Migration of Anadromous Juvenile Bull Trout in the Skagit River, 1990-2009

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December 2010

FPT 11-01

Acknowledgements

The Skagit River juvenile monitoring study was initiated in 1990 and has been supported by a combination of funds from the Washington State legislature, Seattle City Light, Salmon Recovery Funding Board, and Dingell-Johnson Federal Aid from the US Fish and Wildlife Service. Preparation of this report was funded by Cooperative Agreement #13320-9-J027 between Washington Department of Fish and Wildlife and the US Fish and Wildlife Service.

The Skagit downstream monitoring study was initiated by Dave Seiler and Steve Neuhauser of the Wild Salmonid Production Evaluation Unit of the Washington Department of Fish and Wildlife. Successful operation of the downstream traps is possible due to the hard work of Jim Repoz, Dean Toba, Eric Kummerow, and other dedicated technicians. Pete Topping and Mike Ackley made numerous logistical and technical contributions that ensured successful capture and safe passage of juvenile salmonids. Burlington-Northern Santa Fe Railroad allowed the main stem traps to be anchored to the railroad bridge. Dike District 17 provided permission for vehicles to be parked on their property next to the main stem trap. Property owners Modesta Armendarez and Julio Pilmento provide access to drinking water and utilities as well as space for the main stem traps to be stored on their property during the off season.

Mark Hino and Matt Klungle developed the data management system used to archive Skagit River data. Brett Barkdull, Andrew Fowler, and Mark Downen provided bull trout spawner data. Dale Gombert prepared the map for this report. Eric Beamer from the Skagit River Systems Cooperative shared bull trout data from the estuary monitoring program.

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Executive Summary

Local extinctions and population declines of bull trout (*Salvelinus confluentus*) led the United States Fish and Wildlife Service to list this species as threatened under the Endangered Species Act. Coterminous listing of all five Distinct Population Segments (DPS) in the continental United States was announced in 1999. Due to their diverse life histories and iteroparous spawning, the health of bull trout populations is particularly difficult to assess. Bull trout in the Coastal-Puget Sound DPS use four different life history strategies – resident, fluvial, adfluvial, and anadromous. The anadromous form is unique to this recovery region and perhaps the least understood of all the life history strategies. The goal of this report is to characterize anadromous juvenile bull trout migrations and associated environmental variables in the Skagit River. The Skagit River watershed contains 26 of the 57 local bull trout populations in the Puget Sound Management Unit and all four life history strategies. A juvenile fish trap, operated near Mount Vernon, has collected biological information on juvenile salmonid migrants since 1990. This report (1) summarizes bull trout life history from Skagit juvenile trap collections, (2) evaluates whether juvenile trap catches are a valid index of abundance, (3) determines whether catch expansions to a total abundance estimate are warranted, and (4) identifies the contributions of spawner abundance, rearing temperatures, and food availability to anadromous juvenile bull trout.

Catches of juvenile bull trout were assumed to be anadromous based on the unimodal pattern of the outmigration and the corresponding seasonality of catches in an estuary monitoring program conducted by the Skagit River Systems Cooperative (SRSC). Catch of juvenile bull trout in the Skagit juvenile trap has averaged 186 fish per season with no apparent trend over time. Downstream movements occurred primarily at night. Migration occurred between April and mid-July with peak catches in late May. Catch was determined to be a valid index of total abundance; however, we concluded that expansion of catch to a total abundance estimate was not defensible because existing trap data violated two assumptions necessary for this estimation.

Lengths of anadromous juvenile bull trout have ranged from 90 to 290-mm fork length (FL). Average annual lengths ranged from 124.8 to 143.7-mm FL. Catches in the downstream trap under-represented catches of larger bull trout when compared with juvenile size distributions compiled from estuary collections and from scale back-calculations of anadromous spawners. Non-detection of larger bull trout appeared to miss a substantial (31%) portion of the population in only one of the five years that size distributions were compared.

Correlations between environmental variables and anadromous juvenile bull trout catches were based on the assumption that the majority of migrants were age-2 fish. This assumption was supported by existing bull trout age and length data from the Skagit River and elsewhere but remains to be directly validated. Lengths of anadromous juvenile bull trout were predicted by a combination of rearing temperature and spawner carcasses. Results indicated that chronically low escapements of pink and chum salmon combined with high stream temperatures may limit early growth of anadromous bull trout. Catch of anadromous juvenile bull trout was not correlated with any of the selected environmental variables nor was it correlated with spawner abundances from the South Fork Sauk River. Variables that influence anadromous bull trout production and survival will only be detectable as downstream catch if each life history strategy is a constant proportion from year to year. However, the mechanisms that influence the anadromous component of a given brood year are unknown.

Initial comparison of juvenile anadromy in the Skagit River with a previous study on the Hoh River indicates that both age structure and migration timing differs between these river systems. Further work in the Skagit River is needed to resolve the relative contributions of source populations to the anadromous life history form and validate assumptions regarding the age structure of juvenile migrants.

Introduction

Bull trout (*Salvelinus confluentus*) are a cold-water, iteroparous salmonid endemic to northwestern North America. Their current geographic range extends from the Klamath River drainage in Oregon to the Liard River and Yukon River drainages in British Columbia and Alaska (Haas and McPhail 1991). Interior populations exist on both sides of the Continental Divide. Coastal populations are found in Puget Sound, the Olympia Peninsula, the Fraser River, and southeast Alaska. Species distinction between bull trout and Dolly Varden (*Salvelinus malma*) is based on morphology, genetics, and geographic distribution (Cavendar 1978, Haas and McPhail 1991, Leary and Allendorf 1997).

Bull trout have complex life histories but are highly philopatric to their natal habitat. Spawning occurs in the fall months in streams with cold-water springs and groundwater infiltration (Rieman and McIntyre 1993, McPhail and Baxter 1996). The primary difference among life history strategies is the selection of rearing habitats following an initial stream rearing period. At least four life history strategies have been identified – resident, fluvial, adfluvial, and anadromous (McPhail and Baxter 1996). Resident fish rear in their natal stream. Fluvial fish rear in large bodies of flowing water (Lowery 2009). Adfluvial fish rear in lakes or reservoirs (Jeppson and Platts 1959, Fraley and Shepard 1989). Anadromous fish migrate within and through marine habitats during their rearing stage (Brenkman and Corbett 2005, Brenkman et al. 2007). Each strategy has unique growth and life history patterns associated with the corresponding ecological interactions, and a mix of strategies can be represented within a single population.

Ecological requirements of bull trout vary among life history strategies. The presence (Rieman and Chandler 1999, Dunham et al. 2003) and growth (Selong et al. 2001) of juvenile bull trout in streams is influenced by stream temperature. Juvenile rearing habitat is also characterized by high levels of shade, undercut banks, large woody debris volume and pieces, gravel in riffles, and low levels of fine sediment and bank erosion (Dambacher and Jones 1997, Watson and Hillman 1997). An ontogenetic diet shift from aquatic insects to piscivory is prevalent in the migratory forms (McPhail and Baxter 1996, Lowery 2009). Diet shifts are associated with a larger body size and later age at maturity in the migratory than the resident forms (Rieman and McIntyre 1993, McPhail and Baxter 1996). During the rearing period, anadromous bull trout undergo substantial migrations among drainages (Brenkman et al. 2007).

Local extinctions and population declines of bull trout have led to conservation concerns across their range. In 1999, the United States Fish and Wildlife Service listed bull trout as threatened under the Endangered Species Act (USFWS 1999). For recovery purposes, bull trout are considered as five coterminous distinct population segments (DPS) - Coastal-Puget Sound, St. Mary-Belly River, Columbia River, Klamath River, and Jarbidge River. Bull trout in the Coastal-Puget Sound DPS are unique in their expression of an anadromous life history strategy. For this reason, information on the anadromous life history strategy is a specific need for recovery of the Coastal-Puget Sound DPS. Anadromous bull trout were observed as early as the 1880s in Puget Sound (Cavendar 1978). In recent years, increases in juvenile monitoring and acoustic tag studies have further identified anadromous bull trout in the Hoh, Skagit, and Dungeness river drainages (Brenkman and Corbett 2005, Kinsel et al. 2008, Topping et al. 2008).

