Life History of Dwarf Longnose Sucker (*Catostomus catostomus*) in the Elk River Watershed

by

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ABSTRACT

In 2004, a population of dwarf longnose sucker was discovered co-existing with the normal form within the Elk River Watershed of south-eastern British Columbia. This thesis evaluated morphological, genetic and life history characteristics of this dwarf longnose sucker form to determine whether the dwarf morphotype warranted designation as an evolutionary significant unit and to determine any special habitat requirements. In addition to size, distinct morphological differences were indicated between Elk River Watershed dwarf and normal adult longnose sucker, with dwarf adults appearing to retain morphological features of juveniles and sharing morphological features with Salish sucker, which is a separate dwarf longnose sucker form that is considered endangered. Slight, but significant, genetic differences were indicated between Elk River Watershed dwarf and normal longnose sucker forms, and compared to Salish sucker, suggesting some basis for separate designation of the dwarf form. Dwarf longnose sucker are widespread in the Elk River Watershed, and most abundant in small, cool lentic water bodies that contained dense vegetative cover, potential oxycline fluctuation and/or limited fish species diversity. Dwarf adult longnose sucker showed some habitat preference differences compared to normal longnose sucker, with the findings suggesting that dwarf longnose sucker have adopted a more opportunistic life-history strategy than normal longnose sucker. It is postulated that an ontogenetic niche shift has allowed dwarf longnose sucker to more successfully exploit habitats experiencing periodic disturbances (e.g., hypoxia) that, in turn, has led to the occurrence of two longnose sucker morphotypes in the Elk River Watershed.

ACKNOWLEDGEMENTS

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Especially deep thanks to my mother and father, who championed me throughout the preparation of my thesis. And I will truly miss the goading of my family and friends upon (finally) completing this thesis - I hope that this document will provide the inspiration for at least one of them to pursue higher academic goals in the future so that I, too, will have the opportunity to offer similar 'encouragement'! Finally, a sincere note of appreciation to Shari, whose timely support, guidance and presence made my thesis and defense that much more meaningful and enjoyable.

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CHAPTER 1: GENERAL INTRODUCTION

The phenotypic and life history traits of a species reflect the outcome of its adaptive responses to variation in environmental conditions such as resource availability and habitat features. The adaptive responses exhibited by a species are considered integral to adaptive radiation and divergence of population processes and can eventually lead to species formation (Smith and Skulason 1996). By extension, the occurrence of greater ecological variation within the geographical range of a species theoretically provides that species with greater opportunity for divergence in morphological and other phenotypic traits for those populations that are undergoing adaptive radiation and that are subject to divergent natural selection.

Arguably the most significant factor affecting the North American distribution of most extant temperate freshwater fishes was the Pleistocene glaciations (McPhail and Lindsey 1986; Bernachez and Wilson 1998; Landry et al. 2007). As many as twenty glaciation events (i.e., advances and retreats) are thought to have occurred during the Pleistocene (Martinson et al. 1987), with the most recent Wisconsinan period deglaciation occurring between 15,000 and 8,000 years ago (Dyke and Prest 1987). Each glaciation cycle was associated with wide-scale destruction, creation and/or alteration of lake and river systems which in turn affected the aquatic biota residing in these freshwater environments. During the most recent deglaciation, the formation of large proglacial lakes facilitated the dispersal of temperate freshwater fish species across vast geographical ranges of North America (Crossman and McAllistar 1986). Moreover, with the retreat of the glaciers, vast areas of freshwater habitat became available, providing

these fish species with numerous ecological opportunities to exploit “empty niches” largely devoid of any biological competitors relative to those areas that had not been glaciated.

Perhaps as a direct consequence of adaptive response to glaciation cycles, northern freshwater fishes that inhabit postglacial water bodies can often show considerable intraspecific phenotypic variability in physiological, morphological, behavioural and/or life history characteristics (Bernatchez and Wilson 1998; Robinson and Parsons 2002; Thibert-Plante and Hendry 2011). Phenotypic variation within and among populations of Salmoninae (e.g., charr and trout), Coregoninae (whitefish) and Gasterosteidae (sticklebacks) have been well documented and have received the greatest attention by evolutionary biologists (Lu and Bernatchez 1999; Taylor 2004; Hendry et al. 2009; Bernatchez et al. 2010; Hudson et al. 2011; Karvonen et al. 2013a,b; MacColl et al. 2013). In addition, high phenotypic variability has been demonstrated in Osmerid (smelt), Centrarchid (sunfish), Percid (perch) and Catostomid (suckers) fishes (Robinson and Wilson 1994; Smith and Skulason 1996; Taylor 1999; Robinson and Schluter 2000; Barrette et al. 2009). The occurrence of high intraspecific phenotypic variation across such phylogenetically diverse families and sub-families suggests that fishes of northern temperate freshwaters may be genetically predisposed to rapid adaptive radiation and population divergence in postglacial area water bodies.

High phenotypic variability is perhaps most strongly illustrated among intraspecific forms existing in sympatry (i.e., a population unrestricted to dispersal by geographical

barriers thereby allowing species interaction during breeding [Landry et al. 2007; Hendry et al. 2009; Hudson et al. 2011]) where, due to differentiation in resource use, habitat availability, behaviour and/or other factors, various forms have become partially reproductively isolated and in some cases, genetically distinct (Pigeon et al. 1997; Lu and Bernatchez 1999; Lu et al. 2001; Vonlanthen et al 2009). Interestingly, for these sympatric populations, higher phenotypic variability is more characteristic of species-poor environments. This suggests that an absence of interspecific competitors allows species to more readily exploit niches that would otherwise be less biologically available to them and, in turn, this provides a platform for character release resulting in greater phenotypic variation within the species (Robinson and Wilson 1994; Landry et al. 2007; MacColl et al. 2013).

Although strongly interrelated with physiological, behavioural and life history traits, until relatively recently, differences in morphological traits have generally served as the focus for most studies of phenotypic variation among northern temperate freshwater fishes (e.g., Norton et al. 1995). Morphological variation exhibited by sympatric species most often appears to reflect adaptations for diet specialization among planktivorous, benthivorous or piscivorous modes of feeding (Robinson and Wilson 1994; Keeley et al. 2005). Remarkably consistent among fish species and populations, morphological adaptations for selective feeding on smaller diet items include longer and more narrowly spaced gill rakers, smaller mouths and smaller heads (Keeley et al. 2005). Within sympatric fish populations, such morphological differences can develop in association

with a shift from a benthic to a planktonic diet, particularly in water bodies absent of direct competitors that can limit the exploitation of the planktonic niche (Trudel et al. 2001; Landry et al. 2007). Morphological variation surrounding jaw features, musculature and dental traits and formulae are also common in some sympatric fish populations (see Robinson and Wilson 1994). Intraspecific phenotypic variation can also appear as a consequence of forms inhabiting different habitats, such as between populations exploiting lake and stream habitats (Thompson et al. 1997; Keeley et al. 2005). In such cases, lake forms tend to exhibit more slender body form and shorter paired fins than their stream-form counterparts (Imre et al. 2002).

Because body size is one of the most important characteristics of an organism, it is a major factor in determining niche differentiation both within and among species (Wilson 1975). In some sympatric fish populations, ‘dwarf’ and ‘normal’ phenotypes of the same species co-exist in relative reproductive isolation (Robinson and Wilson 1994; Pigeon et al. 1997; Trudel et al. 2001). Dwarf fish have been defined as those that reach sexual maturity at a smaller size, exhibit slower growth rate, have an earlier age at maturation, and do not attain the same size as the normal phenotype (Rogers et al. 2002; Bernatchez et al. 2010). Physiologically, dwarf fish can exhibit higher metabolic rates than their normal phenotypic counterparts, which in turn may result in a shorter life span of the dwarf morphotype (Trudel et al. 2001). Sympatric dwarf and normal phenotypes usually forage on different prey items and/or occupy different habitats, most often reflecting a limnetic/pelagic versus epibenthic/littoral diet, respectively (Robinson and Wilson 1994).

As such, the occurrence of intraspecific dwarfism within sympatric populations appears to reflect a morphological adaptation associated with feeding specialization.

A genetic basis for the differences in the morphological traits discussed above has been verified for many fish populations inhabiting postglacial environments (Taylor and McPhail 1985; Thompson et al. 1997; Rogers et al. 2002; Keeley et al. 2005; Barrette et al. 2009; Jeukens et al. 2010; Jeukens and Bernatchez 2011). Fish species showing forms with marked morphological divergence in postglacial environments often exhibit relatively little genetic divergence, suggesting that morphological divergence can proceed more rapidly than genetic divergence (Bernatchez and Wilson 1994; Schluter 2000; Robinson and Parsons 2002). This is consistent with predicted genetic response based on glaciation history whereby widespread dispersal from relatively few glacial refugia could act in a similar fashion as a genetic bottleneck, reducing genetic diversity in fishes colonizing post-glaciated regions (Bernatchez and Wilson 1998). Nevertheless, sufficient genetic variation appears to exist between intraspecfic populations of postglacial temperate freshwater fishes to account for differentiation of morphological traits (Robinson and Wilson 1994), indicating that phenotypic variation can be quantified among species through morphological and genetic analyses.

The Catostomid family of freshwater fishes comprises over 60 species that are broadly dispersed throughout North America (Smith 1992), with several species currently listed as threatened or endangered in Canadian and United States waters (McPhail and Taylor 1999; Tranah et al. 2001). Species within the genus *Catostomus* (suckers) inhabit a wider

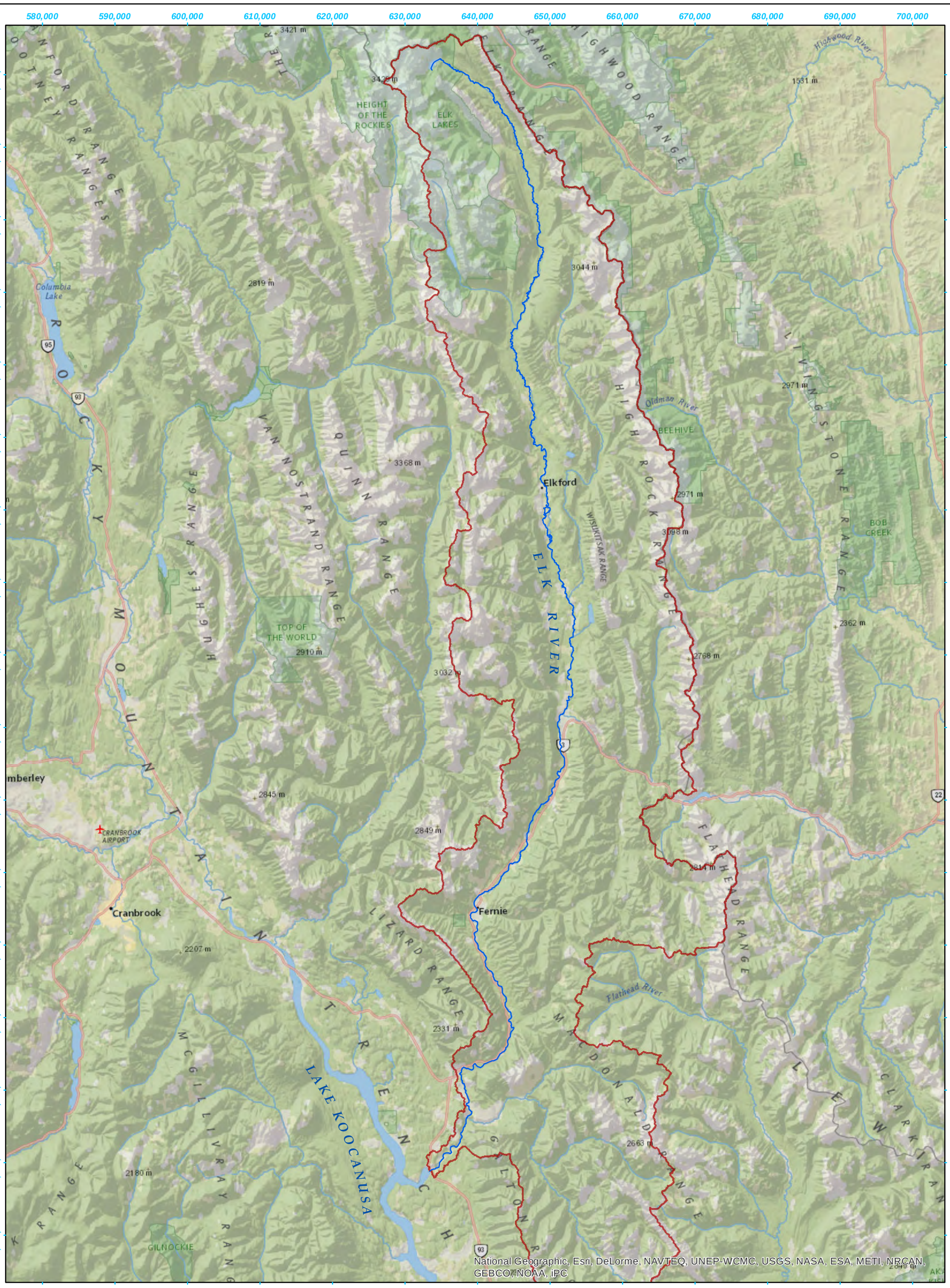
geographical and ecological range than any other North American fish genus (Uyeno and Smith 1972; Scott and Crossman 1973), with the greatest diversity within the genus occurring in mountain streams of intermediate elevation in western North America (Smith 1992). *Catostomus* are generally medium sized, ecologically generalized fishes that, as adults, inhabit a varied range of northern temperate freshwater environments (McPhail 2007). Within this genus, the longnose sucker, *C. catostomus* (Forster), has the widest geographic distribution of any catostomid and is the only cypriniform that is naturally found in Asia as well as North America (McPhail and Lindsey 1970). In North America, longnose sucker range from Labrador and New England west to Alaska and Washington, and from the Great Lakes Basin and Colorado north to the Arctic Ocean. The current range size of North American longnose sucker has reflected postglacial dispersal opportunities provided by large proglacial lakes (Bernatchez and Wilson 1998; Crossman and McAllister 1986) with current populations derived from the Beringia, Great Plains (Missouri-Mississippi system) and Pacific refugia following the Wisconsinan glaciation (McPhail and Taylor 1999).

The widespread occurrence of longnose sucker within a variety of cool water habitats across temperate postglacial areas of North America presents evolutionary biologists with a good opportunity to further test hypotheses regarding postglacial/phylogeographic dispersion, adaptive radiation, population divergence and species formation. Across its range, the longnose sucker shows considerable phenotypic variation that is evident at a morphological level (Scott and Crossman 1973; Hubbs and Lagler 2004). Of particular

interest is the occasional occurrence of ‘dwarf’ populations of longnose sucker (Miller and Hubbs 1948; Rawson and Elsey 1950; Geen 1958; McPhail 1986; Hubbs and Lagler 2004). Recently, a population of dwarf longnose sucker was discovered co-existing with the normal form within the Elk River Watershed of south-eastern British Columbia (Figure 1.1). To date, no analyses have been conducted to determine if this dwarf population is morphologically or genetically distinctive from the normal longnose sucker phenotype. Moreover, the distribution, habitat requirements and life history of dwarf longnose sucker in the Elk River Watershed is currently unknown. Notably, water bodies in this watershed are subject to potential habitat degradation and/or alteration through agricultural and resource-based industry (e.g., forestry, mining) as well as through potential hydro-electric power development. Consequently, not only does the characterization of morphological, genetic and life history traits of this dwarf longnose sucker population present a unique opportunity to further explore adaptive radiation and speciation processes in suckers, but given the anthropogenic stressors to the Elk River habitat, such information is crucial as the foundation for developing conservation strategies should this phenotype be distinctive.

Morphological and Genetic Comparisons between Dwarf and Normal Longnose Sucker

Chapter 2 of this thesis documents morphological and genetic traits of a dwarf form of longnose sucker inhabiting the Elk River Watershed with the purpose of determining whether this dwarf form constitutes a divergent evolutionary unit distinctive from normal



Elk River Watershed location

FIGURE 1.1

DRAFT

1:500,000

0 5 10 15 20 Km

Features

Elk River Watershed

Data Sources

Station Locations provided by Minnow Environmental (OCT 2013)
Stream Network - FWA MacroReaches (1:50,000)
Watershed Polygons - Freshwater Atlas (1:50,000)
Base Maps provided by ArcGIS Online licence.

Map Information	Cartographic Information
Map Projection: UTM 11	Created By: D.Hlushak
Map Datum: NAD 1983	Reviewed By: P.Lepage
Scale: 1:500,000	Map Document: 12.0022.00
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Overview Map

longnose sucker. Dwarf longnose sucker were collected from several locations throughout the Elk River Watershed and subjected to various morphological measurements and to tissue sampling for genetic analysis. Morphological measurements were also collected from normal adult longnose sucker collected within the Elk River Watershed and from museum specimens of similar size to the Elk River Watershed dwarf fish to explore potential differences among dwarf and normal populations. The Elk River Watershed dwarf longnose sucker morphological data were also compared to Salish sucker, a divergent form of longnose sucker found in western Washington state and the Lower Fraser Valley, British Columbia, to explore similarities and the potential for parallel evolution. Genetics evaluation included mitochondrial DNA (mtDNA) analysis using tissue samples collected from dwarf and normal longose sucker collected in the Elk River Watershed. Overall, the work was undertaken to test the hypothesis that, as a result of adaptive response to ecological exploitation of available habitat, sufficient divergence of character has occurred in the Elk River Watershed dwarf longnose sucker population to render it morphologically and genetically distinct from the normal longnose sucker form.

Life History Characteristics of Elk River Watershed Dwarf Longnose Sucker

The understanding of habitat requirements and life history of the Elk River Watershed dwarf longnose sucker population is important for its conservation, regardless of whether this form is considered a divergent evolutionary unit distinctive from normal longnose sucker. Therefore, Chapter 3 of this thesis documents the habitat and life history characteristics of dwarf longnose sucker in the Elk River Watershed. Certain aspects of

population, growth, and reproduction characteristics of the Elk River Watershed dwarf longnose sucker were investigated and reported. The dwarf longnose sucker life history characteristics were compared to those of normal longnose sucker and to the endangered Salish sucker. Information from these comparisons was used as the basis for explaining the mechanism by which of a dwarf form of longnose sucker could have originated in the Elk River Watershed. It was hypothesized that the life history of the dwarf form of longnose sucker in the Elk River Watershed differs from that of normal longnose sucker as a result of changes in life-history strategy that allows the dwarf form to take advantage of limited habitat.

CHAPTER 2: MORPHOLOGICAL AND GENETIC COMPARISONS BETWEEN DWARF AND NORMAL LONGNOSE SUCKERS

Introduction

High phenotypic variation is relatively common within populations of temperate freshwater fishes inhabiting postglacial environments of northern North America (Robinson and Wilson 1994; Bernatchez and Wilson 1998; Robinson and Parsons 2002; Bernatchez et al. 2010). High variability in morphological, behavioural and life history traits within and among species in such habitats is generally thought to reflect the outcome of adaptive responses associated with postglacial dispersal to environments devoid of interspecific competitors and/or predators that provided these fish species with the opportunity to exploit various trophic resources (Smith and Skulason 1996). According to the trophic resource model for speciation, strong intraspecific competition can lead to individuals within these populations becoming increasingly specialized to exploit different niches and/or food resources. In turn, this provides the opportunity for character release and adaptive radiation through diversifying selection (Bernatchez and Wilson 1998; Barrette et al. 2009; Moles et al. 2010). If this adaptive divergence is accompanied by reproductive isolation, the restriction in gene flow could generate further ecologically based reproductive barriers and ultimately lead to species formation (Turner 1999; Parker et al. 2001; Bolnick and Fitzpatrick 2007; Mallet et al. 2009; Berner et al. 2009; Jeukens and Bernatchez 2011).

Within sympatric fish populations, intraspecific phenotypic variation appears to be especially high in salmonids such as char, trout and whitefish (Lu and Bernatchez 1999;

Taylor 1999; Keeley et al. 2007; Bernatchez et al. 2010). Intraspecific variation in sympatric fish populations often appears to reflect an adaptive outcome to differential specialization in dietary niches such as planktivory, benthivory or piscivory (Robinson and Wilson 1994; Keeley et al. 2005; Moles et al. 2010; MacColl et al. 2013). In lake environments, morphologically divergent forms can exist in littoral or pelagic/limnetic habitats where specialization towards benthivorous or planktivorous/piscivorous feeding niches, respectively, prevail (Robinson and Wilson 1994; MacQueen et al. 2011). Similar types of morphological divergence can occur between forms occupying lotic (stream and river) and limnetic (lake and pond) environments, with forms characteristic of the former generally specialized towards benthic and the latter towards pelagic prey items (Keeley et al. 2005; Thompson et al. 2007; Berner et al. 2009). Where phenotypic divergence has occurred within a sympatric population, the most common morphological differences between littoral/lotic and pelagic/limnetic forms relate to body form (robust versus fusiform), feeding apparati (number, spacing and/or shape of gill rakers), head size, mouth size, jaw musculature and dental formulae (Robinson and Wilson 1994; Thompson et al. 1997; Keeley et al. 2005).

Size at sexual maturity is one phenotypic trait that can commonly vary substantially within and among sympatric fish populations. Within certain sympatric fish populations, differential growth rates exhibited by a species can lead to the development of size distributions that include a distinctly smaller form than that normally exhibited by the species (e.g., Bosclair and Leggett 1989). The smaller form, which is conventionally

referred to as a ‘dwarf’ form, often grows more slowly and reaches maturity at a younger age and reduced size compared to the ‘normal’ form (Bodaly et al. 1991; Bernatchez et al. 2010). Ecologically, dwarf and normal forms often occupy different habitats and/or forage for different prey items (Robinson and Wilson 1994; Landry et al. 2007). In addition to size, morphological variation between dwarf and normal forms appears to reflect adaptive responses to the exploitation of different available habitats and/or to development of specialized feeding niches. Such morphological variation can include changes in overall body form, mouth size and orientation, and configuration of feeding apparati (Robinson and Wilson 1994; Keeley et al. 2005; Landry et al. 2007). Although the occurrence of dwarf populations appears to be most prevalent in chars and whitefish (Lu and Bernatchez 1999; Trudel et al. 2001; Berg et al. 2010; Bernatchez et al. 2010), dwarf populations of smelts and suckers also occur on occasion (Beamish 1973; Beamish and Crossman 1976; Lafontaine and Dodson 1997; Lu and Bernatchez 1999; MacColl et al. 2013).

Theoretically, if associated with reproductive isolation, any morphological variation observed between dwarf and normal forms that has a genetic basis may be indicative of adaptive divergence, even if gene flow is initially substantial (Gavrilets 2004). Further restriction on gene flow through ongoing, reproductively-isolating, mechanisms could lead to gradual accumulation of genetic differences important in the speciation process (Gavrilets 2004; Berner et al. 2009; Hendry et al. 2009). Alternatively, distinct morphological differences between dwarf and normal forms can also reflect genetically

programmed developmental responses to different environmental and resource conditions, referred to as phenotypic plasticity (Parker et al. 2001; Robinson and Parsons 2002; Saint Laurent et al. 2003; Thibert-Plante and Hendry 2010; Hudson et al. 2011). Despite seemingly high morphological variability in some northern freshwater fish species, low genetic differentiation is often observed within and among fish populations in postglacial water bodies, including that between dwarf and normal forms (Lafontaine and Dodson 1997; Bernatchez and Wilson 1998; Robinson and Parsons 2002; Landry et al. 2007). Therefore, similar to other natural phenotypic morphological differences within and among fish populations, the occurrence of dwarf forms within a sympatric population may reflect environmentally induced modifications of the phenotype during development with or without subtle genetic differences between the dwarf and normal forms.

The longnose sucker, *Catostomus catostomus* (Forster), has the widest geographic distribution of any catostomid and is the only cypriniform that is naturally found in Asia as well as North America (McPhail and Lindsey 1970). In North America, longnose sucker range from Labrador and New England west to Alaska and Washington, and from the Great Lakes Basin and Colorado north to the Arctic Ocean. The current range size of North American longnose sucker reflects postglacial dispersal opportunities provided by large proglacial lakes (Crossman and McAllister 1986; Bernatchez and Wilson 1998) with current populations derived from the Beringia, Great Plains (Missouri-Mississippi system) and Pacific refugia following the Wisconsinan glaciation (McPhail and Taylor

1999). Despite its vast geographic range and the concomitant opportunity for allopatric divergence, morphological variation among North American longnose sucker populations is relatively minor compared to groups such as the salmonids and sticklebacks (Nordeng 1983; Robinson and Parsons 2002; Bernatchez et al. 2010; MacColl et al 2013). Nevertheless, North American longnose sucker populations have occasionally been designated into subspecies groups including eastern (*C. catostomus catostomus*), western (*C. catostomus rostratus*) and Rocky Mountain (*C. catostomus griseus*) forms based on morphological characteristics (Scott and Crossman 1973; Hubbs and Lagler 2004). Molecular analyses have suggested some genetic divergence among these longnose sucker forms which, in part, supports dispersion from different glacial refugia (Dillinger et al. 1991).

Morphological features and biological aspects of typical longnose sucker have been relatively well documented as a result of its broad geographic range, its minor importance as a commercial fish, and its capture during various scientific studies (Harris 1962; Bailey 1969; Scott and Crossman 1973; Sayigh and Morin 1986; Stanley 1988; Dion et al. 1993; Kloepper-Sams et al. 1994). These descriptions have generally been based on lake or large river-based populations throughout Canada. In brief, longnose sucker are morphologically distinguished from other catostomids by the presence fine scales, an overhanging snout and a completely cleft lower lip. Length at maturity of typical longnose suckers ranges from as low as 265 mm and 290 mm for males and females,

respectively (Bailey 1968; Scott and Crossman 1973), with individuals in some populations reaching 635 mm (McPhail and Lindsey 1970).

Longnose sucker occupy a wide range of cool to coldwater habitats. Adults generally inhabit small- to large-sized lakes and medium- to large-sized rivers characterized by low to moderate water velocities. Juveniles and fry often occupy shallower waters in the same habitat used by adults, including shallow side channels, backwaters and embayments with suitable cover and little to no water velocity. Juveniles can be particularly abundant in beaver ponds and other quiescent waters. Spawning habitat normally includes riffles with gravel substrate or shallow water along lakeshores with cobble to gravel substrate. Notably, as in other *Catostomus* suckers, longnose sucker fry have terminal mouths and feed primarily on plankton, but within the first summer of life, the mouth shifts to a ventral, subterminal position with the diet of juveniles and adults subsequently shifting almost exclusively to benthic organisms.

In addition to various subspecies groups, a number of dwarf and/or peripherally isolated longnose sucker forms have also been described, including *C. catostomus nannomyzon* (Adirondacks and Catskills of New York), *C. catostomus pocatella* (Idaho-Montana), the Jasper sucker *C. catostomus lacustris* (western Alberta), and the Salish sucker (Washington-southwestern British Columbia) (Miller and Hubbs 1948; Rawson and Elsey 1950; McPhail 1986; Hubbs and Lagler 2004). Of these, only the Salish sucker has been studied in any detail (McPhail and Taylor 1999; Pearson and Healey 2003; Helfield and Lundgren 2012). Morphologically, dwarf longnose sucker differ from normal *C.*

catostomus in body proportions, scale counts and size at maturity. Specifically, dwarf forms possess proportionately larger scales, have a deeper head and a shorter snout relative to normal longnose sucker populations. In addition, length at maturity of dwarf forms range from as low as 120 mm and 145 mm for males and females, respectively, with individuals in some populations attaining lengths of 200 mm (McPhail 1986). Habitats occupied by dwarf forms appear to include small streams/pond systems and small oligotrophic lakes. Although little is known about the feeding preferences of dwarf longnose sucker, mouth orientation of adults and juveniles suggest that like normal forms, dwarf forms likely specialize on benthic diet items. Genetic differences between Salish sucker and normal northwestern longnose sucker populations suggest that the former represents a unique evolutionary lineage, although the degree of divergence does not seem sufficient to warrant a separate taxonomic designation (McPhail and Taylor 1999; McPhail 2007).

It is noteworthy that all reported dwarf longnose sucker populations appear to be associated with geographic areas characterized by mountainous habitat, suggesting that these areas provide environments suitable for promotion of adaptive divergence in this species. Physical and ecological barriers associated with mountainous habitats may give rise to widely separated, genetically diverse populations, the nature of which may have led to divergent forms of *C. catostomus* including various dwarf populations. For example, Salish sucker are believed to be derived from a population of longnose sucker that dispersed north from the Columbia River system using a series of drainage

connections and proglacial lakes that occupied Puget Sound following the latest glaciation (McPhail 1986). This area became geographically isolated during the Pleistocene glaciations, and despite both normal western longnose sucker and Salish sucker occurring in the lower Fraser system, there is no evidence of gene-flow between these two forms (McPhail and Taylor 1999).

In 2004, a population of dwarf longnose sucker was discovered co-existing with a normal form within the Elk River Watershed of south-eastern British Columbia (Figure 2.1). This area is geographically separated from areas in which other dwarf longnose sucker populations have been purported (e.g., the lower Fraser River in south-west British Columbia, the Snake River watershed in Idaho, Jasper Lake in Alberta), suggesting that dwarf longnose sucker populations may have developed independently on a number of separate occasions over its range. This study documents morphological and genetic traits of the Elk River Watershed dwarf form of longnose sucker with the purpose of determining whether this dwarf form constitutes a divergent evolutionary unit distinctive from normal longnose sucker. It was hypothesized that as a result of adaptive response to ecological exploitation of available habitat, sufficient divergence of character has occurred in the Elk River Watershed dwarf longnose sucker form to render it morphologically and genetically distinct from the normal longnose sucker form.

