyzed independently (Appendix V). Sample sizes varied for each species, and were not standardized before building models. Therefore, some species were represented more frequently in the group model than others. Cyprinids provided a unique challenge as many species (e.g., bluntnose minnow (*Pimephales notatus*), fathead minnow (*Pimephales promelas*), and

spotfin shiner (*Cyprinella spiloptera*)) do not exceed 10 cm total length, whereas others

(e.g., common shiners (*Luxilus cornutus*), creek chubs (*Semotilus atromaculatus*), and

horneyhead chubs (*Nocomis biguttatus*)) attain larger sizes. Therefore, different models

were constructed for small cyprinids (≤10 cm, excluding carp and dace (*Rhinichthys*

spp.), which could be distinguished) and large cyprinids (>10 cm, excluding carp and

dace). Similar to single species models, a linear regression analysis was conducted for

multi-species groups to determine which measurement(s) and scale type (lateral line or

random) produced the best model.

Size estimation of fish length using single and multi-species models was

compared by using the scale dimension that produced the multi-species model with the

highest r^2. The measurements for that particular dimension of the scales used in

constructing the models were inserted into their respective single and multi-species

models. Subsequently, the resulting estimates were compared. Similarly, to determine if

the body-scale relationship for 1 species could be used for size estimation of a group of

undistinguishable species, size estimates of small cyprinids (e.g., bluntnose minnow,

fathead minnow, spotfin shiner) using an individual species model for a large cyprinid

species (i.e., common shiners, creek chubs, and horneyhead chubs) were compared to the

actual size of fish used in building the models.

In a companion study (Chapter 2) the food habits of river otters in eastern North

Dakota were evaluated using scat analysis. The size of the fish prey of river otters was

estimated using the body-scale relationships established here. To assess the utility of

using scales for size estimation, the proportion of scats containing fish remains (and

lacking ictalurid (catfish) remains, because they lack scales) that also contained scales

usable for size estimation was determined. For comparison, the proportion of scats with pharyngeal teeth was determined for scats containing catostomid (sucker) and cyprinid (carp and minnows) remains. Also, to evaluate if lateral line scales alone could be used for prey size estimation, the proportion of fish detections that were determined using lateral line scales was calculated. Finally, the ability to distinguish multiple individuals of a particular species (or group) within a scat was assessed by using 95% prediction intervals of fish length based upon the size of scales within the scat.

RESULTS

For the 22 species that were evaluated individually, sample sizes ranged from 10-125 and 12-128 samples for lateral line and random scales, respectively (Appendix V). Only a few species (e.g., carp, common shiners, and creek chubs) had large sample sizes ($n > 50$ for both scale types), whereas several had low sample sizes ($10 \leq n \leq 20$ for both scale types) (e.g., shorthead redhorse (*Moxostoma macrolepidotum),* sand shiners (*Notropis stramineus*), freshwater drum (*Aplodinotus grunniens*)) (Appendix V). As a result, for species that were assessed individually mean sample sizes were 35.8 (SE = 5.8, $n = 22$) and 38.2 (SE = 5.9, $n = 22$) for lateral line and random scales, respectively. Most of the samples were collected from the Forest and Turtle Rivers, and were obtained over a wide size range for several species (e.g., carp, freshwater drum, and white suckers (*Catostomus commersoni*)). But, the size range was limited (not over the entire possible size distribution) for other species (e.g., white bass (*Morone chrysops*), bigmouth shiners (*Notropis dorsalis*), and largescale stonerollers (*Campostoma oligolepis*).

For most individual species models, positive relationships existed between a single fish scale dimension and fish total length using lateral line and random scales (Tables 3.1 and 3.2). Generally, relationships had high r^2 values, with 29 of 44 of the best (the lateral line and random model with the highest r^2 for each species) single variable models having $r^2 \geq 0.70$ (Table 3.1). Using lateral line scales, the best model for all 22 species was significant, with 20 of 22 having $P < 0.0001$ (Table 3.1). The best lateral line models had r^2 values ranging from 0.317 ($P = 0.029$) for sand shiners to 0.994 ($P < 0.0001$) for bluegill (*Lepomis macrochirus*). For 20 of 22 species, the best random scale model was significant, with no relationships being established for sand shiners and largescale stonerollers (Tables 3.1 and 3.2). For the best random scale models, r^2 ranged from 0.136 ($P = 0.1199$) to 0.959 ($P < 0.0001$) for sand shiners and freshwater drum, respectively (Table 3.1). The best body-scale relationship for blackside darters (*Percina maculata*) had the lowest r^2 (0.440, $P < 0.0001$) among species with a positive body-scale relationship.

Lateral line models usually were better predictors of fish total length than random models in single variable models, with 20 of 22 species having higher r^2 values for the best lateral line model than the best random model (Figure 3.2; Table 3.1). The mean r^2 of the best single variable lateral line models (averaging across the best model for each species) ($\bar{x} = 0.833$, SE = 0.035, $n = 22$) was higher than that for the best random models ($\bar{x} = 0.667$, SE = 0.050, $n = 22$) (paired $t_{21} = 5.03$, $P < 0.001$). The differences in r^2 values between the best models (from the best lateral line model to the best random model) for each species ranged from -0.032 for shorthead redhorse to 0.571 for largescale stonerollers. For a majority of species (14, 63.6%) the best lateral line model had a r^2

value that was ≥0.10 higher than the best random model, with a mean difference of 0.167

(SE = 0.03, $n = 22$).

Scale length was the measurement that resulted in the highest mean r^2 ($\bar{x} = 0.787$,

SE = 0.05, $n = 22$) for single species lateral line models, and provided the best fit for nine

species, the most of any measurement (Tables 3.1 and 3.7). Scale height provided the best

fit in lateral line models for 6 species, posterior radius for 4 species, diagonal for 2

species, and posterolateral radius for 1 species (Table 3.1). Scale length on average ($\bar{x} =$

0.609, SE = 0.06, $n = 22$) also provided the best fit for random models (Table 3.7).

However, scale height provided the best fit for the most species (8) (Table 3.1). The best

fit for random models of 6 species was attained using scale length, posterolateral radius

for 5 species, posterior radius for 2 species, and diagonal for 1 species (Table 3.1).

For most species specific models, including >1 variable increased the adjusted R^2

in comparison with single variable models. The maximum adjusted R^2 was attained for

most models (33 of 44) by including 2-4 variables (Table 3.4). However, because the

variables were highly correlated, in most cases there was not a substantial increase in

adjusted R^2 by adding variables to the model (Table 3.4, Appendix VI). Only 8 (4 lateral

line and 4 random) of the 44 models improved ≥0.05 in adjusted R^2 by including >1

variable. Furthermore, only the models for largescale stonerollers improved ≥0.10 with

additional variables. Because many of the models improved little, the mean improvement

by using >1 variable was 0.027 (SE = 0.01, $n = 22$) and 0.042 (SE = 0.01, $n = 22$) for

lateral line and random models, respectively.

A positive relationship also existed when multiple species were included in

models established between scale size and fish total length (Table 3.3). In some cases,

multi-species models (e.g., centrarchids) still possessed high (>0.90) r^2 values (Table 3.3). Some multi-species models had r^2 that were intermediate between r^2 values of individual models of species included in group models. But, r^2 of the multi-species model usually was slightly lower than that of the species in the group with the lowest individual r^2 (Tables 3.2 and 3.3). As with single species models, lateral line scales provided better models than random scales, with a mean difference between the best models (for each group) of 0.161 (SE = 0.056, $n = 6$) (paired $t_5 = 2.88$, $P = 0.035$), ranging from 0.047 to 0.399 for white bass/freshwater drum and darters (*Etheostoma nigrum* and *Percina maculata*), respectively. The majority of lateral line multi-species models attained the highest r^2 using scale length (Table 3.3). Random scale multi-species models reached their maximum r^2 using the length, height, or posterior radius measurement (Table 3.3). Similar to single species models, including >1 variable yielded little improvement in adjusted R^2 ($\bar{x} = 0.026$, SE = 0.010, $n = 6$; $\bar{x} = 0.027$, SE = 0.015, $n = 6$, for lateral line and random models, respectively) (Table 3.5).

In most cases there were only slight differences between estimated fish sizes between single and multi-species models (Table 3.6). When differences were larger, it was usually for cyprinid species that grow to relatively large sizes (i.e., creek chubs, common shiners, horneyhead chubs, and largescale stonerollers). The lengths of these species were typically underestimated by multispecies models when included in the ≤10 cm group, and overestimated in the >10 cm group. Differences (as large as 4.3 cm and 5.6 cm using lateral line and random models, respectively), were typically the largest at extreme scale (and fish) sizes, particularly with the largest individuals. Overall (and for

most species), using lateral line models minimized differences between predicted lengths, as they provided more precise estimates of fish size (Table 3.6).

Generally, using a species specific body-scale relationship for one of the large cyprinid species (e.g. common shiners, creek chubs, and horneyhead chubs) does not provide precise estimates of the size of small species (e.g., bluntnose minnows, fathead minnows, and spotfin shiner). Using large species lateral line models, mean differences between size estimates of small cyprinids and their actual sizes were 0.45 cm (SE = 0.09, $n = 184$, overestimated), 1.57 cm (SE = 0.12, $n = 184$, overestimated), and 0.60 cm (SE = 0.08, $n = 184$, underestimated) for common shiners, creek chubs, and horneyhead chubs, respectively. For random models the mean differences were 1.58 cm (SE = 0.11, $n = 184$, overestimated) and 2.64 cm (SE = 0.14, $n = 184$, overestimated) for common shiners and creek chubs, respectively. However, the random horneyhead chub model did provide a relatively precise estimate of small cyprinid size ($\bar{x}_{difference} = 0.15$ cm, SE = 0.12, $n = 184$).

In the companion river otter diet study, 88.2% of scats containing fish remains (and lacking ictalurid remains) contained scales that could be used for fish size estimation. Of scats containing catostomid remains 97.4% contained usable scales, whereas only 23.7% contained pharyngeal teeth. Usable scales were included in 92.2% of scats with cyprinid remains, while only 40.0% contained pharyngeal teeth. Size estimates of 57.0% of fish for which body-scale relationships were established ($n = 671$) were attained using lateral line scales. The sizes of the remaining fish were estimated using random scales. Using 95% prediction intervals of fish length based on the size of scales sorted from scats, multiple fish of the same species (or group) were detected in 71 scats.

DISCUSSION

The body-scale relationship is well known in the fisheries literature, so it was not surprising that there are positive relationships (in most cases) between scale size and fish total length (Whitney and Carlander 1956, Hile 1970, Carlander 1982, Francis 1990, Pierce et al. 1996). However, given the strength of the relationships in other studies (r^2 typically >0.85), and lateral line models in this study, the lack of a relationship for sand shiners and largescale stonerollers using random scales was somewhat surprising (Pierce et al. 1996, Giordano 2005, Miranda and Escala 2007, Table 3.2). But, in previous studies scales have typically been taken from a specific location (e.g., at the tip of the pectoral fin when it is flattened against the body) on the fish to minimize variation, and thereby maximizing r^2 values (Regier 1962, Scarnecchia 1979, Carlander 1982, Pierce et al. 1996). However, since scales vary in size and shape over the body of the fish, and the exact location on the body where the scale originated can't be determined from the scale itself, this method would inaccurately estimate the size of fish prey (Phillips 1948, Joeris 1956, Scarnecchia 1979, Daniels 1996, Roberts et al. 2007). Therefore, predictive relationships need to be established using scale samples from the entire body. This study documented that at least in most cases there is a positive relationship between scale size and fish total length when doing so (Table 3.2).

For 20 of 22 species, the best lateral line model was better than the best random model (Table 3.1). This is because lateral line scales are restricted to a relatively small area, as the lateral line occurs in a line down the sides of a fishes' body, generally in a single row of scales in the center of the fish (but it is curved or off-center in some species). The best example of the benefits of using lateral line body-scale relationships

instead of random models was the common shiner. The best lateral line model had a very strong linear relationship, with an r^2 value of 0.958. But, the best random model had much more variation, resulting in a much lower r^2 (0.615) (Table 3.1, Appendix XV). Because lateral line scales can be differentiated from other scales on the body, and provide better body-scale relationships (higher r^2), lateral line scales should be used (when possible) to estimate the size of fish prey.

Generally, the best scale measurement for estimating fish size is scale length. Length had the highest mean r^2 value of any measurement for both lateral line and random models, maximized r^2 for the most species (9) using lateral line scales, second most species (6) using random scales, and produced the best model for 6 multi-species models (4 lateral line and 2 random) (Tables 3.1 3.3, and 3.7). Additionally, length has been the most frequent measurement used in other studies, some of which also have shown length to be the best scale measurement (Daniels 1996, Pierce et al. 1996, Giordano 2005, Miranda and Escala 2007). Scale height is also a good measurement for estimating prey size for many species, as it was the best predictor of fish length for the most species (8) using random scales, second most (6) using lateral line scales, provided the best predictor for 3 multi-species models (1 lateral line and 2 random), and has previously been shown to be a better measurement than scale length for white suckers (Giordano 2005). However, for single species models height was on average only the third best predictor using lateral line scales, and fourth using random scales (Table 3.7). The low mean r^2 for scale height was because it was generally a poor predictor of fish length for cyprinids (except for dace for which height was a good predictor).

A diagonal was also a good scale measurement, providing the second best fit on average for both lateral line and random models (Table 3.7). But, the diagonal measurement was the best predictive variable for only a few species, and 1 multi-species model (Tables 3.1 and 3.3). Previous studies have used posterior radii to establish body-scale relationships of cyprinids (Hile 1970). But, in this study, the posterior radius yielded the best relationship in only 3 of 24 cyprinid models. However, the posterior radius was much more frequently the model with the 2nd highest r^2, and produced the best model for the random scale multi-species model for cyprinids ≤10 cm. Therefore, the posterior radius is a good measurement for cyprinids, but scale length generally produced better body-scale relationships. Miranda and Escala (2007) also came to the same conclusion for European cyprinids, including one species included in this study (carp).

Although other scale measurements (i.e., diagonal and posterior radius) occasionally provided the best fits, they were typically not as good of predictors as scale length or height. Because the variable that results in the best model varies by species (and multi-specie group), in future studies several measurements should be taken when establishing body-scale relationships. This approach will ensure that the most precise measurement is used for prey size estimation. But, because scale length and height are usually the best measurements, and are also the easiest to measure, they should be the primary focus of future studies.

Using multi-variable models typically resulted in higher adjusted R^2 values than single variable models, suggesting that using more than one scale measurement would provide more precise fish size estimation (Table 3.4). However, the variables are highly correlated, causing improvements by including additional variables to be small (≤0.05 in

adjusted R^2) (Tables 3.4, Appendix VI). Because there were not substantial improvements in predictive capabilities by including >1 variable, single variable models were determined to be best suited for fish size estimation, and were subsequently used in the river otter diet study (Chapter 2). However, future researchers should continue to compare single and multi-variable models to ensure that is the case for other fish species.

The body-scale relationship varies between species, so using multi-species models was expected to have resulted in lower r^2 than individual species models. This typically was the case, but for some groups r^2 was intermediate between the values for the individual species included in the group (Tables 3.2 and 3.3). The r^2 of multi-species models was usually only slightly lower than the r^2 of that of the species in the group with the lowest r^2. This indicates that interspecies differences in the body-scale relationship are relatively small. Also, differences between predictions using single and multi-species models were typically small, further indicating the similarity of body-scale relationships between species (Table 3.6). As a result, using multi-species models only has a minimal impact on estimates of mean size, and calculations of relative frequency and frequency of occurrence of prey size categories. However, because multi-species models were less precise than single-species models, whenever possible a single-species model should be used.

For non-differentiable cyprinids (those other than carp and dace) scale size can be used to differentiate some species. Common shiners, creek chubs, horneyhead chubs, and largescale stonerollers attain longer lengths (>10 cm) than the other cyprinids in the study area. As a result, their scales are larger than those of other species (at least for larger individuals). None of the small cyprinid individuals possessed scales greater than 2.45

mm in length. Therefore, using 2.50 mm as a standard it was possible to identify

cyprinids to one of the larger species. In contrast to the non-differentiable cyprinids, the

other multi-species groups did not have scale sizes that enabled the distinction between

species.

Using the body-scale relationship for 1 species to estimate the size of a group of

non-differentiable species could have application in some instances. For example, the

random body-scale relationship for horneyhead chubs could be used to estimate the size

of small cyprinids, because of small differences between size estimates using its species-

specific model, and the size of fish used in building the models. However, the multi-

species model for small cyprinids still provided a more precise estimate. Because

researchers can't beforehand determine if a single species will accurately estimate the

size of a group, in future studies group models still should be constructed.

Unfortunately, the sample size of several species (e.g., freshwater drum,

largescale stoneroller, and shorthead redhorse) was limited. In some instances this

resulted in atypical results. For instance, the random models for freshwater drum and

bluegill were very good fits to the data (Table 3.2). Similarly, low sample size (and a

limited size range) likely contributed to low r^2 values of sand shiners and largescale

stonerollers, particularly using random scales. Also, the best random body-scale

relationship for shorthead redhorse and blacknose dace (*Rhinichthys atratulus*) had higher

r^2 values than lateral line models. The randomization process for the lateral line samples

of shorthead redhorse and blacknose dace resulted in samples being obtained more

commonly from the most extreme regions (just posterior to the operculum, and on the

caudal peduncle) than the interior portions of the fish. If the samples had been collected

more evenly over the length of the body (for shorthead redhorse, blacknose dace, and other species) then the r^2 values of lateral line models may have been higher, or the values for random models may have been lower. In either case, there likely would have been a greater discrepancy between lateral line and random models for some species, with the lateral line models providing a better predictor of fish length in all cases.

For some species the distribution of samples was uneven over the range of possible lengths. For example, bluegill and black crappie (*Pomoxis nigromaculatus*) samples were clumped, so there were several distinct groups of fish of different lengths. For others (e.g., white bass, largescale stoneroller, and bigmouth shiner) samples were not obtained over the entire possible length distribution. Generally, samples were rare for large individual fish, resulting in some species (i.e., carp and freshwater drum) having most of their samples from small individuals, and having a few samples much larger than all others. For instance, samples from only 3 carp with total lengths greater than 38 cm were collected (largest was 68.9 cm), and only 6 were longer than 24 cm, whereas 126 were <24 cm. Future research should obtain larger sample sizes of scales, including more samples of large individual fish. This probably would not change the nature of the relationship, but would likely increase r^2 values for many models (although it may decrease it for models that already have a high r^2), and thereby increase the precision of prey size estimates.

In the companion study (Chapter 2), 88.2% of river otter scats with fish remains (and not containing ictalurid remains, which lack scales) contained scales in which size estimation could occur. Usable scales were included in 92.2% and 97.4% of scats with cyprinid and catostomid remains, respectively. In contrast, pharyngeal teeth (another

structure that could potentially be used for size estimation) occurred in only 40.0% and 23.7% of scats with cyprinid and catostomid remains, respectively. Vertebrae were common in scats (probably more common than pharyngeal teeth) but their frequency, as well as the frequency of other bony structures was not assessed. However, they were clearly not as common in scats as scales.

Based on the results of this study, lateral line scales were preferred for use in prey size estimation in the companion river otter diet study (Chapter 2). But, the size of all fish could not be estimated using lateral line scales. Of the 671 fish for which size estimation occurred, 57.0% were estimated using lateral line scales, with the remainder having to be estimated using random scales. Therefore, although lateral line scales provide more precise estimates of fish length, (and therefore should be used when possible) random body-scale relationships still need to be established and used for size estimation.

Despite its advantages, using scales for estimating the size of fish prey of river otters and other piscivores does have limitations. Perhaps the largest limitation is that not all fish possess scales. One of the most abundant North American fishes that lack scales are the catfishes of Ictaluridae, and accordingly they are commonly reported as prey in river otter diet studies (Field 1970, McDonald 1989, Serfass et al. 1990, Noordhuis 2002, Giordano 2005, Table 2.1). Therefore, by only using scales for size estimation, the size of some fish in the diet (occasionally a large portion) can't be evaluated. To avoid this, future studies should assess the utility of other structures for size estimation of ictalurids and other species that lack scales. One structure that should be investigated for potential use in estimating the size of ictalurids is pectoral spines. Pectoral spines are unique to ictalurids, distinct from other fish structures, are relatively abundant in scats, and can be

identified to the species level in some cases. Additionally, a relationship between spine size and fish length has previously been noted for the channel catfish (*Ictalurus punctatus*) (Klaasen and Townsend 1973).

Another limitation of using scales is that it is difficult to determine the actual number of fish consumed. In some instances it is possible to document multiple individuals of the same species (or group) within a scat by having non-overlapping 95% prediction intervals of fish size based on the size of scales in the scat, as previously noted by Wise (1980) using vertebrae. Using this technique in the river otter diet study, 2 fish of the same species were documented in 66 scats, and 3 fish of the same species were recorded in 5 scats. But, to distinguish multiple fish of the same species the estimated lengths have to be very different in some cases. For instance, estimated lengths of carp needed to be at least 7.2 cm or 10.9 cm apart (for lateral line and random scales, respectively) to be distinguished from one another. Furthermore, differences needed to be at least 12.5 cm (lateral line) or 17.1 cm (random) for white suckers. Small fish species such as darters and small cyprinids needed a smaller distinction between estimated lengths (at least 2.5 cm or 4.3 cm for lateral line and random models for darters, and 3.3 cm and 4.4 cm for small cyprinids, respectively). But, even such small differences are substantial for these groups, because their maximum size is about 10 cm in length. When foraging, piscivores are probably more likely to consume multiple small fish than multiple large individuals. But, since predicted lengths need to be several centimeters apart to separate individual fish, multiple individuals of small fish species could not be differentiated. For instance, multiple small cyprinid individuals could not be

distinguished within a scat using scales. But, remains of at least 25 individuals were documented in 1 scat, based upon the number of pharyngeal teeth the scat contained.

This study documented the utility of scales for estimating the prey size of river otters and other piscivores. Because of their abundance in scats, the existence of identification keys to the family level, the positive relationships between scale size and fish length, and the noninvasive method of establishing predictive relationships, scales are the structure best suited for use in fish prey size estimation. Additional research should be conducted on body-scale relationships to determine if other studies are in agreement with what was observed in this study, and to evaluate the relationships for species and groups (e.g., salmonids) that were not evaluated here. When possible, lateral line scales should be used for size estimation because they do provide a more precise estimation of fish length. But, because not all scats contain lateral line scales, body-scale relationships for non-lateral line scales need to be used as well. Also, because not all fish possess scales (e.g., catfish and sticklebacks), to completely describe the size of fish in the diet, additional structures need to be used. Additional study is needed in the identification of scales to the species level. Currently, identification is possible at least to the family level (in most cases), and often to smaller taxonomic groups. But, with additional research I believe that groups can be subdivided further, and more species differentiated. In doing so, a more precise estimate of the fish prey size of river otters and other piscivores can be obtained. Further research is also needed to determine if in passage through the digestive system of the river otter (or other piscivore) scales become degraded, thereby effecting prey size estimates.

Figure 3.1. Scale measurements used in assessing body-scale relationships of 22 fish species and 6 multi-species groups of fish of the Red River tributaries of eastern North Dakota. AR = anterior radius, ALR= anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius.
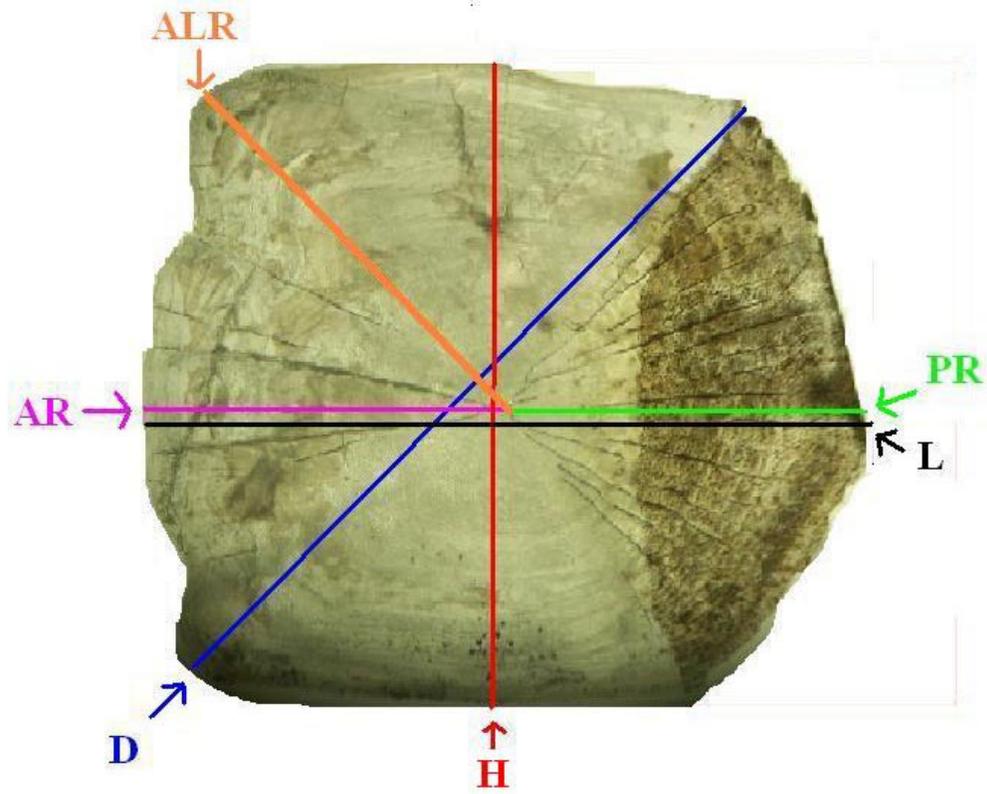
Figure 3.2. Comparison of the coefficient of determination (r^2) values between the best lateral line (LL) and random (R) single variable body-scale relationships of 22 fish species in the Red River of the North tributaries of eastern North Dakota using samples collected June – November 2007.
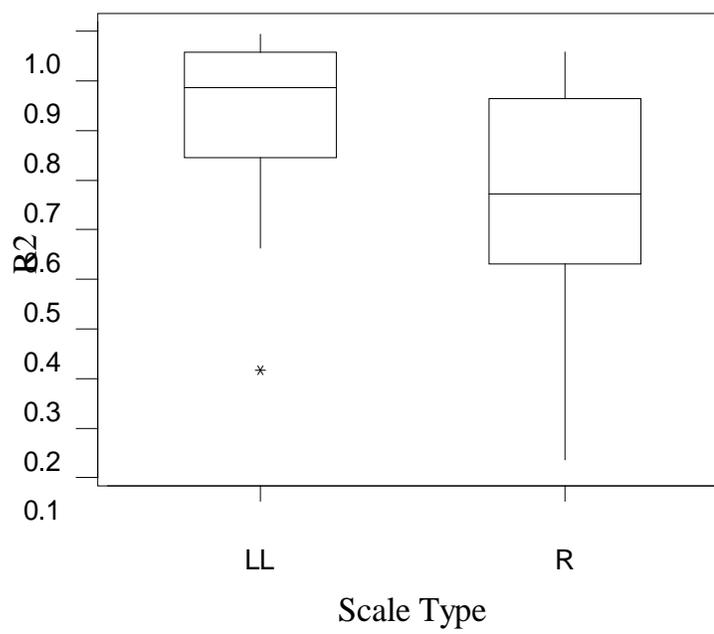
Table 3.1. The coefficient of determination (r^2), significance of relationship (P), and measurements of the best single variable lateral line and random body-scale relationships for 22 fish species of the Red River of the North tributaries of eastern North Dakota using samples collected June – November 2007. AR = anterior radius, ALR = anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius, PLR = posterolateral radius. *Indicates an insignificant relationship ($P \geq 0.05$).

