RECLAMATION

Managing Water in the West

Technical Report for Arrowrock Dam Biological Opinion #1009.0405 OALS #00-912 and Upper Snake River Biological Opinion # 1009.2700

Inferences from Weir Counts of Population Size and Environmental Influence on Migration Timing for Adfluvial Bull Trout (*Salvelinus confluentus*)

North Fork and Middle Fork Boise River Summary 1999-2004

U.S. Department of the Interior
Bureau of Reclamation

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North Fork and Middle Fork Boise River Summary 1999-2004

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INFERENCES FROM WEIR COUNTS OF POPULATION SIZE AND ENVIRONMENTAL INFLUENCE ON MIGRATION TIMING FOR ADFLUVIAL BULL TROUT (*Salvelinus confluentus)* IN THE NORTH AND MIDDLE FORKS OF THE BOISE RIVER, IDAHO

Abstract

Bull trout (*Salvelinus confluentus)* were captured using steel frame picket weir traps set across the North and Middle Forks of the Boise River in Southwestern Idaho. Trapping occurred between the months of August and October in years 1999 through 2004 in the North Fork Boise River. Trapping in the Middle Fork Boise River occurred during the same seasonal period in 2002 and 2003. Over 1,300 bull trout representing age classes 3+ - 11+ were sampled. Bull trout were found to move primarily at night and movement was related to stream temperature and flow fluctuations. Data suggests that growth in bull trout appears to be greatest in age class 3+ fish that show movement in the main river system. Reduced growth rates in fish age classes 6+ and older suggest a shift in assimilation of energy from growth to reproduction. A relationship between survival of captured bull trout and annual precipitation levels was investigated. Adult fish counts, total fish captured, and estimates of population size in the North Fork Boise River have declined for adfluvial bull trout over the six year sampling period. The study results indicate that environmental conditions relating to habitat such as temperature, precipitation, reservoir volume, and stream discharge play a major role in the movement and persistence of this population of fish.

Introduction

The sub-populations of bull trout in the Boise River Basin form one of the Southern-most distributions in the Columbia River basin (Rieman et al. 1997). Although the Boise River Basin is fragmented by a series of dams (Lucky Peak, Arrowrock, Anderson Ranch), the sub-basins that feed Arrowrock and Anderson Ranch reservoirs support substantial habitat. In addition, Bull trout presence has been recorded throughout the Arrowrock Basin as well as migration documented in both Arrowrock and Anderson Ranch watersheds (Rieman and McIntyre 1995, Partridge 2000, Flatter 2000).

In compliance with the Endangered Species Act (ESA), the U. S. Fish and Wildlife Service (USFWS) developed a recovery plan and proposed critical habitat designation which included guidelines for management agencies to facilitate bull trout recovery. Since bull trout have a rather extensive range in the Columbia River segment, teams were established by major watersheds or regions. The Boise Basin bull trout populations are located in the Southwest Basin recovery unit. The federal bull trout recovery team has outlined several important objectives for bull trout recovery. These were: 1) maintenance and restoration of the distribution of bull trout 2) maintenance and restoration of habitat for all life history forms 3) conservation of genetic diversity, and 4) implementation of recovery actions and assessment of their success (USFWS 2002). Meeting the objectives of recovery require that accurate estimates of population size, assessment of distribution, and trends in abundance are known for bull trout populations within

each recovery unit. In 1999, U.S. Bureau of Reclamation (Reclamation) and Boise National Forest (BNF) developed a cooperative program to begin gathering baseline data to be used to meet the recovery objectives and also follow ESA Section 7 consultation requirements (USBR 1999, USFWS 1999). Work began in July 1999 and is ongoing. The purpose of the work is to assess temperature, precipitation, and stream discharge conditions as they relate to bull trout movement, population size, and survival on a large-watershed scale. Work to address the study objectives was initially focused on the North Fork Boise River basin which contains the largest population of adfluvial bull trout and most stream miles of spawning and rearing habitats. Weir work was expanded to include the Middle Fork Boise River in 2002 and 2003. Flooding and poor conditions in the Middle Fork Boise River precluded weir installation in 2004. The following objectives were addressed through weir trap operation:

1. To quantify population size and trends of migratory bull trout within the Boise River drainage
2. To quantify fish length at age and growth rates of bull trout within the Boise River watershed
3. To examine survival of bull trout and environmental conditions that may affect survival.

As part of a recovery planning and compliance with mandates established under the ESA, we focused on development of a cost efficient monitoring program for adult adfluvial bull trout. Weir count data can be used to estimate population size, survival, and natural variation in population size and structure. Appropriate land use, water use, and fisheries management decisions can be made for management and conservation of bull trout populations based upon these data in the Boise River system.

The work presented in this report focuses on large-scale environmental conditions and the influence that these conditions may have on the migratory bull trout population in the North and Middle Forks of the Boise River. This report presents data collected from the fish counts using steel frame picket weir traps operated on the major migration corridors of the North Fork and Middle Forks of the Boise River.

Study Area

The Boise River basin is located in southwestern Idaho and is a major tributary to the Snake River (Figure 1). Three dams were constructed on the upper Boise River system: Arrowrock, Anderson Ranch, and Lucky Peak dams. Lucky Peak Dam, an Army Corps of Engineers project, is located at the lowest elevation in the Boise river at river kilometer (rkm) 103 (river mile 64) with a full pool elevation of 931 meters (3,055 ft) above sea level. Arrowrock Dam, Reclamation project is 19 rkm (12 river miles) upstream of Lucky Peak Dam on the main-stem Boise River. Arrowrock dam has a full pool elevation of 980 meters (3,215 ft) above sea level. Anderson Ranch Dam, also a Reclamation project, is the most upstream of the three projects, located at rkm 81 (50 river miles) of the South Fork of the Boise River with a full pool elevation of 1,272 meters (4,173 ft) above sea level. These reservoirs are operated collectively as one system for irrigation, flood control, and recreation. Fish passage is not available at any of the three dams. A proportion of bull trout entrained through Arrowrock Dam are trapped and returned to Arrowrock Reservoir through a project conducted by Reclamation since year 2000.

The upper Boise River basin above Arrowrock Dam covers 5,700 km² (2,200 mile^2) of the granitic rock dominated landscape with elevations ranging from 931 m (3057 ft.) to 3,231 m (10,600 ft.) above sea level. The upper Boise River includes three sub-basins: the North,

Middle, and South Forks of the Boise River. The Boise River system is fed primarily by snowmelt run-off with highest flows occurring in April-May and lowest in September-October. Average daily stream flows range from 4.25 m^3/s (150 ft^3/s) to over 339.8 m^3/s (12,000 ft^3/s) in the mainstem Boise River below the North and Middle Fork confluence. Land uses in the Boise River watershed include grazing, recreation, and both commercial and individual timber harvest. The majority of the Boise River basin lies within Forest Service or Wilderness area boundaries.

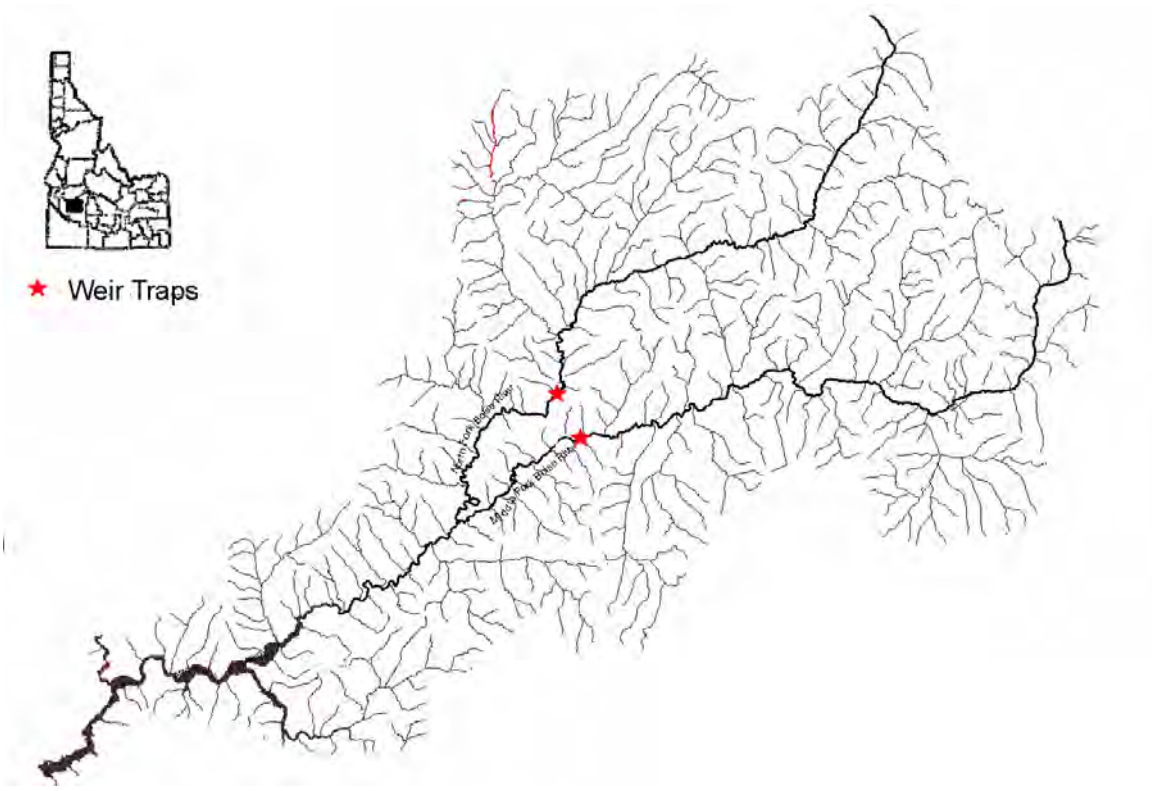

Figure 1. North and Middle Forks of the Boise River watershed with Arrowrock and Lucky Peak reservoirs. Location of weir traps = ★