The Puget Sound Management Unit of the Coastal-Puget Sound DPS consists of 57 local populations of bull trout and 5 potential local populations (USFWS 2004). Twenty six of the identified populations in this management unit are in the Skagit River watershed. Skagit River bull trout are considered to be relatively intact and healthy populations and therefore serve as a reference for other watersheds in the management unit. Skagit River bull trout display all four life histories and individuals have been observed to change life histories between spawning events (Kraemer 2003). Dolly Varden also occur in the Skagit River but are known only from the upper Skagit (USFWS 2004) and are not believed to have an anadromous life history in this watershed (Jeff Chan, USFWS, personal communication). The availability of a 20-year data set on juvenile anadromy in the Skagit watershed provides an opportunity to better characterize the anadromous life history strategy and associated environmental variables.

Objectives

This report summarizes twenty years of biological information on anadromous juvenile bull trout in the Skagit River. Juveniles are captured along with other migrant salmonids in a downstream trap near Mt. Vernon. Salmonids moving downstream through this portion of the river are typically en route to the Skagit estuary and eventually into Skagit Bay. The Skagit juvenile monitoring study began in 1990. The target species for the juvenile monitoring study have been wild coho and Chinook salmon. However biological data have been consistently collected for all species including bull trout.

The goal of this report is to characterize juvenile bull trout migration patterns and identify environmental variables that are associated with variation in these patterns. The first objective of this report is to summarize bull trout life history information from the Skagit River downstream trap between 1990 and 2009. The second objective is to determine whether bull trout catch in the downstream trap was a valid index of abundance. The third objective was to determine whether bull trout catch could be justifiably expanded to a total migration estimate. The fourth objective was to evaluate the contributions of spawner abundance and environmental variables on the abundance of anadromous juvenile bull trout.

Methods

Juvenile Fish Traps

Juvenile salmonids were caught with two types of traps: a floating inclined-plane screen trap (i.e., scoop trap) and a screw trap (Volkhardt et al. 2007). Details of these traps and their construction can be found in Kinsel et al. (2008). The traps were operated in parallel in the lower Skagit River just downstream of the Burlington Northern Santa Fe railroad bridge at river mile (R.M.) 17 (Figure 1). The traps will hereafter be referred to as the "Skagit downstream trap".

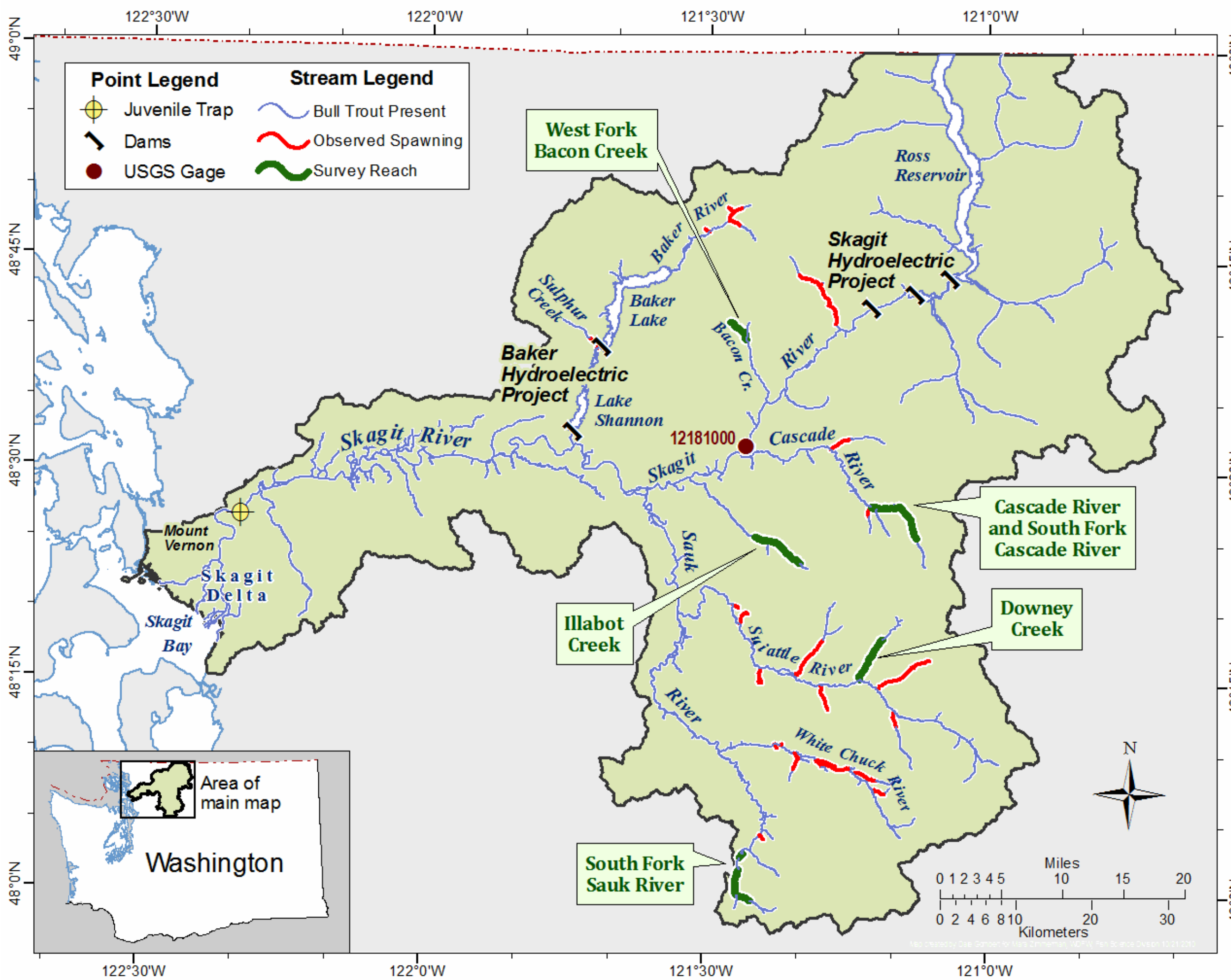

Figure 1.─Location of Skagit River downstream trap and areas of known bull trout spawning. Map shows areas where bull trout spawning is currently surveyed (dark green) and observed historically (dark red) by the Washington Department of Fish and Wildlife.

Fish Collection

From 1990 to 1996, the Skagit River juvenile monitoring study was conducted between April and June (Table 1). This time period corresponded with the initial study goal of estimating Skagit River wild coho production. In 1997, the trapping season was expanded to a January to August time period in order to evaluate freshwater production of wild Chinook.

During each trapping season, the main stem trap was fished every night and every third day. Each day, the trap was checked for fish at dawn and dusk and as well as additional times when required by debris loads or catches. During each trap check, fish were identified to species and enumerated. Total catch was summarized by statistical week. Statistical week is defined as Monday through Sunday with the first and last week of the year begin less than 7 days in length. Fork length (FL) was measured from a subsample of bull trout as well as wild Chinook, coho, and steelhead.

Table 1.─Operation of the juvenile fish trap on the Skagit River, 1990-2009. Hours of operation are reported as a total and percent of entire trapping season. Operation hours are reported separately for inclined-plane (IPT) and screw traps.