	Lateral Line			Random		
	r^2	Measure.	P	r^2	Measure.	P
Catostomidae						
Shorthead Redhorse (*Moxostoma macrolepidotum*)	0.8502	PR	<0.0001	0.8821	PR	<0.0001
White Sucker (*Catostomus commersoni*)	0.9034	D	<0.0001	0.8172	H	<0.0001
Centrarchidae						
Black Crappie (*Pomoxis nigromaculatus*)	0.9801	H	<0.0001	0.9353	L	<0.0001
Bluegill (*Lepomis macrochirus*)	0.9942	D	<0.0001	0.9568	L	<0.0001
Cyprinidae						
Bigmouth Shiner (*Notropis dorsalis*)	0.5626	PR	<0.0001	0.5495	PLR	<0.0001
Blacknose Dace (*Rhinichthys atratulus*)	0.6303	H	<0.0001	0.6594	H	<0.0001
Bluntnose Minnow (*Pimephales notatus*)	0.7920	L	<0.0001	0.6516	PLR	<0.0001
Carp (*Cyprinus carpio*)	0.9634	L	<0.0001	0.9145	L	<0.0001
Common Shiner (*Luxilus cornutus*)	0.9578	L	<0.0001	0.6151	PR	<0.0001
Creek Chub (*Semotilus atromaculatus*)	0.9415	L	<0.0001	0.7814	PLR	<0.0001
Fathead Minnow (*Pimephales promelas*)	0.9381	PLR	<0.0001	0.6145	D	<0.0001
Horneyhead Chub (*Nocomis biguttatus*)	0.9647	L	<0.0001	0.8595	H	<0.0001
Largescale Stoneroller (*Campostoma oligolepis*)	0.7106	H	0.0003	0.1394	H	0.2088*
Longnose Dace (*Rhinichthys cataractae*)	0.7494	H	<0.0001	0.3950	PLR	0.0069
Sand Shiner (*Notropis stramineus*)	0.3169	PR	0.0289	0.1362	PLR	0.1199*
Spotfin Shiner (*Cyprinella spiloptera*)	0.8000	L	<0.0001	0.5965	L	0.0012
Esocidae						
Northern Pike (*Esox lucius*)	0.9520	H	<0.0001	0.7792	L	<0.0001
Moronidae						
White Bass (*Morone chrysops*)	0.9349	H	<0.0001	0.8230	H	<0.0001
Percidae						
Blackside Darter (*Percina maculata*)	0.8707	L	<0.0001	0.4760	H	<0.0001
Johnny Darter (*Etheostoma nigrum*)	0.7336	L	<0.0001	0.4396	H	<0.0001
Yellow Perch (*Perca flavescens*)	0.7974	L	<0.0001	0.6860	L	<0.0001
Sciaenidae						
Freshwater Drum (*Aplodinotus grunniens*)	0.9893	PR	<0.0001	0.9585	H	<0.0001
Mean	**0.8333**			**0.6667**		

Table 3.2. The slope, intercept, coefficient of determination (r^2), and the significance of the relationship (P) of single variable models of lateral line and random body-scale relationships of 22 fish species in the Red River of the North tributaries of North Dakota using samples collected June – November 2007. AR = anterior radius, ALR = anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius, PLR = posterolateral radius. *Indicates an insignificant relationship ($P \geq 0.05$). **Bold** indicates the model with the highest r^2.

	Lateral Line				Random			
	Slope	Intercept	*P*	*r*²	Slope	Intercept	*P*	*r*²
Catostomidae								
Shorthead Redhorse (*Moxostoma macrolepidotum*) $n_{LL} = 16$ $n_R = 15$								
L	3.2242	1.4251	<0.0001	0.5838	3.2320	0.5941	<0.0001	0.8177
H	3.1467	1.1178	<0.0001	0.6631	2.8708	1.0357	<0.0001	0.8365
D	2.7516	1.2975	<0.0001	0.6790	2.7057	1.0241	<0.0001	0.8703
AR	5.0082	2.0844	<0.0001	0.2438	3.3160	6.9659	<0.0001	0.7623
ALR	4.4651	1.6719	<0.0001	0.3584	4.0497	1.5206	<0.0001	0.8654
PR	**4.9094**	**2.6452**	**<0.0001**	**0.8502**	**4.3793**	**4.5491**	**<0.0001**	**0.8821**
White Sucker (*Catostomus commersoni*) $n_{LL} = 82$ $n_R = 84$								
L	3.2328	4.2899	<0.0001	0.8889	3.2969	5.6259	<0.0001	0.8065
H	4.7312	2.7034	<0.0001	0.8948	**4.8328**	**4.0946**	**<0.0001**	**0.8172**
D	**3.2914**	**4.4730**	**<0.0001**	**0.9034**	3.6086	5.2913	<0.0001	0.7321
AR	5.5828	6.0714	<0.0001	0.8879	6.0266	6.9984	<0.0001	0.7842
ALR	6.0799	5.1420	<0.0001	0.9027	4.9073	9.6950	<0.0001	0.6749
PR	7.2949	3.3804	<0.0001	0.8077	6.7981	4.9781	<0.0001	0.7772
Centrarchidae								
Black Crappie (*Pomoxis nigromaculatus*) $n_{LL} = 29$ $n_R = 28$								
L	3.6809	1.1242	<0.0001	0.9753	**3.4603**	**1.6734**	**<0.0001**	**0.9353**
H	**3.2388**	**1.2492**	**<0.0001**	**0.9801**	3.0844	1.9814	<0.0001	0.9014
D	2.9907	1.4651	<0.0001	0.9715	2.9785	1.9275	<0.0001	0.9138
AR	5.5772	2.9855	<0.0001	0.9327	5.1875	3.4235	<0.0001	0.9067
ALR	5.0705	2.3946	<0.0001	0.9615	4.5833	3.3055	<0.0001	0.9065
PR	8.4068	1.2756	<0.0001	0.8259	8.7146	0.6861	<0.0001	0.9169
Bluegill (*Lepomis macrochirus*) $n_{LL} = 18$ $n_R = 16$								
L	3.2242	1.4251	<0.0001	0.9875	**3.2320**	**0.5941**	**<0.0001**	**0.9568**
H	3.1467	1.1178	<0.0001	0.9938	2.8708	1.0357	<0.0001	0.9300
D	**2.7516**	**1.2975**	**<0.0001**	**0.9942**	2.7057	1.0241	<0.0001	0.9279
AR	5.0082	2.0844	<0.0001	0.9878	4.8643	1.5280	<0.0001	0.8869
ALR	4.4651	1.6719	<0.0001	0.9937	4.0497	1.5206	<0.0001	0.8782
PR	9.5980	0.6104	<0.0001	0.9810	8.0827	0.9040	<0.0001	0.9395
Cyprinidae								
Bigmouth Shiner (*Notropis dorsalis*) $n_{LL} = 22$ $n_R = 26$								
L	2.0664	3.1016	<0.0001	0.5469	2.1496	3.3545	0.0002	0.4464
H	1.8028	3.1259	0.0017	0.3965	1.0287*	4.6198*	0.0543*	0.1457*
D	1.8670	3.1468	0.0007	0.4473	1.8121	3.5517	0.0017	0.3409
AR	1.4514*	5.7526*	0.5653*	0.0168*	2.6297*	5.3440*	0.1731*	0.0759*
PLR	2.6459	3.3782	<0.0001	0.5431	**3.2343**	**3.0690**	**<0.0001**	**0.5495**
PR	**2.2797**	**3.4509**	**<0.0001**	**0.5626**	2.1488	3.9076	0.0008	0.3825
Blacknose Dace (*Rhinichthys atratulus*) $n_{LL} = 21$ $n_R = 26$								
L	2.2890	4.7785	0.0053	0.3429	3.6079	3.6896	<0.0001	0.5010
H	**4.0816**	**2.8095**	**<0.0001**	**0.6303**	**4.8547**	**2.7156**	**<0.0001**	**0.6594**
D	2.8591	3.9350	0.0003	0.5104	3.9732	3.2875	<0.0001	0.5093
AR	4.6062*	6.1536*	0.1024*	0.1342*	11.4647	4.5620	0.0189	0.2088
PLR	2.4474	5.3901	0.0137	0.2799	4.2525	4.1941	0.0006	0.3963
PR	2.4040	5.3881	0.0077	0.3183	3.6382	4.4704	0.0002	0.4388

Table 3.2. Continued.

	Lateral Line				**Random**			
	Slope	**Intercept**	***P***	***r²***	**Slope**	**Intercept**	***P***	***r²***
Bluntnose Minnow (*Pimephales notatus*) $n_{LL} = 35$ $n_R = 37$								
L	**2.8735**	**1.9973**	**<0.0001**	**0.7920**	2.5189	2.7598	<0.0001	0.6463
H	1.9321	2.2956	<0.0001	0.7850	1.5207	3.9184	<0.0001	0.4772
D	1.9718	2.5301	<0.0001	0.7813	1.8364	3.4134	<0.0001	0.6097
AR	11.7438	2.6054	<0.0001	0.6548	7.4006	4.6117	0.0040	0.2133
PLR	3.4585	2.2857	<0.0001	0.7520	**3.0951**	**3.0961**	**<0.0001**	**0.6516**
PR	3.4458	2.2793	<0.0001	0.7168	2.7330	3.1778	<0.0001	0.5866
Carp (*Cyprinus carpio*) $n_{LL} = 125$ $n_R = 128$								
L	**2.4548**	**0.5749**	**<0.0001**	**0.9634**	**2.3818**	**2.0683**	**<0.0001**	**0.9145**
H	2.7546	-0.5492	<0.0001	0.8871	2.5737	1.7872	<0.0001	0.8000
D	2.2939	0.4292	<0.0001	0.9411	2.3453	1.8186	<0.0001	0.8648
AR	5.0410	0.8651	<0.0001	0.9123	4.4613	3.0841	<0.0001	0.8706
ALR	4.4299	0.7380	<0.0001	0.8743	4.0912	3.1079	<0.0001	0.8409
PR	4.4569	1.3065	<0.0001	0.9494	4.7786	1.7677	<0.0001	0.8852
Common Shiner (*Luxilus cornutus*) $n_{LL} = 64$ $n_R = 56$								
L	**3.4499**	**1.7104**	**<0.0001**	**0.9578**	3.0418	3.8078	<0.0001	0.5805
H	1.6489	4.4621	<0.0001	0.7416	1.7283	5.6142	<0.0001	0.5180
D	1.7815	4.1586	<0.0001	0.8051	1.8869	5.2841	<0.0001	0.5504
AR	12.3154	3.1566	<0.0001	0.8548	7.4722	6.6538	<0.0001	0.2841
PLR	3.6136	3.1245	<0.0001	0.8859	3.7353	4.4841	<0.0001	0.5862
PR	4.3285	2.0678	<0.0001	0.9288	**4.1449**	**3.5944**	**<0.0001**	**0.6151**
Creek Chub (*Semotilus atromaculatus*) $n_{LL} = 59$ $n_R = 64$								
L	**4.5488**	**1.0350**	**<0.0001**	**0.9415**	4.3238	2.8557	<0.0001	0.7495
H	4.0643	2.0485	<0.0001	0.8861	4.3661	3.0696	<0.0001	0.7246
D	3.8616	1.9851	<0.0001	0.9188	4.0272	3.3207	<0.0001	0.7417
AR	15.2945	4.2896	<0.0001	0.6609	15.3298	5.1883	<0.0001	0.4961
PLR	6.0092	1.5722	<0.0001	0.9168	**5.9096**	**3.3178**	**<0.0001**	**0.7814**
PR	5.3735	1.9674	<0.0001	0.8901	5.1446	3.5612	<0.0001	0.7668
Fathead Minnow (*Pimephales promelas*) $n_{LL} = 13$ $n_R = 21$								
L	4.0775	1.5154	<0.0001	0.8599	2.6983	3.4837	0.0004	0.4961
H	2.0708	2.9076	0.0002	0.7252	2.1445	3.5824	0.0001	0.5547
D	2.3362	2.7040	0.0002	0.7266	**2.5230**	**3.2705**	**<0.0001**	**0.6145**
AR	9.7590	3.3418	0.0189	0.4071	6.3636	4.4857	0.0046	0.3523
PLR	**4.8466**	**1.9876**	**<0.0001**	**0.9381**	3.8750	3.4970	0.0002	0.5388
PR	5.0261	1.8826	<0.0001	0.8388	2.7935	4.1450	0.0031	0.3758
Horneyhead Chub (*Nocomis biguttatus*) $n_{LL} = 43$ $n_R = 48$								
L	**3.1860**	**1.0893**	**<0.0001**	**0.9647**	3.4199	1.4799	<0.0001	0.8170
H	2.9870	1.4413	<0.0001	0.7931	**3.6695**	**1.2060**	**<0.0001**	**0.8595**
D	3.0028	0.8779	<0.0001	0.9292	3.2853	1.7315	<0.0001	0.8404
AR	15.4959	2.6042	<0.0001	0.6779	13.2172	4.4094	<0.0001	0.5205
PLR	4.2290	1.1782	<0.0001	0.9312	4.6259	1.8361	<0.0001	0.8255
PR	3.7196	1.5413	<0.0001	0.9527	3.9694	1.8276	<0.0001	0.8027

Table 3.2. Continued.

| | **Lateral Line** | | | | **Random** | | | |
	Slope	Intercept	*P*	r^2	Slope	Intercept	*P*	r^2
Largescale Stoneroller (*Campostoma oligolepis*) $n_{LL} = 13$ $n_R = 13$								
L	1.8834	5.9118	0.0061	0.5100	0.2117*	10.6927*	0.8338*	0.0042*
H	**2.0728**	**4.4037**	**0.0003**	**0.7106**	0.8492*	9.0276*	0.2088*	0.1394*
D	2.2272	3.9454	0.0003	0.7085	0.6566*	9.5342*	0.4156*	0.0611*
AR	6.1714	7.5297	0.0314	0.3557	2.2639*	10.0981*	0.5207*	0.0385*
PLR	3.1057	4.6271	0.0038	0.5487	0.5509*	10.2408*	0.6607*	0.0182*
PR	2.2953	6.1698	0.0115	0.4548	0.0886*	11.0452*	0.9437*	0.0005*
Longnose Dace (*Rhinichthys cataractae*) $n_{LL} = 18$ $n_R = 17$								
L	3.6161	3.5117	<0.0001	0.6997	2.2520	5.4061	0.0177	0.3209
H	**5.8446**	**1.7238**	**<0.0001**	**0.7494**	3.2996	4.8554	0.0253	0.2914
D	4.3524	2.7252	<0.0001	0.7480	2.6997	5.0844	0.0182	0.3189
AR	10.9583	5.3942	0.0045	0.4058	6.9697*	6.4820*	0.1623*	0.1259*
PLR	4.2399	4.1717	0.0004	0.5592	**2.9251**	**5.5950**	**0.0069**	**0.3950**
PR	3.6961	4.3854	0.0002	0.6002	2.6130	5.5981	0.0127	0.3482
Sand Shiner (*Notropis stramineus*) $n_{LL} = 15$ $n_R = 19$								
L	1.6143*	3.4964*	0.0721*	0.2276*	0.7390*	4.9332*	0.1425*	0.1221*
H	0.2595*	5.7017*	0.5885*	0.0231*	0.3124*	5.4725*	0.4754*	0.0304*
D	0.2690*	5.6791*	0.5963*	0.0222*	0.6274*	4.9282*	0.1706*	0.1075*
AR	-0.1912*	6.2633*	0.9578*	0.0002*	1.0531*	5.7206*	0.4702*	0.0311*
PLR	1.5207*	4.3736*	0.1740*	0.1372*	**1.1605***	**4.7869***	**0.1199***	**0.1362***
PR	**1.8792**	**3.7478**	**0.0289**	**0.3169**	0.7921*	5.1154*	0.1517*	0.1170*
Spotfin Shiner (*Cyprinella spiloptera*) $n_{LL} = 17$ $n_R = 14$								
L	**3.1949**	**0.6211**	**<0.0001**	**0.8000**	1.8355	3.4755	0.0012	0.5965
H	0.9214	4.3754	0.0065	0.3992	1.2497*	4.3211*	0.0515*	0.2803*
D	1.0468	4.1596	0.0061	0.4046	1.5953	3.6216	0.0075	0.4615
AR	4.1123*	4.9637*	0.1742*	0.1194*	3.3893	5.6556	0.0326	0.3271
PLR	2.8257	2.6194	0.0008	0.5408	2.4053	3.5807	0.0025	0.5468
PR	3.9772	1.0837	<0.0001	0.6688	2.1766	3.6335	0.0028	0.5378
Esocidae								
Northern Pike (*Esox lucius*) $n_{LL} = 39$ $n_R = 44$								
L	5.7289	6.0980	<0.0001	0.9468	**6.0186**	**6.6233**	**<0.0001**	**0.7792**
H	**8.9319**	**2.4029**	**<0.0001**	**0.9520**	8.9844	5.4994	<0.0001	0.7712
D	6.1474	5.2299	<0.0001	0.9463	6.7268	5.8032	<0.0001	0.7672
AR	8.3515	7.9286	<0.0001	0.9447	8.1150	9.3480	<0.0001	0.7315
ALR	8.8429	7.7866	<0.0001	0.9348	8.9251	8.9449	<0.0001	0.7488
PR	17.3089	4.3102	<0.0001	0.8741	12.1453	10.7126	<0.0001	0.5012
Moronidae								
White Bass (*Morone chrysops*) $n_{LL} = 25$ $n_R = 30$								
L	4.6132	1.9254	<0.0001	0.9318	3.3745	4.2415	<0.0001	0.6739
H	**4.7386**	**1.1386**	**<0.0001**	**0.9349**	**3.7319**	**2.9911**	**<0.001**	**0.8230**
D	4.1476	1.3916	<0.0001	0.9202	2.9929	3.8849	<0.0001	0.7568
AR	6.4160	3.4908	<0.0001	0.7972	4.4888	5.5978	<0.0001	0.6556
ALR	5.9756	2.8450	<0.0001	0.8305	3.8248	5.5456	<0.0001	0.6536
PR	10.3871	2.6762	<0.0001	0.8417	10.7746	2.4668	<0.0001	0.5852

Table 3.2 Continued.

	Lateral Line				Random			
	Slope	Intercept	*P*	*r*²	Slope	Intercept	*P*	*r*²
Percidae								
Blackside Darter (*Percina maculata*) $n_{LL} = 44$ $n_R = 43$								
L	**5.5117**	**0.9496**	**<0.0001**	**0.8707**	3.4857	3.6622	<0.0001	0.3733
H	4.5670	1.9834	<0.0001	0.6537	**3.3704**	**3.4821**	**<0.0001**	**0.4760**
D	4.7489	1.3847	<0.0001	0.7543	3.3145	3.3479	<0.0001	0.4489
AR	6.2197	2.5121	<0.0001	0.7149	4.0711	4.3599	<0.0001	0.3252
ALR	5.6366	2.9141	<0.0001	0.5667	3.5403	4.5241	<0.0001	0.3326
PR	8.6611	3.7484	<0.0001	0.3613	8.3210	4.3367	0.0001	0.3090
Johnny Darter (*Etheostoma nigrum*) $n_{LL} = 36$ $n_R = 55$								
L	**4.2542**	**1.2516**	**<0.0001**	**0.7336**	2.2834	3.1999	<0.0001	0.2756
H	3.1270	1.8330	<0.0001	0.6876	**2.5621**	**2.4637**	**<0.0001**	**0.4396**
D	3.3346	1.5255	<0.0001	0.7205	2.8361	2.2001	<0.0001	0.4197
AR	5.7877	1.6714	<0.0001	0.7229	3.2478	3.2745	<0.0001	0.2789
ALR	5.2441	1.8581	<0.0001	0.6503	3.5045	2.9622	<0.0001	0.3838
PR	7.8522	2.8984	<0.0001	0.5223	5.9838	3.5598	<0.0001	0.2561
Yellow Perch (*Perca flavescens*) $n_{LL} = 43$ $n_R = 44$								
L	**3.8131**	**2.9761**	**<0.0001**	**0.7974**	**2.8937**	**5.3816**	**<0.0001**	**0.6860**
H	4.1355	3.9923	<0.0001	0.7459	2.8554	5.9082	<0.0001	0.5735
D	3.6724	3.2019	<0.0001	0.7840	2.4664	5.9652	<0.0001	0.5773
AR	5.1554	4.7154	<0.0001	0.7428	3.9071	6.4222	<0.0001	0.6434
ALR	4.8659	5.0793	<0.0001	0.7309	3.4366	6.6857	<0.0001	0.5842
PR	9.9158	3.1189	<0.0001	0.7811	6.9354	6.1103	<0.0001	0.5888
Sciaenidae								
Freshwater Drum (*Aplodinotus grunniens*) $n_{LL} = 10$ $n_R = 12$								
L	4.5328	2.2918	<0.0001	0.9850	5.6682	0.2974	<0.0001	0.9026
H	4.7078	1.1724	<0.0001	0.9576	**5.0421**	**0.5357**	**<0.0001**	**0.9585**
D	3.9597	1.8631	<0.0001	0.9758	4.8476	0.1537	<0.0001	0.9154
AR	6.7897	1.9828	<0.0001	0.9726	7.2461	1.3849	<0.0001	0.8422
ALR	6.6381	1.7409	<0.0001	0.9628	6.2001	1.6630	<0.0001	0.9397
PR	**12.7716**	**4.1994**	**<0.0001**	**0.9893**	21.6720	-0.5852	<0.0001	0.9385

Table 3.3. The slope, intercept, significance of the relationship (P), and coefficient of determination (r^2) for single variable multi-species models of fish from the Red River of the North tributaries of eastern North Dakota using samples collected June – November 2007. AR = anterior radius, ALR = anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius, PLR = posterolateral radius. * Indicates an insignificant relationship ($P \geq 0.05$). **Bold** indicates the model with the highest r^2 for each group.

