Bull trout population assessment in northeastern Oregon: a template for recovery planning

Annual Progress Report for 2008

by

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ADDENDUM TO THE 2007 REPORT

Figure 20 in the 2007 Annual Report contains a clerical error; the symbols for two size classes of fish are switched. The correct data are shown in the published manuscript, as Figure 4 in: Al-Chockhachy, R and P. Budy. 2008. Demographic characteristics, population structure, and vital rates of a fluvial population of bull trout in Oregon. Transactions of the American Fisheries Society 137:262-277.

EXECUTIVE SUMMARY

Within the overall framework of conservation and recovery planning for threatened bull trout, we provide critical information on abundance, trend, vital rates, habitat needs, and information on the potential for improving survival at one or more life stages. In addition, we gather information related to population structure (e.g., age, life history, and genetic components). We provide a template against which different strategies for monitoring and evaluation can be evaluated in terms of accuracy, precision, cost/effort, and limiting factors. Our goal is to provide the data and conservation assessment tools to aid in the efforts of the US Fish and Wildlife Service, to determine the necessary courses of action and management actions for recovery of bull trout populations throughout this as well as other provinces. The project was initiated in 2002 and has continued through 2009, with plans to continue work through 2010. To meet our goals, we have developed and implemented each year, a comprehensive mark- recapture program including two tag types, multiple capture techniques (both passive and active) and systematic sampling of two large study areas (South Fork Walla Walla and North Fork Umatilla) with a high degree of effort. 2008 marks the fifth and final year of sampling and study in the North Fork Umatilla.

The efforts of this project have been part of a completed PhD dissertation (Al-Chokhachy 2006) and master's thesis (Homel 2007) and are currently part of an on-going PhD dissertation (Bowerman, *In prep; Appendix 1*) conducted through Utah State University. Results and syntheses of different components of the project are available in previous annual reports (Budy et al 2003, 2004, 2005, 2006, 2007, and herein) as well as in the peer-reviewed manuscripts: Al-Chokhachy et al. 2005; Al-Chokhachy and Budy 2007; Homel and Budy 2008; Homel et al. 2008; Al- Chokhachy and Budy 2007; Al- Chokhachy and Budy 2008; and Al-Chokhachy et al. *in press*.

2008

In 2008, we sampled 22 reaches (~26% of the study site) in the SFWW. Over the summer, a total of 402 bull trout were captured of which, 333 were tagged with PIT tags and 233 of those were also tagged with Floy tags. The remaining PIT tagged fish were < 120 mm and thus only tagged with an 8 or 12 mm PIT tag. In 2008, as in years since 2003, most bull trout were tagged upstream of Burnt Cabin Creek; the average bull trout captured was 143 mm, the smallest bull trout captured was 48 mm, and the largest bull trout caught was 644 mm.

In 2008, we sampled 16 reaches (~40% of the study site) in the NFUM. Over the summer, a total of 88 bull trout were captured of which, 37 were tagged with PIT tags and Floy tags. In 2008, as in years since 2003, most bull trout captured were in the 100 – 150 mm size range; the smallest bull trout captured was 89 mm, and the largest bull trout captured was 425 mm.

We captured more large (>320 mm) bull trout in the SFWW as compared to the NFUM; however both population are composed primarily of smaller, likely resident, or not-yet-migrated bull trout. We observed a dramatic increase in condition of all bull trout in both systems in 2008, and there still appears to be a trend of increasing condition since 2005 estimates. We found no significant changes in growth rates in the SFWW from 2006, and growth rates in the SFWW generally continued to be slightly greater than in the NFUM (but note small *n* in NFUM).

Over a 7-year period in the SFWW, the abundance of adult bull trout > 220 mm averaged 1,793, ranging from highs of 2695 (95% CI 2244 – 3456) to lows of 641 (95% CI 451 - 269). Over a 6-year period in the NFUM, the abundance of adult bull trout > 220 mm averaged 216 ranging from highs of 365 to lows of 61 no confidence intervals could be calculated for this size class in the NFUM due to low sample sizes. Based on the population growth rates (lambda (λ)) calculated from these population estimates, it appears that both the SFWW and the NFUM (λ ~ 1) adult populations are stable; however, the 95% confidence intervals are wide and overlap 1 and thus limit current conclusions about trend with certainty. Larger, 'likely migratory' (> 370 mm) bull trout in the SFWW (calculations not possible for NFUM) appear to be declining in trend (Figure ES).

Based on temperature data, 2008 appeared to be characterized as below average for temperature, over the period of summer study. The upper portions (our study areas; see within) of both rivers fall well-within the temperature standards recommended for bull trout for migration, spawning, and rearing.

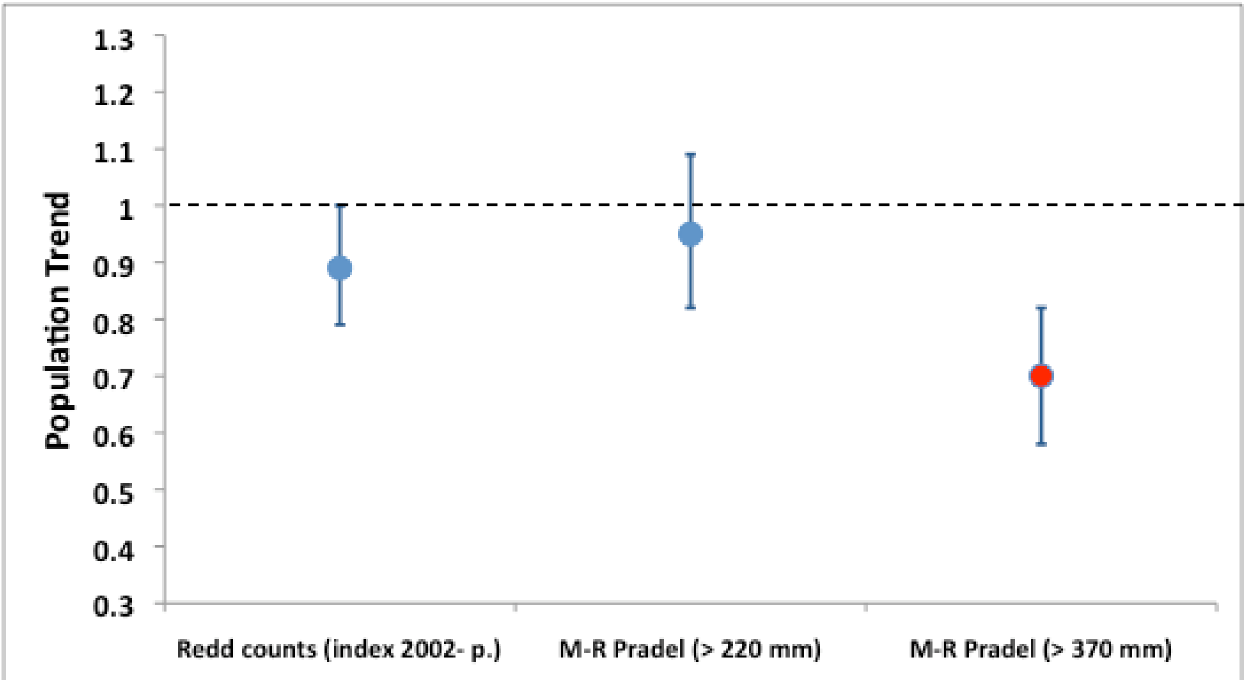

Figure ES: Bull trout population trend estimates for the SFWW (2002 -2008) using mark-recapture Pradel models for all possible adult bull trout (>220 mm) and only large, potentially fluvial bull trout (>370 mm) and using redd count data with count-based regression methods (e.g., Morris and Doak 2002); capture-recapture data consists of active capture and recapture data at 21 reaches sampled yearly during this period (i.e., does not include passive instream antennae data)

Monitoring and evaluation of bull trout populations in the South Fork Walla Walla and North Fork Umatilla rivers, Oregon

INTRODUCTION

When species are in decline or listed under conservation status across a large spatial area, estimates of population abundance and trend are critical for understanding the present and future status of the population (Soule 1987). In addition, the quantification of key demographic parameters (e.g., survival, growth) across age classes and life-history forms is an important part of the process of identifying factors that potentially limit the population, evaluating the importance of vital rates on overall trend, and ultimately directing future recovery and restoration activities. However, for many protected species, estimation of population abundance and demographic parameters is extremely difficult due to (1) their protected status, which limits estimation techniques that may be applied legally, (2) low numbers, (3) high variability, (4) the differential effects of environmental stochasticity at low abundance, (5) the immediate, short-term need for information that typically requires years to collect, and (6) logistical limitations in agency personnel time and/or funding. Nevertheless, population structure (including genetics), abundance, trend, and demographic characteristics are key components required for the recovery planning of any species.

In 1998, bull trout (*Salvelinus confluentus*) were officially listed as a Threatened Species under the 1973 Endangered Species Act (USFWS 1998). Bull trout are native to the northwestern United States and western Canada and are primarily an inland species which were once distributed from the McCloud River in California and the Jarbridge River in Nevada to the headwaters of the Yukon River in Northwest Territories (Cavender 1978). Today bull trout exist only as subpopulations in coastal and inland drainages of Western North America on both sides of the continental divide from Alaska and northern Canada to southern Oregon (Rieman et al. 1997; Dunham et al. 2008); bull trout have been extirpated from the southernmost extent of its historical range in Northern California (Reist et al. 2002) including the McCloud River system (Rode 1988) and other local extirpations (Goetz 1989). Throughout much of the species' range, resident and migratory populations occur and can coexist, and should therefore be better able to persist in the face of change (Northcote 1992; Lichatowich 1999). These life history strategies represent evolutionary diversity that has allowed fish to adapt to, and take advantage of, various resources in the environment (Dingle 1996). These same strategies can also create a diverse population structure which may require a range of habitats (Goetz 1991; Rieman and McIntyre 1993) and are therefore potentially vulnerable to the negative impacts of major environmental changes (Schlosser 1991;

Quinn and Adams 1996). Habitat degradation (Fraley and Shepard 1989), barriers to migration (Rieman and McIntyre 1995; Kershner 1997), the introduction of nonnatives (Leary et al. 1993), and active eradication (Colpitts 1997) have all contributed to the decline in bull trout populations in the Columbia and Klamath River Basins. Bull trout populations may be further impacted by environmental changes such as competition with introduced species (McMahon et al. 2007) and climate warming (Rieman et al. 2007).

The goal of bull trout recovery planning by the U.S. Fish and Wildlife Service (USFWS) is to describe courses of action necessary for the ultimate delisting of this species under the Endangered Species Act, and ensure the long-term persistence of self-sustaining, complex interacting groups of bull trout distributed across the species's native range (Lohr et al. 1999). To meet this overall goal, the USFWS has identified several objectives which require the type of information provided by this project: (1) maintain current distribution of bull trout within core areas in all recovery units and restore distribution where needed to encompass the essential elements for bull trout to persist, (2) maintain stable or increasing trends in abundance of bull trout in all recovery units, and (3) restore and maintain suitable habitat conditions for all bull trout life-history stages and strategies. Furthermore, the USFWS recovery-planning document (Lohr et al. 1999) embraces the idea of core areas. Conserving respective core areas within conservation units is intended to preserve genotypic and phenotypic diversity and allow bull trout access to diverse habitats. The continued survival and recovery of individual core area populations is thought to be critical to the persistence of conservation units and in overall recovery of the Columbia River distinct population segment (Whitesel et al. 2004).

Despite the growing body of knowledge on bull trout (*see* Al-Chokhachy and Budy 2007, 2008; Al-Chokhachy et al., in press; Budy et al. 2003, 2004, 2005, 2006, 2007, 2008; Homel and Budy 2008; Homel et al. 2008, for populations addressed in this document), there are still critical gaps in information that potentially limit our ability to effectively manage bull trout and ensure their continued persistence (Porter and Marmorek 2005). These gaps include detailed population assessment data (e.g., abundance, trend) for all but a few populations, any quantification of juvenile survivalor factors limiting juvenile survival, as well as the relative role of biotic interactions (e.g., competition with non-natives, food availability etc.). Within the overall framework of conservation and recovery planning for threatened bull trout, our research provides critical information on bull trout population abundance, trends in abundance, vital rates, robust evaluations of different monitoring techniques, habitat needs, and information on the potential for improving survival at one or more life stages. In addition, we gather information related to population structure (age, life history, and tissue for genetic information), and the role of declining salmon in the parallel decline of bull trout. Most recently, we have added age-1 fish to our ongoing population evaluation and monitoring. Recent research suggests that population growth may be limited by early life-stage survival and demonstrates the need for further studies that examine factors affecting population dynamics at specific life stages (Al-Chokhachy 2006; Johnston et al. 2007).

We provide a template against which different strategies for monitoring and evaluation can be evaluated in terms of accuracy, precision, and cost per effort. The data and conservation assessment tools provided by this project will ultimately help guide the USFWS in determining the necessary management actions for recovery of bull trout populations throughout this and other provinces; preliminary data from 2002 - 2007 are currently being used by the USFWS Bull Trout Recovery, Monitoring, and Evaluation Technical Group (RMEG).

The South Fork Walla Walla River was initially selected as the comprehensive study area due to its abundance of both resident and migratory fish, complex water management issues associated with fish protection, and a diversity of habitat types. Expansion of research into multiple additional watersheds has allowed for comparisons of critical population-level metrics (e.g., population structure) across ecosystems and varying levels of bull trout abundance. To date, our work includes seven years of population monitoring data (2002 - 2008) from one intensively monitored stream, as well as smaller-scale continuous population assessments for an additional system, the North Fork Umatilla River; 2008 represents the fith and final year of study in the NFUM. Monitoring data in several streams allows us to investigate population trends and other key questions in greater detail and across a range of biotic and abiotic conditions.

STUDY AREAS

South Fork Walla Walla River

The Walla Walla River in northeastern Oregon and southeastern Washington is a tributary of the Columbia River that drains an area of 4,553 km^2 (Walla Walla Subbasin Summary Draft 2001). The tributaries of the Walla Walla River originate in the Blue Mountains at elevations near 1800 m. The mainstem Walla Walla flows for approximately 16 km in Oregon before splitting into the North Fork Walla Walla and the South Fork Walla Walla rivers.

The Walla Walla River historically contained a number of anadromous and resident, native salmonid populations including: spring and fall Chinook salmon (*Oncorhynchus* *tshawytscha*), chum salmon (*O. keta*), and coho salmon (*O. kisutch*), redband trout (*O. mykiss* subpopulation), bull trout, mountain whitefish (*Prosopium williamsoni*), and summer steelhead (*O. mykiss*; the extent of fall Chinook, chum, and coho salmon is not known; Walla Walla Subbasin Summary Draft 2001). Today, steelhead represents the only native anadromous salmonid still present in the Walla Walla River system. However, since 2000 there has been annual supplementation of adult Chinook salmon in the SF Walla Walla River by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR). Populations of native redband trout, bull trout, mountain whitefish, sculpin (*Cottus* spp.), and dace (*Rhinichthys* spp.) still persist in the Walla Walla River, as well as introduced brown trout (*Salmo trutta*).

Little documentation exists on the historical distribution of bull trout in the Walla Walla Subbasin prior to 1990. Anecdotal evidence suggests that large fluvial bull trout were found to utilize the Columbia River. Telemetry studies in the mid-Columbia River region have shown bull trout have to use both primary and secondary tributaries for spawning (FERC Project 2145 Draft 2002). Therefore, it is presumed that bull trout had access to the Columbia River and all of its tributaries prior to the impoundment of the Columbia River (Buchanan et al. 1997). Today, resident and fluvial forms of bull trout exist in the Walla Walla (Walla Walla Subbasin Summary Draft 2001), and both populations spawn in the tributaries and headwaters of the Walla Walla River. Recent telemetry studies with large (> 350 mm) bull trout have not confirmed use of the Columbia River (Mahoney 2001, 2002), although as of 2007 the USFWS have detected bull trout at the Oasis Bridge Road indicating probable use of the Columbia River (Anglin et al. 2008)

Within the Walla Walla River Basin, bull trout are arbitrarily divided into four populations based on geography: North Fork Walla Walla River (NFWW), South Fork Walla Walla River (SFWW), Mill Creek, and the Touchet River (Buchanan et al. 1997). Ratliff and Howell (1992) described the population status of bull trout as “low risk” in the SFWW and Mill Creek, and “of special concern” in the NFWW. Since that report, the status of the SFWW population has remained at low risk, but both the NFWW and Mill Creek populations have been upgraded to “high risk” and “of special concern” respectively (Buchanan et al. 1997). Alterations to migratory corridors linking these populations have occurred, but the degree of genetic, geographical isolation is unknown.

The study site on the SFWW spans nearly 21 km in length. The upper boundary was set at the confluence with Reser Creek (Reach 103), and the lower boundary was set above Harris Park Bridge (on public, county land; Budy et al. 2003, 2004, 2005). In order to account for spatial variation of the study site and the distribution of bull trout, the study site was divided into 102 reaches, 200-m each, using Maptech mapping software (Figure 1).

An initial site was randomly selected from the list of reaches, and thereafter every fifth reach (an approximate 20% sample rate) was systematically designated for sampling in 2002. The UTM coordinates from the mapping software were used to locate the general location of the bottom of each reach, and the closest pool tail to the coordinates was set as the true reach boundary. The reach continued upstream for at least 200 m and the top was set at the first pool-tail above the 200-m mark. Total length was recorded for each reach. Location coordinates (UTM using GPS) were recorded at the boundaries of each reach.

North Fork Umatilla River

The Umatilla River Basin drains an area of approximately 6,592 km^2. The Umatilla River is 143 km long from mouth (at Columbia River RK 440) to where it divides into the NF and SF Umatilla rivers, each fork adding another 16 km in length. The Umatilla mainstem originates in Blue Mountains at 1289 m and descends to 82 m at confluence with Columbia River. Earliest documentation of bull trout in Umatilla basin is from ODFW creel reports dating from 1963. The mainstem Umatilla River is artificially confined for much of its length. Spawning occurs in the North Fork (NFUM) and South Fork (SFUM) Umatilla Rivers. Along with being an important tributary for rearing and migration activities, redd counts indicate that the majority of redds in the Umatilla basin occur in the NFUM between Coyote and Woodward creeks. Peak spawning generally occurs between mid September and mid October over at least a two-month period (ODFW 1995, 1996) when daily average water temperatures ranged from 6-10 ^oC (ODFW 1996). Habitat in the NFUM is fairly complex with low levels of bedload movement, moderate levels of large organic debris, and relatively minimal flow events. Other species occurring in the basin include *O. mykiss* subspecies, sculpin (*Cottus* spp.), Chinook salmon, Redside shiners (*Richardsonius balteatus*), suckers (*Catostomus* spp.), dace (likely *Rhinichthys* spp.), and northern pikeminnow (*Ptychocheilus oregonensis*). Two populations were recognized in the Umatilla basin: the NFUM rated “Of Special Concern” and the SFUM rated at “High Risk” (Buchanan et al. 1997).