				Hours of Operation			
Migration Year	Begin	End	Total Days	IPT	%	Screw	%
1990	04/14/90	06/19/90	66	590.4	42.6%	NA	
1991	04/08/91	06/20/91	73	882.1	49.3%	NA	
1992	04/10/92	06/21/92	72	663.5	33.8%	NA	
1993	04/11/93	06/07/93	57	539.7	39.8%	366.7	36.7%
1994	04/09/94	06/29/94	81	827.9	42.9%	917.3	48.1%
1995	03/25/95	07/17/95	114	1189.2	44.4%	1207.0	45.8%
1996	04/12/96	07/18/96	97	1110.6	48.8%	1111.9	49.1%
1997	02/14/97	09/10/97	208	2719.2	61.5%	2674.8	63.1%
1998	01/18/98	09/11/98	236	3599.0	65.0%	2991.8	66.0%
1999	01/17/99	10/30/99	286	3344.1	50.4%	3270.7	50.4%
2000	01/15/00	10/27/00	286	3042.2	62.2%	3116.1	54.1%
2001	01/16/01	07/30/01	195	2681.7	56.0%	2688.8	59.7%
2002	01/16/02	07/30/02	195	2664.9	61.1%	2630.7	61.7%
2003	01/16/03	07/30/03	195	2658.3	60.3%	2651.3	61.2%
2004	01/23/04	07/28/04	187	2475.8	59.7%	2492.8	60.8%
2005	01/21/05	07/25/05	185	2567.3	59.6%	2574.9	59.8%
2006	01/18/06	07/31/06	194	2593.7	55.8%	2604.8	56.1%
2007	01/19/07	07/25/07	187	2484.4	55.3%	2424.0	54.1%
2008	01/17/08	07/27/08	192	2520.3	54.7%	2291.3	49.8%
2009	01/22/09	07/30/09	189	2544.7	56.2%	2538.6	55.8%

Migration Timing

Migration timing of bull trout was examined using two approaches. The first approach described diel migration behavior. Differences between day and night catch rates were compared for each trapping year using a Kolmolgorov-Smirnov test ($\alpha = 0.05$). The second approach examined seasonal modality of the outmigration. Migration timing for each year was described based on the cumulative catch over each trapping season. Modality in the migration timing would be supported by a steep slope during the trapping period surrounded by periods of time with a zero slope at the beginning and end of the season. Median migration date was represented as the date by which 50% of the cumulative catch occurred. Onset and end of the migration were measured as the dates by which 5% and 95% of the cumulative catch occurred, respectively.

Body Size

Fork lengths of bull trout were summarized by year with descriptive statistical measures (minimum, maximum, average, and standard deviation). Length data were collected from the 2000 trapping season to present.

Bull Trout Catch as Index of Abundance

Validation of the downstream trap data was based on comparisons between the trap data and two additional datasets existing for Skagit River bull trout. The first data set was provided from a sampling program in the Skagit estuary conducted by Skagit River Systems Cooperative (Beamer 2003). The second data set was a series of scale samples from anadromous bull trout spawners in the upper Skagit River and Sauk River (Kraemer 2003).

The SRSC estuary sampling program has been conducted from 1995 to present. Surveys are conducted on a bi-weekly basis between February and August in three habitat types – Swinomish Channel, Skagit Bay, and the delta estuary. Delta estuary sites are all blind tidal channels and are surveyed with fyke traps. The other sites are surveyed with beach seines. In this report, we compare the downstream trap data with collections from the delta blind tidal channels because timing of bull trout catch was similar between the downstream trap and delta collections, size distributions of the delta collections suggested a single age class, and delta blind channels should be the first of the estuary habitats used by migrant bull trout after passing the downstream trap (Beamer and Henderson 2004).

Sampling of bull trout spawners was conducted by WDFW Region 4 in late summer of 2001 and 2002. The WDFW Management Brief summarizing these collections detailed the age, length, growth, and spawning patterns of fluvial and anadromous bull trout in the Skagit River (Kraemer 2003). Age and length data were compiled from 120 anadromous bull trout and corresponded to the 1994 to 2001 downstream migration periods (Appendix 1 and 2 in Kraemer 2003). Data from 3 fish were not used because scales were unreadable. Length-at-age back calculations in this management brief were estimated by assuming a linear relationship between the fish length and scale length (center to annulus) at a given age. In this report, we compare downstream trap data to the length-at-sea-entry estimates derived in the WDFW Management Brief.

Using the two available datasets, two approaches were used to validate the use of downstream trap data as an index of abundance for anadromous juvenile bull trout. The first approach tested whether the capture rate of bull trout in the downstream trap was likely to be size biased. The second approach determined whether annual catch was correlated between the downstream trap and delta blind channel sampling.

Size bias in trap capture rates may limit the usefulness of trap catch data as an index of annual abundance. Size-biased capture rates occur when large fish are better able to avoid the trap and caught at a lower rate than small fish. Size bias was tested by comparing bull trout lengths measured in the downstream trap with those from the delta blind channel collections and the estimated sea-entry lengths from adult scales. A Kolmogorov-Smirnov test compared lengths between sampling methods for all years that data overlapped. Overlapping length data between the downstream trap catches and scale back calculations were available for the 2000 and 2001 migration years. Overlapping length data between the downstream trap catches and delta blind channel collections were available for the 2003 to 2006 migration years.

An inter-annual correlation in juvenile bull trout catches in the downstream trap and delta blind channel surveys would strengthen the argument that catch is a useful index of total migrant abundance. To test this relationship, linear and nonlinear regression models were fit to annual catch in the delta blind channel surveys and the downstream trap for the time series that these monitoring programs have overlapped (1995 to 2009). Catch in the delta blind channel was represented as catch per unit effort (CPUE) or catch in the fyke traps per hectare of channel (E. Beamer, personal communication). Monthly

CPUE was the average site CPUE for each month (2 to 7 sites each month, typically 7). Annual CPUE was the monthly average weighted by the proportion of catch that occurred on a given month. Downstream trap catches were the total catch for each year. No adjustment for trapping effort was made to these numbers because the bull trout migration has been well defined within even the shortest trapping seasons (Appendix A).

Expansion of Bull Trout Catch

Catch of juvenile bull trout can be expanded to a total migration estimate if existing data can be justifiably used to make this expansion. In order to estimate total migration of juvenile bull trout catch in the partial-capture trap must be expanded based on an estimate of trap efficiency (Volkhardt et al. 2007). Species-specific calibration of partial-capture traps account for inter-specific differences in migration timing and swimming behavior. On the Skagit River downstream trap, trap efficiency has been measured for sub yearling Chinook and yearling coho smolts (Seiler et al. 1998, Kinsel et al. 2008). Sub yearling Chinook are captured at the main stem trap, marked and released throughout the trapping season. Yearling coho smolts are captured in upstream tributaries, marked and released over the duration of the coho migration. Throughout this period, catches of juvenile bull trout have been too low to calibrate the trap for this species. In order to determine whether existing trap efficiency data would be useful for expanding bull trout catch data, we examined two key assumptions of abundance estimation studies using mark-recapture methodology (Seber 1973, Hayes et al. 2007):

- *Assumption #1: Marked fish mix at random with unmarked fish.* Random mixing of marked fish and juvenile bull trout would only occur if migration timing was similar between species. A chi-square test of independence was used to compare migration by statistical week between juvenile bull trout and coho smolts for trap years 1990 to 2009. Migration timing was also compared between juvenile bull trout and Chinook parr between 1997 and 2009. Chinook "parr" rear in freshwater for 3-4 months and are larger with a later-timed migration than Chinook "fry" (SRSC and WDFW 2005). Parr migrants were distinguished from the total of sub yearling migrants for the 1997-2009 trapping seasons (Zimmerman et al. In prep).
- *Assumption #2: All fish have an equal probability of capture that does not change over time.* Probability of capture may not be equal for small and large fish because body size impacts swimming ability which affects trap avoidance. As a result, trap efficiency measures for sub yearling Chinook or yearling coho may not be representative of juvenile bull trout. The relationship between trap efficiency and body size was examined by species and year. Ratios of coho and Chinook recapture rates were also examined for consistency among years. For this comparison, Chinook efficiencies were limited to trials during the period of bull trout migration (statistical week 17 to 24).