	Lateral Line				Random			
	Slope	Intercept	*P*	r^2	Slope	Intercept	*P*	r^2
Centrarchidae								
L	3.4511	1.2402	<0.001	0.971	**3.4765**	**1.1097**	**<0.001**	**0.917**
H	**3.1965**	**1.1275**	**<0.001**	**0.975**	3.0402	1.8641	<0.001	0.819
D	2.8669	1.3695	<0.001	0.969	2.9167	1.6305	<0.001	0.861
AR	5.1954	2.5793	<0.001	0.930	5.0582	2.6975	<0.001	0.850
ALR	4.6523	2.1954	<0.001	0.944	4.3657	2.8136	<0.001	0.807
PR	8.8914	0.9918	<0.001	0.897	8.8592	0.7773	<0.001	0.865
Cyprinidae								
Cyprinids ≤10 cm (excluding *Cyprinus carpio* and *Rhinichthys* spp.)								
L	**2.2693**	**3.2831**	**<0.001**	**0.551**	1.6724	4.3477	<0.001	0.343
H	1.0707	4.8645	<0.001	0.261	-0.0025	6.7854	0.751	0*
D	1.3627	4.3541	<0.001	0.373	1.4369	4.5225	<0.001	0.288
AR	7.6666	4.3216	<0.001	0.331	3.4163	5.7766	<0.001	0.088
PR	2.6409	3.6337	<0.001	0.518	**1.9810**	**4.5107**	**<0.001**	**0.356**
PLR	2.6774	3.7121	<0.001	0.513	2.2753	4.4270	<0.001	0.345
Cyprinids >10 cm (excluding *Cyprinus carpio* and *Rhinichthys* spp.)								
L	**2.8134**	**4.7016**	**<0.001**	**0.485**	**1.9268**	**8.6306**	**<0.001**	**0.281**
H	0.8981	10.6343	<0.001	0.185	0.8499	11.5062	<0.001	0.117
D	1.1477	9.5339	<0.001	0.252	1.1014	10.6491	<0.001	0.178
AR	7.946	8.4908	<0.001	0.308	5.354	11.0103	<0.001	0.163
PR	2.9999	6.1976	<0.001	0.415	2.2390	9.0554	<0.001	0.273
PLR	2.7084	7.2633	<0.001	0.363	2.4050	9.1797	<0.001	0.278
Dace (*Rhinichthys* spp.)								
L	3.1444	3.9442	<0.001	0.552	3.0957	4.2469	<0.001	0.481
H	4.8054	2.4093	<0.001	0.588	**4.5832**	**3.1993**	**<0.001**	**0.532**
D	**3.6635**	**3.2535**	**<0.001**	**0.593**	3.6614	3.7423	<0.001	0.479
AR	6.6460	6.0305	0.007	0.183	10.5450	5.1005	0.003	0.197
PR	3.2148	4.7864	<0.001	0.513	3.3210	4.7767	<0.001	0.466
PLR	3.5214	4.6642	<0.001	0.450	3.7813	4.6411	<0.001	0.447

Table 3.3. Continued

Percidae

Darters

Blackside Darter (*Percina maculata*) and Johnny Darter (*Etheostoma nigrum*)

L	**5.9082**	**0.1863**	**<0.001**	**0.804**	4.0780	2.3799	<0.001	0.386
H	4.1310	1.7059	<0.001	0.440	3.1979	2.6366	<0.001	0.278
D	4.7166	0.8101	<0.001	0.591	3.8347	1.9125	<0.001	0.364
AR	7.2973	1.3227	<0.001	0.696	5.1749	2.8855	<0.001	0.344
ALR	6.6735	1.6480	<0.001	0.560	4.6656	2.9459	<0.001	0.348
PR	10.9770	2.5227	<0.001	0.531	**10.7770**	**2.9359**	**<0.001**	**0.405**

Moronidae/Sciaenidae

White Bass (*Morone chrysops*) and Freshwater Drum (*Aplodinotus grunniens*)

L	**4.5589**	**2.0861**	**<0.001**	**0.979**	5.1655	0.8863	<0.001	0.844
H	4.7087	1.1915	<0.001	0.957	**4.8196**	**0.7863**	**<0.001**	**0.932**
D	3.9829	1.7760	<0.001	0.970	4.4323	0.6994	<0.001	0.867
AR	6.5750	3.0399	<0.001	0.947	6.5441	2.9577	<0.001	0.796
ALR	6.5252	2.0593	<0.001	0.948	5.6806	2.8280	<0.001	0.881
PR	12.3776	2.0701	<0.001	0.904	16.7290	-0.8870	<0.001	0.703

Table 3.4. The lateral line and random body-scale models with the highest adjusted coefficient of determination (R^2) when 1–6 variables are included for 22 fish species of the Red River of the North tributaries of eastern North Dakota using samples collected June – November 2007. AR = anterior radius, ALR = anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius, PLR = posterolateral radius. **Bold** indicates the model with the highest adjusted R^2 for each species.

	Lateral Line		Random	
	Variables	Adjusted R^2	Variables	Adjusted R^2

Catostomidae

Shorthead Redhorse (*Moxostoma macrolepidotum*) $n_{LL} = 16$ $n_R = 15$

	Variables	Adjusted R^2	Variables	Adjusted R^2
1	PR	0.8395	PR	0.8730
2	H PR	0.8418	H PR	0.8834
3	**L H AR**	**0.8820**	L AR PR	0.9175
4	L H D AR	0.8787	**L D AR PR**	**0.9232**
5	L H D AR ALR	0.8672	L H D AR PR	0.9150
6	All	0.8536	All	0.9061

White Sucker (*Catostomus commersoni*) $n_{LL} = 82$ $n_R = 84$

	Variables	Adjusted R^2	Variables	Adjusted R^2
1	D	0.9022	H	0.8150
2	H ALR	0.9104	L H	0.8262
3	H ALR PR	0.9110	L H ALR	0.8288
4	L H ALR PR	0.9102	H D AR ALR	0.8341
5	**L H AR ALR PR**	**0.9117**	**L H D AR ALR**	**0.8391**
6	All	0.9107	**All**	**0.8391**

Centrarchidae

Black Crappie (*Pomoxis nigromaculatus*) $n_{LL} = 29$ $n_R = 28$

	Variables	Adjusted R^2	Variables	Adjusted R^2
1	H	0.9794	L	0.9328
2	L H	0.9797	L H	0.9319
3	**H ALR PR**	**0.9802**	**L H D**	**0.9383**
4	L H AR ALR	0.9799	L H D ALR	0.9367
5	H D AR ALR PR	0.9791	L H D ALR PR	0.9342
6	All	0.9782	All	0.9323

Bluegill (*Lepomis macrochirus*) $n_{LL} = 18$ $n_R = 16$

	Variables	Adjusted R^2	Variables	Adjusted R^2
1	D	0.9939	L	0.9537
2	**D ALR**	**0.9947**	L ALR	0.9785
3	H D ALR	0.9945	D AR PR	0.9846
4	H D AR ALR	0.9940	L H D ALR	0.9845
5	H D AR ALR PR	0.9935	**L H D AR ALR**	**0.9871**
6	All	0.9930	**All**	**0.9871**

Cyprinidae

Bigmouth Shiner (*Notropis dorsalis*) $n_{LL} = 22$ $n_R = 26$

	Variables	Adjusted R^2	Variables	Adjusted R^2
1	PR	0.5407	PLR	0.5307
2	**L PLR**	**0.5615**	PR PLR	0.5655
3	L PLR AR	0.5442	L PR PLR	0.5627
4	L D PLR AR	0.5186	**L D PR PLR**	**0.5731**
5	L D PR PLR AR	0.4560	L H D PR PLR	0.5609
6	All	0.4560	All	0.5386

Blacknose Dace (*Rhinichthys atratulus*) $n_{LL} = 21$ $n_R = 26$

	Variables	Adjusted R^2	Variables	Adjusted R^2
1	H	0.6109	**H**	**0.6452**
2	H AR	0.5990	H D	0.6388
3	H PR PLR	0.6032	L H PLR	0.6387
4	**L H PLR AR**	**0.6282**	L H D PLR	0.6357
5	L H D PLR AR	0.6122	L H D PLR AR	0.6214
6	All	0.5854	All	0.6020

Table 3.4. Continued.

	Lateral Line		Random	
	Variables	**Adjusted R^2**	**Variables**	**Adjusted R^2**
Bluntnose Minnow (*Pimephales notatus*) $n_{LL} = 35$ $n_R = 37$				
1	L	0.7857	PLR	0.6417
2	**L H**	**0.8509**	H D	0.6608
3	L H PR	0.8508	**L H D**	**0.6704**
4	L H PR AR	0.8481	H D PLR AR	0.6679
5	L H D PR AR	0.8430	L H D PR PLR	0.6631
6	All	0.8379	All	0.6524
Carp (*Cyprinus carpio*) $n_{LL} = 125$ $n_R = 128$				
1	L	0.9631	L	0.9138
2	L ALR	0.9680	L H	0.9344
3	PR ALR PR	0.9696	L H ALR	0.9424
4	H PR ALR PR	0.9700	L H D ALR	0.9441
5	H D PR ALR PR	0.9705	H D PR ALR PR	0.9443
6	**All**	**0.9709**	**All**	**0.9444**
Common Shiner (*Luxilus cornutus*) $n_{LL} = 64$ $n_R = 56$				
1	L	0.9571	PR	0.6080
2	L PR	0.9575	L AR	0.6449
3	**L PR AR**	**0.9576**	**L D AR**	**0.6880**
4	L D PR AR	0.9571	L D PR AR	0.6841
5	L D PR PLR AR	0.9564	L D PR PLR AR	0.6789
6	All	0.9557	All	0.6725
Creek Chub (*Semotilus atromaculatus*) $n_{LL} = 59$ $n_R = 64$				
1	L	0.9405	**PLR**	**0.7779**
2	L H	0.9470	H PLR	0.7767
3	L D PR	0.9475	H PLR AR	0.7769
4	**L H D PR**	**0.9478**	L H PR PLR	0.7740
5	L H D PR AR	0.9468	L H D PR PLR	0.7713
6	All	0.9451	All	0.7695
Fathead Minnow (*Pimephales promelas*) $n_{LL} = 13$ $n_R = 21$				
1	PLR	0.9324	D	0.5942
2	**L PLR**	**0.9328**	D AR	0.5900
3	L PLR AR	0.9308	**L D PR**	**0.6212**
4	L PR PLR AR	0.9249	L D PR PLR	0.6151
5	L D PR PLR AR	0.9164	L H D PR PLR	0.5955
6	All	0.9025	All	0.5679
Horneyhead Chub (*Nocomis biguttatus*) $n_{LL} = 43$ $n_R = 48$				
1	L	0.9638	H	0.8564
2	D PR	0.9706	**H PLR**	**0.8641**
3	L H PR	0.9713	H D PLR	0.8619
4	L H PLR AR	0.9712	H D PLR AR	0.8596
5	L H PR PLR AR	0.9707	H D PR PLR AR	0.8564
6	**All**	**0.9715**	All	0.8532

Table 3.4. Continued.

	Lateral Line		Random	
	Variables	**Adjusted R^2**	**Variables**	**Adjusted R^2**
Largescale Stoneroller (*Campostoma oligolepis*) $n_{LL} = 13$ $n_R = 13$				
1	H	0.6842	H	0.0612
2	L H	0.7829	**L H**	**0.3222**
3	L H AR	0.7867	L H PR	0.2533
4	**L H PR AR**	**0.8651**	L H PR PLR	0.1737
5	L H D PR AR	0.8525	L H D PR PLR	0.0582
6	All	0.8280	All	-0.0949
Longnose Dace (*Rhinichthys cataractae*) $n_{LL} = 18$ $n_R = 17$				
1	H	0.7337	PLR	0.3547
2	L H	0.7514	L PLR	0.3380
3	**H PLR AR**	**0.7519**	**L D PLR**	**0.3778**
4	H D PLR AR	0.7372	L H D PLR	0.3633
5	L H D PLR AR	0.7154	L H D PR PLR	0.3176
6	All	0.6895	All	0.2550
Sand Shiner (*Notropis stramineus*) $n_{LL} = 15$ $n_R = 19$				
1	PR	0.2644	PLR	0.0854
2	PR AR	0.2901	**H D**	**0.1279**
3	H D PLR	0.2662	H D PLR	0.0833
4	**L H D PR**	**0.3181**	L H D PR	0.0384
5	L H D PR PLR	0.2740	L H D PR AR	0.0081
6	All	0.1832	All	-0.0684
Spotfin Shiner (*Cyprinella spiloptera*) $n_{LL} = 17$ $n_R = 14$				
1	**L**	**0.7867**	L	0.5629
2	L PR	0.7779	**H PR**	**0.6058**
3	L PR AR	0.7628	H PR AR	0.5847
4	L PR PLR AR	0.7437	H D PR AR	0.5677
5	L H D PR AR	0.7219	L H D PR AR	0.5220
6	All	0.6944	All	0.4540
Esocidae				
Northern Pike (*Esox lucius*) $n_{LL} = 39$ $n_R = 44$				
1	H	0.9507	L	0.7739
2	L H	0.9692	L H	0.7875
3	L H ALR	0.9701	L H AR	0.8153
4	L H D ALR	0.9704	**L H D AR**	**0.8162**
5	**L H D ALR PR**	**0.9705**	L H D AR PR	0.8143
6	All	0.9698	All	0.8095

Table 3.4. Continued.

	Lateral Line		Random	
	Variables	**Adjusted R^2**	**Variables**	**Adjusted R^2**
Moronidae				
White Bass (*Morone chrysops*) $n_{LL} = 25$ $n_R = 30$				
1	H	0.9485	H	0.8167
2	L H	0.9572	H ALR	0.8219
3	L H ALR	0.9616	H AR ALR	0.8375
4	**L H ALR PR**	**0.9630**	L H ALR PR	0.8611
5	L H D ALR PR	0.9612	**L H D ALR PR**	**0.8625**
6	All	0.9591	All	0.8595
Percidae				
Blackside Darter (*Percina maculata*) $n_{LL} = 44$ $n_R = 43$				
1	L	0.8676	H	0.4632
2	L H	0.8686	**H PR**	**0.4853**
3	L H ALR	0.8710	H AR PR	0.4740
4	**L H AR ALR**	**0.8732**	H D AR PR	0.4644
5	L H AR ALR PR	0.8701	L H D AR PR	0.4502
6	All	0.8667	All	0.4371
Johnny Darter (*Etheostoma nigrum*) $n_{LL} = 36$ $n_R = 55$				
1	L	0.7257	H	0.4291
2	AR PR	0.7815	H PR	0.4783
3	**H AR PR**	**0.8091**	L H PR	0.4799
4	L H AR PR	0.8082	**L H ALR PR**	**0.4852**
5	L H AR ALR PR	0.8053	L H D ALR PR	0.4766
6	All	0.7994	All	0.4686
Yellow Perch (*Perca flavescens*) $n_{LL} = 43$ $n_R = 44$				
1	L	0.7925	L	0.6786
2	**D PR**	**0.8160**	**L D**	**0.7155**
3	L D PR	0.8130	L D ALR	0.7152
4	L D ALR PR	0.8096	L D AR ALR	0.7103
5	L H D ALR PR	0.8046	L H D AR ALR	0.7059
6	All	0.7995	All	0.6987
Sciaenidae				
Freshwater Drum (*Aplodinotus grunniens*) $n_{LL} = 10$ $n_R = 12$				
1	PR	0.9880	H	0.9543
2	D PR	0.9939	D AR	0.9629
3	L D PR	0.9935	**D AR ALR**	**0.9760**
4	**L D AR PR**	**0.9950**	L D ALR PR	0.9738
5	L H D AR PR	0.9943	H D AR ALR PR	0.9702
6	All	0.9926	All	0.9647

Table 3.5. The adjusted coefficient of determination (R^2) and measurements included in the best models including 1–6 variables for multi-species body-scale relationships of fish from the Red River of the North tributaries of eastern North Dakota using samples collected June – November 2007. AR = anterior radius, ALR = anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius, PLR = posterolateral radius. **Bold** indicates the model with the highest adjusted R^2.

Lateral Line		Random	
Variables	Adjusted R^2	Variables	Adjusted R^2
Centrarchidae			
H	0.975	L	0.916
H PR	0.977	L ALR	**0.944**
L H ALR	**0.978**	L H ALR	0.943
L H AR ALR	**0.978**	L H AR ALR	**0.944**
L H D AR ALR	**0.978**	L H D AR ALR	0.943
All	0.977	All	0.942
Cyprinidae Cyprinids ≤10 cm (Excluding *Cyprinus carpio* and *Rhinichthys* spp.)			
L	54.9	PR	**35.3**
L H	55.5	L AR	**35.3**
L H PLR	57.2	L AR PLR	**35.3**
L H D PLR	57.7	L H AR PLR	35.2
L H D AR PLR	**58.2**	L H AR PLR PR	34.9
All	58.0	All	34.6
Cyprinids >10 cm (Excluding (*Cyprinus carpio* and *Rhinichthys* spp.)			
L	48.0	L	27.4
AR PR	50.7	AR PR	28.2
H AR PR	**51.6**	H PLR AR	29.0
L H AR PR	51.2	H D AR PR	**29.1**
L H D AR PR	50.8	H D AR PLR PR	28.5
All	50.3	All	27.9
Dace Blacknose Dace (*Rhinichthys atratulus*) and Longnose Dace (*Rhinichthys cataractae*)			
D	0.582	H	0.521
H PR	**0.647**	H PLR	**0.535**
H PR PLR	**0.647**	L H AR	0.528
L H PR PLR	0.639	L H D AR	0.517
L H D PR PLR	0.632	L H AR PR PLR	0.505
All	0.621	All	0.492
Moronidae and Sciaenidae White Bass (*Morone chrysops*) and Freshwater Drum (*Aplodinotus grunniens*)			
L	0.979	H	0.930
L PR	0.979	H D	**0.934**
L H ALR	0.982	H D ALR	0.932
H AR ALR PR	0.983	H D AR ALR	0.930
H D AR ALR PR	**0.984**	H D AR ALR PR	0.929
All	**0.984**	All	0.927

Table 3.5. Continued.

Lateral Line		Random	
Variables	**Adjusted R^2**	**Variables**	**Adjusted R^2**
Percidae			
Darters			
Blackside Darter (*Percina maculata*) and			
Johnny Darter (*Etheostoma nigrum*)			
L	0.802	PR	0.399
AR PR	0.809	ALR PR	0.493
L AR PR	0.815	L ALR PR	**0.499**
L H AR PR	**0.817**	L AR ALR PR	0.497
L H D AR PR	0.816	L H D ALR PR	0.499
All	0.813	All	0.496

Table 3.6. Differences in predicted fish total lengths (cm) between single species and multi-species models using the variable with the highest coefficient of determination (r^2) (lateral line, random scales) for the multi-species models by the minimum, maximum, mean, and median scale samples used to construct the models. Models were established using fish sampled in the Red River of the North drainage of eastern North Dakota, June – November 2007. Positive values indicate that the multi-species model produced the largest estimate. Negative values indicate that the single species model provided the largest estimate. AR = anterior radius, ALR = anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius, PLR = posterolateral radius.

	Lateral Line				Random			
Species	**Min**	**Max**	**Mean**	**Med.**	**Min**	**Max**	**Mean**	**Med.**
Centrarchidae (H and L)								
Black Crappie (*Pomoxis nigromaculatus*)	-0.16	-0.38	-0.25	-0.24	-0.55	-0.47	-0.52	-0.52
Bluegill (*Lepomis macrochirus*)	0.04	0.28	0.15	0.20	0.70	1.87	1.23	1.43
Mean	**-0.06**	**-0.05**	**-0.05**	**-0.02**	**0.08**	**0.70**	**0.36**	**0.45**
Cyprinidae								
Cyprinids ≤10 cm (Excluding *Cyprinus carpio* and *Rhinichthys* spp.) (L and PR)								
Bigmouth Shiner (*Notropis dorsalis*)	0.06	0.46	0.25	0.24	0.27	0.23	0.25	0.25
Bluntnose Minnow (*Pimephales notatus*)	0.33	-0.19	0.09	0.08	0.76	-0.23	0.23	0.23
Common Shiner (*Luxilus cornutus*)	0.62	-1.42	0.17	0.31	-0.09	-4.23	-1.61	-1.48
Creek Chub (*Semotilus atromaculatus*)	-0.59	-2.42	-1.28	-0.95	-1.06	-4.32	-2.32	-2.46
Fathead Minnow (*Pimephales promelas*)	0.35	-1.16	-0.50	-0.68	-0.15	-0.68	-0.43	-0.41
Horneyhead Chub (*Nocomis biguttatus*)	1.11	-0.51	0.17	0.17	1.38	-2.76	-0.30	-0.05
Largescale Stoneroller (*Campostoma oligolepis*)	-2.02	-1.61	-1.83	-1.87	-3.30	-2.53	-2.87	-2.86
Sand Shiner (*Notropis stramineus*)	0.42	1.05	0.68	0.72	-0.14	1.22	0.62	0.60
Spotfin Shiner (*Cyprinella spiloptera*)	1.06	0.34	0.70	0.71	0.48	0.42	0.46	0.46
Mean	**0.15**	**-0.61**	**-0.17**	**-0.14**	**-0.21**	**-1.43**	**-0.66**	**-0.64**
Cyprinids >10 cm (Excluding *Cyprinus carpio* and *Rhinichthys* spp.)								
Common Shiner	1.75	0.28	0.86	0.81	3.52	0.39	1.71	1.81
Creek Chub	0.31	-4.25	-1.69	-1.52	2.95	-5.55	-0.72	-0.79
Horneyhead Chub	2.56	1.90	2.24	2.25	3.67	1.05	2.32	2.18
Largescale Stoneroller	0.93	2.37	1.65	1.78	0.48	3.79	2.22	2.19
Mean	**1.39**	**0.07**	**0.76**	**0.83**	**2.65**	**-0.08**	**1.38**	**1.35**
Dace (D and H)								
Blacknose Dace (*Rhinichthys atratulus*)	-0.24	0.67	0.31	0.36	0.37	0.11	0.24	0.23
Longnose Dace (*Rhinichthys cataractae*)	-0.04	-0.64	-0.37	-0.38	-0.91	0.21	-0.37	-0.32
Mean	**-0.14**	**0.01**	**-0.03**	**-0.01**	**-0.27**	**0.16**	**-0.06**	**-0.04**
Moronidae/Sciaenidae (L and H)								
White Bass (*Morone chrysops*)	0.12	0.01	0.05	0.05	-1.81	-1.79	-0.75	-0.46
Freshwater Drum (*Aplodinotus grunniens*)	-0.18	0.03	-0.14	-0.16	0.88	3.45	0.87	0.28
Mean	**-0.03**	**0.02**	**-0.04**	**-0.06**	**-0.47**	**0.83**	**0.06**	**-0.09**
Percidae								
Darters (L and PR)								
Blackside Darter (*Percina maculata*)	-0.60	-0.19	-0.34	-0.34	-1.03	-0.07	-0.65	-0.66
Johnny Darter (*Etheostoma nigrum*)	-0.37	1.00	0.41	0.37	-0.10	1.34	0.51	0.53
Mean	**-0.49**	**0.40**	**0.04**	**0.02**	**-0.56**	**0.63**	**-0.07**	**-0.07**
Overall Mean	**0.26**	**-0.21**	**0.06**	**0.09**	**0.30**	**-0.41**	**0.01**	**0.01**

Table 3.7. Mean coefficient of determination (r^2) for single variable models of body-scale relationships of 22 fish species from the Red River of the North tributaries of eastern North Dakota established from samples collected June – November 2007, by scale measurement. A. For single species models. B. For multi-species models.

A.

	Mean r^2	
Scale Measurement	Lateral Line	Random
Length	0.7867	0.6092
Height	0.7359	0.5913
Diagonal	0.7542	0.6068
Anterior Radius	0.5976	0.4710
Antero- or Posterolateral Radius	0.7182	0.6016
Posterior Radius	0.7288	0.5705

B.

	Mean r^2	
Scale Measurement	Lateral Line	Random
Length	0.7515	0.5623
Height	0.5972	0.4495
Diagonal	0.6545	0.5307
Anterior Radius	0.5845	0.4145
Antero- or Posterolateral Radius	0.6558	0.5310
Posterior Radius	0.6570	0.5377

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Appendix I. Map of North Dakota showing the Red River of the North and its tributaries in eastern North Dakota. The stars indicate the location of the four river otter study areas.

Tongue River

Forest River

Turtle River

Red River

Bismarck

Appendix II. Seasonality of the prey size of river otters (*Lontra canadensis*) in the Red River of the North drainage of eastern North Dakota, July 2006 – November 2007, by prey group. Scats collected 1 March – 31 May were considered as spring, 1 June – 30 August as summer, 1 September – 30 November as fall, and 1 December – 28 February as winter. * Indicates comparison excluded winter. ^ Indicates comparison was between summer and fall. ~ Indicates comparison was between spring and fall. [+] Comparison excluded summer. **Bold** indicates a significant difference ($P < 0.05$)

A. Carp (*Cyprinus carpio*)

Total Length (cm)	Spring (*n* = 81)	Summer (*n* = 62)	Fall (*n* = 213)	Winter (*n* = 21)	Total (*n* = 296)	χ^2	*P*
≤10	4.9	50.0	23.0	4.8	28.7	45.0	**<0.001**
10.1-20	6.2	12.9	51.2	42.9	44.3	68.2	**<0.001**
20.1-30	29.6	8.1	8.0	23.8	17.2	27.0	**<0.001**
30.1-40	37.0	16.1	8.9	23.8	21.6	33.7	**<0.001**
40.1-50	17.3	11.3	7.5	4.8	12.8	6.9	0.074
>50	4.9	1.6	1.4	0.0	2.7	3.5	0.177*

B. Non-carp cyprinids

Total Length (cm)	Spring (*n* = 2)	Summer (*n* = 13)	Fall (*n* = 34)	Winter (*n* = 1)	Total (*n* = 50)	χ^2	*P*
≤10	0.0	76.9	82.4	100.0	78.0	0.2	0.672^
10.1-20	50.0	23.1	17.6	0.0	20.0	0.2	0.672^
20.1-30	0.0	0.0	0.0	0.0	0.0	-	-
30.1-40	50.0	0.0	0.0	0.0	2.0	-	-
40.1-50	0.0	0.0	0.0	0.0	0.0	-	-
>50	0.0	0.0	0.0	0.0	0.0	-	-

Appendix II. Continued.

C. Catostomids

Total Length (cm)	Spring (n = 13)	Summer (n = 4)	Fall (n = 45)	Winter (n = 3)	Total (n = 65)	χ^2	P
≤10	0.0	0.0	2.2	0.0	1.5	-	-
10.1-20	15.4	25.0	64.4	100.0	53.8	13.7	**0.003**
20.1-30	15.4	0.0	13.3	0.0	12.3	0.0	0.850~
30.1-40	23.1	25.0	11.1	0.0	13.8	-	-
40.1-50	23.1	0.0	4.4	0.0	7.7	4.5	**0.035~**
>50	23.1	50.0	4.4	0.0	10.8	4.5	**0.035~**

D. Centrarchids

Total Length (cm)	Spring (n = 35)	Summer (n = 4)	Fall (n = 33)	Winter (n = 10)	Total (n = 82)	χ^2	P
≤10	11.4	0.0	51.5	20.0	28.0	15.7	**0.001**
10.1-20	77.1	100.0	30.3	60.0	57.3	18.5	**<0.001**
20.1-30	11.4	0.0	18.2	20.0	14.6	0.8	0.676+
30.1-40	0.0	0.0	0.0	0.0	0.0	-	-
40.1-50	0.0	0.0	0.0	0.0	0.0	-	-
>50	0.0	0.0	0.0	0.0	0.0	-	-

E. Percids

Total Length (cm)	Spring (n = 12)	Summer (n = 3)	Fall (n = 16)	Winter (n = 1)	Total (n = 32)	χ^2	P
≤10	50.0	0.0	62.5	100.0	53.1	4.0	0.137*
10.1-20	50.0	100.0	37.5	0.0	46.9	4.0	0.137*
20.1-30	0.0	0.0	0.0	0.0	0.0	-	-
30.1-40	0.0	0.0	0.0	0.0	0.0	-	-
40.1-50	0.0	0.0	0.0	0.0	0.0	-	-
>50	0.0	0.0	0.0	0.0	0.0	-	-

Appendix II. Continued.