Methods

Fish Capture

Steel frame picket weirs were operated across the major migratory corridor in both the North and Middle Forks of the Boise River below most known spawning and rearing habitat for bull trout. A 39.50 m (130 ft.) long x 1.53 m (5 ft.) tall steel picket style weir with upstream and downstream traps was constructed across the full width of the North Fork Boise (rkm 22.7 or rm 12.25) and the Middle Fork Boise River (rkm 15.6 or rm 8.42). Both traps were operated adjacent to the U.S. Forest Service Barber Flat guard station from the end of August through October. The Middle Fork weir was operated during the years 2002 and 2003; the North Fork weir has been operated in consecutive years, 1999 through 2004. The weirs were constructed of 15, 3.05 m (10 ft.) angle iron frames with steel conduit pickets spaced 1.25 cm (0.5 in.) apart (Figure 2). The traps were built following design recommendations and guidance from Russ Thurow (1999). Operating time was planned during the post spawning migration of bull trout.

Time and duration of the post-spawning run coincides with periods of lowest river discharge (Reclamation 2004, Flatter 2000). Consideration was given to the flow information and a substrate anchored trap style was chosen. The trap design had been used by other agencies to target post spawning bull trout in a fluvial system, which fit the study goal. The trap acted as a migration barrier for all fish > 1.25 cm (0.5 in.) in width (approximately > 200 mm or 7.9 in. total length for bull trout), capturing fish in traps as they moved upstream or downstream. Traps were checked, and pickets cleaned three to four times per day. To minimize predation of small fish inside the trap boxes, a pine bow was placed in one half of the box area to allow for cover (Thurow 1999). Fish observed holding upstream of the weirs were netted at night using dip nets when possible.

Figure 2. Installation of the North Fork weir trap. Steel frames, pickets, fence posts, and sand bags used for weights and to prevent escape by digging are shown.

The traps withstood discharge exceeding 6.0 m^3/s (212 ft^3/s), but high amounts of debris or freezing led to removal each year. To add strength to the traps, the design was altered by adding 2.5 cm (1.0 in.) x 182.9 cm (72 in.) solid steel rod supports driven 30.0 cm to 40.0 cm (12 to 16 inches) into the substrate behind the supports of the trap (Figure 3). The steel rods allowed the traps to withstand higher water flows and were easier to install in rocky substrate than the steel fence posts used previously.

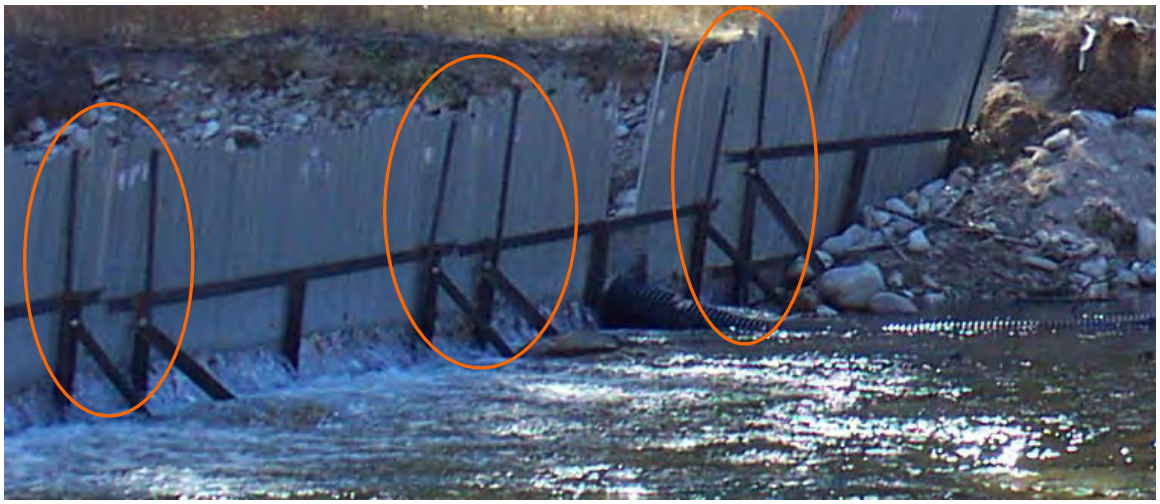

Figure 3. Downstream side of weir trap illustrating steel support rods added in year 2000

Fish Tagging and Handling

All fish captured were identified to species and enumerated. Total length (TL) was recorded for all game species. Bull trout were anesthetized using tricaine methanesulfonate (MS-222) (80 mg/L dilution). When a fish was considered anesthetized (could not right itself) its total length and weight was recorded. A scale sample and fin clip were taken, and the fish was scanned for Passive Integrated Transponder (PIT) tags (AVID computer corporation, Norco, CA 1999). All bull trout > 100 mm TL which did not carry tags were tagged with 2.5 mm x 14 mm, 125 kHz PIT tags in accordance with instruction from Idaho Department of Fish and Game personnel (Kiefer 1999) Bull trout were held and monitored in live wells until full recovery (minimum 15 minutes), and then returned to the vicinity of capture. If bull trout were captured in stationary traps, direction of migration and time of capture was noted. Fish capture was recorded by date and time of trap check. Groupings and pairs of fish were noted. All recaptured bull trout were measured and weighed so that data for growth over the time period from mark to recapture could be calculated. Reclamation initiated a multiple year telemetry project on the North Fork Boise River in 2001. Data and findings from this work can be found in Hostettler (2005) and Salow and Hostettler (2004).

Age and Growth Determination

Two methods were used and compared for assignment of age to bull trout. Scales were collected and processed following methods described in Flatter (2000). Bull trout scale samples were collected from the section of the fish's body posterior to the dorsal fin and dorsal of the lateral line. All scales collected were mounted on clear 2.54 cm x 10.16 cm x 0.05 cm acetate slides and pressed with a Carver heat press at 10,000 PSI, 110°C, for 35 seconds. Impressions were then projected using a microfiche reader. Annuli were counted by three individual readers. Each reader aged the samples twice to calculate average percent error for the individual reader and to calculate error between the readers (Chang 1982). Scale aging work was validated by comparing age estimates of otoliths to those of scales from capture mortalities. In addition to scale aging, length at age was calculated using the multiple year mark-recapture data. Age classes were derived from length frequency and scale ages for the first year the fish was marked and one year was added for each year following that the animal was recaptured, up to four years. Length groups for age classes were then calculated from the average length of the fish in each

age class with its associated error. Length frequency histograms were also used to verify scale and first year age of fish groups that were recaptured multiple years.

Growth was determined by comparing changes in total length for recaptured bull trout. Numerous fish were recaptured over multiple years so growth rates could be calculated for the various age classes. Average annual growth for each age class was determined to be the absolute value of total length when first captured less the total length at capture one year later each fall season during the post-spawning migration. Annual growth rates are calculated as constant growth per day.

Temperature, Solar Radiation, and Stream Flow Measurements

Water temperature was recorded every 2 hours at 12 locations in the mainstem rivers and tributary streams across a range of elevations and stream sizes by Tidbit™ (Onset Computer Corporation, Pocasset, MA 1999) temperature loggers. Additionally, data was also collected electronically from three USBR Hydromet stations. Remote access from Hydromet stations gives data for daily-accumulated precipitation, solar radiation, mean daily and hourly stream flow, and mean daily and hourly temperature. The three Hydromet stations used for data collection were located near Twin Springs, Big Smoky Guard Station, and Atlanta, Idaho (USBR 2004).