Variables Influencing Anadromous Juvenile Bull Trout

We explored whether catch of anadromous juvenile bull trout in the downstream trap could be predicted from existing data on spawner abundance, temperature, and food availability. In this analysis, we assumed that anadromous juvenile bull trout were primarily age-2 fish. This assumption was based on scales recovered from anadromous spawners (Table 2). Based on this assumption, anadromous juvenile bull trout were assigned to a brood year and associated with rearing conditions during two freshwater growing seasons (as age-0 and age-1 fish).

Table 2.—Age of bull trout during first migration to salt water based on scales recovered from anadromous spawners in the Skagit River (Kraemer 2003).

Migration year	*n*	Age structure Age-2	Age-3
1994	2	100.0%	0.0%
1995	1	100.0%	0.0%
1996	5	100.0%	0.0%
1997	10	100.0%	0.0%
1998	22	100.0%	0.0%
1999	26	92.3%	7.7%
2000	34	100.0%	0.0%
2001	20	95.0%	5.0%

WDFW monitoring of bull trout spawners in the Skagit basin began in 1988. A reach of the South Fork Sauk River has been annually surveyed for bull trout redds since this time. Over the last decade, additional survey reaches were added in Downey Creek, Illabot Creek, West Fork Bacon Creek, and the Cascade River (Figure 1). However, basin-wide correlations in spawner abundances are just beginning to be understood and the relative contributions of each population to anadromous life history form is unknown. This makes redd survey data from any particular area, including the South Fork Sauk, a tenuous representation of the entire Skagit basin. Despite this uncertainty, we explored whether a correlation existed between spawner abundances in the South Fork Sauk and catch of anadromous juveniles in the downstream trap.

Water temperature and food availability are two environmental variables that may limit survival of juvenile bull trout, although any specific contributions to the anadromous life history form are unknown. We examined whether these variables predicted either abundance or body size of juvenile bull trout caught in the downstream trap. The contribution of each environmental variable was explored for the age-0 an age-1 growing seasons for bull trout. Water temperature was represented by temperature at the Marblemount stream gage (USGS #12181000). Food availability was represented by the abundance of pink and chum spawners estimated by WDFW Region 4 and tribal co-managers (http://wdfw.wa.gov/mapping/salmonscape/). Pink and chum spawners return a concentrated pulse of marine derived nutrients during the fall time period (pinks are mostly odd year returns). Carcasses provide direct nutrition to juvenile bull trout as well as indirectly boosting ecosystem productivity. Food availability was also represented by catch of sub yearling migrants (pink, chum, and Chinook) in the downstream trap. This measure served as an index of emergent fry that provide a pulse of food resources during the late winter period (Lowery 2009).

Results

Catch

Catch of juvenile bull trout in the Skagit River downstream trap has averaged 186 fish (± 103, 1 standard deviation) per season between 1990 and 2009 (Appendix A, Figure 2). A minimum catch of 31 fish occurred in 2005 and a maximum catch of 448 fish occurred in 1994.

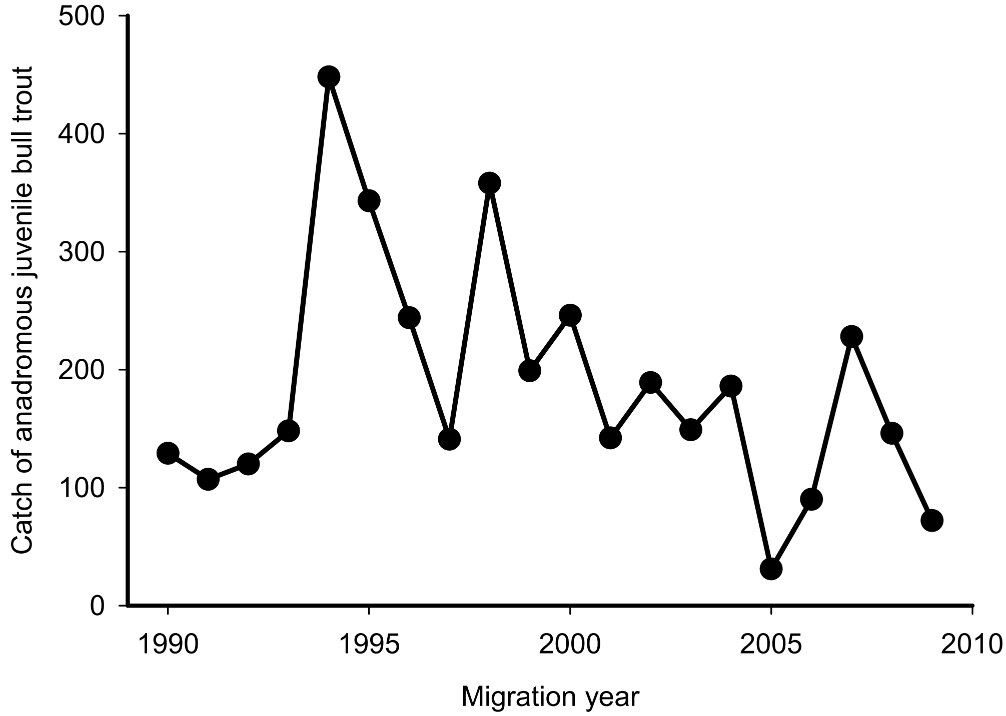

Figure 2.─Catch of juvenile bull trout in the Skagit River downstream trap, 1990-2009.

Migration Timing

In the inclined-plane trap, catch rates were significantly higher at night than during the day in all but 3 years (Figure 3; Table 3; 1992, 2005, and 2006). In the screw trap, night catch rates were higher than day catch rates in all but three years (1995, 1997, 2006). Median day time catch rates never exceed zero in the inclined-plane trap and ranged between 0 and 0.13 fish per hour in the screw trap. Median night time catch rates ranged from 0 to 0.29 fish per hour in the inclined-plane trap and 0 to 0.31 fish per hour in the screw trap.

Seasonal catches of juvenile bull trout occurred over a defined period between early April and late July (Figure 4). Minimal to no catch occurred early and late in the trapping season (Figure 5). Onset of migration was between April 3 and May 23. Median catch of juvenile bull trout occurred between May 9 and June 5. End of the migration was between June 4 and August 7.

Table 3.─Differences in day and night catch rates (fish per hour) of juvenile bull trout in inclined-plane and screw trap on the Skagit River, 1990-2009. Catch rates were compared between statistical week 17 and 24.

Migration Year	Inclined-plane trap		Screw trap	
	U-Statistic	*p*-value	*U*-Statistic	*p*-value
1990	258	<0.001		
1991	528	<0.001		
1992	333	0.195		
1993	897	0.02		
1994	156	0.009	244	<0.001
1995	155	0.049	199	0.71
1996	455	0.001	528	0.005
1997	428	0.008	423	1
1998	292	<0.001	278	<0.001
1999	316	0.007	272	0.01
2000	189	<0.001	180	<0.001
2001	330	0.045	160	<0.001
2002	218	0.001	113	<0.001
2003	315	0.002	288	0.005
2004	277	0.004	162	<0.001
2005	423	0.074	369	0.016
2006	360	0.086	316	0.063
2007	183	<0.001	153	<0.001
2008	926	0.002	214	0.022
2009	369	0.024	354	0.045