F. Northern Pike (*Esox lucius*)

Total Length (cm)	Spring (*n* = 14)	Summer (*n* = 3)	Fall (*n* = 15)	Winter (*n* = 3)	Total (*n* = 35)	χ^2	*P*
≤10	0.0	0.0	0.0	0.0	0.0	-	-
10.1-20	0.0	66.7	6.7	0.0	8.6	-	-
20.1-30	21.4	0.0	53.3	0.0	31.4	5.0	0.082*
30.1-40	28.6	0.0	13.3	66.7	22.9	1.0	0.311~
40.1-50	42.9	0.0	20.0	33.3	28.6	1.8	0.184~
>50	7.1	33.3	6.7	0.0	8.6	-	-

G. White Bass (*Morone chrysops*) or Freshwater Drum (*Aplodinotus grunniens*)

Total Length (cm)	Spring (*n* = 21)	Summer (*n* = 1)	Fall (*n* = 6)	Winter (*n* = 2)	Total (*n* = 30)	χ^2	*P*
≤10	0.0	0.0	0.0	0.0	0.0	-	-
10.1-20	14.3	0.0	0.0	50.0	13.3	-	-
20.1-30	47.6	100.0	33.3	0.0	43.3	0.4	0.535~
30.1-40	33.3	0.0	33.3	50.0	33.3	0.0	1.000~
40.1-50	4.8	0.0	33.3	0.0	10.0	-	-
>50	0.0	0.0	0.0	0.0	0.0	-	-

Appendix III. Relative abundance of fish families and species during sampling using fyke nets and minnow traps 28 September to 2 November 2007 in river otter study areas on the Forest and Turtle Rivers of eastern North Dakota. The total Forest River study area includes sampling in the Forest River, Lake Ardoch, and Kelly Slough wetland (where only 128 bluntnose minnows were captured).

Species	Forest River (*n* = 127)	Lake Ardoch (*n* = 291)	Forest River Study Area (*n* = 546)	Turtle River (*n* = 253)	Total (*n* = 799)
Catostomidae	**1 (0.008)**	**8 (0.027)**	**9 (0.016)**	**29 (0.115)**	**38 (0.047)**
Quillback (*Carpiodes cyprinus*)				3 (0.012)	3 (0.004)
Shorthead Redhorse (*Moxostoma macrolepidotum*)				10 (0.039)	10 (0.012)
Smallmouth Buffalo (*Ictiobus bubalus*)	1 (0.008)	4 (0.014)	5 (0.009)	1 (0.004)	6 (0.007)
White Sucker (*Catostomus commersoni*)		4 (0.014)	4 (0.007)	15 (0.059)	19 (0.024)
Centrarchidae	**10 (0.079)**	**20 (0.069)**	**30 (0.055)**	**3 (0.012)**	**33 (0.041)**
Black Crappie (*Pomoxis nigromaculatus*)	2 (0.016)	6 (0.021)	8 (0.015)		8 (0.010)
Bluegill (*Lepomis macrochirus*)	8 (0.063)	14 (0.048)	22 (0.040)	1 (0.004)	23 (0.029)
Rock Bass (*Ambloplites rubestris*)				2 (0.008)	2 (0.002)
Cyprinidae	**101 (0.795)**	**110 (0.378)**	**339 (0.623)**	**115 (0.454)**	**454 (0.568)**
Bluntnose Minnow (*Pimephales notatus*)	9 (0.071)		137 (0.251)		137 (0.171)
Carp (*Cyprinus carpio*)	37 (0.291)	100 (0.344)	137 (0.251)	46 (0.182)	183 (0.229)
Fathead Minnow (*Pimephales promelas*)	55 (0.433)	7 (0.024)	62 (0.113)	8 (0.032)	70 (0.088)
Sand Shiner (*Notropis stramineus*)				26 (0.103)	26 (0.032)
Spotfin Shiner (*Cyprinella spiloptera*)		3 (0.010)	3 (0.005)	35 (0.138)	38 (0.047)
Esocidae					
Northern Pike (*Esox lucius*)		**2 (0.007)**	**2 (0.004)**	**3 (0.012)**	**5 (0.006)**
Ictaluridae	**14 (0.110)**	**151 (0.519)**	**165 (0.302)**	**78 (0.308)**	**243 (0.304)**
Black Bullhead (*Ameiurus melas*)	9 (0.071)	99 (0.340)	108 (0.198)	2 (0.008)	110 (0.138)
Channel Catfish (*Ictalurus punctatus*)	1 (0.008)		1 (0.002)	75 (0.296)	76 (0.095)
Madtom spp. (*Noturus* spp.)	4 (0.031)	52 (0.179)	56 (0.103)		56 (0.070)
Yellow Bullhead (*Ameiurus natalis*)				1 (0.004)	1 (0.001)
Moronidae					
White Bass (*Morone chrysops*)	**1 (0.008)**		**1 (0.002)**	**22 (0.087)**	**23 (0.029)**
Percidae					
Yellow Perch (*Perca flavescens*)				**1 (0.004)**	**1 (0.001)**
Sciaenidae					
Freshwater Drum (*Aplodinotus grunniens*)				**2 (0.008)**	**2 (0.002)**

Appendix IV. Relative abundance of fish category sizes included in sampling conducted 28 September to 2 November 2007 in river otter study areas on the Forest and Turtle Rivers in eastern North Dakota.

Fish	Total Length (cm)					
	$\leq$10	10.1-20	20.1-30	30.1-40	40.1-50	>50
Catostomidae (*n* =38)	0.0263	0.0526	0.1316	0.3684	0	0
Centrarchidae (*n* =33)	0.5455	0.3030	0.1515	0	0	0
Cyprinidae						
Carp (*Cyprinus carpio*) (*n* =183)	0.2623	0.6995	0.0383	0	0	0
Other Cyprinids (*n* =271)	1	0	0	0	0	0
Esocidae Northern Pike (*Esox lucius*) (*n* =5)	0	0	0	0.8000	0.2000	0
Moronidae/Sciaenidae (*n* =25) White Bass (*Morone chrysops*) or Freshwater Drum (*Aplodinotus grunniens*)	0	0.9600	0	0	0.0400	0
Total	**0.6133**	**0.3076**	**0.0432**	**0.0324**	**0.0036**	**0**

Appendix V. Sample size of scales collected from fish of the Red River of the North tributaries of eastern North Dakota, by river, and the range and mean total length (cm) of sampled fish. For sample sizes, the number of lateral line scale samples precedes the number of random scale samples.

Species	Length Range	Mean Length	Samples By River (Lateral Line, Random Scales)									Total
			Bois de Sioux	Elm	Forest	Goose	Park	Pembina	Tongue	Turtle	Wild Rice	
Catostomidae												
Shorthead Redhorse (*Moxostoma macrolepidotum*)	7.1-24.6	19.0	1, 1	4, 3						11, 11		**16, 15**
White Sucker (*Catostomus commersoni*)	6.4-44.9	20.7		2, 2	48, 47	5, 6	4, 4	1, 2		22, 23		**82, 84**
Centrarchidae												
Bluegill (*Lepomis macrochirus*)	2.9-18.3	9.9	1, 1		16, 14					1, 1		**18, 16**
Black Crappie (*Pomoxis nigromaculatus*)	4.4-21.0	10.8	1, 1		6, 5				7, 7	7, 7	8, 8	**29, 28**
Green Sunfish (*Lepomis cyanellus*)	2.8	2.8									1, 1	**1, 1**
Orangespotted Sunfish (*Lepomis humilis*)	6.2-7.9	7.1	4, 4									**4, 4**
Rock Bass (*Ambloplites rupestris*)	13.0-25.0	17.7			4, 4					2, 2		**6, 6**
Cyprinidae												
Bigmouth Shiner (*Notropis dorsalis*)	4.7-7.3	6.0			17, 20					5, 6		**22, 26**
Blacknose Dace (*Rhinichthys atratulus*)	3.5-9.4	7.0			17, 22		3, 3			1, 1		**21, 26**
Bluntnose Minnow (*Pimephales notatus*)	2.7-8.6	6.6			35, 37							**35, 37**
Brassy Minnow (*Hybognathus hankinsoni*)	8.7	8.7						1, 1				**1, 1**
Carp (*Cyprinus carpio*)	3.0-68.9	12.1	21, 21	3, 3	41, 42					50, 52	10, 10	**125, 128**
Common Shiner (*Luxilus cornutus*)	3.3-16.8	9.6		3, 3	37, 34	6, 3	2, 2	2, 2	4, 4	10, 8		**64, 56**
Creek Chub (*Semotilus atromaculatus*)	3.5-23.7	12.5			29, 33	15, 15	3, 2	2, 1	3, 4	7, 9		**59, 64**
Emerald Shiner (*Notropis atherinoides*)	7.5-8.4	7.8	4, 4									**4, 4**
Fathead Minnow (*Pimephales promelas*)	3.4-7.4	6.0		2, 2	8, 14	1, 1	2, 2	0, 2				**13, 21**
Horneyhead Chub (*Nocomis biguttatus*)	3.2-15.8	10.1			43, 48							**43, 48**
Largescale Stoneroller (*Campostoma oligolepis*)	8.9-12.9	11.2			13, 13							**13, 13**
Longnose Dace (*Rhinichthys cataractae*)	5.8-10.9	8.2			16, 16			1, 0		1, 1		**18, 17**
Pearl Dace (*Margariscus margarita*)	7.1-7.8	7.5							0, 2			**0, 2**
Sand Shiner (*Notropis stramineus*)	4.8-7.5	6.1	3, 4	2, 3				2, 2		8, 10		**15, 19**
Spotfin Shiner (*Cyprinella spiloptera*)	5.3-8.6	6.9	5, 5	4, 3	1, 1					5, 3	2, 2	**17, 14**

Species	Length Range	Mean Length	Samples By River (Lateral Line, Random Scales)									Total
			Bois de Sioux	Elm	Forest	Goose	Park	Pembina	Tongue	Turtle	Wild Rice	
Esocidae												
Northern Pike (*Esox lucius*)	13.2-55.0	23.8	1, 1		33, 36	1, 1				3, 5		**39, 44**
Moronidae												
White Bass (*Morone chrysops*)	5.8-15.3	10.9	8, 8		1, 1					16, 21		**25, 30**
Percidae												
Blackside Darter (*Percina maculata*)	3.4-9.0	6.9			31, 30	8, 8			1, 1	4, 4		**44, 43**
Johnny Darter (*Etheostoma nigrum*)	2.6-7.3	5.0			21, 27	12, 24		1,1		2, 3		**36, 55**
Yellow Perch (*Perca flavescens*)	6.5-21.9	11.9			32, 33				7, 7	1, 1	3, 3	**43, 44**
Sciaenidae Freshwater Drum (*Aplodinotus grunniens*)	3.6-43.5	12.7	8, 9							2, 3		**10, 12**

Appendix VI. Pearson correlation coefficients between variables used in lateral line and random body-scale relationship models of 22 fish species from the Red River of the North tributaries of eastern North Dakota. AR = anterior radius, ALR = anterolateral radius, D = diagonal, H = height, L = length, PR = posterior radius, PLR = posterolateral radius

	Lateral Line						Random				

Catostomidae

Shorthead Redhorse (*Moxostoma macrolepidotum*)

	L	H	D	AR	ALR		L	H	D	AR	ALR
H	0.864					**H**	0.878				
	<0.001						<0.001				
D	0.956	0.948				**D**	0.959	0.955			
	<0.001	<0.001					<0.001	<0.001			
AR	0.914	0.770	0.859			**AR**	0.984	0.828	0.926		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.887	0.907	0.913	0.938		**ALR**	0.951	0.944	0.952	0.927	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.866	0.812	0.873	0.601	0.637	**PR**	0.981	0.917	0.967	0.937	0.958
	<0.001	<0.001	<0.001	0.014	0.008		<0.001	<0.001	<0.001	<0.001	<0.001

White Sucker (*Catostomus commersoni*)

	L	H	D	AR	ALR		L	H	D	AR	ALR
H	0.968					**H**	0.957				
	<0.001						<0.001				
D	0.987	0.983				**D**	0.943	0.917			
	<0.001	<0.001					<0.001	<0.001			
AR	0.983	0.957	0.979			**AR**	0.979	0.944	0.945		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.979	0.970	0.983	0.989		**ALR**	0.914	0.922	0.788	0.923	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.968	0.930	0.946	0.911	0.909	**PR**	0.965	0.950	0.918	0.936	0.894
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Centrarchidae

Black Crappie (*Pomoxis nigromaculatus*)

	L	H	D	AR	ALR		L	H	D	AR	ALR
H	0.994					**H**	0.972				
	<0.001						<0.001				
D	0.993	0.994				**D**	0.989	0.993			
	<0.001	<0.001					<0.001	<0.001			
AR	0.977	0.977	0.990			**AR**	0.988	0.965	0.981		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.981	0.987	0.990	0.983		**ALR**	0.987	0.981	0.990	0.991	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.923	0.906	0.879	0.829	0.863	**PR**	0.983	0.960	0.974	0.952	0.962
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Appendix VI. Continued.

Lateral Line						Random				

Bluegill (*Lepomis macrochirus*)

	L	H	D	AR	ALR		L	H	D	AR	ALR
H	0.994					H	0.990				
	<0.001						<0.001				
D	0.996	0.999				D	0.994	0.996			
	<0.001	<0.001					<0.001	<0.001			
AR	0.998	0.995	0.997			AR	0.982	0.963	0.973		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001	<0.001	
ALR	0.994	0.999	0.997	0.993		ALR	0.985	0.976	0.982	0.994	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.997	0.991	0.992	0.992	0.991	PR	0.953	0.959	0.954	0.882	0.894
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Cyprinidae

Bigmouth Shiner (*Notropis dorsalis*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.781					H	0.567				
	<0.001						0.003				
D	0.855	0.954				D	0.786	0.875			
	<0.001	<0.001					<0.001	<0.001			
PR	0.972	0.772	0.841			PR	0.949	0.536	0.710		
	<0.001	<0.001	<0.001				<0.001	0.005	<0.001		
PLR	0.807	0.719	0.735	0.845		PLR	0.924	0.670	0.813	0.939	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.340	0.194	0.248	0.177	0.148	AR	0.436	0.158	0.363	0.201	0.236
	0.122	0.387	0.265	0.431	0.512		0.026	0.440	0.068	0.325	0.245

Blacknose Dace (*Rhinichthys atratulus*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.679					H	0.856				
	0.001						<0.001				
D	0.851	0.912				D	0.915	0.922			
	<0.001	<0.001					<0.001	<0.001			
PR	0.930	0.620	0.782			PR	0.975	0.841	0.926		
	<0.001	0.003	<0.001				<0.001	<0.001	<0.001		
PLR	0.905	0.651	0.791	0.941		PLR	0.963	0.808	0.890	0.963	
	<0.001	0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.490	0.560	0.582	0.198	0.191	AR	0.480	0.487	0.452	0.352	0.456
	0.024	0.008	0.006	0.389	0.407		0.013	0.012	0.020	0.078	0.019

Appendix VI. Continued.

	Lateral Line						Random				
	L	H	D	PR	PLR		L	H	D	PR	PLR

Bluntnose Minnow (*Pimephales notatus*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.835					**H**	0.810				
	<0.001						<0.001				
D	0.851	0.987				**D**	0.889	0.969			
	<0.001	<0.001					<0.001	<0.001			
PR	0.969	0.810	0.833			**PR**	0.977	0.763	0.845		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
PLR	0.930	0.887	0.881	0.931		**PLR**	0.940	0.861	0.928	0.934	
	<0.001	0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.864	0.819	0.819	0.788	0.823	**AR**	0.503	0.669	0.622	0.356	0.475
	<0.001	0.001	<0.001	<0.001	<0.001		0.002	<0.001	<0.001	0.030	0.003

Carp (*Cyprinus carpio*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.967					**H**	0.971				
	<0.001						<0.001				
D	0.993	0.984				**D**	0.988	0.992			
	<0.001	<0.001					<0.001	<0.001			
PR	0.980	0.960	0.974			**PR**	0.980	0.942	0.961		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
PLR	0.970	0.983	0.979	0.976		**PLR**	0.985	0.974	0.981	0.980	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.984	0.944	0.977	0.932	0.934	**AR**	0.977	0.962	0.976	0.918	0.947
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Common Shiner (*Luxilus cornutus*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.864					**H**	0.863				
	<0.001						<0.001				
D	0.903	0.991				**D**	0.905	0.987			
	<0.001	<0.001					<0.001	<0.001			
PR	0.978	0.866	0.901			**PR**	0.987	0.827	0.870		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
PLR	0.954	0.926	0.948	0.951		**PLR**	0.960	0.914	0.940	0.952	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.937	0.869	0.899	0.904	0.903	**AR**	0.876	0.820	0.855	0.797	0.834
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Appendix VI. Continued.

	Lateral Line						Random				
Creek Chub (*Semotilus atromaculatus*)											
	L	**H**	**D**	**PR**	**PLR**		**L**	**H**	**D**	**PR**	**PLR**
H	0.940					**H**	0.945				
	<0.001						<0.001				
D	0.966	0.979				**D**	0.969	0.986			
	<0.001	<0.001					<0.001	<0.001			
PR	0.982	0.907	0.945			**PR**	0.979	0.921	0.951		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
PLR	0.981	0.946	0.967	0.975		**PLR**	0.981	0.945	0.967	0.983	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.814	0.835	0.802	0.713	0.773	**AR**	0.844	0.855	0.856	0.767	0.818
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001
Fathead Minnow (*Pimephales promelas*)											
	L	**H**	**D**	**PR**	**PLR**		**L**	**H**	**D**	**PR**	**PLR**
H	0.878					**H**	0.869				
	<0.001						<0.001				
D	0.893	0.983				**D**	0.905	0.967			
	<0.001	<0.001					<0.001	<0.001			
PR	0.943	0.739	0.759			**PR**	0.975	0.818	0.857		
	<0.001	0.004	0.003				<0.001	<0.001	<0.001		
PLR	0.975	0.869	0.878	0.955		**PLR**	0.921	0.864	0.905	0.900	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.673	0.793	0.739	0.463	0.631	**AR**	0.640	0.600	0.630	0.540	0.550
	0.012	0.001	0.004	0.111	0.021		0.002	0.004	0.002	0.011	0.010
Horneyhead Chub (*Nocomis biguttatus*)											
	L	**H**	**D**	**PR**	**PLR**		**L**	**H**	**D**	**PR**	**PLR**
H	0.866					**H**	0.949				
	<0.001						<0.001				
D	0.959	0.962				**D**	0.971	0.980			
	<0.001	<0.001					<0.001	<0.001			
PR	0.992	0.836	0.938			**PR**	0.985	0.935	0.958		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
PLR	0.976	0.870	0.954	0.978		**PLR**	0.973	0.944	0.967	0.979	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.839	0.856	0.866	0.776	0.763	**AR**	0.766	0.768	0.777	0.665	0.714
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Appendix VI. Continued.

Lateral Line						Random				

Largescale Stoneroller (*Campostoma oligolepis*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.511					**H**	0.876				
	0.074						<0.001				
D	0.864	0.825				**D**	0.924	0.955			
	<0.001	0.001					<0.001	<0.001			
PR	0.983	0.490	0.862			**PR**	0.989	0.828	0.891		
	<0.001	0.089	<0.001				<0.001	<0.001	<0.001		
PLR	0.900	0.614	0.858	0.923		**PLR**	0.910	0.859	0.892	0.924	
	<0.001	0.026	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.819	0.560	0.740	0.738	0.660	**AR**	0.809	0.821	0.770	0.740	0.614
	0.001	0.047	0.004	0.004	0.014		0.001	0.001	0.002	0.004	0.026

Longnose Dace (*Rhinichthys cataractae*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.863					**H**	0.824				
	<0.001						<0.001				
D	0.934	0.941				**D**	0.963	0.828			
	<0.001	0.001					<0.001	<0.001			
PR	0.946	0.829	0.898			**PR**	0.988	0.789	0.934		
	<0.001	<0.001	0.001				<0.001	<0.001	<0.001		
PLR	0.887	0.783	0.855	0.936		**PLR**	0.967	0.765	0.896	0.978	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
AR	0.619	0.609	0.579	0.389	0.321	**AR**	0.777	0.838	0.813	0.724	0.656
	0.006	0.007	0.012	0.111	0.194		<0.001	<0.001	<0.001	0.001	0.004

Sand Shiner (*Notropis stramineus*)

	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.557					**H**	0.728				
	0.031						<0.001				
D	0.624	0.950				**D**	0.871	0.926			
	0.013	<0.001					<0.001	<0.001			
PR	0.960	0.484	0.592			**PR**	0.944	0.685	0.790		
	<0.001	0.067	0.020				<0.001	0.001	<0.001		
PLR	0.807	0.787	0.898	0.827		**PLR**	0.893	0.710	0.816	0.914	
	<0.001	0.001	<0.001	<0.001			<0.001	0.001	<0.001	<0.001	
AR	0.566	0.751	0.754	0.415	0.649	**AR**	0.535	0.469	0.542	0.282	0.336
	0.028	0.001	0.001	0.124	0.009		0.018	0.043	0.017	0.241	0.160

Appendix VI. Continued.

Lateral Line						Random				
Spotfin Shiner (*Cyprinella spiloptera*)										
	L	H	D	PR	PLR		L	H	D	PR	PLR
H	0.680					**H**	0.402				
	0.003						0.154				
D	0.681	0.990				**D**	0.727	0.872			
	0.003	<0.001					0.003	<0.001			
PR	0.873	0.690	0.693			**PR**	0.936	0.248	0.588		
	<0.001	0.002	0.002				<0.001	0.392	0.027		
PLR	0.785	0.891	0.898	0.837		**PLR**	0.813	0.477	0.638	0.878	
	<0.001	<0.001	<0.001	<0.001			<0.001	0.084	0.014	<0.001	
AR	0.416	0.171	0.139	0.032	0.086	**AR**	0.645	0.690	0.780	0.365	0.338
	0.097	0.511	0.595	0.902	0.742		0.013	0.006	0.001	0.200	0.238

Esocidae
Northern Pike (*Esox lucius*)

	L	H	D	AR	ALR		L	H	D	AR	ALR
H	0.956					**H**	0.945				
	<0.001						<0.001				
D	0.991	0.971				**D**	0.985	0.973			
	<0.001	<0.001					<0.001	<0.001			
AR	0.993	0.962	0.991			**AR**	0.989	0.950	0.983		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.984	0.969	0.986	0.992		**ALR**	0.982	0.966	0.986	0.990	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.971	0.911	0.951	0.945	0.936	**PR**	0.846	0.749	0.810	0.824	0.791
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Moronidae
White Bass (*Morone chrysops*)

	L	H	D	AR	ALR		L	H	D	AR	ALR
H	0.943					**H**	0.910				
	<0.001						<0.001				
D	0.980	0.963				**D**	0.962	0.974			
	<0.001	<0.001					<0.001	<0.001			
AR	0.952	0.886	0.923			**AR**	0.991	0.901	0.947		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.946	0.932	0.941	0.980		**ALR**	0.964	0.933	0.958	0.974	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.934	0.896	0.944	0.805	0.808	**PR**	0.913	0.863	0.900	0.876	0.827
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Appendix VI. Continued.

Lateral Line						Random				
Percidae										
Blackside Darter (*Percina maculata*)										
	L	**H**	**D**	**AR**	**ALR**		**L**	**H**	**D**	**AR**	**ALR**
H	0.829					**H**	0.817				
	<0.001						<0.001				
D	0.904	0.951				**D**	0.897	0.937			
	<0.001	<0.001					<0.001	<0.001			
AR	0.905	0.782	0.810			**AR**	0.935	0.841	0.890		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.833	0.803	0.802	0.927		**ALR**	0.838	0.881	0.899	0.908	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.620	0.537	0.596	0.331	0.234	**PR**	0.750	0.591	0.611	0.550	0.437
	<0.001	<0.001	<0.001	0.028	0.126		<0.001	<0.001	<0.001	<0.001	<0.001
Johnny Darter (*Etheostoma nigrum*)										
	L	**H**	**D**	**AR**	**ALR**		**L**	**H**	**D**	**AR**	**ALR**
H	0.834					**H**	0.696				
	<0.001						<0.001				
D	0.874	0.941				**D**	0.768	0.959			
	<0.001	<0.001					<0.001	<0.001			
AR	0.903	0.801	0.833			**AR**	0.925	0.752	0.814		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.832	0.764	0.798	0.901		**ALR**	0.814	0.886	0.890	0.907	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.810	0.620	0.682	0.599	0.558	**PR**	0.747	0.437	0.526	0.544	0.466
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	0.001	<0.001	<0.001	<0.001
Yellow Perch (*Perca flavescens*)										
	L	**H**	**D**	**AR**	**ALR**		**L**	**H**	**D**	**AR**	**ALR**
H	0.964					**H**	0.961				
	<0.001						<0.001				
D	0.977	0.982				**D**	0.974	0.984			
	<0.001	<0.001					<0.001	<0.001			
AR	0.981	0.948	0.962			**AR**	0.974	0.939	0.950		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.966	0.966	0.976	0.967		**ALR**	0.962	0.947	0.949	0.977	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.922	0.873	0.898	0.879	0.865	**PR**	0.888	0.847	0.850	0.780	0.779
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Appendix VI. Continued.