The study site on the NFUM spans nearly 8 km in length. The upper boundary was set at the confluence of Johnson, Woodward, and Upper NF Umatilla creeks (416053 E, 5065070 N), and the lower boundary was set at the confluence of NF and SF Umatilla rivers (110407763 E, 5064070 N). In order to account for spatial variation of the study site and the distribution of bull trout, the study site was divided into 41 reaches, approximately 200-m each, using Maptech mapping software (Figure 2).

An initial site was randomly selected from the list of reaches, and thereafter every fifth reach (an approximate 20% sample rate) was systematically designated for sampling in 2003. The UTM coordinates from the mapping software were used to locate the general location of the bottom of each reach, and the closest pool tail to the coordinates was set as the true reach boundary. The reach continued upstream for at least 200 m and the top was set at the first pool-tail above the 200-m mark. Total length was recorded for each reach. Location coordinates (UTM using GPS) were recorded at the boundaries of each reach.

METHODS

Size Designations

Since the onset of the bull trout population assessment in northeastern Oregon in 2002 and in any bull trout publications and reports published by the USGS Utah Cooperative Fish and Wildlife Research Unit at Utah State University, the following size designations for bull trout have been used. Bull trout smaller than 220 mm represent juvenile, not sexually mature fish (Al-Chokhachy 2006), and bull trout 220 mm or larger represent both resident and migratory sexually mature fish (Al-Chokhachy et al. 2005, Al-Chokhachy and Budy 2007). The >220 mm cutoff (here after adult) for sexually mature adults is a conservative estimate as we have found smaller adults in our study sites and smaller resident adult bull trout have been found in other systems (WDW 2000; Dunham et al. 2008). Further size categories are used for population growth rate estimates and survival estimates where both Passive Integrated Transponder (PIT) and T-bar anchor tags (Floy tags) are used for mark recapture events. Small bull trout are 120-220 mm, small adults are 220-370 mm, and large, likely migratory, adults are >370 mm; based on % migratory in Alchokhachy and Budy (2008) and others (Rieman et al.1993; Shephard 1989). The size categories >220mm and >370mm are now considered the most important for trend and population analyses. The >120 mm cutoff was chosen as a safe size for inserting Floy tags and 23-mm PIT tags. We do know, however, that not all bull trout >370 mm are migratory (particularly in fluvial systems) but, there is a presumption that larger fish are migratory. The development of smaller “super PIT tags” (8-mm and 12-mm) has made it safe and feasible to insert PIT tags into smaller (<120 mm) bull trout. Since 2007 we have been tagging bull trout 100-120 mm with 12-mm PIT tags. In 2003 age-at-length estimates were calculated from otolith analysis and are as follows; <120 mm = age-1, 120-220 mm = age-2 and -3, 220-370 mm = age-4and -5, and >370 mm = ≥ age-6 (Budy et al. 2004).

Fish Sampling

Capture.—We used multiple sampling techniques to capture bull trout including angling, and electroshocking down to a seine. All captured bull trout were weighed (nearest 0.1 g), measured (nearest mm total length, TL, and fork length), and condition (K_{TL}) was calculated (Fulton's $K_{TL} = W / L^3 * 100{,}000$). Scales were taken from a subsample of live, released fish. A small subsample of adults was taken in the SFWW for fecundity and sex ratio estimates. We also obtained information from mortalities (non-project related) found in each stream. From these subsamples, stomachs and hard parts (e.g., otoliths) were removed for age, growth, and diet analyses.

Marking.—In all study streams, bull trout (> 120 mm TL) were marked with unique PIT tags and Floy tags, and subsequently recaptured using a combination of passive in-stream PIT-tag antennae (hereafter detector; *see* below) and snorkeling resights. Since 2007 we marked smaller bull trout (> 100 mm TL) in the SFWW stream with unique PIT tags. Prior to tagging, bull trout were anesthetized until they exhibited little response to stimuli. An 8-, 12- or 23-mm PIT tag was then placed into a small incision on the ventral side of the fish, anterior to the pelvic fins. In addition, an external Floy tag, unique to year and stream, was inserted adjacent to the dorsal fin in bull trout (>120 mm TL). After tag implant, scales were taken from the right side at the base of the dorsal fin for aging and growth information and in the SFWW adipose fins from bull trout (70-119 mm) were removed for identification and genetic analyses. All fish were placed in a flow-through recovery container within the channel, monitored until full equilibrium was restored, and returned to slow-water habitat near individual capture locations.

Resighting.—To resight Floy-tagged fish, we conducted daytime bull trout snorkel surveys in 22 reaches (mean reach length = 244 m) of the SFWW, and 16 reaches (mean = 212 m) of the NFUM. To avoid double-counting fish, snorkeling surveys started at the highest reaches working downstream to the bottom of the study site, because many fish were migrating to the headwaters for spawning. This approach likely minimized the incidence of double counts. Water temperature, start, and end times were all recorded for each snorkeling session. All bull trout (tagged and untagged), O. *mykiss* spp., and mountain whitefish were enumerated and placed into 50-mm size classes, and all juvenile Chinook salmon were enumerated but not delineated by size. Accurate identification of fish species and size estimation was emphasized. In each channel unit snorkeled, two observers proceeded in an upstream direction while scanning for fish across their assigned lane, such that the entire channel was surveyed.

Recapture.—We recaptured previously tagged bull trout (2002 – current) using a combination of techniques including: electroshocking down to a seine, angling, trap netting, and passive fish detection using pass-through PIT-tag technology described below. All actively captured bull trout were passed over a handheld PIT-tag reader and checked for Floy tags from previous years. When recaptured, all bull trout were weighed and measured for estimates of annual growth, and we recorded information regarding location of recapture. Recapture events also provided critical information for estimates of bull trout survival, annual population estimates, and to parameterize the Pradel mark and recapture model.

Passive fish detection.—PIT-tag detectors were installed in-stream and continuously collect information on tagged bull trout from two locations within the SFWW. One detector is located at Harris Park Bridge (UTM coordinates: 110408261 E, 5076370 N) at the bottom of the study site, and the second detector is located just above the confluence with Bear Creek (approximately 7 km upstream; UTM coordinates: 110414281 E, 5077108 N). The Harris Park Bridge detector (WW1) has been running since mid-September 2002, and the Bear Creek detector (WW2) has been operational since mid-October 2002. Additional detectors are located downstream at Nursery bridge, Burlingame diversion, and Oasis Bridge on the Walla Walla River. Having more detectors further downstream on the SFWW and on other rivers allows us to monitor fish migrations and connectivity within the Walla Walla basin. All detectors are linked either through phone or satellite, and data is uploaded to the PTAGIS website (<*www.psmfc.org/pittag/Data_and_Reports/index.html* > under "*Small-scale Interrogation Site Detections -Query*").

There is one NFUM detector (UM1) located on US Forest Service land under a road bridge (UTM coordinates: 110407659 E, 5064089 N) near the confluence with the South Fork Umatilla River. The detector has been collecting data since autumn 2004. Another detector (UM 2) has subsequently been installed on the main-stem Umatilla River approximately 14.5 km downstream of UM 1.

<u>Growth</u>

Growth information was obtained from bull trout previously tagged in the SFWW (2002-2007) and NFUM (2003-2007) and recaptured during the 2008 summer field season. Length and weight gains were determined between initial tagging and subsequent recapture events. These length and weight gains were evaluated based on annual growth, and delineated by size class at initial tagging.

Population Estimates

We used snorkeling and tagging data to parameterize mark-resight population estimates using a Lincoln-Petersen bias-adjusted estimator (Chapman 1951), and estimated the overall population size for three size groupings of bull trout: > 120 mm, > 220 mm, and > 370 mm. We estimated the standardized population sizes for each reach using tagging and snorkeling data for each individual reach and reach-based counts were expanded to estimate stream subpopulation abundance.

Population Growth Rate

Obtaining reliable estimates of population trend, to determine whether the population is increasing or decreasing is a particularly challenging task that requires several years of data. For this report we estimated population trend based on population estimates from the SFWW mark-resight data (2002-2008), SFWW redd count data (1994-2008), the NFUM mark-resight data (2003-2008) and NFUM redd count data (1994-2008) via linear regression of log-transformed annual changes in population growth rate (λ) as a function of time step (Morris and Doak 2002; Budy et al. 2007) and using a mark – recapture Pradel model. All redd count data was obtained from the USFWS.

Survival

Survival estimates have not been updated for the 2008 report. Please see the 2007 annual report (Budy et al. 2008) for the latest survival estimates.

Diet Analysis

Each year (2002-2008) we sacrificed up to ten individual bull trout to evaluate stomach content for diet analysis. All stomachs were preserved in 95% ethanol for further prey identification in our laboratory. We identified aquatic macroinvertebrates found in bull trout stomachs to order, and all fish prey to the species level when possible. Prey fish were counted and weighed (blot-dry wet weights to nearest 0.001 g), while macroinvertebrate prey were weighed *en masse* by classification. Intact prey fish were measured to the nearest mm (backbone and standard length). Unidentified fish prey were apportioned into identified prey categories based on a weighted average of identified fish prey. Data are reported as % by weight.

Fecundity

Each year (2002-2008) we used the same sacrificed individual bull trout, used in the diet analysis, to evaluate age and length at sexual maturity, and to estimate a bull trout length-fecundity relationship for the SFWW river population. We collected fish across all size classes (except age-0) during the first two weeks of August to maximize egg development in females. We enumerated all eggs from mature females. Since 2002 we have collected and enumerated eggs from 15 mature females.

Temperature

We measured in-stream temperature every 90 minutes using temperature loggers at three sites in the SFWW (upper SFWW between reaches 83 and 85, below Bear Creek and at Harris Park bridge). No temperatures were recorded on the NFUM from August 2007- August 2008 as high spring flows washed the temperature loggers away. We summarized temperature as daily maximum, average, and minimum for ease of assessment.

RESULTS and DISCUSSION

Fish Sampling

We weighed (to the nearest 0.1 g) and measured (TL to the nearest mm) all captured bull trout. We combined all bull trout length and weight data from 2002 – 2008 in the SFWW and 2003 – 2008 in the NFUM and developed a strong relationship for weight at length (Figures 3 and 4) for both streams.

South Fork Walla Walla River

We sampled 22 reaches during the 2008 field season, which accounted for approximately 26% of the study site. Over the summer, a total of 402 bull trout were captured of which 333 were tagged with PIT tags and 233 of those were tagged with Floy tags. In 2008, as in all years since 2003, most bull trout were tagged upstream of Burnt Cabin Creek (Figure 5). In 2008, the average bull trout captured was 143 mm (± 3.8, 1 SE) and 64.7 g (± 11.8, 1 SE). The smallest bull trout captured was 48 mm (0.9 g) and the largest bull trout caught was 644 mm (2.45 kg). Length-frequency distributions of captured bull trout in the SFWW have varied little from 2002 through 2008, with most captured fish in the 100 – 200 mm size range (Figure 6). More large (> 400 mm) bull trout were captured in the SFWW compared to the NFUM (Figures 6 and 7).

Condition.—Condition (Fulton’s K) of bull trout captured in the SFWW from 2002-2008 varied by size class and year; in general, condition was lowest for juvenile and small adult (< 370 mm) bull trout (7-year mean = 0.88) and highest for large (> 370 mm) bull trout (7-year mean = 0.95; Figure 8). These results make sense when compared to growth data over the same period, where larger fish put on more weight but less length resulting in higher condition values (Figures 8 and 15). Condition of juvenile (< 120 mm) bull trout in 2008 (K ± 1 SE = 0.91 ± 0.04) increased relative to all years since 2003 but was still lower than 2002 values (0.97 ± 0.03; Figure 8). When all size classes are combined, average condition follows a similar pattern to that of juvenile (< 120 mm) bull trout where condition for all size classes combined in 2008 (0.89 ± 0.02) increased relative to all years since 2003 but was still lower than 2002 (0.92 ± 0.01; Figures 8 and 9). In 2008 average condition in the SFWW (0.89 ± 0.02) was lower than in the NFUM (0.90 ± 0.01); however, average condition over the entire study period for the SFWW (7-year mean = 0.88) was the same as the NFUM (6-year mean = 0.88; Figure 9). Average condition for these populations was lower than that exhibited by Metolius River (Deschutes River basin, Oregon) adfluvial bull trout (mean K_{TL} range: 1.02 – 1.65; Thiesfeld et al. 1999) and bull trout from southeast Washington (K_{FL} range: 1.00 – 1.23; Underwood et al. 1995).

Snorkel surveys.—We performed snorkeling surveys in 22 reaches in the SFWW in 2008. The distribution of observed bull trout in 2008 was similar to that of 2007, where bull trout appeared to be more uniformly distributed across all study reaches with highest densities in reaches 63 and 28 and lowest densities in reaches 43 and 23 (Figure 10). The total number of bull trout observed during snorkel counts in 2008 was higher than in 2007 and numbers were similar to those observed in previous years where the same number of reaches were snorkeled (Figure 10; Budy et al. 2006, 2007, 2008). Observations were likely biased toward fish > 120 mm (80 %) due to the cryptic nature of small fishes (Figure 11; Thurow 1997). In 2008, bull trout observed in the SFWW ranged from 70 to 620 mm (Figure 11).

North Fork Umatilla River

We sampled 16 reaches in 2008 which accounted for 43% of the study site. Bull trout were captured or observed in all but one sampled reaches. Over the summer, a total of 88 bull trout were captured and 37 were tagged with PIT and Floy tags. The number tagged varied by sample reach (1 to 9 per reach; Figure 12). Most bull trout captured in the NFUM (2003 - 2008) were in the 100 - 150 mm size range, and the largest bull trout captured in 2008 was a 425 mm fish (854.6 g), while the smallest bull trout captured was 89 mm (6.3 g; Figure 7). The number of bull trout captured and observed in 2008 was the lowest since the beginning of the project in 2003. We noticed large-scale changes in habitat structure and channel form. A number of reference reaches appeared physically different from previous years, but we did not collect habitat information. It is hard to tell whether the decrease in bull trout numbers is due to a population decrease or a redistribution of fish due to habitat changes.

Condition.—Similar to previous years, condition (Fulton's K) in the NFUM in 2008 varied little between juvenile bull trout, <120 mm (K ± 1 SE = 0.90 ± 0.008) and small adult bull trout, 120-370 mm (0.89 ± 0.01). However, as we observed in the SFWW over the entire study period, condition of fish >370 mm was higher (6-year mean = 1.02) than that of the smaller size classes combined (6-year mean = 0.88; Figure 13). This is not a surprising result as younger fish tend to exhibit lower condition values due to fast growth rates and lack of weight relative to length, where older fish tend to exhibit higher condition values due to an increase in weight relative to length gain. Condition for all sampled bull trout in 2008 was higher in the NFUM (0.90 ± 0.01) than in the SFWW (0.89 ± 0.02; Figure 9).

Snorkel surveys. —We performed snorkel surveys in all 16 reaches, but no bull trout were observed in four of the middle reference reaches (Figure 14). As with the number tagged, most bull trout (89 % of total) were observed in stream reaches upstream of Coyote Creek (Figures 12 and 14). Observations appeared to be biased toward fish > 120 mm (82 %, Figure 11). Bull trout observed in the NFUM ranged from 70 to 370 mm. As in previous years since 2003, observed numbers of bull trout were substantially lower in the NFUM than in the SFWW (SFWW = 354, NFUM = 56; Figure 11). Numbers of bull trout observed in 2008 were substantially lower to those of previous years (Figure 14; Budy et al. 2004, 2005, 2006, 2007, 2008).

<u>Growth</u>

Since 2002 we have recaptured 79 bull trout in the SFWW and 5 bull trout in the NFUM for estimates of annual growth. Average annual growth of tagged bull trout varied across size classes and systems. In the SFWW, small bull trout (120-220 mm, age- 2 and -3) exhibited larger annual growth in length, 60 mm/year (± 2 SE = 7), than small adults (220-370 mm, age- 4 and -5), 48 mm/year (± 9), and larger growth in length than large adults (>370 mm, ≥ age 6), 22 mm/year (± 7; Figure 15). In 2008, fish that were tagged under 120 mm (age-1) were recaptured and measured for growth. This size class exhibited the highest annual growth in length, 68 mm/year, although the sample size was small and the variability was high (n = 3; ± 44; Figure 15).

In terms of body mass, the trend was opposite to that of length. Small (220-370 mm, age- 4 and -5) and large (>370 mm, ≥ age 6) adults exhibited higher growth rates, 141.2 g/year (± 27.1) and 185.2 g/year (± 84.9) than small bull trout (120-220 mm, age- 2 and -3) 90.9 g/year (± 19.9), although variability was high and sample sizes are small

(Figure 15). Small bull trout in the NFUM grew slower than small bull trout in the SFWW in terms of length, 59 mm/year and weight, 75.7 g/year (Figure 15). Since no bull trout larger than 220mm have been recaptured in the NFUM we cannot make comparisons of larger size and age classes.

Population Estimates

South Fork Walla Walla River.—The SFWW bull trout population was significantly larger than the NFUM population (Figure 18). Estimated abundance of bull trout in the SFWW varied greatly by size grouping. Over a 7-year period, the average abundance of bull trout > 120 mm has ranged from 7,287 (95% CI = 6,243 – 8,895) in 2002 up to 10,600 (95% CI = 8,080 – 16,598) in 2006, with 2008 estimated at 8,337 (95% CI = 6,282 - 13,731; Figure 16). The abundance of bull trout > 220 mm has ranged from 2,695 (95% CI = 2,244 – 3,456) in 2002 down to 641 (95% CI = 451 – 1,269) in 2008. In 2008, we estimated the abundance of large bull trout (> 370 mm) at 166 (95% CI = 100 - 835). Whereas the population abundance of bull trout across all size classes appears to have decreased in 2008 the high variance does not allow us to make statements of significant population decreases across years.

North Fork Umatilla River.—Similar to population abundance trends observed in the SFWW, estimated abundance of bull trout in the NFUM also varied greatly by size grouping. In 2008 sample sizes were too low to calculate meaningful confidence intervals. Since 2003, the abundance of bull trout > 120 mm has ranged from a high of 2,434 (95% CI = 1,705 – 5,045) in 2004 to a low of 680 (2008 sample size was too small to calculate meaningful CI's) in 2008 (Figure 17). The abundance of bull trout > 220 mm has varied substantially over this period, from 343 in 2004 down to 61 in 2005, with a 2008 estimate of 161 fish. The abundance estimate of large bull trout (> 370 mm) for 2008 was approximately 2 fish, which is similar to the 2005 and 2006 estimates but much lower than the 23, 22, and 22 bull trout estimated in 2003, 2005 and 2007, respectively (Figure 17). Overall, abundance estimates for the > 120 mm size category demonstrated high variability, but while there is no significant increase or decrease in population numbers there does seem to be a decreasing trend since 2003.