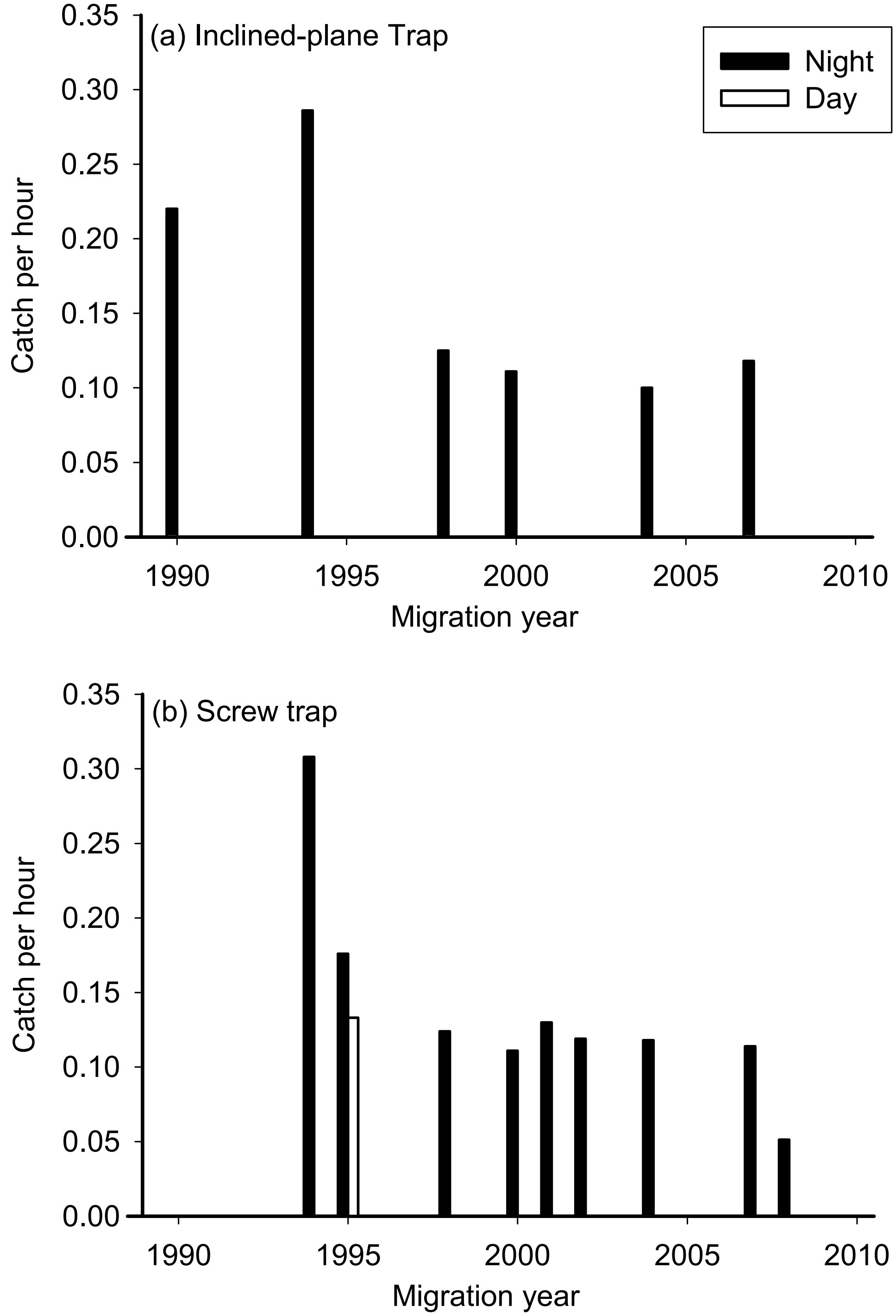

Figure 3.─Median catch rates of juvenile bull trout in Skagit downstream trap during day (white) and night (black) time periods. Inclined-plane trap (*a*) was operated every year between 1990 and 2009. Screw trap (*b*) was operated every year between 1994 and 2009. No bars indicate that the median catch rate was zero.

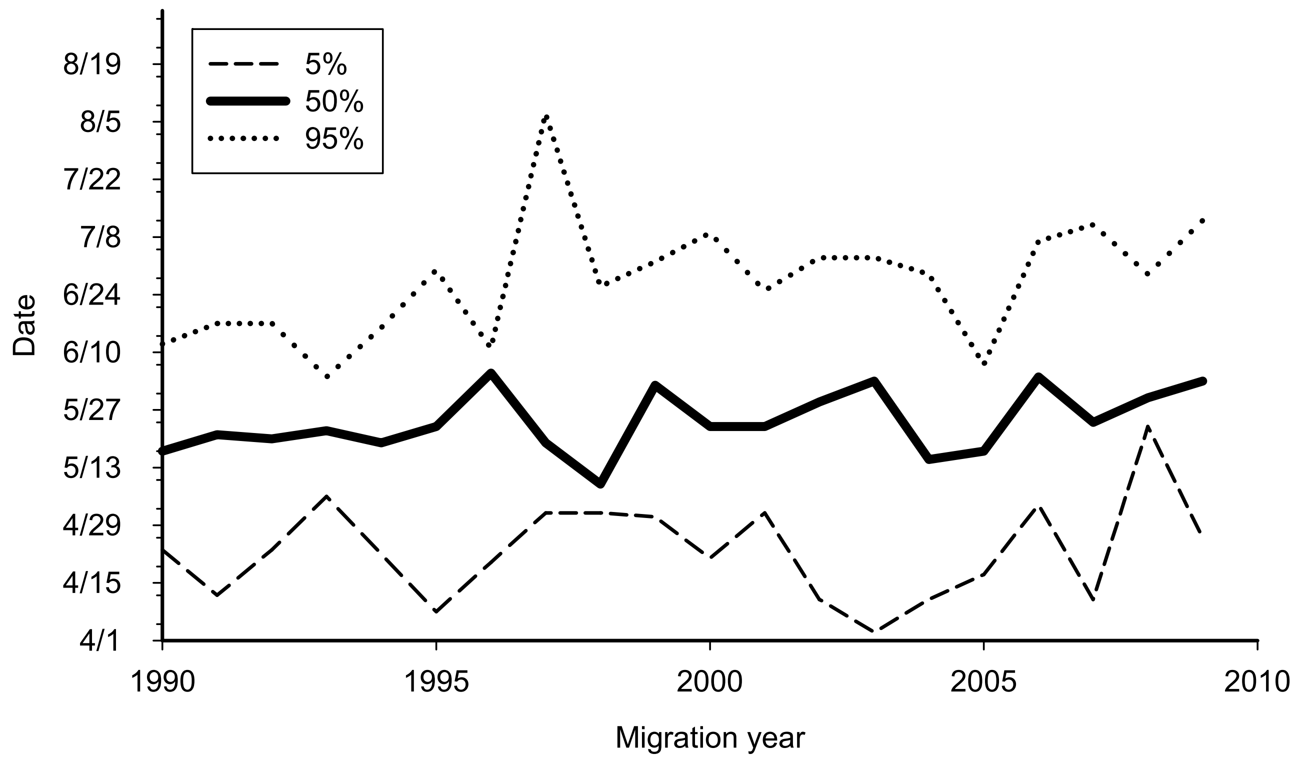

Figure 4.─Seasonal timing of juvenile bull trout catch in Skagit River downstream trap, 1990-2009. Data are cumulative catch summaries for each trap year. Cumulative catch is represented as 5% (dashed), 50% (solid), and 95% (dotted).