Lateral Line						Random				
Sciaenidae										
Freshwater Drum (*Aplodinotus grunniens*)										
	L	**H**	**D**	**AR**	**ALR**		**L**	**H**	**D**	**AR**	**ALR**
H	0.988					**H**	0.985				
	<0.001						<0.001				
D	0.997	0.997				**D**	0.998	0.985			
	<0.001	<0.001					<0.001	<0.001			
AR	0.998	0.986	0.995			**AR**	0.993	0.960	0.991		
	<0.001	<0.001	<0.001				<0.001	<0.001	<0.001		
ALR	0.996	0.993	0.997	0.997		**ALR**	0.991	0.992	0.992	0.980	
	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001	
PR	0.987	0.963	0.976	0.979	0.969	**PR**	0.955	0.980	0.953	0.914	0.954
	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001

Appendix VII. The best body-scale relationships for shorthead redhorse (*Moxostoma macrolepidotum*) established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 16. B. Using random scales, n_r = 15.

A.
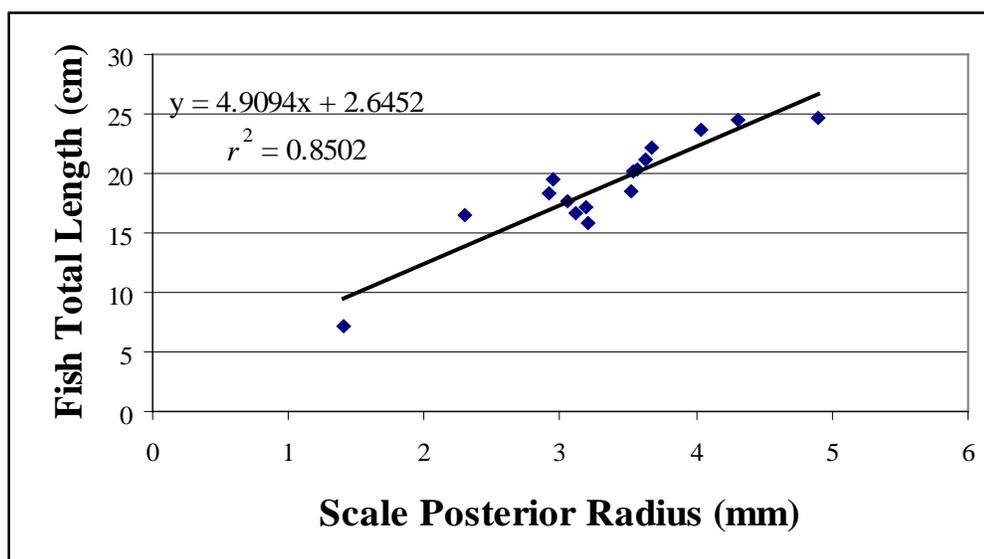
B.
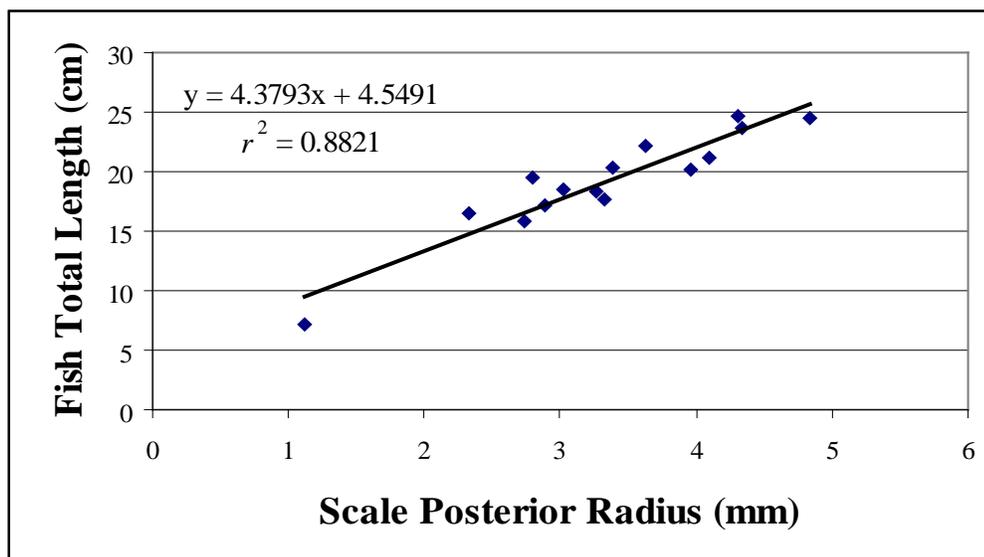
Appendix VIII. The best body-scale relationships for white sucker (*Catostomus commersoni*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 82$. B. Using random scales, $n_r = 84$.

A.
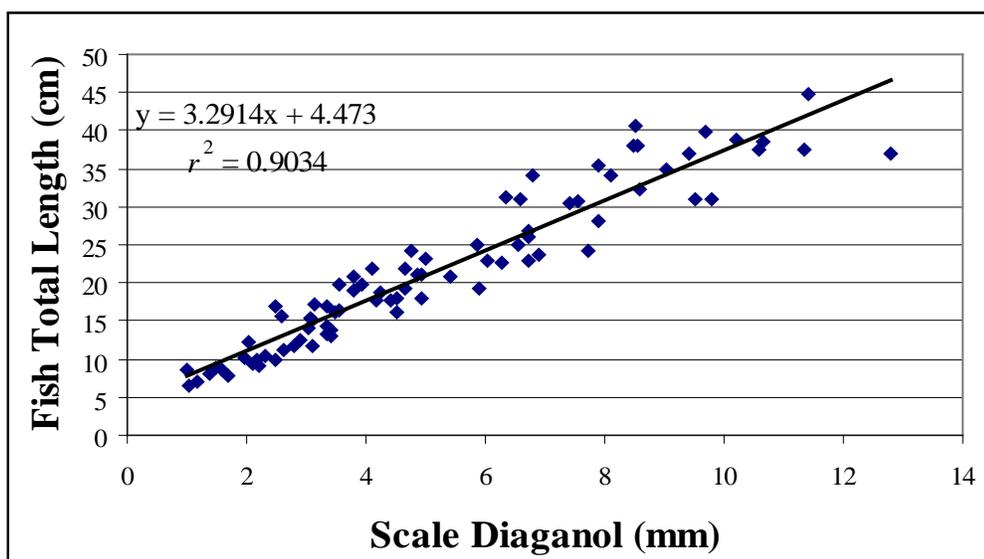
B.
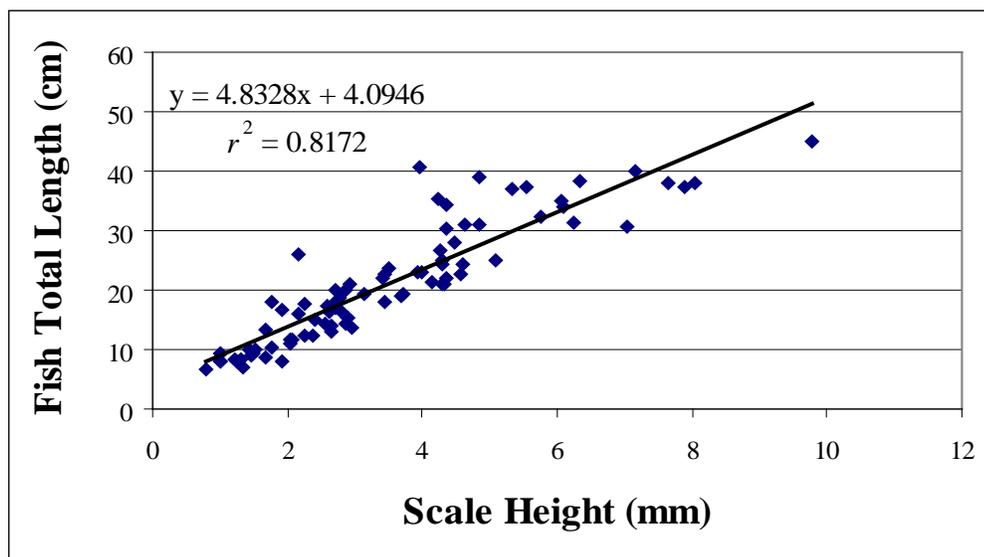
Appendix IX. The best body-scale relationships for black crappie (*Pomoxis nigromaculatus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 29$. B. Using random scales, $n_r = 28$.

A.
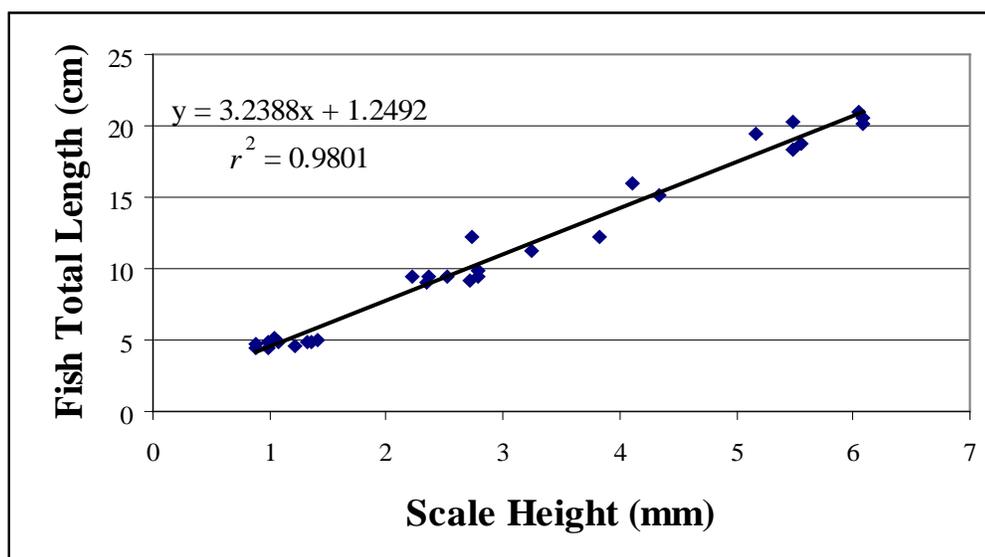
B.
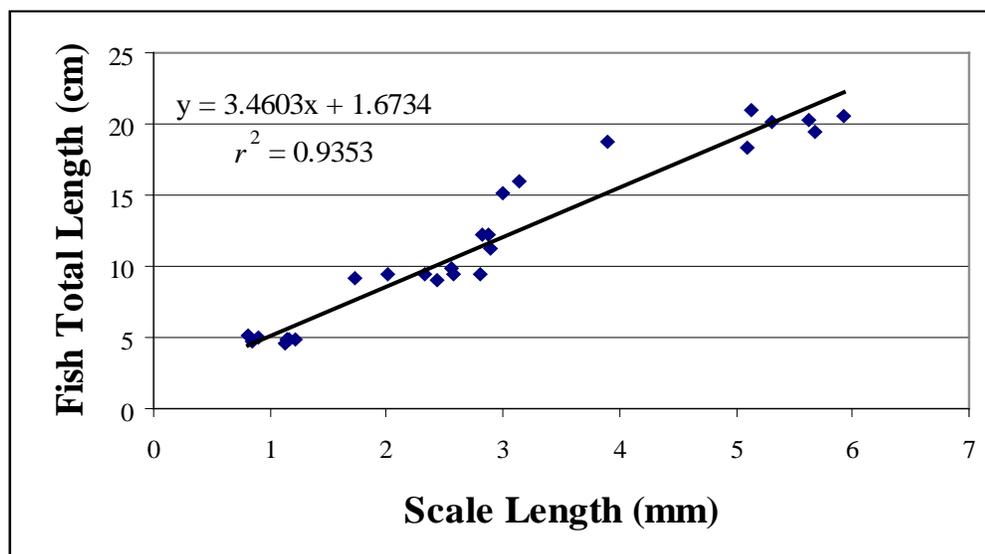
Appendix X. The best body-scale relationships for bluegill (*Lepomis macrochirus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 18. B. Using random scales, n_r = 16.

A.

Fish Total Length (cm)

$y = 2.7516x + 1.2975$

$r^2 = 0.9942$

Scale Diagonal (mm)

B.

Fish Total Length (cm)

$y = 3.232x + 0.5941$

$r^2 = 0.9568$

Scale Length (mm)
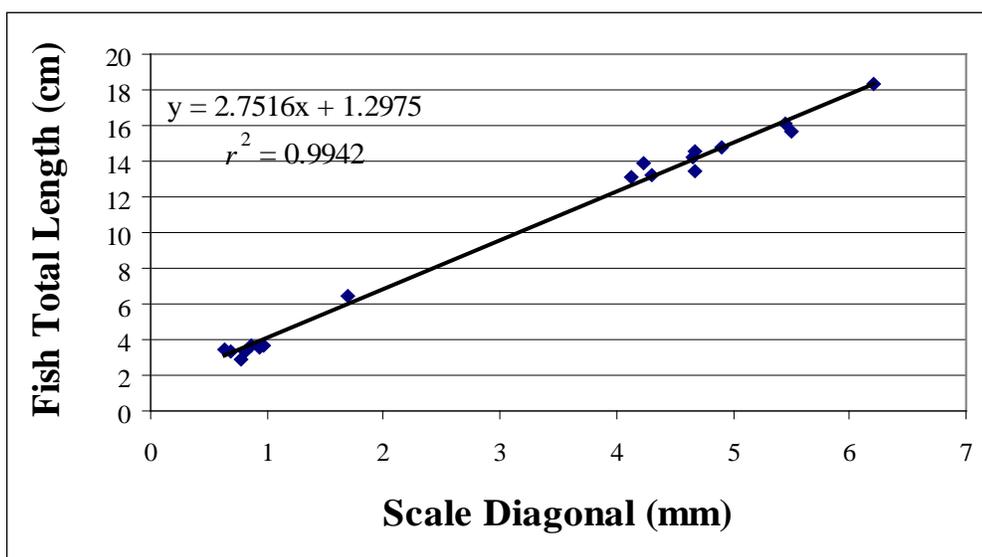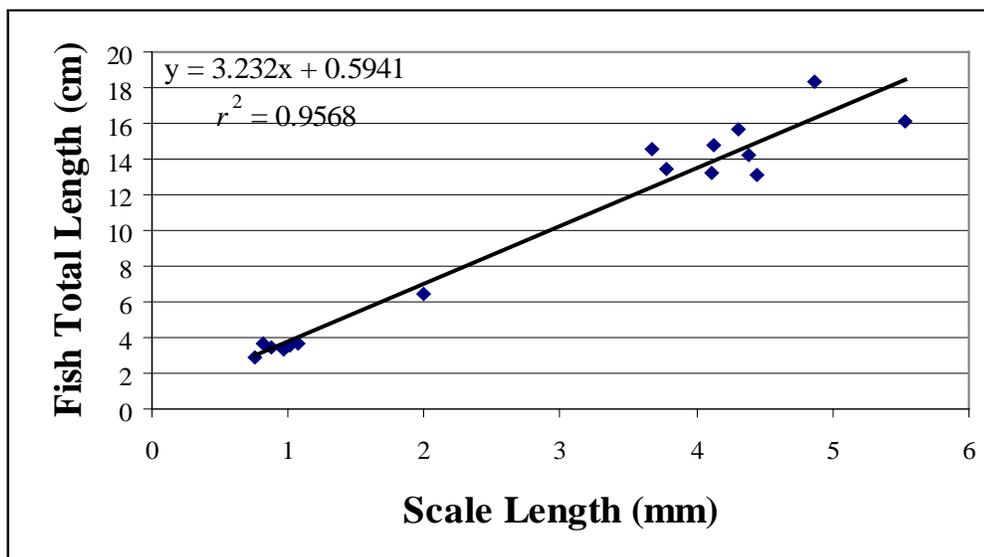
Appendix XI. The best body-scale relationships for bigmouth shiner (*Notropis dorsalis*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 22. B. Using random scales, n_r = 26.

A.
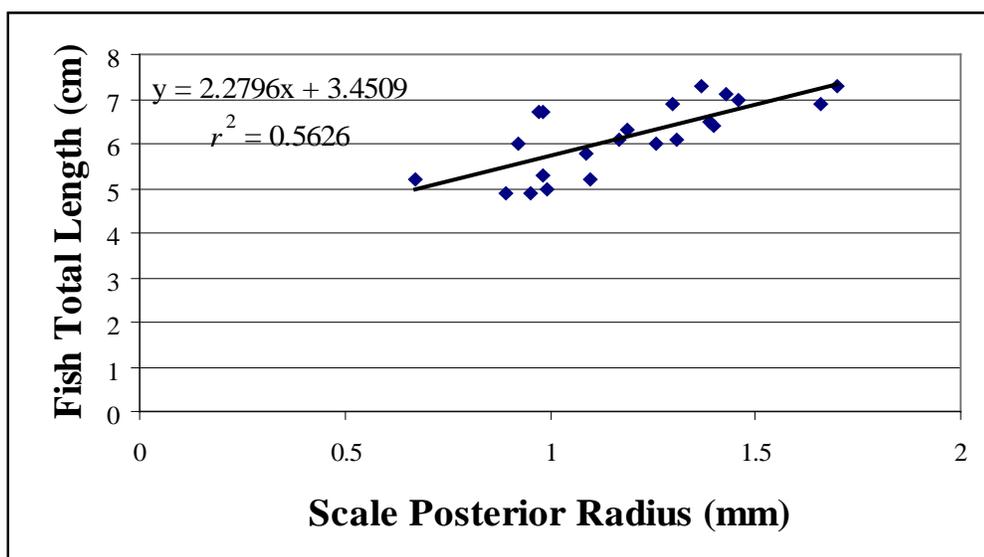
B.
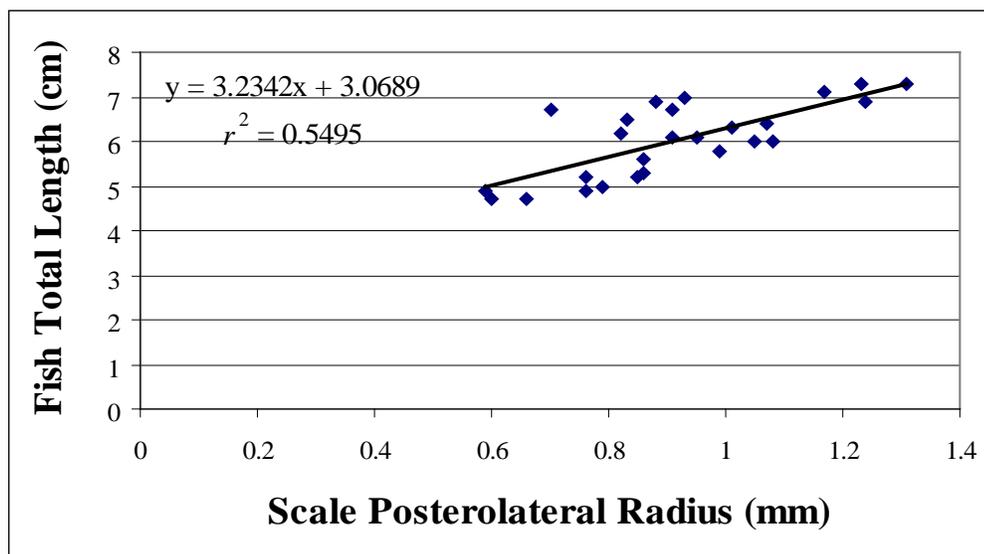
Appendix XII. The best body-scale relationships for blacknose dace (*Rhinichthys atratulus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 21. B. Using random scales, n_r = 26.

A.
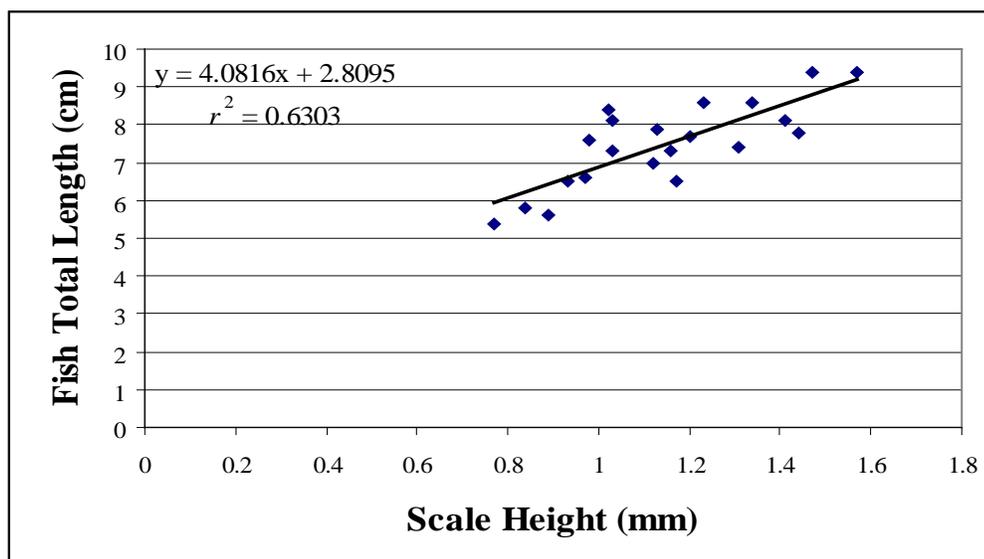
B.
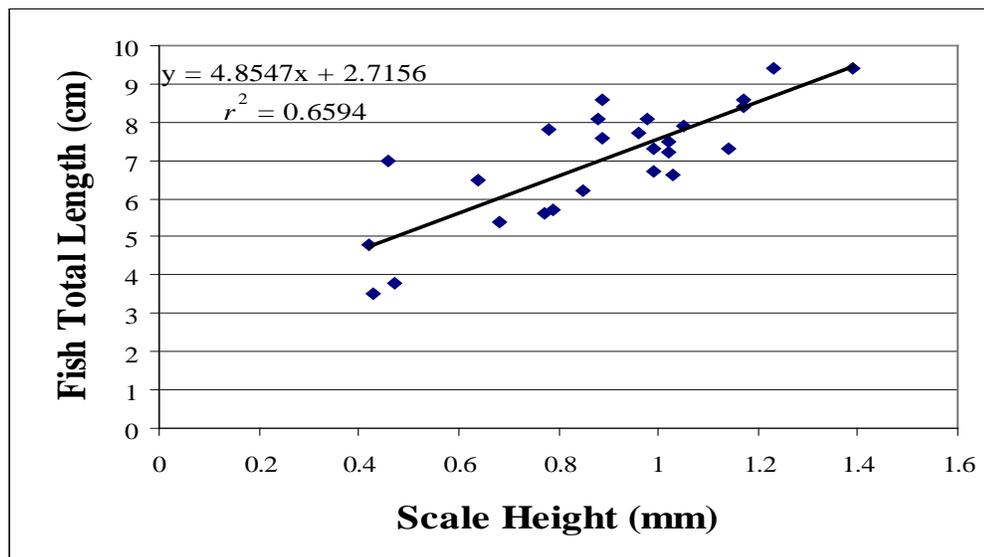
Appendix XIII. The best body-scale relationships for bluntnose minnow (*Pimephales notatus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 35$. B. Using random scales, $n_r = 37$.

A.

$y = 2.8735x + 1.9973$

$r^2 = 0.7920$

B.

$y = 3.0951x + 3.0961$

$r^2 = 0.6516$
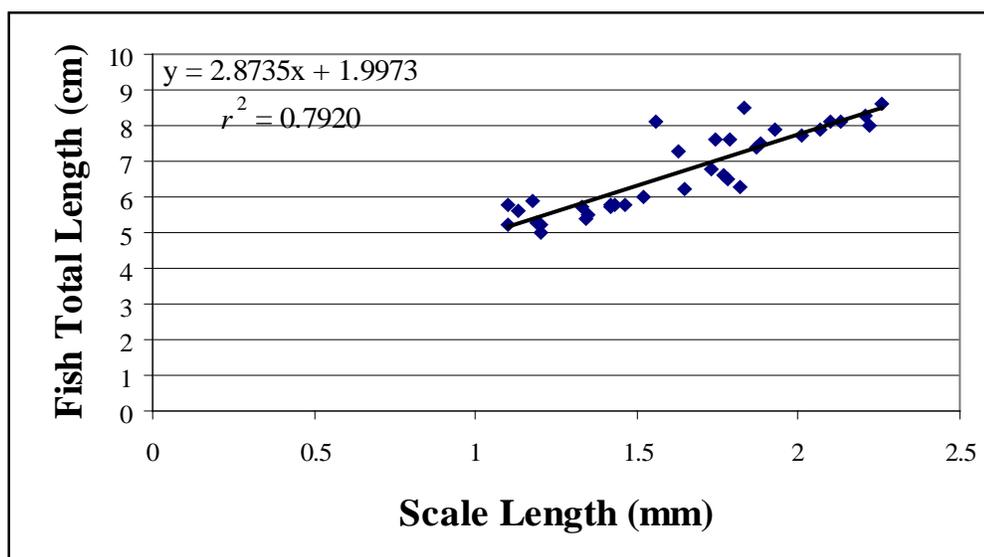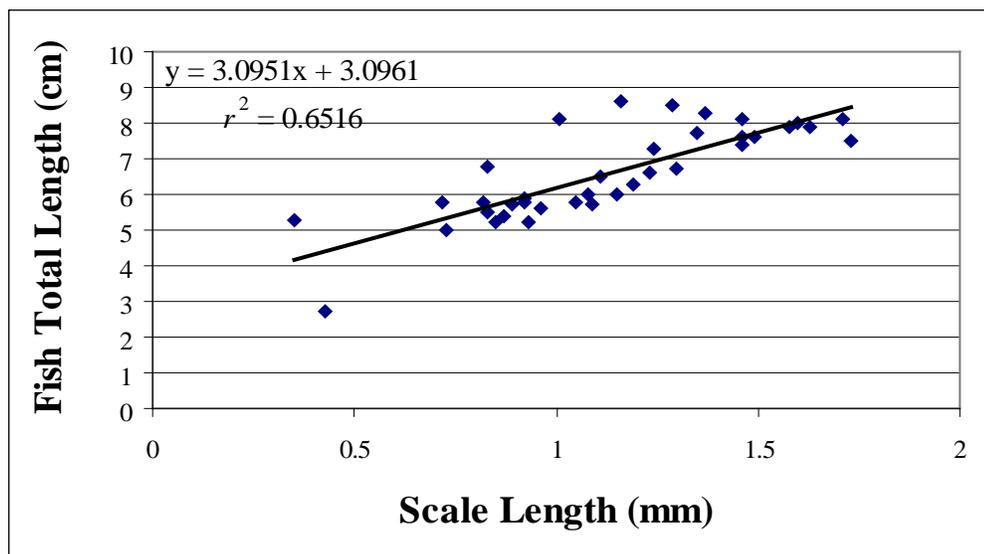
Appendix XIV. The best body-scale relationships for carp (*Cyprinus carpio*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 125. B. Using random scales, n_r = 128.

