Population Dynamics and Movement of Smallmouth Bass in the Snake River, Idaho

A Thesis
Presented in Partial Fulfillment of the Requirements for the
Degree of Master of Science
with a
Major in Natural Resources
in the
College of Graduate Studies
University of Idaho
by
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May 2018

Authorization to Submit Thesis

This thesis of Conor McClure, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Population Dynamics and Movement of Smallmouth Bass in the Snake River, Idaho" has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

The Smallmouth Bass *Micropterus dolomieu* is one of the most socially, economically, and ecologically important species in North America. The Snake River, Idaho, supports a popular Smallmouth Bass sport fishery, but little is known about the population. Additionally, anglers and Idaho Department of Fish and Game staff in the study area have expressed concern about the harvest of Smallmouth Bass associated with spawning congregations in and near the lower reaches of several major tributaries (i.e., Payette and Weiser rivers). This thesis describes the population dynamics, demographics, and movement of Smallmouth Bass in the Snake River, Idaho between Swan Falls Dam and Brownlee Dam. Results of this study indicate the population can be characterized by fast growth, good size structure and body condition, low exploitation, and highly variable movement throughout the system. Under current conditions, management changes (e.g., minimum length limit increase, seasonal fishing restrictions) in the system do not seem warranted. Furthermore, this research provides guidance for managers in the western United States where information on the distribution and ecology of Smallmouth Bass in streams and rivers is limited.

Acknowledgements

I would like to thank Dr. Michael Quist and Dr. Dan Schill for guidance during my master's program. I thank Joe Kozfkay and Mike Peterson for their friendship and providing me with logistical support, field support, as well as insight into the systems that we worked in, without which this project would not have been possible. I thank Brett High of IDFG for his friendship, mentoring, help, and support over the past five years. I thank many people from the Idaho Department of Fish and Game including Brett Amdor, Tyler Archibald, Jacob Calvitti, Steve Dempsy, Jeff Dillon, Kyle Gatt, Brian Jack, Kayla Kinkade, Martin Koenig, Jared Kunz, Brian Marek, Craig Mickelson, Wyatt Tropea, Joe VanPatten, and Nate Woods for their help and support. I thank John Anderson, Jim Chandler, and Tracy Richter of the Idaho Power Company for their help and support. I thank Dave Banks of Oregon Department of Fish and Wildlife for his help with fieldwork in Oregon along with my committee members (Dr. Timothy Johnson and Dr. Kerri Vierling) for their insights and support. I am grateful to my fellow graduate students (Zach Beard, Shannon Blackburn, Phil Branigan, Tucker Brauer, Stacey Feeken, John Heckel, Zach Klein, and Curtis Roth) for their friendship over the past few years and all the positive reinforcement and sincerely helpful critiques. I thank the Idaho Bass Nation and Idaho Bass Federation for their fiscal support. I also thank undergraduate technicians Kasey Barney, Charlie Kerrick, and Mike Thomas. Lastly, and certainly not least, I thank my wife Kate McClure for supporting me through my master's program.

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Chapter 1: General Introduction

Black basses *Micropterus* spp. are popular sport fishes with a world-wide distribution. The broad distribution of black bass is attributed to their popularity and ability to thrive in diverse habitats, both in lentic and lotic systems (Coble 1975; Ridgeway 1988; Phillip et al. 1997). Since the 1800s, black basses have been distributed across North America, and sizable portions of Asia, Africa, Europe, and South America (Lapman 1946; Robbins and MacCrimmon 1974). One of the black basses, the Smallmouth Bass *Micropterus dolomieu,* is of particular importance in North America.

The Smallmouth Bass is important in North America due to the social and economic roles it supports, as well as its ecological value (USFWS 2011; Schade and Bonar 2005; Stepien et al. 2007; Carey et al. 2011). The Smallmouth Bass is native to a large portion of the midwestern and northeastern United States (Scott and Crossman 1973). However, introductions (intentional and unintentional) and changing climate conditions have resulted in an expanded distribution (Schade and Bonar 2005; Stepien et al. 2007; Carey et al. 2011). An introduction of Smallmouth Bass to the state of California in 1874 was the first recorded introductions west of their native distribution (Lapman 1946). Since that time, introductions in other western systems have occurred. Introduced populations of Smallmouth Bass present a conundrum for fisheries managers. On one hand, they can negatively influence native fishes (Reiman 1991, Tabor 1993), on the other hand they are a popular sport fish (Carey et al. 2011). One of the systems in western United States where Smallmouth Bass were introduced is the Snake River in Idaho. The Snake River currently supports a popular fishery along much of its length, particularly along its lower half.

One of the first introductions of Smallmouth Bass in Idaho likely occurred in the late 1800s, but the specific date and location of the introduction is unknown (Munther 1970). Another author reported that Smallmouth Bass were first introduced to the Snake River, Idaho, in 1942 by the Idaho Department of Fish and Game (IDFG), but the specific stocking location was not documented (Keating 1970). Regardless of how Smallmouth Bass were introduced to the Snake River, they dispersed and established population(s) in the Snake River downstream of Swan Falls Dam and in lower reaches of the Boise, Payette, and Weiser rivers, three tributaries to the Snake River (Kozfkay 2006), and in Brownlee Reservoir which was created in 1958 with the completion of Brownlee Dam. Following the completion of Brownlee Dam, the abundance of Smallmouth Bass in portions of the system has increased (Kozfkay 2006) as has the popularity of the fishery.

Notwithstanding the fishery's popularity, little research has been conducted on the Smallmouth Bass population(s) in the Snake River and its major tributaries (i.e., Boise, Payette, Weiser rivers). Following the completion of Brownlee Dam, the IDFG sampled the Snake River in 1972. The river was not sampled again by IDFG until 2006. In 1990, the Idaho Power Company began sampling the river, but much of the Smallmouth Bass information has not been summarized. Thus, more information on the population dynamics and movement of Smallmouth Bass in the system is needed to better manage the fishery.

Gathering information on primary rate functions that influence population dynamics such as growth, recruitment, and mortality is essential for basic fish population management (Ricker 1975). Population dynamics of Smallmouth Bass in their native distribution have been well documented (Paragamian and Cobble 1975; Marinac-Sanders and Coble 1981; Paragamian 1984; Raffetto et al. 1990; Jansen et al. 2008). However, research describing the population dynamics of Smallmouth Bass in their western distribution is far less comprehensive. Collecting information on the population dynamics and demographics of Smallmouth Bass in the Snake River, Idaho, will help managers and researchers develop a better understanding of Smallmouth Bass ecology west of their native distribution. Furthermore, much of the research on Smallmouth Bass in the west has focused on the predatory effects of Smallmouth Bass on native populations of fishes (Poe et al. 1991; Naugthon et al. 2004; Carey et al. 2011) or the large-scale distribution and movement of Smallmouth Bass (Munther 1970; LaVigne 2008; Rubenson and Olden 2016).

Knowledge of how fish move in a system is important for management. Movement data allow managers to identify variation in the distribtion and abundace of fish across space and time (Larimore 1952; Pine et al. 2012). Such knowledge allows managers to regulate a fishery accordingly. Movement patterns of Smallmouth Bass have been well documented in and outside of their native distribution. Several studies have described Smallmouth Bass movement patterns as sedentary, with fish often moving less than 5 km during the course of the study (Larimore 1952; Fajen 1962). Other studies have reported a greater range of movement (Munther 1970; Todd and Rabeni 1989; Langhurst and Schoenike 1990 and Rubenson and Olden 2016). In the Snake River, movement patterns of Smallmouth Bass are not well understood. In recent years, IDFG staff and anglers have expressed concern about the harvest of Smallmouth Bass from the lower portions of the Payette and Weiser rivers during the late winter and early spring when large congregations thought to be are present. In the spring, Smallmouth Bass are thought to enter the lower reaches of these tributaries from the Snake River to spawn with dispersal back to the Snake River during the summer.

Describing Smallmouth Bass movement throughout the year provides Idaho managers with the information needed to better understand and manage the fishery.

Since little is known about the Smallmouth Bass population in the Snake River, the results of this study were used to describe the population. The goals of the study were to develop a better understanding of Smallmouth Bass ecology in the western United States and to provide managers with basic population information that would allow them to better manage the fishery for the angling public. More specifically, the study objectives were to (1) describe the population dynamics and demographics of Smallmouth Bass in the Snake River, and (2) evaluate movement of Smallmouth Bass in the Snake River between Swan Falls Dam and the Snake River.

Thesis Organization

This thesis is divided into four chapters. Chapter two details a large-scale field study that was conducted in 2016 to describe the population dynamics and demographics of Smallmouth Bass in the Snake, Boise, Payette, and Weiser rivers in Idaho. Chapter three describes a field study conducted in 2017. The purpose of the study was to describe the movement patterns of Smallmouth Bass in the Snake, Boise, Payette, and Weiser rivers and Brownlee Reservoir in Idaho. Chapter four provides general conclusions and recommendations drawn from this work.

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Chapter 2: Population dynamics and demographics of Smallmouth Bass in the Snake River, Idaho

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Abstract

The Snake River in Idaho supports a popular Smallmouth Bass *Micropterus dolomieu* sport fishery, but little is known about the population dynamics of Smallmouth Bass in the system. The purpose of the study was to describe the population dynamics and demographics of Smallmouth Bass in the Snake River, Idaho. A total of 4,929 Smallmouth Bass was sampled during electrofishing surveys on the Snake River (separated into nine segments) and three major tributaries (i.e., Boise, Payette, and Weiser rivers). Age was estimated for 1,869 fish sampled from the Snake River (n = 1,433) and three major tributaries (n = 436). Capture per unit effort (CPUE) for all nine segments combined on Snake River was 36.6 fish/hour (± SE; ± 4.4). On the tributaries, CPUE varied from 43.6 – 125.0 fish/hour. Relative weight of all fish in the Snake River and tributaries varied from 86 – 107 indicating that fish were in relatively good body condition. Fish in the system grew fast with relative growth index values often near or exceeding 100 for all age classes in both the Snake River and tributaries. Total annual mortality for the Snake River was 45.1% (± 0.7%) and was lower in the tributaries varying from 36.8% to 40.5%. Furthermore, catch-and-release is a common practice among anglers in the study area resulting in a low exploitation estimate of 5.3% (90% CI; 2.2%) for the Snake River and tributaries combined. Three separate simulations were performed to evaluate the effects of varying minimum length limits on the fishery. Under current conditions, changes in management (e.g., minimum length limit increase) in the system do not seem warranted.

Introduction

Black basses *Micropterus* spp. are popular sport fishes around the world largely due to their aggressive nature, ability to grow to trophy sizes, and capacity to thrive in a diversity of habitats (Coble 1975; Phillip et al. 1997). They occur across North American and have been introduced to systems in Asia, Africa, Europe, and South America (Robbins and MacCrimmon 1974). In the United States, black basses are generally considered the most popular group of freshwater sport fishes (USFWS 2011). In particular, the Smallmouth Bass *Micropterus dolomieu* is one of the most socially, economically, and ecologically important species in North America. They are present in systems across the United States and are found in a variety of habitats (e.g., lakes, rivers, and streams) across various latitudes (Coble 1975). Their native distribution includes portions of several major rivers in the central and eastern United States, including the Ohio, Tennessee, and Mississippi rivers, as well as the Saint Lawrence-Great Lakes system (Scott and Crossman 1973). Shifts in climate and introductions (intentional and unintentional) have resulted in an expanded distribution of the species (Schade and Bonar 2005; Stepien et al. 2007; Carey et al. 2011).

The transfer of Smallmouth Bass outside their native distribution began in the 1800s. One of the first recorded introductions of Smallmouth Bass west of their native distribution took place in California in 1874 (Lampman 1946). Following the introduction in California, introductions in Oregon and Washington occured in the 1920s (LaVigne et al. 2008). In addition to these early introductions, Munther (1970) reported that Smallmouth Bass were introduced to the Snake River in the late 1800s, but provided no supporting evidence as to the specific location. In Idaho, Keating (1970) reported that the first introduction of Smallmouth

Bass to the Snake River was facilitated by the Idaho Department of Fish and Game (IDFG) in 1942. Smallmouth Bass dispersed after introduction and became established in the mainstem of the Snake River downstream of Swan Falls Dam and in the lower reaches of the Boise, Payette, and Weiser rivers. Following the completion of the Hells Canyon Hydroelectric Project (i.e., Brownlee, Oxbow, and Hells Canyon dams) in the 1950s and 1960s, the Smallmouth Bass population(s) in the portion of the Snake River between Swan Falls Dam and Brownlee Reservoir increased substantially during the last few decades (Kozfkay et al. 2006). Impoundment of the Snake River made the system more suitable for Smallmouth Bass by increasing water temperatures and stabilizing flows in the river upstream of Brownlee Dam. As a result, the Snake River in this area, now supports a popular Smallmouth Bass sport fishery.

Currently, a daily bag limit of six fish (Smallmouth Bass and Largemouth Bass *Micropterus salmoides* in aggregate) with a minimum length limit of 305 mm is used to manage the population in the Snake River and its major tributaries (i.e., Boise, Payette, and Weiser rivers) between Swan Falls Dam and Brownlee Reservoir. Over the past five decades, IDFG has collected minimal information on Smallmouth Bass, only sampling the Snake River in 1972 and 2006 (Kozfkay et al. 2006). The Idaho Power Company began sampling Smallmouth Bass in the Snake River between Swan Falls Dam and Brownlee Reservoir in 1990, but the information has not been summarized. Additionally, local anglers and IDFG staff have recently expressed concern about the harvest of Smallmouth Bass during seasonal congregations in and around the lower reaches of the Weiser and Payette rivers. Despite the popularity of the fishery in the Snake River, Idaho, little is known about the Smallmouth Bass population.

Numerous studies have described the population dynamics of Smallmouth Bass in their native distribution (Paragamian and Cobble 1975; Marinac-Sanders and Coble 1981; Paragamian 1984; Raffetto et al. 1990; Jansen et al. 2008), but less research has been conducted on Smallmouth Bass west of their native distribution. Although some researchers have studied the population dynamics of Smallmouth Bass in the western United States (Keating 1970; Walrath et al. 2015), a majority of research has focused on distribution and movement (Munther 1970; LaVigne 2008; Rubenson and Olden 2016) or the predatory effects of Smallmouth Bass on native fishes (Poe et al. 1991; Naugthon et al. 2004; Carey et al. 2011).

Basic information on the population dynamics and demographics has not been collected for the Smallmouth Bass population in the Snake River between Swan Falls Dam and Brownlee Reservoir. The objectives of this study were to describe the population in terms of age, growth, mortality, and size structure. We used the information to evaluate different management scenarios (e.g., changes to the minimum length limit) using an age-structured population model. By collecting and analyzing data on population dynamics and demographics, natural resource managers will be able to develop informed management alternatives. Furthermore, the information will allow managers to better understand the population dynamics and ecology of an introduced population of Smallmouth.

Methods

Study area

The Snake River has a drainage area of 282,000 km^2 and originates in northwest Wyoming. It flows through western Wyoming before turning west and entering Idaho. Near

Heise, Idaho, the Snake River leaves the mountains and crosses the Snake River Plain of southern Idaho as it flows west across the state. Near the town of Homedale, Idaho, the river leaves Idaho and enters Oregon for a distance of approximately 16.5 river kilometers (rkm). Several river kilometers downstream of the town of Adrian, Oregon, the river then serves as the border between Oregon and Idaho until the Oregon and Washington border. The Snake River also acts as the border between Idaho and Washington until the river turns west into Washington near Lewiston, Idaho, and later joins the Columbia River near Pasco, Washington. Twenty-two dams have been constructed on the mainstem of the Snake River, fifteen of which are in Idaho.