Population Growth Rate

Based on the population growth rates (lambda, λ) calculated from population estimates using a Dennis Time Series it appears that the population of bull trout >120mm in both the SFWW (λ = 1.03; 95% CI 0.93 – 1.15) and the NFUM (λ = 0.88; 95% CI = 0.60 – 1.30) populations are stable (Table 1). Similarly, based on population growth rates calculated from redd data from 1994 -2008 both populations appear stable (SFWW, λ =

1.08; 95% CI = 086 – 1.35; NFUM, λ = 1.09; 95% CI = 083 – 1.43). When using redd data from the years 2002-2008 (to match the years of population estimates) to calculate the population growth rate it appears that the adult, likely migratory, portion of the SFWW population is in decline (λ = 0.89; 95% CI = 0.79 – 1.0) but the NFUM population is stable (λ = 0.93; 95% CI = 0.75 – 1.16). According to Pradel population trend estimates, the adult (>220 mm) bull trout population in the SFWW is stable but the larger, likely migratory, (>370 mm) population in the SFWW is in decline (Table 2, Figure ES). Similar calculations were not possible for the NFUM as catch numbers are too low. A λ value greater than 1 indicates positive population trend, a value equal to 1 indicates no change in population growth rate, and a value less than 1 indicates that the population is declining. It is very important to note however, that as the 95% confidence intervals are wide and overlap 1, we cannot make these conclusions about trend with certainty at this time (Budy et al. 2007).

Table 1. Population growth estimates (λ) based on population estimates for all bull trout >120 mm in the South Fork Walla Walla River (2002-2008) and the North Fork Umatilla River (2003-2008), and the population growth estimates based on redd data for the same periods. The population growth estimate based on redd data for the South Fork Walla Walla River (1994-2007) and North Fork Umatilla River (1994 – 2008) are also included.

		Dennis Time Series	95% Confidence Interval	
River	Data Source	Lambda (λ)	Lower	Upper
South Fork Walla Walla River	population estimate 2002 – 2008	1.03	0.93	1.15
	redd counts 2002 - 2008	0.84	0.73	0.96
	redd counts 1994 - 2008	1.08	0.86	1.35
North Fork Umatilla River	population estimate 2003 – 2008	0.88	0.6	1.3
	redd counts 2003 - 2008	0.93	0.75	1.16
	redd counts 1994 - 2008	1.09	0.83	1.43

Table 2. Bull trout population trend estimates for the SFWW (2002 -2008) using mark-recapture Pradel models for all possible adult bull trout (>220 mm) and only large, potentially fluvial bull trout (>370 mm); capture-recapture data consists of active capture and recapture data at 21 reaches sampled yearly during this period (i.e., does not include passive instream antennae data).

Size Class	Data Source	Lambda (λ)	95% Confidence Interval	
			Lower	Upper
>220 mm	M-R Pradel 2002 – 2008	0.95	0.82	1.09
>370 mm	M-R Pradel 2002 – 2008	0.70	0.58	0.82

Diet Analyses

Using dissected stomachs of sacrificed fish, we quantified (% of diet by wet weight) diet information from nine bull trout from the SFWW in 2008. The primary prey items were aquatic macroinvertabrates (89%), fish eggs (10.8%), and terrestrial invertebrates (0.2%). Aquatic macroinvertebrates included chironomids, plecopterans, dipterans, trichopterans, ephemperopterans, and coleopterans. The fish eggs we found were in the stomach of one bull trout and from the size of the eggs and the time of year the fish was caught, we suspect they are bull trout eggs. We compared the diets of bull trout captured in the SFWW in 2003, 2005, 2006, and 2007. Our extremely small sample size (due to ESA permit limitations) limits conclusions about diet; however, we observed a change in stomach content in 2008 relative to 2007 and we saw eggs as part of the diet for the first time since 2003, although they were only in one fish (Figure 18). Compared to previous years, there was a very low abundance of terrestrial insects in the 2008 stomach analysis, but this may be due to the small sample size rather than a diet shift or change in prey availability. Further, we do not have quantitative invertebrate abundance data for 2008 to compare prey availability to diet composition. We have not observed any evidence of cannibalism in bull trout diets since 2003 and for the first time since 2003 we found no evidence of any fish in 2008 diets. The lack of fish in the diets is surprising as the average size of fish sacrificed in 2008 was 379 mm (724 g), a size where we would expect bull trout to be piscivorous.

Fecundity

We only have fecundity data from 15 sacrificed, mature females since 2002 in the SFWW. Our data suggests that bull trout appear to reach sexual maturity near 200 mm, or ages 3 to 4, in the SFWW. The number of eggs per female increased significantly with size where the smallest female (205 mm TL) had 343 eggs and the largest female (564 mm TL) had 3,969 eggs (Figure 19). These size data are consistent with research from adjacent basins, which indicates bull trout may become sexually mature between 150-200 mm (Hemmingsen et al. 2001). Although the age at maturity of bull trout in the SFWW appears to be younger than the average age at maturity of 5-7 years, the size at maturity fits within the range of sizes at maturity of < 80 - > 800 mm reported by Dunham et al. (2008). Migratory bull trout tend to mature at larger sizes (> 370 mm) than resident individuals, which can mature at sizes as small as 100 mm or less in headwater streams (Koizumi et al. 2006). The SFWW has a mixture of resident and migratory bull trout and thus the mixture of small and large mature bull trout is to be expected. If we make a conservative estimate of spawning bull trout being > 220 mm, the SFWW spawning population in 2008 was approximately 640 individuals. This number is below that required to maintain genetic diversity indefinitely (Rieman and Allendorf 2001). It is therefore, of utmost importance to maintain connectivity to other spawning populations to help maintain genetic diversity when, as in the case with the SFWW and NFUM, populations have low numbers of spawners (Rieman and Allendorf 2001).

Temperature

We measured temperature using temperature loggers at three sites in the SFWW. Daily minimum and maximum temperatures varied less across the year in the higher reaches (one site above Skiphorton Creek; annual range = 1.0 – 10.4 ºC), than middle reaches near Bear Creek (annual range = 1.2 – 12.6 ºC) and lowest reaches near Harris Park (annual range = 0.6 – 14.8 ºC; Figure 20). Diel fluctuations were also less in upper reaches and were greater in the summer months (August 2007 and July - August 2008) throughout the study area (Figure 20). Bull trout require a narrow range of cold temperature conditions to reproduce and survive. Summer maximum temperatures are generally considered a limiting factor for juveniles and adults (Rieman and McIntyre 1993). The best bull trout habitat in several Oregon streams was where water temperatures seldom exceeded 15 ºC (Buckman et al. 1992; Ratliff 1992; Ziller 1992) and the SFWW fits within this description as the highest temperature recorded was 14.8 ºC. Temperature has also been found to be an important criterion for spawning (Rieman and McIntyre 1993; Buchanan and Gregory 1997) with multiple studies showing spawning beginning when temperatures fall below 9 ºC (Fraley and

Shepard 1989; Mcphail and Murray 1979; Riehle 1993). Average August temperatures in the upper reaches of the SFWW (main spawning area) fell below 9 ºC which coincides with the onset of spawning. According to the 2008 temperature data the SFWW falls well within the temperature standards recommended for habitat restoration criteria for bull trout (Buchanan and Gregory 1997). Temperatures fit within reported ranges for migratory cues, spawning, and rearing.

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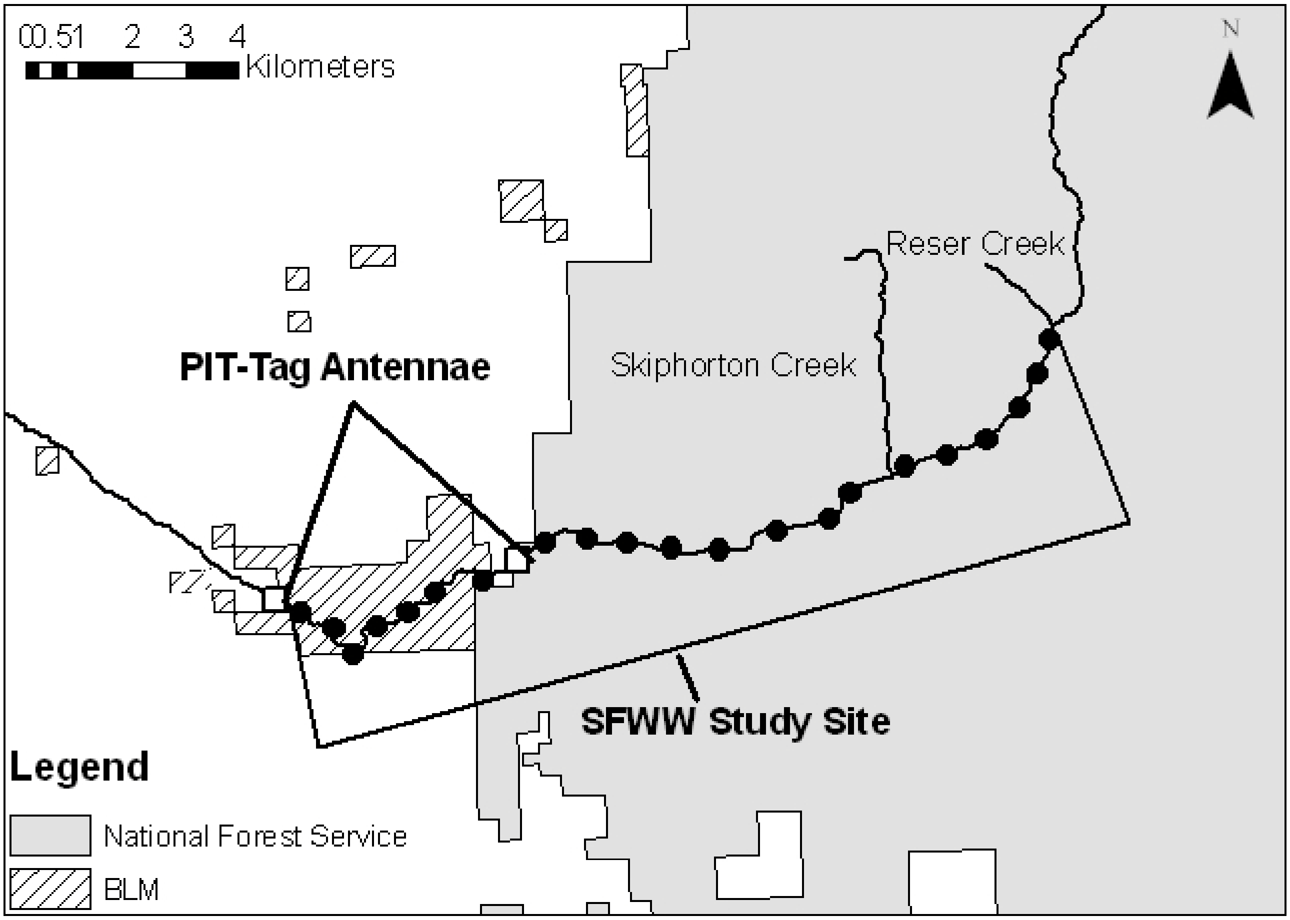

Figure 1. Map of the South Fork Walla Walla River showing original 22 study reaches (dark circles) and antennae locations (white squares).

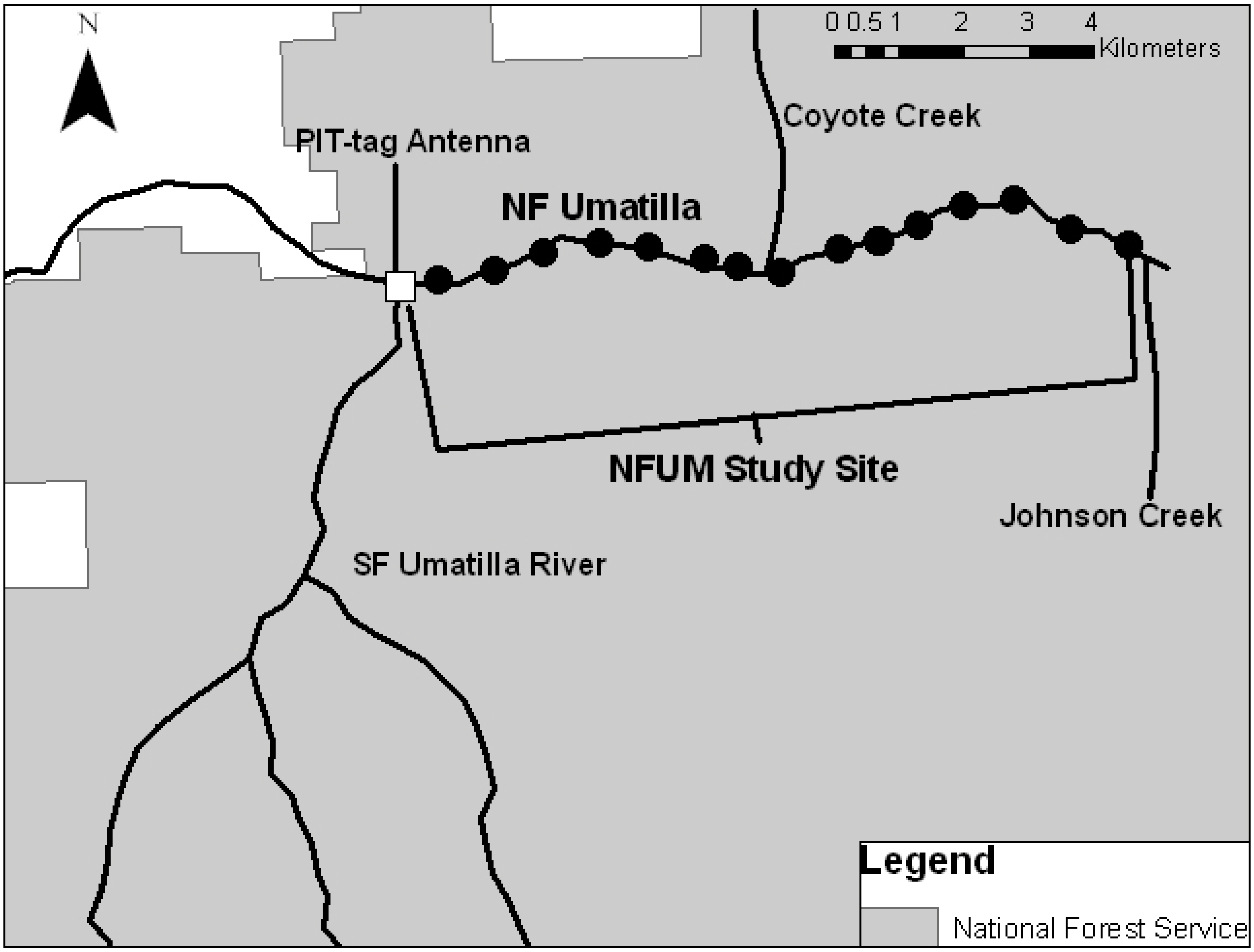

Figure 2. Map of the North Fork Umatilla River showing 15 study reaches (dark circles) and antenna location (white square).

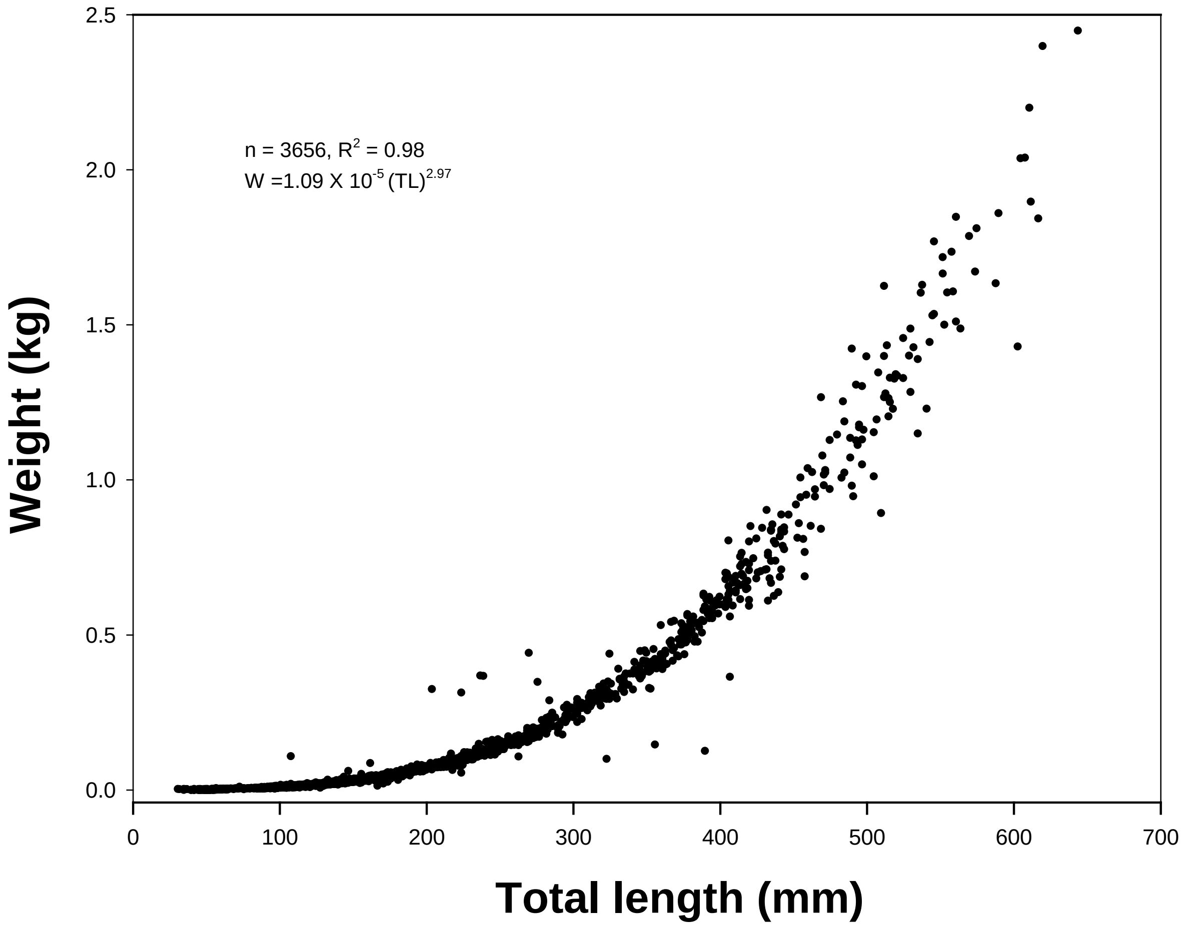

Figure 3. Length-weight relationship for all bull trout captured and handled in the South Fork Walla Walla River from 2002 – 2008. Regression equation and sample size is given.