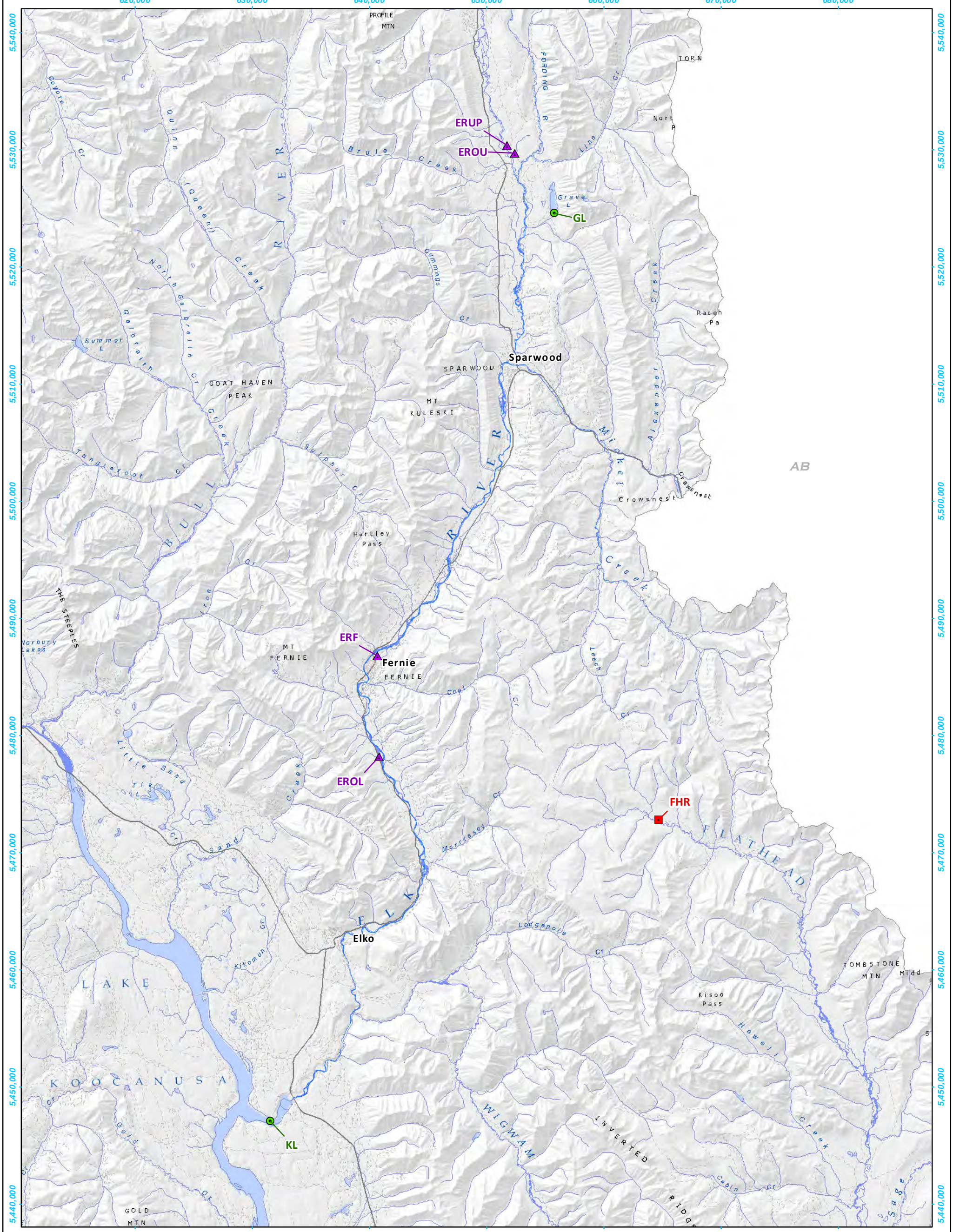
Materials and Methods

Study Area

The Elk River Watershed is located in southeastern British Columbia, and drains south from the Elk Lakes to Lake Koocanusa at the British Columbia – Montana border (Figures 1.1 and 2.1). Areas sampled for longnose sucker generally included oxbows and side-channels of the Elk River as well as adjacent ponds and slower moving tributaries to the Elk River since similar habitats were shown to be important for other dwarf longnose sucker populations (McPhail 1986; Pearson and Healey 2003). Although sampling to determine dwarf longnose sucker presence was conducted at a total of thirteen locations, three areas, including an 'Upper Ponds' area (ERUP), Maiden Lake (ERF) and a 'Lower Oxbow' area (EROL; Figure 2.1) were sampled intensively for the collection of morphometric and genetic data since these areas contained high densities of dwarf longnose sucker. Normal longnose sucker were collected at Grave Lake and Lake Koocanusa (Figure 2.1). Dwarf longnose sucker samples collected from the Flathead River Watershed, which is a separate system located adjacent to the Elk River Watershed (Figure 2.1), were also included in the morphometric and genetic analysis. Location and habitat details for each study area are provided in Tables 2.1 and 2.2.

Field Sampling and Fish Processing

Fish communities were sampled from May – July and in October 2005 using standard cylindrical double-ended minnow (funnel) traps (42 x 21 cm with 0.6 cm mesh and 2.5 cm diameter opening) constructed of galvanized metal. Minnow traps were baited with



Elk River Watershed sampling locations used for dwarf longnose sucker morphological and genetic investigation

FIGURE 2.1

1:300,000

0 5 10 15 Km

Features

Station Type

- Dwarf LNS population
- Normal LNS population
- Adjacent dwarf LNS population

Note: LNS = Longnose sucker

Data Sources

Station Locations provided by Minnow Environmental (OCT 2013)
Stream Network - NTS Water Lines (1:250,000)
Watershed Polygons - Freshwater Atlas (1:50,000)
Overview Base Map provided by Bing Maps licence.

Map Information	Cartographic Information
Map Projection: UTM 11	Created By: D.Hlushak
Map Datum: NAD 1983	Reviewed By: P.Lepage
Scale: 1:300,000	Map Document: 12.0022.00
Issue Date:	MXD_Data\Figure_2_1

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Overview Map

Table 2.1: Collection locations and sample sizes of longnose sucker used for the morphological and genetics analyses.

River System	Site name	Coordinates (UTM)	Morphological Samples	Genetics Samples	Longnose Sucker form
Elk River	Upper Ponds (ERUP)	0 651 727 E, 5 530 385 N	50	35	dwarf
Elk River	Maiden Lake (ERF)	0 644 464 E, 5 468 525 N	9	9	dwarf
Elk River	Oxbow Lower (EROL)	0 640 831 E, 5 478 206 N	20	16	dwarf
Elk River	Oxbow Upper (EROU)	0 652 417 E, 5 529 756 N	7	0	dwarf
Elk River	Grave Lake (GL)	0 655 795 E, 5 524 580 N	19	18	normal
Kootenay River	Koocanusa Lake (KL)	0 631 543 E, 5 447 109 N	0	8	normal
Columbia River	Flathead River Pond (FHR)	0 625 080 E, 5 451 228 N	9	9	undetermined

Table 2.2: Habitat and fish community characteristics of study areas used for longnose sucker morphological and genetic sampling. Areas marked by an asterisk indicate intensively monitored locations.

Study Area	Habitat and Fish Community Description
Upper Ponds (ERUP)*	Oxbow with no current upstream connection to Elk River and beaver dams separating a parallel set of oxbows. Elk River influences water levels only at highest flow periods. Substrate predominantly silt overlying sand and gravel. High density of aquatic plants throughout, including *Chara* , mare's tail (*Hippurus vulgaris*), burreed (*Sparganium* sp.) and sedges (*Carex* sp.). Moderate amounts of instream woody debris and overhanging vegetation. Fish community includes longnose sucker and longnose dace.
Upper Oxbow (EROU)	Side-channel / oxbow influenced by the Elk River only duirng very high water periods. Substrate predominantly silt overlying sand or gravel. Almost 100% coverage by dense *Chara* throughout pond area, and bordered by sedge marsh to the north and by mature coniferous forest to the south. Fish community includes longnose sucker, longnose dace and mountain whitefish.
Maiden Lake (ERF)*	Tributary of the Elk River existing as a series of small man-made and natural (beaver) ponds adjacent to the Elk River near the Town of Fernie. Elk River influences water levels only at highest flow periods. Man-made ponds generally bordered by rip-rap, containing substrate of sand and gravel with limited natural instream cover. Natural ponds with predominantly silt substrate and abundant woody debris (including standing deadwood), overhanging vegetation and emergent macrophytes (e.g., cattails) providing instream cover. Fish community includes redside shiner, longnose sucker, longnose and leopard dace.
Lower Oxbow (EROL)*	Chain of beaver ponds on an existing side-channel and oxbow system off the main Elk River. Water levels influenced by the Elk River under moderate to high flow periods. Substrate predominantly sand and gravel. Aquatic vegetation generally sparse except at marshy areas adjacent to the main river, where *Chara* and emergent sedges and grasses are common. Some woody debirs throughout the system, although generally associated with beaver dams. Rip-rap borders portions along the left bank next to a highway. Fish community includes redside shiner, longnose sucker, cutthroat trout, and longnose and leopard dace.
Grave Lake (GL)	Small lake with no direct conncection to the Elk River (groundwater flow only). Generally deep (maximum and average depth of 28 and 17.3 m, respectively), steeply contoured lake bathymetry with littoral areas characaterized by rocky substrates and minimal cover except at south end of lake, where gently sloping bathymetry and sandy substrate occur. Emergent bulrushes (*Scirpus* sp.) and large woody debris provide fish cover at the south portions of the lake. Fish community includes kokanee, rainbow trout, mountain whitefish, redside shiner and longnose sucker.
Koocanusa Lake (KL)	Large (145 km long) reservior created by the damming of the Kootenay River (Libby Dam in Montana). Generally deep (maximum and average depth of 112 and 38 m, respectively, at full pool), steeply contoured lake that can have water level fluctuate by as much as 50 m seasonally. Littoral areas are generally rocky, with minimal vegetative cover present in the lake except at the inlet of the Kootenay River, where sedge wetlands border the natural channel. Fish community includes rainbow, cutthroat, lake, bull and brook trout, kokanee, burbot, mountain whitefish, sturgeon, northern pikeminnow, peamouth, redside shiner, largescale and longnose sucker, pumpkinseed, and slimy and torrent sculpin.
Flathead River Ponds (FHR)	Chain of beaver ponds well upstream of the Flathead River, that are unlikely to be influenced by the Flathead River during high flow periods. Substrate predominantly fine silt, with shoreline areas containing some cobble-boulder substrate with fine sand or organic silt interstitially. Aquatic vegetation very sparse, with woody debris (including standing deadwood) the primary form of fish cover. Fish community included only longnose sucker.

dry cat food and deployed as overnight, bottom sets. In lake and large pond habitats, experimental gill nets (eight 7.6 x 1.82 m panels with mesh size from 1.3 to 12.7 cm stretched mesh) were deployed as short-duration (i.e., ≤ 3 hour), bottom sets near dusk.

Following capture, all longnose sucker were anaesthetized in the field using a dilute clove oil solution (Anderson et al. 1997) and measured to the nearest 0.5 millimetre (fork and total length) using a standard measuring board, and to the nearest milligram (mg) or decigram (dg) using a Pocket-Pro® balance (Acculab™, Bradford, MA) or spring scales (Pesola AG, Rebbmattli, Switzerland), respectively, depending on fish size. Additional morphometric data, including standard length, body depth at the origin of the dorsal fin, distance between paired fins, pelvic to anal fin length, postpelvic fin length, head length, head depth, snout length, lip length, lip width, postorbital length, and eye diameter (as defined in Hubbs and Lagler 2004) were measured using digital calipers from a sub-set of individuals sacrificed for more detailed biological measures. These morphometric characteristics were used by McPhail and Taylor (1999) to distinguish Salish from north-western longnose sucker, and therefore served as the focus for morphological analysis. Morphometric data were also taken from preserved normal longnose sucker specimens collected from across Canada that were available through access to the Royal Ontario Museum (ROM) collection (Toronto, ON). A total of 94 juvenile normal longnose sucker were sampled from the ROM collection for the morphological analysis, with care taken to ensure that fork lengths of the sampled individuals were within the range of the dwarf adult longnose sucker sampled from the Elk River Watershed (see Appendix A).

Genetic tissue samples were collected from longnose suckers captured at five areas within the Elk River Watershed, as well as at one area within the adjacent Flathead River system (Table 2.1). The genetic tissue samples consisted of a small piece of caudal fin tissue, removed in the field using scissors and forceps. The tissue samples were placed into individually labeled vials and preserved using 95% ethanol.

Laboratory Analysis

Variation in the longnose sucker mitochondrial DNA genome was examined by sequencing Polymerase Chain Reaction (PCR)-amplified fragments from two genes: a 307 base-pair (bp) region of the cytochrome *b* gene and a 468 bp region of the NADH subunit 2 (ND2) gene. These genes had previously been used to distinguish normal longnose sucker from Salish sucker (McPhail and Taylor 1999). Attempts to sequence a third mitochondrial DNA gene (ATPase6) were unsuccessful. Because mitochondrial DNA show high rates of evolution and generally follow a clonal pattern of inheritance, sequence of these genes are often used for examining population structure and relationships among closely related species of fishes (Wilson et al. 1985; Lee et al. 1995). The cytochrome *b* gene encodes for a transmembrane protein important in the respiratory chain of cellular metabolism, while the ND2 gene is involved in the control of mitochondrial DNA replication and RNA transcription.

Total genomic DNA was extracted using a standard semi-automated glass fiber DNA extraction protocol (Ivanova et al. 2006) at the Canadian Centre for DNA Barcoding (University of Guelph, Guelph, ON). Amplifications were carried out in 12.5 µL total

volumes containing 2 µL of diluted DNA, 5% trehalose (D-(+)-Trehalose dehydrate), 1.25 µL of 10x reaction buffer, 2.5 mM of magnesium chloride ($MgCl_2$), 1.25 pmol of each primer, 50 µM of dNTP (Promega) and 0.3 units of Platinum *Thermus aquaticus* (Taq) DNA polymerase. Initial attempts to sequence the PCR amplified fragments on undiluted DNA failed, perhaps as a result of PCR inhibitors present in DNA extracts commonly found in fin clips. Subsequently, prior to PCR sequencing, the DNA extracts were diluted 10-fold.

The primers used to amplify cytochrome b were derivatives of universal primers described by Kocher *et al*. (1989), including L14841a (CCA TCC AAC ATC TCA GCA TGA TGA AA) and H15149a (CCC TCA GAA TGA TAT TTC TCC TCA). The thermocycling conditions included denaturation at 94˚C for 60 sec, five cycles of 94˚C for 40 sec, 45˚C for 40 sec, and 72˚C for 60 sec, followed by 35 cycles of 94˚C for 40 sec, 51˚C for 40 sec, and 72˚C for 60 sec with a final extension at 72˚C for 5 min and a final hold at 10˚C indefinitely. The primers used to amplify ND2 included t-Met (AAG CTA TCG GGC CCA TAC CC; Park et al. [1993]) and ND2C (AAG CAT GGG GTC AAC GGC TGG GG; McPhail and Taylor [1999]). Thermocycling conditions for ND2 included denaturation at 94˚C for 60 sec, followed by 35 cycles of 94˚C for 60 sec, 58˚C for 60 sec, and 72˚C for 90 sec with a final extension at 72˚C for 5 min and a final hold at 10˚C indefinitely. Attempts to amplify ATPase6 with primers L8558 (TAT GCG TGT GCT TGG TGT GCC A) and H9208 (AGC TTC TTC GAC CAA TTT ATG AG; from Giuffra et al. [1994]) were unsuccessful in producing a good quality single-band PCR

product despite several attempts to optimize annealing temperature and $MgCl_2$ concentration.

Prior to sequencing, PCR products were separated on a 2% agarose E-Gel96 gel (Invitrogen, Carlsbad, CA) and visualized under ultraviolet light where they were photographed with an AlphaImager 3400 imaging system (Alpha Innotech, San Leandro, CA). Unpurified PCR products were diluted (3x) and sequenced with corresponding primers and BigDye Terminator v3.1 cycle sequencing kit (see Ivanova and Grainger 2007) and analyzed on an Applied Biosystems ABI 3730 Genetic Analyzer (Life Technologies Corp., Carlsbad, CA). Sequences were then assembled using CodonCode software (CodonCode Corp., Dedham, MA) and manually edited.

Data Analysis

Longnose suckers were initially categorized as dwarf adults, normal adults and normal juveniles based on evaluation of gonad development and secondary sex characteristics that were assessed during field collections made immediately prior to the spring spawning period. Principal Component Analysis (PCA) was then used to summarize morphological characteristics among these categories. To account for natural differences in relative body size, the raw morphometric data were calculated as the proportion of fork length (body length and depth measurements) or head length (various head features) for each individual (see Burnaby 1966). The proportioned data were then examined with PCA using SPSS Version 12.0 software (SPSS Inc., Chicago, IL). Principal components with eigenvalues greater than 1 (i.e., those that accounted for a substantial proportion of

total variation; Jackson 1993) were further evaluated based on visual examination of bivariate plots of the PCA scores. In addition, the dwarf adult, normal adult and normal juvenile principal component scores were compared among areas using a one-way Analysis-of-Variance (ANOVA) to determine whether the principal axes explained a significant proportion of morphological variation. The principal component matrix was also examined to determine those morphological features most important in describing differences between populations.

Cytochrome *b* and ND2 sequences were aligned by eye and pairwise sequence divergences were calculated using the Kimura two-parameter distance model. The sequence divergence data were then clustered using Neighbour-Joining methods based on the BOLD system (Ratnasingham and Hebert 2007). Under this method, maximum-parsimony analysis of the sequence data is conducted and a maximum-likelihood solution is sought. Pairwise comparisons of fixation index (F_{ST}) values for the cytochrome *b* and ND2 haplotype data were conducted for all Elk River Watershed dwarf longnose sucker (ERUP, ERF and EROL), normal longnose sucker (Grave and Koocanusa lakes) and the Flathead River pond (FHR) populations using Arlequin (Ver. 3.1) software (Excoffier et al. 2005). Comparisons of pairwise $F_{ST,}$ which can be used to evaluate short term genetic differences between populations (Reynolds et al. 1983, Statkin 1995), were assessed at a 0.05 p-value. The Elk River Watershed dwarf and normal longnose sucker haplotype data were then compared to sequences for Salish sucker and normal longnose sucker

from northwestern North America, which were available from Genbank under accession numbers U40553-U40559 (cytochrome *b*) and U43209-U43222 (ND2).

Results

Morphological Variation

Adult longnose sucker, which were distinguished from juveniles by the presence of well-developed gonads and/or the occurrence of secondary sex characteristics that included the presence of caudal/anal fin tubercles and a distinct red lateral band colouration, were classified into ‘dwarf’ (n = 91) and ‘normal’ (n = 23) forms based, in part, on length-at-weight relationships (Figure 2.2). Summarization of the twelve longnose sucker morphological features by PCA resulted in the extraction of four principal component axes with eigenvalues greater than one, which collectively accounted for 72% of the morphological variation (Table 2.3). The first principal component (PC1) indicated high positive weightings of relative post-anal fin length, paired fin length and post-orbital length, and strong negative weightings of relative post-pelvic length (Table 2.3). The plotted data showed clear separation of adult dwarf and adult normal longnose sucker from juvenile and Flathead River longnose sucker (Figure 2.3), with the adult dwarf population significantly different from only the latter two (ANOVA, $p < 0.00001$). This suggested that adult longnose sucker, whether dwarf or normal forms, had relatively shorter caudal peduncle/tail length, proportionately longer body length and a more anterior eye position compared to juvenile normal and Flathead River specimens.

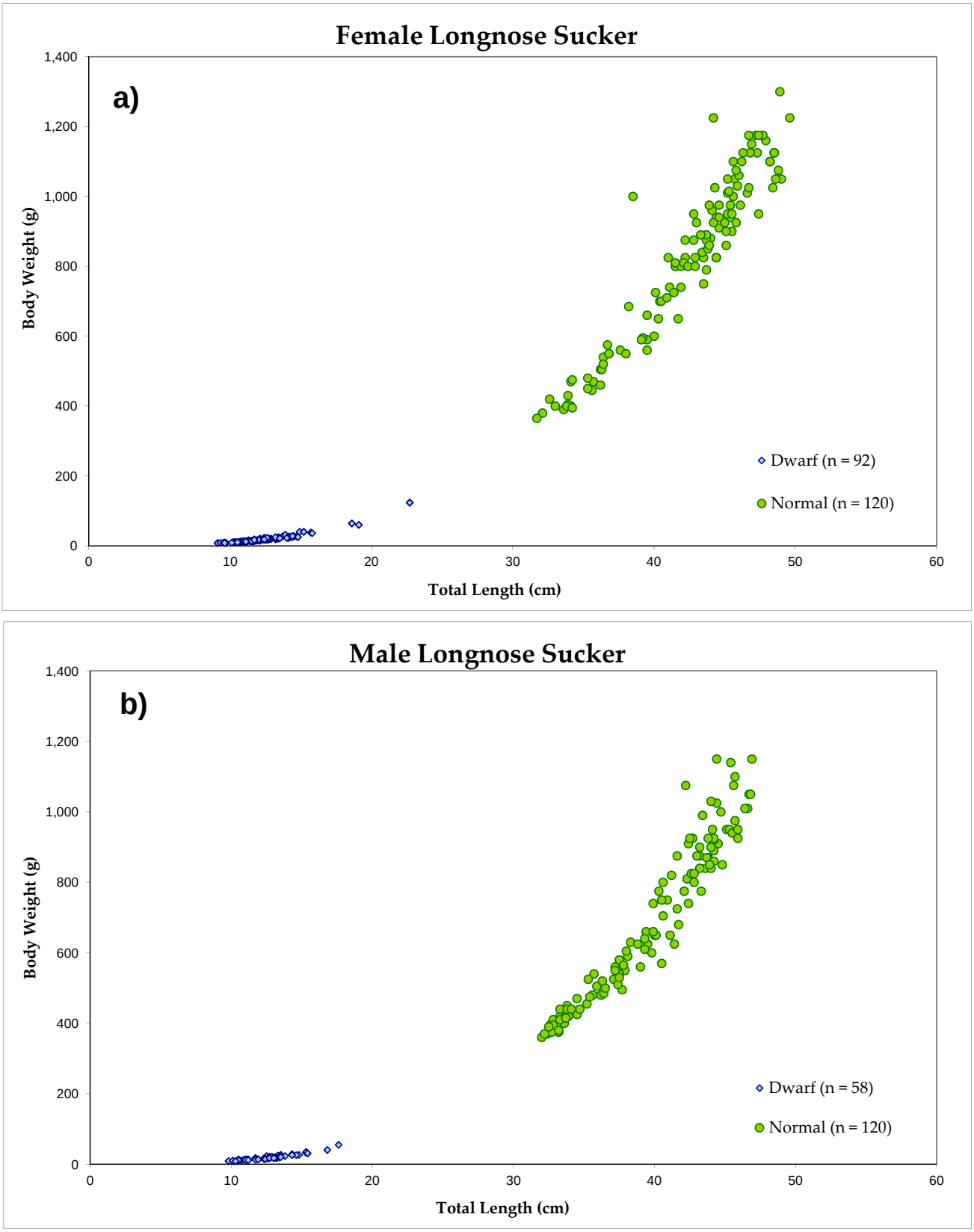


Figure 2.2: Fork length at weight of dwarf (diamond symbols) and normal (round symbols) morphotypes of a) femle and b) male adult longnose sucker (*Catostomus catostomus*). Dwarf individuals were captured in the Elk River Watershed in 2005 and normal individuals were captured in large lakes of nothern Ontario by Environment Canada in 2008.

Table 2.3: Loading coefficients for a principal component analysis of twelve external characteristics for dwarf adult, normal adult and juvenile, and Flathead River system adult longnose sucker morphology. Eigenvalues from each principal component are listed below the column of coefficients.

Morphological variable	Principal component 1	Principal component 2	Principal component 3	Principal component 4
Post-pelvic fin length	-0.939	0.123	0.070	0.059
Pelvic to anal fin length	0.929	-0.001	-0.031	-0.079
Paired-fin distance	0.872	0.018	0.066	-0.202
Post-orbital length	0.705	-0.181	-0.095	0.079
Total length	-0.423	0.239	0.036	0.311
Lip length	-0.202	-0.697	0.448	0.124
Eye diameter	0.220	-0.669	0.272	0.403
Snout length	-0.009	0.664	0.130	-0.545
Head length	0.222	0.654	-0.117	0.496
Body depth	-0.100	0.608	0.406	0.078
Lip width	0.151	0.108	0.865	-0.202
Head depth	0.437	0.552	0.198	0.552
Eigenvalue	3.54	2.59	1.28	1.23
Proportion (%) of total	29.5	21.6	10.7	10.2

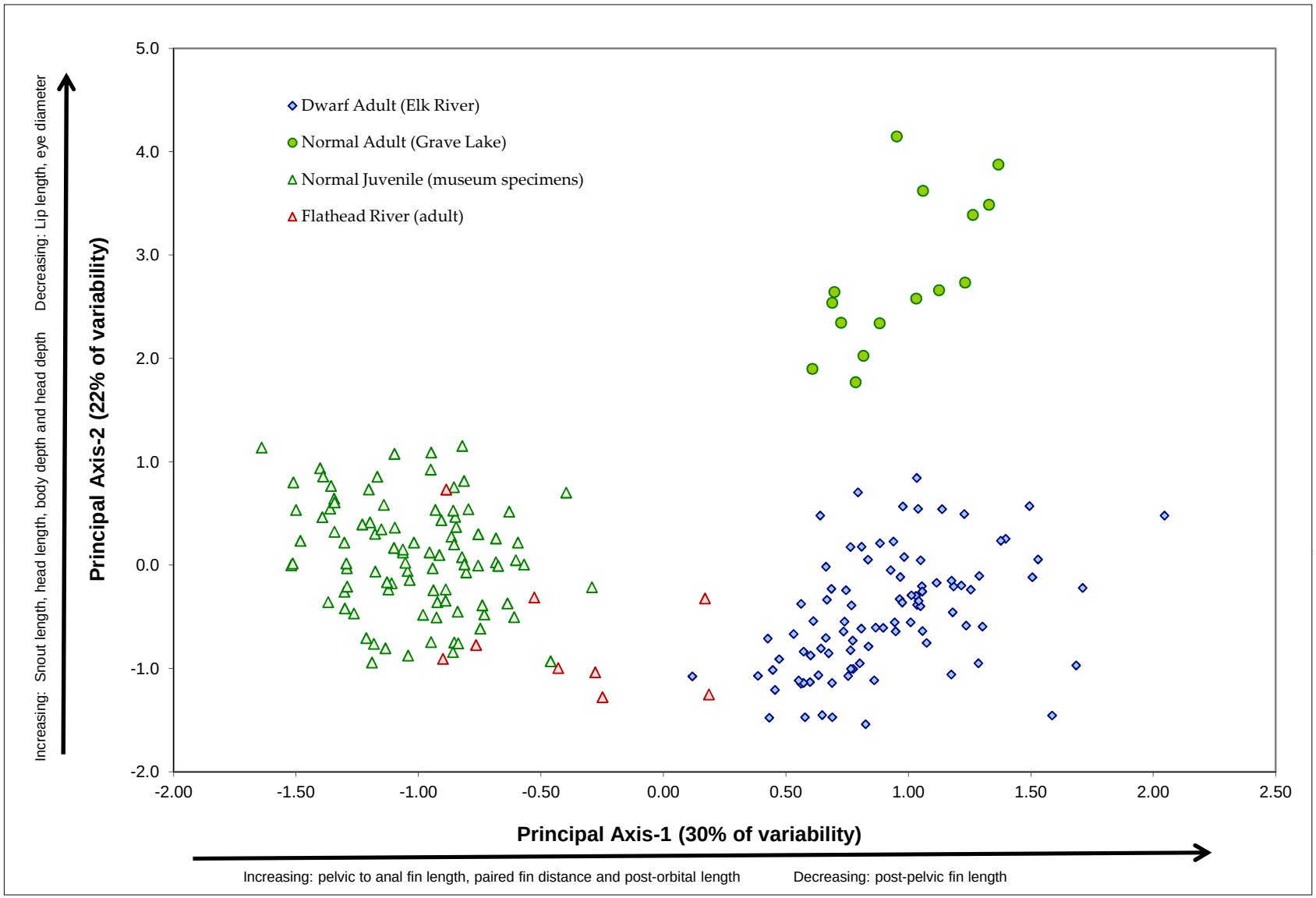


Figure 2.3: Principal components scores for four populations of longnose sucker based on the first and second principal axes based on external morphological features.

Principal component axis two (PC2) clearly separated adult dwarf, juvenile normal and Flathead River longnose sucker from the adult normal form based on high positive weightings of relative snout length, body depth, head length and head depth together with strong negative weightings of lip length and eye diameter (Figure 2.3). Elk River Watershed adult dwarf longnose sucker differed significantly from both the adult and juvenile normal populations based on PC2 scores (ANOVA, $p < 0.00001$), although considerable overlap in PC2 scores was observed between the adult dwarf and juvenile normal populations (Figure 2.3). No significant difference in PC2 scores were indicated between the adult dwarf and Flathead River longnose sucker (ANOVA, $p = 0.64$). Collectively, the PC2 data suggested that adult dwarf, juvenile normal and Flathead River fish possessed proportionately larger lips and eyes, smaller snouts and heads, and were less robust than the adult normal longnose sucker form.

Relative lip width weighted most strongly on the third principal component axis (PC3) whereas relative head length and depth, snout length and eye diameter weighted most strongly on the fourth principal component (PC4; Table 2.3). Despite adult dwarf longnose sucker showing significant differences to normal populations based on comparison of mean PC3 and PC4 scores (ANOVA, $p > 0.002$), considerable overlap in data points was generally observed in the plotted data (Figure 2.3) suggesting that adult dwarf morphological features represented by these axes were within the range found within normal populations.

Evaluation of a separate PCA conducted using only longnose sucker within a similar size range (i.e., adult dwarf, juvenile normal and Flathead River fish) indicated that, in addition to shorter caudal peduncle/tail length and greater body length and post-orbital length differences noted above, adult dwarf longnose sucker had greater eye diameter than juvenile normal and Flathead River system fish. Similarly, PCA conducted using only adult longnose sucker (dwarf, normal and Flathead River system fish) morphological data highlighted the fact that dwarf fish were less robust than their normal form counterparts, and also suggested a proportionately shorter caudal peduncle/ tail length compared to the Flathead River system fish. Thus, the morphological data indicated that Elk River Watershed dwarf longnose sucker clearly differ physically from normal forms found within and outside this watershed, although specific morphological differences vary depending on whether comparisons with dwarf forms are made to adult or juvenile normal forms.

Genetics

A sequence of 307 base pairs was obtained for the cytochrome *b* gene from the 95 individuals examined. Four haplotypes were resolved from these samples, although three of these haplotypes were represented by three or fewer individuals (Table 2.4) suggesting weak haplotype differentiation. Only three cytochrome b positions were polymorphic, all of which included a single substitution. Two A – G transitions and one C – G transversion were apparent among the four haplotypes (Appendix B). No significant differences in cytochrome b haplotypes were indicated in pairwise comparisons of the

Table 2.4: Haplotype identification and count from longnose sucker collected in the Elk River, Grave Lake, Koocanusa Lake and the Flathead River system for cytochrome *b* and ND2 genes.