The study area included the portion of the Snake River downstream of Swan Falls Dam (~ 32 km south of Boise, Idaho) to Brownlee Dam (Figure 2.1). However, the primary focus of this study was in the segment of the Snake River from Swan Falls Dam to Farewell Bend (i.e., upstream termination of Brownlee Reservoir), a distance of approximately 200 rkm, and included the lower portion (20 rkms upstream from the mouth) of the Boise, Payette, and Weiser rivers. Swan Falls Dam is the oldest hydroelectric dam on the Snake River and was constructed by the Trade Dollar Mining Company in 1901 to provide power to Silver City, Idaho, for gold and silver mining operations in the Owyhee Mountains (HAER No. ID-20). The dam was acquired in 1916 by the Idaho Power Company who currently owns and operates the dam. In 1958, the Idaho Power Company finished construction of Brownlee Dam, the first and most upstream of three dams built between 1958 and 1967 that make up the Hells Canyon Hydroelectric Project. The dams and reservoirs are used for flood control, recreation, and power generation.

The Boise, Payette, and Weiser rivers are large tributaries in Idaho that join with the Snake River between Swan Falls Dam and Farewell Bend (Figure 2.1). The Weiser River is the northern-most major tributary to the Snake River in the study area. The Weiser River basin drains 2,672 km^2 and has an average annual discharge of 0.9×10^9 m^3. The Payette River drains approximately 5,214 km^2 and discharges an average of 2.7×10^9 m^3 of water to the Snake River on an annual basis. The Boise River is the most southern major Idaho tributary to the Snake River in the study area. The Boise River basin drains an area of 6,598 km^2 and contributes an annual average discharge of 2.4×10^9 m^3 of water to the system.

Sampling design

Stratified random sampling was used to sample the Snake River and three major tributaries. In 2006, IDFG divided the Snake River from Swan Falls Dam to Farewell Bend into nine segments based on potential management boundaries. The distance between Swan Falls Dam and Brownlee Dam is approximately 200 rkm. Segments varied in length from 11.3 rkm to 32.2 rkm and were used during this study (Figure 2.1). Forty reaches, approximately 2 rkm long, were randomly selected from the segments. The number of reaches sampled per segment was based on segment length (Scheaffer et al. 2006) with more sampled reaches in longer segments compared to short segments. Additionally, three 2-rkm-long reaches were selected from the lower segments of the Boise and Payette rivers. Due to low flows and access restrictions, three 500-m-long reaches were sampled on the Weiser River.

Fish collection

Sampling on the Snake River was conducted using jet-powered boats outfitted with electrofishing equipment (Midwest Lake Electrofishing Systems [MLES], Polo, Missouri;

Infinity Control Box; Smith-Root, Vancouver, Washington; AUA-6 Anode Array). Sampling on the Boise and Payette rivers was conducted using two rafts outfitted with the same electrofishing equipment used on the jet-powered boats. Sampling on the Weiser River was conducted using a canoe outfitted with a MLES Infinity Control Box, a transfer box, and two hand-held anodes. Fish were sampled using pulsed direct current at 60 Hz and 25% duty cycle. Power output was standardized to 2,750-3,250 watts (Miranda 2009). Smallmouth Bass were netted using 6.3-mm delta-style, knotless mesh dipnets. Sampling on the Snake and Weiser rivers occurred in a downstream direction moving back and forth across the river channel. On the Boise and Payette rivers, one raft floated downstream near each riverbank. Each 2 rkm reach was divided into four 500 m sub-units to minimize stress on captured fish and provide an in-reach estimate of variance on the catch rate. Electrofishing time (i.e., "current on" effort) was recorded for each 500 m sub-unit except for two of the Payette River reaches when the timer on the electrofishing box malfunctioned and did not record effort. Smallmouth Bass were assigned an identification number and measured to the nearest mm (total length). Weight and dorsal spines were collected from 10 fish per cm length group (Quist et al. 2012). The first and second dorsal spines were removed near the base of the spine, placed in a coin envelope, allowed to dry, and later processed and aged in the laboratory following Koch and Quist (2007). We tagged 826 Smallmouth Bass in the Snake River and major tributaries greater than 260 mm with a T-bar anchor tags between the pterygiophores of the second and third dorsal spines (Dell 1968; Guy et al. 1996). Each tag had a unique identification number on one side and a phone number on the other that allowed anglers to report the capture and (or) harvest of fish to IDFG. An additional 305 Smallmouth Bass captured during angling events were tagged in Brownlee Reservoir. Fish were returned alive to the water near the point of capture. Additionally, data from mark-recapture surveys were used to correct for size-selectivity of electrofishing gear (Beamesderfer and Rieman 1988). Three mark-recapture surveys were performed on the Snake River, one on the Payette River, and one on the Boise River for a total of five mark-recapture surveys. During the mark-recapture surveys, as many fish as possible were marked and later recaptured. A majority of the sampling occurred from May – September 2016; however, one of the Snake River mark-recapture events and the tributary mark-recapture events occurred July – August 2017.

Summarization and analysis

Catch per unit effort (CPUE) was estimated for each reach as the number of Smallmouth Bass captured per hour of electrofishing. Mean CPUE for each of the nine river segments and the three tributaries was then estimated as the mean of the reaches.

Proportional size distribution (PSD) was used to describe length structure:

$$\text{PSD}= \frac{\text{Number of fish} \geq \text{quality length}}{\text{Number of fish} \geq \text{stock length}}$$

where stock length (S) is 180 mm and quality length is 280 mm (Gablehouse 1984; Neumann et al. 2012). We also estimated PSD of preferred- (PSD-P; 350 mm) and memorable-length (PSD-M; 430 mm) Smallmouth Bass. Proportional size distribution index values were estimated for each reach. Mean PSD for each of the nine river segments and the three tributaries was then estimated as the mean of reaches.

Body condition of fish greater than 150 mm was evaluated using relative weight (W_r):

$$W_r = \left(\frac{W}{W_s}\right) \times 100,$$

where W is the weight of the fish and W_s is the length-specific standard weight of the fish (Wege and Anderson 1978; Kolander et al. 1993; Neumann et al. 2012). Unfortunately, weight data were unavailable for the Weiser River, one reach on the Payette, and four reaches on the Snake River due to a malfunctioning scale. Relative weight was reported by standard length category (i.e., substock [150 mm – 179 mm], Stock – Quality [180mm – 279mm], Quality – Preferred [280 mm – 349 mm], Preferred – Memorable [350 mm – 429 mm], Memorable – Trophy [430 mm – 509 mm], and Trophy [≥ 510 mm]) and summarized by segment and tributary.

A von Bertalanffy growth model was fit for Smallmouth Bass for the Snake River and three major tributaries combined:

$$L_t = L_\infty \times (1 - e^{-K(t-t_0)}),$$

where L_t is the length of the fish at time t, L_∞ is the mean maximum length, K is the growth coefficient, and t_0 is the time when the length of the fish would theoretically equal 0 mm (von Bertalanffy 1938; Quist et al. 2012).

The Dahl-Lea method was used to estimate back-calculated lengths-at-ages:

$$L_i = \left(\frac{S_i}{S_c}\right) \times L_c,$$

where L_i is the back-calculated length of the fish when the ith increment was formed, L_c is the length of the fish at the time of capture, S_c is the radius of the spine at the time of capture, and S_i is the radius of the spine at the ith increment (Francis 1990; Quist et al. 2012). Mean back-calculated lengths-at-ages (MBCLA) were reported by year class and summarized by segment and tributary.

Growth was evaluated using Relative Growth Index (RGI):

$$\text{RGI} = \left(\frac{L_t}{L_s}\right) \times 100,$$

where L_t is the observed length at age (t) and L_s is the predicted age-specific standard length (Jackson et al. 2008). Relative growth index values were reported by age and summarized by segment and tributary.

Total annual mortality (A) was estimated using weighted catch curves for age-2 and older fish (Ricker 1975; Smith et al. 2012). Annual angler exploitation was estimated and summarized for the Snake River and tributaries from reports to IDFG's reporting system (Meyer et al. 2012). The Snake River and tributaries were combined as too few fish were reported in the tributaries to provide a reliable estimate of exploitation. Additionally, exploitation was also calculated for Brownlee Reservoir. Estimate of tag loss for Smallmouth Bass (10.5 ± 1.5% in year 1) and reporting rate (54.1%) were provided by Meyer and Schill (2014) and were used in the exploitation estimates.

A principal component analysis (PCA) was performed using the stats package in *program R* (R Core Team 2017). The analysis was used to examine patterns in different river segments and three tributaries based on nine variables (i.e., RGI, CPUE of all fish, CPUE of stock-length fish, CPUE of quality-length fish, CPUE of preferred-length fish, CPUE of memorable-length fish, PSD, PSD-P, and PSD-M). Loadings greater than 0.30 and less than -0.30 were used to describe orientation of points on the plot.

Finally, a Beverton-Holt Yield-Per-Recruit model was used to evaluate the effect of varying management practices (e.g., minimum length limits) on Smallmouth Bass. Simulations were performed using Fisheries Analysis and Modeling Simulator (FAMS; Loftus Consulting, Annapolis, Maryland) assuming a Type II fishery (Ricker 1975). Conditional natural mortality (cm) was set at 40% given our estimates of A, F, and M. Distribution of exploitation rates varied from 0 – 100%. The current minimum length limit is

305 mm and was used as a baseline for comparison against two other potential increases in the minimum length limit including 356 mm and 406 mm. Three hundred and fifty-six millimeters was used to compare to Smallmouth Bass regulations in a section of the Snake River upstream of the study area that is managed with a 356 mm minimum length limit. Therefore, we evaluated the potential effects of a 356 mm minimum length limit on fish in our study. We also considered an even more restrictive minimum length limit (406 mm) that has been discussed among managers in Idaho. The slope and intercept of a $\log_{10}$ transformed regression of fish weight on fish length was used the length-weight relationship (Table 2.1). Maximum age was set at 9 years, the oldest estimated age from our population. A logarithmic fecundity-length relationship was obtained from the literature (Kilambi et al. 1977). Constant recruitment (1,000 individuals/year) was simulated under the assumption that all age-3 and older Smallmouth Bass were mature, 50% of the population was female, and 100% of females reproduced every year. In the simulations, we evaluated the abundance of fish in the popultion at 356 mm, 406 mm, and 456 mm under varying exploitation. Additionally, we evaluated how total yield (kg) was affected by varying exploitation. Finally, we evaluated the potential for recruitment overfishing by plotting spawning potential ratio (SPR) against exploitation (Goodyear 1993):

$$\text{SPR} = [100\ (P_{exploited} \,/\, P_{unexploited})]$$

where P is the lifetime egg production of a cohort of recruits. Potential of overharvest was set at a SPR of 20% (Goodyear 1993).

Results

A total of 4,929 Smallmouth Bass was sampled during electrofishing surveys on the Snake River and three major tributaries. In the Snake River, CPUE varied from 15.3 – 83.1 fish/hour among segments and was highest in segment 1 and lowest in segment 5 (Figure 2.2). When all segments on the Snake River were combined, CPUE was 36.6 fish/hour (± SE; ± 4.4). On the tributaries, CPUE varied from 43.6 – 125.0 fish/hour and was the highest (mean ± SE; 125.0 ± 40.1 fish/hour) in the Weiser River. The Weiser River also had the highest CPUE of substock fish. For preferred-length fish, CPUE was low, less than 4.0 fish/hour among all segments and major tributaries. Catch per unit effort of memorable-length fish was also low, less than 2.0 fish/hour among segments and tributaries. No trophy-length fish were encountered during sampling.

Proportional size distribution of Smallmouth Bass varied from 25 – 77 (Figure 2.3) among the segments in the Snake River. Segments 8 and 9 near Brownlee Reservoir and segment 1, just downstream of Swan Falls Dam generally had the lowest PSD values. Length structure in the tributaries was similar to the mainstem Snake River (PSD = 46). In the tributaries, PSD was highest in the Boise River (52), followed by the Payette (44) and Weiser (42) rivers. Proportional size distribution for memorable-length fish was highest is segment 9 (9) and in the Payette River (11).

Relative weight of all fish in the Snake River and tributaries varied from 86 – 107 indicating that fish were in relatively good body condition (Figure 2.4). In general, body condition appeared to decline from upstream (near Swan Falls Dam) to downstream (near Brownlee Reservoir). Additionally, longer fish tended to be in poorer condition than shorter fish. In the tributaries, average W_r for all fish was near 100 and most similar to the upper and middle segments (i.e., segments 1 – 7) of the Snake River. Similar to the mainstem Snake River, body condition of Smallmouth Bass in tributaries declined with increasing length, but the pattern was not consistent.

Age was estimated for 1,869 fish sampled from the Snake River (*n* = 1,433) and three major tributaries (*n* = 436). Growth was similar among segments in the Snake River (Table 2.2). In all nine segments, RGI was greater than 100 for age-1, age-2, and age-3 fish indicating fast growth. For the remaining age classes, (i.e., age 4 – age 9) RGI was greater than 100 in eight of nine segments and was never less than 89 for any age class. When all nine segments in the Snake River were combined, RGI was greater than or equal to 106 for all ages. Growth rates were similar among the tributaries, but were slower than the Snake River. Relative growth index values were typically near or greater than 100 for all three tributaries and never below 94 for any age class.

Estimates of total annual mortality varied from 37.3% - 60.2% among the nine segments of the Snake River (Figure 2.5). Segment 5 had the lowest estimate of total annual mortality (37.3 ± 2.8%) and segment 8 had the highest (60.2 ± 4.5%). When data from all nine segments were combined, mortality was 44.5% (± 0.7%). In general, total annual mortality was lower in the tributaries than in the Snake River and varied from 36.8% to 40.5%. The Boise River had the lowest estimate of mortality (36.8 ± 2.2%) and the Weiser River had the highest (40.3 ± 5.3%). Estimated exploitation was 5.3% (90% CI; 2.2%) for the Snake River and its tributaries, and stimated use (i.e., caught, but not harvested) was 14.9% (4.3%). In Brownlee Reservoir, estimated exploitation was 16.2% (6.3%) and estimated use was 39.2% (10.9%).

The first two principal component axes explained 57.2% of the variation. Catch per unit effort of quality-length fish (loading = -0.48), CPUE of preferred-length fish (-0.52), PSD (-0.37), and PSD-P (-0.38) were highly loaded on the first axis. Catch per unit effort of all fish (-0.39), CPUE of stock-length fish (-0.52), CPUE of memorable-length fish (0.34), and PSD-M (0.42) were highly loaded on the second axis. Although values varied among segments and tributaries, several patterns were evident (Figure 2.6). Specifically, reaches in segment 1 differed from the other segments and were characterized by high CPUE and high CPUE of stock-length fish. Reaches in segments 8 and 9 were similar to reaches in the Weiser River with low CPUE of preferred- and memorable-length fish, low PSD, and low PSD-P. Reaches in the remaining segments and tributaries were not strongly related with the various mean CPUEs or PSDs.