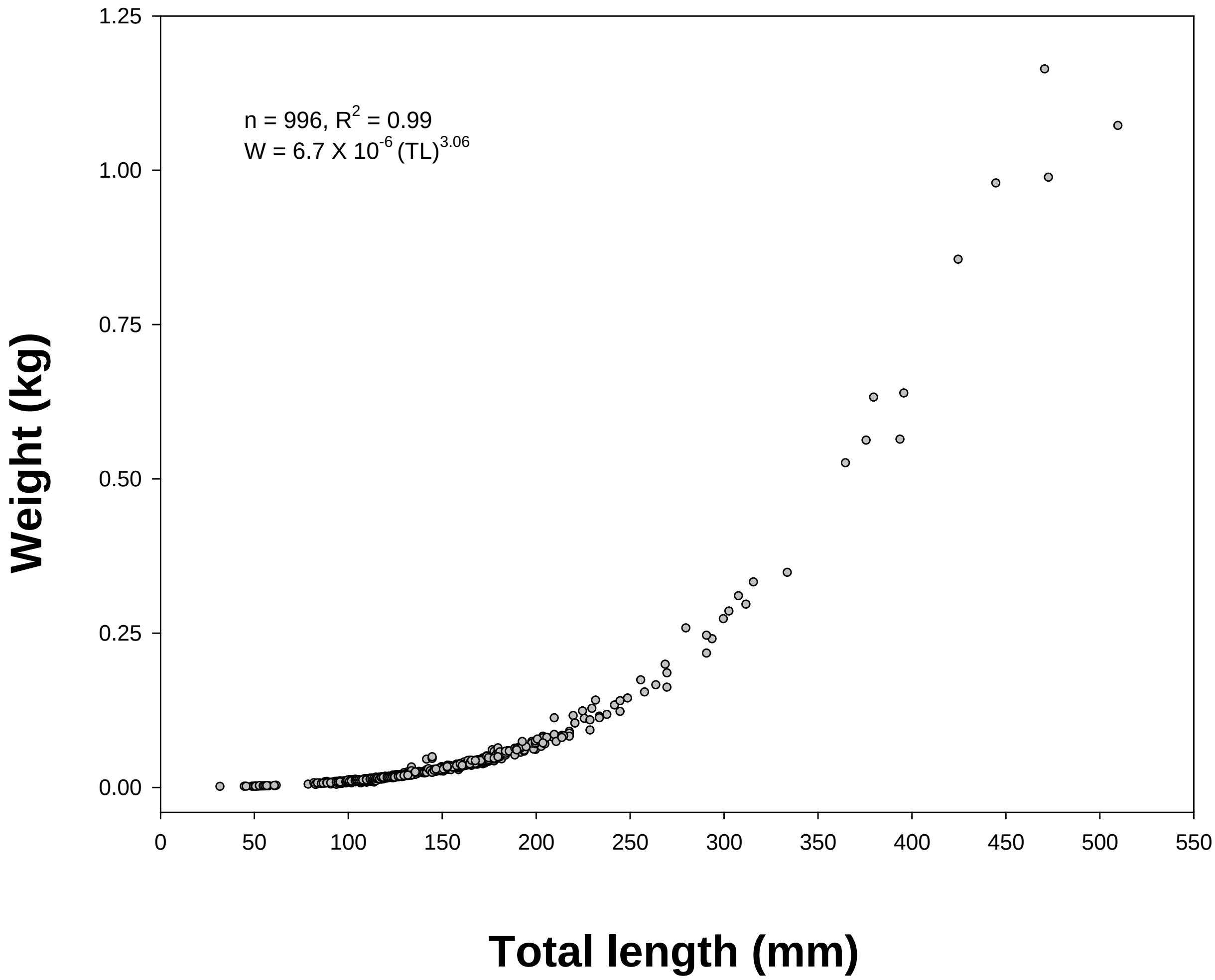

Figure 4. Length-weight relationship for bull trout captured and handled in the North Fork Umatilla River from 2003 – 2008. Regression equation and sample size is given.

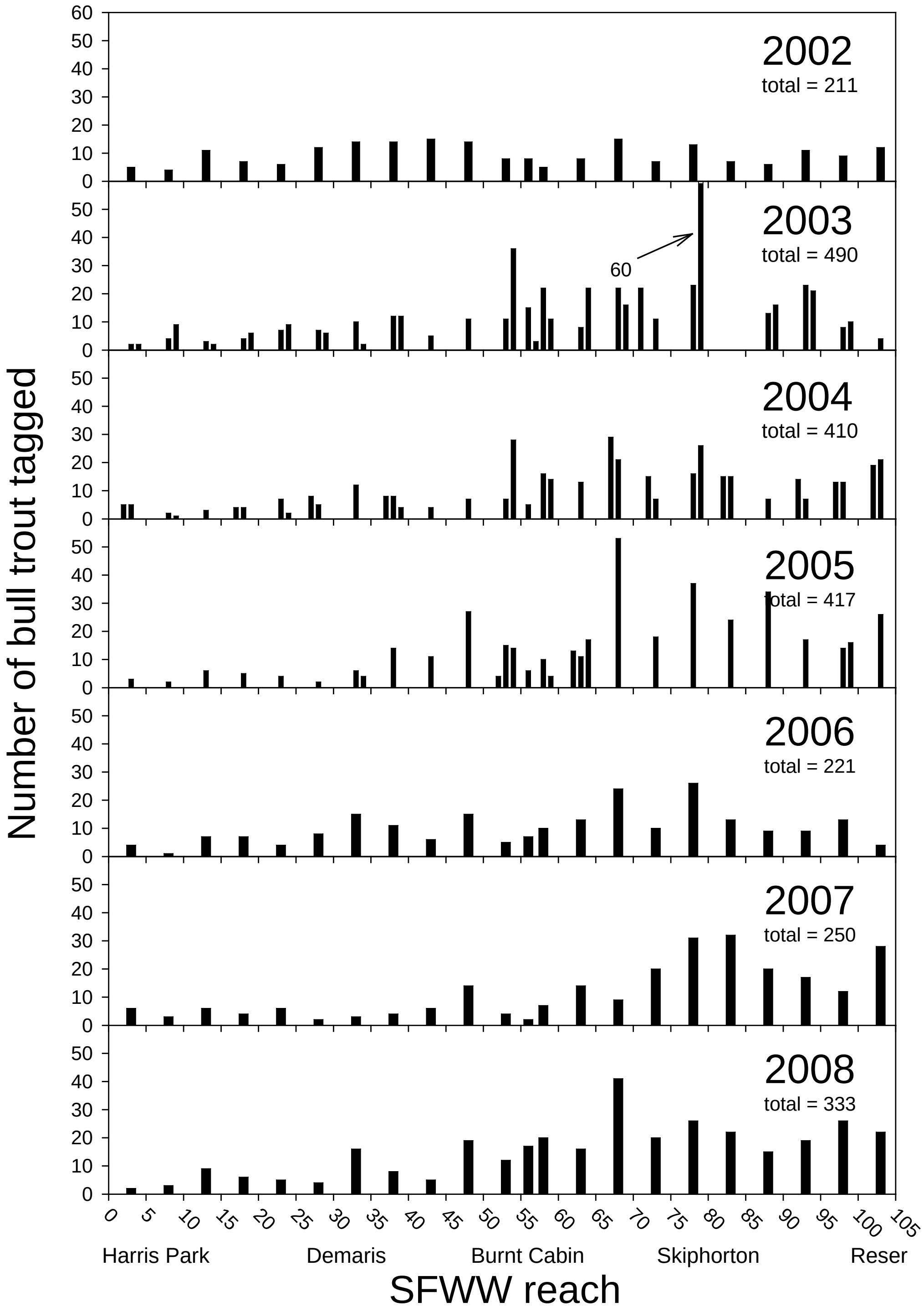

Figure 5. Number of bull trout tagged by reach in the South Fork Walla Walla River, 2002 - 2008. Reaches are numbered from bottom to top of the study site. Total numbers tagged are given below sample year. Note: 2007 and 2008 numbers include 104 and 100 bull trout <120 mm respectively. Percentage of stream sampled in 2003 and 2004 and 2005 increased to approximately 47%, 47% and 33% of study site, respectively.

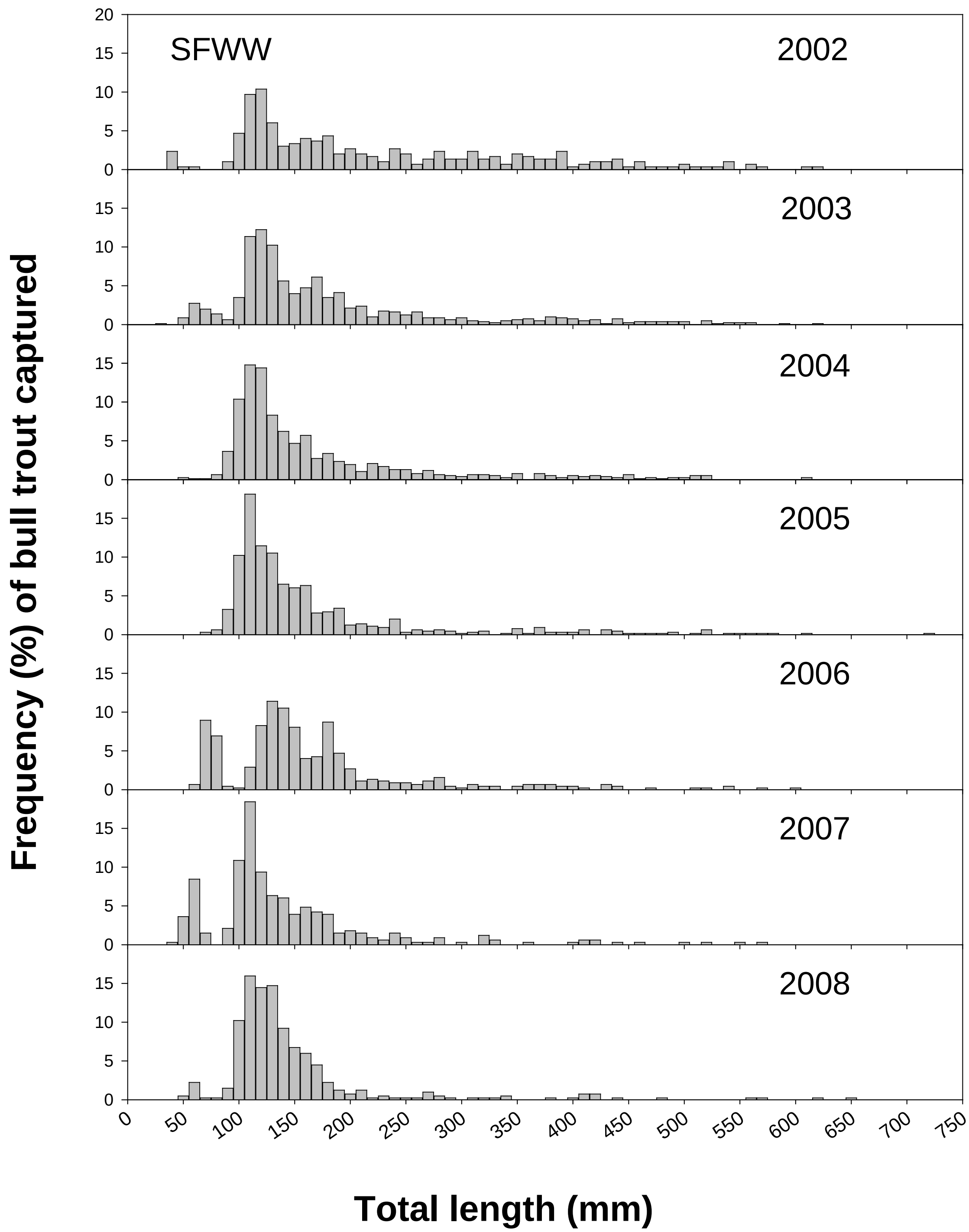

Figure 6. Length-frequency (% of catch) distribution of bull trout captured and handled in the South Fork Walla Walla River, 2002 - 2008.

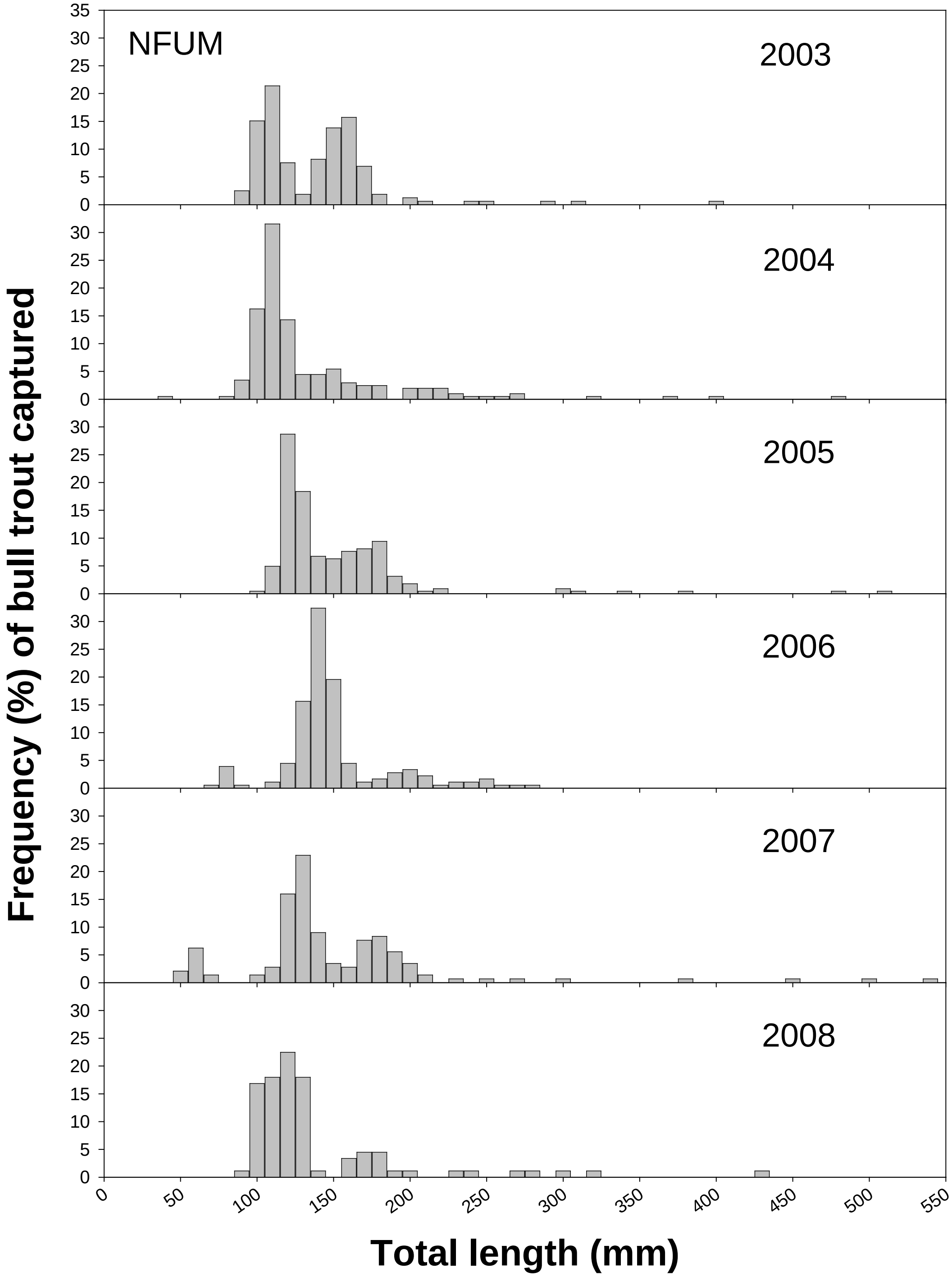

Figure 7. Length-frequency (% of catch) distribution of bull trout captured and handled in the North Fork Umatilla River, 2003 - 2008.

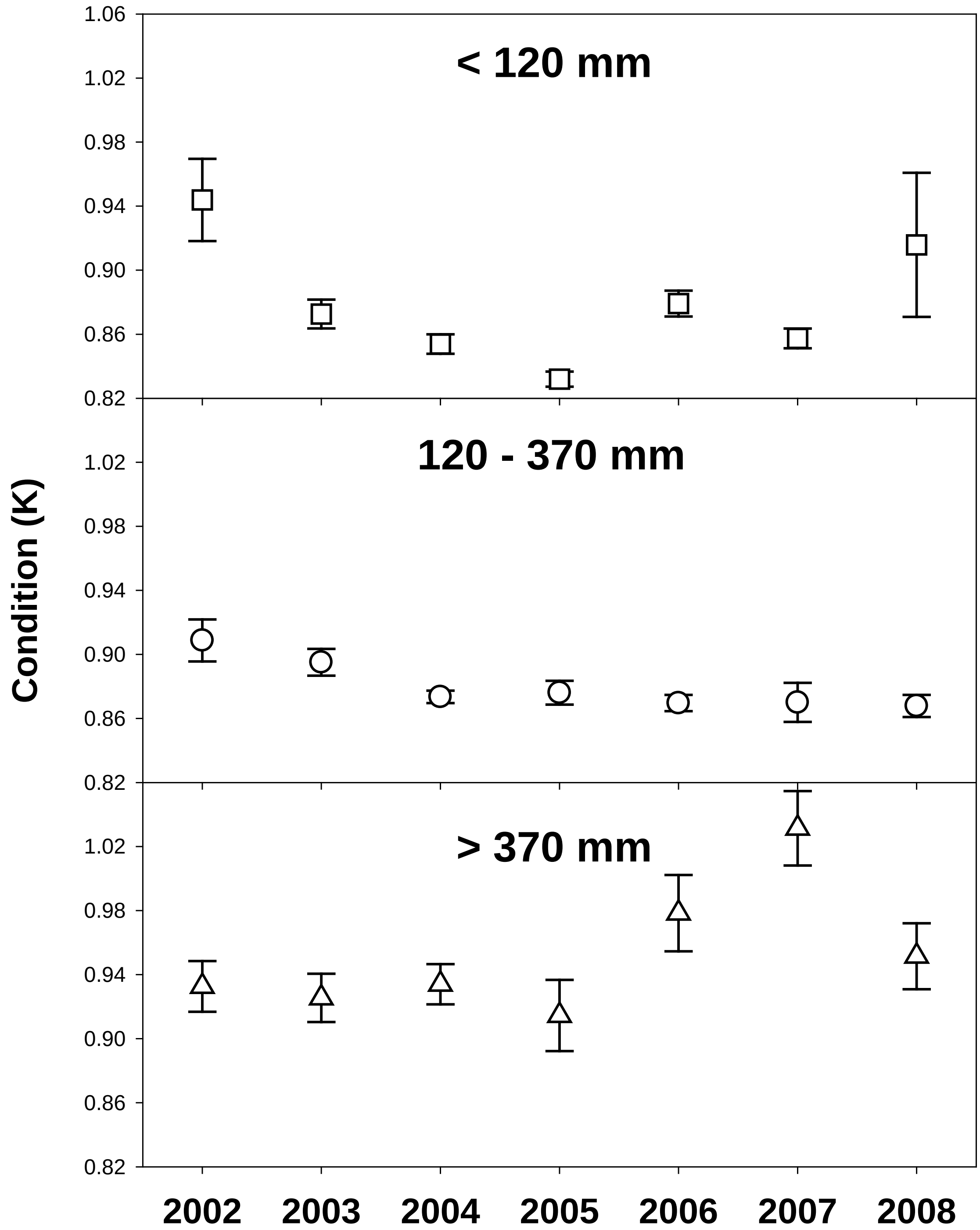

Figure 8. Condition (Fulton's K ± 1 SE) of three different size classes of bull trout sampled in the South Fork Walla Walla River, 2002 - 2008.