Data Analyses

Population Size

A total population size was estimated for weir captured bull trout (total length > 300 mm from Flatter 2000) by mark-recapture techniques as shown in Sheaffer et al. (1996).

Mark-Recapture population equations:

$$\check{N} = \frac{nt}{s} \quad \text{and variance of N is} \quad V(\check{N}) = \frac{t^2 n (n - s)}{s^3}$$

Where $\check{N}$ = estimate of population size
t = number of bull trout marked in 1999
n = number of bull trout marked in 2000
s = number of recaptured bull trout

This equation assumes no immigration, emigration, mortality, or alternate year spawning that can lead to significant errors in the estimate when assessing trend data.

Fish Survival

Population level survival for bull trout was calculated using the tag-recapture model from Everhart and Youngs (1981). A tag-recapture distribution table was made using all years of data collection from the North Fork weir. Survival was then estimated using the following equations for variable survival by tag-recapture:

$$S = \frac{R - F}{R_{(year + 1)}}$$

Where:
F is the fraction of the population taken by sampling and R is the number of fish recaptured for all years from any one year tagging release.

The variance was estimated using:

$$V(S) = S^2 \left| \frac{1-R}{R*M} + \frac{1-R_{(year+1)}}{R_{(year+1)}*M_{(year+1)}} + \frac{F}{T(R-F)} \right|$$

Where:

M is the number of fish tagged in any one year and T is the recapture total of all recaptures of tags recaptured after the last year of tagging.

Survival for tagged fish over time was calculated by dividing the number of tagged fish that were recaptured each year by the original tagged sample. Survival between each year and through time was compared for tagged fish.

Determining Effects of Environmental Conditions to Movement

To determine the effects of precipitation and temperature on seasonal migration timing, daily mean stream discharge data and water temperature data were used as independent variables with daily catch of bull trout as the dependent variable for each year in statistical analyses (SAS institute 1999). Bull trout were separated into juvenile (< 300 mm TL) and adult (> 300 mm TL) size classes for catch per day dependent variables. The size threshold of bull trout (300 mm TL) was chosen to maintain consistency with other studies that have been conducted within the basin (Flatter 2000). The overall trends in mean daily water temperature and stream discharge were negatively correlated to date. To remove the effect of date from the model, stream discharge, and water temperature were run using linear regression with date as the independent variable. The residuals from the date regression models were then used to examine the effects of water temperature and stream discharge on catch of bull trout per day. Water temperatures recorded at the North Fork Boise River weir trap and the Twin Springs Hydromet gauge were consistently correlated with three-degree temperature differences. Stream discharge from the North Fork constitutes 31% of the discharge recorded at Twin Springs (calculated from 1947-1950 Hydromet data (USBR 2004)) comparing both systems and they fluctuate at similar levels. Water travel time from the North Fork Boise River weir to the Twin Springs gauge is 1.98 hours during the fall migration period (calculated from mean fall stream discharge data).

Determining Effects of Environmental Conditions on Survival

The mean spring stream discharge, and accumulated winter precipitation was used to examine the affect it may have on the numbers of fish captured in each age class. The length at age was assigned to all bull trout captured using mark-recapture data. The number of bull trout captured representing each year when the fish would be age 0+ (its year of emergence) was then used as the dependent variable. The independent variables used were accumulated precipitation for that year (sum of daily precipitation November 1- March 31), and spring stream discharge (average daily maximum April 1-June 30). Data were used for the analyses that included the years before the study data were recorded (before 1999) so that age classes of bull trout that would have emerged prior to 1999 could be analyzed with environmental data.

Results

Fish Capture

The combined fish capture was 3764 fish representing seven genera and eleven species (Table 1). A total of 1381 bull trout (36.7 % of total fish captured) were captured and 1181 were tagged over the six years of the study. The majority of fish captured were mountain whitefish (48.0 % of total), usually in middle to late October during their spawning migration. Rainbow trout were the third most abundant species captured (12.1 % of total), but total capture was low in comparison to bull trout and whitefish. Most bull trout were captured during the night period from 21:00 to 06:00, and the majority of bull trout were captured moving downstream or netted from in front of the trap fence at night.

Table 1. Total number of fish captured from the Boise River weir traps through the study years 1999 to 2004.

Species	**1999 North Fork Fish**	**2000 North Fork Fish**	**2001 North Fork Fish**	**2002 North Fork Fish**	**2002 Middle Fork Fish**	**2003 North Fork Fish**	**2003 Middle Fork Fish**	**2004 North Fork Fish**	**Total**
Bull Trout (*Salvelinus confluentus*)	264	434	244	138	99	84	15	103	**1381**
Rainbow trout (*Oncorhynchus mykiss*)	142	127	70	22	8	62	4	19	**454**
Mountain whitefish (*Prosopium williamsoni*)	168	123	286	1071	8	90	26	37	**1809**
Westslope cutthroat (*Oncorhynchus clarki lewisi)*	2	1	0	0	1	0	0	0	**4**
Brook trout *(Salvelinus fontinalis*)	3	0	0	0	0	2	0	0	**5**
Sculpin sp.(*Cottus sp*.)	0	0	0	1	0	0	0	1	**2**
Largescale sucker (*Catostomus macrocheilus*)	12	1	0	2	1	4	2	1	**23**
Mountain Sucker (*Castostomus platyrhynchus*)	0	0	0	0	0	0	0	1	**1**
Pikeminnow (*Ptychocheilus oregonensis*)	32	7	0	3	15	8	2	5	**72**
Long nosed Dace (*Rhinichthys cataractae*)	0	0	3	0	3	2	0	1	**9**
Kokanee trout (*Oncorhynchus nerka kennerlyi*)	0	0	0	0	3	1	0	0	**4**
Total	**623**	**693**	**603**	**1237**	**138**	**253**	**49**	**168**	**3764**

Fish Tagging and Handling

A total of 1181of the 1381 bull trout were PIT tagged at the weir traps over the six years of study. Sixteen bull trout were mortalities that could be associated with handling, trapping, or poor body condition when trapped. Several bull trout were captured in the traps but not processed due to poor condition of the animal or the fact that several animals escaped from live wells prior to processing. Of the 1181 bull trout tagged 646 were juvenile sized bull trout (<300 mm TL) and were not used in the population estimates. The percent of juvenile sized bull trout captured declined over the first five years of study from 57.92 % of total bull trout captured in 1999 to 20% of total bull trout captured in 2003 (Figure 4), however this ratio increased significantly in 2004. There were no individual bull trout that were recaptured in all six consecutive years of the study. One bull trout was captured four of the six years, twenty-one bull trout were captured in three of the six years of the study, and 129 bull trout were captured in at least two of the six years of the study. Many bull trout were marked and not recaptured the following year, but two or three years following the original mark date suggesting a relatively high frequency of alternate year migration patterns or high infidelity to spawning and summer habitats.