The number of simulated fish available at the different lengths of interest (i.e., 356 mm, 406 mm, and 456 mm) varied depending on the minimum length limits and exploitation rates. Among all three lengths of interest, the number of fish in the population decreased as exploitation increased (Figure 2.7). At low rates of exploitation (i.e., 4%) the difference in the number of fish available at different lengths was negligible (+ 5.7%). However, when exploitation was increased to 20% and the minimum length limit was increased from 305 mm to 356 mm, the result was a 40% increase in the number of fish available at both 356 mm and 406 mm. A lower minimum length limit (e.g., 305 mm verses 356 mm) resulted in higher yield per recruit at all levels of exploitation (Figure 2.8). For example, at a low rate of exploitation (i.e., 4%), an increased minimum length limit from 305 mm to 356 mm resulted in 29.8% reduction in the number of fish available for harvest. Increasing the minimum length limit from 305 mm to 406 mm resulted in a 60.8% decrease in the biomass of fish available for harvest. Spawning potential ratio never fell below 20% with any of the three lengths limits (Figure 2.9). Even at a high rate of exploitation (i.e., 53%) SPR was 49.1% for the current 305 mm minimum length limit, suggesting recruitment overfishing is unlikely a concern.

Discussion

Indices such as CPUE, PSD, W_r, and RGI can provide managers with meaningful insight on different aspects of fish population dynamics and are commonly used by fisheries managers as a means to describe, monitor, and manage a fishery (Bonds and Zee 2010). However, managers are cautioned not to base decisions solely on the calculations of a single index, but should instead view an index such as CPUE in relation to other indices (e.g., W_r, RGI, PSD). We observed several interesting patterns across a large portion of the study area. Trends in CPUE were similar between the current study and a study conducted by IDFG in 2006 on the same stretch of river. In 2006, CPUE varied from 1.2 – 95.9 fish/hour (Kozfkay et al. 2006) and in the current study CPUE varied from 15.4 – 83.1 fish/hour. The variability of CPUE among the segments is likely attributed to varying habitat conditions. The river in segment 1 is characterized by deep pools, clear water, and rocky substrate. In downstream segments, irrigation return flows increases turbidity of the river. Additionally, the river transitions from rocky substrate to a substrate dominated by sand and silt. Multiple studies indicate that Smallmouth Bass are more abundant in areas with rocky substrate than fine substrates (Coble 1975; Hubert and Lackey 1980; Probst et al. 1984; Dauwalter 2007).

Similar to catch rates, size structure of Smallmouth Bass (i.e., PSD) was highly variable among segments. In 2006, IDFG reported that the PSD of Smallmouth Bass in all segments combined was 39 (Kozfkay et al. 2006). We estimated a similar PSD (46) for all nine segments in the Snake River. A 2005 study conducted by IDFG on a different portion of the Snake River approximately 340 rkm upstream of the study area also calculated PSD for Smallmouth Bass (Teuscher and Scully 2005). In this portion of the Snake River, PSD varied from 29 – 55. Research from a study in the native distribution of Smallmouth Bass has also described similar variability in PSD vales in and among populations (Jansen et al. 2008). Variability in PSD values can be attributed to various factors such as fishing regulations and habitat conditions (Green et al.1995; Beamesderfer and North 1995; Teuscher and Scully 2005). With low exploitation occurring in the study area, it is likely that the variability in size structure is a result of habitat characteristics rather than harvest regulations.

Body condition of fish (i.e., W_r) can vary in and among systems and among seasons (Orth et al. 1983; Austen and Orth 1988). Body condition of Smallmouth Bass in the current study appeared to be good with W_r values of Smallmouth Bass in the Snake, Boise, and Payette rivers at or near 100. However, as length structure increased, body condition tended to decrease. A similar trend was documented by IDFG in 2006 in the same system (Kozfkay et al. 2006). The decrease in W_r is difficult to explain. However, several potential explanations exist. Savino and Stein (1982) reported that as structural complexity in aquatic systems increased, the ability of Largemouth Bass *Micropterus salmoides* larger than 300 mm to capture prey was limited. Eurasian watermilfoil *Myriophyllum spicatum*, an invasive aquatic plant, is present in Snake River and forms thick stands in many places. The stands could limit the visibility of predatory fishes such as Smallmouth Bass which could reduce feeding ability. Low prey abundance could also potentially explain the lower relative weights of Smallmouth Bass as length structure increases. Wege and Anderson (1978) reported that low prey biomass was significantly correlated with mean relative weight of 200 – 300 mm Largemouth Bass and resulted in low mean relative weights. However, to better understand the causes of the low reported W_r of larger fish in the current study, more information is needed.

Smallmouth Bass exhibited moderate to fast growth in the Snake, Boise, Payette and Weiser rivers. In 2005, IDFG calculated a mean length at age for Smallmouth Bass in the Snake River in southeast Idaho (Teuscher and Scully 2005). The mean length at age estimates were similar to the MBCLA for the current study. When comparing growth rates of Smallmouth Bass from the current study to a study in the Red River, Wisconsin, (Paragamian and Coble 1975) MBCLA of Smallmouth Bass were also similar. Conversely, a study in Coeur d' Alene Lake located in northern Idaho, described slow Smallmouth Bass growth rates where fish typically reached 305 mm at age 7 (Walrath et at. 2013). Slow growth has also been described in other systems. For example, 305 mm was not attained by a Smallmouth Bass population in Massachusetts until age 6. Smallmouth Bass in the current study typically reached 305 mm by age 4.

Total annual mortality varied considerably (i.e., 36.8% – 60.2%) among the segments in the Snake River and the three major tributaries. Variability in mortality rates for riverine Smallmouth Bass populations can often be explained by variation in environmental conditions (e.g., food availability; Austen and Orth 1988) or harvest rates (Coble 1975, Paragamian 1984; Teuscher and Scully 2005). For example, mortality rates of Smallmouth Bass in southeast Idaho varied among fish sampled in two sections of the Snake River with mortality rates being higher in one section (48%) than the other section (32%; Teuscher and Scully 2005). In this case, the higher mortality rates were believed to be a result of exploitation. In the current study, exploitation was low. Of the 827 tags released, only 22 were reported as harvested, providing an exploitation estimate of 5.3% (90% CI; 2.2%). Therefore, variable mortality calculations in the current study were not attributed to exploitation and are more likely a function of varying environmental conditions. Furthermore, the initial concerns expressed by anglers and IDFG staff about the harvest of Smallmouth Bass from the lower reaches of the Payette and Weiser rivers prior to and during spawning season appear to be unfounded based on low exploitation (5.3%). Harvest of pre-spawn and spawning Smallmouth Bass may occur, but any effect at the population level is likely minimal.

Although we have described Smallmouth Bass population structure and patterns in the Snake River, understanding how the various metrics are related is important. The PCA provided an integrated analysis that allowed us to examine patterns in the Smallmouth Bass population. In the current study, segment 1 was not grouped with any other segment or tributary. Segment 1 is located near the tailwater of Swan Falls Dam and is dominated by an abundance of deep pools (> 2 m) and rocky substrate. Smallmouth Bass have been documented to show preference for such conditions (Coble 1975; Hubert and Lackey 1980; Probst et al. 1984; Dauwalter 2007). Deep pools and rocky substrate are not as common in the other segments of the river. Additionally, habitat in other segments of the river is more degraded due to agricultural inputs to the system through irrigation return flows. Segments 2 – 7, along with the Boise and Payette rivers, formed the second grouping. This section of the study area is shallower and more turbid than segment 1. Lack of preferred habitat could potentially explain the weak orientation of these segments in the analysis. Segments 8, 9, and the Weiser River formed the third grouping. This portion of the river is similar to the section of river described by the second grouping of segments, but likely experiences some influence from Brownlee Reservoir. Low capture rates of larger fish and poor size structure are common in this portion of the river. However, causes for these results are not obvious. In addition to describing Smallmouth Bass population structure and ecology in the Snake River, we also sought to describe harvest scenarios for Smallmouth Bass.

Estimated exploitation suggests that harvest is unlikely an issue in the fishery and that a change in regulations would have little influence on the population. At a low rate of exploitation (< 6%), changes in the minimum length limit have little effect on the number of fish available at the 356 mm, 406 mm, and 456 mm length intervals. If the minimum length limit were increased from 305 mm to 406 mm, at a higher rate of exploitation (20%), the number of fish available at 406 mm and 456 mm would increase by approximately 50%. Increasing the minimum length limit would also have little effect on yield (kg) at the low exploitation rate (5.4%) observed in the current study. Additionally, the population is unlikely in danger of recruitment overfishing. Goodyear (1993) suggested a fishery could collapse if SPR decreased below 20%. Eeven under current regulations (305 mm minimum length limit) and exceptionally high exploitation (80%), SPR never fell below 20%.

Population metrics from the current study are similar to values reported from other popular Smallmouth Bass populations in Idaho (Teushcer and Scully 2005; Kozfkay et al. 2006). Density, as indexed by CPUE, in the Snake River and three major tribs is generally moderate to high. Also, growth rates (i.e., RGI values) are fast and similar to other southern Idaho populations. However, fish in the population are not long lived as demonstrated by the moderate to higher mortality rates and relatively few fish in the older age classes. Additionally, W_r values indicate that the population as a whole has average body condition. The PSD values indicate that quality-length and longer fish are available for harvest by anglers. Furthermore, catch-and-release is a common practice among anglers in the study area resulting in low exploitation. Therefore, under current conditions, changes in management (e.g., minimum length limit increase or bag limits) in the study area do not seem warranted.

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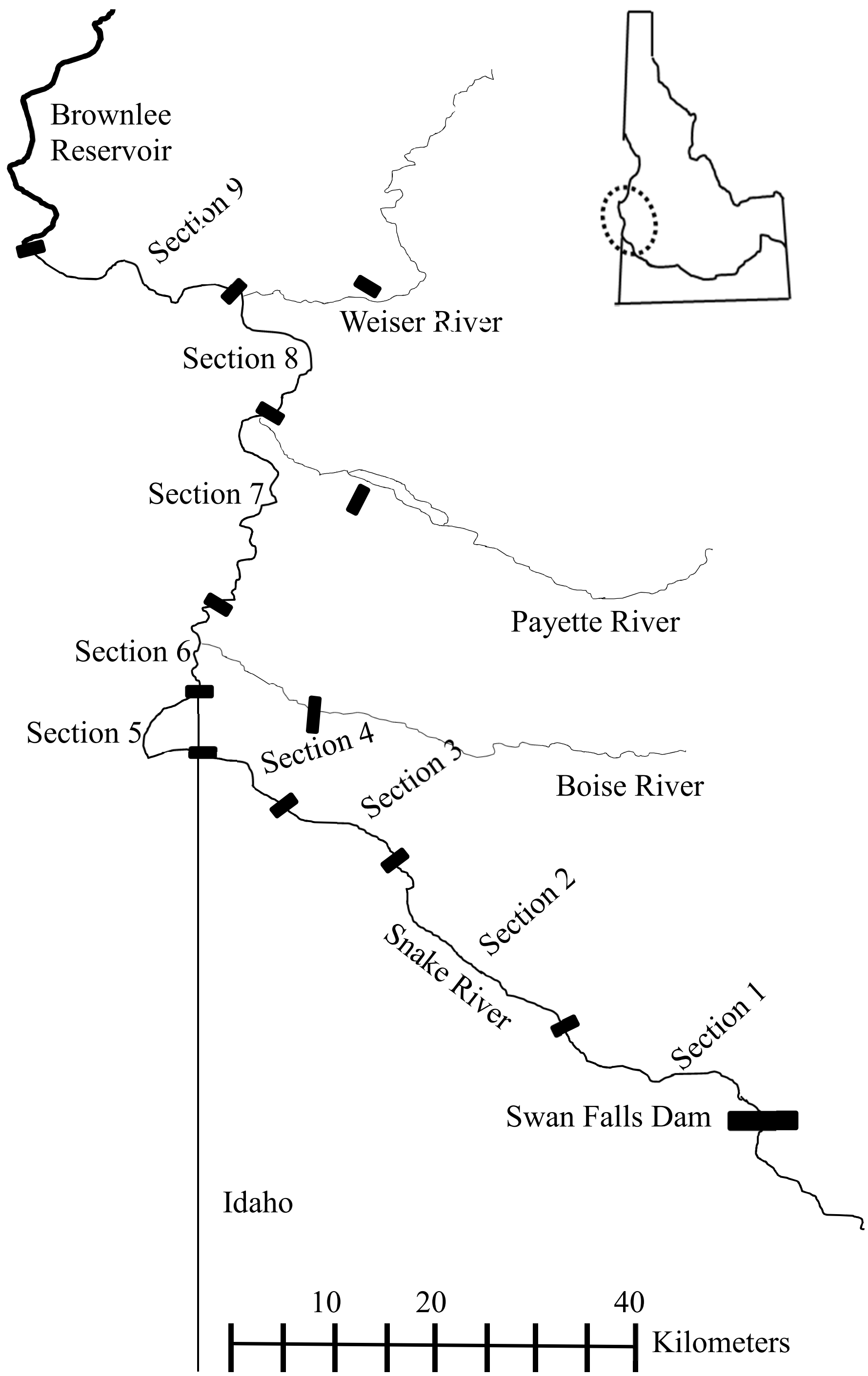


Figure 2.1-Map of the study area between Swan Falls Dam and Brownlee Dam, Idaho. The river flows from south to north. The small black bars indicate segment breaks.

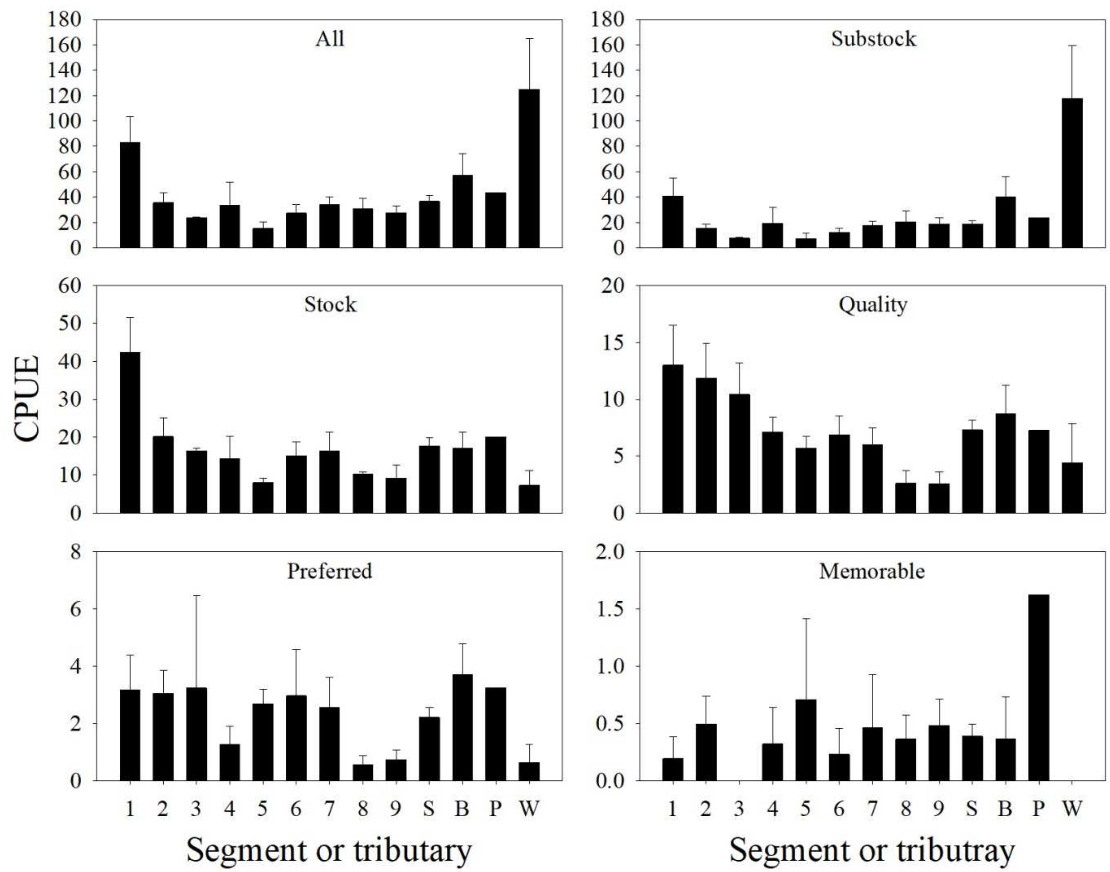


Figure 2.2-Catch per unit effort (CPUE = number of fish/hour of electrofishing) of Smallmouth Bass sampled in 2016 from nine segments in the Snake River, Idaho, all nine segments combined (S), and three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). Catch rates are provided for all fish, substock (<180 mm), stock- (≥ 180 mm), quality- (≥ 280 mm), preferred- (≥ 350 mm), and memorable-length (≥ 430) fish. Error bars represent one standard error (SE).