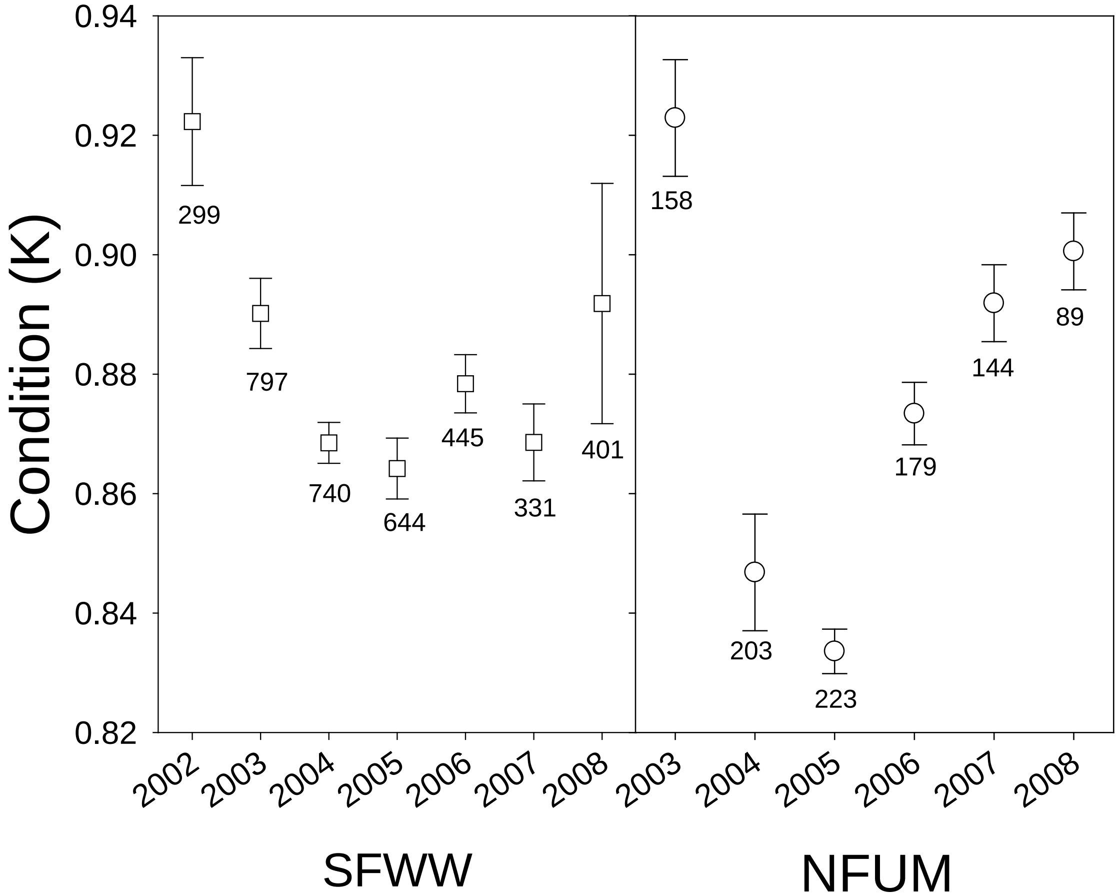

Figure 9. Average condition (Fulton's K ± 1 SE) of bull trout (all sizes combined) sampled in the South Fork Walla Walla River (2002 - 2008) and North Fork Umatilla River (2003 – 2008). Sample size is given below error bars.

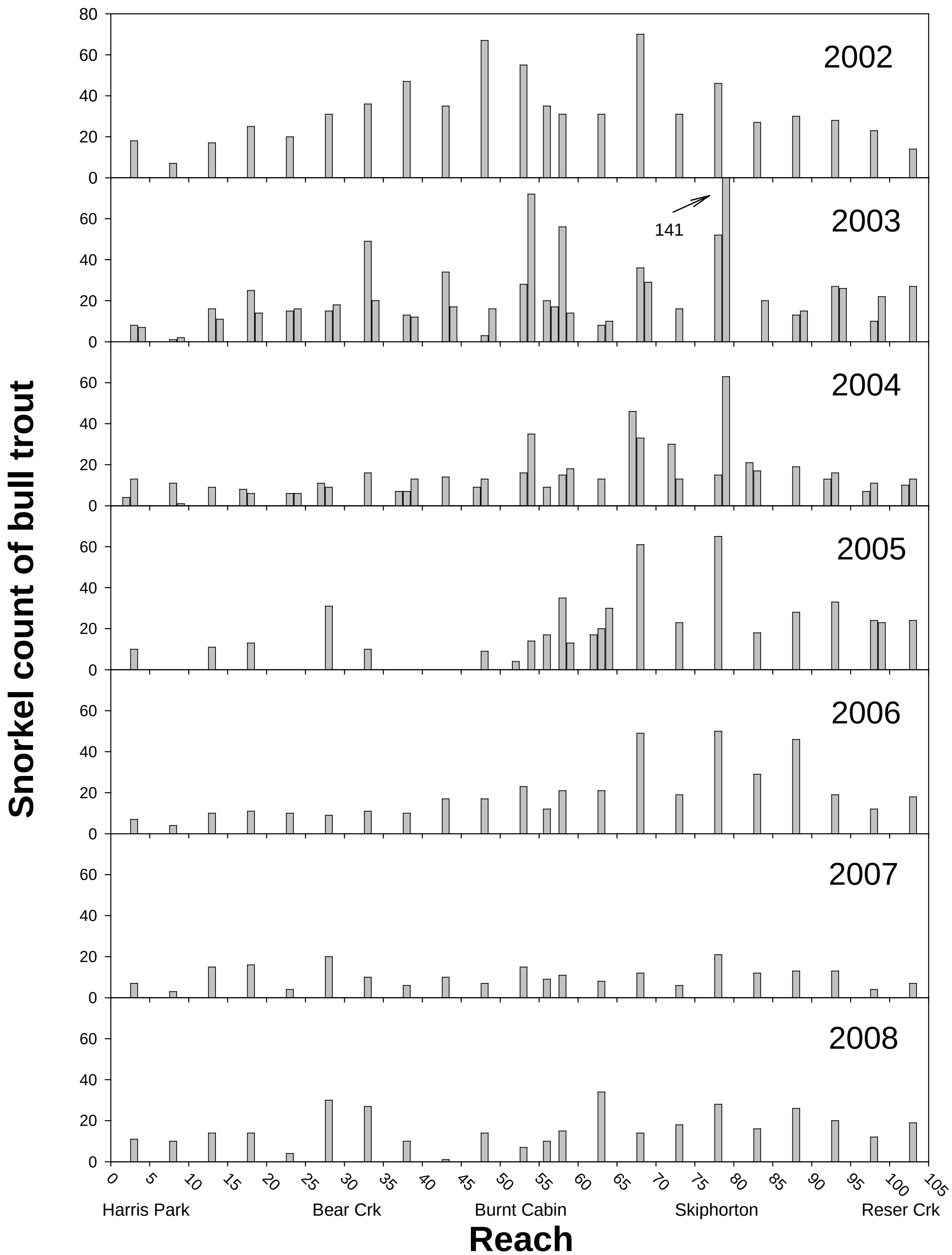

Figure 10. Number of bull trout by reach counted during snorkel surveys in the South Fork Walla Walla River, 2002 - 2008. Reaches are numbered from bottom to top of the study site. No bar implies that no sampling was conducted in a particular reach. Percentage of stream sampled in 2003 and 2004 and 2005 increased to approximately 47%, 47% and 30% of study site, respectively.

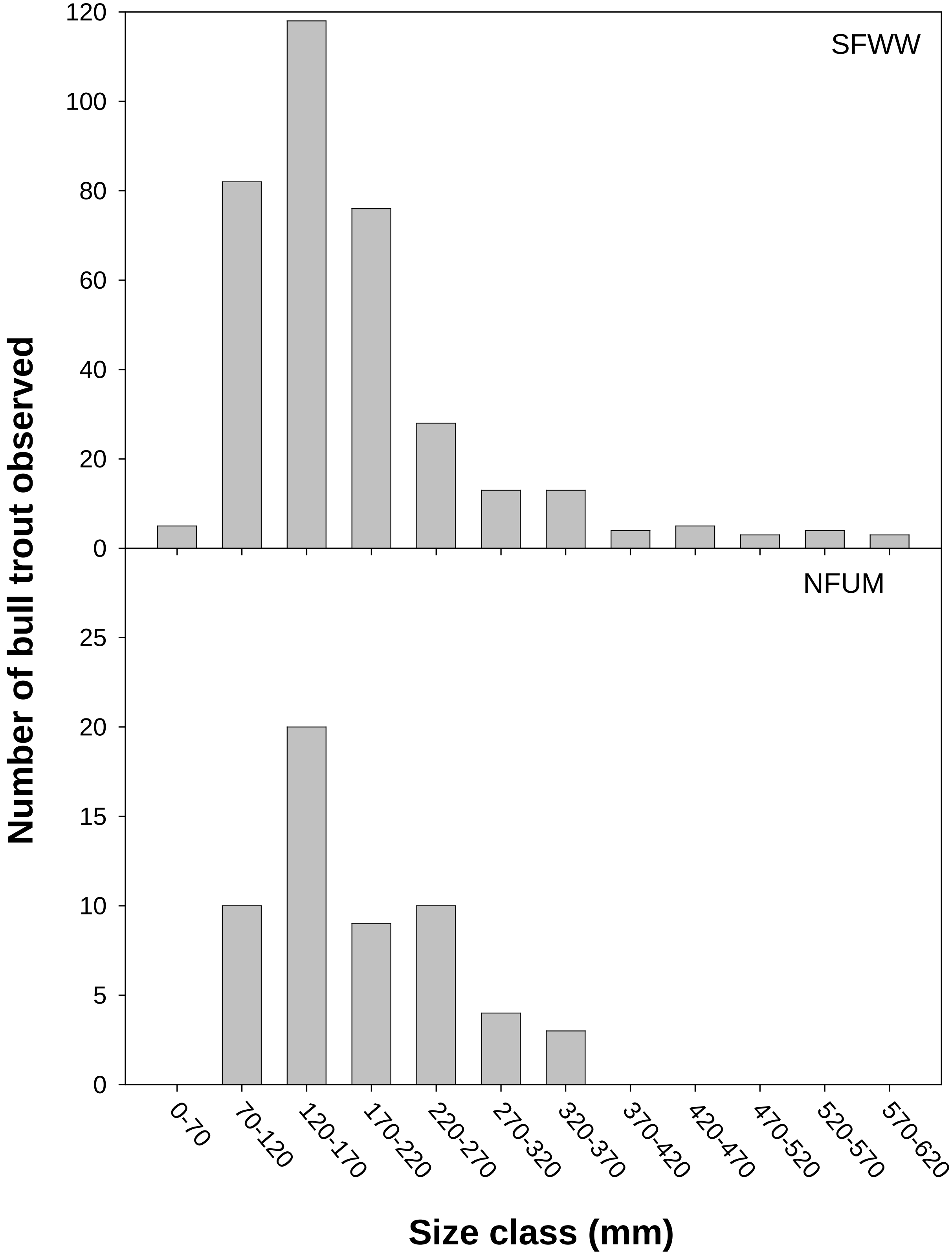

Figure 11. Number of bull trout in 50-mm size bins observed during snorkel surveys in the South Fork Walla Walla River and North Fork Umatilla River in 2008. Note changes in y-axis scales.

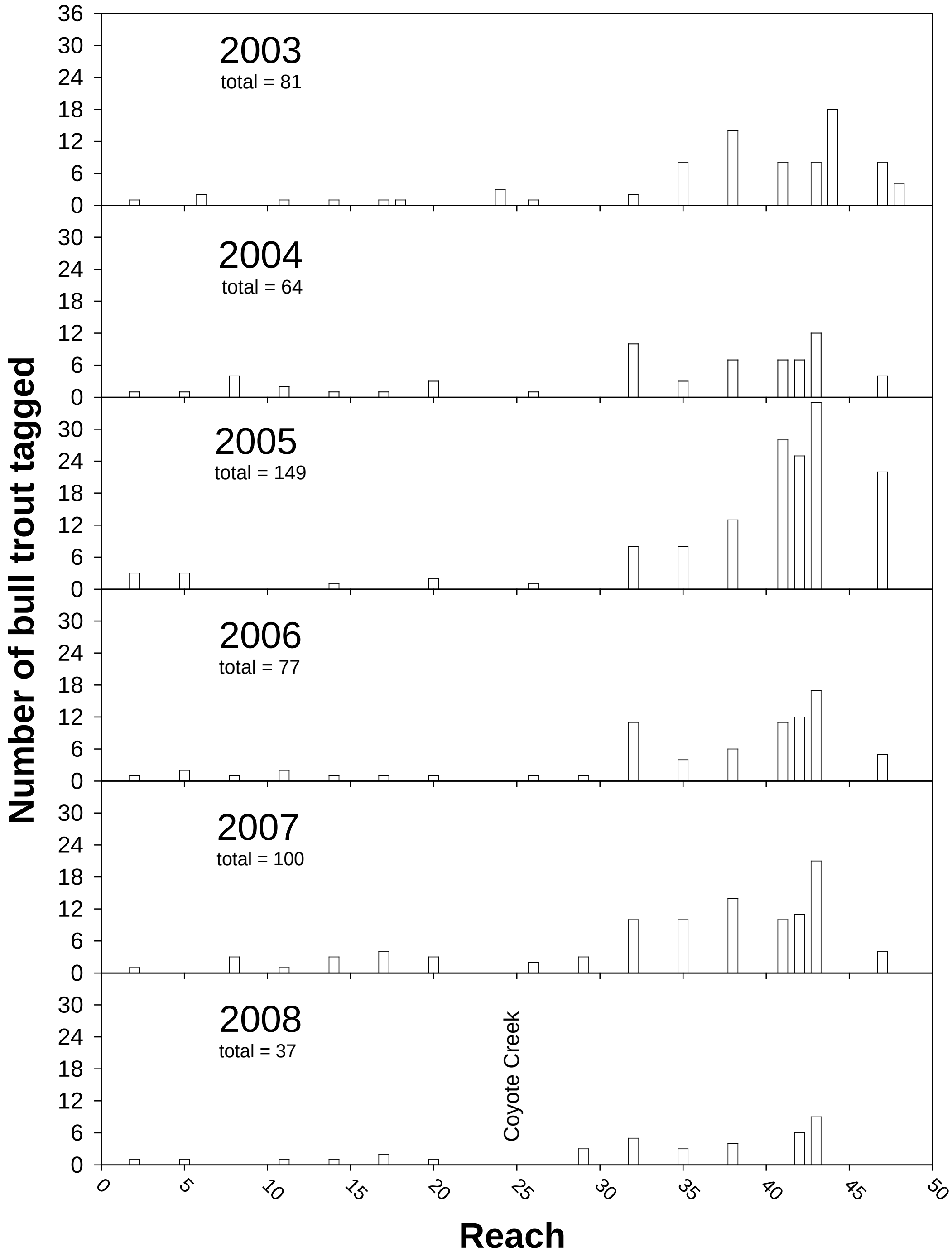

Figure 12. Number of bull trout tagged by reach in the North Fork Umatilla River, 2003 - 2008. Reaches are numbered from bottom (reach 1) to top (reach 47) of the study site. Total numbers tagged are given below sample year.

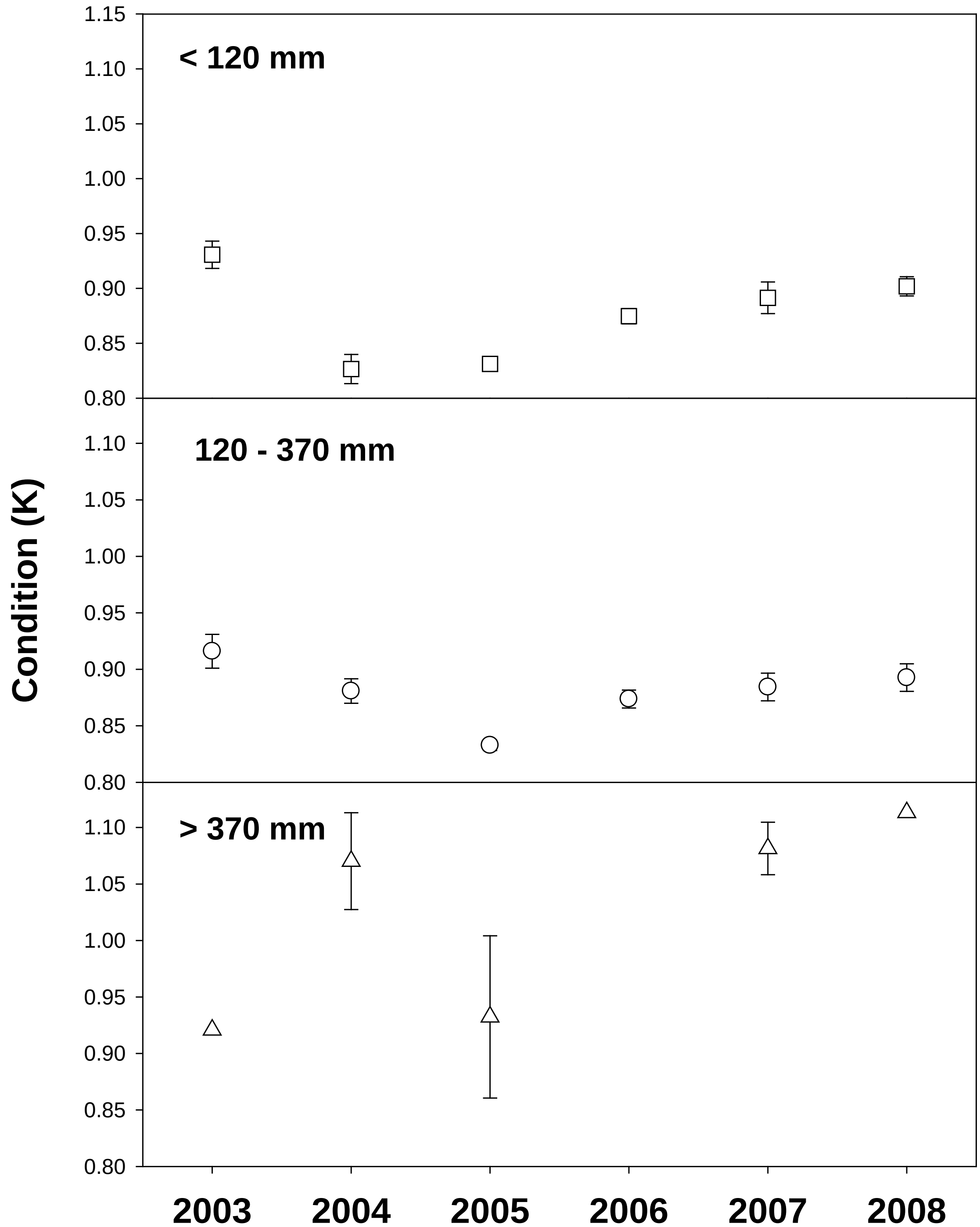

Figure 13. Condition (Fulton's K ± 1 SE) of three different size classes of bull trout sampled in the North Fork Umatilla River, 2003 - 2008. Note: no bull trout >370 mm were captured in 2006 and one bull trout >370 mm was captured in 2008.