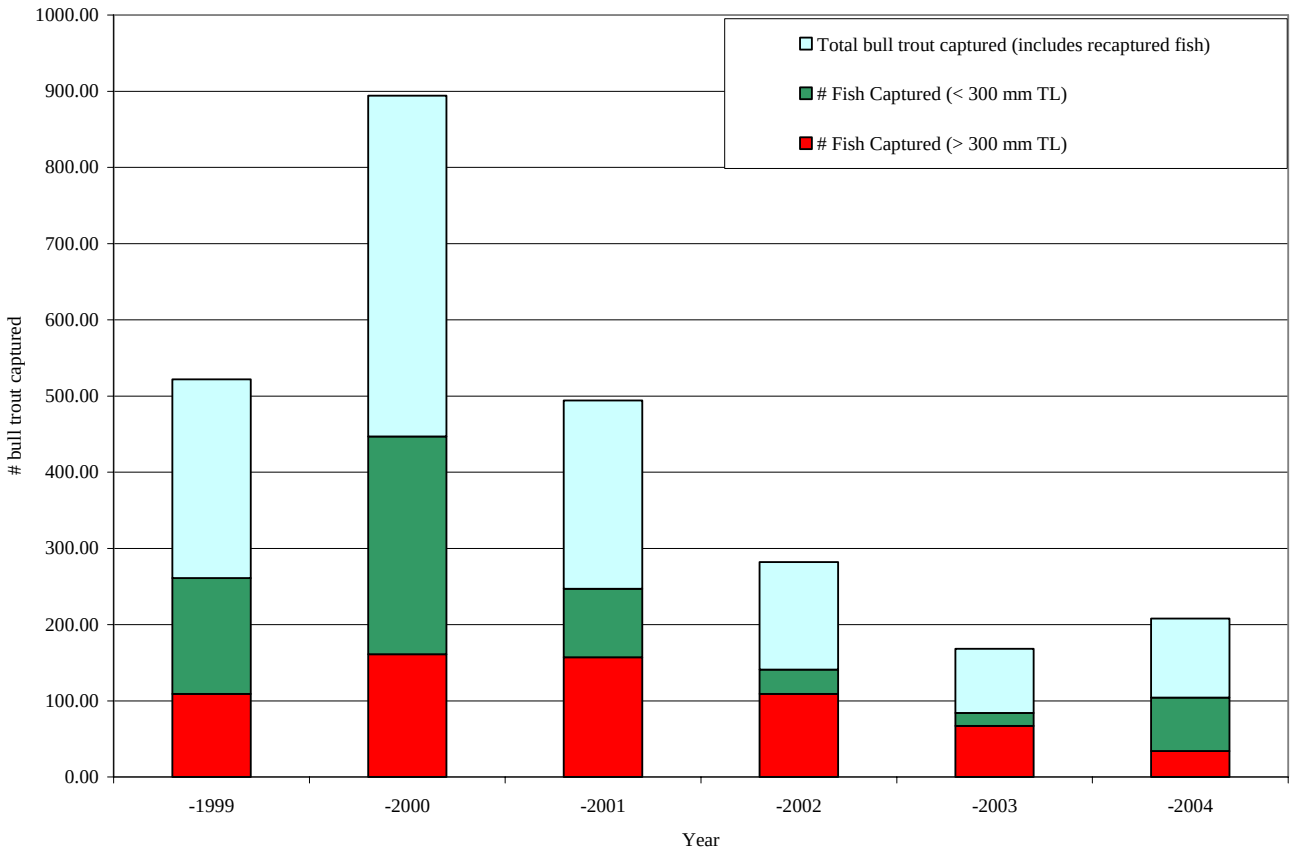

Figure 4. Total bull trout captured and measured (including recaptured fish) with adult and juvenile sized bull trout shown each year at the North Fork Boise River weir trap.

Figure 4 illustrates the total catch and composition of the catch (juvenile and adult fish) of bull trout captured at the North Fork Boise River weir trap over the six years of study. There

was a reduction in the number of all bull trout captured after 2000, and an especially significant decline in adult fish captured between 2001 and 2004.

Population estimates

Mark-recapture population estimates for adult bull trout ranged from 879 bull trout in 1999 to 146 bull trout in 2003 (> 300 mm TL). Mark-recapture estimates and error for the estimates reduced substantially over the four years of the study (Figure 5). Trends in estimates for adult bull trout indicate a significant decline in the population size which is supported by total capture rates and with telemetry data (Salow and Hostettler 2004).

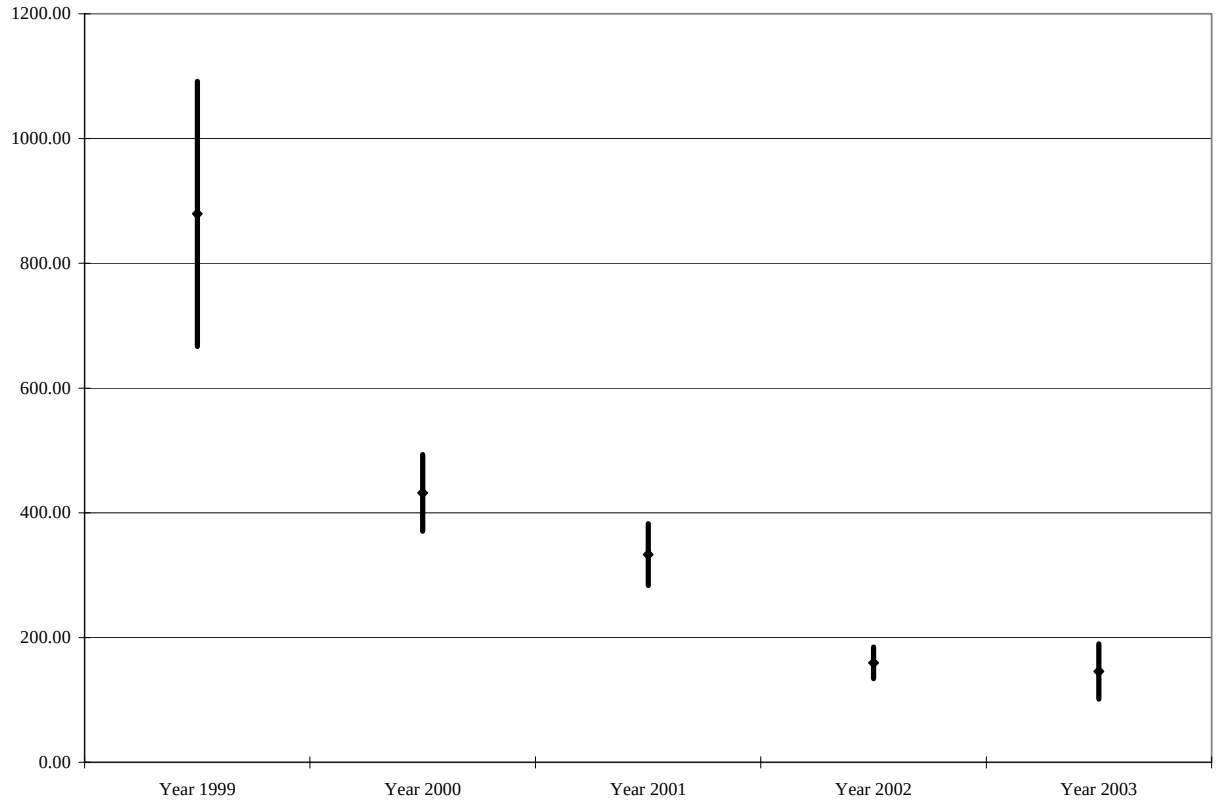

Figure 5. Mark-recapture population estimates for bull trout > 300 mm TL captured at the North Fork Boise River weir trap, years 1999-2004.

Age and Growth

Length frequency data gives inferences to length at age (Figure 6); however there is substantial variation in individual growth that confounds length at age determination from length frequency diagrams. Table 2 shows length and age groups for the two methods of aging. The smallest bull trout captured at the weir were age class 3+. The majority of the fish marked at the weir trap in years 1999, 2000, and 2004 were age classes 4+ and 5+, but the percent composition the catch changed in other years of the study with fish < 300 mm TL comprising over 50% of the total bull trout captured in 1999, but only 20% of the bull trout captured in 2003 (Figure 4). Additionally, Table 1 illustrates total catch of all fish species declined significantly over the six years of trap operation, particularly of mountain whitefish, regardless of environmental conditions during trapping. Bull trout from age classes 0+ through 2+ were not captured at the

weir trap, so data for age classes 0+ through 2+ estimates were derived from length frequency data or scales taken from fish during tributary electrofishing (Salow and Cross 2003).