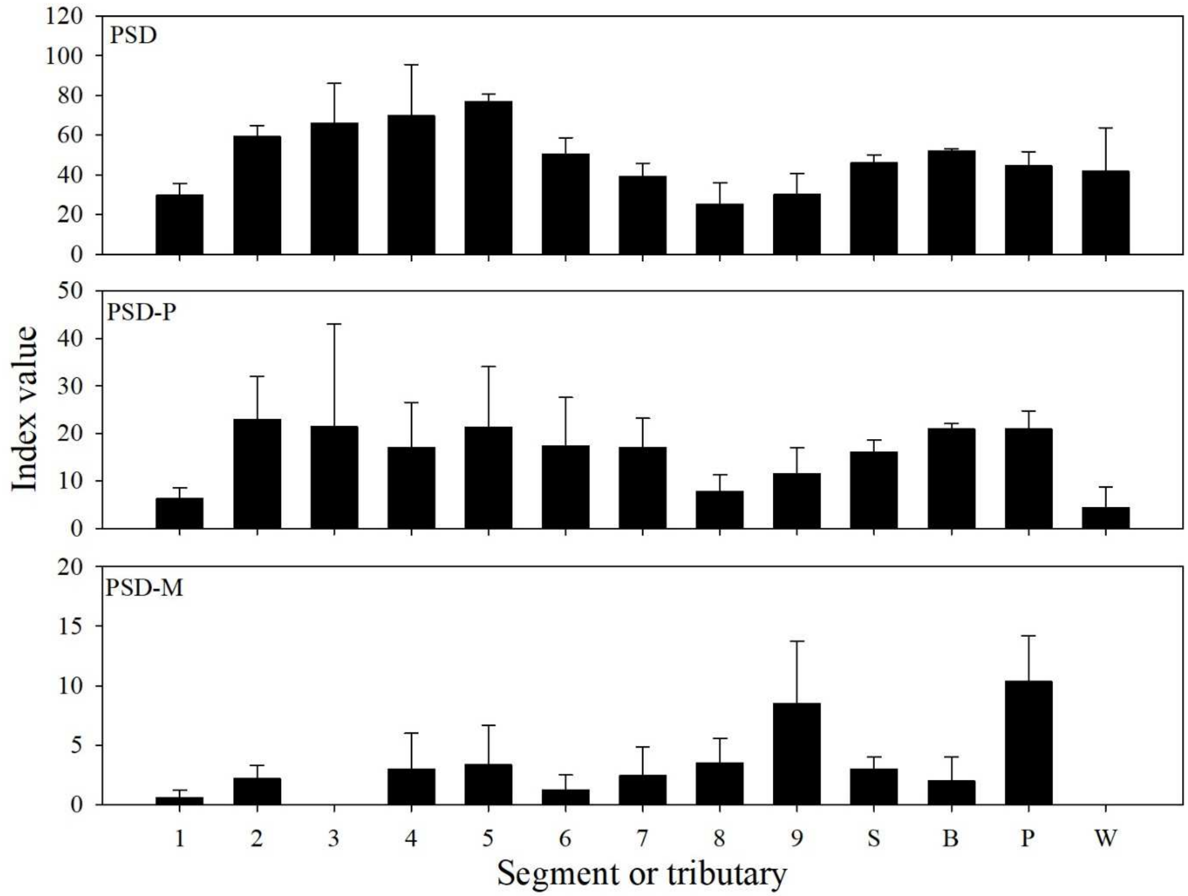


Figure 2.3-Proportional size distribution (PSD) index values of Smallmouth Bass sampled in 2016 from nine segments in the Snake River, Idaho, all nine segments combined (S), and the tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). Additionally, preferred (PSD-P, ≥ 350 mm) and memorable (PSD-M, ≥ 430 mm) values are provided as well. Error bars represent one SE.

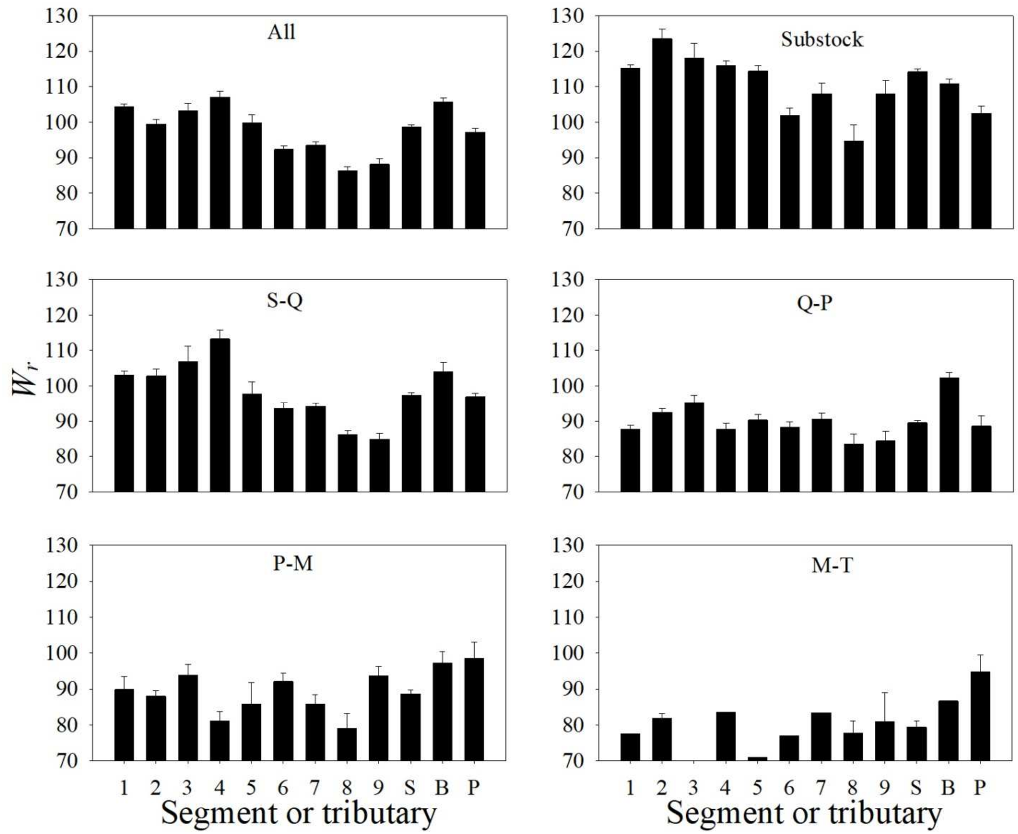


Figure 2.4-Relative weight (W_r) index values of Smallmouth Bass sampled in 2016 from nine segments in the Snake River, Idaho, all nine segments combined (S), and the tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). Index values are provided for all fish, substock (<180 mm), stock – quality (S-Q; 180 – 279 mm), quality – preferred (Q-P; 280 – 349 mm), preferred – memorable (P-M; 350 – 429 mm), and memorable – trophy (M-T; 430 – 509 mm) length fish. Error bars represent one SE.

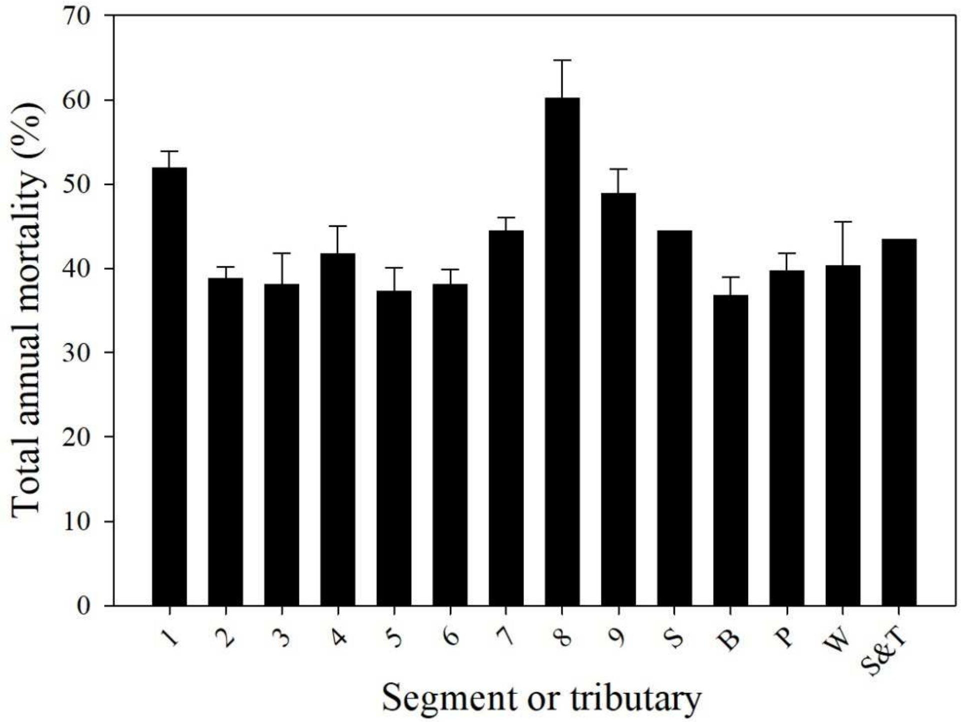
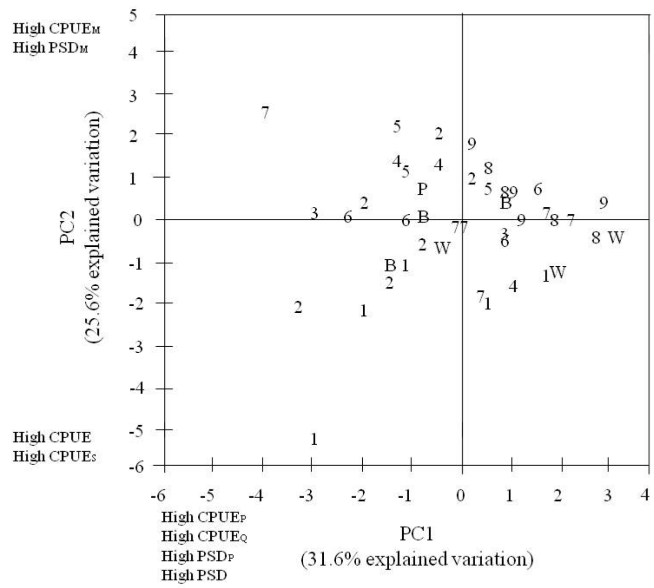


Figure 2.5-Total annual mortality (A) estimates for Smallmouth Bass sampled in 2016 from the nine segments in the Snake River, Idaho, all nine segments combined (S), and the tributaries (T; Boise [B], Payette [P], and Weiser [W] rivers). Numbers in parenthesis are one SE.



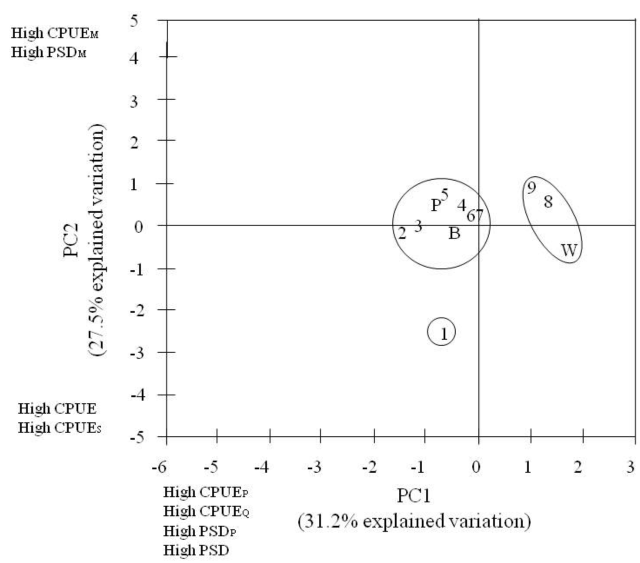


Figure 2.6-Principal components analysis of the nine segments of the Snake River and tributaries (Boise [B], Payette [P], and Weiser [W] rivers). Principal component (PC) scores represent RGI values, CPUE of all fish (fish/hour), CPUE of stock-length fish (≥ 180 mm), CPUE of quality-length fish (≥ 280 mm), CPUE of preferred-length fish (≥ 350 mm), CPUE of memorable-length fish (≥ 430 mm), PSD, PSD-P (≥ 350 mm), and PSD-M (≥ 430 mm) values.