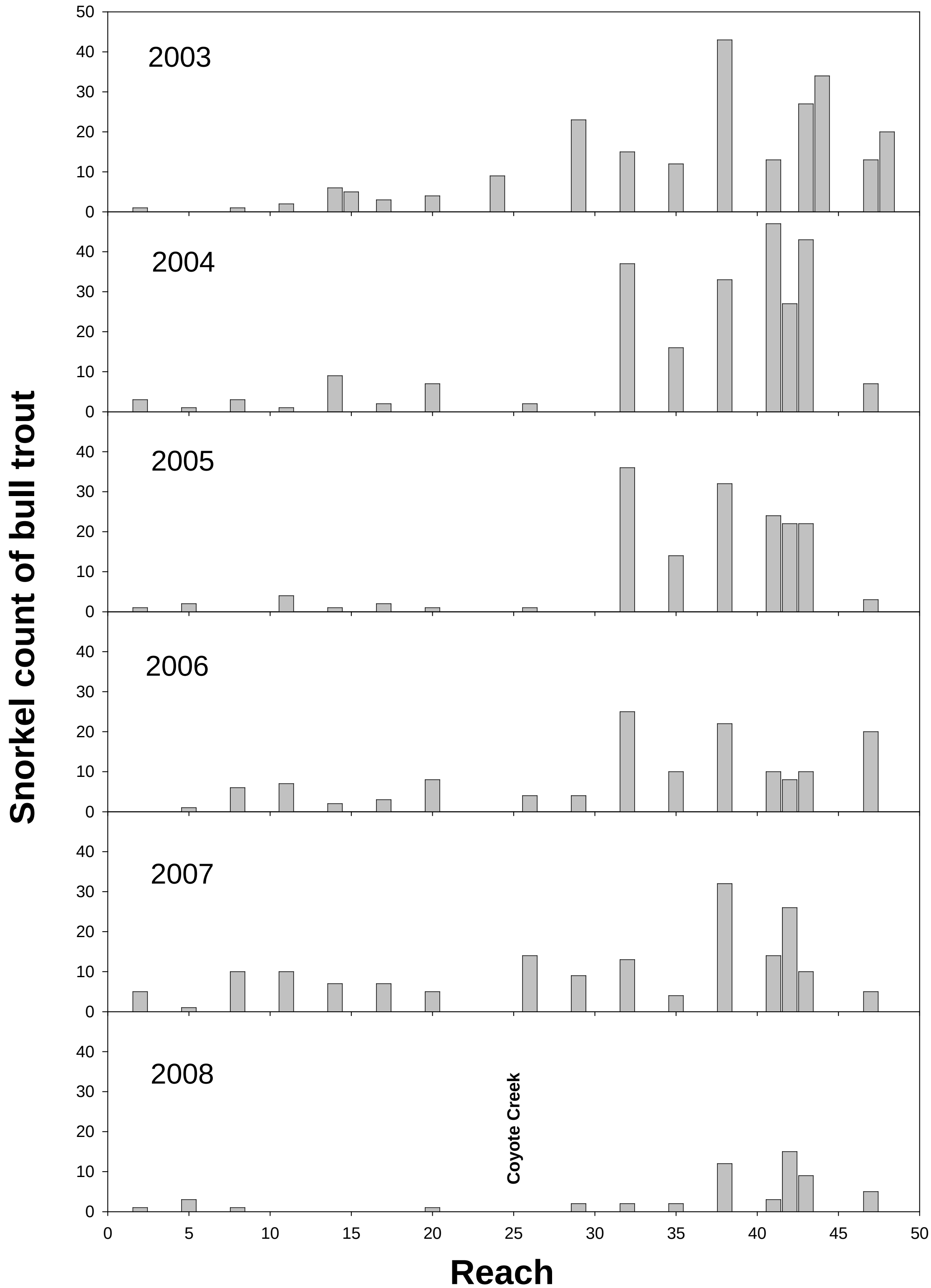

Figure 14. Number of bull trout counted by reach during snorkel surveys in the North Fork Umatilla River, 2003 - 2008. Reaches are numbered from bottom (reach 1) to top (reach 47) of the study site.

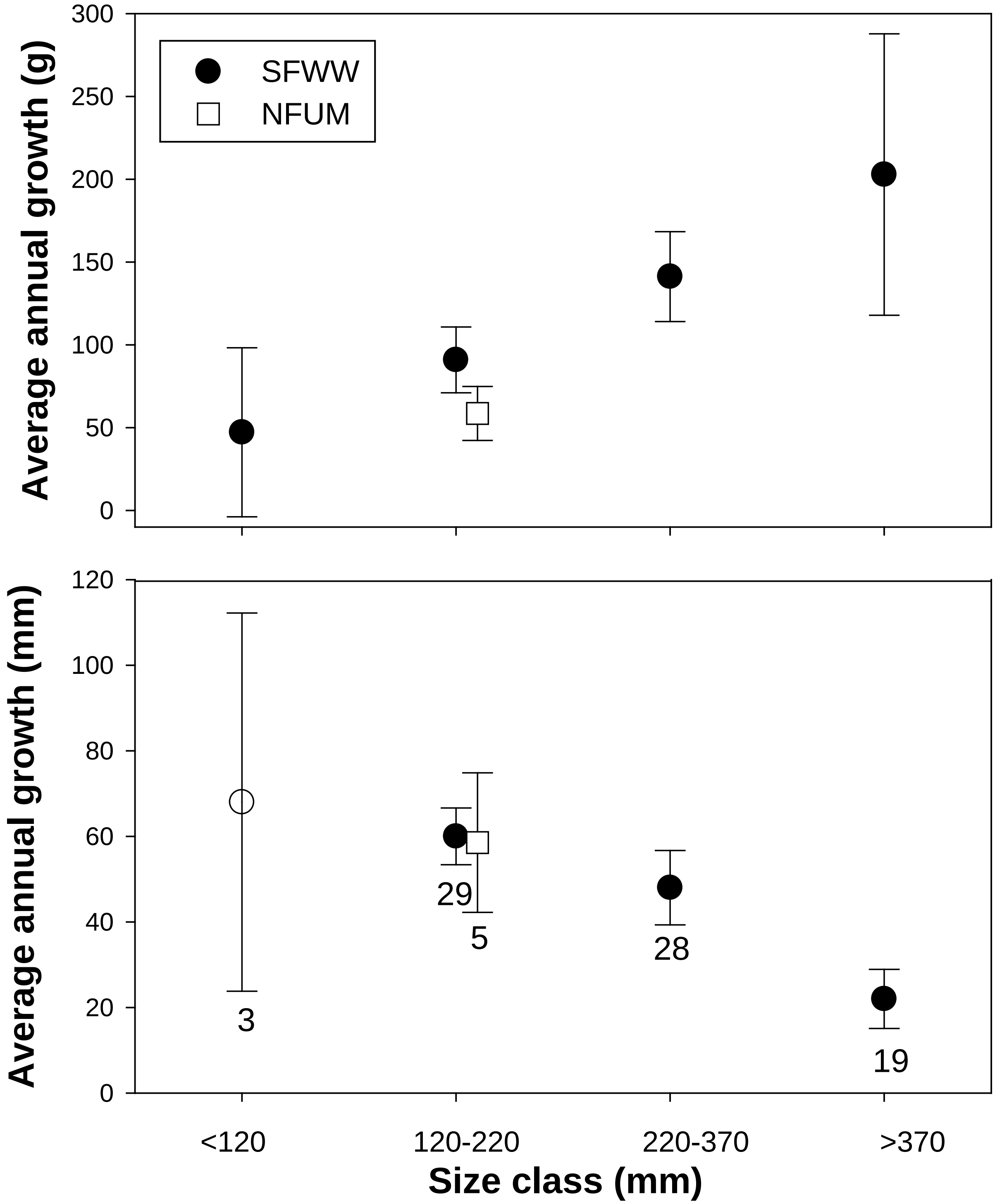

Figure 15. Average annual growth (± 2 SE) in weight (g, top panel) and length (mm, bottom panel) for three size classes of tagged and recaptured bull trout in the South Fork Walla Walla (SFWW), 2002 - 2008 and the North Fork Umatilla (NFUM) 2003 - 2008. Sample sizes are given below error bars. Note: no bull trout >220 mm have been recaptured for growth estimates in the NFUM.

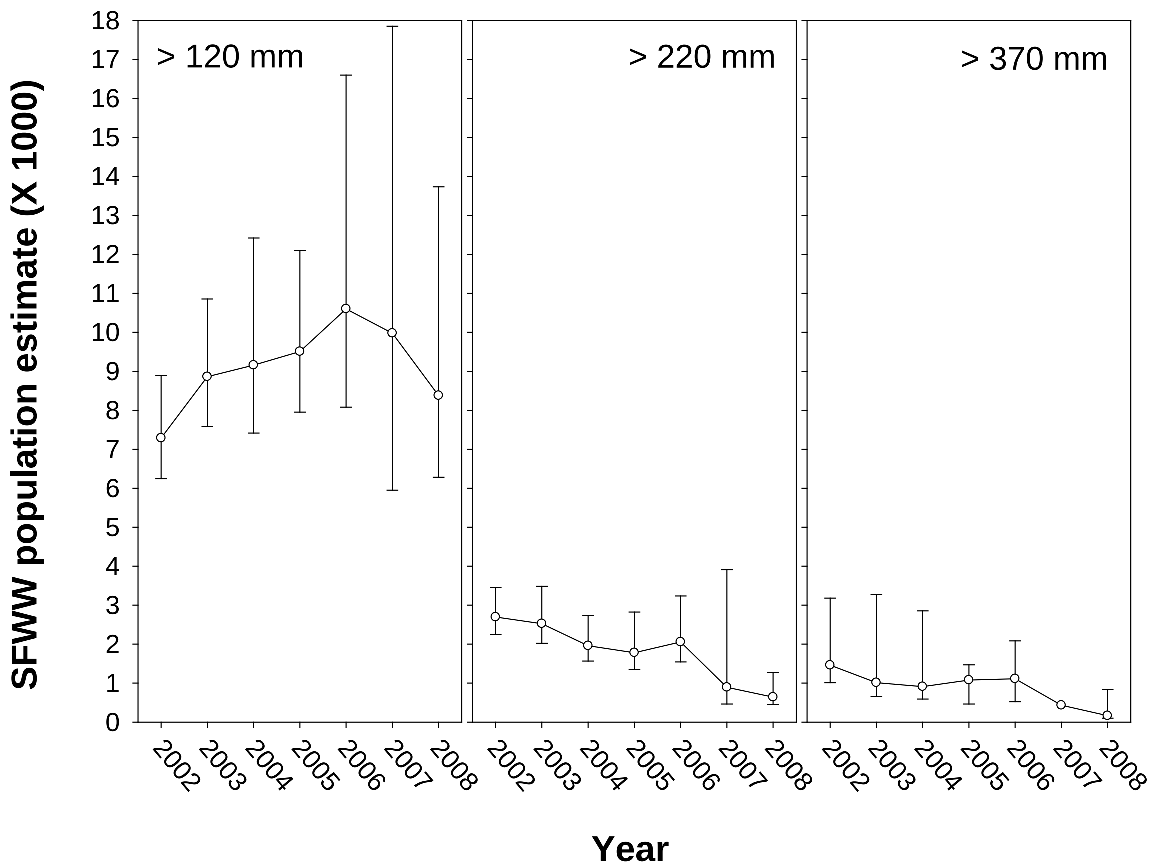

Figure 16. Annual population estimates (± 95% CI) for three size groupings of bull trout in the South Fork Walla Walla River, 2002 - 2008. Due to low sample size, no confidence intervals were obtainable for the bull trout population component > 370 mm TL in 2007.

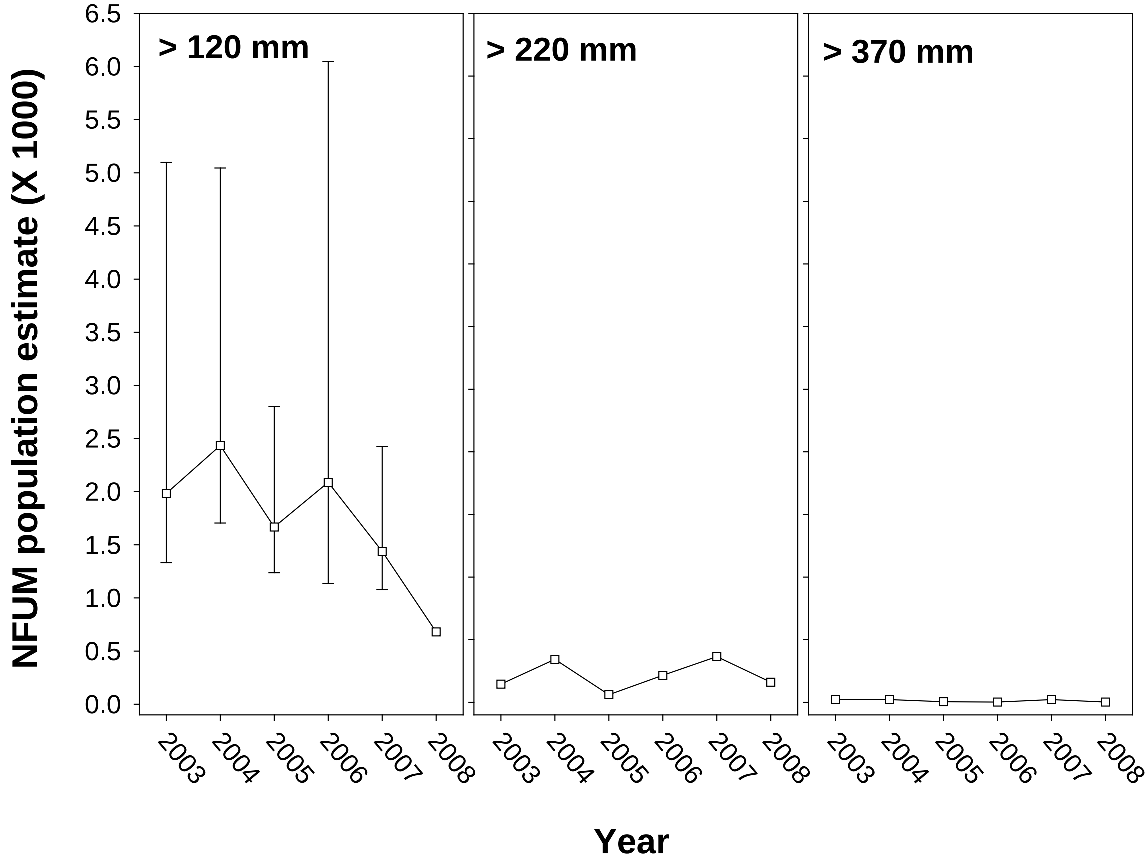

Figure 17. Annual population estimates (± 95% CI) for three size groupings of bull trout in the North Fork Umatilla River, 2003 - 2008. Where no error bars are shown, sample sizes were too low to for 95% CI calculations.

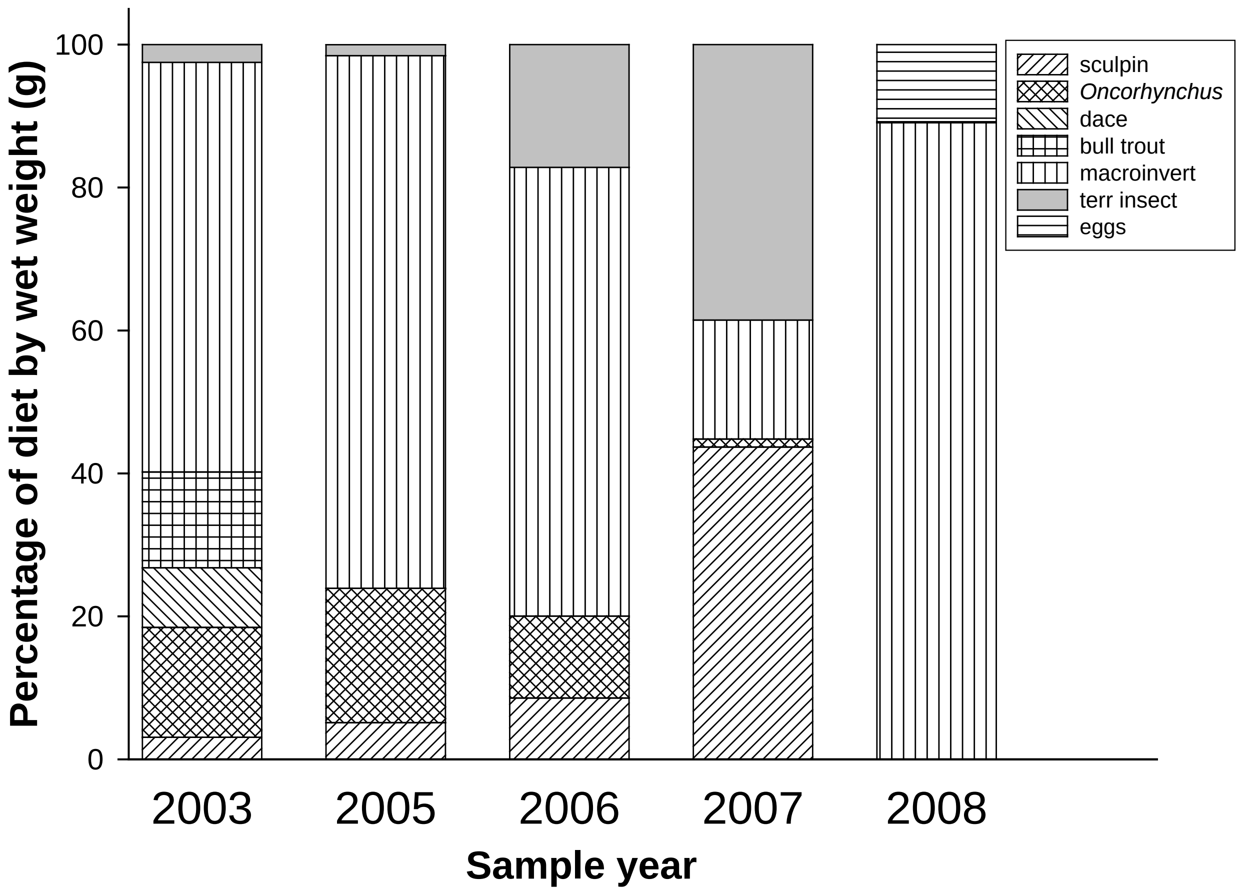

Figure 18. Diet composition (% of diet by wet weight) of bull trout captured in the South Fork Walla Walla River in 2003, 2005, 2006, 2007 and 2008. "*Oncorhynchus*" includes all salmonid species, except bull trout. "Macroinvert" includes all aquatic invertebrates. "Terr insect" includes all terrestrial invertebrates. "Eggs" are bull trout eggs.