A.

$y = 2.4548x + 0.5749$
$r^2 = 0.9634$

B.

$y = 2.3818x + 2.0683$
$r^2 = 0.9151$
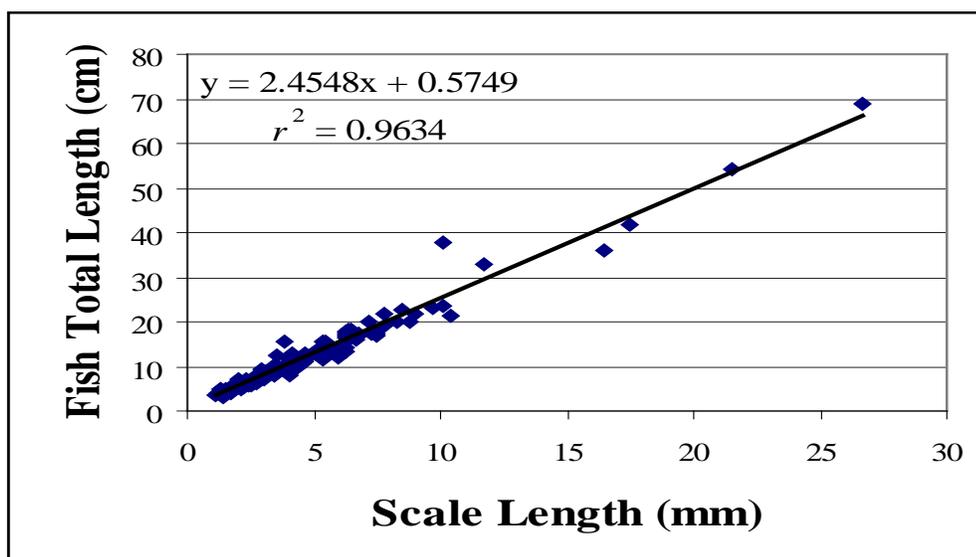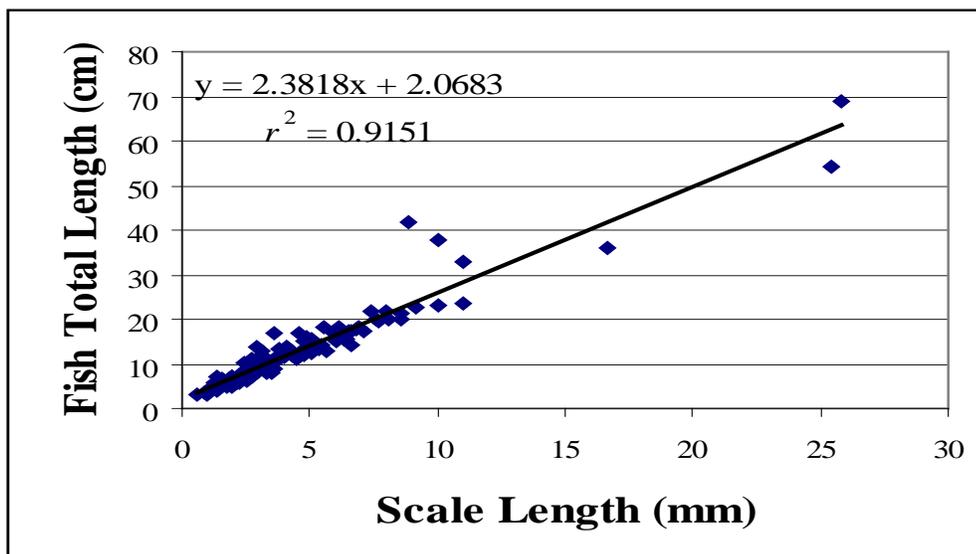
Appendix XV. The best body-scale relationships for common shiner (*Luxilus cornutus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 64. B. Using random scales, n_r = 56.

A.
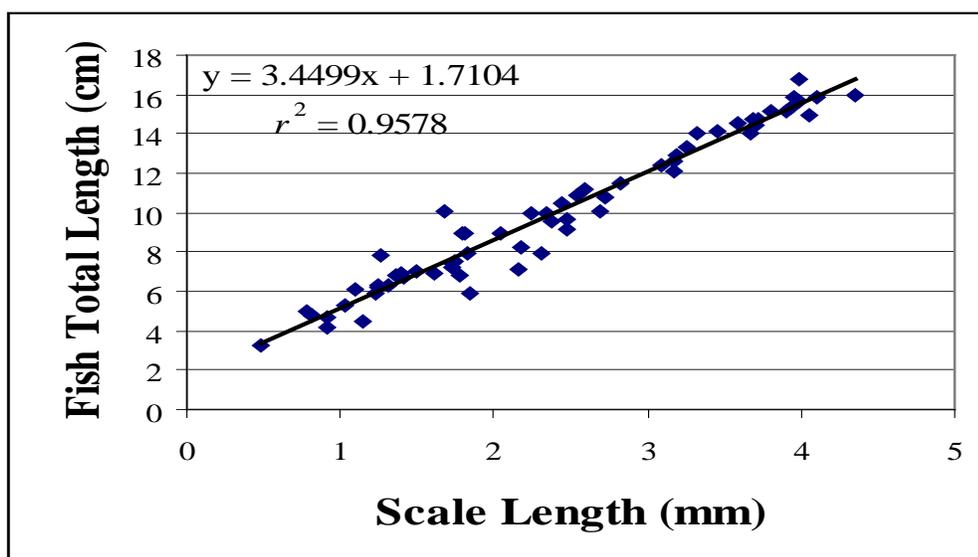
B.
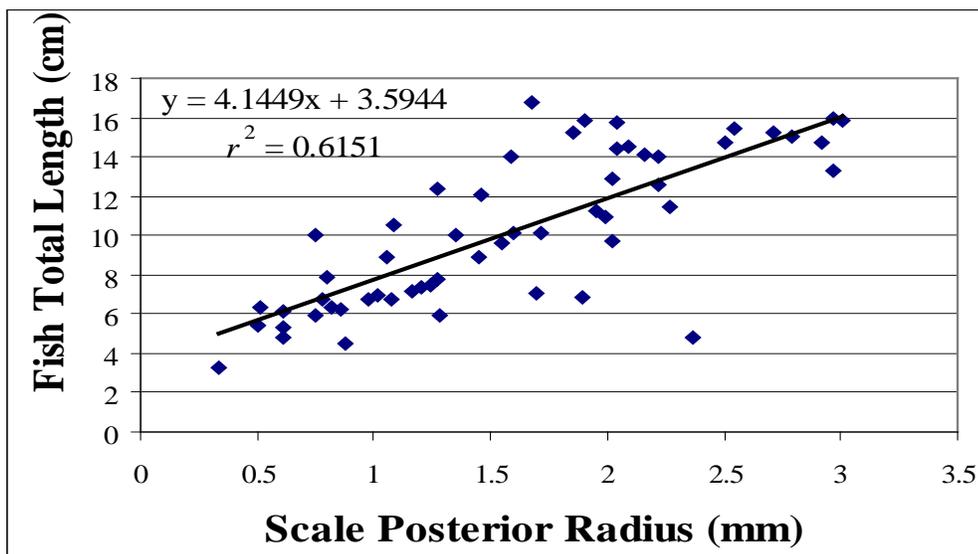
Appendix XVI. The best body-scale relationships for creek chub (*Semotilus atromaculatus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 59. B. Using random scales, n_r = 64.

A.
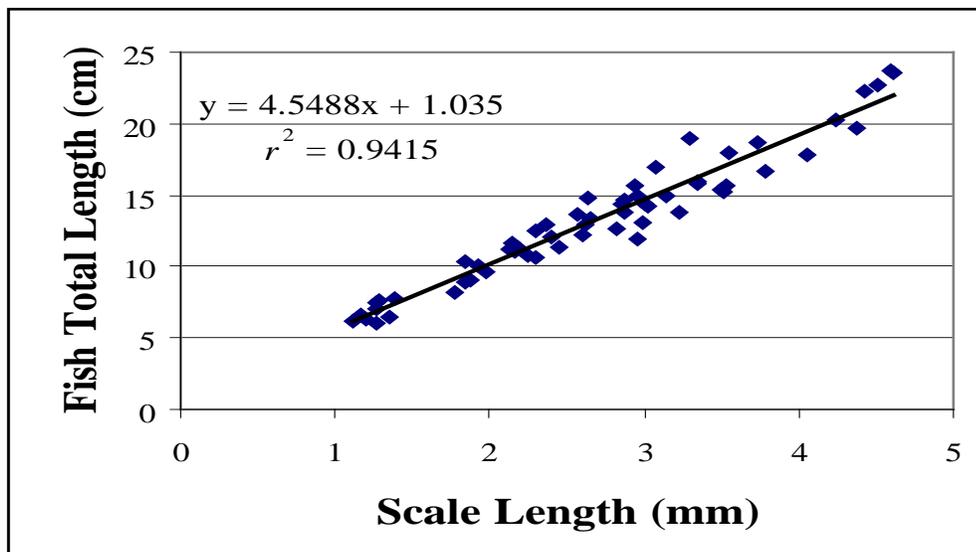
B.
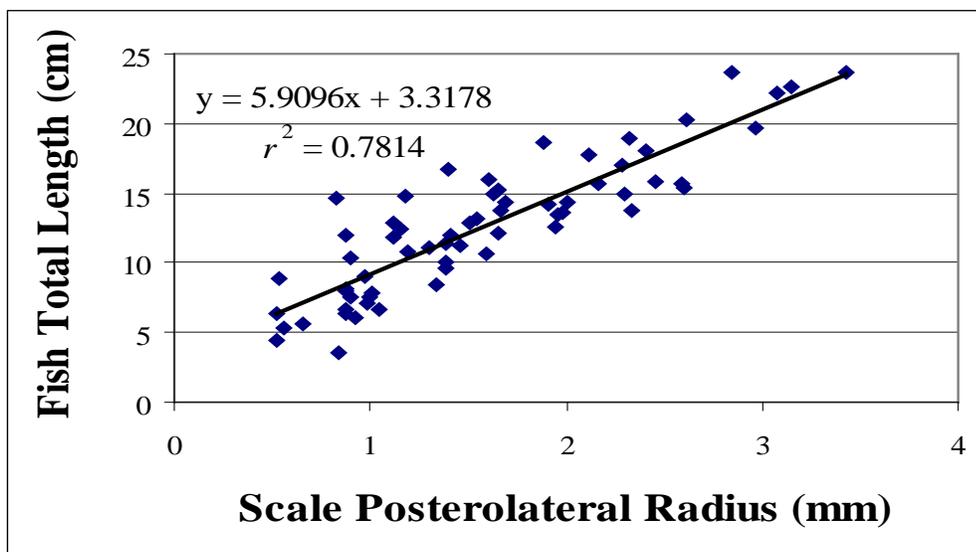
Appendix XVII. The best body-scale relationships for fathead minnow (*Pimephales promelas*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 13. B. Using random scales, n_r = 21.

A.
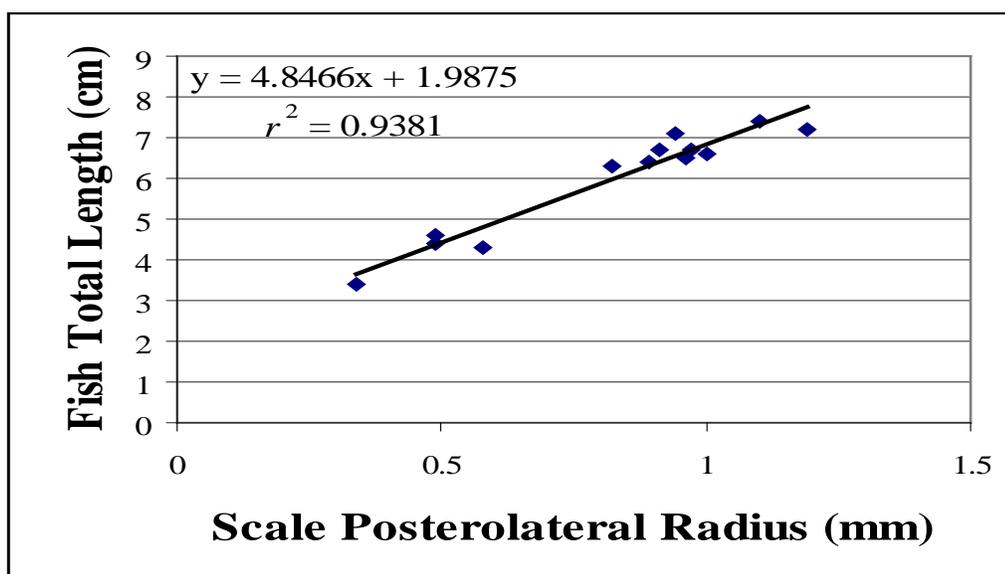
B.
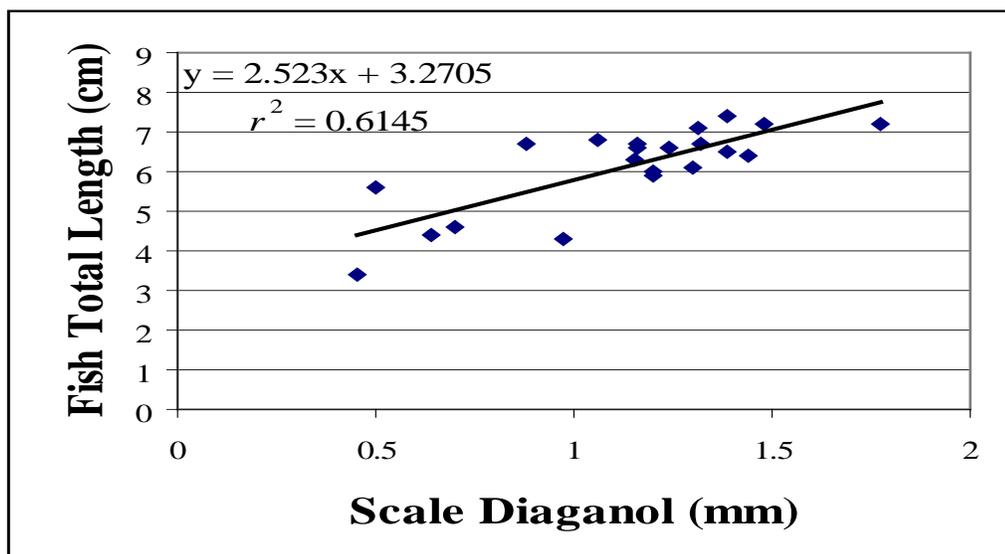
Appendix XVIII. The best body-scale relationships for horneyhead chub (*Nocomis biguttatus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 43$. B. Using random scales, $n_r = 48$.

A.
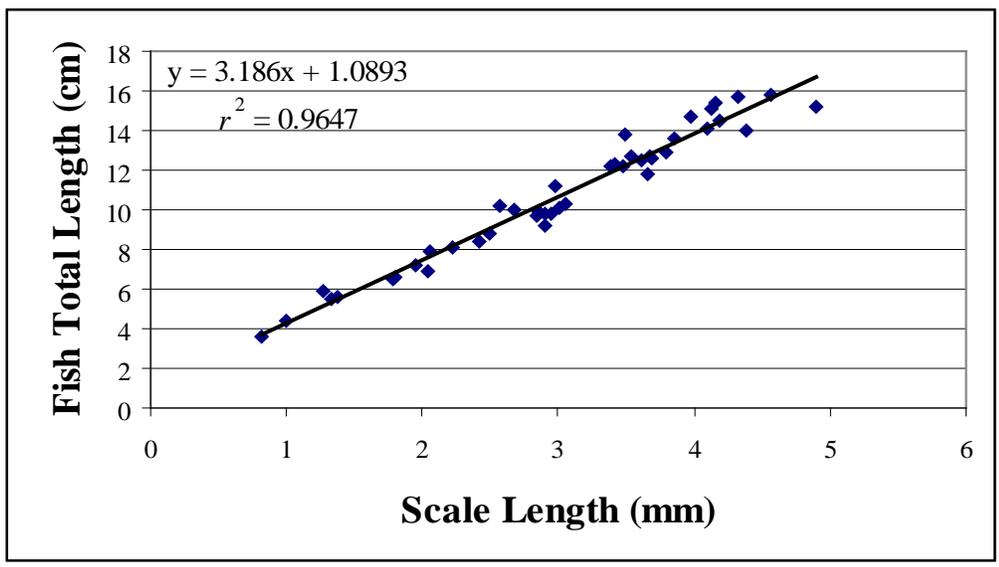
B.
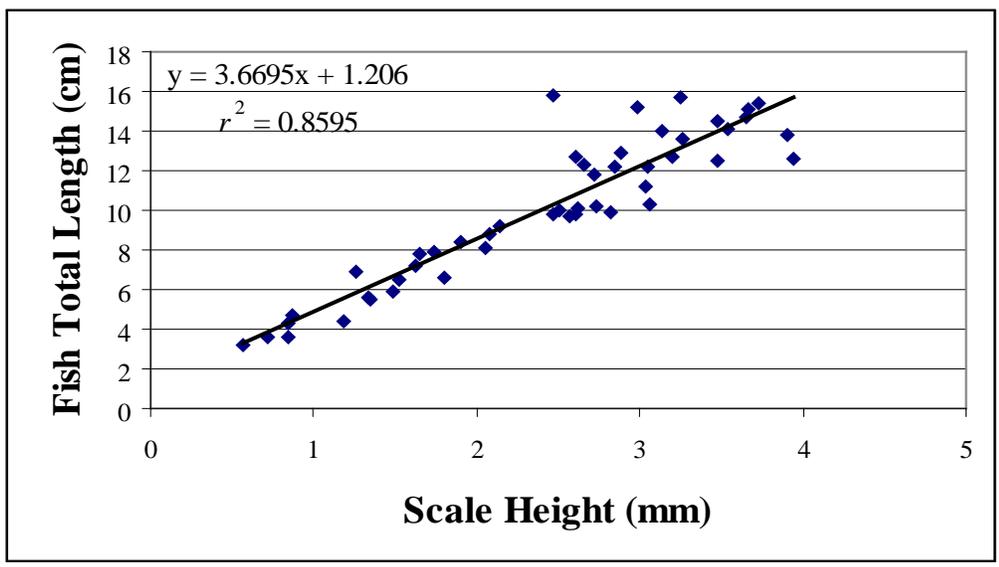
Appendix XIX. The best body-scale relationships for largescale stoneroller (*Campostoma oligolepis*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 13. B. Using random scales, n_r = 13.

A.

The equation on graph A:
$$y = 2.0728x + 4.4037$$
$$r^2 = 0.7106$$

B.

The equation on graph B:
$$y = 0.8492x + 9.0276$$
$$r^2 = 0.1394$$
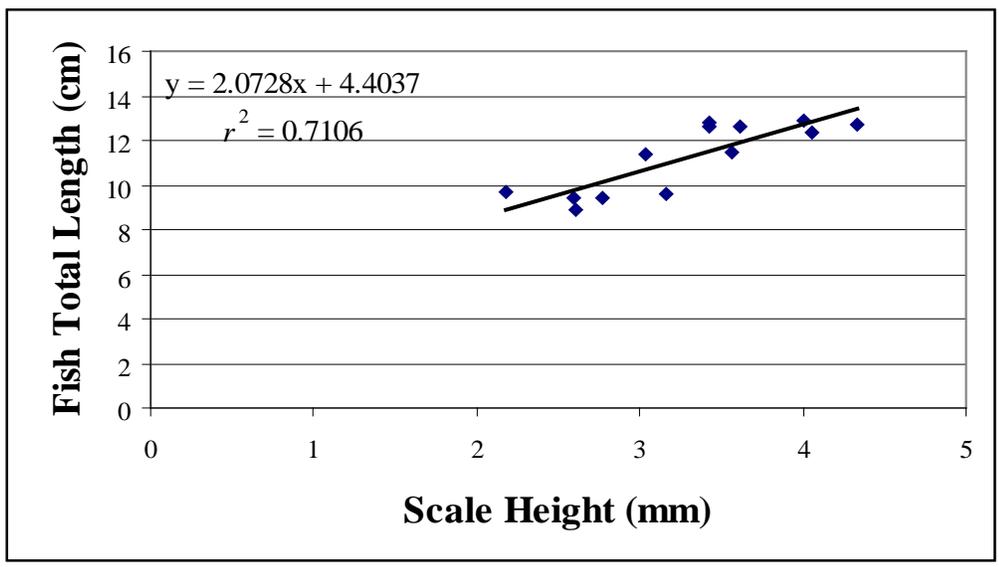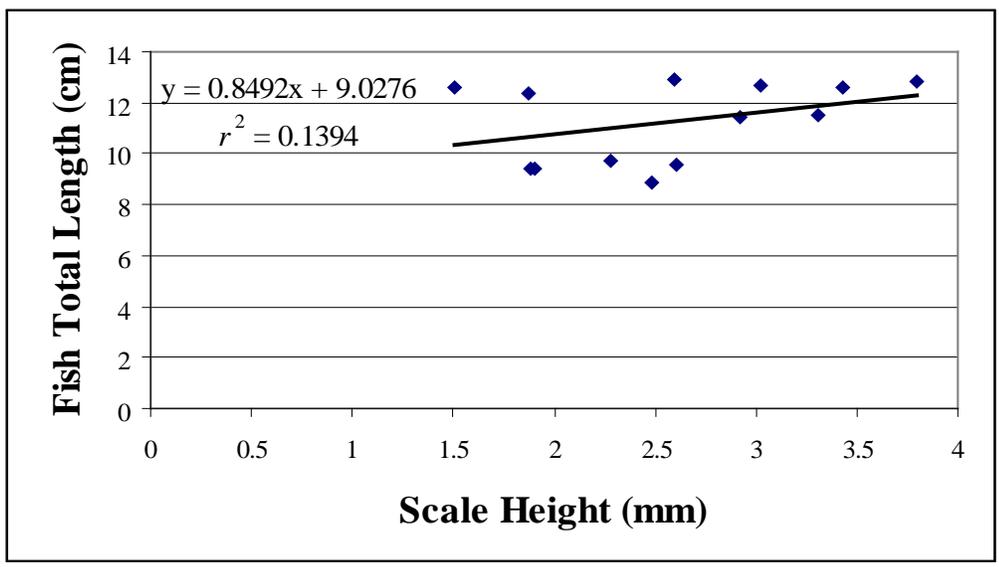
Appendix XX. The best body-scale relationships for longnose dace (*Rhinichthys cataractae*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 18. B. Using random scales, n_r = 17.

A.
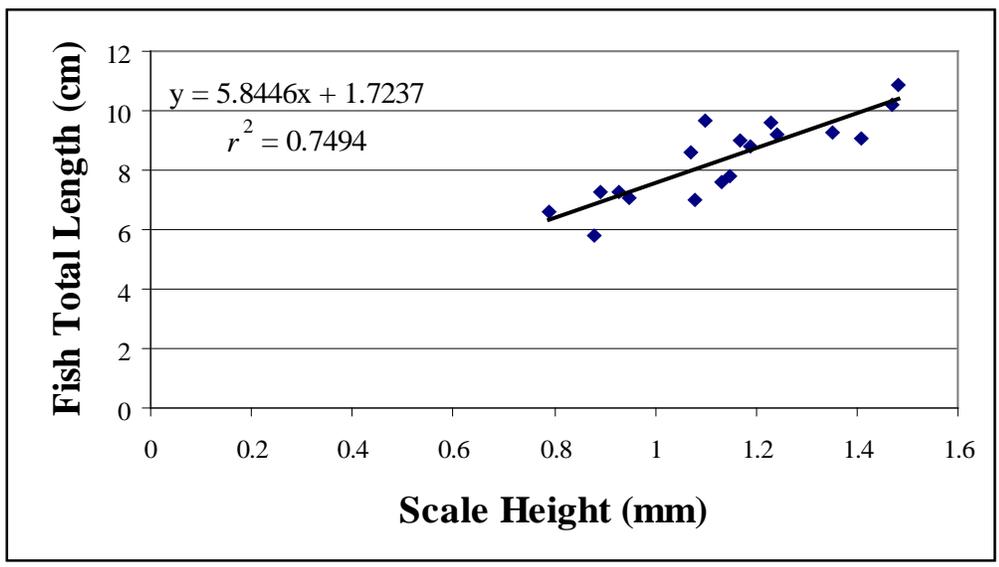
B.
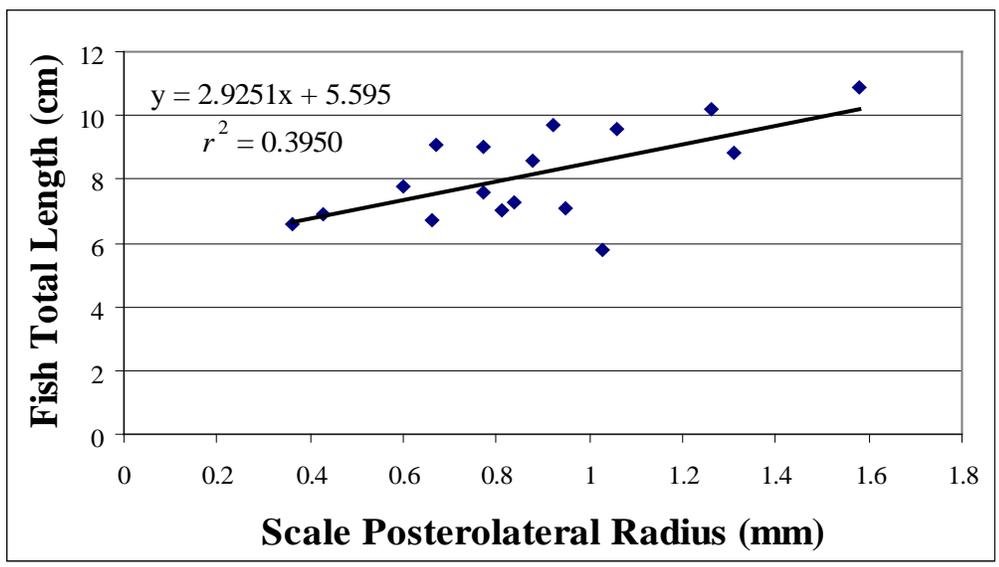
Appendix XXI. The best body-scale relationships for sand shiner (*Notropis stramineus*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 15$. B. Using random scales, $n_r = 19$.