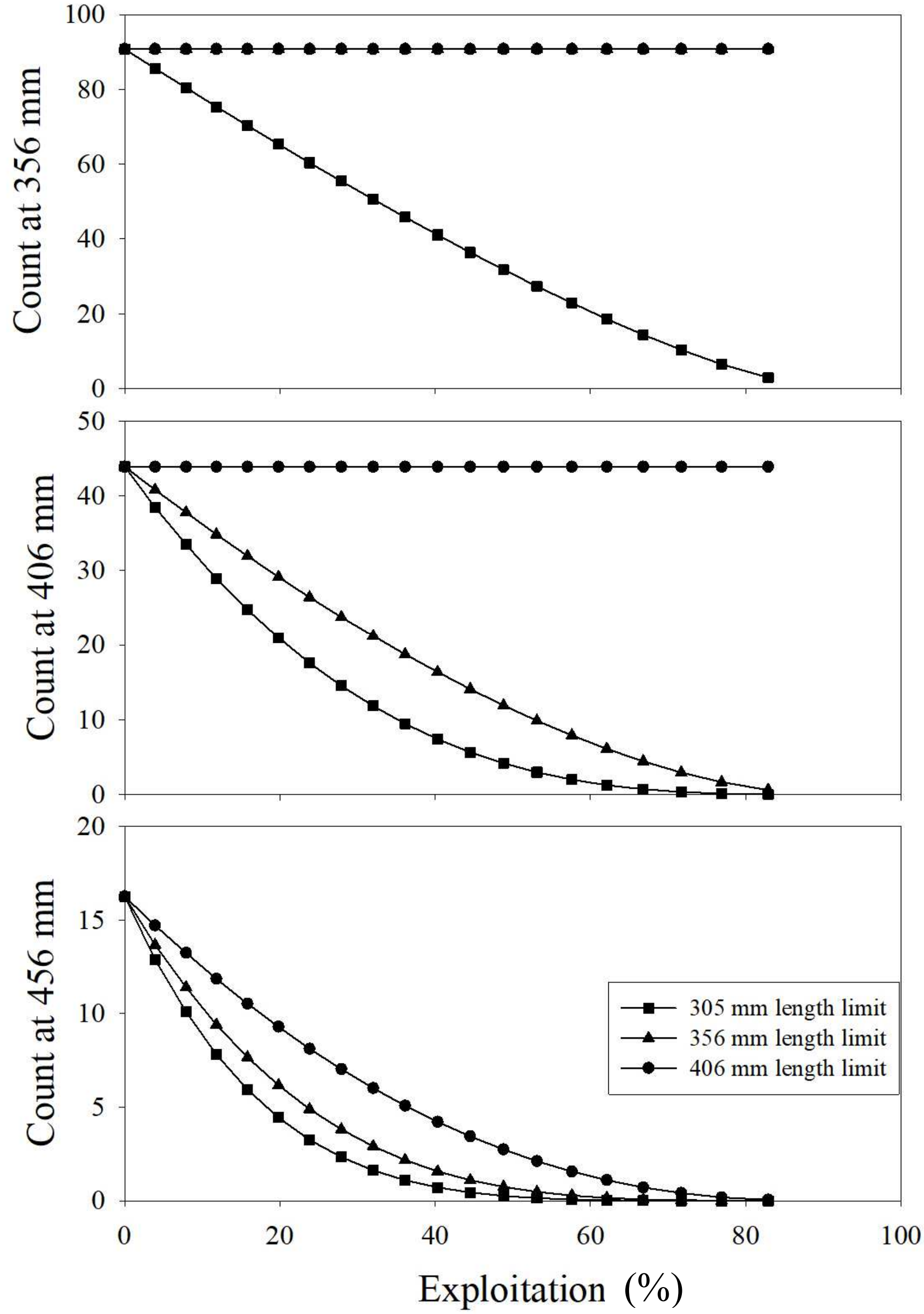


Figure 2.7-Simulated response to the number of Smallmouth Bass available at three minimum length limits (305 mm, 356 mm, and 406 mm) in the Snake, Boise, Payette, and Weiser rivers. Conditional natural mortality (*cm*) was set at 0.40.

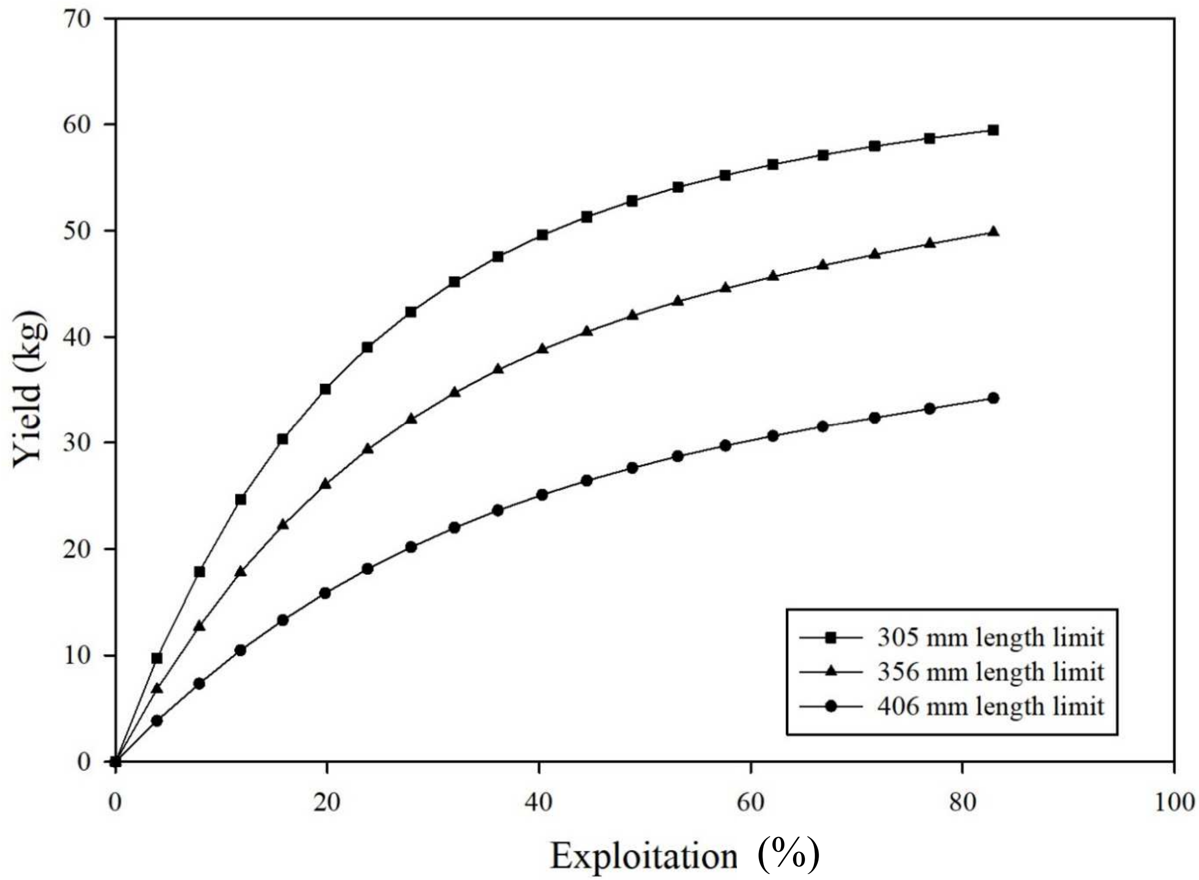


Figure 2.8-Simulated yield for Smallmouth Bass in the Snake, Boise, Payette, and Weiser rivers with conditional mortality set at 40%. The simulations were conducted for three minimum length limits: 305 mm, 356 mm, 406 mm.

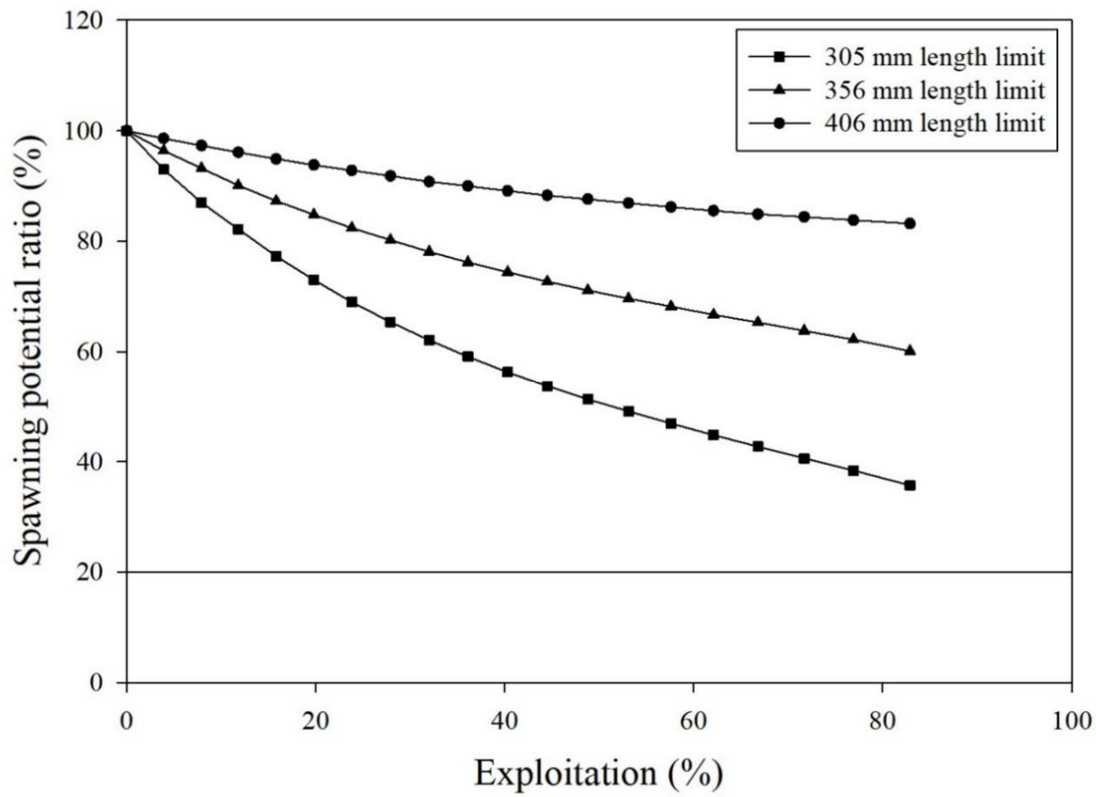


Figure 2.9-Simulated spawning potential ratio for Smallmouth Bass in the Snake, Boise, Payette, and Weiser rivers with conditional mortality set at 40%. The simulations were conducted for three minimum length limits: 305 mm, 356 mm, 406 mm. The bar at 0.2 represents the threshold for recruitment overfishing.

Table 2.1-Parameter estimatees used in population simulations of Smallmouth Bass from the Snake, Boise, Payette, and Weiser rivers combined. The numbers in parentheses are one SE.

Variable	Description	Rivers: Snake River and tributaries combined
b	The y-intercept of the regression line of weight on length*	-4.612
m	Slope of the regression line of weight on length*	2.893
L_{∞}	Theoretical maximum mean length (mm)	570 (13.28)
K	Growth coefficient (rate at which fish approach L_{∞})	0.187 (0.00)
t_0	Time when length theoretically equals 0 (years)	-0.542 (0.02)
Age_{max}	Maximum age of fish in the sample (years)	9
log F	Fecundity-length relationship	1.77 log L - 0.7285

Table 2.2-Mean back-calculated length at age (mm) for Smallmouth Bass sampled in 2016 from nine segments in the Snake River (S) and the tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). The first number in parentheses represent one SE and the second number represents RGI. The * indicates that there was one fish in the sample.

		Mean back-calculated length at age								
River segment	(*n*)	1	2	3	4	5	6	7	8	9
1	317	109.3	186.2	252.0	297.8	321.6	350.6	381.0	370.1*	
		(1.3, 129)	(2.4, 115)	(2.8, 107)	(6.1, 124)	(9.9, 99)	(11.9, 97)	(28.8, 103)	(89)	
2	243	118.1	202.8	274.4	316.4	362.1	397.7	443.9	474*	
		(1.5, 136)	(2.9, 119)	(3.0, 117)	(5.0, 108)	(7.5, 111)	(6.7, 106)	(13.0, 112)	(114)	
3	38	114.1	203.7	281.7	332.0	369.2	425.0*			
		(3.3, 140)	(5.7, 129)	(5.8, 121)	(11.7, 117)	(11.8, 114)	(115)			
4	80	114.6	210.9	281.9	325.9	364.3	379.9	431.0*		
		(2.2, 135)	(5.4, 126)	(5.1, 120)	(7.3, 111)	(12.3, 113)	(29.9, 95)	(109)		
5	46	106.7	198.8	284.1	331.0	363.1	381.4	398.1*		
		(2.5, 121)	(6.8, 103)	(4.1, 120)	(9.3, 116)	(11.9, 115)	(15.4, 105)	(101)		
6	122	109.5	205.3	276.8	324.7	370.6	400.5	399.6	421*	
		(2.0, 129)	(3.4, 121)	(4.4, 117)	(6.9, 110)	(9.7, 111)	(13.9, 115)	(3.6, 100)	(101)	
7	273	107.2	201.2	259.0	315.9	364.0	401.5	433.0		
		(1.1, 121)	(1.8, 119)	(3.2, 108)	(4.3, 106)	(7.7, 109)	(13.3)	(22.9, 110)		
8	141	103.6	197.2	263.1	324.5	403.3	453.8	456.8*	478*	
		(2.1, 112)	(3.7, 116)	(5.5, 110)	(10.2, 113)	(25.8, 115)	(23.2, 111)		(115)	
9	180	101.0	184.9	238.3	284.3	345.9	382.5	430.8	458.9	478.1*
		(1.6, 112)	(4.2, 112)	(6.8, 102)	(13.8, 95)	(20.7, 109)	(16.4, 99)	(14.6)	(11.1, 113)	(110)
S	1440	109.2	197.2	264.3	313.5	359.9	392.5	422.1	443.5	478*
		(0.6, 125)	(1.2, 117)	(1.5, 112)	(2.6, 122)	(4.0, 109)	(5.4, 109)	(8.9, 107)	(17.1, 106)	(110)
B	161	93.6	184.8	252.2	317.4	360.4	396.0	412.5	438.2	481.9*
		(2.1, 98)	(5.8, 102)	(7.7, 99)	(11.2, 105)	(15.3, 107)	(20.9,109)	(23.4)	(26.2, 99)	(111)
P	159	89.5	179.7	247.6	301.7	336.9	406.2	425.7	446.4	465.7
		(1.8, 97)	(4.3, 105)	(7.1, 106)	(11.8, 94)	(12.8, 116)	(11.6, 111)	(13.8)	(9.9)	(7.4, 108)
W	71	91.3	183.7	240.3	292.2	324.7				
		(2.8, 98)	(11.0, 123)	(11.7, 102)	(29.4, 100)	(49.5, 97)				

Chapter 3: Movement of Smallmouth Bass in the Snake River, Idaho

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Abstract

The Snake River, Idaho, between Swan Falls and Brownlee dams supports a popular fishery for Smallmouth Bass *Micropterus dolomieu*. Recently, anglers expressed concern about the harvest of Smallmouth Bass associated with spawning congregations in and near the lower reaches of several major tributaries (i.e., Payette and Weiser rivers). Therefore, Idaho Department of Fish and Game (IDFG) staff was interested in evaluating what effect harvest might be having on Smallmouth Bass in the river as well as for fish that might use the downstream reservoir. From March – August in 2016, Smallmouth Bass ≥ 260 mm (n = 1,131) were tagged with t-bar anchor tags to evaluate exploitation and large-scale movement patterns. Movement was estimated from 63 reported tags for which area descriptions provided sufficient detail to confidently assign a recapture location. Extent of fish movement varied among segments and tributaries from 0.0 – 128.0 river kilometers (rkm). Additionally, from March – May, 2017 Smallmouth Bass (≥ 305 mm; n = 149) in the Snake, Boise, Payette, and Weiser rivers and in Brownlee Reservoir were implanted with radio transmitters. Of the 149 Smallmouth Bass released with radio transmitters, 107 were relocated at least once. Additionally, 79.6% of fish with radio transmitters had a maximum extent of movement ≥ 5.0 rkm and 42.6% had a maximum extent of movement ≥ 30.0 rkm. One radio-tagged fish moved 167.0 rkm upstream. Average daily movement of Smallmouth Bass varied among river segments and was greatest in the spring and summer. Fish from the different segments, tributaries, and reservoir moved all over the study area indicating an absence of clear population boundaries. As such, Smallmouth Bass in the study area function more as one

large population as opposed to multiple sub-populations. Thus, the continued management of the Smallmouth Bass fishery in the Snake, Boise, Payette, and Weiser rivers and in Brownlee Reservoir as one population is appropriate.