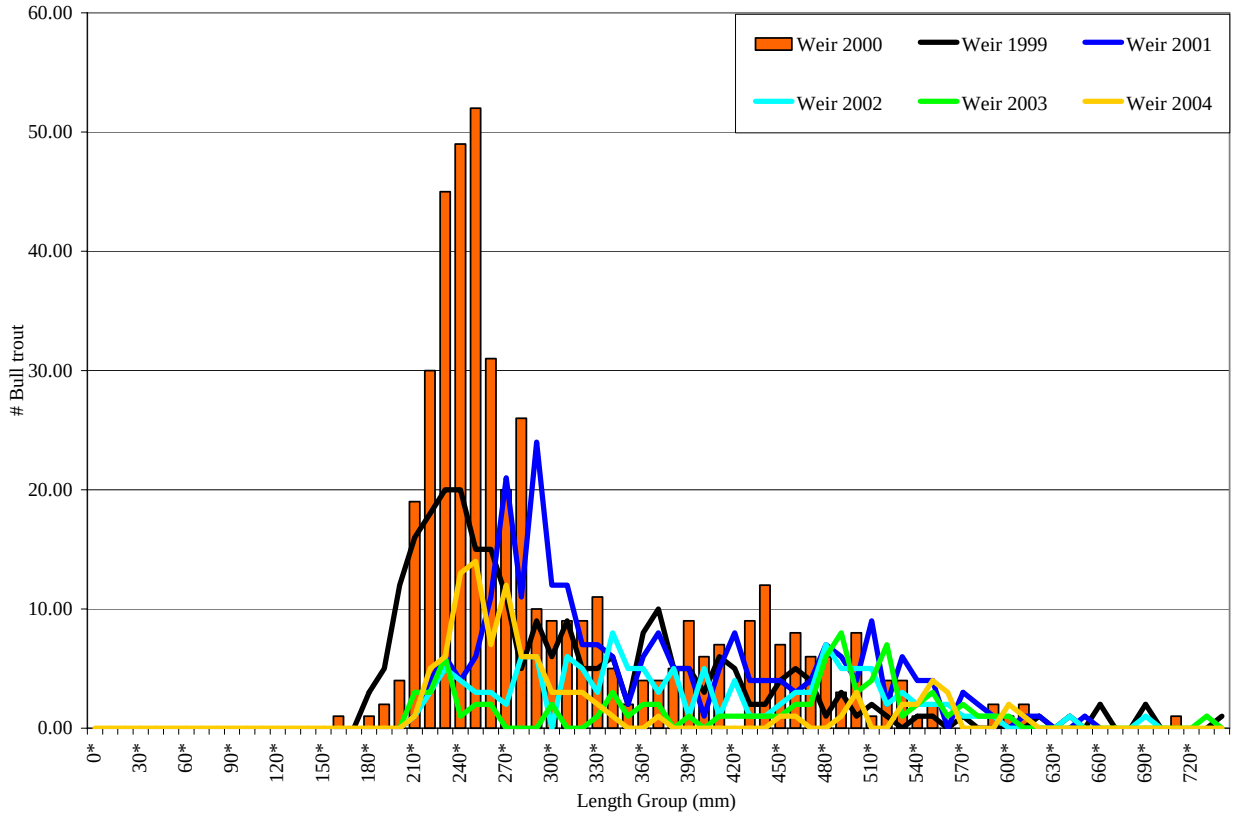

Figure 6. Length frequency diagrams for all bull trout captured at the North Fork weir trap differentiated by year.

Table 2. Length at age estimates and associated error for two methods of aging bull trout captured at the North Fork Boise River weir trap and the upper North Fork Boise River.

	Multiple year recapture		*Scale aging*	
Age Class	**Mean length**	**St. Error**	**Mean Length**	**St. Error**
0+	47.35	n/a	n/a	n/a
1+	95.48	n/a	105.38	1.64
2+	144.20	n/a	135.86	2.49
3+	180.00	n/a	206.65	6.20
4+	246.00	4.58	285.02	4.98
5+	322.67	6.57	335.57	5.39
6+	390.33	26.67	370.33	6.87
7+	432.50	9.65	457.30	7.29
8+	480.44	8.24	497.46	8.07
9+	528.46	7.95	519.15	8.45
10+	582.50	8.79	553.5	5.87
11+	613.00	19.30	550.5	6.63
12+	705	25.00	n/a	n/a

Annual Patterns of Growth

Figure 7 shows annual growth rates and mean total length for bull trout captured at the North Fork Boise River weir trap over the six years of study. Data for age classes 0+ through 2+ was added from length frequency and mark recapture data obtained during electrofishing data collected in the tributary streams to the North Fork Boise River upstream of the weir trap (Salow and Cross 2003). The highest growth rates were found in fish age 3+ that were captured for the first time at the weir trap. Data from bull trout captured upstream in screw traps and during electrofishing show high rates of growth for this age class of fish when moving from smaller tributary streams into the main-stem river, recaptured in the weir traps. Growth rates declined substantially for age classes 6+ through 11+.

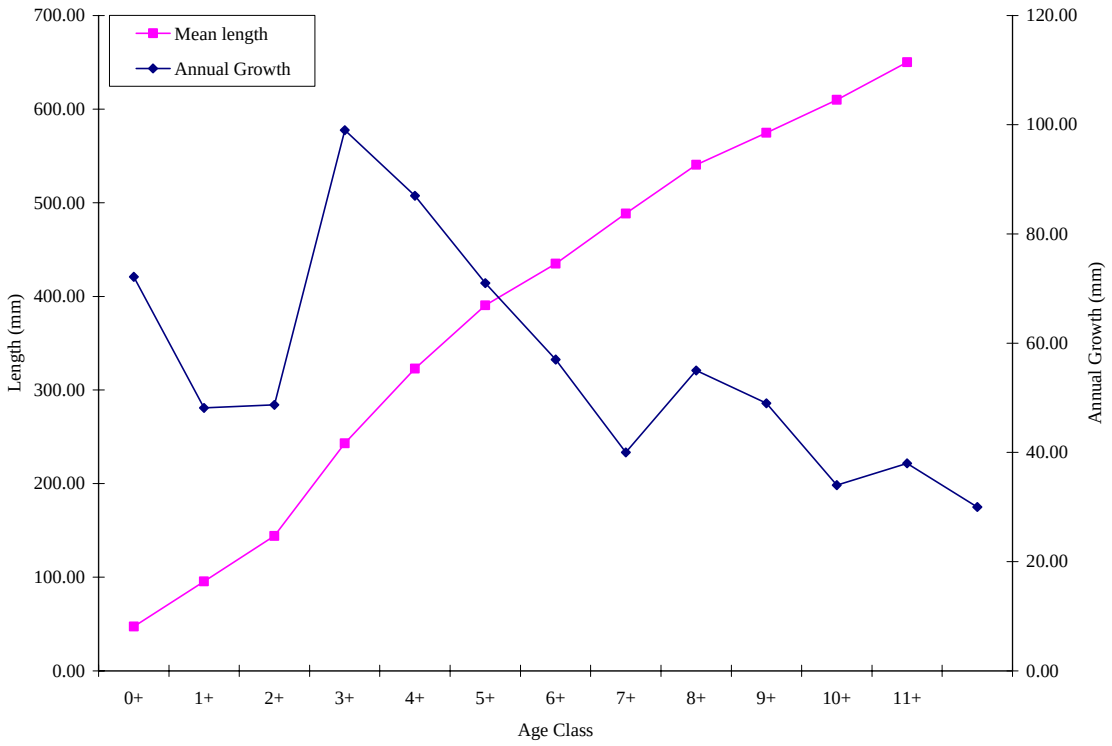

Figure 7. Age classes of bull trout and annual growth (mm/year) for fish captured more than one year at the North Fork Boise River weir trap. Data for fish in age classes 0+ to 2+ is taken from Salow and Cross 2003.

Survival

Variable Survival: Tag-recapture model

The population survival could only be estimated for three years from the six years of tagging data due to the data required for the model (Table 3). The model calculated survival for fish tagged during the year listed. For example, survival for year 2000 was calculated from fish recaptured from the 1999 tagging. For fish captured at the weir trap, survival would be from time of tagging (September or October) of the year previous to the time of recapture in that current year. Comparing the three years for which survival could be calculated, there is a significantly lower value for fish in the 2000 to 2001 year.

Table 3. Estimates of survival between year in bull trout captured in the North Fork Boise River using a tag-recapture model

Year	Fraction of population sampled (F)	Total Recaptures from all fish tagged in year (R)	Number of fish tagged that year (M)	Total fish recaptured in that year (C)	Recapture total of tags recaptured after last year (T)	Survival (S)	Variance (Survival) (V(S))	St. Dev. (survival)
1999	*	34	259	*	34	*	*	*
2000	0.04	52	393	20	66	3.247	0.0788	0.2807
2001	0.10	16	188	44	38	1.590	0.0364	0.1908
2002	0.18	10	94	30	18	4.911	0.4387	0.6623
2003	0.22	2	52	17	3	*	*	*
2004	*	*	92	5	*	*	*	*

Movement in Response to Environmental Conditions

The weir trap boxes were checked three to four times daily to monitor movement patterns as they relate to light conditions on a daily basis as well as movement related to seasonal and annual temperature, flow, and precipitation levels. Capture efficiency of stationary weir traps is dependent on fish movement. Movement and consequently capture rates of fish, especially small bull trout, were strongly related to precipitation received during the weir trap operations (Figure 8).