A.
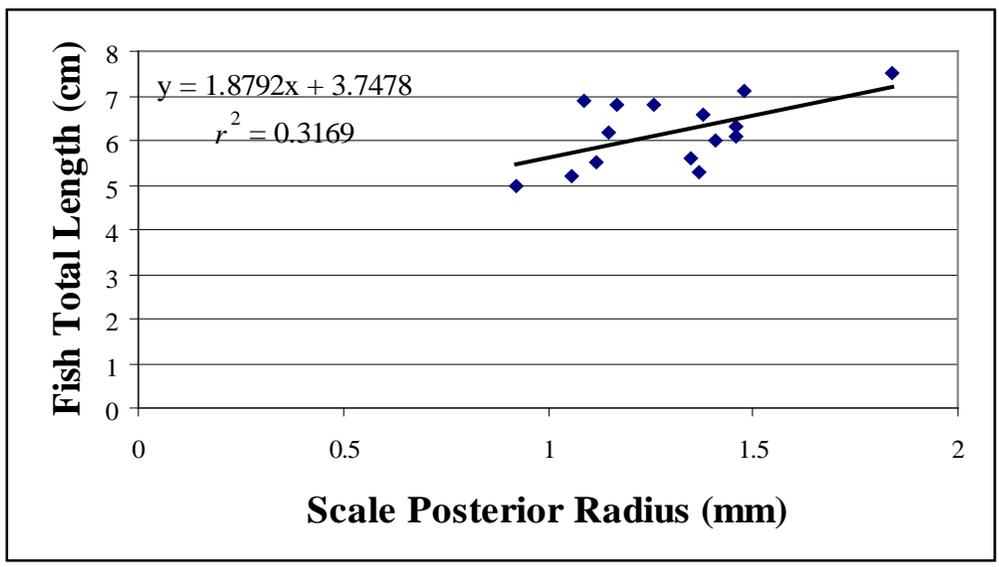
B.
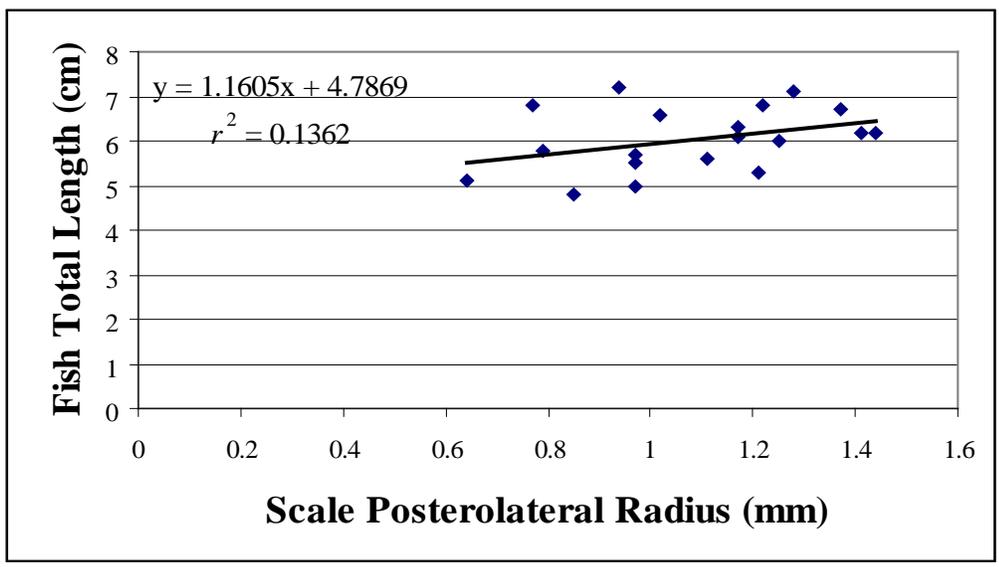
Appendix XXII. The best body-scale relationships for spotfin shiner (*Cyprinella spiloptera*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 17$. B. Using random scales, $n_r = 14$.

A.
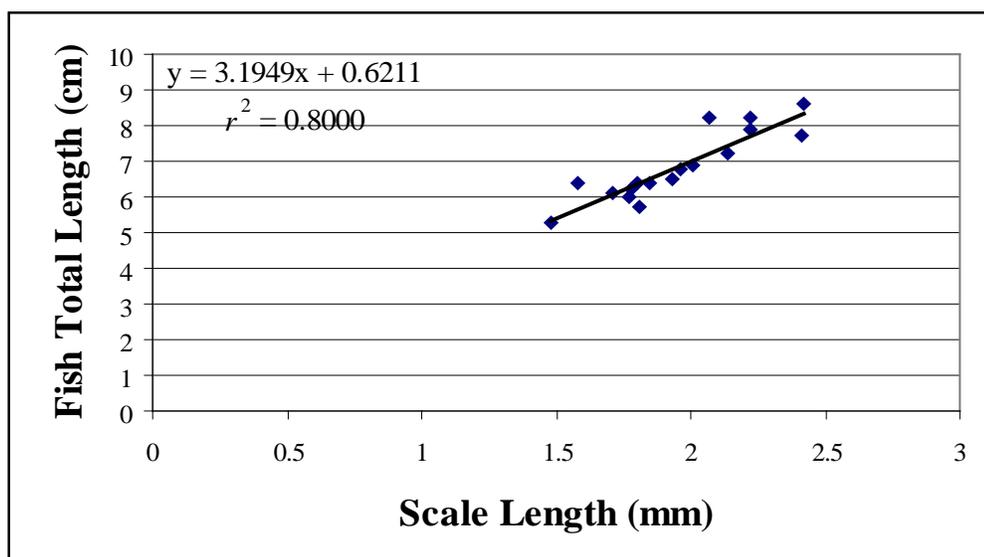
B.
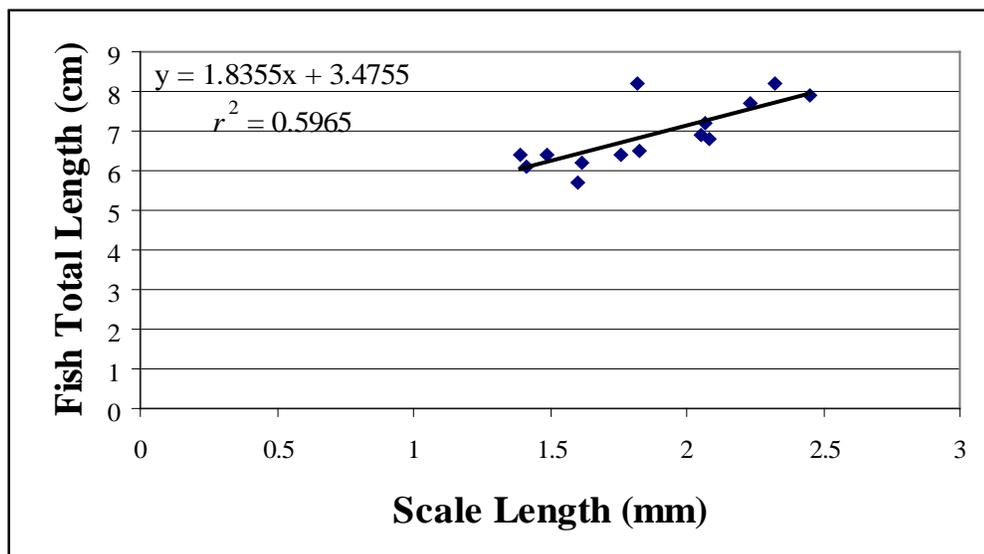
Appendix XXIII. The best body-scale relationships for northern pike (*Esox lucius*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 39$. B. Using random scales, $n_r = 44$.

A.
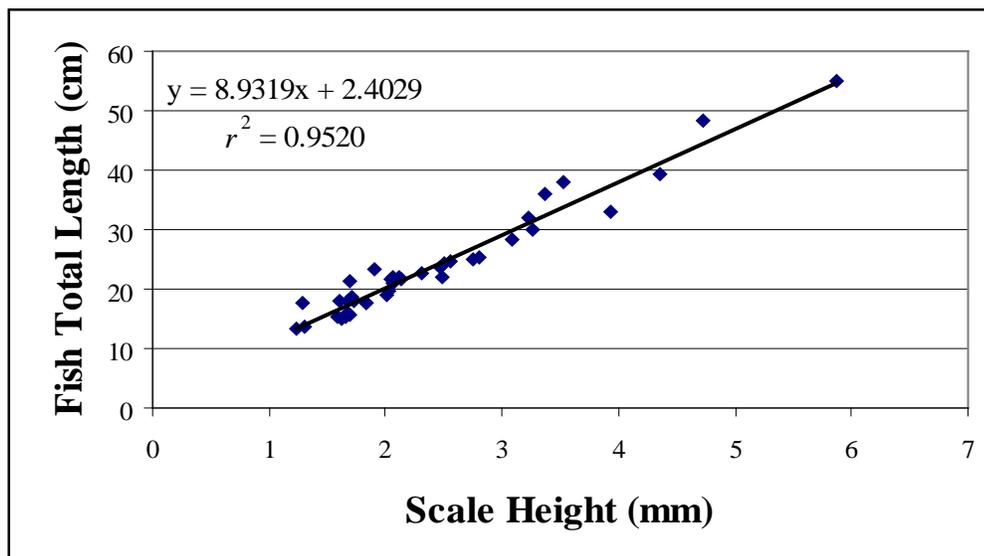
B.
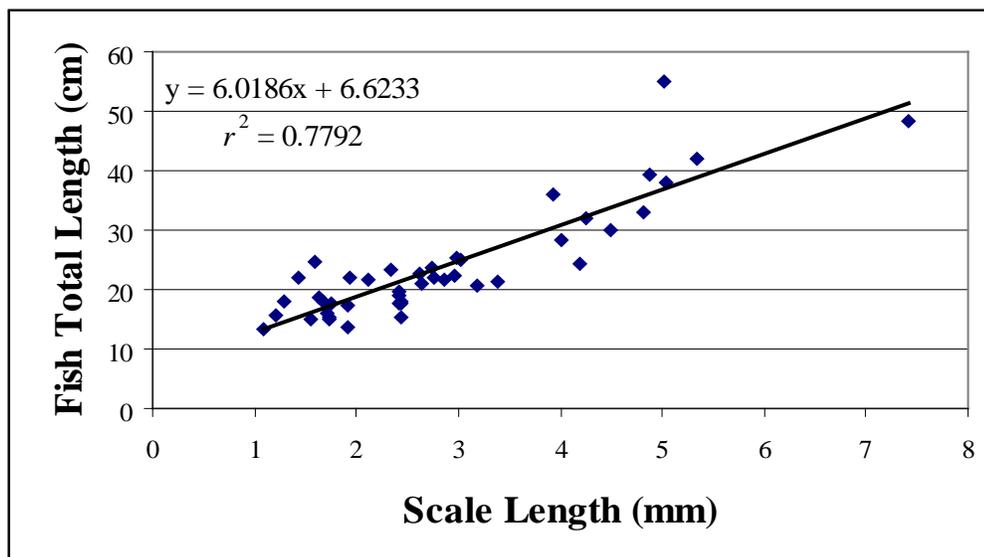
Appendix XXIV. The best body-scale relationships for white bass (*Morone chrysops*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 25$. B. Using random scales, $n_r = 30$.

A.
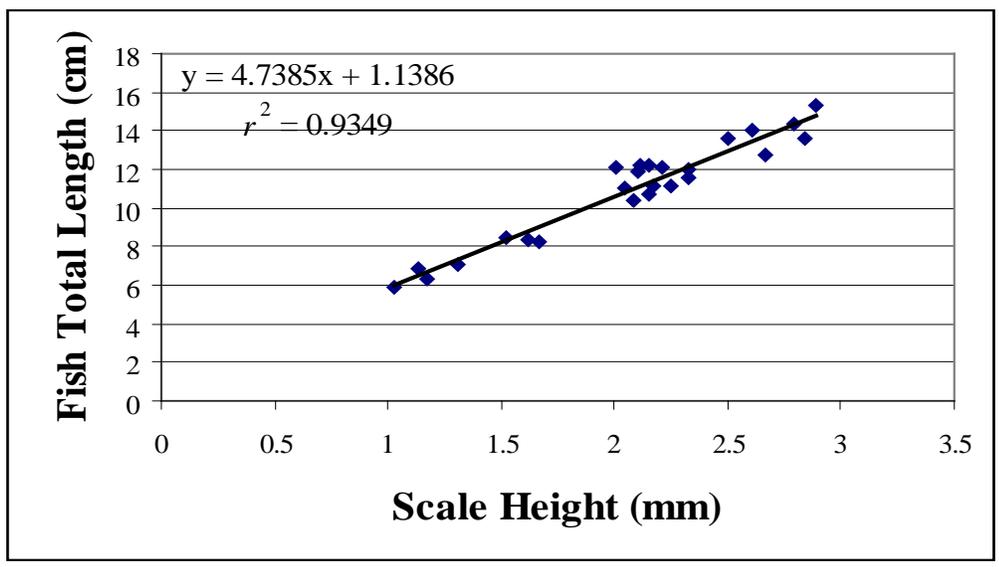
B.
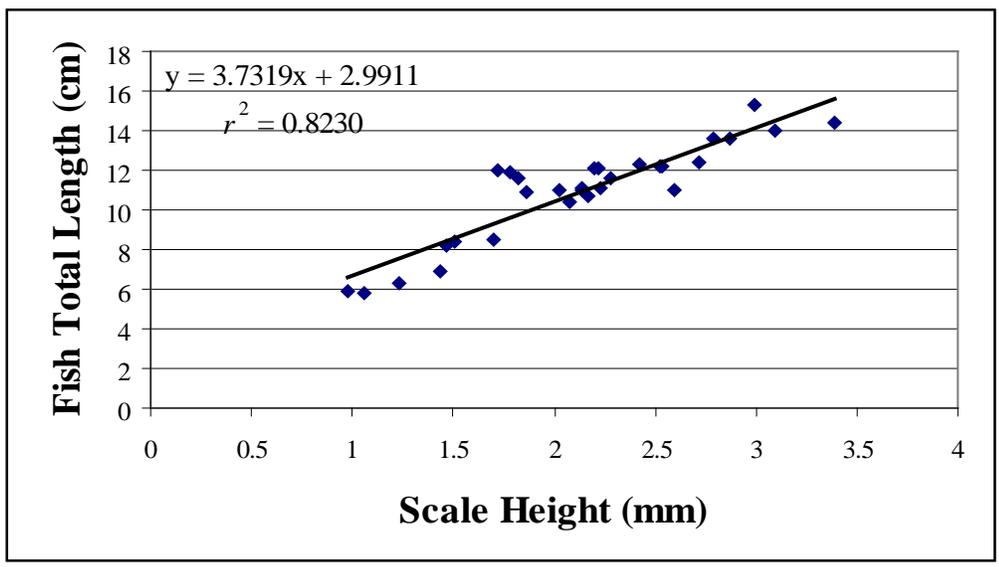
Appendix XXV. The best body-scale relationships for blackside darter (*Percina maculata*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 44$. B. Using random scales, $n_r = 43$.

A.
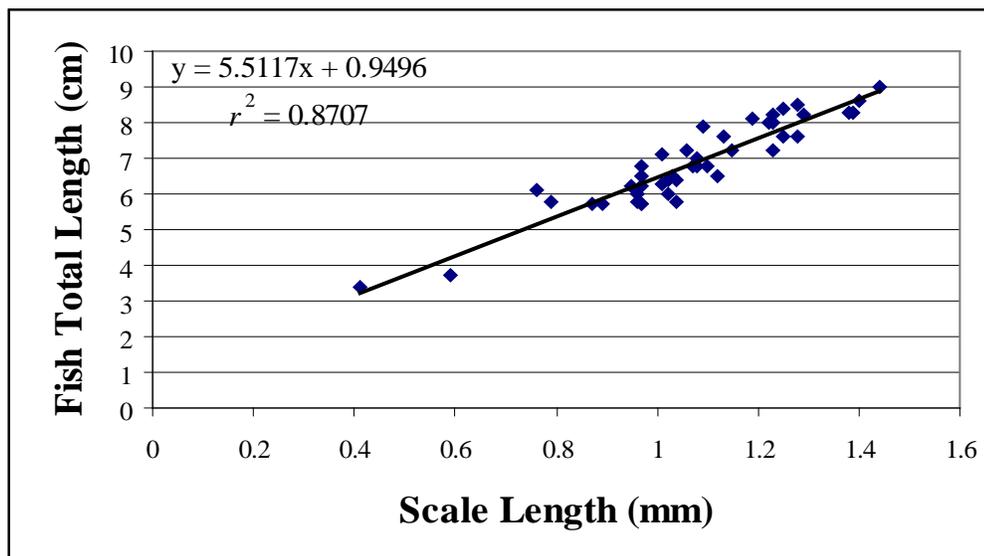
B.
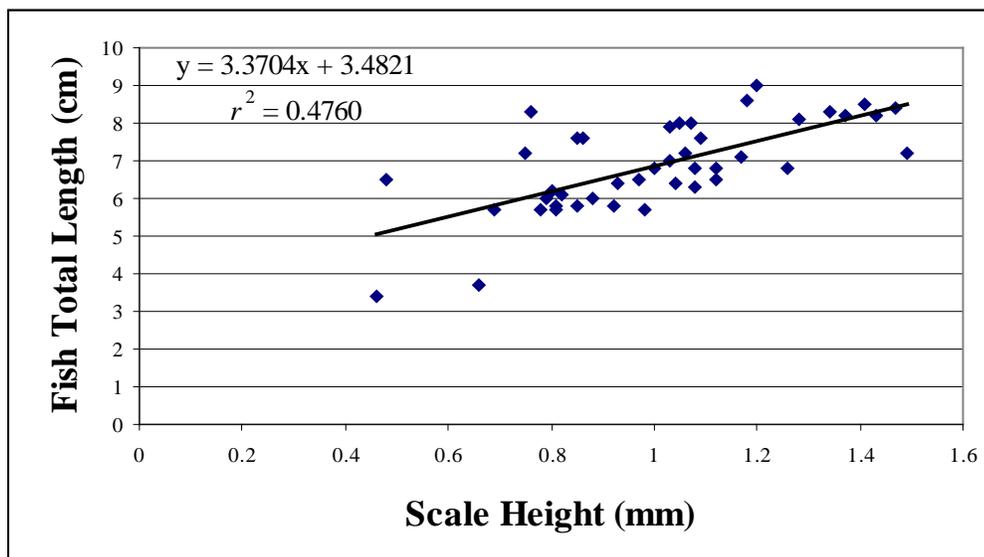
Appendix XXVI. The best body-scale relationships for Johnny darter (*Etheostoma nigrum*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 36. B. Using random scales, n_r = 55.

A.
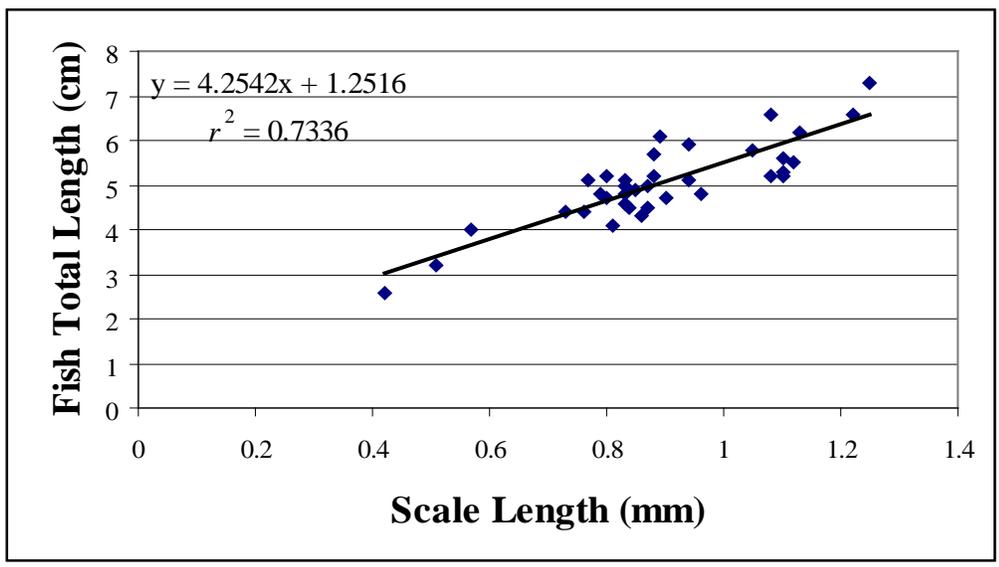
B.
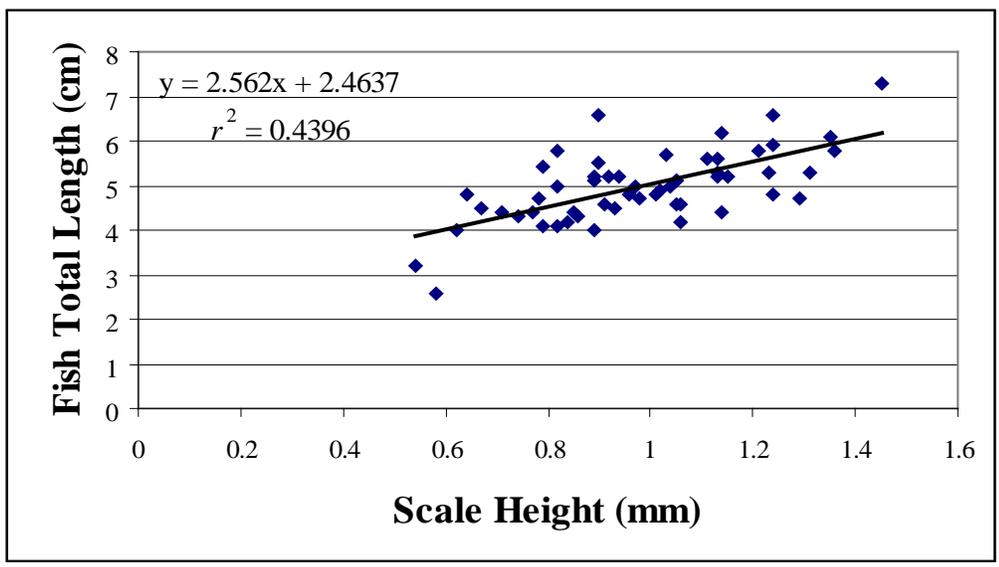
Appendix XXVII. The best body-scale relationships for yellow perch (*Perca flavescens*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 43$. B. Using random scales, $n_r = 44$.

A.
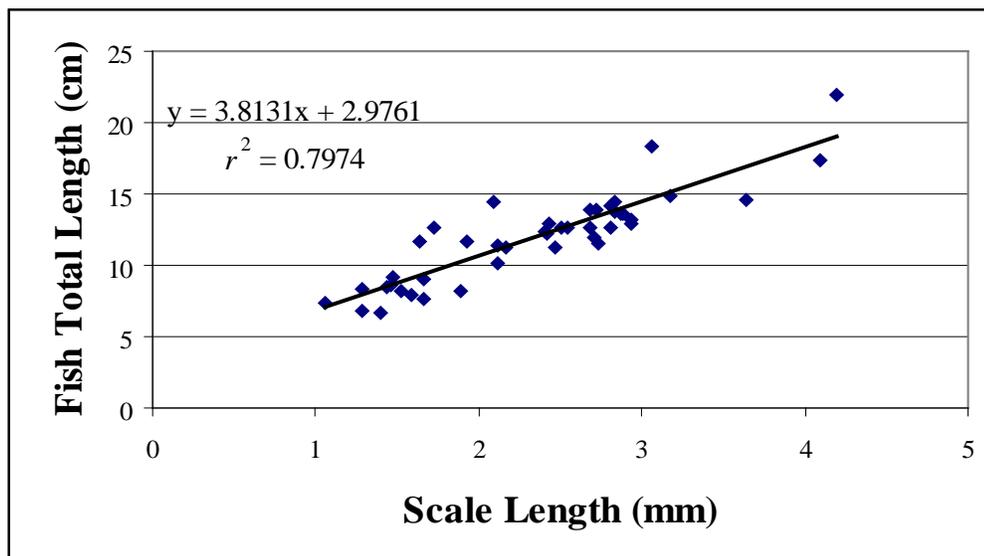
B.
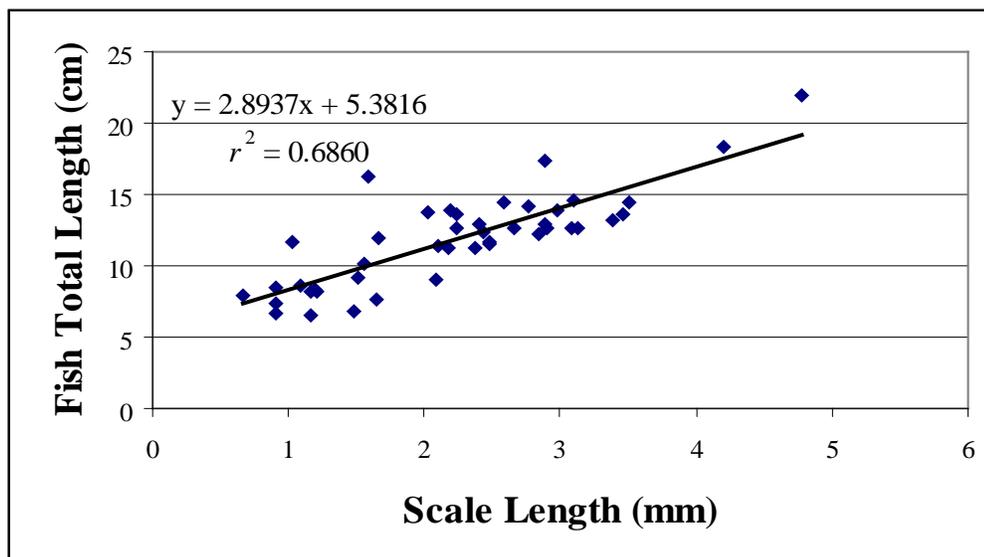
Appendix XXVIII. The best body-scale relationships for freshwater drum (*Aplodinotus grunniens*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 10. B. Using random scales, n_r = 12.