Introduction

Understanding how fish move in a system is critical for effective management (Larimore 1952; Pine et al. 2012). Knowledge of fish movement allows managers to describe population boundaries, identify changes in the spatial abundance and distribution of fish, and regulate the fishery accordingly. Fishery scientists use a variety of methods to evaluate movement including radiotelemetry, angler reports of tagged fish, and sampling surveys across space and time (Larimore 1952; Fajen 1962; Munther 1970; Langhurst and Schoenike 1990). Such methods can be used to determine various aspects of fish movement including population boundaries, immigration and emigration, habitat preferences, requirements for growth and reproduction, as well as spatial and temporal patterns in movement dynamics (Larimore 1952; Pine et al. 2012).

The Smallmouth Bass *Micropterus dolomieu* is one of the most popular sport fishes in North America. Smallmouth Bass are native to portions of the central and eastern United Sates, but widespread introductions and habitat alterations have led to their expanded distribution (Robbins and MacCrimmon 1974; Schade and Bonar 2005; Stepien et al. 2007; Carey et al. 2011). They can now be found in most states. Additionally, the successful colonization of Smallmouth Bass in many systems can be attributed to their ability to thrive in a variety of habitats in both lentic and lotic systems (Coble 1975).

Smallmouth Bass are known to move regularly through river systems. Seasonal movement patterns of Smallmouth Bass are well documented and vary among systems (Larimore 1952; Fajen 1962; Munther 1970; Todd and Rabeni 1989; Langhurst and Schoenike 1990; Gunderson VanArnum et al. 2004; Rubenson and Olden 2016). Several studies have reported that movement of Smallmouth Bass is restricted to an area of less than 5 km (Larimore 1952; Fajen 1962), whereas other studies have reported more extensive movement (Munther 1970; Todd and Rabeni 1989; Langhurst and Schoenike 1990 and Rubenson and Olden 2016). Movement may occur for a variety of reasons (e.g., spawning, changes to habitat, thermal cues) and result in changes to the spatial abundance and distribution of fish (Fajen 1962; Munther 1970; Montgomery et al. 1980; Todd and Rabeni 1989; Langhurst and Schoenike 1990; Gunderson VanArnum et al. 2004, Rebenson and Olden 2016).

Smallmouth Bass were first reportedly stocked in the western US in the late 1800s and early 1900s (Lampman 1946; Munther 1970; LaVigne et al. 2008). Since that time, their popularity among anglers in the west has increased (Carey et al. 2011). One popular Smallmouth Bass fishery is located on the Snake River, Idaho, between Swan Falls and Brownlee dams (Figure 3.1). Although it has been suggested that Smallmouth Bass have been present in the system since the 1800s (Munther 1970), there has been a dramatic increase in abundance of Smallmouth Bass in the Snake River downstream of Swan Falls Dam since the early 1970s (Kozfkay et al. 2006). Increases in abundance coincided with reservoir development and altered hydrology following completion of the Hells Canyon Dam Complex. Recently, fisheries managers in Idaho have been interested in Smallmouth Bass movement as anglers and IDFG staff in the area have expressed concern about the harvest of Smallmouth

Bass associated with spawning congregations in and near the lower reaches of several major tributaries (i.e., Payette and Weiser rivers). The origin of adult Smallmouth Bass in spawning congregations is unknown, though it is possible they migrate upstream from Brownlee Reservoir. However, this is purely speculative as little is known about the movement of Smallmouth Bass in the study area.

The objectives of this study were to determine (1) the extent of movement of Smallmouth Bass, (2) the seasonal movement of Smallmouth Bass, and (3) whether Smallmouth Bass are moving from Brownlee Reservoir into the Snake River and tributaries. Two methods (i.e., angler reports of tagged fish, radiotelemetry) were used to assess fish movement in the system. Describing movement of Smallmouth Bass in the Snake River and its major tributaries provided information about seasonal changes in the spatial distribution of fish, how and when fish moved in the system, and whether or not sub-populations exited in the study area.

Methods

Study area

The Snake River originates in Yellowstone National Park, Wyoming. It flows south through western Wyoming before turning west and entering Idaho through Palisades Reservoir near the town of Swan Valley, Idaho. Approximately 69 river kilometers (rkm) downstream of Palisades Dam, near the town of Heise, Idaho, the Snake River leaves the mountainous region of eastern Idaho and begins to cross the Snake River Plain as it flows west across the southern portion of the state (Figure 3.1). Near the western edge of Idaho, approximately 13 rkm downstream of the town of Homedale, the river leaves Idaho and enters

Oregon for approximately 16.5 rkm. Following this stretch, the river then serves as the border between Oregon and Idaho until it reaches the Oregon and Washington border to the north. The Snake River then serves as the border between Idaho and Washington until Lewiston, Idaho, when the river turns west and enters Washington where it flows for 217 rkm until its confluence with the Columbia River at Burbank, Washington. The upstream and downstream boundaries of the study area were Swan Falls (rkm 0) and Brownlee dams (274 rkm) respectively (Figure 3.1). The study area also included the lower portions (20 rkm upstream from the confluence with the Snake River) of three major tributaries: Boise, Payette, and Weiser rivers. The Boise River is the most southern of the three tributaries. It contributes 2.4 $\times 10^9$ m^3 of water annually and joins the Snake River at rkm 105. The Payette River joins the Snake River at approximately rkm 148 and lies between the Boise and Weiser rivers. The Payette River contributes 2.7×10^9 m^3 of water annually to the Snake River, the most of the three tributaries. The Weiser River is located the furthest north of the three tributaries, contributes the least amount of water to the system (0.9×10^3 m^3 annual discharge), and joins the Snake River near rkm 171.

We divided the Snake River from Swan Falls to Brownlee dams into six segments (Figure 3.1). Segments were chosen based on potential population boundaries and to capture movement between the reservoir and the tributaries. The segments varied in length from 23 - 78 rkm. Segments 1 – 5 were on the Snake River (rkm 0 – 200). Segment 1 began at Swan Falls Dam and ended at Homedale, Idaho. The upstream portion of segment 1 is characterized by deep pools and rocky substrate. As the river progress downstream, there are fewer deep pools, but the rocky substrate largely remains. In segments 2 – 5, deep pools and rocky substrate are less common. Additionally, agricultural inputs in the form of irrigation return flow increase the turbidity of the water and result in portions of the river bottom being covered by a layer of fine sediment. Segment 6 was considered Brownlee Reservoir. Segment 6 began just downstream of Farewell Bend State Recreation Area, Oregon (rkm 201), and ended at Brownlee Dam (rkm 274). The lower portions (i.e., approximately 20 rkm upstream of the confluences) of the three major tributaries (i.e., Boise, Payette, and Weiser rivers) were also included in the study.

Sampling design

T-bar anchor tags

From March – August in 2016, Smallmouth Bass (n = 1,131) were sampled using electrofishing and angling in the Snake, Boise, Payette, and Weiser rivers and in Brownlee Reservoir (rkm 0 – 274). Total length (mm) and weight (g) were measured for all tagged fish. Smallmouth Bass ≥ 260 mm were tagged with t-bar anchor tags (Dell 1968; Guy et al. 1996) during electrofishing surveys and angling events. Each tag had a unique identification number and a website address on one side. On the other side was a phone number. Anglers could use either the website address or the phone number to report the capture and (or) harvest of Smallmouth Bass to the Idaho Department of Fish and Game (IDFG). Three hundred and five fish were tagged and released in Brownlee Reservoir (rkm 201 – 274). Seven fish were tagged during a night electrofishing event. The other 298 were tagged with the help of local bass clubs during several angling tournaments in March, 2016. Eight hundred and twenty-six tags were released in the Snake River (rkm 0 – 200) and lower portions of the Boise, Payette and Weiser rivers between May – August, 2016, during electrofishing and angling surveys. A global positioning system (GPS) waypoint was used to document the release location of individual fish. Area descriptions from angler reports of recaptured fish (via hook and line) were used to determine distances from the initial tagging location.

Radiotelemetry

Tags were dispersed among the six segments to capture movement of fish throughout the study area (Table 3.1). During multiple electrofishing surveys from March – May, 2017, we sampled 149 Smallmouth Bass in the Snake, Boise, Payette, and Weiser rivers and in Brownlee Reservoir. Captured fish were placed in a holding tank on the boat. Total length (mm) and weight (g) were documented for all tagged fish. Fish were then anesthetized prior to surgery. Fish were implanted with individually coded Lotek Wireless MST-930 radio transmitter tags (4.0 g; Lotek Wireless Fish and Wildlife Monitoring, Newmarket, Ontario) in their peritoneal cavity anterior to the pelvic girdle using a modified version of the technique described by Ross and Kleiner (1982). Radio transmitter tags were programmed to 151.380 MHz with a burst rate of 8 s. Minimum expected battery life of the transmitters was 225 days. Only fish ≥ 305 mm were tagged. Transmitters did not exceed 3.0% of the fish's body weight as suggested by Zale et al. (2005). Prior to implantation, the functionally of all tags was tested. Incisions were closed with 2 – 3 interrupted 3-0 nylon sutures. Following surgery, fish were placed in a holding tank and allowed to recover prior to release. Prior studies have reported low transmitter expulsion and low mortality using similar procedures (Martin et al. 1995; Zale et al. 2005). Following recovery, fish were released near the point of capture and a waypoint was recorded using a GPS unit. Fish were relocated using both fixed receiver stations and mobile techniques (i.e., jet boat or raft).

Lotek model SRX 400, 600, and DL receivers were outfitted with either a fixed or folding three-element directional Yagi antenna. Fixed receivers were installed at six locations along the Snake River (rkm 16, rkm 67, rkm 105 [Boise River confluence], rkm 148 [Payette River confluence], rkm 171 [Weiser River confluence], and rkm 184; Figure 3.1). Mobile tracking took place on the Snake, Boise, Payette, and Weiser rivers by jet boat or raft. Attempts were made to relocate fish twice per month from May – September and once per month from October – February. The entire river, including tributaries were tracked and took ~ 12 – 13 days to complete. The reservoir was not tracked as radio transmitters were ineffective as much of the reservoir is deeper than 10 m. Fish relocations were georeferenced using a GPS unit. Distance of fish movement between relocations was measured using a geographical information system (GIS) and summarized.

Data analysis

Initial release and recapture location data of fish with t-bar anchor tags were imported into ArcMap Gis version 10 (Environmental Systems Research Institute, Redlands, California). Movement was calculated by subtracting the fish's point of relocation (i.e., recapture) from the initial release location (Dobos et al. 2016). Movement was expressed as the total distance between the initial release location and the recapture location. Distances were summarized by the segment where fish were tagged and released.

The initial release location and subsequent relocation data of Smallmouth Bass with radio transmitters were imported into ArcMap GIS version 10. Fish were assigned to the segment where they were tagged and released. Movement was summarized for all fish based on the various extents of movement. Extent of movement was defined as the difference between the farthest upstream and farthest downstream detections of individual fish during the entirety of the study (Langhurst and Schoenike 1990). Daily movement rate was estimated as the total distance moved (upstream or downstream) divided by the number of days between relocations. Downstream movement was expressed by a negative value and upstream movements produced positive values (Dobos et al. 2016). Mean daily movements of Smallmouth Bass were summarized by season (i.e., spring, summer, winter, and fall). Seasons were defined in close alignment with the spring and fall equinox and the summer and winter solstice: March 16 – June 20 (spring), June 21 – September 22 (summer), September 23 – December 21 (fall), and December 22 – February 6 (winter) when tracking ceased.

Results

Of the 1,131 Smallmouth Bass tagged with t-bar anchor tags in 2016, 117 tags were reported by anglers in the following year. Movement information was estimated from 63 reports where the area descriptions provided sufficient detail to confidently assign a recapture location (Table 3.2). Most fish (87.3%) were recaptured in the same segment where they were released. Angler reports also provided managers with information on harvest and use rates. Extent of fish movement varied among segments and tributaries from 0.0 – 128.0 rkm (Figure 3.2). The longest movements of fish with t-bar anchor tags occurred for fish tagged and released in segment 6 and the shortest movements occurred for fish released in segment 3 and the Weiser River. The longest movement (128.0 rkm) was by a fish that moved from segment 6 (Brownlee Reservoir) upstream into the Payette River before being captured, but not harvested by an angler in the spring (Table 3.1). Movement information was not estimated for segment 2 as no tags were returned from the segment.

Of the 149 Smallmouth Bass released with radio transmitters, 107 were relocated at least once. Each segment and tributary had a relocation rate of ≥ 60%, except for segment 6 (Figure 3.3). Fish from segment 6 were only relocated if they were captured and reported by an angler or if they moved out of the reservoir. One fish in the study was relocated 109 times, but this fish remained in close proximity to the fixed antenna at the mouth of the Payette River. Extent of movement varied from 0 – 167 rkm among segments and tributaries for fish tagged with radio transmitters (Figures 3.4 and 3.5). Many fish (28.7%) moved less than 10 rkm, but 42.6% moved 30 rkm or more. Similar to fish tagged with t-bar anchor tags, fish released in segment 6 had the greatest maximum extent of movement with four fish moving more than 80 rkm and one fish moving 167.0 rkm upstream (Figure 3.5). Interestingly, a fish from segment 1 moved downstream more than 115 rkm to segment 5. Median movement in the Snake River varied from 13 – 38 rkm. Fish from segment 6 had the highest median movement. For fish tagged in the tributaries, median movement varied from 10 – 17 rkm. The lowest median movement among the tributaries occurred in the Payette River and the highest occurred in the Weiser River. Fish tagged in all three tributaries (Boise, Payette, and Weiser rivers) had small maximum extents of movement (< 40 rkm) when compared to fish from the five segments of the Snake River and segment 6. Additionally, 59% of fish tagged and released in the tributaries eventually moved into the Snake River.

Average daily movement of Smallmouth Bass varied among river segments and seasons (Figure 3.6). Fish from segments 5 and 6 also had higher daily movement rates when compared with the other segments and tributaries. In the spring, average daily movement indicated that fish from segments 1 – 3 generally moved downstream (Figure 3.6). In contrast, fish from segments 4 – 6 generally moved upstream. Movement continued in summer and fish in segments 3 and 4 generally moved upstream. Furthermore, movements over 4.4 rkm/day were recorded for several fish in segments 4 and 5. In the fall, movement rates were relatively low with several exceptions. Several longer daily movements were recorded for fish initially released in segments 1, 2, and 6. Fish tagged in segment 6 that had entered the Snake River also appeared to move downstream toward the reservoir. By winter, little daily movement upstream or downstream was recorded. Additionally, many of the tags failed by winter and only 16 detections were recorded during that time period.