Locality	Total Sample Size (n)	Longnose Sucker form	Cytochrome b Haplotypes (n)				ND2 Haplotypes (n)						
			H1	H2	H3	H4	H1	H2	H3	H4	H5	H6	H7
Upper Ponds (ERUP)	35	dwarf	-	35	-	-	23	12	-	-	-	-	-
Maiden Lake (ERF)	9	dwarf	2	6	-	1	4	3	-	-	-	1	1
Oxbow Lower (EROL)	16	dwarf	1	15	-	-	10	4	-	-	-	-	2
Grave Lake (GL)	18	normal	-	17	1	-	-	-	16	1	1	-	-
Koocanusa Lake (KL)	8	normal	-	8	-	-	-	4	4	-	-	-	-
Flathead River Pond (FHR)	9	undetermined	-	9	-	-	-	-	9	-	-	-	-

Elk River Watershed dwarf and normal longose sucker populations with the exception of dwarf fish collected at the Upper Ponds (ERUP) and Maiden Lake (ERF; Table 2.5). The ERF dwarf longnose sucker population showed highest variability in cytochrome *b* haplotypes among all the populations sampled, but the most common sequence encountered was the same as that found most frequently (or exclusively) at the remaining study areas (Table 2.4). This suggested the variation in cytochrome *b* sequences at ERF was not likely to genetically differentiate this population from others in the Elk River Watershed. No significant differences in cytochrome *b* sequences were indicated between the Elk River Watershed and Flathead River pond longnose sucker populations (Table 2.5).

A sequence of 468 base pairs was obtained for the ND2 gene from the 95 longnose sucker subject to analysis. Seven haplotypes were identified from these specimens, with dwarf longnose sucker ND2 haplotypes differing from normal longnose sucker and Flathead River system longnose sucker for all but one of these haplotypes (H2; Table 2.4). The H2 haplotype was shared among each of the three dwarf longnose sucker populations (i.e., ERUP, ERF, EROL) and the Koocanusa Lake normal longnose sucker population, suggesting some genetic overlap (Table 2.4). Sex ND2 positions were polymorphic, with four A – G transitions, one C – T transition and one A – C transversion indicated among the seven haplotypes (Appendix B). No significant differences in ND2 haplotypes were indicated in pairwise comparisons between dwarf longnose sucker populations of ERUP, ERF and EROL suggesting no substantial genetic

Table 2.5: Fixation indices (F_{ST}) statistical comparisons (p-values) between Elk River Watershed dwarf and normal longnose sucker populations based on cytochrome *b* haplotype sequences. Shading indicates significant pairwise difference at the 0.05 level.

Phenotypic Form and Sampling Locality		Dwarf Longnose Sucker			Normal Longnose Sucker	
		Upper Ponds (ERUP)	Maiden Lake (ERF)	Oxbow Lower (EROL)	Grave Lake (GL)	Koocanusa Lake (KL)
Dwarf Longnose Sucker	Maiden Lake (ERF)	0.00781	-	-	-	-
	Oxbow Lower (EROL)	0.31738	0.35742	-	-	-
Normal Longnose Sucker	Grave Lake (GL)	0.35547	0.05371	0.75098	-	-
	Koocanusa Lake (KL)	0.99902	0.44922	0.99902	0.99902	-
Flathead River Longnose Sucker	Flathead River Pond (FHR)	0.99902	0.44238	0.99902	0.99902	0.99902

separation among these groups (Table 2.6). However, all three of these dwarf longnose sucker populations showed significant difference differences in ND2 haplotypes compared to normal longnose sucker from Grave and Koocanusa lakes and longnose sucker from the neighbouring Flathead River system (Table 2.6). The Koocanusa Lake normal longnose sucker population also showed significant differences in ND2 haplotypes compared to the Grave Lake and Flathead River pond longnose sucker, despite some overlap in haplotypes among areas. Collectively, the ND2 gene sequence data suggested some genetic divergence between dwarf longnose sucker and Elk River Watershed normal and Flathead River system longnose sucker.

Pairwise comparisons between the Elk River Watershed longnose sucker data and Salish sucker data from McPhail and Taylor (1999) indicated significant differences in cytochrome b and ND2 sequences between groups, regardless of whether Elk River Watershed dwarf or normal longnose suckers were used for comparisons (Table 2.7). Interestingly, the Elk River Watershed dwarf and normal longnose sucker also showed significant differences in cytochrome b and ND2 haplotypes compared to normal 'northwestern' longnose sucker (Table 2.7)

Discussion

These results confirmed the existence of two distinct size-based morphotypes within the Elk River Watershed longnose sucker population, including dwarf and normal forms. Compared to the normal adult form, dwarf longnose sucker were characterized by shorter head length, larger mouth and eyes, shorter snout and more slender body form. In

Table 2.6: Fixation indices (F_{ST}) statistical comparisons (p-values) between Elk River Watershed dwarf and normal longnose sucker populations based on ND2 haplotype sequences. Shading indicates significant pairwise difference at the 0.05 level.

Phenotypic Form and Sampling Locality		Dwarf Longnose Sucker			Normal Longnose Sucker	
		Upper Ponds (ERUP)	Maiden Lake (ERF)	Oxbow Lower (EROL)	Grave Lake (GL)	Koocanusa Lake (KL)
Dwarf Longnose Sucker	Maiden Lake (ERF)	0.45020	-	-	-	-
	Oxbow Lower (EROL)	0.54883	0.90332	-	-	-
Normal Longnose Sucker	Grave Lake (GL)	0.00000	0.00000	0.00000	-	-
	Koocanusa Lake (KL)	0.00000	0.00781	0.00098	0.00391	-
Flathead River Longnose Sucker	Flathead River Pond (FHR)	0.00000	0.00000	0.00000	0.99902	0.01855

Table 2.7: Fixation indices (F_{ST}) statistical comparisons (p-values) between dwarf and normal longnose sucker of the Elk River Watershed, Flathead River Pond longnose sucker, Salish sucker and northwestern North America normal longnose sucker populations based on cytochrome *b* and ND2 haplotype sequences. Shading indicates significant pairwise difference at the 0.05 level.

Gene	Phenotypic Form and Sampling Locality	Elk River Watershed		Flathead River Pond Longnose Sucker	Salish Sucker
		Dwarf Longnose Sucker	Normal Longnose Sucker		
Cytochrome *b* gene	Elk River Watershed Normal Longnose Sucker	0.28809	-	-	-
	Flathead River Pond Longnose Sucker	0.99902	0.99902	-	-
	Salish sucker	0.00000	0.00000	0.00000	-
	Northwestern North America Normal Longnose Sucker	0.00000	0.00000	0.00000	0.00000
ND2 gene	Elk River Watershed Normal Longnose Sucker	0.00000	-	-	-
	Flathead River Pond Longnose Sucker	0.00000	0.42383	-	-
	Salish sucker	0.00000	0.00000	0.00000	-
	Northwestern North America Normal Longnose Sucker	0.00000	0.00098	0.20508	0.00000

addition to differences in these morphological features, the genetics data showed significant differences in ND2 gene haplotypes between dwarf and normal longnose sucker populations of the Elk River Watershed. The genetics data also indicated significant differences in cytochrome *b* and ND2 genes between the Elk River Watershed longnose sucker populations (both dwarf and normal forms) compared to Salish sucker and other northwestern North America longnose sucker.

The occurrence of these two distinct longnose sucker morphotypes in the Elk River Watershed is somewhat unique relative to other sympatric fish species populations in which dwarf and normal forms co-exist, as the latter often tend to develop as a result of diet specialization. Although some differences in mouth and head features were observed between dwarf and normal longnose sucker of the Elk River Watershed, the general morphology of each form was consistent with a benthivorous feeding habit. For other fish species showing size-based polymorphisms, morphological changes generally appear to be driven by diet specialization among benthivorous, planktivorous and/or piscivorous forms in various habitats (Lu and Bernatchez 1999; Trudel et al. 2001; Robinson and Parsons 2002; Keeley et al. 2005; Berg et al. 2010; Bernatchez et al. 2010). For example, size-related polymorphisms in many sympatric populations of salmonids (e.g., Arctic char, lake whitefish) are often characterized by the dwarf form occupying littoral habitats where a benthivorous feeding mode is adopted, and the normal form occupying pelagic habitats where feeding habits tend towards planktivory or piscivory (Robinson and Wilson 1994; Trudel et al. 2001; Parker et al. 2001; Berg et al. 2010). The retention of

benthic feeding mode in both Elk River Watershed longnose sucker morphotypes suggested that other factors contribute to the bi-modal size distribution of longnose sucker in this system.

The occurrence of Elk River Watershed dwarf and normal longnose sucker forms occupying similar habitat type (i.e. lentic) is also unusual among sympatric species containing both dwarf- and normal-sized individuals in their population. In addition to size-related polymorphisms stemming from diet specialization, differences in external features among sympatric populations appear to be induced by variation in ecological conditions. For instance, dramatic within-species differences in body and fin morphology have been shown between stream- and lake-dwelling populations. Larger and/or longer paired and caudal fins can occur in various stream fish populations compared to lake populations, purportedly to maintain position in flowing water using less energy, representing a potential adaptive response to differences in water velocity between habitats (Imre et al. 2002; Keeley et al. 2005). Some fish may also exhibit deeper and/or more robust body form under increased flow conditions (Thompson et al. 1997; Pakkasmaa and Piironen 2001). In lentic environments, within species changes in body form can be associated with littoral versus profundal habitats, with fish in the latter habitat generally characterized by more slender body and head form to accommodate more energy efficient cruising. In the Elk River Watershed, key morphological differences between dwarf and normal adult longnose sucker included more slender body form, shorter snout and larger lips and eyes in the dwarf morphotype. These differences

were not consistent with typical stream-lake or littoral-pelagic habitat species pairs, suggesting that differences in the body form between Elk River Watershed longnose suckers were not associated with flow characteristics or preferences for residing at different depths in the water column.

As an alternative to the habitat differences discussed above, the differences in body and head form observed between dwarf and normal adult morphotypes could reflect a variation in type of littoral habitat available and the benthic resource differences associated with this variation. The highest densities of Elk River Watershed dwarf longnose sucker were captured in shallow littoral habitat of small ponds/wetlands characterized by dense macrophyte growth, abundant loose cobble substrate and/or abundant woody debris. Normal longnose sucker adults were collected in lake habitat containing predominantly silt bottom, with any macrophytes, loose cobble or woody debris limited to a relatively narrow area along the shoreline (see Chapter 3). The more slender, less deep body form, shorter snout and larger lips and eyes of dwarf longnose sucker may allow more selective and efficient removal of benthos clinging to macrophytes and woody debris in ponds with dense vegetative cover. In contrast, opposite physical features found in normal longnose sucker residing in lakes with limited vegetative cover may be more suitable for sifting through large volumes of silt substrate to search out burrowing invertebrates in a more generalist manner. Therefore, differential derivation of dwarf and normal longnose sucker body shape may be associated with

slight differences in available benthic habitat, representing a slight variation of the trophic model for sympatric specialization.

Interestingly, morphological features that separated dwarf adult from normal adult longnose suckers also separated juvenile and adult stages of the normal form. This suggested that the adult Elk River system dwarf longnose sucker may retain morphological characteristics of juvenile normal form. Ontogenetic changes in body proportions and ontogenetic niche shifts commonly occur for many species of fish (Werner and Gilliam 1984; Shaw and Curry 2011). In some polymorphic populations, dwarf adults share habitats and resources with juvenile normals (Parker et al. 2001; Classen and Dieckmann 2002). Coupled with an absence of predators in Elk River Watershed habitats where dwarf longnose sucker were abundant (Table 2.1; see also Chapter 3), reproductive benefits may be achieved for individuals that mature at a young age and smaller size (i.e. dwarfs) while retaining the juvenile body size and other external features that optimize the effective exploitation of habitats normally characteristic of juveniles (Parker et al. 2001). The lack of predators may be an important feature potentially affecting ontogenetic changes as dwarf forms in predator-free environments would experience a more consistent, directional selective pressure whereas normal individuals in an environment with predators may benefit from ontogenetic changes (Moles et al. 2010). Although the ecology of Elk River Watershed dwarf longnose suckers is unknown, the phenotypic differentiation of longnose sucker in the Elk River Watershed could be described using a standard resource polymorphism model (Smith and

Skulason 1996) taking energetic intake or phenotype associations into account (Taylor 1999; Trudel et al. 2001; Evans et al. 2012).

It is noteworthy that the size-related polymorphism in Elk River Watershed longnose sucker was not consistent with differences in reproductive timing and strategies (Gross 1996). Although spawning timing likely overlapped between dwarf and normal forms based on evaluation of reproductive condition during June sampling, dams constructed by humans and beavers created physical barriers between pond habitat populated by dwarf longnose sucker and the study lakes inhabited by normal longnose sucker, likely preventing pairings between forms. The occurrence of "sneak" mating by males was also not consistent with Elk River Watershed longnose sucker size-based polymorphisms since small, sexually mature females were also present in the population, which in turn would afford little reproductive advantage for a sneak-mating strategy. Therefore, a resource-based mechanism appears to be the most likely process directing the development of dwarf forms in the Elk River Watershed.

The data presented here also suggested that Elk River Watershed longnose sucker populations, whether dwarf or normal, differed morphologically from other Canadian populations. Specifically, the Elk River Watershed longnose sucker possessed a shorter caudal peduncle/tail area but larger body and more anterior eye position than juvenile normal museum specimens collected Canada-wide. With the construction of the Libby Dam in Montana USA in 1975, fish populations in the Elk River and upper Kootenay River have been reproductively isolated from the remaining Columbia River drainage.

The slight differences in morphology of the Elk River longnose sucker potentially reflect a regional variation compared to other northwestern longnose suckers. Notably, the Elk River Watershed longnose suckers were generally collected in small pond habitats whereas museum specimens were largely representative of large lakes and river systems. The morphological differences shown between Elk River and these other populations, and specifically the difference in caudal peduncle/tail length, might reflect an adaptive or plastic response to inhabiting small versus large water bodies, the latter potentially associated with fish exhibiting longer tails to facilitate more efficient cruising. Finally, differences between Elk River Watershed and museum specimens may also simply reflect differential changes in body proportions associated with preservation and prolonged storage of museum specimens. Additional genetic and morphological analyses are required to confirm these hypotheses.

Of additional interest was the occurrence of a potential dwarf form of longnose sucker observed in the Flathead River system, which lies south-east of the Elk River Watershed and forms a separate tributary to the Columbia River. The Flathead River system fish were identified as adults based on lateral band colouration and male production of milt following application of slight abdominal pressure at the time of the June survey. Although the Flathead River longnose sucker sample size was small, morphologically these fish were intermediate between the Elk River Watershed dwarf specimens and the museum normal specimens, but genetically grouped with the adult normal longnose sucker collected from Grave Lake and Koocanusa Lake. Another dwarf longnose sucker

population was historically reported from the Snake River sub-basin of the Columbia system. The occurrence of at least three geographically separate sub-watersheds of the Columbia River system containing dwarf populations of longnose sucker suggests that this species exhibits a highly plastic response to allow exploitation of variously sized water bodies within the Columbia River system.

In addition to morphological differences, the genetics data suggested slight, but significant, differences in the ND2 gene haplotypes between dwarf and normal longnose sucker of the Elk River Watershed. Although expression of the ND2 gene is not likely to be reflected in observable morphological traits (i.e., ND2 is involved in the control of mitochondrial DNA replication and RNA transcription), the results were consistent with differences shown between dwarf and normal lake whitefish (*Coregonus clupeaformis*) forms that showed greater sequence polymorphism in (and expression of) genes involved in DNA replication and repair in the dwarf form (Jeukens et al. 2010). Other genetic differences shown between dwarf and normal forms have been linked to gene expression for morphological traits or adaptation to abiotic (ecological) conditions. For example, differences in genes associated with the rapamycin (mTOR) pathway were shown between Arctic char (*Salvelinus alpinus*) dwarf and normal forms that appear to result in reduced muscle protein accretion under growth-favouring conditions in the dwarf form (MacQueen et al. 2011). Dwarf lake whitefish have shown significant haemoglobin gene upregulation in the brain compared to the normal form, which appears to be linked to significantly larger red blood cell nuclei in the benthic-dwelling dwarf form compared to

the pelagic-dwelling normal form (Evans et al. 2012). Hypothetically, this provides the dwarf form with a competitive advantage under lower oxygen conditions found in the hypolimnion. Thus, the differences observed in ND2 sequences between dwarf and normal longnose sucker of the Elk River Watershed suggest some genetic distinctness of the dwarf form that may have arisen in response to ecological conditions. However, examination of differences between longnose sucker forms for other genes that can be more directly linked to differences in morphology (e.g., mTOR pathway genes) and/or ecological response (e.g., haemoglobin alpha and beta chain genes) would be useful for confirming a genetic basis for the size-related differences between dwarf and normal forms.

Morphological comparisons of Elk River Watershed dwarf longnose sucker to literature accounts of Salish sucker indicated that both forms possess shorter snouts, but that shallower and deeper heads, respectively, were found compared to normal forms. Genetically, the Elk River Watershed longnose sucker differed significantly from Salish sucker and normal longnose sucker from northwestern North America based on both the cytochrome *b* and ND2 genes. However, because both the dwarf and normal forms of Elk River Watershed longnose sucker differed from these other longnose sucker forms, the differences may have, in part, reflected natural subgroups among geographic sample areas that have been identified previously (Dillinger et al. 1991; McPhail and Taylor 1999).

Overall, this study confirmed the occurrence of two distinct morphotypes existing sympatrically in the Elk River Watershed and, like numerous similar studies, slight genetic divergence was indicated between morphotypes (Bernatchez and Wilson 1994; Parker et al. 2001; Robinson and Parsons 2002). Ecologically, and unique in the fact that both morphotypes specialize on benthic diet, the dwarf and normal morphotypes appear to be associated with different habitat, with each form possessing physical features suitable for optimally exploiting each different habitat. An ontogenic niche shift, which results in adult individuals retaining juvenile size and other physical features in order to exploit predator-free habitats that normally would be inhabited by normal juveniles, represents a plausible cause for derivation of the dwarf longnose sucker form in the Elk River Watershed. Accordingly, the occurrence of dwarf and normal longnose sucker forms in the Elk River Watershed may reflect a conditional response to the environment that has led to some divergence at the genetic level. This is supported by the occurrence of slight morphological differences among separate populations of dwarf longnose sucker in the Columbia River system (i.e., the Elk River and Flathead River system groups described in this study), as well as to Salish sucker of the Lower Fraser River system, and the relatively minor genetic divergence that has been shown between these dwarf forms and their normal form counterparts. Based on these results, some divergence of character has likely occurred between the Elk River Watershed dwarf and normal forms, although it is unclear whether the dwarf form is truly morphologically and genetically distinct. The data suggest that phenotypic plasticity may be favoured over adaptive genetic divergence in longnose sucker, allowing exploitation of variable environments in space

and time (e.g., Hollander 2008; Lande 2009). Despite the Elk River Watershed dwarf population not likely representing a unique element in the evolutionary history of *C. catostomus*, the sympatric division of dwarf and normal forms based on potential specialization as a result of foregoing an ontogenetic niche is unique among fish species.

CHAPTER 3: LIFE HISTORY CHARACTERISTICS OF ELK RIVER WATERSHED DWARF LONGNOSE SUCKER

Introduction

Freshwater fishes represent one of the most threatened faunas in North America with extinction rates for this group estimated to be five-fold higher than those of terrestrial vertebrates and three orders of magnitude greater than historical vertebrate extinction rates (Riccardi and Rasmussen 1999). Anthropogenic influences, including habitat destruction, alteration and/or degradation, over exploitation, introduction of non-native species and potential changes in climate are key factors contributing to reduced fish species biodiversity and extinction in freshwater systems (Hauer et al. 1997; Miller et al. 1989; Winemiller 2005). Interestingly, of the 116 fish species listed as threatened or endangered in the continental United States, 82 (or 71%) are small bodied species (i.e., maximum standard length < 15 cm; Winemiller 2005), suggesting that habitats supporting such species tend to be disproportionately threatened.

British Columbia naturally supports a relatively depauperate freshwater fish fauna of approximately 70 native species (contrast with approximately 131 native species in Ontario). Naturally low freshwater fish species diversity in British Columbia may reflect relatively recent origin from common refugia located peripheral to the Wisconsonian ice sheets during the last glacial retreat, which began some 15,000 years ago (McPhail and Lindsey 1986; Dyke and Prest 1987). As a result, freshwater fish fauna in many British Columbia aquatic ecosystems may not have reached equilibrium species diversity (Taylor 2003). Consequently, empty niches are likely available for exploitation by species and/or

different life stages of an individual species that traditionally would not be associated with such habitats, providing a platform for adaptive radiation (Robinson and Wilson 1994; Lu and Bernatchez 1999; Robinson and Parsons 2002). Adaptive radiation is the process of species diversification from an ancestral form that occurs as a result of the introduction of a species into various new ecological or geographic niches to produce additional forms specialized for exploitation of newly available resources or trophic levels (Gavrilets and Losos 2009; Hudson et al. 2011). Through phenotype plasticity and gradual accumulation of genetic changes, the development of these specialized forms can potentially represent the incipient stages of speciation (Smith and Skulason 1996; Thibert-Plante and Hendry 2011). Overall, this process enables sympatric species to successfully exploit resources and presumably facilities long-term co-existence of various forms (Schluter 2000).

Traits that commonly vary among co-existing forms in northern temperate water bodies as a consequence of low fish species diversity and greater niche availability include behavioral, life history and morphological characters, the species expression of which can often be linked with specific habitats or resources (Robinson and Wilson 1994; Lu and Bernatchez 1999; Keeley et al. 2005; Moles et al. 2010; Landry and Bernatchez 2010; MacColl et al. 2013). For example, sympatric species inhabiting flowing water habitats morphologically tend to be more robust and have larger paired fins than those associated with lake habitat. Resource based polymorphisms often tend to be reflected in changes in head/mouth morphology and accompanying behavioral shifts that result in a benthic-

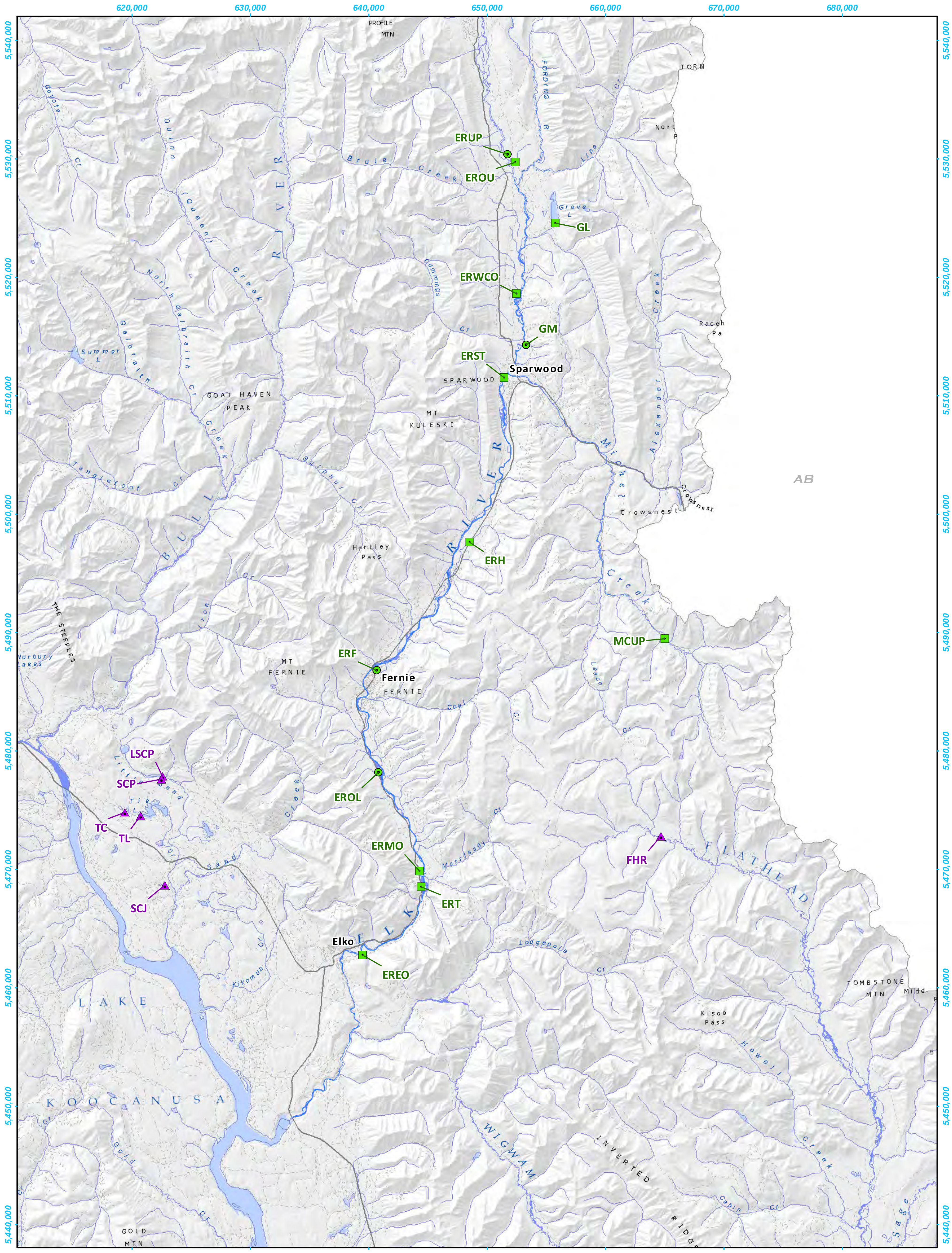
feeding versus a pelagic-feeding existence. Whether habitat or resource based, specialization or change in diet, in one form or another, appears to drive phenotypic diversity most frequently within sympatric populations. Accordingly, ecological-based polymorphisms are often included in speciation models (Parker et al. 2001; Trudel et al. 2001).

Perhaps as a consequence of the relatively depauperate fish assemblage in British Columbia, the existing species often show considerable intraspecific morphological diversity (Tamkee et al. 2010). Historically, this frequently resulted in several species descriptions for fish currently regarded as a single species (Hubbs and Lagler 2004; Keeley et al. 2005). Provincially, a high level of faunal distinctiveness in fish species may reflect relatively limited dispersal within and between watersheds as a result of extensive mountainous terrain that, in turn, has led to greater opportunities for adaptive radiation.

One trait that frequently varies within sympatric polymorphic populations is body size (i.e., size at age). Body size is among the most important characteristics of an organism, and is a major factor in niche differentiation among closely related species and among life stages within a species (Wilson 1975; Marrin 1983; Meiri et al. 2011; MacColl et al. 2013). Indeed, temporal change in a species' relative body size compared to its environment is often considered evidence of several other modifications in life history characteristics of the organism that allow niche differentiation (Knouft 2002). Within certain sympatric fish populations, differential growth rates exhibited by a species can

lead to the development of size distributions that include a distinctly smaller ‘dwarf’ form and a larger ‘normal’ form (Bosclair and Leggett 1989; Barrette et al. 2009; Moles et al. 2010). This smaller form often grows more slowly and reaches maturity at a younger age and reduced size compared to the normal form (Bodaly et al. 1991). The smaller form also often occupies a different habitat and/or forages on different prey items than the normal form (Robinson and Wilson 1994; Landry et al. 2007; Bernatchez et al. 2010). In addition to size, morphological variation between dwarf and normal forms appears to reflect adaptive responses to the exploitation of different habitats and/or to development of specialized feeding niches, which can be reflected as morphological changes in overall body form, mouth size and orientation, and configuration of feeding apparati (Robinson and Wilson 1994; Keeley et al. 2005; Landry et al. 2007).

In 2004, a population of dwarf longnose sucker was discovered co-existing with a normal form within the Elk River Watershed of south-eastern British Columbia (Figure 3.1). Although a number of dwarf and/or peripherally isolated longnose sucker forms have been described historically, including *C. catostomus nannomyzon* (Adirondacks and Catskills of New York), *C. catostomus pocatella* (Idaho-Montana), the Jasper sucker *C. catostomus lacustris* (western Alberta), and the Salish sucker (Washington-southwestern British Columbia) (Miller and Hubbs 1948; Rawson and Elsey 1950; McPhail 1986; Hubbs and Lagler 2004), the Elk River is geographically well separated from these areas, suggesting that dwarf longnose sucker populations have developed independently in the Elk River Watershed. As discussed previously (Chapter 2), the sympatric occurrence of



Elk River Watershed sampling locations used for dwarf longnose sucker life history investigation and neighbouring watershed areas sampled to assess dwarf longnose sucker presence/absence

FIGURE 3.1

1:300,000

0 5 10 15 Km

Elk River Watershed - Intensively

Elk River Watershed - General

Adjacent Watershed -

Data Sources
Station Locations provided by Minnow Environmental (OCT 2013)
Stream Network - NTS Water Lines (1:250,000)
Watershed Polygons - Freshwater Atlas (1:50,000)
Overview Base Map provided by Bing Maps licence.

Map Information
Map Projection: UTM 11
Map Datum: NAD 1983
Scale: 1:300,000
Issue Date:

Cartographic Information
Created By: D.Hlushak
Reviewed By: P.Lepage
Map Document: 12.0022.00
MXD_Data\Figure_3_1

GIS Standard Map Disclaimer:
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Overview Map

two distinct longnose sucker morphotypes in the Elk River Watershed was confirmed based on morphological characteristics and, to a lesser extent, on slight genetic divergence between dwarf and normal forms. Ecologically, the longnose sucker size polymorphisms shown in the Elk River Watershed appeared to reflect a variation in life history strategy whereby dwarf adults exploit habitat typically utilized by normal juveniles and in doing so, the adult dwarf form appeared to have retained some features characteristic of normal juveniles, including smaller size.

The distinct morphological differences but minor genetic differences exhibited between dwarf and normal longnose sucker of the Elk River Watershed were consistent with environmentally induced plastic responses shown in many sympatric fish populations of northern temperate waters. As indicated above, at least four other dwarf longnose sucker populations have been documented previously in North America, the occurrence of which reflects the possibility of parallel evolution in this species. Of these, the Salish sucker has been studied in greatest detail and is considered an evolutionary significant unit listed as endangered by the American Fisheries Society and the Committee on the Status of Endangered Species in Canada (COSEWIC 2002; Pearson and Healey 2003; Helfield and Lundgren 2012).

Although some investigation of the habitat requirements and natural history of Salish sucker has been conducted (McPhail 1987; Pearson and Healey 2003; Helfield and Lundgren 2012), similar study of the Elk River watershed dwarf longnose sucker has not been completed. Intraspecific diversity has been recognized as an important component

of biodiversity, and therefore understanding the extent of phenotypic specialization in particular habitats (i.e., local adaptation) and the habitat requirements and life history for phenotypes within and among local populations is an important aspect of biodiversity conservation. Moreover, understanding the habitat requirements and life history of any rare or endangered species can provide important insights into extinction risks. Notably, the Elk River is part of the Columbia River watershed, within which non-native fish species account for approximately 40% of the total number of fish species in the Canadian portion of this system (McPhail and Carveth 1994). The presence of non-native species can result in extinction of native species via predation, disease transmission, competition and habitat modification, or may also affect the natural patterns of species diversity within geographic areas (Taylor 2003). Therefore, the documentation and understanding of habitat requirements and life history of the Elk River Watershed dwarf longnose sucker population is important for its conservation.