A.
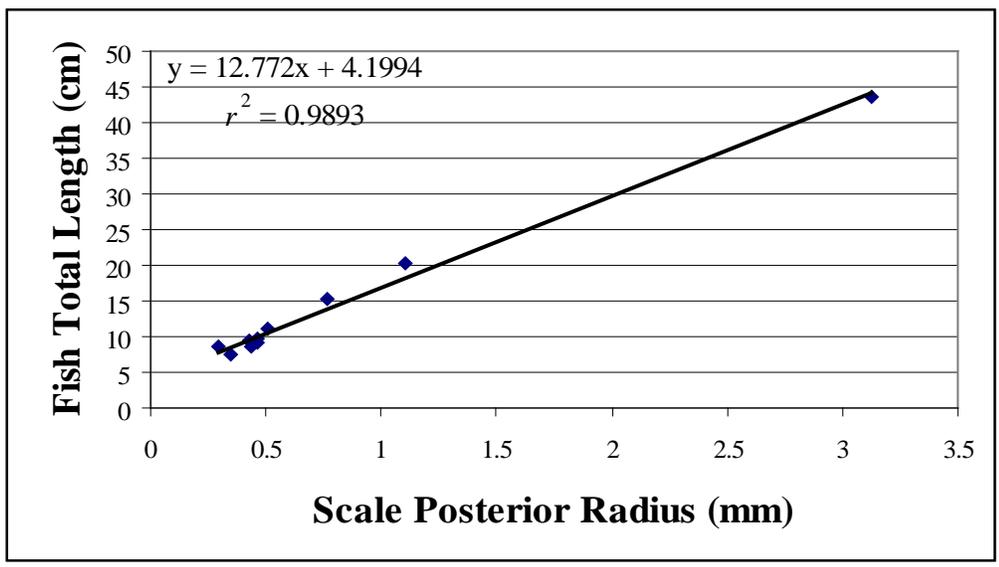
B.
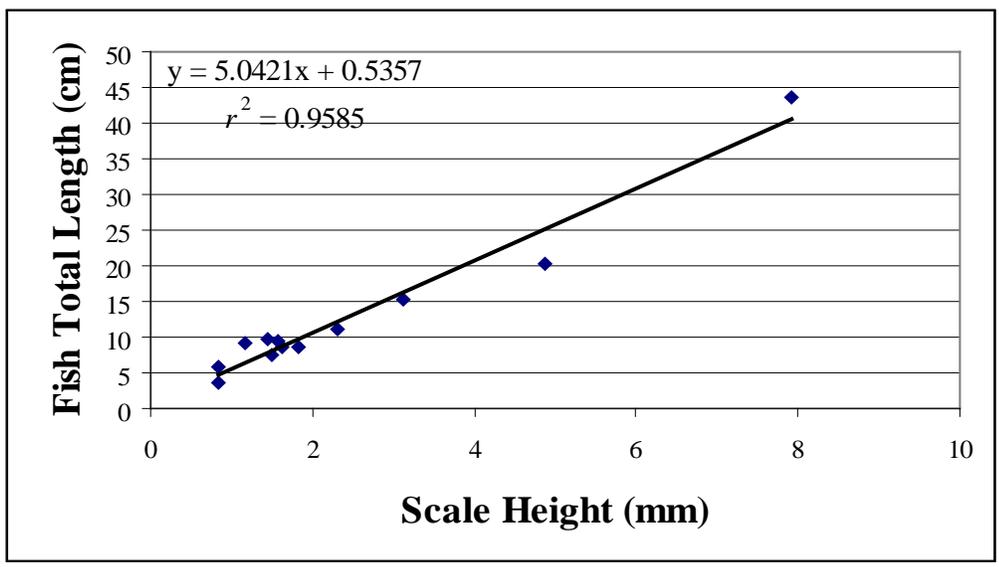
Appendix XXIX. The best multi-species body-scale relationship for centrarchids, established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 58$. B. Using random scales, $n_r = 55$.

A.

$$y = 3.1965x + 1.1275$$
$$r^2 = 0.9755$$

B.

$$y = 3.4765x + 1.1097$$
$$r^2 = 0.9174$$
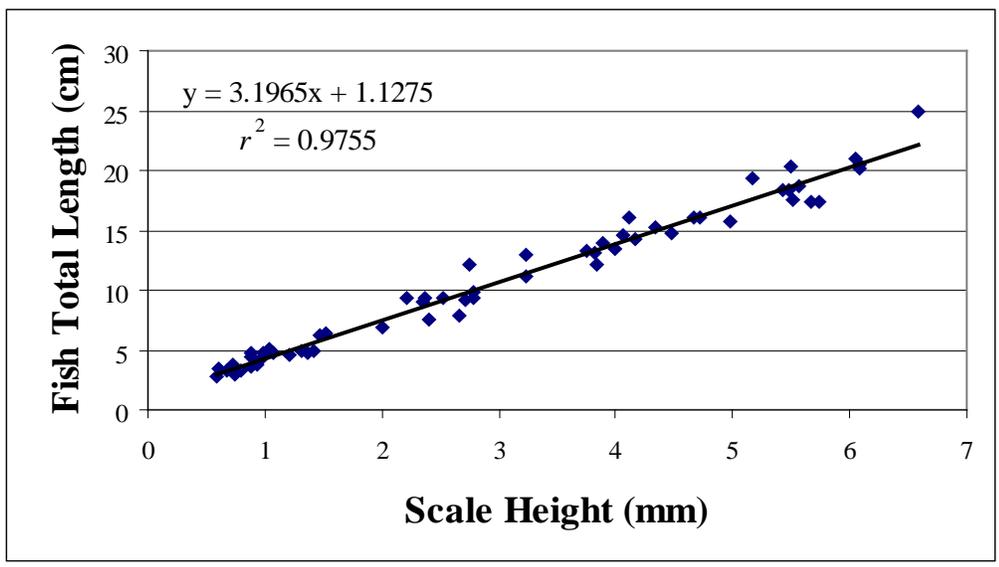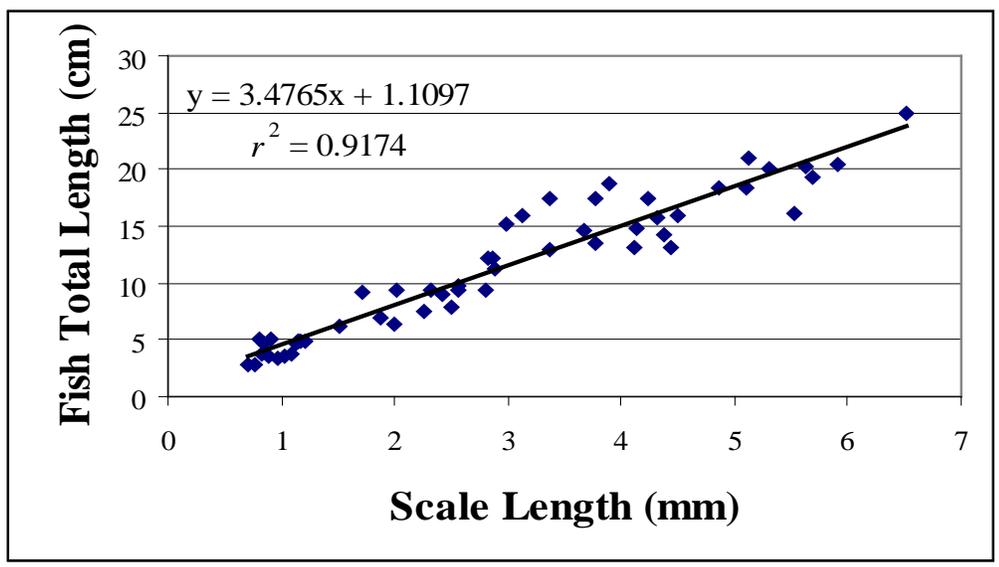
Appendix XXX. The best body-scale relationships for cyprinids ≤10 cm (excluding carp (*Cyprinus carpio*) and dace (*Rhinichthys* spp.)), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 177. B. Using random scales, n_r = 197.

A.
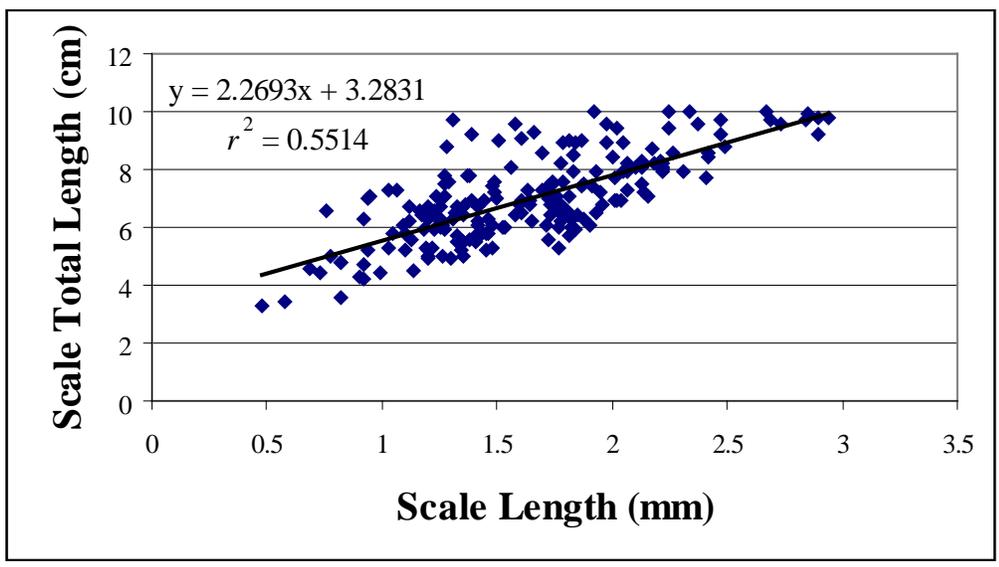
B.
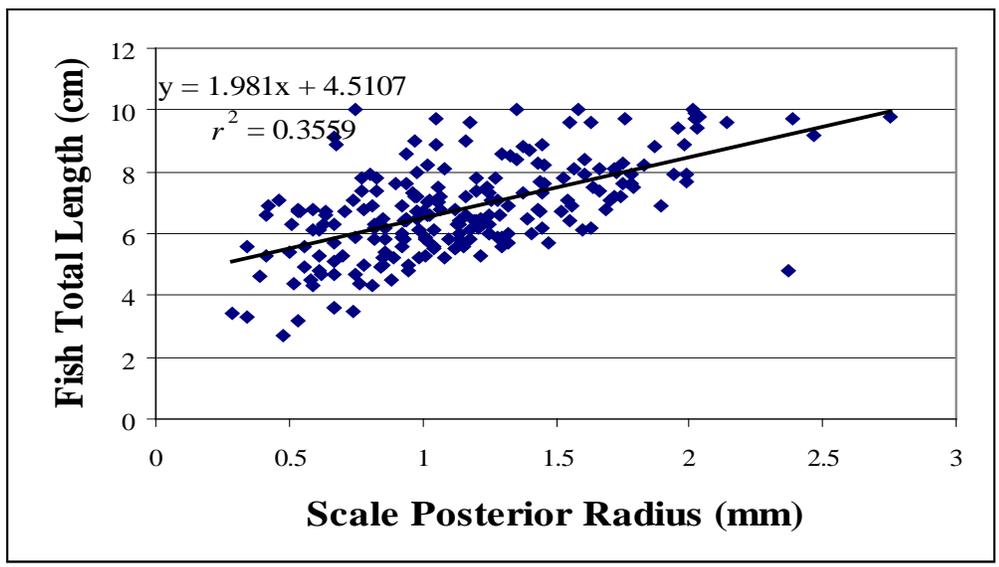
Appendix XXXI. The best body-scale relationships for cyprinids >10 cm (excluding carp (*Cyprinus carpio*) and dace (*Rhinichthys* spp.)), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, n_{LL} = 109. B. Using random scales, n_r = 107.

A.
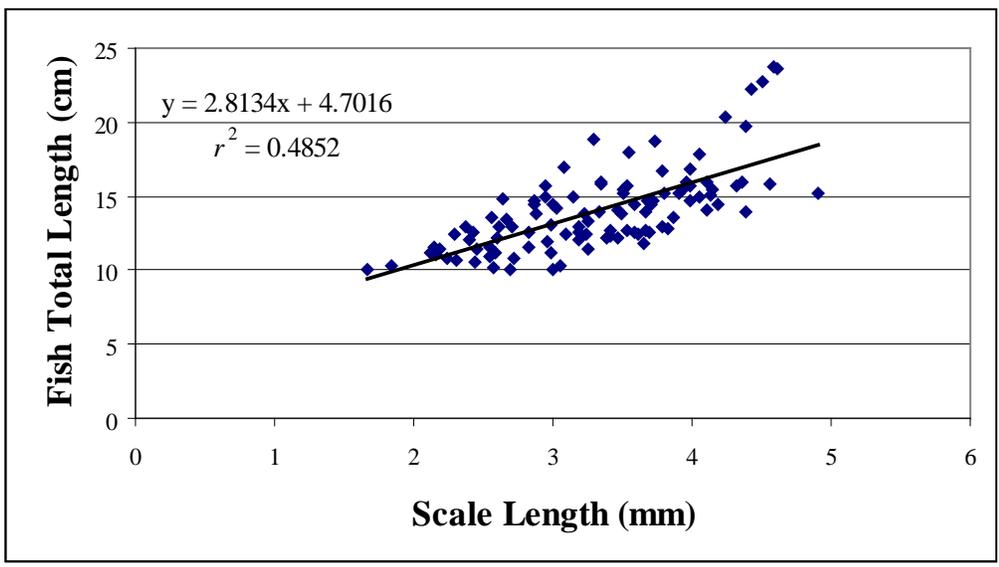
B.
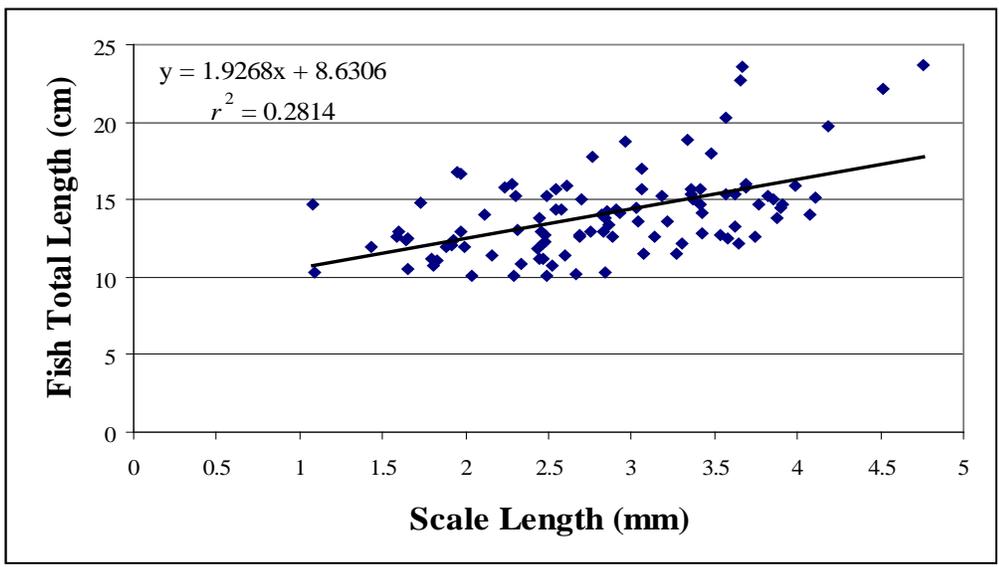
Appendix XXXII. The best body-scale relationships for dace, including blacknose dace (*Rhinichthys atratulus*) and longnose dace (*Rhinichthys cataractae*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 39$. B. Using random scales, $n_r = 43$.

A.
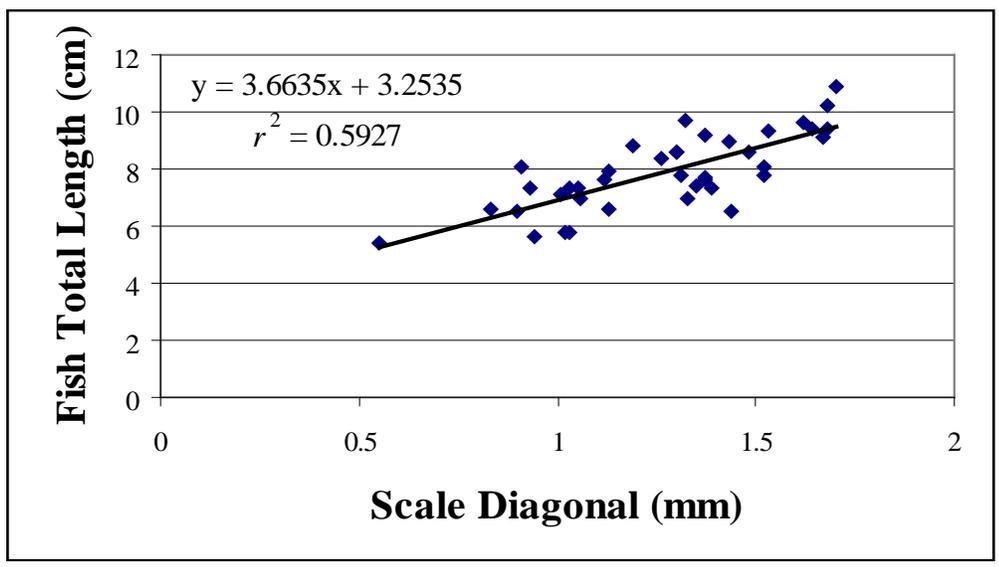
B.
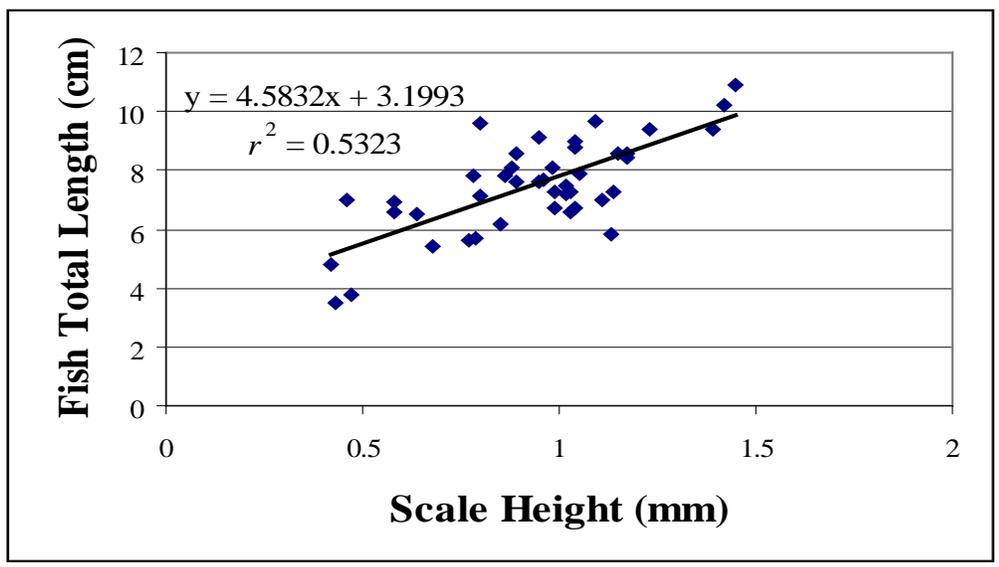
Appendix XXXIII. The best body-scale relationships for a combined model of white bass (*Morone chrysops*) and freshwater drum (*Aplodinotus grunniens*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 35$. B. Using random scales, $n_r = 42$.

A.
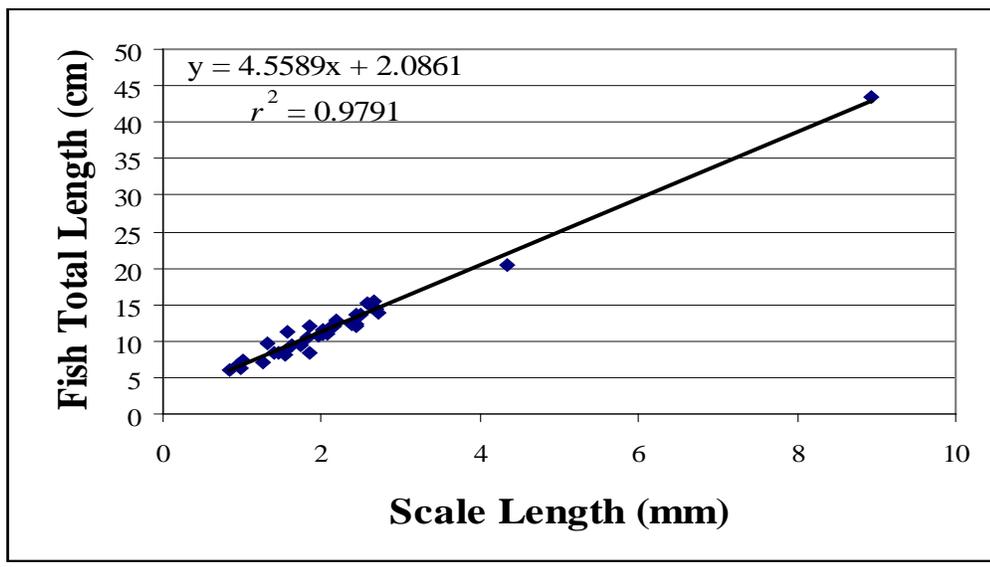
B.
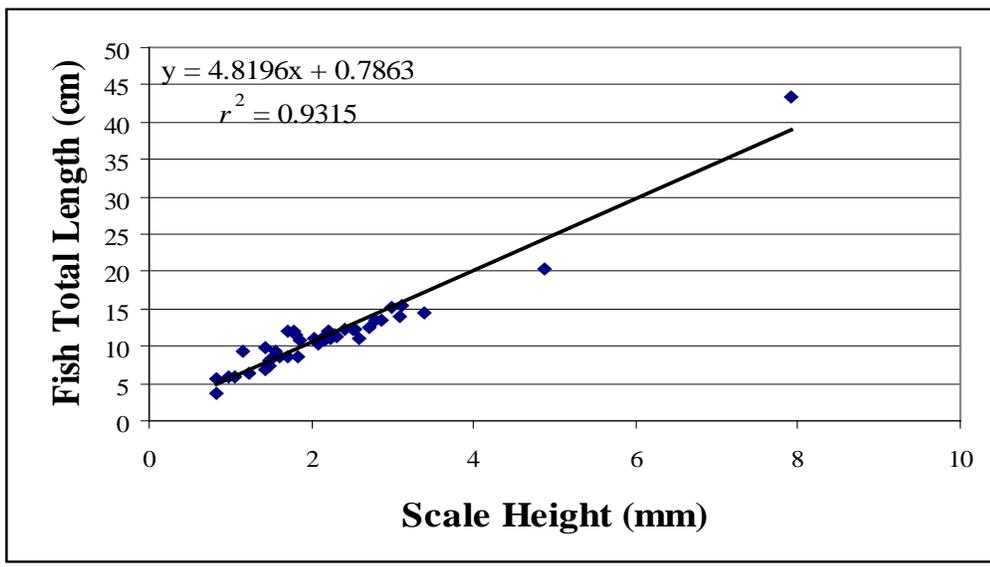
Appendix XXXIV. The best body-scale relationships for darters, including blackside darters (*Percina maculata*) and Johnny darters (*Etheostoma nigrum*), established from sampling June – November 2007 in the Red River of the North tributaries of eastern North Dakota. A. Using lateral line scales, $n_{LL} = 80$. B. Using random scales, $n_r = 98$.

A.

Scatter plot with x-axis "Scale Length (mm)" from 0 to 1.6 and y-axis "Fish Total Length (cm)" from 0 to 10.

$y = 5.9082x + 0.1863$

$r^2 = 0.8042$

B.

Scatter plot with x-axis "Scale Posterior Radius (mm)" from 0 to 0.6 and y-axis "Fish Total Length (cm)" from 0 to 10.

$y = 10.777x + 2.9359$

$r^2 = 0.4050$