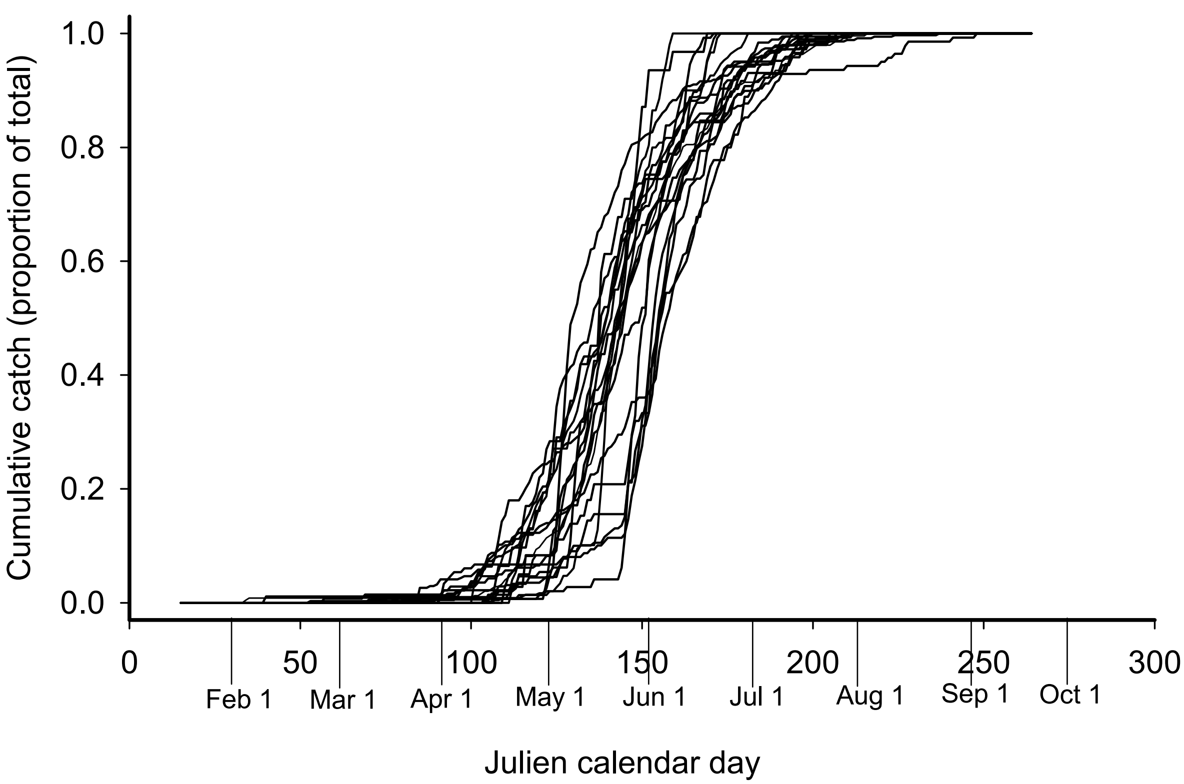

Figure 5.─Cumulative catch of juvenile bull trout catch in Skagit River downstream trap, 1990-2009. One line represents a single trap year.

Body Size

Juvenile bull trout caught in the Skagit River downstream trap ranged from 90-mm to 290-mm fork length (FL), although few of the captured fish were longer than 200-mm FL (Table 4). Average annual lengths ranged from 124.8-mm to 143.7-mm FL.

Table 4.─Fork lengths of juvenile bull trout captured in the Skagit River juvenile trap, 2000-2009. Data are average, 1 standard deviation, minimum, and maximum values.

Migration year	Number sampled	Average (mm)	St. Dev.	Minimum	Maximum
2000	245	135.8	17.0	90	195
2001	133	143.3	19.5	104	205
2002	4	138.8	29.2	91	170
2003	140	139.6	19.6	100	270
2004	190	143.7	23.0	102	240
2005	32	141.4	16.4	115	176
2006	90	124.8	16.9	90	176
2007	233	127.9	14.6	98	176
2008	135	140.0	16.9	105	210
2009	77	138.0	24.4	106	290

Validation of Bull Trout Catch as Index of Abundance

Juvenile bull trout in the downstream trap were consistently shorter than those in the scale collections and delta blind channel collections (Figure 6, Appendix B), although the magnitude of the difference varied among years. Based on scale estimates, the difference was minimal in magnitude for the 2000 migration year but notable for the 2001 migration year (Figure 7). Based on delta blind channel collections, the difference was notable in some years (i.e., 2003, 2005) but minimal in other years (i.e., 2004, Figure 8). When considered together, these comparisons demonstrate that bull trout caught in the downstream trap were 3 to 24-mm FL shorter on average than those in the delta blind channel or adult scale collections (excluding 2002 when trap sample size was just 4 fish, Appendix B). These comparisons also demonstrated that the bull trout longer than 140-mm FL were consistently under-represented in the downstream trap catches relative to the other two sampling methods (Figure 7, Figure 8).

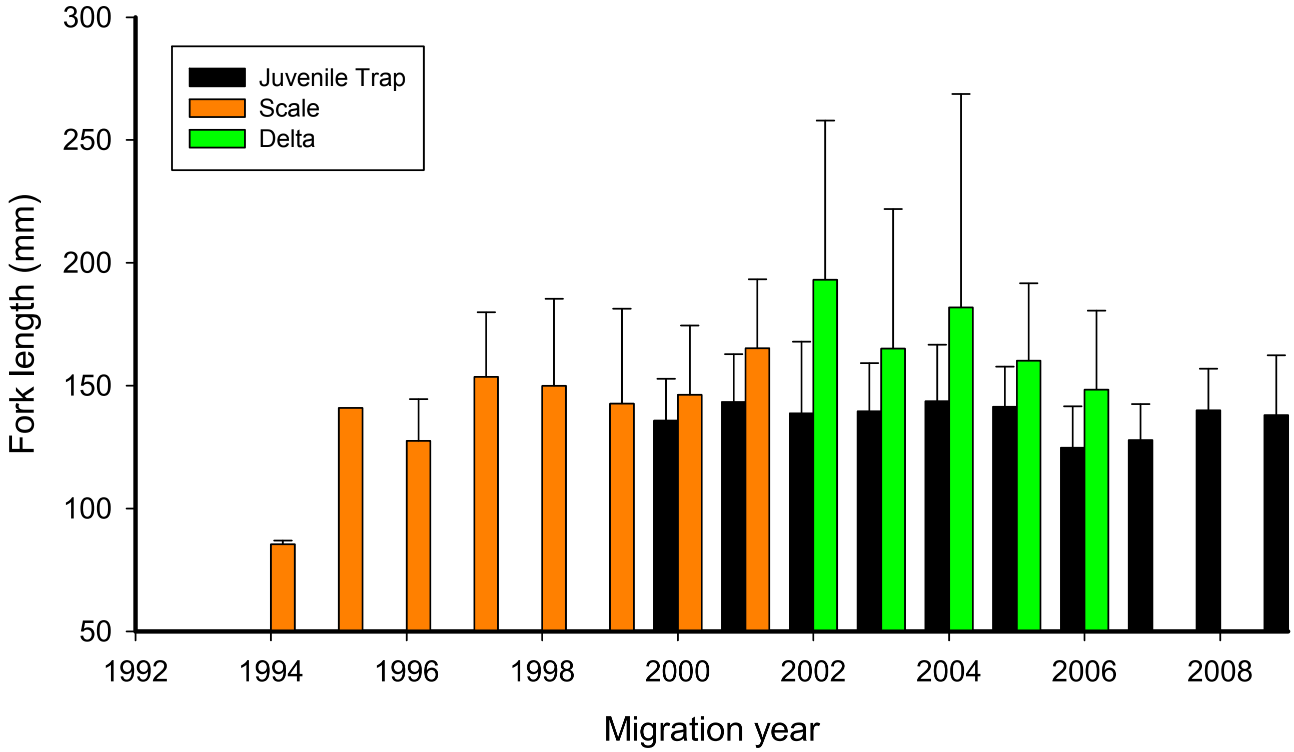

Figure 6.─Length of juvenile bull trout upon salt-water entry based on three sampling methods in the Skagit River, 1994-2009. Sampling methods are a downstream trap near Mt. Vernon (black), fyke nets in the Skagit delta (green), and back-calculated lengths from scales of anadromous spawners (orange). Data are means and standard deviations for February to June collections in each migration year.