The objective of the current study was to describe the habitat and life history characteristics of dwarf longnose sucker in the Elk River Watershed and to compare these features to those of normal longnose sucker and to the endangered Salish sucker. Certain aspects of population, reproduction and growth characteristics of the Elk River Watershed dwarf longnose sucker were investigated and reported. Mechanisms which may have been instrumental in producing a dwarf form of longnose sucker in the Elk River Watershed are also considered based on the information gathered during the study.

Study Area

The Elk River, located in southeastern British Columbia, drains south from the Elk Lakes to Koocanusa Lake at the British Columbia – Montana border (Figure 3.1). Elk River Watershed areas sampled for dwarf longnose sucker extended from approximately the town of Elkford to the river outlet at Lake Koocanusa. Fishing for dwarf longnose sucker concentrated on oxbows and side-channels of the Elk River, adjacent ponds and slow flowing reaches of tributaries that discharge into the Elk River as similar habitats were shown to be important for another dwarf form of longnose sucker, the Salish sucker (McPhail 1987; Pearson and Healey 2003; Helfield and Lundgren 2012). A total of thirteen locations were sampled in or immediately adjacent to the Elk River, of which four were sampled more intensively and served as the focus for this study because they contained relatively high densities of dwarf longnose sucker (Table 3.1). The intensively sampled areas included, from upstream to downstream, an 'Upper Ponds' area (ERUP), Goddard Marsh (GM), Maiden Lake (ERF) and a 'Lower Oxbow' area (EROL). Location and habitat details for each intensively sampled area are provided in Table 3.1. A number of areas within and outside of the Elk River Watershed were sampled mainly to determine presence/absence, including an Elk River watershed lake (Grave) and suitable habitats in adjacent Bull, Flathead, and Kootenay river watersheds (Figure 3.1).

Table 3.1: Location and habitat description details of ERW areas used to evaluate dwarf longnose sucker life history. Areas marked by an asterisk indicate intensively monitored locations.

Study Area	Coordinates (11 U)	Habitat Description	Average Dissolved Oxygen	
			mg/L	% Saturation
Upper Ponds (ERUP)*	0 651 727 E 5 530 385 N	Former oxbow with no current upstream connection with Elk River and beaver dams separating a parallel set of oxbows. Elk River influences water levels only at highest flow periods. Substrate predominantly silt overlying sand and gravel. High density of aquatic plants throughout, including *Chara* , mare's tail, burreed and sedges. Moderate amounts of instream woody debris and overhanging vegetation.	8.6	80.1
Upper Oxbow (EROU)	0 652 417 E 5 529 756 N	Side-channel / oxbow influenced by the Elk River only duirng very high water periods. Substrate predominantly silt overlying sand or gravel. Almost 100% coverage by dense *Chara* throughout pond area, and bordered by sedge marsh to the north and by mature coniferous forest to the south.	11.0	104.9
Grave Lake (GL)	0 655 795 E 5 524 580 N	Small lake with no direct conncection to the Elk River (groundwater flow only). Generally deep (to 23 m), steeply contoured lake bathymetry with littoral areas characaterized by rocky substrates and minimal cover except at south end of lake, where gently sloping bathymetry and sandy substrate occur. Emergent bulrushes (*Scirpus* sp.) and large woody debris provide fish cover at the south portions of the lake.	8.8	85.1
Weiger Creek Oxbow (ERWCO)	0 652 496 E 5 518 633 N	Oxbow of the Elk River that has since been modified by addition of berns and culverts to create a series of ponds intended for use by livestock. The ponds tend to be relatively deep with steep banks, with substrate consisting predominantly of gravel and cobble. Some cover structure for fish is provided by overhanging vegetation and woody debris, but no aquatic vegetation was observed in the ponds.	nm	nm
Goddard Marsh (GM)*	0 653 323 E 5 514 291 N	Low-lying cattail marsh formed as the result of a beaver dam located immediately adjacent to the Elk River. Substrate predominantly fine silt and sand. Cattail (*Typha* sp.) and horsetail (*Equisetum* sp.) provide dense coverage throughout marsh.	8.3	76.3
Sparwood Town (ERST)	0 651 460 E 5 511 544 N	Former oxbow with no current upstream connection with Elk River and beaver dams now creating a series of small ponds. The Elk River may influence water levels only at highest flow periods. Substrate predominantly silt overlying sand and gravel. Low density of aquatic plants including pondweeds and sedges. Moderate amounts of instream woody debris and overhanging vegetation.	nm	nm
Michel Creek Upper Ponds (MCUP)	0 665 037 E 5 489 486 N	Chain of beaver ponds on small creek that feeds into Michel Creek, which is a tributary to the Elk River. Water levels not likely influenced by Michel Creek except under very high flow periods. Substrate predominantly sand and mud. Aquatic vegetation (*Chara*) very dense throughout upper ponds, with woody debirs (standing deadwood, logs) also abundant throughout the system. Cobble-gravel borders portions along the left bank next to a railline.	9.2	81.6
Hosmer (ERH)	0 648 548 E 5 497 619 N	Tributary to the Elk River with numerous beaver ponds throughout. Substrate generally fine silt at slow-flowing areas and cobble in flowing areas. Instream vegetation ncludes moder amounts of *Chara* and filamentous green algae. Overhanging vegetation and woody debris provide instream cover.	9.2	78.0
Maiden Lake (ERF)*	0 644 464 E 5 468 525 N	Tributary of the Elk River existing as a series of small man-made and natural (beaver) ponds adjacent to the Elk River near the Town of Fernie. Elk River influences water levels only at highest flow periods. Man-made ponds generally bordered by rip-rap, containing substrate of sand and gravel with limited natural instream cover. Natural ponds with predominantly silt substrate and abundant woody debris (including standing deadwood), overhanging vegetation and emergent macrophytes (e.g., cattails) providing instream cover.	8.0	81.6
Lower Oxbow (EROL)*	0 640 831 E 5 478 206 N	Chain of beaver ponds on an existing side-channel and oxbow system off the main Elk River. Water levels influenced by the Elk River under moderate to high flow periods. Substrate predominantly sand and gravel. Aquatic vegetation generally sparse except at marshy areas adjacent to the main river, where *Chara* and emergent sedges and grasses are common. Some woody debirs throughout the system, although generally associated with beaver dams. Rip-rap borders portions along the left bank next to a highway.	9.4	90.7
Morriisey Oxbow (ERMO)	0 644 311 E 5 469 887 N	Former oxbow with no current upstream connection with Elk River. Beaver ponds located in upper portion of former river channel. Substrate predominantly silt overlying sand and gravel. Moderate density of aquatic plants throughout, including mostly burreed and smartweed. Instream cover includes some large woody debris and undercut banks.	10.2	98.2
Tunnels area (ERT)	0 644 425 E 5 468 537 N	Inlet off main-channel of the Elk River, with water levels influenced by Elk River under moderate to high flow periods. Substrate predominantly silt overlying cobble. Aquatic vegetation includes abundant burreed instream and overhanging sedges and grasses along shorelines. Some large woody debris instream.	7.5	71.9
Elko Oxbow (EREO)	0 639 467 E 5 462 797 N	Side-channel / oxbow currently influenced by the Elk River under moderate flow periods. Substrate predominantly silt overlying sand or gravel. Open pond area bordered by dense horsetail/aquatic grass coverage.	-	-

Materials and Methods

Life history features of the dwarf longnose sucker in the Elk River Watershed were documented through the collection of distribution, habitat, population size, and growth and reproduction information. Field samples were collected between May 18th and July 3rd and again between October 14th and 21st, 2005. In some cases, information collected in 2005 was augmented using initial observations made in 2004, prior to undertaking this study. To the extent possible, Elk River Watershed longnose sucker data were compared to published information for normal longnose sucker and Salish sucker, with raw data used when available.

General Population Features

General population features of Elk River Watershed dwarf longnose sucker were determined through evaluation of presence/absence (i.e., distribution and habitat usage), population and home range size, diet and fish species associations. For evaluation of general population features, fish communities were sampled using standard cylindrical double-ended minnow (funnel) traps (42 x 21 cm with 0.6 cm mesh and 2.5 cm diameter opening) constructed of galvanized metal. Minnow traps were baited with dry cat food and deployed as overnight, bottom sets that were checked and emptied every one or two days. Supporting information recorded for each deployed trap included location (global positioning system [GPS] coordinates), set and retrieval time, water depth, habitat description and field measurement of water temperature and dissolved oxygen

concentration at each water body using a portable YSI 85 field meter (YSI Inc., Yellow Springs, OH).

All captured fish were identified and counted, with all non-target species released shortly thereafter. At intensively monitored areas, a subset of captured longnose sucker were anaesthetized in a mild clove oil solution (Anderson et al. 1997) and measured to the nearest 0.05 millimeter (fork and total length) using a standard measuring board and to the nearest 0.001 gram using an Acculab™ Pocket-Pro® balance (Sartorius Group, Goettingen, Germany) and subsequently released following external evaluation of maturity and sex. The maturity (juvenile or adult) and sex of all captured longnose sucker was assessed based on the combination of the presence or absence of secondary sex characteristics such as colouration (i.e., lateral red stripe), pelvic and/or caudal fin tubercles, and anal fin morphology (Stanley 1988; Pearson and Healey 2003). Catch-per-unit-effort (CPUE) was calculated as the number of fish captured per minnow trap per 24-hour period for each species, with average CPUE compared among water bodies to provide information on relative dwarf longnose sucker numbers in each respective fish community. Longnose sucker length, weight, maturity and sex data were used to calculate the relative proportion of juveniles, adult females and adult males in the population (i.e., number of each fish at each maturity level divided by the total number of longnose sucker captured), as well as to provide the size range and size-at-maturity for each sex.

The evaluation of dwarf longnose sucker population (ERUP, GM and ERF) and home range (ERUP only) size was conducted using mark-recapture techniques. After anaesthetization, recording of sex, and measurement of length and weight, another subset of individuals was outfitted with individually numbered, ⅛" [0.3 cm] oval Fingerling FTF-69 tags (Floy Tag Inc., Seattle, WA). Additional dwarf longnose sucker were also 'marked' by clipping of the left or right pelvic fin according to monitoring location and/or season. All tagged and marked fish were released at their capture location following recovery from the anesthetic. Subsequent catches of all tagged and marked fish were noted in catch records. After a minimum of 10 days from the tag installation date, measurements of length and weight were taken from all recaptured tagged fish. The mark-recapture data from tagged and marked individuals were used to calculate estimates of dwarf longnose sucker abundance and density using a refinement of the Lincoln-Peterson method for closed populations (Seber 1982; Lettnik and Armstrong 2003). The population estimate was conducted for ERUP, GM and ERF water bodies as these study areas met the assumptions of the Lincoln-Peterson model (i.e., limited to no fish immigration or emigration was likely from these areas between site visits).

Catch records for tagged individuals were also used to determine linear home range size and to provide information on daily movement of dwarf longnose sucker at ERUP. Distances among sampling stations at ERUP were obtained using a range finder and/or GPS unit. Maximum linear home range size for each individually tagged longnose sucker was calculated as the distance between the initial location of capture and the

furthest location of recapture between May and October, 2005. Daily distances traveled were calculated using similar methods as indicated above, but only for fish recaptured within 24 hours of the previous capture. To explore whether water temperature strongly influenced dwarf longnose sucker movement patterns, relationships between CPUE and water temperature were evaluated using Spearman rank-order correlation coefficients with a one-tailed test of significance (Zar 1999).

Diet analysis was conducted on a sub-sample of sacrificed individuals collected from intensively monitored study areas. Following removal of reproductive tissues, digestive tracts were removed, placed into plastic sealable sampling bags and preserved using 10% formalin. In a laboratory, the digestive tracts were emptied and the contents examined under a dissecting microscope to qualitatively determine the relative importance of invertebrates and/or algae in the diet of longnose suckers.

Growth Characteristics

The evaluation of longnose sucker growth included analysis of age distribution, age- and size-at-maturity relationships, and growth rates. Age was determined using clean, dry operculae removed from a sub-set of sacrificed individuals. In a laboratory, annuli from operculae were interpreted as zones of discontinuous or compact circuli, which were read with the aid of a stereomicroscope using low magnification (i.e., 3 – 10 times; Perry and Casselman 2012). Fin rays removed from a limited number of fish collected at Goddard Marsh were also aged using methods outlined by Beamish (1973) to evaluate agreement in age estimates using operculae and fin rays since fin rays are more often used for aging

Catostomids (Stanley 1988). The age data were used to provide length-at-age and age-at-maturity estimates, with these data then compared between the sexes and to published literature for other longnose sucker populations. Growth rates were calculated separately for each sex based on the difference in fork length of individually tagged fish and the sampled population between the spring-summer and fall capture data. Differences in growth rate between dwarf longnose sucker sexes were evaluated using ANOVA.

Reproduction

The evaluation of longnose sucker reproduction included analysis of spawning timing, relative gonad size, fecundity, egg size and length of the incubation period. The spawning period duration was evaluated based on observations of egg or milt production following application of gentle abdominal pressure on each individual longnose sucker during field collections. A subset of individuals were sacrificed, the visceral cavity of each fish opened, and the gonad subsequently removed and weighed to the nearest milligram (0.001 g) using an Acculab™ VI analytical balance (Sartorius Group, Goettingen, Germany). Ovarian tissue for fecundity and egg size estimates were collected into labeled 250 mL Whirl-Pak® sample bags and preserved using 10% buffered formalin. Fecundity estimates were later conducted in a laboratory by enumerating eggs from three pre-weighed sub-samples per individual gonad sample and counting the eggs with the aid of a stereomicroscope at magnification of five times. The total number of eggs per female was estimated using the mean number of eggs per sub-sample and the sub-sample weight relative to the whole gonad weight. Gonadosomatic index (GSI; gonad weight/(body weight – gonad weight) x 100; Bolger and Connolly 1989) was

calculated separately for each sex for spring (May-June) and fall (October) captures and compared using analysis of variance (ANOVA). Relationships between GSI and fork length, weight and age were evaluated using the correlation analysis using methods described previously. The GSI, fecundity and egg size data were compared to normal adult longnose sucker data using ANOVA.

Longnose sucker embryos were cultured to determine incubation period and larval size. Ripe fish from the Upper Ponds and Goddard Marsh were retained alive in aerated buckets of water and transported to a field laboratory for processing. Eggs from a total of twenty females were fertilized using milt pooled from at least three males for each female. Prior to gamete removal and fertilization, water was filtered using 0.45 µm filter paper to remove suspended solids and any organic material that might interfere with the fertilization process. Females and males were anaesthetized using a clove oil-ethanol mixture following which gametes were immediately stripped from ripe individuals. Milt was evenly distributed to each egg sample using a syringe within two minutes of removing eggs from the female. Once the milt was added to the eggs, filtered water was added to the combined gametes and the sample agitated to ensure complete mixing. The embryos were then allowed to sit undisturbed for a three-hour water hardening period, following which they were transported to a laboratory-based embryo incubation system.

The embryo incubation system was set up at Elkview Coal operations in Sparwood, British Columbia. The system consisted of two gravity fed, four-basket flow-through vertical incubators (MariSource, Milton, WA) fed with clean source water drawn from

the Elk River. Embryo baskets were modified with dividers to create five separate incubation compartments per basket (i.e., 20 separate incubation compartments per vertical incubation unit). In addition, the bottom of each embryo basket and the basket lid were outfitted with 500 µm mesh screening to prevent the loss of larvae or fry. From a head tank, water was fed by gravity via a valve-controlled system to the incubation units which were constructed with the assistance of personnel from the Freshwater Fisheries Society of British Columbia (FFSBC) to ensure proper functioning and that the incubation system met industry fish rearing standards.

Following water hardening, embryos from each water hardened sample were counted and separated for transfer to the incubation units in the field laboratory. Embryos from individual females were placed into separate compartments with the time of transfer and the sample code for each individual compartment recorded. The incubation units were monitored daily, with each incubation tray removed to inspect the general condition of the embryos and to remove any dead or decaying eggs, which were readily distinguishable by slightly darker colouration and/or the presence of fungus relative to healthy eggs. The embryos were closely monitored for development throughout the incubation period. The date of hatch was recorded for each sample, following which close observations were conducted to determine the overall health of the larvae and to assess the yolk-sac absorption (YSA) stage. The removed larvae were sacrificed by anaesthetization in a dilute clove oil solution prior to transfer to labelled high-density polyethylene (HDPE) jars containing a 10% formalin solution. Larval length was

measured at the Department of Fisheries and Oceans Canada (DFO) Freshwater Institute (Winnipeg, MB) using a microscope based micrometer.

Water temperature, dissolved oxygen and conductivity were measured daily in each incubation unit using a YSI 85D field meter, and flow entering each unit was also measured daily using a 4-L container and stopwatch. The initial flow-rate through each system was adjusted to 5 L/min but increased to 10 L/min to reduce embryo mortalities following discussion with FFSBC personnel. A StowAway Tidbit temperature logger (Onset Computer Corp., Pocasset, MA) set to record water temperature four times daily was also placed into the bottom tray of the incubation unit to allow determination of embryo development based on thermal units (TU).

Results and Discussion

Distribution, Habitat and Habitat Use

Longnose sucker were widespread in the Elk River Watershed, being present at eleven of the thirteen areas sampled and extending from areas near the town of Elkford to the Elko Reservoir (Figure 3.1; Table 3.2). Of these areas, Grave Lake was the only water body in which both dwarf and normal longnose sucker form were collected. In total, 7,628 longnose sucker (including recaptures) were collected in the Elk River Watershed over the study duration, with highest catches encountered at intensively monitored areas including ERUP, ERF and GM (Table 3.2). Dwarf longnose sucker were also captured in the Flathead River system, which is immediately east of the Elk River Watershed and forms a separate tributary to the

Table 3.2: Summary of Elk River Watershed minnow trap fish catches. Catch-per-unit-effort (CPUE) represents number of fish captured per trap per day.

Study Area[a]	Survey Timing	Trap Hours	Longnose Sucker					Longnose Dace		Redside Shiner		Leopard Dace		Mountain Whitefish		Cutthroat Trout		Brook Trout		Bull Trout	
			Male	Female	Juveniles	Total	Average CPUE	Total	Average CPUE	Total	Average CPUE	Total	Average CPUE	Total	Average CPUE	Total	Average CPUE	Total	Average CPUE	Total	Average CPUE
ERUP	Spring[b]	7,073	1,588	788	1,384	3,760	16.2	253	1.1	-	0	-	0	-	0	-	0	-	0	-	0
	Fall[c]	409	88	55	348	491	28.7	2	0.0	-	0	-	0	-	0	-	0	-	0	-	0
ERF	Spring	1,197	32	133	244	409	9.6	158	3.0	1,813	49.2	3	0.1	-	0	-	0	-	0	-	0
	Fall	528	-	279*	220	499	16.8	1	0.0	2,291	81.4	-	0	-	0	-	0	-	0	-	0
GM	Spring	7,256	590	363	1,270	2,223	7.8	1,150	4.3	-	0	-	0	-	0	17	0.1	3	0.0	4	0.0
EROL	Spring	2,503	38	38	69	145	1.3	13	0.1	555	5.7	9	0.1	-	0	2	0.0	-	0	-	0
ERMO	Spring	430	12	2	10	24	1.3	-	0	-	0	-	0	-	0	1	0.1	-	0	-	0
EROU	Spring	3,312	36	11	4	51	0.4	2	0.0	-	0	-	0	2	0.0	-	0	-	0	-	0
ERT	Spring	397	-	-	5	5	0.3	2	0.1	-	0	-	0	-	0	-	0	-	0	-	0
GL	Spring	1,207	2	2	11	15	0.2	-	0	1,219	34.1	-	0	-	0	-	0	-	0	-	0
ERWCO	Spring	131	1	-	-	1	0.1	-	0	-	0	-	0	-	0	-	0	-	0	3	0.6
EREO	Spring	237	-	1	-	1	0.1	-	0	-	0	-	0	-	0	-	0	-	0	-	0
ERST	Spring	277	-	4	-	4	0.3	-	0	-	0	-	0	-	0	-	0	-	0	-	0
MCUP	Spring	376	-	-	-	-	0	-	0	-	0	-	0	-	0	3	0.2	-	0	-	0
ERH	Spring	295	-	-	-	-	0	-	0	-	0	-	0	-	0	-	0	-	0	2	0.2
Totals		25,843	2,387	1,397	3,565	7,628	5.2	1,581	0.6	5,878	10.6	12	0.0	2	0.0	24	0.0	3	0.0	9	0.1

[a] See Table 3.1 for study area codes and habitat descriptions

[b] Spring fish sampling period extended from May 18th to July 3rd, 2005

[c] Fall fish sampling period extended from October 14th to 21st, 2005

Columbia River. A dwarf longnose sucker population was also historically reported from the Snake River sub-basin of the Columbia system (Hubbs and Lagler 2004). The occurrence of dwarf longnose sucker from at least three separate sub-watersheds suggests that dwarf populations may be geographically scattered throughout the Columbia River system.

Within the Elk River Watershed, dwarf longnose sucker were most abundant in small, shallow lentic water bodies adjacent to or directly connected to the Elk River, including beaver ponds, marshes, oxbows and slow-moving side channels that were only seasonally influenced by Elk River flow. Habitat at these areas was generally characterized by cool water temperatures (i.e., ≤17˚C) and moderate to high dissolved oxygen concentrations (i.e., > 6 mg/L and ≥70% saturation) at water depths sampled by minnow trap. At the Upper Ponds, mean water temperature was 13.1 ± 3.1˚C between May and October, with a maximum water temperature of 20.4 ˚C observed in August (Figure 3.2). The water temperatures at the Upper Ponds were within the reported range preferred by normal longnose sucker (i.e., 10 to 15˚C mid-summer; Brown and Graham 1953) and were not unlike temperatures common to habitats containing Salish sucker that can often exceed 20˚C but are typically below 16˚C during the summer (Pearson and Healey 2003: Helfield and Lundgren 2012). Exceptions to generally high dissolved oxygen concentrations were suggested at Maiden Lake and the Upper Oxbow, where nocturnal hypoxia at depths greater than approximately 1 to 1.2 m was the suspected cause of fish

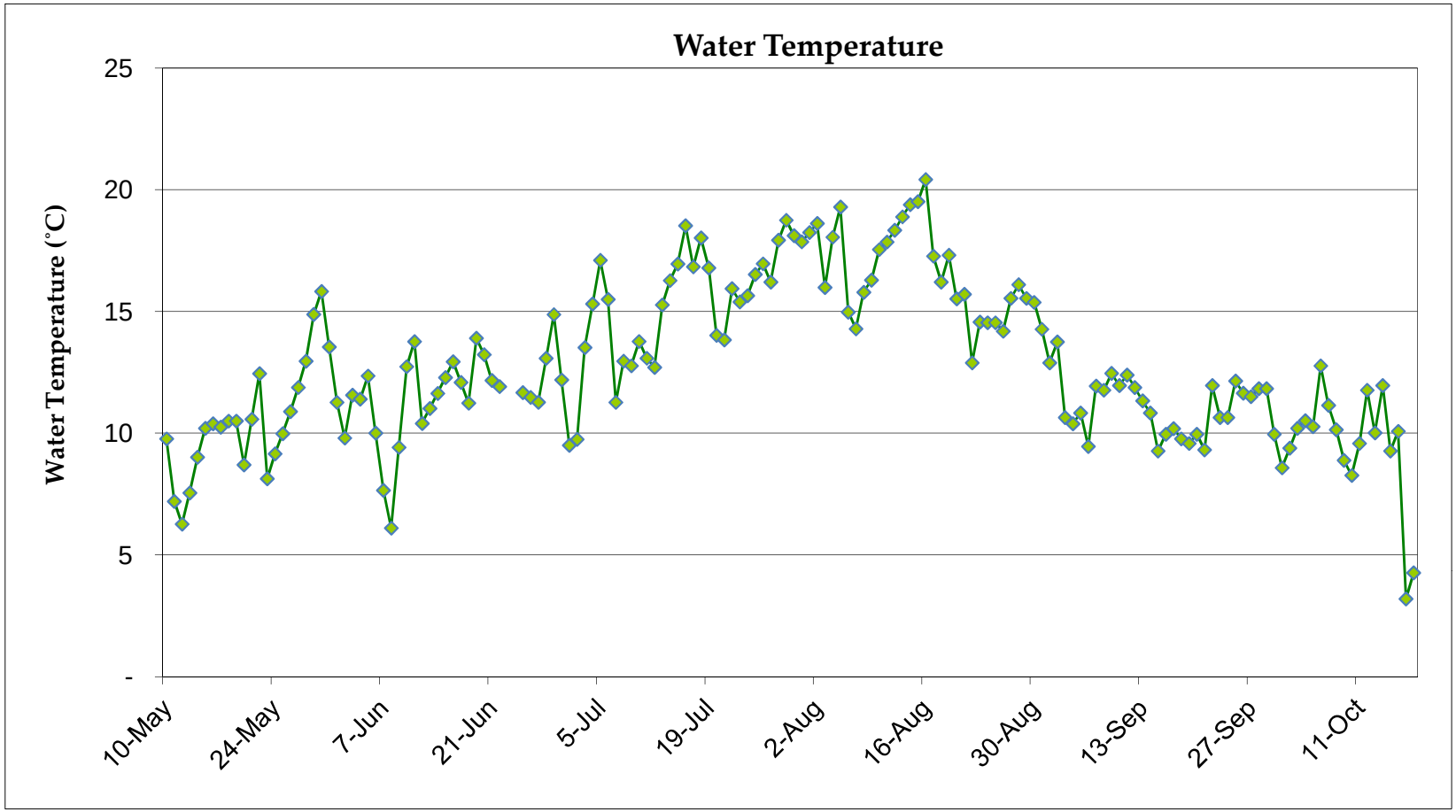

Figure 3.2: Water temperature at ERUP from May 10th to October 17th, 2005

mortalities observed in minnow traps set overnight at these depths. Dissolved oxygen concentrations above 6 mg/L are considered optimum for normal longnose sucker (Edwards 1983).

Elk River Watershed water bodies with highest dwarf longnose sucker catches generally contained dense cover of emergent vegetation (e.g., *Typha* sp., *Equisetum* sp.), submergent vegetation (e.g., *Chara* sp., *Potamogeton* sp.), and/or woody debris (e.g., Upper Ponds, Goddard Marsh; Tables 3.1 and 3.2). High numbers of dwarf longnose sucker were also captured at water bodies that contained variable to limited cover but were suspected of exhibiting pronounced diurnal fluctuation in water column oxycline depth (e.g., Maiden Lake, Upper Oxbow; Table 3.2). These habitats contrast markedly with that of normal adult longnose sucker, which typically inhabit relatively deep (20 - 40 m), clear, well-oxygenated waters that have limited littoral zone area, rapidly increasing water depth, and sparse to no vegetative or other type of physical cover structure (Edwards 1983; Gorman et al. 2008). However, habitat of Elk River Watershed water bodies containing abundant dwarf longnose sucker were very similar to those described for Salish sucker by McPhail (1986), Pearson and Healy (2003) and Helfield and Lundgren (2012).

Population estimates for dwarf longnose sucker at the Upper Pond area ranged from 2,449 individuals (2,167 individuals $\cdot$ ha^{-1}) in July to 3,299 individuals (2,919 individuals $\cdot$ ha^{-1}) in October. The higher population estimate for October appeared to be associated with a greater proportion of juveniles (Figure 3.3), and thus potentially reflected new

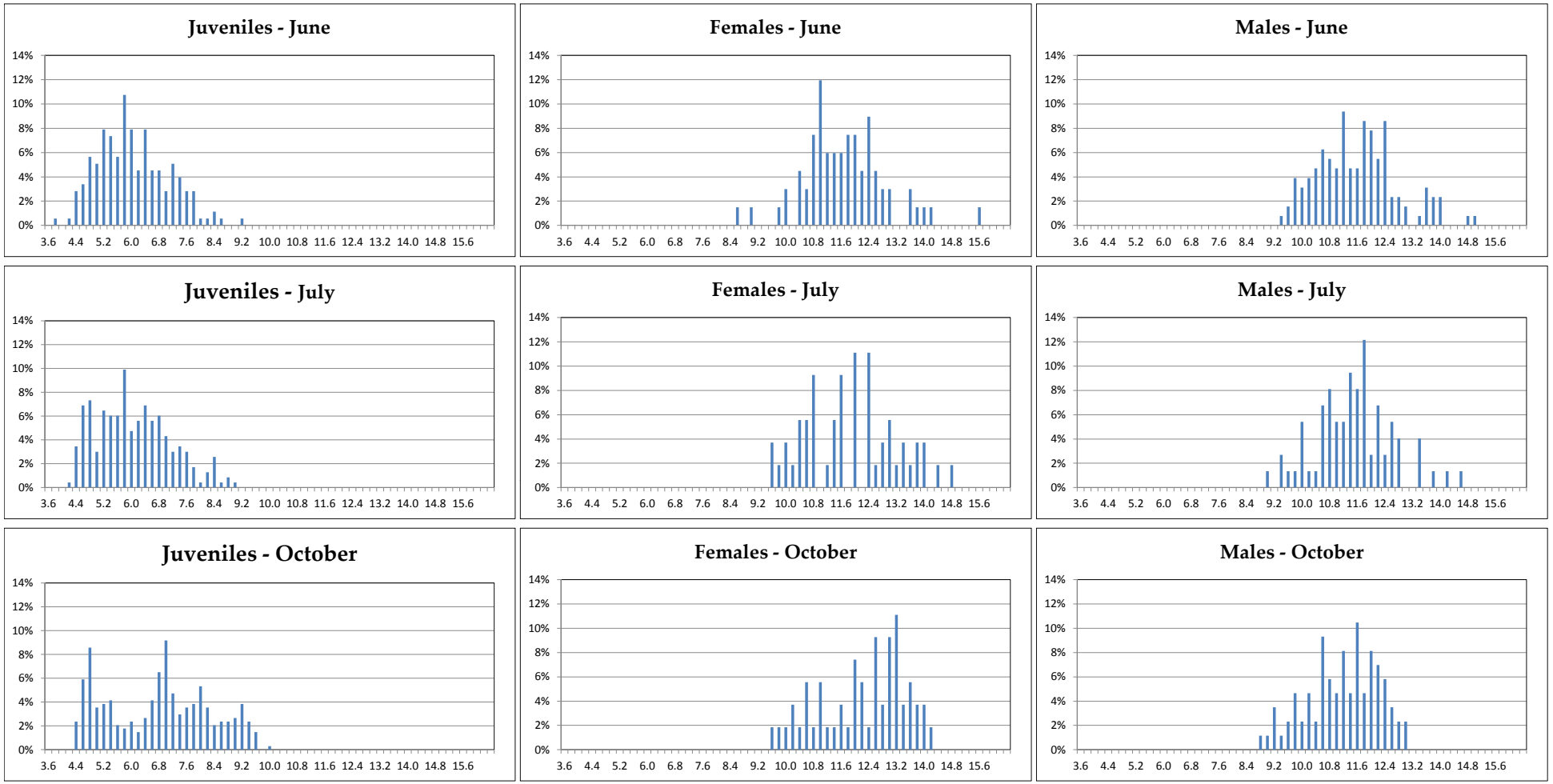

Figure 3.3: Length-frequency distributions of juvenile, female and male dwarf longnose sucker captured at the Upper Ponds during June, July and October 2005.

recruitment. The population estimate for Maiden Lake was 2,457 individuals (1,434 individuals · ha^{-1}) in October 2005, and 53 individuals (286 individuals · ha^{-1}) were estimated to inhabit Goddard Marsh in June 2004. No estimates of longnose sucker populations at other water bodies are available, although Salish sucker in a small creek system in southwestern British Columbia were believed to number in the low thousands (Rosenfeld 2000; COSEWIC 2002).