Discussion

Movement of Smallmouth Bass has been extensively studied and shown to be highly variable among systems (Larimore 1952; Munther 1970; Todd and Rabeni 1989; Langhurst and Schoenike 1990; VanArnum et al. 2004; Rubenson and Olden 2016). Migratory behavior of Smallmouth Bass suggests that fish may leave their "home area" of a river for a variety of reasons, including movement to spawning areas (VanArnum et al. 2004), or to areas of thermal refuge (Munther 1970; Langhurst and Schoenike 1990), or for reasons not completely understood (Fajen 1962; Todd and Rabeni 1989), and then later return to their home area. VanArnum et al. (2004) reported on the seasonal movements of Smallmouth Bass in several Kentucky rivers and found evidence of discrete summer and winter locations, as well as spawning areas. Additionally, the authors documented homing behavior of Smallmouth Bass where 4 of 15 displaced Smallmouth Bass returned to the original site of capture. In the Snake River, Idaho, downstream of the current study area near the confluence with the Salmon River, Munther (1970) reported movement of Smallmouth Bass to deep pools ($\geq$ 2.3 m) in late fall, likely in preparation of winter. We did not evaluate fine-scale movement patterns in our study, but the extent of movement of Smallmouth Bass from both the t-bar anchor tags and radio transmitter tags indicated that some fish in the current study exhibited sedentary behavior for a portion of the year. In contrast, the long-distance movements more than 100 rkm by some Smallmouth Bass in the study demonstrates that a component of the population is highly mobile. The reasons for migratory or seasonal movement of fish (e.g., spawning, thermal refuge) are likely similar to those previously identified for Smallmouth Bass in other areas of their distribution (Munther 1970; Langhurst and Schoenike 1990; VanArnum et al. 2004). The extent of movement of Smallmouth Bass in the Snake River can be described further by daily movement patterns.

Several movement patterns were common when evaluating daily movement rates of Smallmouth Bass. Generally, fish moved more on a daily basis in the spring and summer than in the other seasons. Furthermore, fish were observed moving in both upstream and downstream directions. A pattern of greater movement in the spring and summer is likely related to thermal cues and spawning behavior. Previous studies on Smallmouth Bass have observed changes in behavior and movement related to temperature changes and spawning (Graham and Orth 1986; Gunderson VanArnum et al. 2004; Rubenson and Olden 2016). For example, Rebenson and Olden (2016) documented upstream movement of Smallmouth Bass during a 9-week period in the North Fork of the John Day River, Oregon, during which time new nests were documented at locations progressively farther upstream. Smallmouth Bass moved regularly in the Snake River and Brownlee Reservoir, but movement of fish in segments 1 and 2 decreased from spring to summer. The reason for a reduction in movement is unknown. In fall, daily movement rates of Smallmouth Bass were low and movements were generally downstream. Although, most daily movements were small, one fish moved downstream at a rate of 19 rkm/day. Langhurst and Schoenike (1990) also described a downstream movement of 19 rkm in one day by a Smallmouth Bass during fall as the fish moved from the Embarrass River to the Wolf River, Wisconsin. By winter, movement in any direction in the Snake River had essentially ceased. In contrast to the variable seasonal movement of fish in the six segments of the study area, daily movement in the tributaries was minimal.

Overall, fish moved and used a large part of the study area during the year. Although it is possible that there are sedentary portions of the Smallmouth population in the study area, it appears a large part of the population is mobile with near 80% of relocated fish moving ≥ 5 rkm and more than 40% moving 30 rkm or more. Several studies have reported long-distance movements of Smallmouth Bass. Langhurst and Schoenike (1990) recorded a downstream movement of 109 rkm by a Smallmouth Bass from the Embarrass River to Wolf River in Wisconsin. Rubenson and Olden (2016) also reported a movement of 109 rkm by a Smallmouth Bass in the North Fork of the John Day River, Oregon. The 167.0 rkm movement by a Smallmouth Bass in the current study is one of the farthest recorded movements for the species. A small proportion (17.5%) of fish tagged in Brownlee Reservoir were observed moving upstream from the reservoir in the spring and early summer. Of the seven fish that moved upstream from the reservoir, two were relocated at the mouth of the Weiser River and two were relocated in the Payette River. None were located in the Boise River. Additionally, 26.6% (4 of 15) of fish that were tagged in segment 5 near the reservoir were relocated in the Weiser River and 13.3% (2 of 15) were relocated at the mouth of the Payette River in the spring. Of the six fish from segment 5 located in or around tributaries, four were documented returning downstream following their spring movement further suggesting the Weiser and Payette rivers are used by some fish for spawning. These movement pattern are consistent with anecdotal angler observations, as well as previously held ideas by the IDFG, that some Smallmouth Bass move from the reservoir or Snake River into the major tributaries to spawn in the spring.

Throughout this study, fish from different segments and tributaries used all portions of the system and failed to show clear population boundaries. With many fish moving over 40 rkm and some over 100 rkm, it appears Smallmouth Bass in the study area function more as one large population as opposed to multiple sub-populations. Fish movement was greatest in the spring and summer with fish moving upstream and downstream. During fall, fish generally moved downstream and by winter, little fish movement was observed. Additionally, exploitation rates calculated from the t-bar anchor tag study (Chapter 2) were low (5.3%) over an entire year. Furthermore, only four Smallmouth Bass with t-bar anchor tags were harvested in the Payette and Weiser rivers in the spring or summer and one fish was harvested in the Boise River. Thus, harvest of spawning Smallmouth Bass in the tributaries is not likely a management concern. Contrary to preconceived notions, it is likely that Smallmouth Bass that use or reside in the rivers are harvested at a lower rate (5.3%) (90% CI; 2.2%) than Smallmouth Bass that use or reside in the reservoir (16.2%) (90% CI; 6.3%) Based on the findings of the study, continued management of Smallmouth Bass in the study area as one population is warranted, despite the large geographical area. Additionally, further research into the movement and distribution of Smallmouth Bass in western streams and rivers is important as their distribution continues to expand creating a conundrum for fisheries managers. Smallmouth Bass often prey on native fishes such as salmonids (Reiman et al.1991; Tabor et al. 1993). Managers are then tasked with balancing the management of native fishes and introduced populations of Smallmouth Bass simultaneously.

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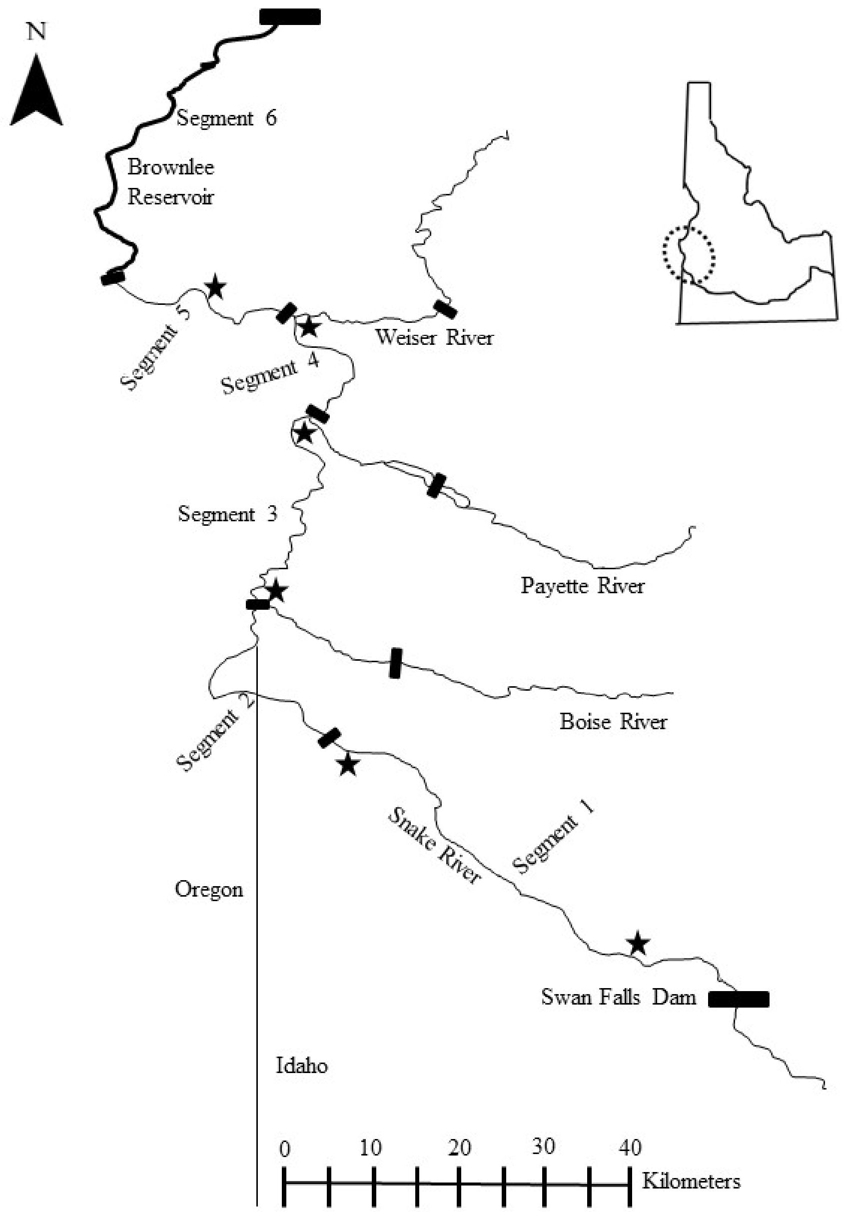

Figure 3.1-Map of the study area between Swan Falls Dam and Brownlee Dam, Idaho. The river flows from south to north. Black boxes indicate segment breaks. Stars indicate fixed receiver sites.

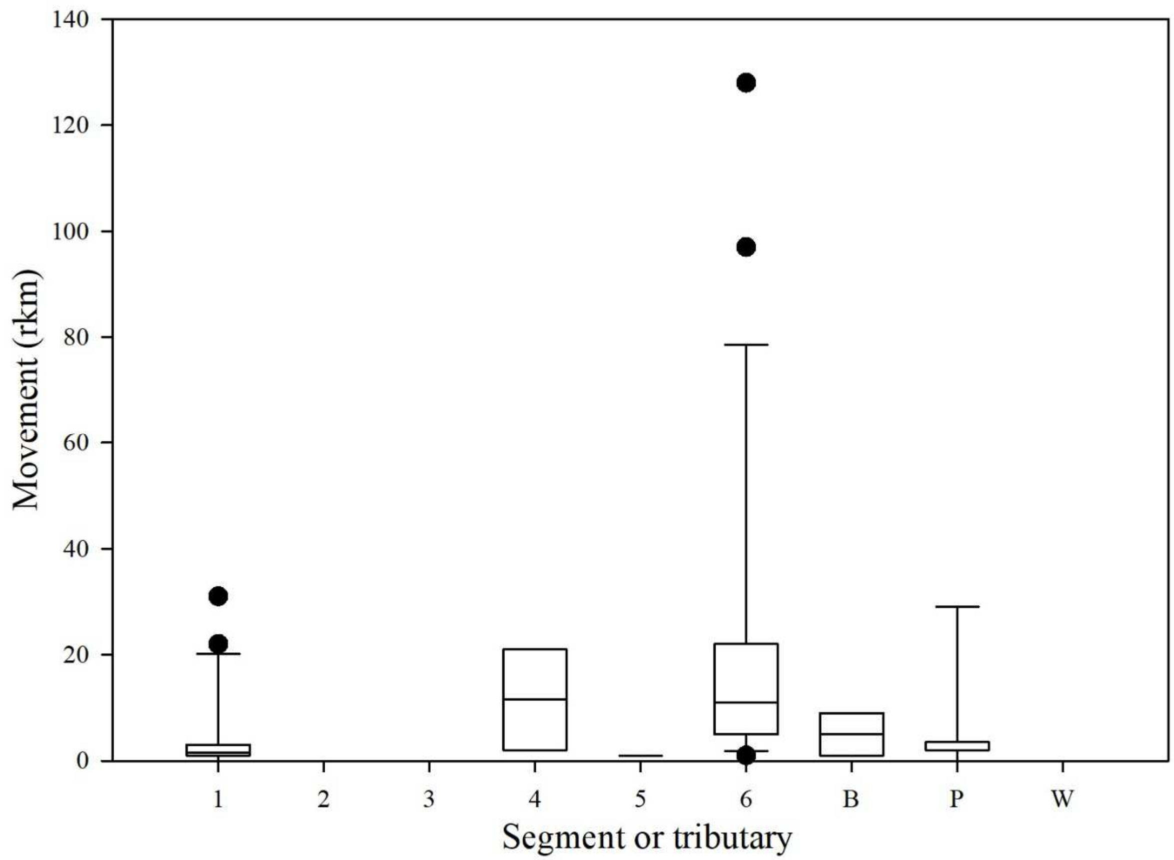

Figure 3.2-Extent of movement (rkm) for Smallmouth Bass sampled and tagged with t-bar anchor tags in 2016 in the Snake River (segments 1 – 5), Brownlee Reservoir(segment 6), and the three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). The segment or tributary indicates where a fish was tagged and released.

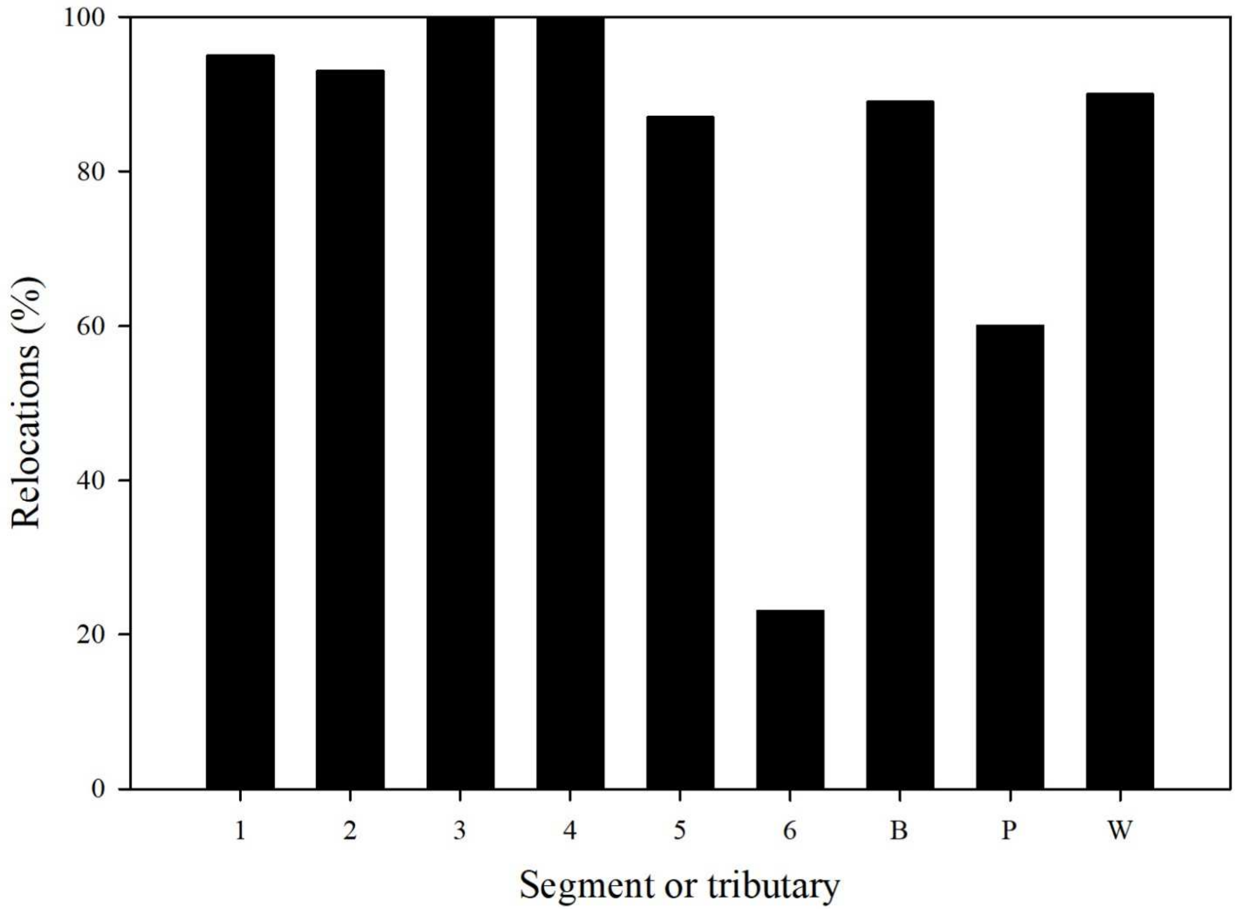

Figure 3.3-Proportion of Smallmouth Bass relocated at least one time during radiotelemetry surveys in 2017 in the Snake River (segments 1 – 5), Brownlee Reservoir (segment 6), and the three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). The segment or tributary indicates where a fish was tagged and released.