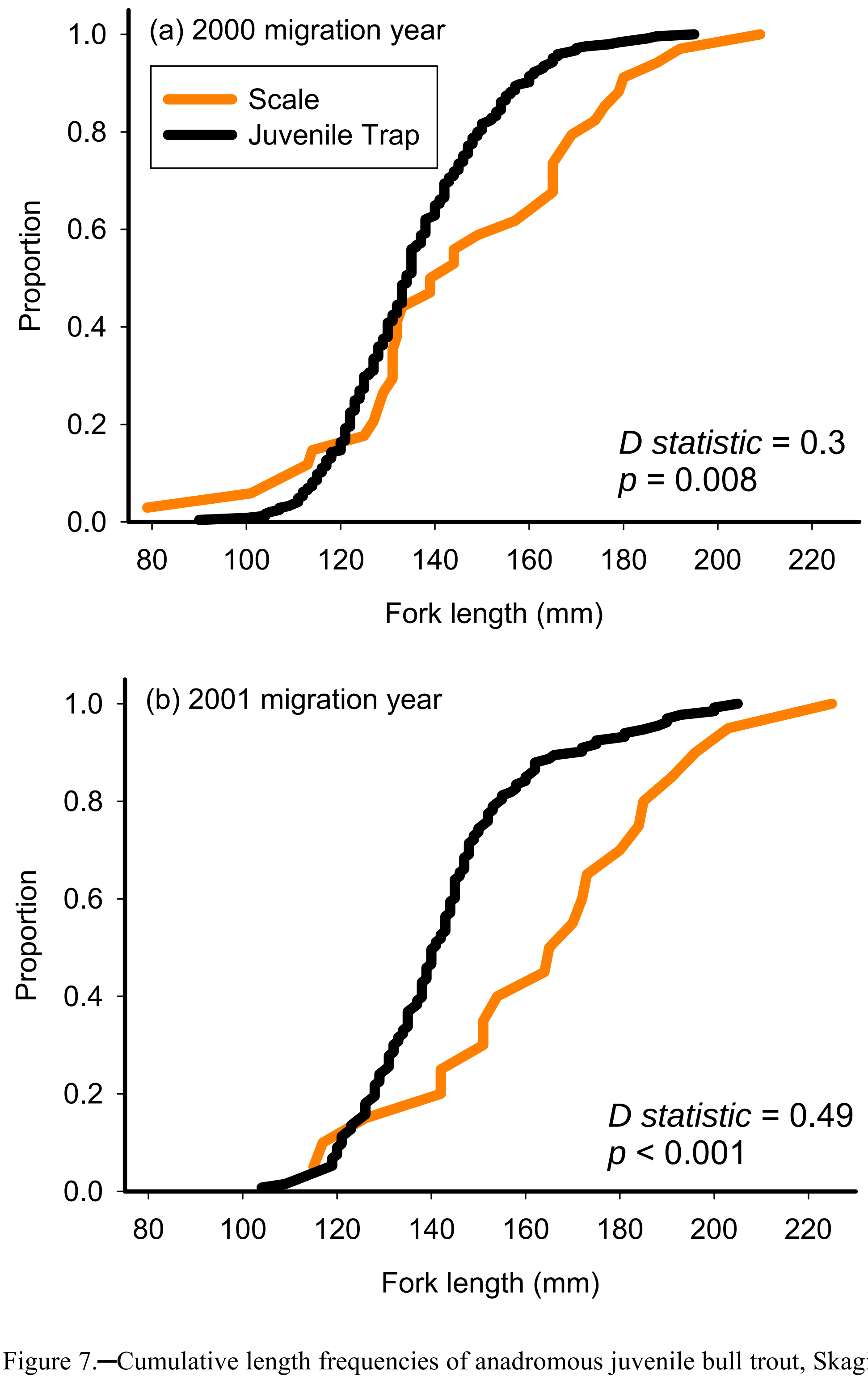

Figure 7.─Cumulative length frequencies of anadromous juvenile bull trout, Skagit River. Data are downstream trap measures (black) and back-calculated lengths from adult scales (orange) corresponding to the 2000 (*a*) and 2001 (*b*) downstream migrations.

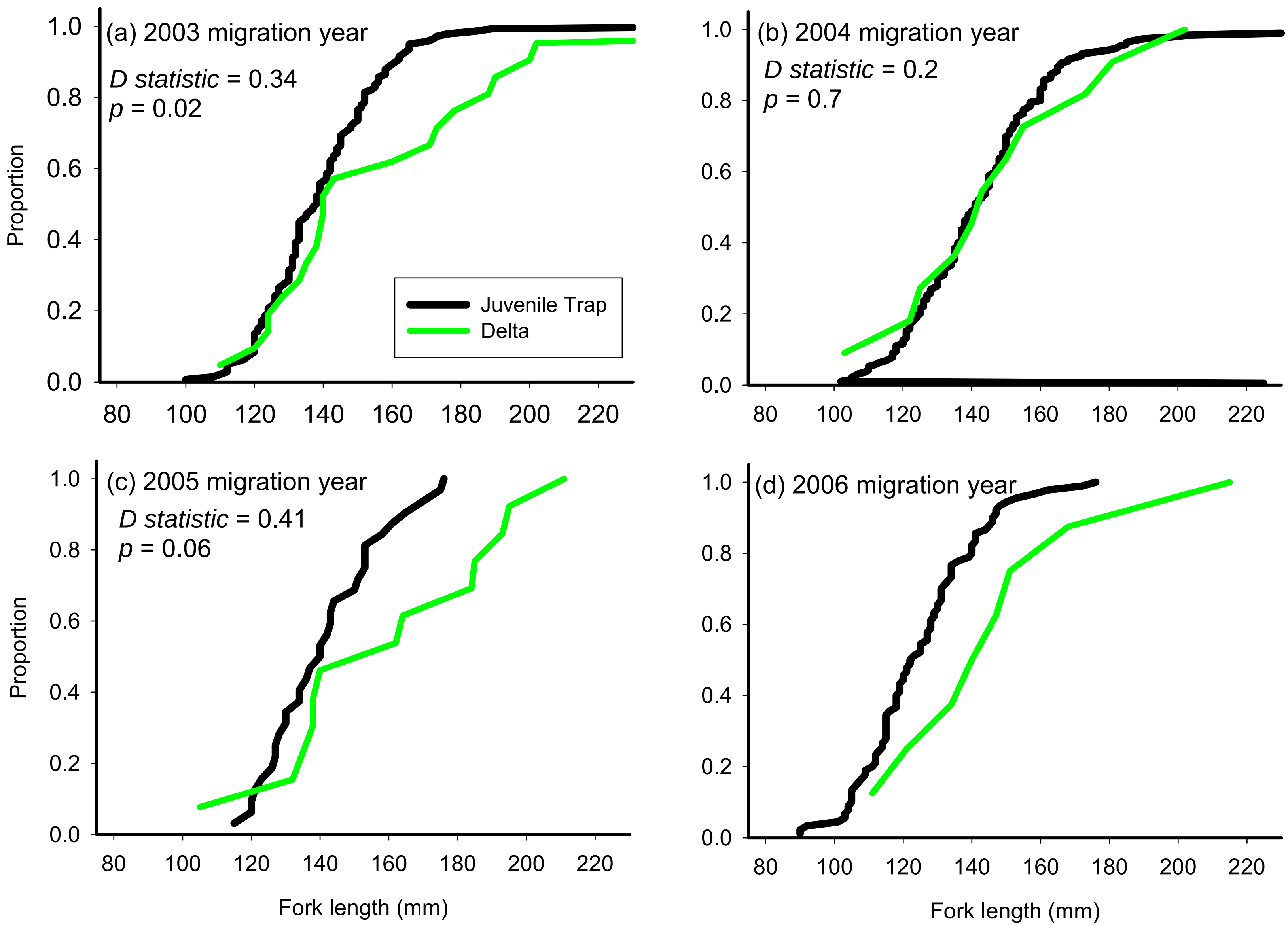

Figure 8.—Cumulative length frequencies of juvenile anadromous bull trout from the Skagit River based on two sampling methods, juvenile downstream rap near Mt. Vernon (juvenile trap, black) and fyke nets in delta blind channels (delta, green). Data correspond to the 2003 (*a*), 2004 (*b*), 2005 (*c*), and 2006 (*d*) downstream migrations. Kruskal-Wallis test could not be performed for 2006 due to low sample size.