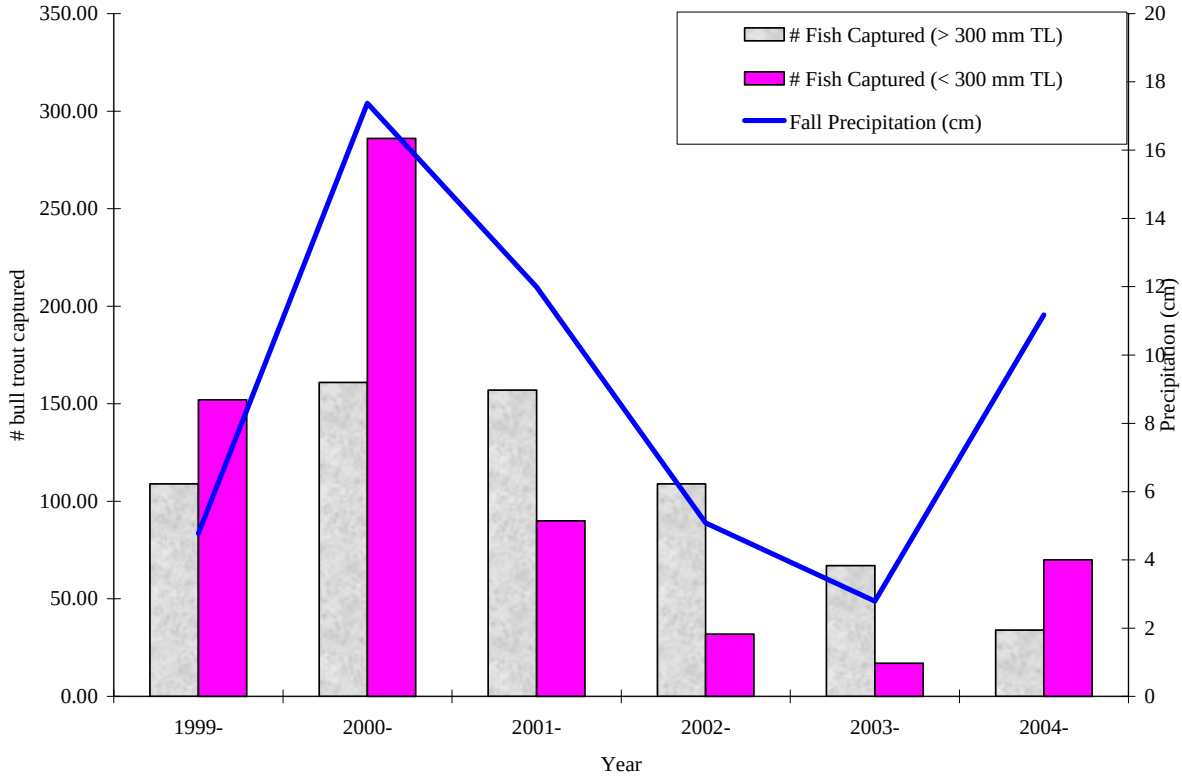

Figure 8. Precipitation during the fall period of fish capture and total bull trout captured for each year, 1999 to 2004, at the North Fork Boise River weir trap.

Daily Movement at the North Fork Trap

Bull trout migrated primarily at night: 41% of captured bull trout were captured between 1700 and 2200 hours and 53.4% were captured from 2400 to 700. The remaining 6.0% were captured between 700 and 1700 hours. All of the bull trout that were captured in year 2000 were captured in the downstream trap indicating that the fish were moving downstream. Years 1999, 2001 - 2004 had a small percentage of bull trout captured in the upstream trap (1 to 5 fish each year). Adult bull trout had a tendency to be captured as singles or pairs; however, smaller bull trout often moved in groups of three or more and were noted to move with bull trout or other species of fish that were of similar size.

Seasonal Movement at the North Fork Trap

The regression models showed a significant positive relationship for the number of juvenile bull trout (< 300 mm TL) caught per day with temperature in four out of the six years of trapping. Though the overall trend through time during the trap operation in the fall has a general decline in temperature, the number of juvenile bull trout caught each day increased with positive changes in mean daily stream temperature (adjusted $r^2 = 0.12$, $p = 0.009$). Generally, increases in temperature corresponded to recent precipitation events that increased stream flow. Since temperature and stream flow in all years were significantly negatively correlated, the independent effects of the two variables on movement were difficult to delineate. Solar radiation also affected movement at the weir traps. In four of the six years, juvenile bull trout catches per day declined significantly when solar energy increased, this also occurred for adult sized bull trout in two of six years, and was the primary variable that described variation in movement for adult fish in these years (adjusted $r^2 = 0.21$, $p < 0.0001$). Mean daily stream temperature was negatively correlated to stream flow in all six years and to solar radiation in two of six years; however, variation in both stream flow and solar radiation both between and within years was very high and patterns are inconsistent across all six years. There was a significant relationship shown for adult bull trout (300 mm TL) captured per day with flow, but only in one year of six, year 2001 (adult bull trout catch per day = - 1.04 (stream flow residuals) + 2.91, $p < 0.05$). Catch per day of adult-sized bull trout increased with declining flow conditions in year 2001.

Discussion

Fish Capture, Tagging and Handling

Temporary weir or fence traps are commonly used to capture salmonids for migration and population research in the Pacific Northwest (Westover and Baxter 1999, Clayton 2000). Very low catch rates were experienced for juvenile bull trout < 200 mm TL at the North and Middle Fork Boise River weir trap during the two years of operation. Several factors may explain the poor catch at these life stages. First, the weir trap was probably size selective for larger bull trout. Stelfox (1997) found that many bull trout < 150 mm TL could pass through the 14 mm widths of his picket-style trap. The smallest bull trout found gilled between pickets at the North Fork weir was 220 mm TL, which suggests that smaller bull trout could move through the pickets. Though several bull trout < 200 mm TL were captured in the trap, they represented a small proportion of total weir catch. Second, predation of juveniles in the trap may have occurred, even though a pine bow was placed in one half of the trap area as cover for juvenile fish. Third, juvenile adfluvial bull trout may move less during the autumn and may exhibit strong spring movement thus would be under-represented in the weir catch (Ratliff et al. 1996).

Stelfox (1997) found that most juvenile bull trout captured in his weir trap were age class 3+, ranging in size from 151 mm to 200 mm TL. The capture and age groups from this work support Stelfox's results. Additionally, the distribution data from captures across the basin support the hypothesis that young age classes of adfluvial bull trout remain in headwater streams for their first three years of life (age classes 0+ - 2+) and do not begin migration until they are age class 3+ (Fraley and Shepard 1989, Rieman and McIntyre 1993, Stelfox 1997). To better understand bull trout life history and population dynamics, Hostettler (2003) began work on juvenile migration and factors that key movement in juvenile adfluvial bull trout. Findings from this work show that both migration rate and probability of downstream migration to reservoir wintering habitat is dependent on fish body size. Fall downstream migration distance was found to be shorter with smaller body size, which supports the lower weir catch data for smaller fish (Hostettler 2005).

Population estimates

A conservative mark-recapture equation (Sheaffer et al.1996) was used to estimate adult, post-spawning bull trout marked at the weir. This equation is biased because it does not account for changes in natural mortality between years, variation in summer habitat use, and alternate year spawning patterns that have been documented to exist in the Boise River basin (Salow and Hostettler 2004), maturation/recruitment of juveniles into the spawning population, or straying. Incorporating a range of immigration will drive the estimate to decrease with as immigration increases (fewer marked bull trout recaptured the next year), and will be amplified by incorporating tag loss (numbers of marked bull trout that would have been recaptured if tag loss did not occur). We used fin clips to mark fish that were tagged to estimate a range of tag loss. Only one fish was recaptured that had a fin clip and no PIT tag. This fish had also been radio tagged and lost the radio, so it is possible the PIT tag was lost when the radio was expelled. Tag loss therefore may not play a large roll in estimation bias, and most bias likely comes from the alternate year spawning patterns and summer habitat infidelity (fewer bull trout recaptured that were tagged the previous year).

A population estimate for juvenile bull trout was not calculated because of the low recapture rates for juvenile size bull trout at the weirs in the years following the first capture. Low recapture data for juvenile bull trout also supports adfluvial and fluvial life history theory where juvenile bull trout would rear in a reservoir or large river before returning to natal streams to spawn (Pratt 1992, Rieman and McIntyre 1993). Many fish that were < 300 mm when marked were recaptured two or three years after and so could not be used in a mark-recapture estimate based on annual catch rates. Several bull trout were found to overwinter in the mainstem Boise river, Arrowrock reservoir, or South Fork Boise River and to not complete migration the following spring (Salow and Hostettler 2004). Additionally, bull trout appear to show variation in summer habitat use that will also bias estimates. Some fish were marked at the North Fork weir and recaptured the following year at the Middle Fork weir, suggesting that they did not summer in the North Fork drainage. Since the Seber-Le Cren mark-recapture population equation assumes a closed population, no immigration (juveniles maturing) or emigration (mortality or entrainment) from the population or movement between watersheds is considered.

Water conditions in the basin may also affect capture rates for juvenile bull trout. The Boise River watershed experienced multiple years of drought beginning in 2000 and peaking in 2001. Those drought years followed the heavy snow pack years of 1997 and 1998. The efficiency of capture at stationary traps depends on the movement of the target species.

Movement in bull trout, especially juvenile size bull trout, is influenced by stream flow and temperature (Salow 2001, Hostettler 2003). Our data reflects the low precipitation and warmer fall weather in 2001 through 2003 and the high precipitation during the trapping periods in years 2000 and 2004 (Figure 8).

Age and Growth

Substantial differences exist between aging methods for length at age from scales and mark-recapture estimates. Scale aging had high rates of error when fish were older because the annuli became hard to distinguish as they were closer together. Multiple year recapture data may be more accurate for actual length at age and growth rates, although extrapolating the information to the population level may have high associated rates of error as individual growth rates varied significantly. The high variation in individual growth rates in fish age classes 6+ or older may reflect the high alternate year migration patterns and lack of migration from reservoir or river habitats observed in Salow and Hostettler (2004). Additionally, sample sizes are dramatically different between the two methods: only one bull trout was captured in four of the six years of study, 21 fish were captured in three of the six years of study, while over 1200 scales were aged.