The maximum home range size of individual longnose sucker captured at the Upper Ponds from June to October was approximately 494 m of linear channel. From late June to early July, dwarf longnose sucker moved a maximum of 302 m from their location of capture, with the average maximum linear distance moved being approximately 107 m (n = 50; Table 3.3). Of 50 tagged fish, 16 were collected only at a single location, with an additional eight fish returning to the original location of capture after moving as much as 206 m away, suggesting some fidelity to specific locations. In mid-October, five tagged fish were collected as far as 494 m away from their original capture location. The linear home range of normal longnose sucker has not been well documented, but tracking of seasonal movements suggested that these fish can travel long distances over short periods around the time of spawning (i.e., >6.5 km), with more limited travel occurring during the remainder of the year (e.g., ≤ 614 linear meters bi-weekly; Sweet and Hubert 2010). The linear distance traveled by Upper Pond longnose sucker was comparable to that of Salish sucker, with the maximum within-year linear distance traveled by the latter

Table 3.3: Tracking details and home range sizes of dwarf longnose sucker captured at the Upper Ponds (ERUP) between June 4th and July 2nd, 2005. Fish are sorted by sex and increasing length.

Tag Number	Fish ID	Fork Length (cm)	Body Weight (g)	Sex	Tagging Date	Days Tracked	Number of Times Recaptured	Linear Home Range (m)	Mean Daily Range (m)
283	ERUP-140	9.9	11.35	female	18-Jun	2	1	0	0
291	ERUP-148	10.2	15.48	female	19-Jun	1	1	206	206
265	ERUP-114	10.3	11.71	female	10-Jun	9	3	206	44
299	ERUP-156	10.8	15.31	female	19-Jun	13	1	171	13
247	ERUP-95	10.9	12.30	female	7-Jun	25	1	171	7
259	ERUP-108	10.9	14.34	female	10-Jun	10	1	171	17
255	ERUP-104	11.0	14.24	female	10-Jun	4	2	206	52
267	ERUP-124	11.0	15.88	female	18-Jun	2	1	0	0
210	ERUP-67	11.2	15.75	female	4-Jun	28	1	0	0
248	ERUP-96	11.3	14.27	female	7-Jun	11	3	206	27
243	ERUP-91	11.6	16.37	female	7-Jun	7	1	171	24
261	ERUP-111	12.4	17.63	female	10-Jun	9	2	206	52
240	ERUP-88	12.6	21.77	female	7-Jun	13	2	206	18
282	ERUP-139	12.6	22.86	female	18-Jun	2	1	0	0
298	ERUP-155	12.8	22.51	female	19-Jun	1	1	88	88
256	ERUP-105	13.3	22.27	female	10-Jun	21	1	88	4
257	ERUP-106	14.6	27.77	female	10-Jun	8	1	206	26
252	ERUP-100	9.3	9.05	juvenile	7-Jun	13	2	88	48
208	ERUP-65	10.1	11.84	male	4-Jun	6	1	0	0
217	ERUP-74	10.2	10.44	male	4-Jun	27	2	72	6
216	ERUP-73	10.6	12.03	male	4-Jun	21	2	88	8
193	ERUP-50	10.7	12.57	male	4-Jun	12	1	88	7
236	ERUP-84	10.8	12.95	male	7-Jun	5	1	88	18
239	ERUP-87	10.9	12.86	male	7-Jun	9	1	88	10
249	ERUP-97	11.1	12.80	male	7-Jun	12	6	206	28
223	ERUP-42	11.3	14.81	male	5-Jun	15	3	206	10
232	ERUP-80	11.4	14.81	male	7-Jun	26	8	88	6
199	ERUP-56	11.6	15.88	male	4-Jun	8	1	0	0
231	ERUP-79	11.7	15.47	male	7-Jun	20	5	206	16
197	ERUP-54	12.0	17.16	male	4-Jun	25	3	206	17
222	ERUP-40	12.1	17.20	male	5-Jun	27	3	171	17
215	ERUP-72	12.1	18.94	male	4-Jun	16	1	0	0
228	ERUP-76	12.1	19.89	male	7-Jun	11	1	88	8
220	ERUP-101	12.1	18.35	male	10-Jun	15	2	0	0
253	ERUP-102	12.2	18.23	male	10-Jun	24	2	302	27
225	ERUP-64	12.4	20.31	male	4-Jun	20	3	88	31
227	ERUP-48	12.5	19.31	male	7-Jun	18	2	171	24
196	ERUP-53	12.5	19.37	male	4-Jun	8	2	0	0
238	ERUP-86	12.5	19.54	male	7-Jun	25	4	206	15
209	ERUP-66	12.6	20.80	male	4-Jun	16	1	0	0
212	ERUP-69	12.6	21.81	male	4-Jun	15	4	0	0
200	ERUP-57	12.9	22.70	male	4-Jun	21	2	0	0
204	ERUP-61	12.9	22.84	male	4-Jun	16	2	0	0
192	ERUP-49	13.0	22.40	male	4-Jun	23	1	0	0
205	ERUP-62	13.2	26.22	male	4-Jun	8	1	171	21
202	ERUP-59	13.3	24.11	male	4-Jun	1	1	88	88
229	ERUP-77	13.6	25.94	male	7-Jun	24	3	0	0
201	ERUP-58	13.7	26.24	male	4-Jun	12	2	88	15
235	ERUP-83	13.7	25.77	male	7-Jun	24	4	262	5
224	ERUP-47	14.5	30.78	male	7-Jun	13	1	0	0

varying from 81 to 497 m (mean = 238 ± 32 m) between May and October (Pearson and Healy 2003).

Individual daily movement of dwarf longnose sucker at the Upper Pond ranged from <1 to 206 m, with an average of 41 ± 64 m (mean ± SD; n =36) observed during June and early July. The daily movement of longnose sucker at the Upper Pond was much lower than that of individual normal-sized longnose sucker tracked in a Wyoming reservoir from March to June (mean of 1,156 ± 2,185 m; Sweet and Hubert 2010), but was within the range observed for Salish sucker in a southwestern British Columbia wetland between May and October (range from < 1 to 376 m, mean of 120 m; Pearson and Healy 2003) and similar to other small-bodied sucker species (Booth and Shipley 2012). Although longnose sucker activity rates have been reported to be strongly influenced by water temperature (Harris 1962; Baily 1969; Scott and Crossman 1973; Barton 1980; Pearson and Healy 2003), no significant relationship was shown between catch-per-unit-effort (a proxy for activity) and water temperature at the Upper Pond or Goddard Marsh in this study (Figure 3.4).

Stomach content analysis of dwarf longnose suckers indicated a varied diet consisting of organic detritus, vegetative matter, zooplankton and benthic invertebrates (Table 3.4). Organic detritus was the most frequently encountered diet item (96% frequency of occurrence). Although organic material in gut contents of other Catostomids may occur incidentally as a result of the consumption of cased/tube-dwelling insects (e.g., Dauble 1980, 1986), organic detritus was the only item observed in approximately 23% of dwarf

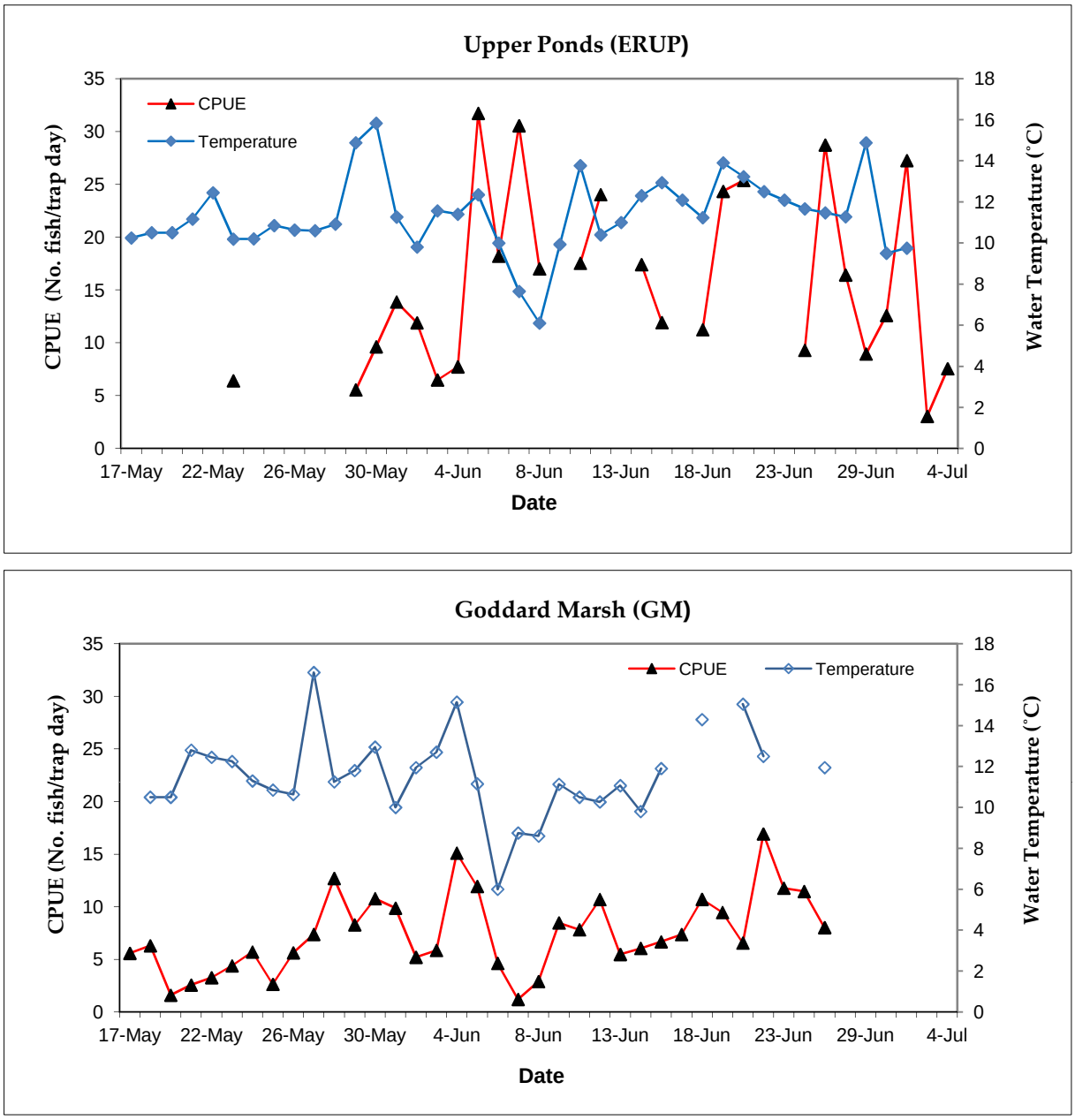

Figure 3.4: Dwarf longnose sucker catch-per-unit-effort (CPUE) compared to water temperature at Upper Pond and Goddard Marsh study areas between May 17th and July 4th, 2005.

Table 3.4: Frequency of occurrence of food resources in the diet of dwarf longnose sucker of the Elk River Watershed. With the exception of detritus and and filamentous algae presence (p), values represent total number counted from stomachs of each individual fish.

Individual Fish Identifier	Vegetation			Crustacea				Insecta		
	Detritus	**Filamentous Algae**	**Seeds**	**Cladocera**	**Copepoda**	**Harpacticoids**	**Ostracoda**	**Baetidae**	**Ceratopogonidae**	**Chironomidae**
EROL-3	p	-	-	-	-	-	-	-	-	-
EROL-4	p	-	5	-	-	-	-	-	-	1
EROL-5	p	-	-	6	-	-	-	-	-	-
EROL-12	p	-	-	-	-	-	1	-	-	5
EROL-13	p	p	-	-	-	-	-	-	-	3
EROL-16	p	-	-	-	-	-	-	-	-	-
EROU-1	p	-	-	-	34	-	-	5	8	7
EROU-2	p	-	-	-	-	-	-	7	2	11
ERUP-5	p	-	-	-	-	-	-	-	-	1
ERUP-6	p	p	-	-	-	-	-	-	-	-
ERUP-12	p	-	-	4	-	-	2	-	-	4
ERUP-15	p	-	-	-	-	-	-	-	-	-
ERUP-18	p	-	-	-	-	-	-	-	-	-
ERUP-19	p	-	-	-	-	-	-	-	-	2
ERUP-21	p	-	-	-	-	-	-	-	-	1
ERUP-25	p	-	-	-	-	-	-	-	-	1
ERUP-27	p	-	-	-	1	-	-	-	-	2
ERUP-31	p	-	-	-	-	-	-	-	-	-
ERUP-158	p	-	-	7	6	4	4	2	-	16
ERUP-162	-	p	-	-	-	-	-	-	-	-
ERUP-163	p	-	-	-	-	-	-	-	-	-
ERUP-164	p	-	-	-	-	-	-	1	-	-
ERUP-166	p	-	-	-	-	-	-	-	-	2
Frequency of Occurrence	95.7%	13.0%	4.3%	13.0%	13.0%	4.3%	13.0%	17.4%	8.7%	56.5%
Average Number Present	-	-	0.22	0.74	1.78	0.17	0.30	0.65	0.43	2.43

longnose sucker stomachs, suggesting that detritus may be intentionally consumed. Diet analysis of normal longnose sucker by Sayigh and Morin (1986) found detritus in 100% of sampled individuals (n = 30), whereas Welker and Scarnecchia (2003) found detritus in only 2% of sampled individuals (n = 74). Chironomid larvae were also an important diet item (57% frequency of occurrence), with other benthic insects and crustaceans observed less frequently in the diet of dwarf longnose sucker (Table 3.4). Filamentous green algae, which have been shown to be an important food item in some normal longnose sucker populations (e.g., Sayigh and Morin 1986; Welker and Scarnecchia 2003), was present in the stomachs of only 13% of dwarf longnose sucker (Table 3.4). Despite adaptations for benthic feeding (e.g., subterminal mouth), cladoceran and copepod zooplankton were observed in the diet of low numbers of dwarf longnose sucker, which is consistent with reported diet items of normal longnose sucker (Scott and Crossman 1973; Barton 1980; Sayigh and Morin 1986). The diet items observed in the Elk River Watershed dwarf longnose sucker were comparable to those of normal longnose sucker, suggesting no feeding specialization that typically exists between sympatric dwarf and normal forms (Trudel et al. 2001; Robinson and Parsons 2002). Overall, the diet analysis indicated that Elk River Watershed adult dwarf longnose sucker are generalist omnivores with diet composition similar to that of normal longnose sucker populations.

Adults comprised approximately 53% of the sampled dwarf longnose sucker population among the Elk River Watershed study areas (Table 3.2). Adults could be separated from

juveniles in the field by colouration. When not in spawning condition, adults were generally dark brown, greenish or near-black dorsally fading to silver brown ventrally with adults in spawning condition showing light (females) to dark (males) red-orange colouration laterally. Juveniles were silver to gray dorsally and white ventrally throughout the year (Figure 3.5). Mature males in spawning condition were clearly distinguished from females by the occurrence of a bright red-orange lateral stripe and anal fin nuptial tubercles (Figure 3.5). Outside of the spawning period, males could be separated from females based on relative anal fin size which, similar to other Catostomids, was larger in males (Stanley 1988). Males represented approximately 63% of the adult longnose sucker population among all Elk River Watershed study areas, which was comparable to the ratio reported for other longnose sucker and Catostomid populations (e.g., Bailey 1969; Dauble 1980).

Other fish species found in association with dwarf longnose sucker in water bodies of the Elk River Watershed included longnose and leopard dace (*Rhinichthys cataractae* and *R. falcatus*, respectively), redside shiner (*Richardsonius balteatus*), mountain whitefish (*Prosopium williamsoni*), cutthroat trout (*Oncorhynchus clarki*), eastern brook trout (*Salvelinus fontinalis*) and bull trout (*S. confluentus*; Table 3.2). Longnose dace occurred together with longnose sucker at the greatest number of sites, but were generally observed at relatively low densities compared to longnose sucker with the exception of at Goddard Marsh (Table 3.2). At locations inhabited by redside shiner, which included open water ponds with relatively limited vegetative cover, this species was the most

Figure 3.5: Male (a) and female (b) longnose sucker collected from the Elk River Watershed. The upper specimen in each photo represents a normal adult, the two specimens at the bottom centre and right in each photo represent dwarf adults, and the bottom left specimen represents a juvenile dwarf longnose sucker.

abundant fish captured. Interestingly, longnose sucker were absent or present only in low numbers at locations in which piscivorous species such as cutthroat or bull trout were present (Table 3.2). As a result of their widespread occurrence, numerous cool water fish species can co-occur with normal longnose sucker (Scott and Crossman 1973). In waterbodies containing Salish sucker, coho salmon (*Oncorhynchus kisutch*), cutthroat trout, three-spine stickleback (*Gasterosteus aculeatus*), western brook lamprey (*Lampetra richardsoni*) and prickly sculpin (*Cottus asper*) may also be present (McPhail 1987; Pearson and Healey 2003).

Age and Growth

The maximum age of female and male dwarf longnose sucker sampled from the Elk River Watershed was eight (n = 85) and five (n = 38) years, respectively. Approximately 40% of females and nearly all males were sexually mature by their second year, with all females and males reaching sexual maturity by their third year. Normal longnose sucker generally reach a maximum age of between 10 and 19 years, with minimum age of sexual maturity occurring in years 5 – 8 for females and years 4 – 6 for males (Harris 1962; Bailey 1969; Scott and Crossman 1973; Barton 1980). Salish sucker can reach five to six years of age, with females and males becoming sexually mature in years 3 to 4 and years 2 to 3, respectively (McPhail 1987; COSEWIC 2002; Pearson and Healey 2003). Therefore, Elk River Watershed dwarf longnose sucker appear to be shorter lived and mature at a much younger age than normal populations, but have age characteristics similar to those of the Salish sucker.

On average, mature female and male dwarf longnose sucker captured in the Elk River Watershed were similar in fork length (FL) and weight, averaging 11.9 cm and 19.1 g (n = 352) and 11.5 cm and 16.0 g (n = 421), respectively. The smallest mature female was 9.5 cm long (FL) and weighed 9.1 g, with the largest female reaching a fork length of 21.5 cm and weighing 123.5 g. The smallest mature male (9.0 cm FL, 8.2 g) was similar in size to that of the females, but males did not grow to as large a size, the largest reaching a fork length of only 16.7 cm and a 55.0 g total mass. Sexual maturity in female and male longnose sucker is normally reached at lengths of a little as approximately 29 cm and 26 cm, respectively (Bailey 1969). Salish sucker can reach sexual maturity at lengths of 9.5 to 14.5 cm FL for females and 8.7 to 12.0 cm FL for males (McPhail 1987; COSEWIC 2002; Pearson and Healey 2003), with other 'dwarf' populations containing males that may reach sexual maturity at 10.6 to 13 cm FL (Scott and Crossman 1973; Pearson and Healey 2003). Therefore, longnose sucker in the Elk River Watershed reached sexual maturity at a smaller size than normally encountered for the species and at a similar size to Salish sucker and other dwarf forms, confirming that individuals in the Elk River population are a dwarf population.

Dwarf longnose sucker females were slightly longer at age than males, with both sexes showing decreasing rate of growth with age (Figure 3.6). Tagged females grew 2.3 times faster (0.075 ± 0.013 mm $\cdot$ day^{-1}; mean $\pm$ SEM; n = 12) than males (0.034 ± 0.013 mm $\cdot$ day^{-1}; mean $\pm$ SEM; n = 6) at Upper Pond and Maiden Lake between June and October, although the difference in growth rate between the sexes was not significant ($p = 0.072$).

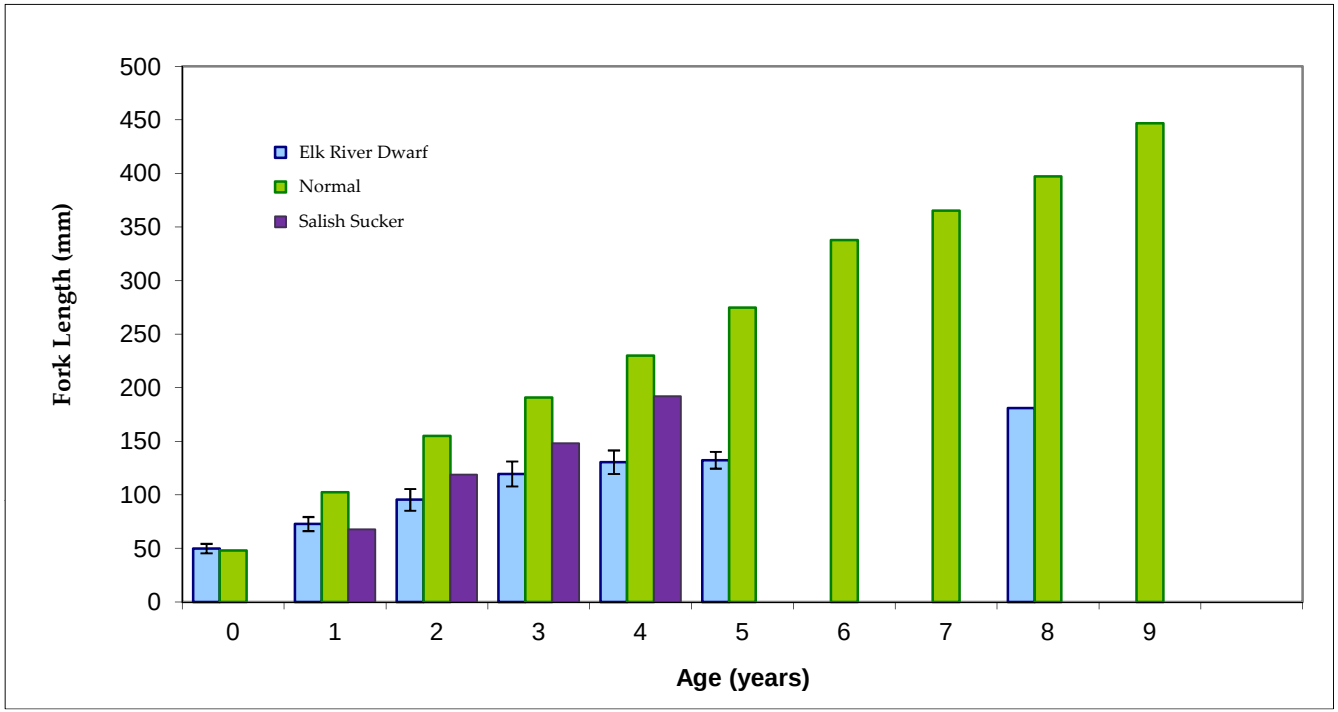

Figure 3.6: Mean length-at-age for Elk River Watershed dwarf longnose sucker, normal longnose sucker, and Salish sucker. Standard error bars around the mean are provided for the Elk River Watershed dwarf longnose sucker data.

A similar dwarf female growth rate was suggested by the fork length distribution for fish sampled at the Upper Pond (mean of 0.050 mm · day^{-1}), but the fork length distribution of dwarf male at this area showed no substantial change between June and October (Figure 3.3). Higher female compared to male growth rates have also been reported for some normal longnose sucker populations (e.g., Barton 1980) and for Salish sucker (Pearson and Healy 2003). Although differences in growth between sexes were also reported for Salish sucker, seasonal growth rates for Elk River Watershed female and male dwarf longnose sucker were 33% and 52% lower than for Salish sucker (0.112 ± 0.010 mm · day^{-1} and 0.071 ± 0.011 mm · day^{-1}), respectively. Moreover, overall growth rates of dwarf longnose sucker were generally much lower, both in incremental and relative terms, than normal longnose sucker or Salish sucker at comparable ages (Figure 3.6). Collectively, these data indicated that dwarf longnose sucker grow at a substantially slower rate than other longnose sucker populations.

Reproduction

Ripe female dwarf longnose sucker were observed in late May (beginning May 29th and 23rd at the Upper Ponds and Goddard Marsh, respectively) to as late as early July (July 2nd at the Upper Ponds), suggesting a spawning period of almost six weeks. The seasonal timing and length of the spawning period for Elk River Watershed dwarf longnose sucker was similar to that of other longnose sucker populations. Normal longnose sucker spring movement patterns suggest that spawning generally begins in mid- to late-April, peaks in mid-June, and is completed by early to mid-July, with the majority of spawning occurring over 5 to 20 days within this period (Brown and Graham 1954; Harris 1962; Bailey 1969;

Sweet and Hubert 2010). Salish sucker also appear to spawn from April to mid-July (COSEWIC 2002).

Spawning dwarf longnose sucker were not observed directly at the Upper Ponds or Goddard Marsh despite undertaking both diurnal and nocturnal visits in an attempt to confirm spawning location and habitat preferences. No congregations of dwarf longnose sucker were observed at any inlets or outlets of lentic habitats in which high numbers of adults were captured, regardless of flow conditions. Therefore, water discharge rate was not likely a trigger for spawning in dwarf longnose sucker in contrast to that reported for normal longnose sucker populations (Barton 1980; Montgomery et al. 1983). It was assumed that spawning likely occurred within ponds on exposed gravel or rocky substrate similar to habitat used by some normal lake inhabiting longnose sucker populations (Scott and Crossman 1973; McPhail 2007).

Daily water temperatures during the spawning period averaged 11.5 ± 2.0 ˚C at the Upper Ponds (range from 6.1 to 15.8 ˚C) and 11.4 ± 1.9 ˚C at Goddard Marsh (range from 6.0 to 15.2 ˚C). Water temperatures over the dwarf longnose sucker spawning period were comparable to those for normal longnose sucker populations, with 10 ˚C appearing to be a spawning trigger for the Elk River Watershed dwarf longnose sucker just as for normal longnose sucker populations (Brown and Graham 1954; Harris 1962; Geen et al. 1966; Bailey 1969). Although the reproductive trigger for dwarf longnose sucker appeared to be temperature related, other factors such as photoperiod or summation of degree days may also important (e.g., Andreasen and Barnes 1975).

Gonadosomatic indices (GSI) for dwarf longnose sucker females were variable early in the spawning period, averaging 8.3 ± 5.2 and ranging from 1.5 to as high as 19.4 in late May. No significant correlations were shown between GSI and fork length or age in females for this time period (r^2 of 0.202 and 0.232, respectively). Upon application of pressure on the abdomen, females that appeared to be spent occasionally released a few eggs from their vents into early July. By mid-October, dwarf longnose sucker female GSI averaged 6.7 ± 0.6, which was not significantly different from that of normal females (6.5 ± 1.9; Mann-Whitney p = 0.746) collected at approximately the same time of year. Therefore, maturation of oocytes appeared to be relatively rapid in female dwarf longnose sucker, with oocytes likely present shortly following spawning and for much of the year, but yolk accumulation likely occurring more gradually from fall to spring of the following year. A similar pattern of oocyte development has been observed in other Catastomids (Andreasen and Barnes 1975).

Dwarf longnose sucker males showed prominent secondary sexual characteristics (i.e., bright red-orange colouration and nuptial tubercles on anal and caudal fins) from late May until approximately mid- to late-June. Dwarf male GSI averaged 3.6 ± 1.0 early in the spawning period (May) and 2.1 ± 1.1 late in the spawning period (July), with the highest average GSI of 6.9 ± 0.4 observed in mid-October. The gradual decrease in GSI from May to July suggested that males may spawn more than once over the spawning period. With application of slight pressure on the abdomen, males produced milt from mid-May to July, as well as during mid-October in 2005, with previous monitoring in

2004 indicating that males could produce milt continually from early April through September. Male Salish sucker were also reported to produce milt in the fall (Pearson and Healey 2003). A weak significant positive correlation was indicated for regressions of dwarf male GSI and fork length, but no significant relationship was shown between dwarf male GSI and age (r^2 of 0.518 and 0.307, respectively).

The GSI of dwarf male longnose sucker was significantly higher than that of normal males collected in autumn (t-test, $p < 0.0001$), potentially reflecting more rapid gonad development in the dwarf population. The pattern in dwarf longnose sucker GSI suggested very rapid proliferation of spermatocytes following spawning, with spermatogenesis being complete by fall and testes remaining at this stage during overwintering and until just prior to spawning. The production of spermatogonia (i.e., milt) throughout the year differs from the pattern observed in most normal male Catostomids (Andreasen and Barnes 1975), and may be due to the allocation of excess energy to reproduction rather than growth in dwarf longnose sucker. This is supported by observations between dwarf and normal forms of Arctic char in Iceland, in which the dwarf form showed reduced muscle protein accretion compared to the normal form under growth-favouring conditions (MacQueen et al. 2011). The absence of secondary sexual characteristics following the spawning period and high GSI in fall suggested that male dwarf longnose sucker spawning is not prolonged through the summer and fall.

Dwarf longnose sucker fecundity ranged from 335 to 7,049 eggs (n = 29; 98 to 181 mm FL). Fecundity was positively correlated with female fork length, body weight and age

(r^2 of 0.662, 0.694 and 0.555, respectively). On average, fecundity was significantly lower in dwarf female longnose sucker compared to normal longnose sucker (2,587 ± 1,571 versus 42,456 ± 18,615 eggs per female, respectively; $p < 0.00001$), likely reflecting the dramatic differences in body size (Figure 3.7). Mean egg weight of dwarf longnose sucker ranged from 0.23 to 1.61 mg, with no significant correlations indicated relative to fork length, body weight or age (r^2 of 0.132, 0.267 and 0.086, respectively). Although dwarf longnose sucker egg weight was significantly lower than egg weight for normal longnose sucker (average of 0.90 and 1.35 mg, respectively; $p < 0.00001$), comparisons based on relative egg weight (i.e., egg weight as a proportion of total gonad weight) indicated proportionately larger egg size in dwarf compared to normal females ($p < 0.00001$). Collectively, these data indicated that dwarf longnose sucker produce significantly fewer and smaller eggs compared to the normal form, but that greater allocation of energy (as indicated by greater egg size as a proportion of gonad size) towards reproduction may be used by dwarf female longnose sucker.