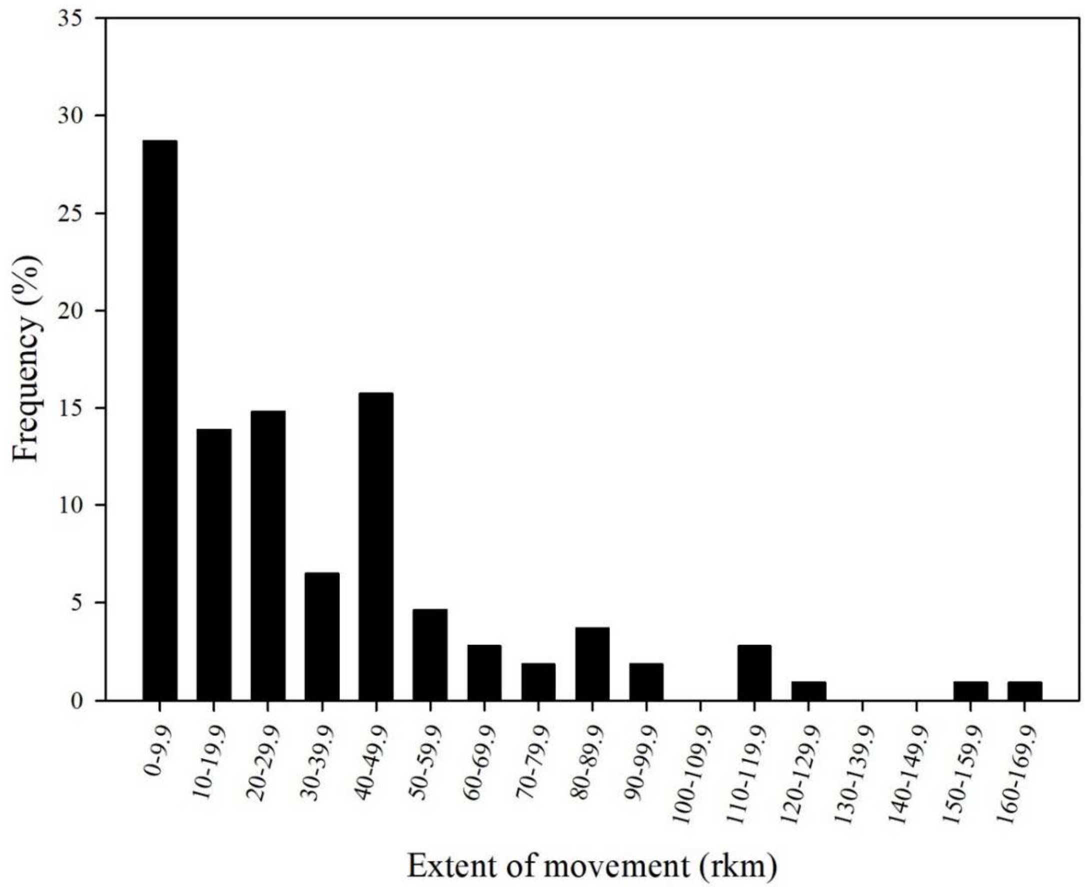

Figure 3.4-Proportional extent of movement (rkm) for all Smallmouth Bass sampled and tagged with radio transmitter tags in 2017 in the Snake River (segments 1 – 5), Brownlee Reservoir (segment 6), and the three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers).

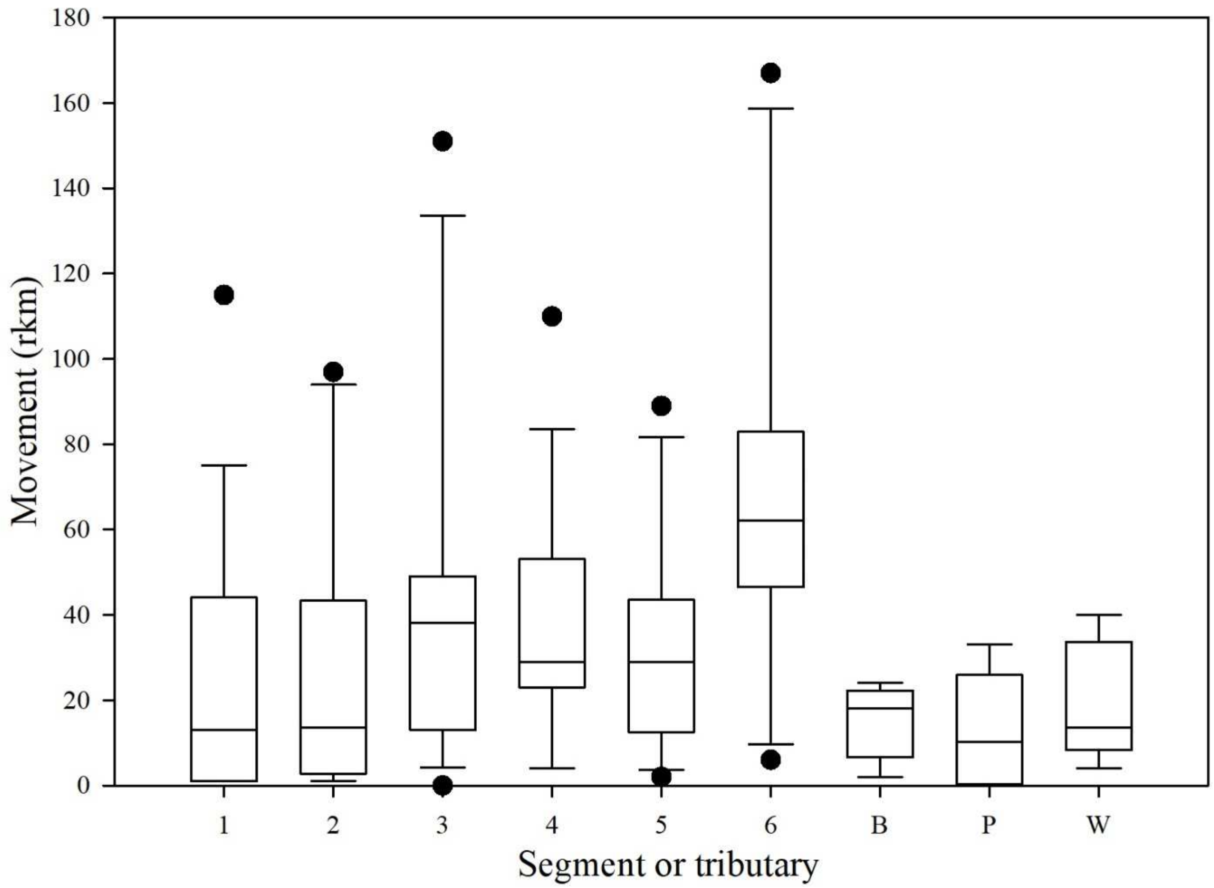

Figure 3.5-Extent of movement (rkm) for Smallmouth Bass sampled and tagged with radio transmitter tags in 2017 in the Snake River (segments 1 – 5), Brownlee Reservoir(segment 6), and the three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). The segment or tributary indicates where a fish was tagged and released.

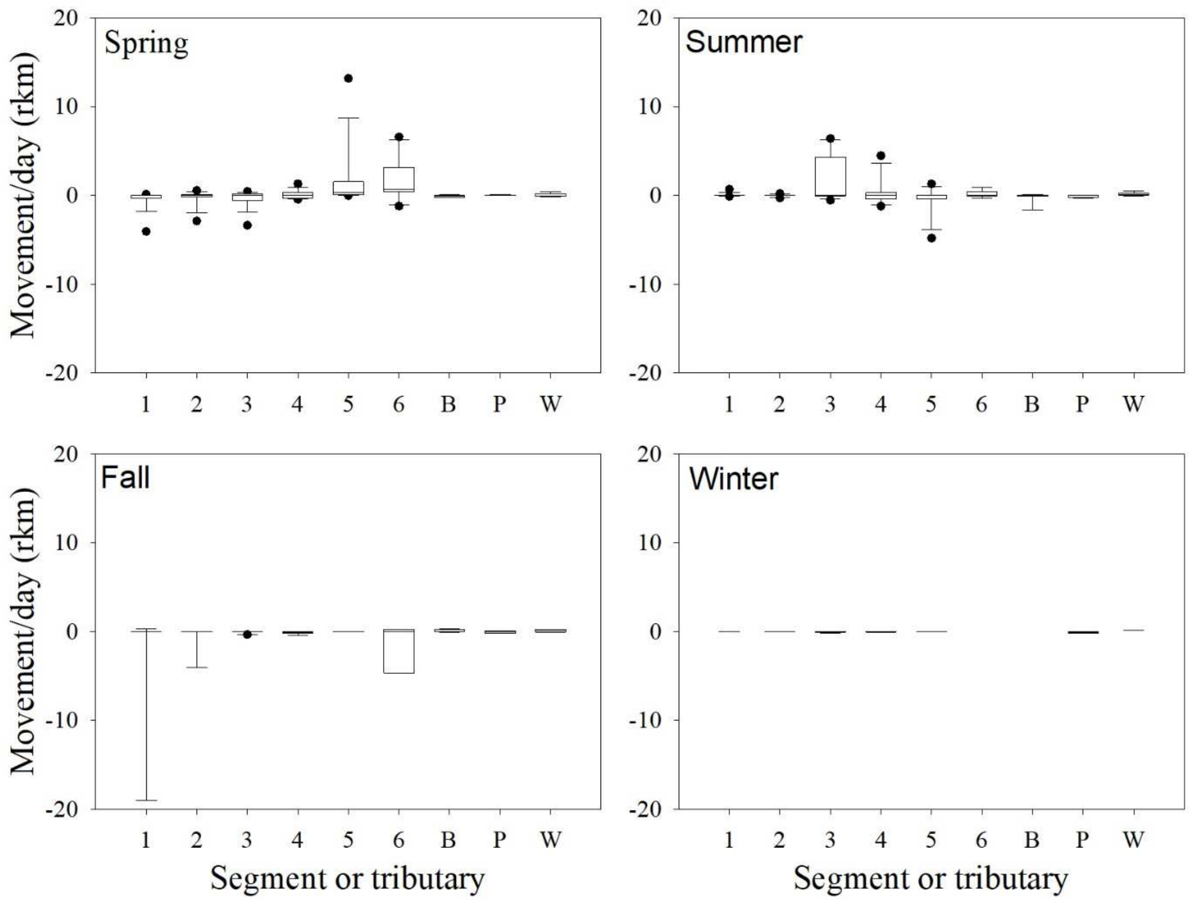

Figure 3.6-Movement of Smallmouth Bass implanted with radio transmitters in 2017 in the Snake River (segments 1-5), Brownlee Reservoir (segment 6), and the three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers). The segment or tributary indicates where a fish was tagged and released. Positive values indicate an upstream movement. Negative values indicate a downstream movement. The box plots show the median, first, second, third, and fourth quartiles. Outliers are represented by the

Table 3.1-Release location Smallmouth Bass sampled and implanted with radio transmitters (n = 149) in 2017 in the Snake River (segments 1 – 5), Brownlee Reservoir (segment 6), and the three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers).

Segment or tributary	
Tagging and release location	(n)
1	20
2	15
3	15
4	15
5	15
6	40
B	9
P	10
W	10

Table 3.2-Movement of Smallmouth Bass sampled and tagged (n = 63) with t-bar anchor tags in 2016 during electrofishing and angling surveys in all five segments of the Snake River (1 – 5), segment 6 (Brownlee Reservoir), and the three tributaries (i.e., Boise [B], Payette [P], and Weiser [W] rivers).

*One fish was recaptured downstream of the study area in the Hells Canyon Reservoir.

		Recapture location								
Release Location	(*n*)	1	2	3	4	5	6	B	P	W
1	20	20	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	1	0	0	1	0	0	0	0	0	0
4	2	0	0	0	0	0	0	0	1	1
5	1	0	0	0	0	1	0	0	0	0
6	27*	0	0	0	1	1	23	0	1	0
B	2	0	0	1	0	0	0	1	0	0
P	9	0	0	1	0	0	0	0	8	0
W	1	0	0	0	0	0	0	0	0	1

Chapter 4: General Conclusions

This thesis contributes to the understanding of the population dynamics, demographics, and movement of Smallmouth Bass in the western United States. Data collected from electrofishing surveys was used to describe the population in terms of various rate functions (i.e., growth rates, mortality rates, and exploitation rates), size structure (i.e., proportional size distribution [PSD], relative weight [W_r]), age structure, and relations among these indicies (i.e., principal components analysis). In the Snake River, fish grew at a fast rate with a relative growth index value of 106. The population appeared to be robust with most PSD index values over 40 in the Snake River and three major tributaries (i.e., Boise, Payette, and Weiser rivers). Fish were in good condition with W_r values near 100, except for large size classes. Additionally, the information collected was used in simulations to evaluate potential regulation changes in the form of varying minimum length limits. Under current exploitation rates (5.3%), changes to the existing regulations would have little influence on yield, size structure of the population, or the sustainability of the fishery. Based on simulations, regulation changes are not likely needed unless fishing-related mortality exceeds 20%.

Investigations into the movement of Smallmouth Bass provided several interesting results. Movement of fish in the Snake River was highly variable (0.0 – 168.0 river kilometers [rkm]) with 57.4% of fish moving 20 rkm or more over the course of the study. Furthermore, seven fish were recorded moving over 100 rkm, which represent some of the longest recorded movements of Smallmouth Bass. Seasonally, Smallmouth Bass were most mobile in the spring and summer, both in upstream and downstream directions. Movement rates declined in the fall and had essentially ceased by winter. A small proportion (10%) of

Smallmouth Bass were documented moving from Brownlee Reservoir to several tributaries (i.e., Payette and Weiser rivers) in the spring suggesting that there might be an adfluvial component to the population. No fish were recorded moving from Brownlee Reservoir into the Boise River. Exploitation of Smallmouth Bass in the tributaries was low with only four fish being harvested in the spring and summer months in the Payette and Weiser rivers. The low rate of exploitation suggests that overexploitation of riverine Smallmouth Bass is not a concern.

This research project was one of the most comprehensive studies of Smallmouth Bass west of their native distribution and provided insight into the population dynamics, demographics, and movement of Smallmouth Bass in the Snake River and in the western United States where they are not native. From a management standpoint, it appears the population is quite mobile with many fish moving 10 rkm or more. Additionally, the population appears to be robust with moderate to high catch rates (CPUE), fast growth rates, good size structure, above average body condition, and low exploitation. The Smallmouth Bass fishery is quite popular among anglers and will likely remain so given characteristics of the population and current management practices.