In the Boise River system, fish recaptured at the weir from a previous year were at least 6 to 7 years old. One of the assumptions about that size class is if they were captured twice going downstream at the weir, the second-year capture indicates that the fish was sexually mature and possibly attempted to spawn. However; the Boise River system has a high degree of alternate year spawning documented so although the fish may have migrated upriver, they may have sought thermal refugia and simply spent the summer in cooler headwater streams (Salow and Hostettler 2004). The data does show that these fish made the upstream migration and therefore supports several studies throughout the Northwest that report the dominant spawning age class as 6 + (Fraley and Shepard 1989, Ratliff et al. 1996, Stelfox 1997). In addition, growth rates were found to significantly decline in fish during the 6+ to 7+ years and older suggesting a shift from energy used primarily for growth to energy used primarily for reproduction.

Average adult-sized (fish > 300 mm TL) bull trout captured were 418 mm (TL) which is smaller than average-sized adfluvial adult bull trout in other systems (Fraley and Shepherd 1989, Pratt 1991, Conner et al. 1997). Two possible explanations may account for the difference in mean adult bull trout size between this work and other work in the Northwest. First, 300 mm TL was used as the cut-off value to differentiate adult from juvenile bull trout. This length value was used to be consistent with previous work done in the Boise system (Flatter 2000). The upper size limit would reduce the adult mean total length, but increase the juvenile total length. If the mean length was calculated from bull trout 6+ and older, mean TL is 459.8 mm (364 mm to 730 mm). This is still smaller than the average sized adult adfluvial bull trout reported for other Northwest systems. Alternatively, Arrowrock reservoir is an oligotrophic system with large summer drafting events (drafted to < 15% of full pool most years) and short summer water residence time that most likely limits both primary productivity through reduced surface area and temperatures and secondary production through entrainment. Water column samples showed very low levels of zooplankton and chlorophyll-a in reservoir tows (USBR unpublished data). Low reservoir productivity may reduce bull trout growth rates when the fish use these reservoirs as overwintering habitat (Conner et al 1997, Beauchamp and Van Tassell 1999). Most drafting in Arrowrock occurs in the late summer and refill begins in the fall when bull trout are returning

(Salow and Hostettler 2004). This may lead to a relatively infertile reservoir in which many bull trout overwinter.

Growth data for juvenile size bull trout supports other reported findings (Ratliff et al. 1996, Pratt 1991, Stelfox 1997, Conner et al. 1997). Greatest growth was during the summer season and for fish < 300 mm that were migrating within the main-stem rivers. The data can be shown to support life history theory where bull trout will migrate to optimize temperature (metabolic) and forage availability that leads to increases in growth. Recapture sample size was low, but juvenile bull trout growth trends were consistent with those of Ratliff and Howell (1992) where juvenile bull trout in the reservoir grew an average of 14 mm per month. Growth was highest for the one juvenile bull trout that was marked during a summer trapping project and recaptured during the fall weir operation, growing 0.96 mm per day.

Ratliff et al. (1996) suggests that juvenile bull trout migrate directly into the reservoir in the spring at age classes 2+ to 3+. This is slightly younger than what was found during the Boise River weir operation. Most juvenile sized bull trout within the Boise River system were found to be age classes 4+ or 5+. Hostettler (2003) found that juvenile or sub-adult size bull trout in the Boise River system may not move directly into the reservoir in the fall, and that size was a strong indicator of the distance and rates of migration. Diel patterns of movement within the Boise River were similar to those described in other studies: that most of the downstream directed movement of migratory bull trout occurred during the fall, and at night (Stelfox 1997, Muhlfeld et al. 2001).

Adult bull trout migrating from the reservoir to tributaries showed decreases in both weight and annual growth during the migration period. The growth data for adult bull trout are consistent with other reported findings (Conner et al. 1997, Westover and Baxter 2000). Adult growth was highest in winter as fish return to larger water systems from spawning habitats (annual growth per day = 0.15 mm versus growth per day during the summer months of migration = -0.13 mm). Greatest growth must have occurred during winter because adult bull trout that were captured prior to the spawning season and recaptured following had lost weight. Growth rates of Arrowrock adult bull trout were lower than those reported for Lake Billy Chinook, Oregon, where adult bull trout were reported to grow 167 mm per year (Ratliff et al. 1996). Growth rates were more similar to Chester Morse Lake, Washington, where the reported range was 30 - 70 mm per year (Conner et al. 1997). Growth rates for the Arrowrock bull trout were also close to those reported for the Wigwam River, British Columbia, where mean growth was 47.3 mm per year for males and 45.4 mm per year for females (Westover and Baxter 2000). Flatter (2000) and Salow and Hostettler (2004) documented migration routes into the North Fork with distances greater than 100 km from Arrowrock Reservoir. Bull trout were recaptured at North Fork Boise River rkm 22.7, returning in the post-spawning migration. Bull trout have been documented spawning more than 46 kilometers upstream of the recapture location. Generally, a migrant life history proposes an increased risk in mortality from increased predation and stress due to migration. The risk of migration is offset by increased reproductive success or fecundity due to increased growth. The adult fish growth information supports this concept of risk and growth interactions. The bull trout that were captured were relatively large and heavy fish in May and June, possibly due to overwintering in a reservoir or regulated river with a large prey base as shown by our total gill net catches (Salow 2002). Migration and possible spawning caused a substantial reduction in weight of these bull trout, which may reflect the risk associated with migration.

Environmental Influences on Movement and Survival

Bull trout moved in size segregated groups, at night and in paired adult movement which support findings of Fraley and Shepard (1989) who documented night and paired movement of adult bull trout prior to spawning. They noted that juvenile size bull trout moved in large groups and rarely with larger adult bull trout. Behavioral characteristics such as group movement and avoidance of larger bull trout by juveniles may be a survival strategy to avoid predation. Year 2001 was the driest year of the six years of the study which may have had substantial impact on survival in spawning and rearing habitat and overall reduction of habitat in spawning and rearing streams.

The Boise River data indicates a potential relationship between the survival of bull trout and annual stream discharge and cumulative precipitation in the river basin. Several age classes of bull trout captured at the weir showed year-to-year trends with the exception of years 1998 - 2000. This may be related to the extremely low snow pack during the winter of 2000 to 2001 and consequentially low stream discharge in the summer of 2001. The survival model supports this hypothesis (Table 4) with low survival during the period from 2000 to 2001. Low winter snow pack and low stream discharge will reduce the habitat available for fishes in headwater streams, increase incidence of frazzle ice formation, and impact prey and habitat available for spawning bull trout during the summer and fall periods. Several assumptions cannot be addressed with the data provided. These include assumption is that there is constant mortality with each year of life, which is not valid (for example, mortality will be expected to be higher for age 0+ fish than for age 8+ fish). Additionally, sample size for each age class varies with natural mortality, capture efficiency of the weir trap, and the error associated with aging work. Sample size poses a problem with making conclusions about the relationship between flow, precipitation, and bull trout survival. Variability in precipitation and numbers of bull trout per age class was high, making the power of any statistical test low. However, support for an observed relationship was derived from the fact that year class strength exhibited natural mortality from year to year and the pattern of strong age classes were apparent through all six years. Additionally, bull trout life history must also be considered. Age classes 0+ to 5 + are rearing years for adfluvial bull trout and consequently these age classes could have weak capture rates in migratory corridors (Fraley and Shepherd 1989, Ratliff et al 1996). In this study, these age classes were rearing in tributary streams during sequential dry years (2000-2003), and therefore may have suffered higher mortality rates with high stream temperatures and reduced habitat availability. The observed relationship raises an important question however. Additional work is needed to understand the influence of the level of precipitation and flow on bull trout survival as it will help assess the corresponding trends in population size related to natural versus anthropogenic conditions. These questions become particularly important during water limited years when making decisions for water management.

Temperature has been described as a factor driving the expression of life history forms (migrant versus resident) (Winemiller and Rose 1992, Rieman and Chandler 1999). Temperature impacts migration timing and growth in other salmonids as well (Beacham et al. 1988). In addition, temperature has been shown to be a major factor affecting juvenile bull trout growth (McMahon et al. 1999) and consequently age at maturation and stream survival (Winemiller and Rose 1992). Movement of juvenile bull trout at the North Fork Boise River migratory corridor was related to changes in water temperature, stream flow, and solar radiation. At the North Fork Boise River trap, both mean temperature during the day and mean daily flow described a proportion of the variation in juvenile bull trout daily catches. The findings for juvenile size bull

trout support the contention that temperature is a cue of bull trout life history aspects such as migration (Fraley and Shepherd 1989, Pratt 1992).