Development from fertilization to hatching under experimental conditions required from 13 to 24 days (mean 21 days) at an average water temperature of 8.0˚C, with average peak hatch occurring at 26 days and average last hatch requiring 39 days under mean water temperatures of 8.3˚C and 9.3˚C, respectively (n = 30 trials). The corresponding degree days to average initial, peak and final hatch were 168, 220 and 360 thermal units, respectively. During incubations, dissolved oxygen levels were usually 80% saturated or greater, and were not less than 70% in either the incoming water or any individual trays.

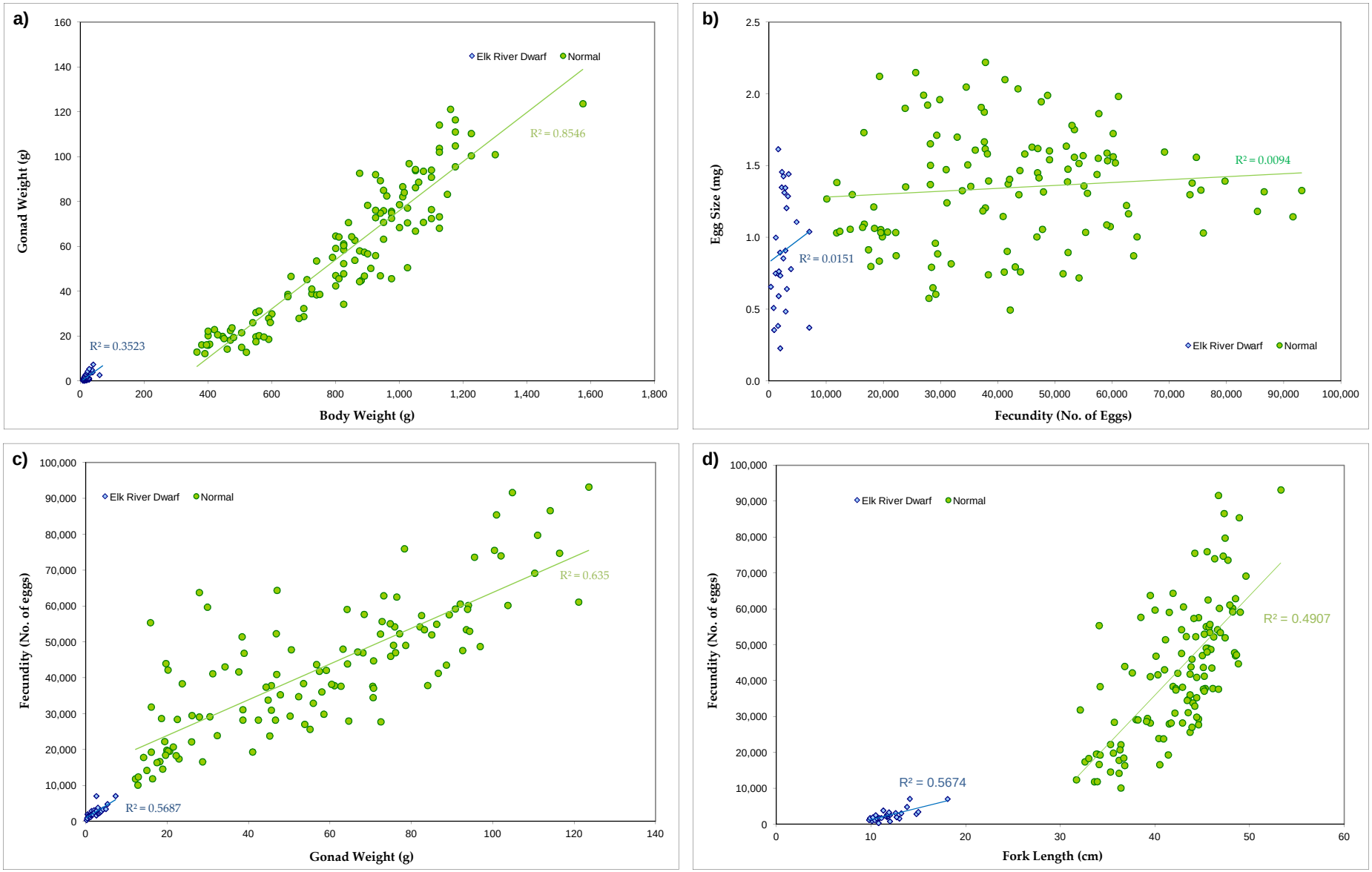

Figure 3.7: Relationships between gonad and body weight (a), egg size and fecundity (b), fecundity and gonad weight (c) and fecundity and length (d) for Elk River Watershed dwarf longnose sucker and normal longnose sucker females.

The dwarf longnose sucker incubation period was longer than that reported for normal longnose sucker (8 to 14 days), although the incubation period for the latter was based on slightly warmer water temperature (i.e., 10 to 15˚C; Geen et al. 1966; Edwards 1983). Yolk sac absorption generally occurred within two to three days of hatch. At hatching, the larvae averaged approximately 7.48 ± 0.61 mm long (range from 5.86 to 9.42 mm; n = 1,216). Larvae were noticeably pigmented along the dorsal surface, with some individuals also possessing a line of pigmentation laterally at the level of the vertebral column (Figure 3.8). In the field, the water column of the Upper Pond was fished using a fine-meshed dip net and sand substrate was sieved in mid-June, but no longnose sucker larvae were encountered in either habitat. However, sieving of clean gravel substrate from the Upper Pond on June 18th resulted in the collection of nine larval fish. The presence of larvae in gravel was consistent with literature accounts indicating that longnose sucker spawn in gravel with the fry remaining in the substrate for one to two weeks prior to emergence to the water column (Scott and Crossman 1973).

Dwarf Longnose Sucker Life History Strategy

Dwarf longnose sucker of the Elk River Watershed resided in habitats characteristic of those used elsewhere by normal longnose sucker juveniles, but grew much more slowly, attained a much smaller maximum size, reached sexual maturity at a younger age, produced fewer but proportionately larger eggs, and were shorter lived than the normal longnose sucker form. Other characteristics, including preference for cool water habitat, diet habits, relative home range size, length of spawning season and population sex ratio,

Figure 3.8: Photographs of larval dwarf longnose sucker collected from vertical incubation trays shortly following hatch.

appeared to be similar between Elk River Watershed dwarf longnose sucker and normal North American longnose sucker forms. With the exception of spawning season length, the differences in Elk River Watershed longnose sucker life history compared to normal populations were consistent with a change to a more opportunistic life-history strategy. Fishes exhibiting an opportunistic life-history strategy mature early, produce small eggs and clutches, and have extended spawning seasons in which reproduction may occur frequently (Winemiller and Rose 1992). Despite smaller egg and clutch size, high reproductive effort is maintained by fish using opportunistic strategies through production of large eggs relative to body size and/or by undertaking multiple spawning. An opportunistic life-history strategy is generally used by fishes that inhabit water bodies experiencing frequent, intense, density-independent ecological disturbances that occur at irregular spatiotemporal intervals (Winemiller 2005). Although such ecological disturbances may result in high adult mortality, the opportunistic life-history attributes allow fish to efficiently repopulate habitats over relatively small spatial scales following any substantial disturbances (Winemiller and Rose 1992; Schlosser 1995).

In the Elk River Watershed, nocturnal hypoxia was suspected at water depths below approximately one metre at Maiden Lake. Because aquatic vegetation was not particularly abundant in this lake, it is hypothesized that high sediment oxygen demand was the cause of low dissolved oxygen concentrations in the Maiden Lake water column. At other areas of relatively high dwarf longnose sucker abundance (e.g., Upper Ponds, Goddard Marsh and the Lower Oxbow), high productivity was suggested by the presence

of dense aquatic vegetation (Table 3.1). It is suspected that the combination of relatively large amounts of decaying vegetation and shallow water conditions at these areas make them susceptible to low dissolved oxygen concentrations overnight or under periods of winter ice cover. Therefore, diurnal and/or seasonal periods of extremely low dissolved oxygen concentration (i.e., hypoxia) could be the ecological disturbance driving change in the life-history strategy of longnose sucker.

Small fish tend to be less sensitive to hypoxia (Doudoroff and Shumway 1970; Smale and Rabeni 1995; Robb and Abrahams 2003; Reardon and Thibert-Plante 2010) as a result of more efficient gas exchange at smaller size (Hughes 1984). Moreover, hypoxic environments are also known to provide small-bodied fish refuge by acting as a barrier to larger piscivorous fishes because of lower tolerance to hypoxia exhibited by these species and/or physical limitations (e.g., gape size) imposed by small body size for any piscivorous fish that are able to survive hypoxic events (Reardon and Thibert-Plante 2010; Bajer et al. 2012). Interestingly, physiological divergence in red blood cell morphology has been observed between dwarf and normal morphs of lake whitefish, supporting hypoxia as a potential driver for dwarfism (Evans et al. 2012). Therefore, by remaining small, dwarf longnose sucker are not as likely to be physiologically excluded from Elk River Watershed habitat that periodically becomes hypoxic, with the hypoxic conditions also eliminating predation-related mortality for individuals surviving hypoxic events.

In remaining small, Elk River Watershed longnose sucker seem to have foregone the ontogenetic niche shift from shallow, densely vegetated habitat similar to that found at the Upper Ponds, to large, deep, slow-moving river or large lake habitat that would normally occur between juvenile and adult stages. Optimally, individual fish should shift between juvenile and adult niches in such a way that the ratio of mortality over individual growth rate is minimized for each stage (Werner and Gilliam 1984). Greater physiological tolerance for hypoxia with smaller size in combination with an absence of large piscivorous fish in environments subject to periodic hypoxia may result in a lower mortality-to-growth ratio for dwarf longnose sucker remaining in periodically hypoxic habitats compared to the potential advantages of shifting to a more oxygen stable niche with greater predation risk.

The Elk River, which is dominated by rocky, relatively fast flowing running water habitat, provides marginal longnose sucker habitat, notwithstanding its use as a potential travel corridor and/or for spawning. In addition, very few lakes containing suitable habitat for normal longnose sucker (i.e., greater than 20 m deep with substrate including a mixture of rocky to soft bottom; Scott and Crossman 1973; McPhail 2007) exist in the Elk River Watershed (see Figure 3.1), with these lakes and the Elk River itself also known to possess large-bodied piscivorous fish (e.g., cutthroat and bull trout). Therefore, the mortality risk is likely greater for (juvenile) longnose sucker residing outside of the periodically hypoxic water bodies of the Elk River Watershed compared to the river itself or associated lakes. By foregoing the ontogenetic niche shift that would normally occur

between juvenile and adult longnose sucker, higher survival rates may be realized for dwarf longnose sucker residing in periodically hypoxic environments.

Density-dependent influences on growth represent an alternative explanation for the presence of a dwarf longnose sucker form in the Elk River Watershed. High intraspecific competition in the absence of predators can result in increased competition for food resources, leading to reduced food availability that in turn results in decreased annual growth rates for individual fish (Henderson 1985; Ylikarjula et al. 2002; Grant and Imre 2005; Headly and Lauer 2008). Elk River Watershed dwarf longnose sucker were most abundant in water bodies absent of any large-sized piscivorous fish, with a dwarf longnose sucker density of greater than 2,000 fish $\cdot$ ha^{-1} observed at the Upper Ponds. Diet analysis suggested that juvenile and adult dwarf longnose sucker likely feed on similar items, and therefore competition for food resources may be particularly high in certain water bodies, especially considering that other fish species most commonly found in association with longnose sucker (e.g., redside shiner, longnose dace) have similar diets. These observations provided some support for interpretation of dwarfism in the Elk River Watershed longnose sucker simply as a density-dependent 'stunting' of growth. However, low numbers of dwarf-sized individuals were captured at several locations in the Elk River Watershed, suggesting that high longnose sucker density was not a precursor to small fish size at these areas. Therefore, the occurrence of dwarf longnose sucker in the Elk River Watershed did not appear to be a density-dependent phenomenon.

Overall, the adoption of an opportunistic life history strategy that allows adult longnose sucker to exploit habitats that potentially experience irregular but periodic hypoxia appears to be a plausible explanation for the occurrence of a dwarf form in the Elk River Watershed. By forgoing the ontogenetic niche shift that would normally occur between littoral and profundal habitat, adult dwarf longnose have retained small body size with energy usage allocated towards early sexual maturation and reproduction rather than growth. Although small body size may allow dwarf longnose sucker to better tolerate low dissolved oxygen conditions, the main benefit to adopting an opportunistic life history strategy where small adult body size is retained may be to quickly populate (or repopulate) water bodies experiencing frequent hypoxia.

CHAPTER 4: CONCLUSIONS

British Columbia naturally supports a relatively low diversity of freshwater fish species that, in turn, can result in freshwater environments that contain unexploited niches suitable for colonization by enterprising conspecifics. In the absence of predators and other interspecific competitors, colonizing species have opportunities for habitat/niche expansion that, through competition, can drive behavioural, life history and morphological evolution. Over time, the accumulation of genetic changes associated with such character release can ultimately result in the formation of a new species.

In the Elk River Watershed, two distinct size-based morphotypes of longnose sucker were identified, including a smaller 'dwarf' form and a larger 'normal' form. In addition to size, the Elk River Watershed dwarf longnose sucker were characterized by shorter head length and snout, larger mouth and eyes and more slender body form than adult normal longnose sucker. These morphological characteristics also distinguished juvenile normal from adult normal longnose sucker, suggesting that adult dwarf longnose sucker retain some juvenile morphological characteristics. Coupled with the distinctive morphological differences between Elk River Watershed dwarf and normal longnose sucker, some genetic support for separation of the forms was established based on ND2 gene sequencing. Collectively, the occurrence of dwarf and normal longnose sucker forms in the Elk River Watershed appeared to reflect a conditional response to environmental conditions, with slight but significant genetic divergence suggesting that the dwarf form may be in the incipient stages of progression towards an evolutionarily significant unit separate from the normal form.

The size-based polymorphism exhibited in the Elk River Watershed by longnose sucker is unusual in that derivation of the dwarf adult form may reflect an ontogenetic niche shift in which juvenile morphological features are retained in the adult form. Intraspecific diversity has been recognized as an important component of biodiversity and, therefore, understanding the geographic range, natural history and habitat requirements of this dwarf longnose sucker form, and how they might differ from the normal form, is integral to its potential conservation.

Dwarf longnose sucker were widespread in the Elk River Watershed, and were most abundant in small, shallow lentic water bodies adjacent to or directly connected to the Elk River. These water bodies were characterized by cool water temperatures and contained dense cover of aquatic vegetation and/or woody debris, or had limited cover but may have experienced pronounced diurnal fluctuation in water column oxycline depth. Fish species diversity at water bodies containing high numbers of dwarf longnose sucker was low (i.e., two to five species), with piscivorous fish species generally absent or present only in juvenile stages. Dwarf adult longnose sucker showed different habitat preferences, had smaller home range size, showed smaller maximum size, younger age-at-maturity, lower maximum age, slower growth rate, lower fecundity and smaller but proportionately larger egg size compared to adult normal longnose sucker. These characteristics were consistent with the adoption of an opportunistic life-history strategy in which an ontogenetic habitat shift that normally occurs between juvenile and adult life stages is not undertaken. Presumably, this life history change allows dwarf longnose

sucker to better exploit environments that experience unpredictable disturbances which, for other species and the normal longnose sucker form, are otherwise limiting. In the Elk River Watershed, intermittent or seasonal hypoxia of pond and river oxbow environments could represent the key habitat factor limiting exploitation by fish.

The dwarf longnose sucker population of the Elk River Watershed showed significant genetic differences compared to Salish sucker, which is an endangered dwarf longnose sucker form that shows a unique evolutionary lineage. However, the Elk River Watershed dwarf longnose sucker and Salish sucker shared several habitat, habitat use, age, growth and reproductive characteristics. Interestingly, habitats supporting Salish sucker have been suspected of exhibiting hypoxia, which suggests that the Elk River Watershed dwarf longnose sucker and Salish sucker illustrate a similar life history strategy that may include adoption of an opportunistic approach to exploit available habitats.

Conservation of dwarf longnose sucker can likely be accomplished by maintaining a few healthy local populations in the Elk River system and by ensuring no large-scale habitat degradation. Given the relatively small home range size requirements, only a small amount of suitable habitat is needed to maintain a healthy population of dwarf longnose sucker in the Elk River Watershed. Furthermore, the life history characteristics of dwarf longnose sucker suggest that introductions to constructed or suitable natural habitats would likely be successful. Therefore, while management strategies for the Elk River Watershed dwarf longnose sucker population should focus on population monitoring and

preserving existing habitats in which it is found, the life history requirements of this longnose sucker form also provides the opportunity for managers to augment the local population by introductions to suitable natural or man-made habitats.

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APPENDIX A

FISH MEASUREMENT DATA

Table A.1: Meristic data for longnose sucker collected at the Elk River Upper Ponds (ERUP). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
ERUP-1	10.1	11.7	12.5	21.10	30.99	29.36	44.80	24.56	15.18	10.79	10.89	5.80	9.64	6.56	F	17.32	0.446	1962	0.227	0.425	4
ERUP-2	5.3	6.3	6.8	10.46	19.12	17.23	24.68	14.48	9.51	7.17	5.71	4.10	5.39	3.73	J	2.78				0.060	
ERUP-3	10.4	12.0	12.8	20.58	33.89	32.35	47.97	26.77	15.89	11.10	10.55	5.46	8.61	5.54	F	19.01	0.409	804	0.509	0.403	4
ERUP-4	8.3	10.1	10.8	17.55	30.93	24.59	37.76	23.49	13.79	10.18	9.27	5.08	7.93	5.13	F	11.60	0.314	884	0.355	0.201	4
ERUP-5	5.7	6.7	7.1	11.18	20.34	16.99	26.05	16.25	9.89	7.23	6.08	4.53	5.52	3.85	J	3.22				0.051	3
ERUP-6	5.8	6.9	7.3	11.96	20.88	18.61	26.97	15.71	9.31	6.66	6.25	3.83	5.44	3.83	J	3.64				0.063	3
ERUP-7	8.3	9.9	10.4	17.67	30.55	25.41	38.12	22.26	12.57	9.15	9.37	5.74	7.68	5.41	F	11.19	1.268	1710	0.742	0.257	4
ERUP-8	9.7	11.3	12.0	21.44	36.00	27.12	40.89	24.62	13.98	9.49	10.63	6.22	8.81	6.46	F	17.71	2.985	3830	0.779	0.465	4
ERUP-9	8.7	10.2	10.9	19.07	29.79	26.94	39.98	23.64	13.54	8.72	9.93	5.10	8.31	5.12	M	13.00	0.400			0.324	4
ERUP-10	7.8	9.1	9.7	14.48	27.32	22.86	32.70	20.35	12.27	8.44	7.33	5.14	6.96	4.93	f-i	7.95	0.310			0.164	3
ERUP-11	4.6	5.4	5.7	9.15	15.82	12.51	19.06	13.09	7.30	5.83	4.93	3.16	4.24	4.06	J	1.88					
ERUP-12	8.8	10.2	10.9	18.86	33.11	25.41	37.37	22.12	12.54	8.06	10.18	4.90	7.46	4.99	F	12.59	1.722	1925	0.895	0.343	4
ERUP-13	9.0	10.5	11.2	18.70	31.23	28.68	40.02	22.63	14.37	9.18	9.24	4.95	8.26	5.50	f-i	13.18	2.104	2507	0.854	0.325	5
ERUP-14	9.2	10.8	11.5	17.08	34.26	27.81	40.47	24.03	15.35	10.14	9.55	4.99	8.14	5.93	F	14.16	0.220	335	0.656	0.236	4
ERUP-15	10.4	12.0	12.7	21.88	36.74	29.05	43.04	26.69	16.48	10.87	11.04	5.95	9.99	5.96	F	21.61	3.611	2532	1.426	0.603	5
ERUP-16	10.7	13.0	13.8	21.92	38.43	34.55	49.82	24.68	17.56	11.14	12.41	5.10	10.16	5.72	M	23.01	1.202			0.357	4
ERUP-17	11.5	13.4	14.3	23.63	38.84	34.27	50.94	29.35	18.01	11.29	12.90	5.71	11.66	6.49	M	28.22	0.981			0.411	4
ERUP-18	10.4	12.1	12.9	21.78	32.52	31.98	45.97	25.04	15.91	11.06	9.94	5.91	10.26	5.00	M	20.66	0.861			0.222	5
ERUP-19	9.7	11.8	12.5	19.56	34.56	29.90	45.19	24.75	15.98	10.13	9.51	4.97	9.60	5.07	M	19.11	0.656			0.347	4
ERUP-20	10.1	11.8	12.6	22.92	35.84	31.11	44.11	26.59	16.19	10.82	10.90	6.62	9.88	5.52	F	22.81	3.283	2255	1.456	0.446	4
ERUP-21	7.3	8.6	9.1	15.13	24.53	20.92	32.12	19.72	11.93	8.25	6.90	4.62	6.86	4.25	f-i	7.88	0.126			0.145	3
ERUP-22	5.5	6.6	6.9	12.09	19.72	18.64	24.86	15.98	10.14	6.38	5.82	3.53	5.86	4.07	J	3.86					2
ERUP-23	9.7	11.7	12.4	23.65	35.30	33.26	45.19	25.68	16.89	10.18	9.18	5.09	9.35	5.64	F	23.00	3.522	2684	1.312	0.481	4
ERUP-24	8.3	9.9	10.5	16.85	29.79	24.45	35.59	22.16	13.90	9.24	8.39	4.29	8.05	5.13	M	11.59	0.410			0.107	4
ERUP-25	9.1	11.0	11.7	19.48	34.28	26.65	39.44	24.22	15.98	8.80	9.20	6.54	9.49	5.65	M	17.64	0.673			0.348	3
ERUP-26	10.5	12.5	13.3	23.28	34.33	32.05	48.93	27.07	16.66	10.70	10.68	6.10	8.82	6.51	M	24.52	1.364			0.27	3
ERUP-27	8.9	10.5	11.1	17.63	30.74	25.34	38.38	23.86	14.58	9.27	8.76	5.52	8.25	5.16	M	13.35	0.433			0.124	
ERUP-28	10.0	11.9	12.7	21.11	35.41	29.85	45.72	25.27	16.62	10.23	10.19	6.60	8.68	5.77	M	20.85	0.930			0.355	4
ERUP-29	10.2	11.9	12.6	19.60	34.14	26.45	43.18	24.82	14.80	9.62	9.54	6.05	8.99	5.67	F	17.20	2.610	2874	0.908	0.226	4
ERUP-30	10.3	11.8	12.5	19.16	35.22	29.47	44.42	26.28	15.52	10.12	10.39	7.31	9.21	5.40	F	18.13	1.410	2913	0.484	0.453	4
ERUP-31	9.9	11.6	12.3	19.28	34.84	29.23	44.36	24.60	14.71	9.33	10.30	6.41	8.74	5.42	F	17.54	2.982	2211	1.349	0.399	4
ERUP-32	9.2	10.6	11.3	19.50	31.64	28.48	42.11	23.16	14.52	9.37	9.08	6.26	7.83	5.05	F	15.47	2.612	1618	1.615	0.358	3
ERUP-33	11.8	13.8	14.5	23.10	38.22	35.69	53.05	29.06	17.63	10.70	11.43	7.40	9.74	6.06	F	27.50	5.339	4821	1.108	0.501	5
ERUP-34	11.8	13.9	14.8	22.51	41.78	37.22	52.15	28.96	18.31	10.68	12.75	5.79	9.10	5.85	F	24.82					4
ERUP-35	10.7	12.7	13.5	19.79	36.50	33.29	48.32	26.39	16.37	9.79	10.50	6.34	8.13	5.61	F	22.45					5
ERUP-36	10.7	12.5	13.2	22.46	35.71	31.65	46.45	26.07	15.94	9.88	10.61	6.64	8.48	5.28	F	24.61					5
ERUP-37	10.7	12.7	13.5	18.89	37.11	32.32	47.28	25.43	16.64	9.96	10.69	6.53	9.01	5.14	F	21.47					
ERUP-38	10.8	13.2	14.0	19.54	38.46	31.76	47.40	27.17	16.82	10.33	10.96	7.97	8.70	5.72	F	22.44					
ERUP-39		12.6	13.4												f	18.84					
ERUP-40		12.1	12.8												m	17.20					
ERUP-41		12.4	13.2												m	19.51					
ERUP-42		11.3	12.1												m	14.81					
ERUP-43	10.2	12.4	13.2	18.84	37.01	27.62	43.66	24.75	15.41	9.23	10.32	6.89	8.16	5.50	M	18.11					
ERUP-44		10.2	10.9												f	11.13					
ERUP-45	8.9	11.0	11.7	18.35	28.94	25.41	39.90	23.27	13.81	8.56	8.31	6.10	7.60	4.76	M	12.90					
ERUP-46	9.9	11.6	12.3	17.91	34.05	28.84	46.19	25.39	14.55	9.32	10.08	7.02	8.22	5.08	M	15.45					
ERUP-47	12.6	14.5	15.4	21.87	42.94	36.54	54.75	30.31	18.32	10.44	12.62	7.55	10.19	5.99	M	30.78					
ERUP-48	10.6	12.5	13.4	18.49	36.71	31.43	46.42	26.72	16.34	10.21	10.91	7.17	9.35	5.28	M	19.31					
ERUP-49		13.0	13.9												m	22.40					
ERUP-50		10.7	11.4												m	12.57					
ERUP-51		12.1	12.8												m	17.70					
ERUP-52		10.9	11.5												m	13.69					
ERUP-53		12.5	13.3												m	19.37					
ERUP-54		12.0	12.8												m	17.16					
ERUP-55		11.9	12.6												m	15.86					
ERUP-56		11.6	12.4												m	15.88					
ERUP-57		12.9	13.8												m	22.70					
ERUP-58		13.7	14.5												m	26.24					

Table A.1: Meristic data for longnose sucker collected at the Elk River Upper Ponds (ERUP). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
ERUP-59		13.3	14.1												m	24.11					
ERUP-60		10.7	11.3												m	12.07					
ERUP-61		12.9	13.6												m	22.84					
ERUP-62		13.2	14.0												m	26.22					
ERUP-63		11.7	12.0												m	15.83					
ERUP-64		12.4	13.2												m	20.31					
ERUP-65		10.1	11.3												m	11.84					
ERUP-66		12.6	13.3												m	20.80					
ERUP-67		11.2	11.9												f	15.75					
ERUP-68		11.9	12.5												f	18.27					
ERUP-69		12.6	13.4												m	21.81					
ERUP-70		10.1	10.8												m	10.68					
ERUP-71		10.0	10.5												m	10.10					
ERUP-72		12.1	12.9												m	18.94					
ERUP-73		10.6	11.4												m	12.03					
ERUP-74		10.2	10.8												m	10.44					
ERUP-75		10.6	11.3												m	12.40					
ERUP-76	10.1	12.1	12.8	19.16	35.08	30.13	43.59	26.17	15.66	9.90	10.51	6.72	8.44	5.15	M	19.89					
ERUP-77	11.6	13.6	14.3	20.17	39.15	33.85	51.26	28.76	16.41	10.90	12.06	7.50	9.28	5.66	M	25.94					
ERUP-78	13.5	15.7	16.8	23.94	47.06	38.41	58.83	31.41	19.01	11.76	13.78	8.18	10.35	6.50	M	40.54					
ERUP-79	10.1	11.7	12.4	17.13	34.25	26.87	41.70	24.61	14.96	9.23	9.87	6.45	9.20	5.34	M	15.47					
ERUP-80		11.4	12.1												m	14.81					
ERUP-81		11.7	12.5												m	15.17					
ERUP-82		11.9	12.7												m	16.98					
ERUP-83		13.7	14.5												m	25.77					
ERUP-84		10.8	11.6												m	12.95					
ERUP-85		10.5	11.2												m	11.91					
ERUP-86		12.5	13.3												m	19.54					
ERUP-87		10.9	11.6												m	12.86					
ERUP-88		12.6	13.2												f	21.77					
ERUP-89		15.1	15.9												m	35.50					
ERUP-90		11.1	11.8												f	13.89					
ERUP-91		11.6	12.3												f	16.37					
ERUP-92		10.9	11.6												m	12.45					
ERUP-93		9.5	10.1												f	9.54					
ERUP-94		9.7	10.3												f	10.01					
ERUP-95		10.9	11.6												f	12.30					
ERUP-96		11.3	12.1												f	14.27					
ERUP-97		11.1	11.8												m	12.80					
ERUP-98		13.2	14.1												m	23.56					
ERUP-99		10.2	10.9												m	9.84					
ERUP-100		9.3	9.9												j	9.05					
ERUP-101		12.1	12.8												m	18.35					
ERUP-102		12.2	13.0												m	18.23					
ERUP-103		11.6	12.3												f	17.85					
ERUP-104		11.0	11.6												f	14.24					
ERUP-105		13.3	14.1												f	22.27					
ERUP-106		14.6	15.4												f	27.77					
ERUP-107		11.0	11.6												m	12.88					
ERUP-108		10.9	11.6												f	14.34					
ERUP-109		9.6	10.2												f-i	9.80					
ERUP-110		11.1	11.7												f	13.58					
ERUP-111		12.4	13.2												f	17.63					
ERUP-112		13.0	13.8												m	20.17					
ERUP-113		10.1	10.6												f	10.59					
ERUP-114		10.3	11.0												f	11.71					
ERUP-115		10.6	11.3												f	13.60					
ERUP-116	9.8	11.5	12.3	17.41	33.21	29.24	43.72	25.47	14.88	9.19	10.93	6.96	8.58	5.80	M	15.87					