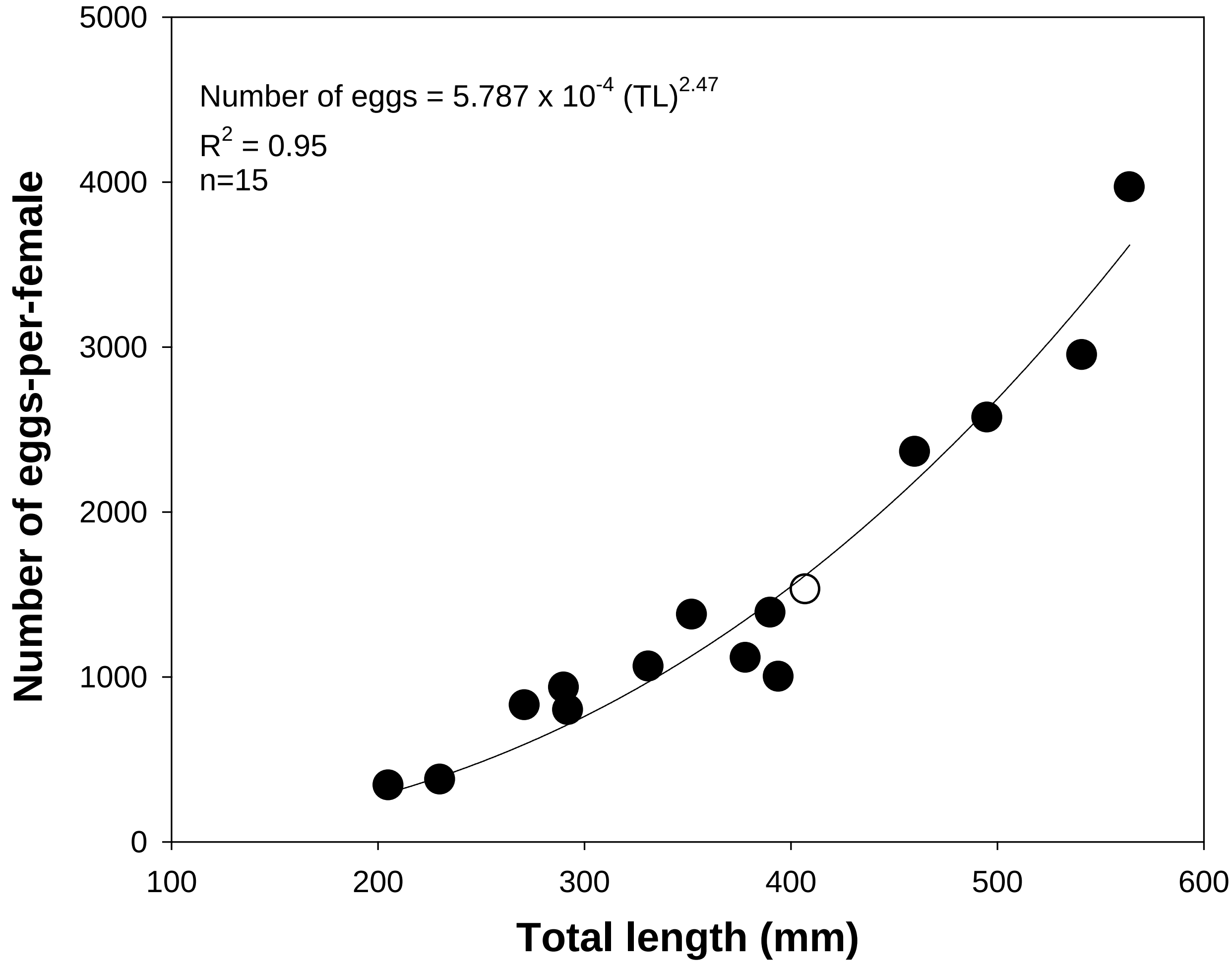

Figure 19. Female length-fecundity relationship for South Fork Walla Walla River bull trout (2002 - 2008).

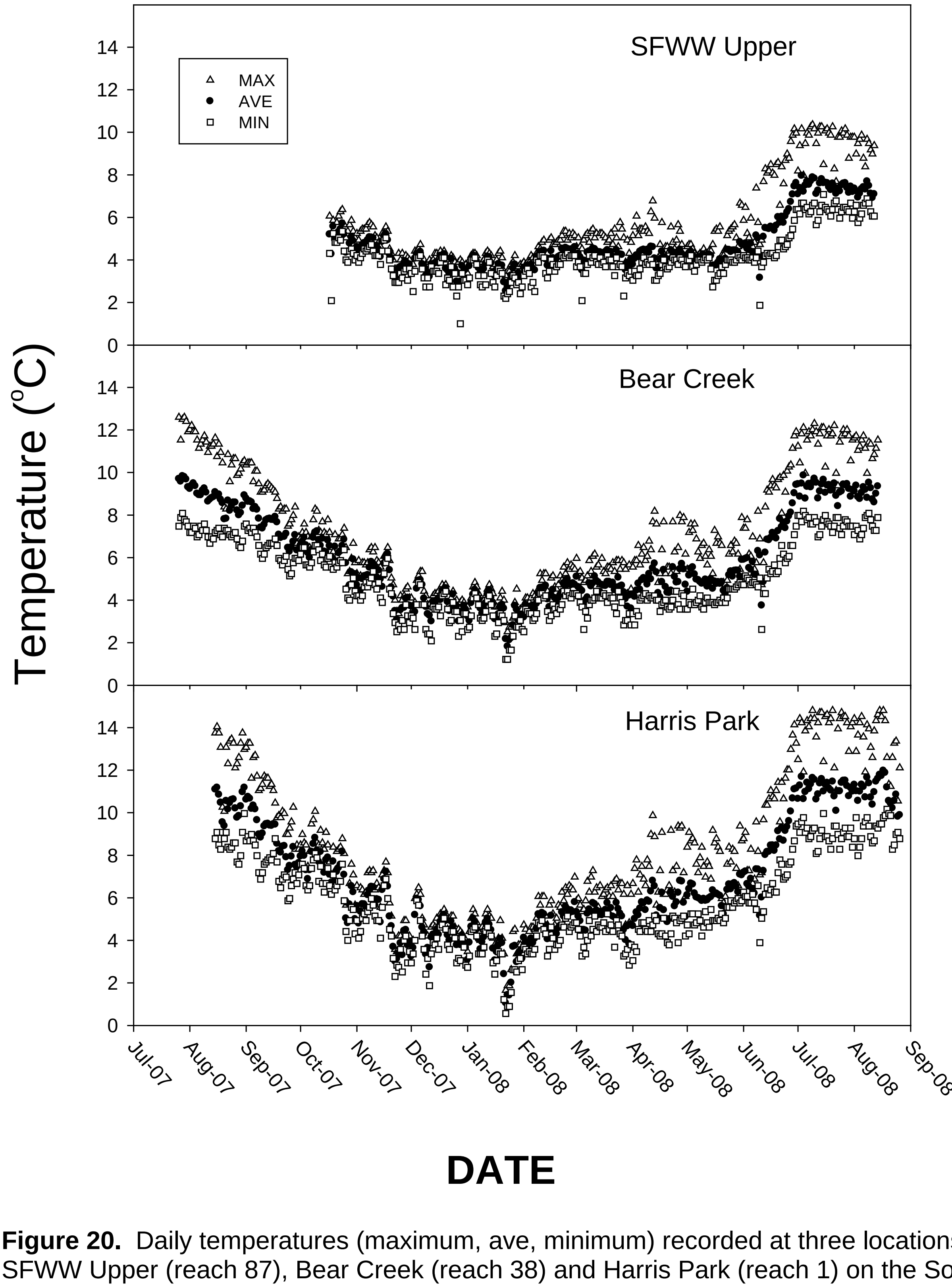

Figure 20. Daily temperatures (maximum, ave, minimum) recorded at three locations SFWW Upper (reach 87), Bear Creek (reach 38) and Harris Park (reach 1) on the South Fork Walla Walla River, July 2007 - August 2008.

APPENDIX 2

Comparison of mark-recapture models to estimate survival for juvenile bull trout.

INTRODUCTION

Many salmonids utilize a range of habitats throughout different life stages, and factors limiting survival may vary for different life stages (Hillborn et al. 2007). In order to prioritize recovery efforts for imperiled populations, it is important for managers to identify which life stages are most vulnerable and how environmental factors affect survival at critical life stages. Bull trout often utilize different habitats during different stages of development and may exhibit multiple, co-existing life history strategies, including resident and migratory forms (McPhail and Baxter 1996). Because habitat needs may vary between different life stages and life-history strategies, recovery efforts should consider habitat requirements specific to each life stage as well as the influence of individual life stages on overall population growth and persistence.

Declines in the distribution and abundance of bull trout have incited research aimed at determining factors limiting population growth rates. Models that predict population responses to environmental and demographic stochasticity suggest that bull trout population growth may be most sensitive to changes in survival for older age classes and early life-stages (Rieman and McIntyre 1993; Al-Chokhachy 2006). The predictive ability of such models, however, depends upon reliable empirical estimates of demographic rates of survival and fecundity. As with any species that exhibits a type III survivorship curve, where mortality rates are high for early life stages, accuracy of survival estimates for bull trout are extremely important, since even very small changes in survival estimates at early life stages can have dramatic effects on predictions of overall population growth (Morris and Doak 2003). Current population models for bull trout are limited by a lack of field-based, age-specific survival estimates for larval and juvenile stages; these stages are often lumped together in population models. Modeling these life stages together precludes identification of specific bottlenecks that may occur during the development period between egg deposition and when juveniles leave rearing habitat. For example, examination of stock-recruitment relationships by Johnston et al. (2007) indicated that recovery of a bull trout population in Alberta, Canada was regulated by early life-stage survival in the rearing creek, but did not identify the source of this population bottleneck. Improving understanding of survival rates and factors affecting survival at specific life stages will help biologists effectively manage resources in spawning and rearing habitat.

Previous population models for bull trout have used demographic parameters for similar species (e.g., brook trout, *s.fontinalis*) to project changes in population growth (Al-Chokhachy 2006), but because of the sensitivity of many models to estimates at early life stages, projections based upon vital rates of other species may lead to spurious conclusions . Additionally, many estimates of juvenile fish survival have been based upon cohort-specific abundance estimates or changes to abundance (Ombredane et al. 1998; Paul et al. 2000), which may be influenced by sampling efficiency or variations in emigration and immigration rates that models often to not account for. This may be of particular concern for bull trout populations, since individuals often exhibit complicated migration patterns and true survival rates are often naturally highly variable across sites, both locally and between river systems. Field-based estimates of survival rates for early juvenile (age-1 and age-2) age classes for bull trout are lacking, although Paul (2000) calculated density-dependent over-summer survival rates for juvenile bull trout within stream exclosures and analyzed the role of juvenile densities on spawner-recruit relationships. Reliable estimates of survival and variability in survival are important not only for improving the accuracy of population models, but also to comprehend the magnitude of natural variability (e.g., changes in water levels, density-dependent interactions) relative to anthropogenic variability (e.g., land-use, water withdrawal). Knowledge of how environmental factors impact survival rates is critical for managers to understand their potential to actually affect changes in survival. Understanding factors that may affect early age-class survival will help managers prioritize habitat protection specific to spawning and rearing, and will improve understanding of the relative importance of this life stage to overall population growth.

Capture-mark-recapture methods have long been used to estimate population sizes, growth rates, and survival rates (Burnham et al. 1987; Lebreton et al. 1992). Recent advances in technology, including in-stream Pit-tag antennae, have allowed researchers to collect additional recapture data on individuals by means of passive detections. Passive in-stream antennae detect fish tagged with PIT tags as they move through the antennae, generating additional recaptures of previously PIT-tagged individuals without further harassment. Such recapture methods have spurred new analytical methods which combine data from both active, discrete recapture events with ongoing, passive recaptures to estimate demographic parameters for the population of interest. While PIT-tag antennae have become increasingly common ways of gathering data which can be used to estimate movement and survival across multiple size classes and populations (Skalski et al. 1998; Al-Chokhachy 2006), there have been few comparisons of how different capture techniques improve the accuracy and precision of estimates for parameters of interest.

We compared two different types of models for estimating survival for juvenile (age-1 and age-2) bull trout using different combinations of recapture data to determine differences in precision among the models and to assess the relative contribution of various recapture methods to improving model fit. We used these two models to compare estimates of over-summer survival from May through September 2008.

METHODS

Site description.—Skiphorton Creek originates in the foothills of the Blue Mountains of northeastern Oregon and enters the South Fork Walla Walla River (SFWW) approximately 112 km upstream from the confluence of the South Fork and mainstem Walla Walla River. Skiphorton Creek is a relatively low volume (0.29 m^3/s at base flow) creek that provides spawning and rearing habitat for relatively high densities of juvenile bull trout. The stream is characterized by complex habitat, including small side channels, pools, undercut banks, and large woody debris. During the summer, the fish assemblage is composed of juvenile or small resident bull trout (primarily <170 mm) and rainbow or steelhead trout (*Oncorhynchus mykiss* spp.). We captured juvenile bull throughout approximately 600 m of Skiphorton Creek directly upstream of the confluence with the SFWW; this section was divided into 10 contiguous reaches of approximately 50 m in length and the entire area censused during each sampling event.

Fish sampling and tagging.— During the summer of 2008, we conducted three mark-recapture sampling events, the first in May, the second in July, and the third in August. During each of these sampling occasions, we captured fish 70-170 mm by electrofishing downstream to seine (electroseining). All captured fish were scanned for PIT tags. We anaesthetized fish >70 mm and once fish were unresponsive to stimuli, we inserted a PIT tag into the ventral cavity, anterior to the pelvic fins. Initially, fish were given tag sizes according to their body size: fish 70-100 mm were implanted with 8-mm PIT tags, fish 100-150 mm implanted with 12-mm tags, and fish > 150 mm implanted with 23-mm tags. After July 2008, all fish 70-150 mm were implanted with 12-mm tags. All captured fish were weighed to the nearest 0.1 grams, and measured to the nearest mm total length (TL). Adipose fins were clipped to identify marked fish. Scales were taken from the right side at the base of the dorsal fin for ageing and growth information, and fish were placed in a flow-through recovery container within the channel and released to slow-water habitat near the point of capture after full equilibrium was restored. All fish recaptured in this manner were passed over a handheld PIT-tag detector for identification, and lengths and weights were recorded to obtain information about growth rates, condition, and movement.

We used additional recapture data collected during both discrete and ongoing occasions during the summer of 2008. We installed an in-stream pass-through PIT-tag detection station comprising of one antenna in Skiphorton Creek just upstream of the confluence with the SFWW to detect PIT-tagged fish and a weir that directed fish to swim through the antenna loop. The detection station operated continuously from July 25 through August 28, and from September 9 through September 23. System failure between August 28 and September 9 was a result of lack of solar gain with which to power the antenna. In addition, during two discrete occasions on August 19 and September 9, we collected recapture data using a portable waterproof PIT-tag antenna available from Biomark, Inc. (see Cucherousset et al. 2005). The portable antenna's maximum distance ranged from 15 to 25 cm, depending on the size and orientation of the tag. The portable antenna operator walked upstream throughout the entire sample area, moving the antenna slowly across the stream bottom, ensuring that all stream areas were passed over within the antenna's detection range. PIT tags were identified as either "live" or "dead" tags in the following manner: after detecting a PIT tag, the antenna operator disturbed the substrate adjacent to the tag and then swept the area again with the antenna. "Live" fish almost always moved immediately when the substrate was disturbed, and always moved after at a second disturbance. Tags that did not move after 3 substrate disturbances were marked as "dead." Dead tags were corroborated when the operator observed the same dead tag in the same location during the second sampling event, whereas no tags that had been reported "live" during the first sampling event were found in the same place during the subsequent antenna detection. While "dead" PIT tags could either be from fish that had died or shed their tags, we assumed these PIT tags were indicative of dead fish, since during the course of this study we have not recaptured any juvenile fish (70-170 mm) that had shed their PIT tags (n=51, as would be evidenced by clipped adipose and no PIT tag) and other studies have shown low rates of PIT tag loss (96% and 99.8%, Ombredane et al. 1998; Gries and Letcher 2002). Bull trout associated with "dead" tags were recorded as dead on the sampling event following the last occasion when the animal was known to be alive (Burnham 1993).

Model selection and comparison.—We used two different types of open population models to estimate survival for juvenile bull trout in the computer program MARK . First, we used a Cormack-Jolly-Seber (CJS) model to estimate apparent survival (Cormack 1964; Jolly 1965; Seber 1965) using data from discrete recapture events collected during electrofishing sampling and using the portable antenna. In the second analysis, we used a model developed by Barker (1997) to estimate survival using live recapture data gathered via ongoing detections at the in-stream antenna in addition to discrete recapture events using electrofishing to detect live fish and the portable antenna to gather recapture information about both live and dead fish. In our study, dead fish were detected during active sampling with the portable PIT tag antenna, but reported dead in the interval between active sampling events in order to conform to model structure. For both the CJS and Barker model frameworks, we grouped all fish 70-160 mm because of a lack of data for fish 140-160 mm, even though the size range sampled likely represents both age-1 and age-2 fish.

Using the CJS model framework, we developed candidate models to assess effects of different factors on both survival and detection probability (Table 1a). Survival probabilities from these models are estimates of "apparent survival," where losses may be due to mortality or to movement of tagged individuals out of the study area (White and Burnham 1999). We identified factors *a priori* that could affect both survival estimates and detection probabilities and included these in candidate models. These factors included differences in sampling method, time effects, and the effects of the following individual covariates: length, condition, and size of the PIT tag.
Using the Barker model framework, we developed similar candidate models, incorporating both environmental, sampling, and covariate effects in the models (Table 1b). This model framework allows for estimation of survival and emigration/immigration as well as recapture probabilities, and can therefore be considered an estimate of "true" survival. Because the Barker model utilizes numerous parameters to parse out probabilities for both discrete and ongoing recapture probabilities (Barker 1997), we were forced to keep models simple in order to have sufficient data to estimate numerous parameters. We were therefore unable to incorporate time effects into our models, and we constrained parameters where data was unavailable (e.g., during the time periods when no dead fish were recovered, we set the dead recovery parameter equal to 0). We did incorporate the effects of individual covariates on survival, and assessed models that incorporated the effects of differences in sampling methods (i.e., electroseining vs. portable antenna recoveries).