There was a significant relationship found for adult bull trout catches with temperature, flow, and solar radiation at the North Fork weir trap in only two years (2001, 2004). One possible explanation is that variation was quite high for adult bull trout catches and sample size of bull trout caught per day was rather low. The low catches per day and highly variable sample would yield a weak, if any, relationship when modeled. Additionally, part of the adult migration may have been missed due to the duration of operation, which may increase when temperatures continue to decline and flow becomes more variable in November and December. Finally, adult bull trout movement might be keyed by threshold conditions rather than incremental changes. Salow and Hostettler (2004) note that downstream movement in radio tagged bull trout began in all fish approximately at the same time each year. This would indicate threshold values due to consistent seasonal changes such as reduced daylight hours and stream temperatures are factors that key the initiation of downstream movement for fish (Fraley and Shepherd 1989, Swanberg 1997). Movement would be anticipated to be more varied between individuals and time of year if sporadic precipitation events that cause changes in temperature or stream flows were driving the onset of migration.

Literature Cited

Beacham, T. D., C. B. Murray, and R. E. Withler. 1988. Age, morphology, developmental biology, and biochemical genetic variation of Yukon River Fall chum salmon (*Oncorhynchus keta*) and comparisons with British Columbia populations. Fishery Bulletin 86 (4): 663-674.

Beauchamp, D. A. and J. J. Van Tassell. 1999. Modeling seasonal trophic interactions of adfluvial bull trout in Lake Billy Chinook, Oregon. Pelton Round Butte Hydroelectric Project Report. FERC No. 2030. Portland General Electric Company, Portland, Oregon.

Chang, Y. B. 1982. A statistical method for evaluating the reproducibility of age determination. Can. J. Fish. Aquat. Sci. 39:1208-1210.

Clayton, T. B. 2000. Movements and status of bull trout (*Salvelinus confluentus)* in the Belly River, Alberta and Montana. In Monita et. al. editors. Bull trout II conference proceedings. In print.

Conner, E., D. Reiser, and K. Binkley. 1997. Abundance and distribution of an unexploited bull trout population in the Cedar River Watershed, Washington. *In* Mackay, W.C., M.K. Brewin, and M. Monita editors. Friends of the Bull Trout Conference Proceedings. pgs. 403-411.

Everhart, W. H. and W. D. Youngs. 1981. Principles of Fishery Science. Second Ed. Cornell University Press. 1981.

Flatter, B. 2000. Life history and population status of migratory bull trout in Arrowrock Reservoir, Idaho. Masters Thesis. Boise State University. Boise, Idaho.

Fraley, J. J. and B. B. Shepard. 1989. Life history, ecology and population status of migratory bull trout (*Salvelinus confluentus)* in the Flathead Lake river system, Montana. Northwest science 63: 133-143.

Hostettler, L. 2003. *Migration of Juvenile Bull Trout (Salvelinus confluentus) from the North Fork Boise River*. Interim report to the U.S. Bureau of Reclamation for Cooperative Agreement No. 1425-01FC107320.

Hostettler, L. 2005. *Influences of Fish Size and Environmental Factors on the Extent and Rate of Autumn Downstream Migration by Bull Trout in the Boise River basin, Idaho.* Master's Thesis. Boise State University. Boise, Idaho.

Kiefer, R. 1999. Fisheries Biologist, Idaho Department of Fish and Game. Personal Communication.

McMahon, T., A. Zale, J. Selong, R. Barrows. 1999. Growth and survival temperature criteria for bull trout. Annual report to National Council for Air and Stream Improvement. Montana State University and U. S. Fish and Wildlife Service Fish Technology Center. Bozeman, Montana.

Muhlfeld, C. C., S. Glutting, R. Hunt, D. Daniels, and B. Marotz. 2001. Winter diel habitat use and movements by juvenile bull trout in the Flathead River, Montana. *In* Practical Approaches for Conserving Native Inland Fishes of the West, symposium. June 6-8, 2001.

Partridge, F. 2000. *Southwest Idaho Bull Trout Restoration (South Fork Boise River) Completion Report*. Idaho Department of Fish and Game.

Pratt, K. L. 1991. Bull trout scale analysis. Metolius River Basin. Final Report. U. S. Forest Service, Deschutes National Forest, Bend, Oregon.

Pratt, K. L. 1992. A review of bull trout life history. *In* Howell P.J. and D.V. Buchanan, editors. 1992. Proceedings of the Gearhart Mountain Bull Trout Workshop. American Fisheries Society, Oregon Chapter. Corvallis.

Ratliff, D. E. and P. J. Howell. 1992. The status of bull trout populations in Oregon. Pages 10-17 *In* P.J. Howell and D.V. Buchanan, editors. Proceedings of the Gearhart Mountain Bull Trout Workshop. Oregon Chapter of American Fisheries Society, Corvallis.

Ratliff, D. E., Thiesfeld, S. L., Riehle, M. D., and D. V. Buchanan. 1996. Distribution, life history, abundance, harvest, habitat, and limiting factors of bull trout in the Metolius River and Lake Billy Chinook, Oregon, 1983-1994. Oregon Dept. of Fish and Wildlife. Portland, Oregon.

Rieman, B. E. and J. D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. U.S. Forest Service, Intermountain Research Station. General Technical Report INT-302, Ogden, UT.

Rieman, B. E. and J. D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124: 285-296.

Rieman, B. E., D. C. Lee, and R. F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River Basins. North American Journal of Fisheries Management 17: 1111-1125.

Rieman, B. E. and G. L. Chandler. 1999. Empirical evaluation of temperature effects on bull trout distribution in the Northwest. Final report No. 12957242-01-0. Rocky Mountain Research Station. Boise, Idaho.

Salow, T. 2001. Population structure and movement patterns of adfluvial bull trout (Salvelinus confluentus) in the North Fork Boise River Basin, Idaho. Masters thesis. Boise State University. Boise, Idaho.

Salow, T. 2002. Trap and Transport of Bull Trout (Salvelinus confluentus) from Lucky Peak Reservoir to Arrowrock Reservoir, Idaho. Summary report submitted to the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Snake River Area Office, Boise, Idaho.

Salow, T. , and D. M. Cross. 2003. Distribution, Abundance, and Influence of Habitat Conditions for Bull Trout (Salvelinus confluentus) in the North Fork Boise River Basin, Idaho. Summary report submitted to the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Snake River Area Office West. Boise, ID.

Salow, T., and L. Hostettler. 2004. Movement and Mortality Patterns of Adult Adfluvial Bull Trout (Salvelinus confluentus) in the Boise River Basin, Idaho. Summary report submitted to the Arrowrock Bull Trout Advisory Group, U.S. Bureau of Reclamation, Snake River Area Office, Boise, Idaho.

SAS Institute Inc., SAS/STAT® User's Guide, Version 8. Cary, NC: SAS Institute Inc., 1999.

Shaeffer R. L., W. Mendenhall, and R. L. Ott. 1996. Elementary Survey Sampling, Fifth Edition.Wadsworth Pub. Co. Belmont, CA.

Stelfox, J. 1997. Seasonal movements, growth, survival, and population status of the adfluvial bull trout population in lower Kananaskis Lake, Alberta. *In* Mackay, W.C., M.K. Brewin, and M. Monita editors. Friends of the Bull Trout Conference Proceedings. pgs. 309-316.

Thurow, R. F. 1999. Research Fisheries Biologist, Rocky Mountain Research Station. U.S. Forest Service. Personal Communication.

U.S. Bureau of Reclamation. 1999. Bureau of Reclamation operations and maintenance acitivities in the Snake River Basin upstream of Lower Granite Dam. Biological Assessment submitted to the U.S. Fish and Wildlife Service. File # 10009.2700

U.S. Bureau of Reclamation. 2004. Hydromet archive data at website: http://mac1.pn.usbr.gov/pn6400/webhydarcread.html. Employee access form.

U.S. Fish and Wildlife Service. 1999. Biological Opinion for the Bureau of Reclamation Operation and Maintenance Activities in the Snake River Basin upstream of Lower Granite Dam. File # 1009.2700 Region 1.

U.S. Fish and Wildlife Service. 2002. Draft Recovery Plan for Bull Trout. Region 1.

U.S. Fish and Wildlife Service. Boise, Idaho

Westover, W. T., and Baxter, J. S. 2000. An overview of the Wigwam River bull trout program (1995-1999). Habitat Conservation Trust Fund, Final Report. British Columbia Ministry of the Environment. Fisheries Project Report KO 58.

Winemiller, K. O., and K. A. Rose. 1992. Patterns of life history diversification in North American fishes. Implications for population regulation. Canadian Journal of Fisheries and Aquatic Sciences 49: 2196-2218.