Table A.1: Meristic data for longnose sucker collected at the Elk River Upper Ponds (ERUP). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
ERUP-117	11.0	12.8	13.5	18.98	35.78	32.82	47.92	27.38	16.15	10.35	11.71	7.09	9.67	5.64	M	20.38					
ERUP-118	10.2	11.9	12.6	17.38	33.69	29.80	44.90	25.13	14.52	9.68	10.41	5.73	8.37	5.52	M	16.30					
ERUP-119	9.6	11.3	11.9	16.45	33.19	27.33	41.72	23.87	13.97	8.74	9.52	6.08	8.23	5.64	M	13.41					
ERUP-120	10.0	11.7	12.4	16.92	33.89	28.69	42.05	24.38	14.35	9.33	9.92	6.57	8.56	5.32	M	14.67					
ERUP-121	10.6	12.4	13.1	17.71	34.68	31.28	46.62	26.40	15.12	9.89	10.68	6.20	8.80	5.56	M	17.68					
ERUP-122	10.3	12.0	12.7	17.76	34.28	29.63	43.71	26.34	15.45	9.39	10.43	6.19	8.73	5.91	M	17.30					
ERUP-123	10.6	12.3	13.0	17.76	35.47	29.78	45.42	26.64	14.68	9.75	10.70	6.69	8.55	5.55	M	17.07					
ERUP-124		11.0	11.6												f	15.88					
ERUP-125		11.8	12.5												f	17.06					
ERUP-126		12.0	12.6												f	15.46					
ERUP-127		11.9	12.7												f	18.46					
ERUP-128		11.0	11.7												f	15.10					
ERUP-129		10.2	10.7												f	13.68					
ERUP-130		9.4	10.0												f-i	8.95					
ERUP-131		11.6	12.1												f	16.41					
ERUP-132		10.9	11.6												f	13.56					
ERUP-133		11.6	12.3												f	17.92					
ERUP-134		12.8	14.0												f	25.20					
ERUP-135		14.1	15.0												f	33.23					
ERUP-136		12.3	12.9												f	20.45					
ERUP-137		10.2	10.6												f	10.70					
ERUP-138		12.6	13.3												f	24.72					
ERUP-139		12.6	13.2												f	22.86					
ERUP-140		9.9	10.4												f	11.35					
ERUP-141		12.4	13.1												f	18.96					
ERUP-142		14.2	15.0												f	27.27					
ERUP-143		10.9	11.6												f	14.41					
ERUP-144		11.4	12.0												f	15.71					
ERUP-145		14.6	15.3												f	31.59					
ERUP-146		13.7	14.5												f	30.15					
ERUP-147		12.9	13.6												f	23.75					
ERUP-148		10.2	10.9												f	15.48					
ERUP-149		10.7	11.4												f	12.04					
ERUP-150		11.1	11.7												f	17.89					
ERUP-151		9.7	10.3												f-i	10.65					
ERUP-152		12.5	13.3												f	22.69					
ERUP-153		11.8	12.5												f	18.28					
ERUP-154		11.8	12.4												f	17.72					
ERUP-155		12.8	13.4												f	22.51					
ERUP-156		10.8	11.3												f	15.31					
ERUP-157		11.8	12.5												f	16.82					
ERUP-158	8.8	10.4	11.0												M	13.81	0.143				3
ERUP-159	10.2	11.8	12.5												M	17.77	0.453				3
ERUP-160	8.2	9.5	10.1												M	8.90	0.151				3
ERUP-161	9.1	10.5	11.2												F	12.86	0.415				3
ERUP-162	9.8	11.4	12.1												F	14.46	0.358				4
ERUP-163	11.9	13.8	14.7												F	26.92	0.980				4
ERUP-164	10.7	12.4	13.2												F	20.00	1.131				5
ERUP-165	10.3	11.8	12.5												F	17.31	0.764				4
ERUP-166	11.8	13.7	14.5												F	26.13	1.191				4
ERUP-167	9.6	11.1	11.8												F	14.28	0.456				4
ERUP-168	8.6	9.9	10.5												F	9.60	0.067				3
ERUP-169	9.1	10.6	11.2												M	11.69	0.318				3
ERUP-170	11.6	13.4	14.2												F	26.81	1.150				5
ERUP-171	10.5	12.3	13.0												M	18.61	0.200				4
ERUP-172	10.7	12.4	13.1												M	19.88	0.966				4
ERUP-173	10.5	12.1	12.7												F	17.63	0.843				4
ERUP-174	8.9	10.5	11.2												M	13.30	0.207				3

Table A.1: Meristic data for longnose sucker collected at the Elk River Upper Ponds (ERUP). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
ERUP-175	11.8	13.5	14.3												F	23.83	1.147				5
ERUP-176	11.1	12.7	13.3												F	20.51	1.450	1976	0.734		5
ERUP-177	11.0	12.5	13.2												F	18.75	0.638				4
ERUP-178	8.7	10.2	10.7												M	10.38	0.097				4
ERUP-179	9.6	11.3	1.9												M	13.43	0.206				4
ERUP-180	8.9	10.4	11.0												M	11.36	0.196				3
ERUP-182		12.2	13.0												f	17.73	1.236				
ERUP-183		12.3	13.0												f	20.87	1.392				
ERUP-184		14.4	15.3												f	30.30	2.083				
ERUP-185		13.7	14.5												f	25.44	1.756				
ERUP-186		13.4	14.2												f	22.06	1.541				
ERUP-187		12.5	13.3												m	20.10	0.861				
ERUP-188		13.7	14.6												f	27.10	1.647				
ERUP-189		12.1	12.8												m	16.74	0.648				
ERUP-190		16.3	17.2												f	43.44	3.376				
ERUP-191		12.1	12.9												f	18.99	1.141				
ERUP-192		11.5	12.2												f	17.51	0.954				
ERUP-193		11.2	11.9												m	15.07	0.619				
ERUP-194		13.3	14.2												f	24.88	1.641				
ERUP-195		12.2	13.0												m	18.17	0.730				
ERUP-196		13.3	14.1												f	23.95	1.692				
ERUP-197		12.0	12.7												m	17.00	0.722				
ERUP-198		11.9	12.6												m	17.06	0.670				
ERUP-199		12.6	13.4												m	20.35	0.942				
ERUP-200		11.6	12.4												m	15.65	0.604				
ERUP-201		11.6	12.3												m	16.11	0.595				
ERUP-202		11.6	12.2												m	15.41	0.448				
n	78	201	201	55	55	55	55	55	55	55	55	55	55	55	-	201	72	17	17	31	56
Mean	9.8	11.7	12.3	18.73	33.24	28.57	42.49	24.44	14.86	9.57	9.90	5.95	8.50	5.39	-	17.603	1.139	2226	0.906	0.305	3.9
St. deviation	1.6	1.5	1.8	3.32	5.80	5.19	7.70	3.72	2.36	1.24	1.83	1.09	1.36	0.66	-	6.261	1.019	1085	0.412	0.143	0.7
St. error	0.2	0.1	0.1	0.45	0.78	0.70	1.04	0.50	0.32	0.17	0.25	0.15	0.18	0.09	-	0.442	0.120	263	0.100	0.026	0.1
minimum	4.6	5.4	1.9	9.15	15.82	12.51	19.06	13.09	7.30	5.83	4.93	3.16	4.24	3.73	-	1.880	0.067	335	0.227	0.051	2.0
maximum	13.5	16.3	17.2	23.94	47.06	38.41	58.83	31.41	19.01	11.76	13.78	8.18	11.66	6.56	-	43.440	5.339	4821	1.615	0.603	5.0

Table A.2: Meristic data for longnose sucker collected at Maiden Lake (ERF). Sex identifiification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
ERF-1	8.3	9.8	10.2	15.04	29.09	25.37	37.46	21.43	12.66	8.19	9.04	5.74	7.87	5.06	f - i	9.310	0.380			0.130	3
ERF-2	9.9	11.5	12.2	19.95	34.68	28.25	43.66	24.62	15.99	9.58	9.47	6.48	8.24	4.96	f	17.640	0.387			0.347	3
ERF-3	9.5	10.9	11.6	18.55	33.28	28.30	43.68	24.26	14.42	9.52	9.53	5.78	8.10	5.60	f	15.240	1.003	1697	0.591	0.293	3
ERF-4	8.4	9.8	10.3	16.42	28.29	26.05	38.20	20.98	11.96	7.96	7.47	5.06	6.95	5.36	f	9.540	1.181	1183	0.999	0.138	3
ERF-5	8.1	9.6	10.1	15.97	27.79	24.76	36.54	21.29	12.65	7.61	7.49	4.92	7.03	4.98	m	9.890	0.352			0.209	3
ERF-6	8.8	10.4	11.0	15.86	30.95	25.69	38.61	21.83	13.66	7.97	8.28	5.50	8.39	5.04	m	11.780	0.556			0.173	4
ERF-7	8.4	9.9	10.5	15.65	30.62	34.14	35.76	20.83	13.08	7.97	7.43	5.82	7.31	4.88	m	10.540	0.364			0.164	3
ERF-8	7.8	9.2	9.8	14.26	26.37	23.22	34.99	20.41	12.56	7.66	7.56	5.80	6.86	4.77	m	9.060	0.320			0.093	3
ERF-9	10.4	12.0	12.7	19.94	35.43	28.88	44.16	26.07	16.07	9.29	10.56	6.77	9.19	6.00	m	19.030	0.766			0.273	4
ERF-10	9.2	10.7	11.2												f	13.796					
ERF-11	8.5	10.0	10.7												f	11.430					
ERF-12	7.5	8.8	9.3												f - i	8.963					
ERF-13	8.8	10.5	11.1												f	13.427					
ERF-14	9.4	10.8	11.6												f	12.045					
ERF-15	9.1	10.5	11.2												m	11.622					
ERF-16	9.6	11.0	11.6												f	13.929					
ERF-17	8.6	9.9	10.6												f	9.922					
ERF-18	8.6	10.1	10.6												f	11.040					
ERF-19	7.9	9.1	9.6												f-i	9.236					
ERF-20	8.3	9.7	10.3												f	9.992					
ERF-21	11.1	12.6	13.4												f	24.540					
ERF-22	7.4	8.8	9.2												j	7.444					
ERF-23	6.0	7.2	7.5												j	5.173					
ERF-24	8.2	9.7	10.3												m	8.540					
ERF-25		8.0	8.3												j	6.001					
ERF-26		7.5	7.8												j	4.579					
ERF-27	8.4	9.7	10.2												f-i	10.330					
ERF-28	9.5	11.0	11.7												f	13.633					
ERF-29		9.0	9.5												f-i	8.540					
ERF-30	9.5	11.2	11.7												f	15.017					
ERF-31	11.9	13.6	14.4												f	27.890					
ERF-32	9.7	11.3	11.9												m	14.505					
ERF-33	9.5	10.9	11.5												f	13.887					
ERF-34	7.9	9.2	9.6												j	8.684					
ERF-35	7.8	9.0	9.6												j	8.165					
ERF-36	9.6	11.0	11.7												f	18.650					
ERF-37	7.3	8.5	9.0												j	7.019					
ERF-38	8.3	9.7	10.2												f-i	9.447					
ERF-39	8.7	10.1	10.6												f-i	10.941					
ERF-40	8.5	9.9	10.5												f-i	10.232					
ERF-41	9.7	11.1	11.7												f	16.743					
ERF-42	9.1	10.6	11.1												f-i	11.916					
ERF-43	8.3	9.5	10.1												f-i	8.879					
ERF-44	5.6	6.7	7.1												j	4.274					
ERF-45	6.8	7.9	8.4												j	7.341					
ERF-46	7.1	8.2	8.6												j	5.737					
ERF-47	6.6	7.8	8.3												j	5.277					
ERF-48	6.3	7.3	7.7												j	5.509					
ERF-49		8.9	9.4												f-i	8.069					
ERF-50		10.9	11.5												m	13.406					
ERF-51		13.4	13.8												m	27.620					
ERF-52		12.0	12.6												f	18.041					
ERF-53		10.9	11.5												m	14.646					
ERF-54		13.9	14.6												m	25.900					
ERF-55		10.5	11.1												m	13.005					
ERF-56		13.2	13.9												f	23.830					
ERF-57		15.0	15.9												m	35.320					
ERF-58		10.8	11.4												f-i	13.485					

Table A.2: Meristic data for longnose sucker collected at Maiden Lake (ERF). Sex identifiification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
ERF-59		11.3	12.0												m	15.092					
ERF-60		9.2	9.7												f-i	9.163					
ERF-61		10.6	11.2												m	13.245					
ERF-62		7.1	7.4												j	4.097					
ERF-63		9.1	9.6												j	8.661					
ERF-64		9.3	9.9												m	8.735					
ERF-65		11.0	11.7												f	18.277					
ERF-66		7.8	8.3												j	5.633					
ERF-67		10.0	10.6												f-i	11.590					
ERF-68		9.9	10.3												f-i	10.822					
ERF-69		11.1	11.7												f-i	15.008					
ERF-70		10.8	11.4												f-i	15.077					
ERF-71		10.3	10.9												m	10.090					
ERF-72		8.6	9.0												j	6.880					
ERF-73		9.9	10.5												f	12.734					
ERF-74		10.0	10.7												f	11.328					
ERF-75		10.8	11.3												f	11.780					
ERF-76		10.3	10.9												f	12.903					
ERF-77		7.7	8.1												j	4.399					
ERF-78		9.7	10.1												f	11.332					
ERF-79		10.4	11.0												f	10.870					
ERF-80		9.7	10.2												f	9.162					
ERF-81		10.5	11.0												m						
ERF-82		11.0	11.7												m	13.721					
ERF-83		11.0	11.5												f	16.502					
ERF-84		11.6	12.3												f	16.805					
ERF-85		9.1	9.6												f-i	10.198					
ERF-86		8.3	8.7												j	5.965					
ERF-87		8.1	8.4												j	5.438					
ERF-88		10.8	11.4												f	12.995					
ERF-89		9.1	9.5												f-i	9.629					
ERF-90		13.2	13.9												f	23.950					
ERF-91		10.8	11.3												f	15.431					
ERF-92		10.3	10.9												f	18.675					
ERF-93		10.3	10.9												f-i	12.017					
ERF-94		10.8	11.3												f-i	12.660					
ERF-95		10.2	10.9												f	13.795					
ERF-96		9.3	9.8												f-i	10.074					
ERF-97		10.5	11.1												f	14.432					
ERF-98		10.0	10.5												f-i	11.865					
ERF-99		10.0	10.5												f-i	10.012					
ERF-100		12.8	13.5												f	24.130					
ERF-101		14.4	15.3												f	31.710					
ERF-102		10.8	11.5												f-i	12.980					
ERF-103		10.7	11.3												m	11.553					
ERF-104		10.0	10.5												f-i	14.849					
ERF-105		10.1	10.7												f-i	10.104					
ERF-106		9.9	10.5												f-i	9.407					
ERF-107		10.6	11.2												f-i	12.519					
ERF-108		10.8	11.4												f	14.740					
ERF-109		12.3	13.0												f	18.181					
ERF-110		11.4	12.0												f	17.386					
ERF-111		11.8	12.5												f	16.051					
ERF-112		9.5	10.0												f-i	11.383					
ERF-113		9.6	10.0												f-i	8.730					
ERF-114		9.2	9.6												f-i	8.139					
ERF-115		10.0	10.5												f-i	9.376					
ERF-116		8.9	9.3												j	6.699					

Table A.2: Meristic data for longnose sucker collected at Maiden Lake (ERF). Sex identifiification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
ERF-117		11.6	12.3												f	15.273					
ERF-118		6.7	7.0												j	2.702					
ERF-119		11.5	12.6												f-i	14.306					
ERF-120		9.7	10.3												f-i	9.818					
ERF-121		14.1	14.9												f	27.200					
ERF-122		10.5	11.2												f	13.067					
ERF-123		10.8	11.5												f	13.085					
ERF-124		10.8	11.4												m	13.064					
ERF-125		12.7	13.4												f	20.930					
ERF-126		9.7	10.3												f-i	9.934					
ERF-127		12.2	12.8												f	20.185					
ERF-128		9.7	10.3												f-i	9.961					
ERF-129		9.8	10.3												m	9.345					
ERF-130		13.2	14.1												f	23.770					
ERF-131		9.8	10.2												f-i	9.923					
ERF-132		10.1	10.7												m	10.970					
ERF-133		9.6	10.2												f-i	10.203					
ERF-134		10.7	11.3												m	12.364					
ERF-135		10.1	10.6												f-i	11.725					
ERF-136		12.7	13.4												m	18.079					
ERF-137		9.8	10.4												f-i	10.857					
ERF-138		10.0	10.6												m	11.112					
ERF-139		11.8	12.7												m	15.513					
ERF-140		10.4	10.9												f-i	11.960					
ERF-141		10.3	11.0												f	12.751					
ERF-142		10.0	10.5												f-i	10.639					
ERF-143		10.5	11.0												f	13.875					
ERF-144		11.3	11.9												f	15.008					
ERF-145		10.0	10.5												f-i	11.751					
n	45	145	145	9	9	9	9	9	9	9	9	9	9	9	-	144	9	2	2	9	9
Mean	8.5	10.3	10.9	16.85	30.72	27.18	39.23	22.41	13.67	8.42	8.54	5.76	7.77	5.18	-	12.694	0.590	1440	0.795	0.202	3.2
St. deviation	1.3	1.5	1.6	2.10	3.17	3.20	3.63	2.02	1.51	0.81	1.16	0.59	0.79	0.40	-	5.492	0.320	364	0.288	0.085	0.4
St. error	0.2	0.1	0.1	0.70	1.06	1.07	1.21	0.67	0.50	0.27	0.39	0.20	0.26	0.13	-	0.458	0.107	257	0.204	0.028	0.1
minimum	5.6	6.7	7.0	14.26	26.37	23.22	34.99	20.41	11.96	7.61	7.43	4.92	6.86	4.77	-	2.702	0.320	1183	0.591	0.093	3.0
maximum	11.9	15.0	15.9	19.95	35.43	34.14	44.16	26.07	16.07	9.58	10.56	6.77	9.19	6.00	-	35.320	1.181	1697	0.999	0.347	4.0

Table A.3: Meristic data for longnose sucker collected at the Elk River lower oxbow (EROL). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
EROL-1	10.5	12.6	13.2	19.99	34.77	30.77	47.59	27.21	15.28	11.01	10.82	5.81	8.20	6.03	F	19.58	2.001	3122	0.641	0.247	4
EROL-2	8.8	10.4	10.9	18.15	30.18	26.10	41.88	21.17	14.14	8.20	8.80	4.52	7.96	4.99	F	13.47	0.851	1136	0.749	0.144	3
EROL-3	10.9	13.0	13.7	21.59	35.20	33.75	50.86	28.16	18.25	10.73	11.94	6.66	10.85	5.50	F	26.99	0.606	1580	0.384	0.417	4
EROL-4	10.8	13.2	13.9	24.13	37.20	33.71	48.80	27.99	19.07	10.20	10.71	6.99	10.11	5.94	F	32.07	3.675	3051	1.204	0.917	5
EROL-5	9.5	11.1	11.6	17.86	30.40	30.32	46.04	24.47	15.01	9.48	9.81	5.08	7.73	4.90	F	15.84	1.324	1735	0.763	0.201	4
EROL-6	10.7	12.6	13.5	21.33	34.33	32.85	49.58	27.66	18.24	10.43	11.91	7.81	10.63	4.95	M	26.24	0.935			0.294	5
EROL-7	10.3	11.8	12.5	20.26	36.74	30.41	44.86	25.49	15.60	9.44	10.62	6.43	8.66	5.66	M	22.93	0.719			0.273	4
EROL-8	8.4	9.9	10.5	18.36	29.80	27.04	38.64	21.01	13.22	7.98	8.74	4.30	6.98	4.91	M	13.34	0.371			0.345	3
EROL-9	10.2	11.9	12.6	23.29	34.90	31.35	46.26	26.76	15.99	10.44	10.54	6.86	9.10	5.38	F	22.69	4.263	3312	1.287	0.535	3
EROL-10	8.6	10.1	10.7	16.21	28.26	25.69	33.84	22.05	13.97	8.26	8.79	5.12	7.30	5.94	f-i	12.09	0.160			0.179	3
EROL-11	9.4	11.3	12.0	19.20	32.50	27.86	44.90	24.44	14.44	9.60	10.19	5.16	8.19	5.83	F	15.74	0.049			0.248	3
EROL-12	10.1	11.7	12.4	18.23	32.75	29.82	45.12	25.93	15.17	10.20	10.58	6.00	8.15	5.90	F	18.19	0.341			0.234	4
EROL-13	9.8	11.5	12.1	23.22	36.55	29.00	43.71	24.25	15.28	8.86	9.94	5.80	8.16	5.99	f	20.68	0.064			0.431	4
EROL-14	10.4	12.3	12.9	20.63	34.81	32.45	48.28	25.91	15.66	10.24	11.16	5.96	8.04	5.68	f	20.16	0.405			0.268	5
EROL-15	12.6	14.8	15.7	24.55	46.77	37.71	57.81	29.18	18.40	10.92	13.16	8.01	11.61	6.06	F	38.11	3.831	2847	1.345	0.729	5
EROL-16	13.1	15.0	15.8	27.32	43.58	38.29	58.69	29.83	18.33	11.46	11.70	7.79	10.10	6.39	F	36.18	4.934	3423	1.441	0.82	5
EROL-17	8.8	10.4	11.0	15.96	30.37	24.88	38.63	23.24	14.13	9.14	9.90	5.76	7.38	5.81	f	11.43	0.167			0.14	3
EROL-18	9.1	10.8	11.4	16.79	32.36	25.52	38.75	23.78	14.43	9.12	9.83	6.50	7.98	4.98	f	13.46	0.021			0.196	4
EROL-19	10.7	12.4	13.2	21.08	36.11	31.86	49.47	25.97	15.30	10.09	12.20	6.57	8.76	5.58	M	20.34	0.788			0.296	4
EROL-20	12.0	13.8	14.6	21.36	41.75	36.72	53.39	28.18	16.90	9.38	12.09	6.98	9.18	6.26	M	25.85	1.129			0.378	4
n	20	20	20	20	20	20	20	20	20	20	20	20	20	20	-	20	20	8	8	20	20
Mean	10.2	12.0	12.7	20.48	34.97	30.81	46.36	25.63	15.84	9.76	10.67	6.21	8.75	5.63	-	21.27	1.332	2526	0.977	0.365	4.0
St. deviation	1.3	1.4	1.5	3.00	4.74	3.99	6.29	2.56	1.75	0.98	1.23	1.05	1.28	0.47	-	7.77	1.553	895	0.390	0.223	0.8
St. error	0.3	0.3	0.3	0.67	1.06	0.89	1.41	0.57	0.39	0.22	0.27	0.24	0.29	0.11	-	1.74	0.347	317	0.138	0.050	0.2
minimum	8.4	9.9	10.5	15.96	28.26	24.88	33.84	21.01	13.22	7.98	8.74	4.30	6.98	4.90	-	11.43	0.021	1136	0.384	0.140	3.0
maximum	13.1	15.0	15.8	27.32	46.77	38.29	58.69	29.83	19.07	11.46	13.16	8.01	11.61	6.39	-	38.11	4.934	3423	1.441	0.917	5.0

Table A.4: Meristic data for longnose sucker collected at the Elk River upper oxbow (EROU). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
EROU-1	12.1	14.1	14.9	30.49	43.72	39.79	55.94	28.39	18.73	11.58	12.16	7.09	9.51	7.14	F	40.04	7.329	7049	1.040	1.141	5
EROU-2	15.7	18.1	19.1	28.69	54.71	48.99	74.67	35.47	21.89	13.94	14.69	7.87	11.31	7.13	F	59.98	2.610	7034	0.371	1.400	9
EROU-3	14.2	16.7	17.6	27.59	54.04	43.76	66.88	32.99	20.31	13.81	15.18	7.19	11.67	6.16	M	55.02					
EROU-4	14.4	16.7	17.6	31.44	50.46	45.65	67.40	32.40	21.04	14.60	14.90	8.77	12.20	6.41	F						
EROU-5	12.3	14.3	15.2	27.58	41.87	37.41	53.98	31.73	19.04	13.02	13.93	7.01	10.97	5.71	F	40.09					
EROU-6	14.9	17.5	18.6	30.36	51.94	49.49	71.17	35.14	21.08	13.65	16.31	8.12	12.05	7.00	F	64.14					
EROU-7	19.0	21.5	22.7	39.69	69.21	53.30	81.16	43.84	27.58	18.09	20.09	9.12	15.00	6.84	F	123.53					
EROU-8		17.1	18.1												f	53.41					
EROU-9		19.8	21.0												f	80.83					
EROU-10		13.5	14.3												f	28.72					
EROU-11		12.2	12.9												m	18.46					
EROU-12		12.7	13.4												f	21.85					
EROU-13		13.0	13.6												f	23.03					
EROU-14		12.1	12.6												f	18.40					
EROU-15		11.4	12.1												m	16.70					
EROU-16		13.9	14.7												f	27.97					
EROU-17		10.9	11.7												m	13.76					
n	7	17	17	7	7	7	7	7	7	7	7	7	7	7	-	16	2	2	2	2	2
Mean	14.7	15.0	15.9	30.83	52.28	45.48	67.31	34.28	21.38	14.10	15.32	7.88	11.82	6.63	-	42.87	4.970	7042	0.705	1.271	7.0
St. deviation	2.3	3.1	3.3	4.18	8.95	5.63	9.73	4.83	2.96	2.00	2.46	0.84	1.67	0.55	-	29.38	3.337	11	0.473	0.183	2.8
St. error	0.9	0.7	0.8	1.58	3.38	2.13	3.68	1.83	1.12	0.76	0.93	0.32	0.63	0.21	-	7.35	2.360	8	0.334	0.130	2.0
minimum	12.1	10.9	11.7	27.58	41.87	37.41	53.98	28.39	18.73	11.58	12.16	7.01	9.51	5.71	-	13.76	2.610	7034	0.371	1.141	5.0
maximum	19.0	21.5	22.7	39.69	69.21	53.30	81.16	43.84	27.58	18.09	20.09	9.12	15.00	7.14	-	123.53	7.329	7049	1.040	1.400	9.0

Table A.5: Meristic data for longnose sucker collected at the Flathead River (FHR). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
FHR-1	12.5	14.3	15.3	27.70	34.79	24.99	64.37	30.44	18.01	11.10	12.93	6.25	8.45	4.89	m	34.26	0.960				6
FHR-2	12.3	13.9	14.8	23.48	35.13	22.70	68.99	25.57	16.62	9.90	11.29	5.78	8.10	5.09	m	26.40	0.980				4
FHR-3	9.2	10.6	11.1	17.93	28.36	19.15	46.45	20.97	13.01	8.81	7.03	3.85	6.59	4.31	m	12.49	0.110				4
FHR-4	9.3	10.5	11.2	17.80	25.32	18.59	47.81	21.71	13.47	7.61	7.52	4.43	6.23	4.79	f	12.92	0.300				4
FHR-5	10.4	11.9	12.7	19.48	34.09	20.31	50.09	24.84	16.03	9.83	8.40	4.91	7.91	4.44	m	19.68	0.430				5
FHR-6	10.3	11.6	12.4	19.25	29.71	21.53	52.51	24.81	14.15	9.43	9.41	5.03	7.20	4.48	f	18.43					5
FHR-7	10.8	12.5	13.2	18.85	31.85	22.50	55.85	23.94	14.74	9.47	9.51	4.27	6.93	4.24	m	17.89	0.340				4
FHR-8	11.1	12.6	13.4	19.83	33.61	23.65	55.54	23.55	15.63	9.32	8.71	5.07	7.53	4.47	f	20.41	0.680				6
FHR-9	11.6	13.3	14.1	18.26	35.54	24.20	61.07	27.35	16.19	10.68	10.48	5.68	8.12	4.87	f	22.24	0.650				6
n	9	9	9	9	9	9	9	9	9	9	9	9	9	9	-	9	8	0	0	0	9
Mean	10.8	12.4	13.1	20.29	32.04	21.96	55.85	24.80	15.32	9.57	9.48	5.03	7.45	4.62	-	20.52	0.556	-	-	-	4.9
St. deviation	1.2	1.3	1.5	3.26	3.54	2.24	7.66	2.86	1.61	1.02	1.86	0.78	0.76	0.30	-	6.71	0.315	-	-	-	0.9
St. error	0.4	0.4	0.5	1.09	1.18	0.75	2.55	0.95	0.54	0.34	0.62	0.26	0.25	0.10	-	2.24	0.111	-	-	-	0.3
minimum	9.2	10.5	11.1	17.80	25.32	18.59	46.45	20.97	13.01	7.61	7.03	3.85	6.23	4.24	-	12.49	0.110	-	-	-	4.0
maximum	12.5	14.3	15.3	27.70	35.54	24.99	68.99	30.44	18.01	11.10	12.93	6.25	8.45	5.09	-	34.26	0.980	-	-	-	6.0

Table A.6: Meristic data for normal longnose sucker collected at Grave Lake (GL). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
GL-1	37.1	41.8	44.3	90.02	132.11	103.87	164.00	100.26	62.15	37.38	51.56	13.65	40.81	12.96	f	1090	116.99	-	-	-	-
GL-2	31.5	35.7	37.4	59.20	98.28	90.16	134.60	86.21	46.51	31.76	42.02	11.51	27.31	12.18	m	500	6.97	-	-	-	-
GL-3	31.3	35.9	38.3	68.81	105.92	93.55	146.20	86.29	53.37	34.52	42.84	10.54	29.28	11.22	f	575	41.05	-	-	-	-
GL-4	35.9	40.7	43.4	77.01	125.45	104.82	175.00	99.80	59.43	36.60	50.15	12.73	36.14	11.64	f	890	60.25	-	-	-	-
GL-5	33.0	37.5	39.7	74.42	119.20	95.37	148.23	85.66	52.00	31.51	42.62	13.45	32.66	11.77	f	720	9.92	-	-	-	-
GL-6	35.8	40.4	42.8	71.08	121.47	110.97	161.80	94.37	55.93	36.97	47.71	11.34	30.79	11.70	f	825	15.15	-	-	-	-
GL-7	33.1	38.2	41.0	73.46	11.59	96.57	154.53	86.00	51.69	32.63	42.65	11.69	32.51	11.73	f	745	57.19	-	-	-	-
GL-8	34.6	39.2	41.1	71.22	118.77	96.99	157.23	90.98	53.49	33.36	47.02	11.99	31.34	12.59	f	755	66.38	-	-	-	-
GL-9	43.1	48.0	50.8	83.79	146.63	124.05	192.50	123.70	70.12	45.70	60.70	14.68	42.04	14.94	f	1375	44.96	-	-	-	-
GL-10	32.5	36.3	38.7	71.20	108.90	92.44	148.11	77.35	46.19	31.44	37.83	12.13	27.77	11.00	f	650	15.88	-	-	-	-
GL-11	34.0	37.9	41.4	76.40	110.39	105.07	157.28	96.12	57.10	36.33	49.36	11.86	32.02	14.08	f	780	67.11	-	-	-	-
GL-12	36.2	41.2	44.1	74.02	124.58	101.87	160.28	98.32	53.58	36.40	47.96	11.89	29.30	13.10	f	845	89.41	-	-	-	-
GL-13	33.0	37.5	39.7	71.63	113.06	91.89	141.90	86.39	50.15	30.13	42.33	12.69	28.79	12.59	f	715	57.61	-	-	-	-
GL-14	33.7	38.4	40.9	69.02	117.12	96.81	157.34	84.52	50.29	29.90	41.89	11.89	27.88	13.26	f	705	11.76	-	-	-	-
GL-15	29.1	32.9	35.0	59.44	93.49	87.80	131.60	77.29	46.15	28.53	38.42	13.25	28.40	11.79	m	455	10.91	-	-	-	-
n	15	15	15	15	15	15	15	15	15	15	15	15	15	15	-	15	15	0	0	0	0
Mean	34.3	38.8	41.2	72.71	109.80	99.48	155.37	91.55	53.88	34.21	45.67	12.35	31.80	12.44	-	775.000	44.77	-	-	-	-
St. deviation	3.2	3.5	3.7	7.82	30.17	9.35	15.31	11.51	6.47	4.28	5.88	1.06	4.57	1.09	-	227.777	33.10	-	-	-	-
St. error	0.8	0.9	1.0	2.02	7.79	2.41	3.95	2.97	1.67	1.11	1.52	0.27	1.18	0.28	-	58.812	8.55	-	-	-	-
minimum	29.1	32.9	35.0	59.20	11.59	87.80	131.60	77.29	46.15	28.53	37.83	10.54	27.31	11.00	-	455.000	6.97	-	-	-	-
maximum	43.1	48.0	50.8	90.02	146.63	124.05	192.50	123.70	70.12	45.70	60.70	14.68	42.04	14.94	-	1375.000	116.99	-	-	-	-