To select the best models from within each of the CJS and Barker frameworks, we used Akaike's information criterion corrected for small sample size (AIC_c). We then compared survival estimates and standard errors from each of the top models using the two model frameworks in order to assess differences in estimates and in precision between the two.

RESULTS and DISCUSSION

Fish sampling and tagging.— During the three mark-recapture events conducted throughout the summer of 2008 in Skiphorton Creek, we caught 325 fish between 38 and 159 mm (Figure 1). Of these, 28 were recaptures from previous tagging events in 2008 or 2007. On August 13, we captured one bull trout 380 mm , the only fish >170 mm we captured in the study area. We implanted 270 fish > 70 mm with PIT tags. While sampling for bull trout, we also captured 114 *O. mykiss* (Figure 2), which we enumerated into two size classes.

Model selection and comparison.—For both the CJS and Barker model frameworks, lack of sufficient recapture data precluded precise estimates of time-varying survival. Therefore, we used only simple models that estimated only survival for the 137 day, period (May 2 through September 15). Based upon AICc weights and model likelihood, the top model CJS model incorporated variation in detection probability between the two discrete-time recapture methods, electroseining and backpack PIT-tag detector (Table A1a). The top Barker model likewise incorporated differences in detection probability between the two recapture methods (Table A1b). The estimated probability of recapture varied between the two recapture methods (Figure A3); electroseining had a higher recapture probability (0.175) than the portable backpack detector (0.100). Although recapture probability was considerably lower using the backpack detector, this method of detection did not require electroshocking or handling fish and had minimal impact on study area, thereby making it a worthwhile alternative method of accumulating further recapture data, particularly for sensitive species or stream systems. The top Barker model also included differences in detection probability between sampling periods when dead tags were recovered versus sampling periods when they were not, during which we held the probability of a dead recovery equal to zero. Because the stationary PIT-tag antenna array was not in operation throughout the entire sampling season, we did not have sufficient data to estimate emigration out of the study area. Therefore, we modeled random emigration in the best-fitting Barker model. Barker models that omitted data gathered from dead recoveries had poor model fit (as evidenced by model likelihood of zero and a delta AICc weight of > 9000). Given our sparse data of both live and dead recaptures, it is apparent that the dead recoveries contribute a significant amount of information to improve model fit.
The top Barker model yielded an over-summer survival estimate of 0.903 (95%CI = 0.017), while the top CJS model yielded a slightly lower survival estimate of 0.891 (95% CI 0.023; Figure A4). The Barker model's higher precision is likely a result of its ability to incorporate multiple forms of recapture data, including ongoing recaptures as well as dead recoveries. The CJS model is likely biased lower than the Barker because fish that emigrated from the system during the study period were no longer available for

subsequent recaptures, but could not be accounted for in the model. Because it is apparent that Skiphorton Creek provides predominantly rearing habitat for bull trout, and fish appear to leave the study area between age-1 and age-2, CJS estimates are likely to always be biased low for this system. In the future, use of the stationary PIT-tag detection station at the downstream end of the study area will not only provide important information about when fish leave the system, but will also improve survival estimates and may even provide sufficient information to estimate emigration from Skiphorton Creek. With additional recapture data for fish leaving the system, the fit of the Barker model will likely improve still further, yielding more precise estimates of survival.

FUTURE WORK

In 2009, we will again conduct three mark-recapture events in Skiphorton Creek, equally spaced throughout the summer. We will also conduct three additional discrete recapture events using the portable PIT-tag antenna, evenly spaced between marking events. We will operate the instream PIT-tag detection station just upstream of the confluence with the SFWW throughout the entire sampling season from May through the end of September. Increased operation time of the instream Pit-tag detection station, as well as recapture information will add to data collected in 2008 and improve precision of survival estimates. We will also continue to gather movement information at the instream detection station from juvenile fish moving out of the system and PIT-tagged adults moving into Skiphorton Creek to spawn.

CJS model	Description of model	Delta AICc	Model likelihood
A	Constant survival; recapture probability varies between capture methods	0.000	1.000
A’ (Condition)	Same as A above plus condition as covariate	0.2972	0.8619
A’’ (Length)	Same as A above plus length as covariate	1.1185	0.5716
B	Survival varies between capture methods; recapture probability varies between capture methods	1.8718	0.3922
D	Constant survival; constant recapture probability	7.0875	0.0290

Barker model	Description of model	Delta AICc	Model likelihood
1	Constant survival; recapture probability varies with method; dead recoveries constrained to sample periods when dead tags found; live continuous recoveries vary with antenna use; random emigration	0.000	0.99959
1’	Same as 1 above but assume permanent emigration	15.600	0.0004
2	Constant survival with length as a covariate; constant capture probability; constant dead recovery probability; constant live ongoing recapture probability; random emigration	83.232	0.0000
3	Same as top model 1 above, but without using dead recovery data	9097.7 08	0.0000

Table A1. Sub-set of candidate models evaluated for data fit using a Cormack-Jolly-Seber model framework (a) and Barker model framework (b). The top CJS model (A) and Barker model (1) were used to generate survival estimates for juvenile bull trout.

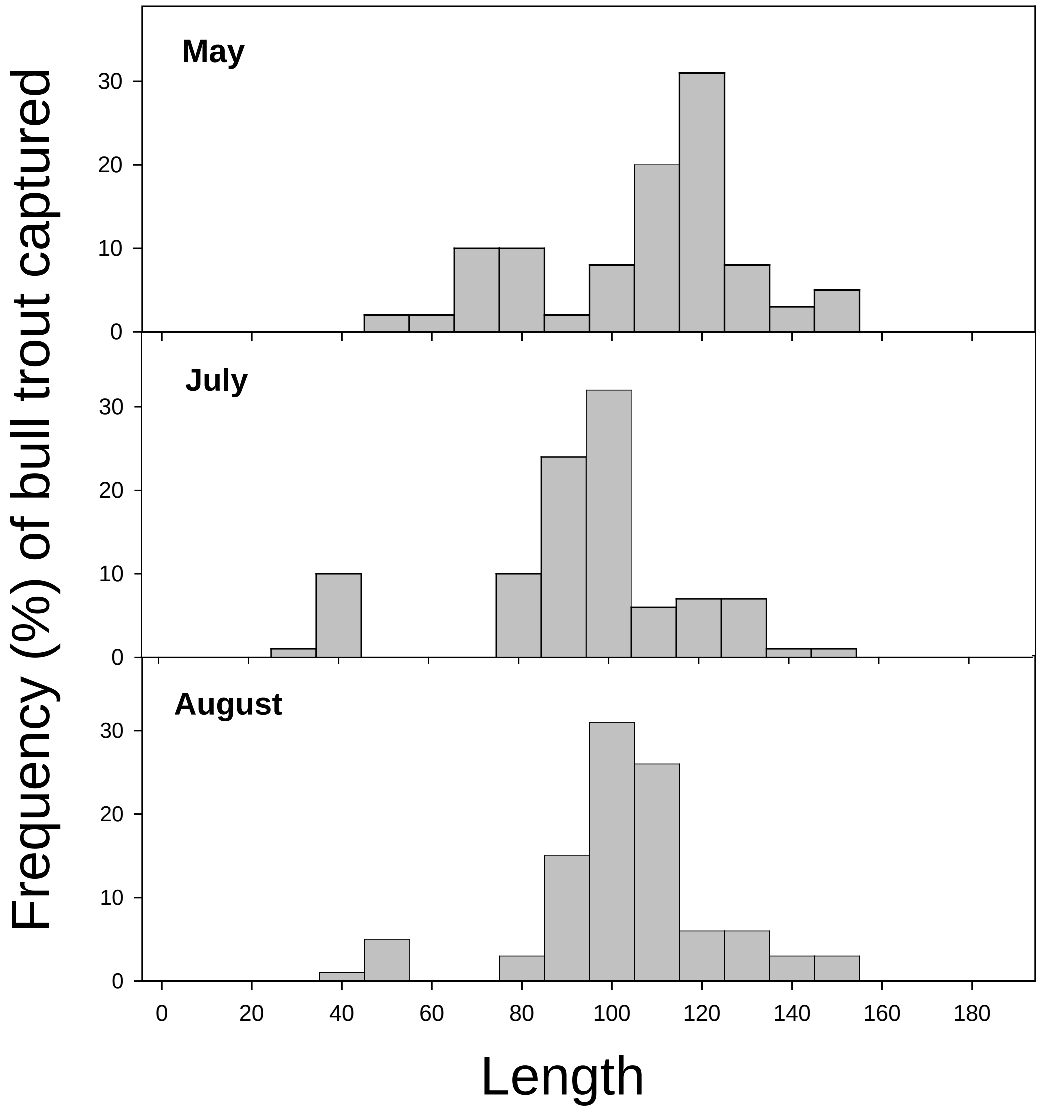

Figure A1. Length frequency (% catch) distribution of juvenile bull trout captured in Skiphorton Creek during 3 separate mark-recapture events in 2008.

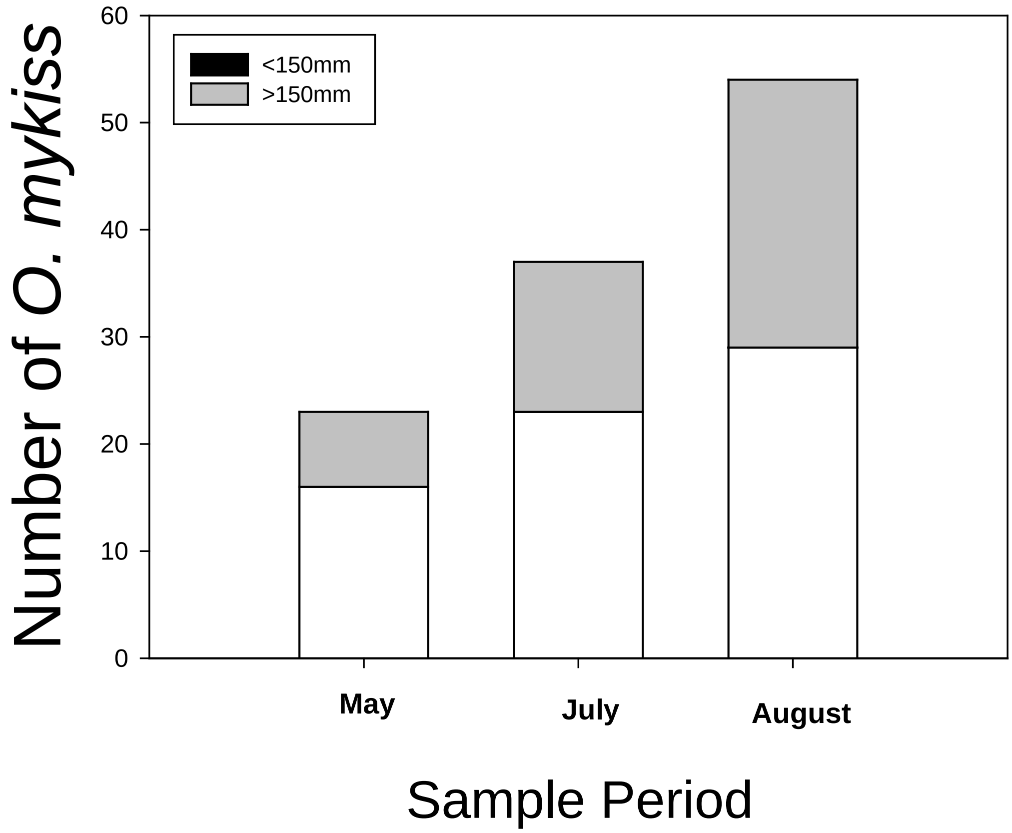

Figure A2. Number of *Oncorhynchus mykiss* in two different size classes caught during three sampling events in Skiphorton Creek, 2008.

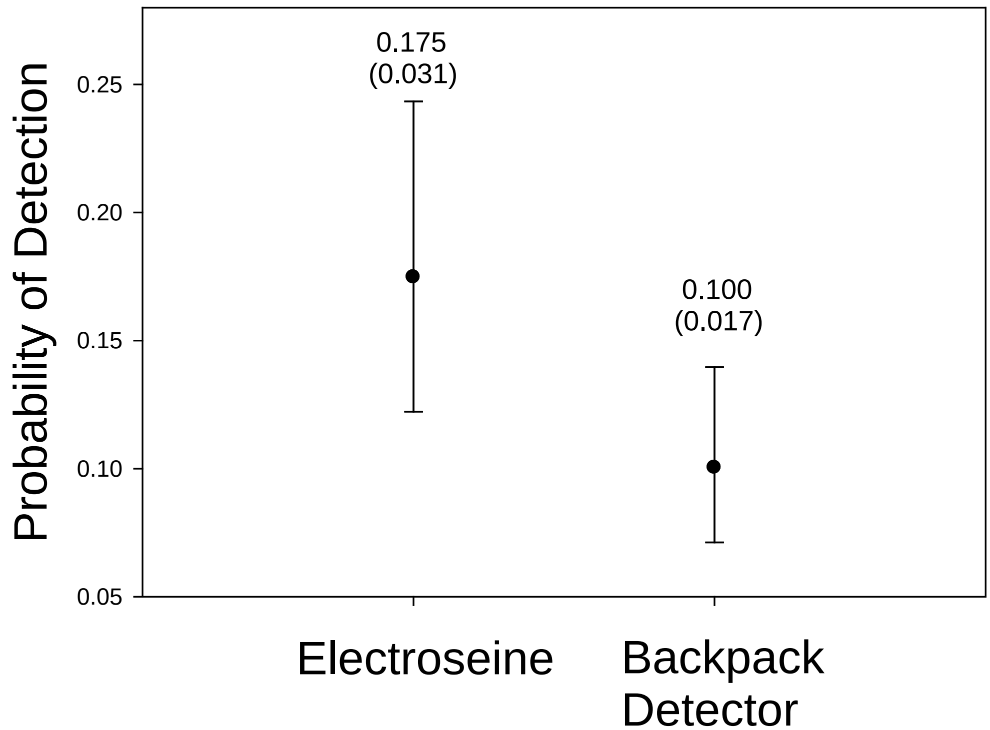

Figure A3. Probability of recapture detection using two different sampling methods for juvenile bull trout, electroseining or a portable backpack PIT-tag detector. Estimates are shown with standard error in parentheses. Error bars represent 95% confidence intervals.

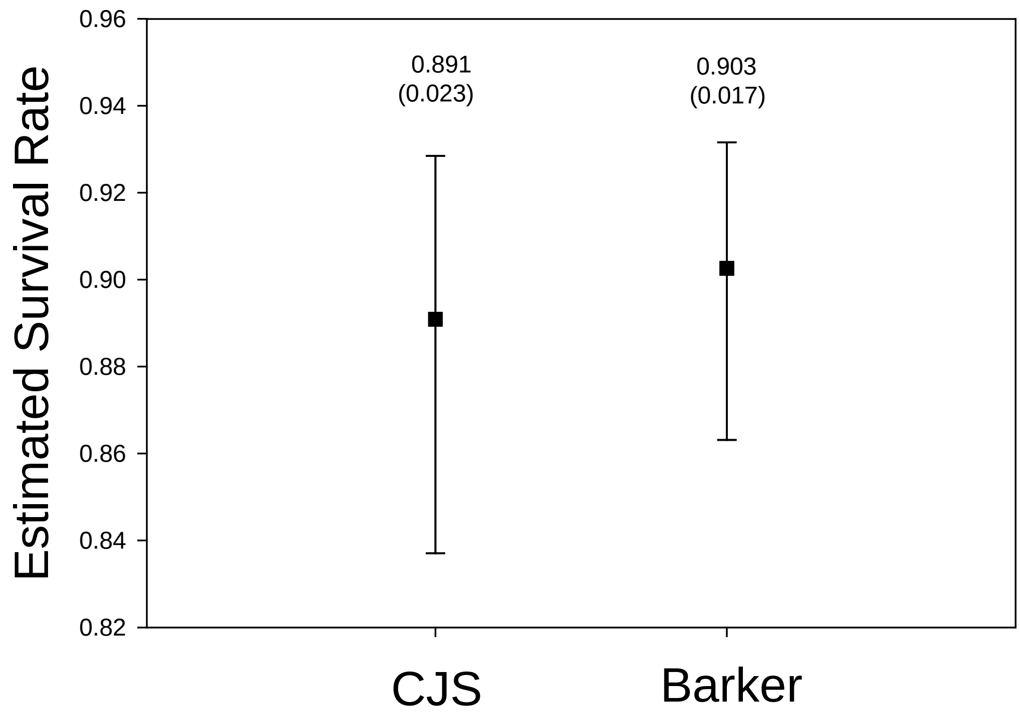

Figure A4. Estimated survival rate for juvenile bull trout (70-170 mm size range) in Skiphorton Creek for a 4.5 month period between 2 May and 15 September, 2008. Two different model frameworks were used to develop estimates, a Cormack-Jolly-Seber model and a Barker model. Estimates are shown with standard error in parentheses. Error bars represent 95% confidence intervals.

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APPENDIX 2

Original objectives and tasks specified to meet the overall 5-year project goals.

Objective 1. Comprehensive bull trout population assessment and monitoring.

Task 1.1 Marking.
Task 1.2 Recapture.
Task 1.3 Snorkel surveys for juvenile densities.
Task 1.4 Adult and egg information, egg-to-parr survival.

Objective 2. Comprehensive stream and riparian habitat assessment and monitoring.

Task 2.1 Habitat assessment.

Objective 3. Innovative pass-through PIT-tag monitoring system.

Task 3.1 Tagging, detection, and fish movement.

Objective 4. Data analysis.

Task 4.1 Analysis of mark-recapture data: population estimates and movement.
Task 4.2 Analysis of snorkel data: parr density and habitat use.
Task 4.3 Analysis of adult and egg data: egg-to-parr survival.
Task 4.4 Analysis of habitat attributes in relation to fish survival and density.

Objective 5. Summarizing available information into a simple population model.

Task 5.1 Assemble and summarize all existing bull trout population and life-history data for the selected tributaries of the Walla Walla Subbasin.
Task 5.2 Building the population life-cycle model.

Objective 6. Describe current habitat conditions and land use patterns as they relate to bull trout survival and growth.

Task 6.1 Summarize and quantify all available habitat data.
Task 6.2 Exploring the relationship between habitat and bull trout population status indicators.
Task 6.3 Model calibration and validation.