Table A.7: Meristic data for dwarf or juvenile longnose sucker collected at Grave Lake (GL). Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
GL-16	9.8	11.3	11.9	18.89	30.92	27.40	42.00	26.52	16.41	10.16	11.78	6.58	8.98	5.77	f-i	15.36	0.024	-	-	0.362	4
GL-17	12.4	14.4	15.3	23.35	41.64	34.80	54.05	30.73	18.81	11.76	12.71	6.44	9.44	6.33	m	32.99	0.941	-	-	0.352	5
GL-18	10.8	12.4	13.2	20.23	36.38	31.30	46.06	27.06	16.01	9.88	11.44	6.02	9.20	5.38	m	20.49	0.687	-	-	-	4
GL-19	9.7	11.2	11.9	19.56	31.49	30.00	45.17	25.55	15.68	9.48	10.67	6.90	8.39	5.41	f-i	15.76	0.085	-	-	-	4
n	4	4	4	4	4	4	4	4	4	4	4	4	4	4	-	4	4	0	0	2	4
Mean	10.7	12.3	13.1	20.51	35.11	30.88	46.82	27.47	16.73	10.32	11.65	6.49	9.00	5.72	-	21.15	0.434	-	-	0.357	4.3
St. deviation	1.3	1.5	1.6	1.97	5.00	3.08	5.13	2.26	1.42	1.00	0.85	0.36	0.45	0.44	-	8.23	0.451	-	-	0.007	0.5
St. error	0.6	0.7	0.8	0.99	2.50	1.54	2.56	1.13	0.71	0.50	0.42	0.18	0.22	0.22	-	4.11	0.226	-	-	0.005	0.3
minimum	9.7	11.2	11.9	18.89	30.92	27.40	42.00	25.55	15.68	9.48	10.67	6.02	8.39	5.38	-	15.36	0.024	-	-	0.352	4.0
maximum	12.4	14.4	15.3	23.35	41.64	34.80	54.05	30.73	18.81	11.76	12.71	6.90	9.44	6.33	-	32.99	0.941	-	-	0.362	5.0

Table A.8: Meristic data for longnose sucker sampled from the Royal Ontario Museum (ROM) fish collection. Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
79041-1	6.4	7.5	8.0	15.23	16.98	11.36	40.21	17.09	10.16	6.53	7.00	3.52	5.84	3.21	j						
33741-1	9.5	11.2	12.0	17.41	30.10	18.24	62.17	24.11	13.43	9.25	9.38	4.30	8.27	4.94	j						
33212-1	7.8	9.0	9.6	14.64	21.93	12.99	49.18	19.44	11.97	6.81	7.88	5.26	8.37	4.59	j						
33212-2	8.9	10.1	10.9	17.85	25.01	15.62	55.74	22.20	13.01	8.36	8.66	5.78	6.70	4.62	j						
33212-3	8.3	9.5	10.0	14.98	23.01	14.31	50.47	20.22	11.94	7.39	8.26	4.97	7.08	4.29	j						
33212-4	9.2	10.5	11.1	18.30	27.60	16.91	55.99	22.51	13.84	9.05	9.13	5.59	8.45	4.55	j						
33212-5	7.1	8.2	8.8	14.58	19.99	13.40	45.37	18.19	10.75	7.34	6.77	3.93	6.32	3.68	j						
33212-6	15.9	17.7	18.9	31.45	46.35	31.97	99.30	36.47	21.82	13.92	15.71	9.77	14.37	5.95	j						
33212-7	15.5	17.1	18.3	28.93	41.74	29.94	93.08	35.73	21.85	12.97	16.10	9.83	13.75	5.94	j						
33212-8	13.5	15.1	16.0	25.41	36.93	26.82	85.23	32.84	19.06	11.73	14.49	8.16	11.08	5.56	j						
33212-9	11.9	13.6	14.4	20.95	33.89	22.99	75.58	28.28	16.40	10.72	12.00	7.21	10.45	5.61	j						
21683-1	9.0	10.5	11.2	18.23	28.20	17.66	57.34	20.54	12.70	7.78	8.19	4.50	6.82	3.45	j						
21683-2	8.4	9.6	10.3	17.27	23.57	16.42	55.00	19.96	12.77	6.94	7.93	4.68	7.08	4.24	j						
21683-3	10.9	12.5	13.2	21.28	30.69	20.20	67.43	24.24	14.87	8.42	10.63	6.20	9.57	4.79	j						
41911-1	7.9	8.8	9.4	17.35	21.39	14.30	47.07	18.98	11.64	6.89	7.69	4.49	6.97	3.89	j						
41911-2	8.2	9.2	9.9	17.27	24.34	14.18	50.69	20.55	12.13	7.41	8.36	5.26	7.85	4.33	j						
41911-3	8.2	9.2	9.7	17.50	23.17	14.79	49.27	20.47	11.88	7.11	8.86	5.11	7.94	4.44	j						
41911-4	8.5	9.5	10.2	17.59	25.92	15.24	51.30	21.02	11.87	6.46	9.04	5.00	8.35	4.22	j						
41911-5	8.3	9.2	9.7	16.66	23.99	13.70	48.37	20.10	12.55	6.70	8.23	4.89	6.94	4.04	j						
31140-1	13.8	15.5	16.4	26.14	44.40	26.87	83.60	30.39	18.58	11.76	12.77	8.02	11.72	5.81	j						
45876-1	8.2	9.4	10.0	15.62	23.24	16.42	53.57	20.61	12.72	7.29	8.32	4.60	6.53	3.91	j						
45876-2	8.2	9.3	10.1	14.78	22.63	15.43	52.22	21.38	12.65	7.44	9.01	4.54	6.42	3.96	j						
45869-1	10.4	12.3	13.2	23.12	32.01	20.62	67.98	27.06	16.00	9.53	12.49	6.34	8.90	4.94	j						
45869-2	10.2	11.5	12.3	20.54	28.64	18.77	60.91	24.18	14.83	8.82	10.74	5.97	8.23	4.84	j						
45870-1	9.3	10.9	11.7	22.00	27.83	15.63	59.76	24.78	15.30	8.39	11.61	6.75	8.90	5.54	j						
35363-1	8.9	10.3	10.9	18.43	25.55	15.93	55.09	22.71	14.00	7.87	9.64	5.28	7.26	4.52	j						
35363-2	10.2	11.7	12.4	20.47	30.46	20.91	67.64	24.04	14.91	8.48	8.69	5.61	8.45	4.22	j						
35363-3	9.4	10.8	11.6	19.95	25.80	19.23	62.50	23.33	13.67	7.83	9.33	5.58	8.20	3.81	j						
35363-4	10.4	11.9	12.6	21.65	29.40	20.96	63.44	24.48	15.37	8.63	9.66	6.28	8.43	4.47	j						
35363-5	8.9	10.3	11.0	18.58	24.37	18.00	56.92	21.61	13.08	8.10	8.62	4.62	7.72	4.42	j						
35363-6	8.8	10.1	10.8	17.31	22.25	16.73	55.03	21.77	13.11	7.80	8.49	5.38	7.49	3.92	j						
35363-7	9.7	10.6	11.6	22.16	27.50	19.46	61.84	23.09	14.60	8.34	9.12	5.87	8.16	4.26	j						
35363-8	10.5	11.9	12.9	22.66	29.43	20.65	68.25	25.84	15.30	9.04	10.88	5.86	7.52	3.99	j						
35363-9	11.0	12.5	13.2	22.28	31.37	23.73	71.24	27.10	15.60	9.14	10.85	6.30	8.36	4.53	j						
35363-10	10.4	12.0	12.6	20.20	31.75	21.03	64.31	26.01	15.15	8.99	10.67	6.08	8.86	4.42	j						
35363-11	9.8	11.2	12.0	20.17	28.21	18.41	62.52	24.48	14.27	8.79	9.54	5.90	8.09	4.39	j						
35363-12	10.7	12.1	12.7	23.96	29.21	23.01	66.14	24.37	15.51	8.86	10.13	5.81	8.28	4.40	j						
35363-13	9.5	10.9	11.7	19.86	26.81	19.92	62.98	23.70	14.03	7.99	9.48	4.90	7.46	4.76	j						
35363-14	9.6	11.1	11.8	20.80	28.50	17.64	60.74	21.95	13.87	8.30	8.92	5.71	7.15	4.22	j						
35363-15	10.0	11.2	12.1	19.43	29.13	21.30	65.98	24.93	14.67	9.33	9.75	6.34	8.54	4.61	j						
35363-16	10.1	11.7	12.5	21.75	29.53	20.90	67.94	24.14	14.65	8.12	9.22	5.45	7.98	4.34	j						
32341-1	9.5	10.8	11.4	17.64	25.66	17.79	56.15	24.65	14.49	8.24	11.77	5.68	8.87	4.80	j						
14419-1	11.8	13.4	14.2	24.60	36.28	24.78	69.67	26.81	16.67	9.73	11.34	7.17	9.48	5.16	j						
14419-2	10.2	11.9	12.6	21.09	30.72	21.04	65.25	25.83	15.42	8.92	10.65	6.55	8.29	4.84	j						
14419-3	10.1	11.7	12.5	20.11	28.53	17.69	63.87	23.61	14.98	8.04	9.55	5.72	8.21	4.84	j						
14419-4	10.8	12.4	13.2	21.46	31.09	22.41	68.71	24.82	16.05	9.25	9.68	5.95	8.63	5.07	j						
14419-5	8.9	10.4	11.0	18.71	25.94	15.87	54.79	22.36	13.31	7.92	9.19	4.89	7.16	4.45	j						
14419-6	9.3	10.8	11.4	17.82	27.88	16.31	58.19	22.44	12.99	7.57	9.29	5.24	6.19	4.71	j						
31104-1	8.4	9.8	10.3	16.55	23.67	16.56	53.28	20.19	12.49	7.43	7.97	4.60	6.33	3.50	j						
14420-1	10.3	11.8	12.3	21.36	32.80	22.04	65.82	26.13	16.28	8.66	11.96	6.51	7.90	4.84	j						
14420-2	8.7	10.1	10.6	19.29	24.92	16.10	52.60	21.45	12.95	7.77	9.49	4.64	6.94	3.85	j						
20418-1	8.8	10.3	11.1	20.39	22.23	17.08	58.90	22.30	13.93	7.43	9.99	5.41	7.53	4.09	j						
20418-2	8.2	9.5	10.1	17.06	26.06	16.09	53.39	19.45	12.33	6.99	8.41	4.68	7.26	3.98	j						
67852-1	9.4	11.0	11.7	18.79	25.75	19.84	64.68	23.82	14.31	7.67	11.06	5.31	7.27	4.71	j						
67857-1	10.2	12.0	12.8	20.40	30.57	21.63	69.00	26.71	15.86	9.47	12.07	7.03	9.85	4.83	j						
67775-1	11.6	13.5	14.5	22.67	33.58	23.26	70.53	28.91	16.33	8.90	14.10	8.60	10.33	5.51	j						
67771-1	8.1	9.4	10.0	16.61	23.30	16.68	54.38	20.33	12.13	6.13	8.74	4.90	7.15	4.06	j						

Table A.8: Meristic data for longnose sucker sampled from the Royal Ontario Museum (ROM) fish collection. Sex identifification included male (m), female (f), immature (i) and juvenile (j) fish.

Fish ID	Standard Length (cm)	Fork Length (cm)	Total Length (cm)	Body Depth (mm)	Paired fin length (mm)	Pelvic-Anal fin length (mm)	Post-Pelvic Length (mm)	Head Length (mm)	Head Depth (mm)	Post-Orbital Length (mm)	Snout Length (mm)	Lip Length (mm)	Lip Width (mm)	Eye Diameter (mm)	Sex	Body Weight (g)	Gonad Weight (g)	Fecundity (no. eggs)	Egg size (ug)	Liver Weight (g)	Age
20065-1	8.1	9.5	10.2	16.55	20.86	12.72	50.55	22.42	13.07	7.47	9.68	4.81	6.24	5.25	j						
19911-1	8.9	10.7	11.4	19.89	27.03	17.06	61.52	22.50	13.44	6.71	10.89	5.21	7.82	4.90	j						
35955-1	9.7	11.1	11.9	17.56	29.69	18.62	63.40	22.90	13.30	8.38	9.76	6.00	7.73	4.85	j						
35955-2	11.2	12.7	13.7	20.68	35.97	20.83	71.17	26.85	15.21	8.53	12.48	7.36	9.24	5.49	j						
35955-3	9.5	10.9	11.7	17.85	25.54	17.82	60.77	24.01	12.84	8.91	9.73	5.78	7.39	4.48	j						
35955-4	9.3	10.6	11.5	17.15	27.36	18.07	60.25	22.59	12.93	7.95	8.93	6.48	8.56	5.04	j						
35955-5	8.9	10.2	11.0	15.13	25.51	16.08	57.38	22.42	12.68	8.15	9.32	6.11	7.24	4.14	j						
54798-1	9.7	11.2	11.8	22.10	30.69	19.51	63.03	23.34	13.88	8.91	9.64	5.63	8.17	4.39	j						
54822-1	8.7	10.3	10.9	18.37	25.60	17.77	58.95	22.44	13.15	7.10	10.47	6.34	8.92	4.14	j						
54822-2	11.2	12.7	13.7	23.05	32.74	19.51	70.83	27.66	16.17	9.26	12.40	7.07	10.10	4.97	j						
25809-1	11.0	12.5	13.6	20.73	33.52	21.74	74.81	27.61	15.23	9.03	12.90	6.26	10.63	5.56	j						
25809-2	10.6	12.2	13.2	20.77	31.39	20.04	68.48	26.35	15.15	8.64	12.22	5.32	10.55	5.24	j						
84253-1	9.6	11.1	12.0	20.77	28.41	17.06	61.02	23.36	14.67	7.93	9.77	6.33	10.07	4.69	j						
84253-2	10.2	11.6	12.4	20.43	31.97	18.79	63.87	27.17	14.96	9.19	11.91	6.55	8.53	5.15	j						
84253-3	12.1	13.7	14.7	25.66	32.36	24.41	76.46	30.00	17.11	9.25	14.06	7.01	10.21	5.83	j						
84253-4	9.2	10.8	11.4	17.96	25.04	18.82	59.88	23.28	14.02	7.91	9.85	5.16	7.29	5.08	j						
84253-5	9.8	11.4	12.1	21.45	30.33	18.64	61.98	25.40	15.89	9.02	10.78	6.60	7.62	5.16	j						
84253-6	9.4	10.7	11.4	19.04	26.42	16.69	56.54	24.74	13.37	8.37	10.36	5.90	8.34	4.94	j						
84253-7	11.9	13.4	14.2	24.32	36.31	20.75	71.07	28.13	17.11	8.93	12.29	8.07	10.63	5.24	j						
84253-8	11.5	13.0	13.9	21.98	36.91	24.62	72.85	27.86	16.35	9.29	12.88	7.11	9.60	6.00	j						
35370-1	9.2	10.6	11.3	21.12	25.93	17.32	58.01	21.20	13.65	6.78	8.93	4.67	7.75	4.63	j						
35370-2	9.7	11.2	11.9	20.97	27.95	19.92	59.35	21.94	14.04	6.92	10.17	5.17	8.60	5.26	j						
35370-3	11.8	13.6	14.5	25.45	37.59	24.36	75.83	27.37	15.88	8.69	12.92	6.41	9.66	5.96	j						
12604-1	10.4	12.1	12.9	22.44	31.55	20.43	66.26	27.22	15.71	9.15	11.58	6.66	9.31	5.42	j						
54851-1	8.9	10.2	10.7	17.75	25.81	20.25	56.77	22.76	13.19	7.57	9.95	5.08	7.31	4.79	j						
6202-1	9.3	10.8	11.5	18.83	25.01	18.57	62.94	22.70	13.57	8.20	8.00	4.89	6.86	5.02	j						
6202-2	8.6	10.3	11.0	16.79	24.90	15.67	58.39	22.78	13.46	9.09	8.42	5.35	7.61	4.77	j						
6202-3	11.9	13.7	14.8	21.47	33.89	22.95	78.85	30.37	17.19	12.00	11.35	7.29	9.15	6.81	j						
6202-4	12.3	13.6	15.0	21.84	34.41	24.02	82.71	28.99	17.56	9.98	11.97	5.85	8.67	6.14	j						
6202-5	11.8	13.5	14.4	20.71	36.02	24.55	77.90	27.34	17.45	9.77	10.77	6.55	8.64	5.50	j						
6217-1	10.9	12.8	13.7	22.34	31.22	22.20	75.11	28.10	16.14	10.18	11.30	6.30	9.70	4.86	j						
6217-2	10.5	12.1	12.9	21.90	30.36	22.82	68.64	25.10	15.83	9.01	10.03	5.81	7.63	5.69	j						
6217-3	11.7	13.4	14.3	23.21	37.40	24.98	76.82	26.82	16.64	9.65	10.92	5.86	9.05	5.45	j						
26216-1	10.5	11.8	13.2	19.10	30.65	22.54	70.16	26.45	16.05	9.06	10.67	5.80	8.34	5.18	j						
26216-2	9.6	11.4	12.2	18.84	28.15	20.24	65.76	24.34	14.29	8.56	10.09	5.07	7.20	5.20	j						
26216-3	11.7	13.3	14.3	22.36	33.24	21.35	74.64	28.33	15.86	10.47	12.14	6.64	8.50	5.38	j						
26216-4	8.6	10.2	11.0	17.99	23.68	16.39	60.38	21.68	13.22	7.68	9.04	5.10	6.20	4.58	j						
n	94	94	94	94	94	94	94	94	94	94	94	94	94	94	-	0	0	0	0	0	0
Mean	9.9	11.4	12.2	20.04	28.86	19.32	63.42	24.35	14.55	8.54	10.28	5.87	8.33	4.78	-	-	-	-	-	-	-
St. deviation	1.6	1.7	1.9	3.05	5.17	3.73	10.12	3.48	2.02	1.35	1.82	1.12	1.48	0.66	-	-	-	-	-	-	-
St. error	0.2	0.2	0.2	0.31	0.53	0.38	1.04	0.36	0.21	0.14	0.19	0.12	0.15	0.07	-	-	-	-	-	-	-
minimum	6.4	7.5	8.0	14.58	16.98	11.36	40.21	17.09	10.16	6.13	6.77	3.52	5.84	3.21	-	-	-	-	-	-	-
maximum	15.9	17.7	18.9	31.45	46.35	31.97	99.30	36.47	21.85	13.92	16.10	9.83	14.37	6.81	-	-	-	-	-	-	-

APPENDIX B

GENETICS INFORMATION

Appendix B.1: Alignment of 297 base pairs of mitochondrial DNA from the 5' end of the cytochrome *b* gene from Elk River Watershed dwarf and normal longnose sucker and Flathead River Pond longnose sucker. Substitutions are indicated as bold red text.

Haplotype	Base Pair Sequence	Base Pair No.
H1	TTTCGGGTCCCTACTAGGCCTTTGTCTTATTACCCAA**G**TCCTAACAGGAC	50
H2	TTTCGGGTCCCTACTAGGCCTTTGTCTTATTACCCAAATCCTAACAGGAC	
H3	TTTCGGGTCCCTACTAGGCCTTTGTCTTATTACCCAAATCCTAACAGGAC	
H4	TTTCGGGTCCCTACTAGGCCTTTGTCTTATTACCCAAATCCTAACAGGAC	
H1	TATTCCTAGCAATACACTATACCTCTGACATCTCAACCGCCTTCTCTTCT	100
H2	TATTCCTAGCAATACACTATACCTCTGACATCTCAACCGCCTTCTCTTCT	
H3	TATTCCTAGCAATACACTATACCTCTGACATCTCAACCGCCTTCTCTTCT	
H4	TATTCCTAGCAATACACTATACCTCTGACATCTCAACCGCCTTCTCTTCT	
H1	GTTGCCCACATTTGCCGAGACGTAAGTTATGGATGACTAATCCGTAGTGT	150
H2	GTTGCCCACATTTGCCGAGACGTAAGTTATGGATGACTAATCCGTAGTGT	
H3	GTTG**G**CCACATTTGCCGAGACGTAAGTTATGGATGACTAATCCGTAGTGT	
H4	GTTGCCCACATTTGCCGAGACGTAAGTTATGGATGACTAATCCGTAGTGT	
H1	TCATGCTAACGGAGCATCGTTCTTCTTTATTTGCATTTATATGCACATTG	200
H2	TCATGCTAACGGAGCATCGTTCTTCTTTATTTGCATTTATATGCACATTG	
H3	TCATGCTAACGGAGCATCGTTCTTCTTTATTTGCATTTATATGCACATTG	
H4	TCATGCTAACGGAGCATCGTTCTTCTTT**G**TTTGCATTTATATGCACATTG	
H1	CCCGAGGACTATACTATGGGTCTTATCTTTATAAAGAGACCTGAAACATT	250
H2	CCCGAGGACTATACTATGGGTCTTATCTTTATAAAGAGACCTGAAACATT	
H3	CCCGAGGACTATACTATGGGTCTTATCTTTATAAAGAGACCTGAAACATT	
H4	CCCGAGGACTATACTATGGGTCTTATCTTTATAAAGAGACCTGAAACATT	
H1	GGTGTCGTTCTCCTTCTATTGGTAATAATGACTGCCTTCGTAGGATA	297
H2	GGTGTCGTTCTCCTTCTATTGGTAATAATGACTGCCTTCGTAGGATA	
H3	GGTGTCGTTCTCCTTCTATTGGTAATAATGACTGCCTTCGTAGGATA	
H4	GGTGTCGTTCTCCTTCTATTGGTAATAATGACTGCCTTCGTAGGATA	

Appendix B.2: Alignment of 468 base pairs of mitochondrial DNA from the 5' end of the ND2 gene from Elk River Watershed dwarf and normal longnose sucker and Flathead River Pond longnose sucker. Substitutions are indicated as bold red text.

Haplotype	Base Pair Sequence	Base Pair No.
H1	CGAACATGACGGTTAAAATCCCTCCTCTGTCAATGAATCCTTATGTACTT	50
H2	CGAACATGACGGTTAAAATCCCTCCTCTGTCAATGAATCCTTATGTACTT	
H3	CGAACATGACGGTTAAAATCCCTCCTCTGTCAATGAATCCTTATGTACTT	
H4	CGAACATGACGGTTAAAATCCCTCCTCTGTCAATGAATCCTTATGTACTT	
H5	CGAACATGACGGTTAAAATCCCTCCTCTGTCAATGAATCCTTATGTACTT	
H6	CGAACATGACGGTTAAAATCCCTCCTCTGTCAATGAATCCTTATGTACTT	
H7	CGAACATGACGGTTAAAATCCCTCCTCTGTCAATGAATCCTTATGTACTT	
H1	ACCATCCTTCTCTCTAGTCTTGGGCTGGGAACCACCCTAACCTTCGCCAG	100
H2	ACCATCCTTCTCTCTAGTCTTGGGCTGGGAACCACCCTAACCTTCGCCAG	
H3	ACCATCCTTCTCTCTAGTCTTGGGCTGGGAACCACCCTAACCTTCGCCAG	
H4	ACCATCCTTCTCTCTAGTCTTGGGCTGGGAACCACCCTAACCTTCGCCAG	
H5	ACCATCCTTCTCTCTAGTCTTGGGCTGGGAACCACCCTAACCTTCGCCAG	
H6	ACCATCCTTCTCTCTAGTCTTGGGCTGGGAACCACCCTAACCTTCGCCAG	
H7	ACCATCCTTCTCTCTAGTCTTGGGCTGGGAACCACCCTAACCTTCGCCAG	
H1	CTCCCACTGACTCCTTGCTTGAATGGGCCTGGAGGTCAATACACTGGCAA	150
H2	CTCCCACTGACTCCTTGCTTGAATGGGCCTGGAGGTCAATACACTGGCAA	
H3	CTCCCACTGACTCCTTGCTTGAATGGGCCTGGAGGTCAATACACTGGCAA	
H4	CTCCCACTGACTCCTTGCTTGAATGGG**A**CTGGAGGTCAATACACTGGCAA	
H5	CTCCCACTGACTCCTTGCTTGAATGGGCCTGGAGGTCAATAC**G**CTGGCAA	
H6	CTCCCACTGACTCCTTGCTTGA**G**TGGGCCTGGAGGTCAATACACTGGCAA	
H7	CTCCCACTGACTCCTTGCTTGAATGGGCCTGGAGGTCAATACACTGGCAA	
H1	TTTTACCACTTATGGCCCAACACCATCACCCCCGAGCAGTTGAAGCAACC	200
H2	TTTTACCACTTATGGCCCAACACCATCACCCCCGAGCAGTTGAAGCAACC	
H3	TTTTACCACTTATGGCCCAACACCATCACCCCCGAGCAGTTGA**G**GCAACC	
H4	TTTTACCACTTATGGCCCAACACCATCACCCCCGAGCAGTTGA**G**GCAACC	
H5	TTTTACCACTTATGGCCCAACACCATCACCCCCGAGCAGTTGA**G**GCAACC	
H6	TTTTACCACTTATGGCCCAACACCATCACCCCCGAGCAGTTGAAGCAACC	
H7	TTTTACCACTTATGGCCCAACACCATCACCCCCGAGCAGTTGAAGCAACC	
H1	ACCAAGTATTTCCTGACCCAGGCCACTGCAGCCGCCATAATCTTGTTTGC	250
H2	ACCAAGTATTTCCTGACCCAGGCCACTGCAGCCGC**T**ATAATCTTGTTTGC	
H3	ACCAAGTATTTCCTGACCCAGGCCACTGCAGCCGC**T**ATAATCTTGTTTGC	
H4	ACCAAGTATTTCCTGACCCAGGCCACTGCAGCCGC**T**ATAATCTTGTTTGC	
H5	ACCAAGTATTTCCTGACCCAGGCCACTGCAGCCGC**T**ATAATCTTGTTTGC	
H6	ACCAAGTATTTCCTGACCCAGGCCACTGCAGCCGCCATAATCTTGTTTGC	
H7	ACCAAGTATTTCCTGACCCAGGCCACTGCAGCCGC**T**ATAATCTTGTTTGC	
H1	AAGCACAACAAATGCTTGACTTGTTGGAGAGTGGGATATTAATAATTTAT	300
H2	AAGCACAACAAATGCTTGACTTGTTGGAGAGTGGGATATTAATAATTTAT	
H3	AAGCACAACAAATGCTTGACTTGTTGGAGAGTGGGATATTAATAATTTAT	
H4	AAGCACAACAAATGCTTGACTTGTTGGAGAGTGGGATATTAATAATTTAT	
H5	AAGCACAACAAATGCTTGACTTGTTGGAGAGTGGGATATTAATAATTTAT	
H6	AAGCACAACAAATGCTTGACTTGTTGGAGAGTGGGATATTAATAATTTAT	
H7	AAGCACAACAAATGCTTGACTTGTTGGAGAGTGGGATATTAATAATTTAT	

Appendix B.2: Alignment of 468 base pairs of mitochondrial DNA from the 5' end of the ND2 gene from Elk River Watershed dwarf and normal longnose sucker and Flathead River Pond longnose sucker. Substitutions are indicated as bold red text.

Haplotype	Base Pair Sequence	Base Pair No.
H1	CCCACCCCCTCGCTACCACTATAGCTATTGCTGCCTTAGCACTTAAAATT	350
H2	CCCACCCCCTCGCTACCACTATAGCTATTGCTGCCTTAGCACTTAAAATT	
H3	CCCACCCCCTCGCTACCACTATAGCTATTGCTGCCTTAGCACTTAAAATT	
H4	CCCACCCCCTCGCTACCACTATAGCTATTGCTGCCTTAGCACTTAAAATT	
H5	CCCACCCCCTCGCTACCACTATAGCTATTGCTGCCTTAGCACTTAAAATT	
H6	CCCACCCCCTCGCTACCACTATAGCTATTGCTGCCTTAGCACTTAAAATT	
H7	CCCACCCCCTCGCTACCACTATAGCTATTGCTGCCTTAGCACTTAAAATT	
H1	GGACTTGCCCCAGTCCACTTCTGACTGCCAGAAGTTTTGCAAGGACTCGA	400
H2	GGACTTGCCCCAGTCCACTTCTGACT**A**CCAGAAGTTTTGCAAGGACTCGA	
H3	GGACTTGCCCCAGTCCACTTCTGACT**A**CCAGAAGTTTTGCAAGGACTCGA	
H4	GGACTTGCCCCAGTCCACTTCTGACT**A**CCAGAAGTTTTGCAAGGACTCGA	
H5	GGACTTGCCCCAGTCCACTTCTGACT**A**CCAGAAGTTTTGCAAGGACTCGA	
H6	GGACTTGCCCCAGTCCACTTCTGACTGCCAGAAGTTTTGCAAGGACTCGA	
H7	GGACTTGCCCCAGTCCACTTCTGACT**A**CCAGAAGTTTTGCAAGGACTCGA	
H1	CCTACTTACGGGACTTATTCTCTCGACCTGGCAAAAGCTTGCACCGTTCG	450
H2	CCTACTTACGGGACTTATTCTCTCGACCTGGCAAAAGCTTGCACCGTTCG	
H3	CCTACTTACGGGACTTATTCTCTCGACCTGGCAAAAGCTTGCACCGTTCG	
H4	CCTACTTACGGGACTTATTCTCTCGACCTGGCAAAAGCTTGCACCGTTCG	
H5	CCTACTTACGGGACTTATTCTCTCGACCTGGCAAAAGCTTGCACCGTTCG	
H6	CCTACTTACGGGACTTATTCTCTCGACCTGGCAAAAGCTTGCACCGTTCG	
H7	CCTACTTACGGGACTTATTCTCTCGACCTGGCAAAAGCTTGCACCGTTCG	
H1	CATTAATTGTACAGCTAG	468
H2	CATTAATTGTACAGCTAG	
H3	CATTAATTGTACAGCTAG	
H4	CATTAATTGTACAGCTAG	
H5	CATTAATTGTACAGCTAG	
H6	CATTAATTGTACAGCTAG	
H7	CATTAATTGTACAGCTAG	