Catch of juvenile bull trout was positively correlated between the downstream trap and delta blind channels of the Skagit River (Figure 9). These data were best fit with a nonlinear function (i.e., logarithmic or quadratic function, Table 5). Of the two appropriate nonlinear models, the logarithmic model had the fewest parameters and was therefore selected to describe the relationship between the two collection types. Three outliers to the correlation occurred in 1997, 2002, and 2005 and were removed prior to analysis.

Table 5.─Regression models fit to juvenile bull trout abundance data from Skagit River downstream trap and delta blind channel collections. Three outlier points (shown in Figure 9) were not included in this analysis.

Model	$adjR^2$	*p value*
Linear *(Delta = 0.0631*Trap + 3.1181)*	0.61	0.002
Logarithmic *(Delta = 12.486*ln(Trap) - 49.157)*	0.72	0.0003
Quadratic *(Delta = - 0.0003*Trap + 0.1833*Trap^2 - 7.8675)*	0.71	0.0003

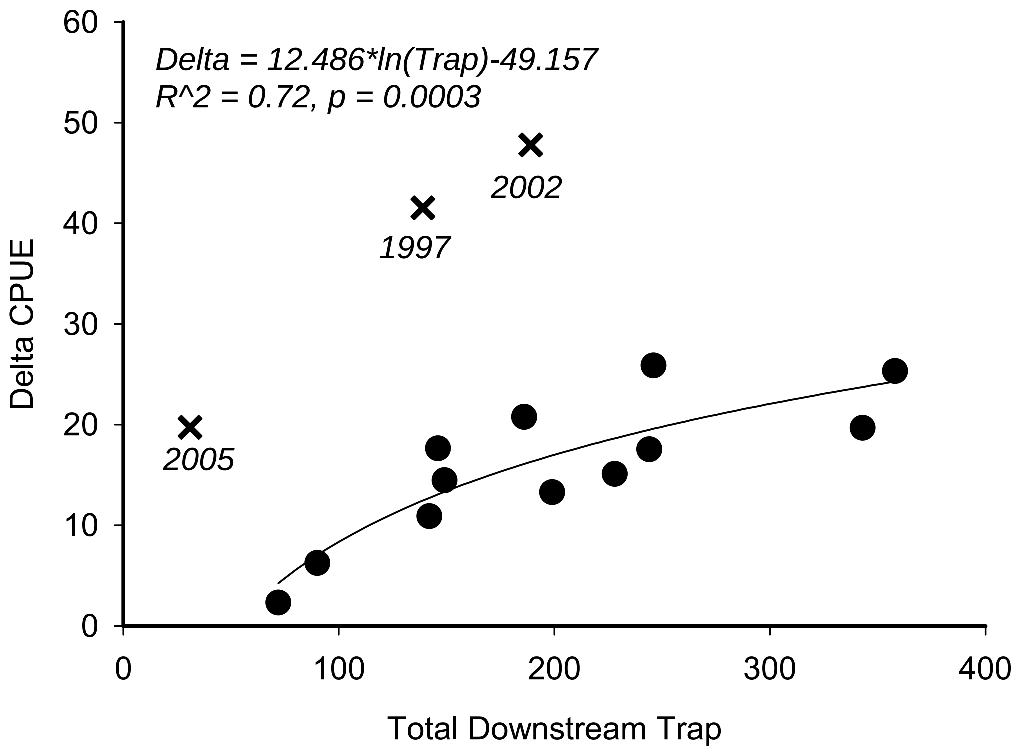

Figure 9.─Correlation between catch of juvenile anadromous bull trout in downstream trap (total catch) and in delta surveys (average seasonal catch per hectare) of Skagit River. Data (circles) are individual years, 1995-2009. Three outliers (X) were removed prior to fitting the data with a logarithmic model.

Expansion of Bull Trout Catch

A comparison of outmigration timing demonstrated that Chinook and coho do not randomly mix with the juvenile bull trout. Outmigration of juvenile bull trout, coho smolts, and Chinook parr occurred between statistical week 20 and 23, corresponding to late May or early June (Table 6). In most years, median migration dates of bull trout were comparable to Chinook parr but later than that of coho smolts. However, bull trout migration occurred over a longer period than coho smolts and more constrained period than Chinook parr (Figure 10).

A comparison of species-specific body size and trap efficiencies demonstrated that bull trout were unlikely to have an equal probability of capture as either Chinook or coho. Efficiencies of the Skagit downstream trap were lower for coho than Chinook in most years (Table 7). Furthermore, the ratio of coho to Chinook body lengths (1.5 to 3.0) and trap efficiencies (0.2 to 1.5) varied widely with no apparent relationship between them. This provided no basis to extrapolate existing trap efficiencies to bull trout. Bull trout body lengths were 1.3 to 1.6 times longer than coho smolts and 2.3 to 4.0 times longer than sub yearling Chinook (Table 7, Figure 11).

Table 6.—Downstream migration compared among juvenile bull trout, coho smolts, and Chinook parr in the Skagit River, 1990-2009. Median migration for each trap year is reported by statistical week. Chi-square results indicate differences in downstream migration timing.

	Median Migration Week			Bull trout v. coho			Bull trout v. Chinook parr		
Migration year	Bull trout	Coho	Chinook parr	χ^2	*df*	*p*	χ^2	*df*	*p*
1990	20	21		69	9	<0.001			
1991	21	21		109	10	<0.001			
1992	21	21		176	9	<0.001			
1993	21	21		70	8	<0.001			
1994	21	22		219	11	<0.001			
1995	22	21		2504	16	<0.001			
1996	23	21		2279	14	<0.001			
1997	21	19	23	165	13	<0.001	135	23	<0.001
1998	19	21	22	801	13	<0.001	403	24	<0.001
1999	23	22	23	1058	14	<0.001	91	25	<0.001
2000	22	21	22	82	15	<0.001	167	23	<0.001
2001	21	20	20	251	15	<0.001	109	23	<0.001
2002	22	21	22	1367	14	<0.001	94	24	<0.001
2003	23	21	22	1283	14	<0.001	348	25	<0.001
2004	20	21	23	849	16	<0.001	309	21	<0.001
2005	21	21	17	15	9	0.10	97	20	<0.001
2006	23	22	23	1346	15	<0.001	49	18	<0.001
2007	21	20	22	921	14	<0.001	178	19	<0.001
2008	22	20	22	246	8	<0.001	94	18	<0.001
2009	23	20	23	412	12	<0.001	58	17	<0.001

Table 7.─Body size and trap efficiency of juvenile salmonids caught in the Skagit River downstream trap, 1990-2009. Data are average fork lengths (mm) and trap efficiency each trap year. Chinook data are for statistical week 17 to 24 (May and June) only.

	Sub yearling Chinook		Yearling coho		Ratio of lengths			Ratio of efficiencies
Year	Length	Efficiency	Length	Efficiency	Coho: Chinook	Bull trout: Chinook	Bull trout: coho	coho: Chinook
1990			94.7	1.32%				
1991			104.3	1.10%				
1992			95.1	0.75%				
1993			96.0	1.22%				
1994	63.8	2.14%	97.1	1.87%	1.52			0.88
1995	56.6	2.02%	97.1	2.47%	1.71			1.23
1996	62.5	2.00%	95.1	1.84%	1.52			0.92
1997	49.6	3.29%	94.5	1.07%	1.91			0.32
1998	58.2	2.89%	95.8	1.31%	1.65			0.45
1999	54.2	1.69%	94.7	1.24%	1.75			0.74
2000	57.5	2.85%	87.8	1.84%	1.53	2.36	1.55	0.65
2001	60.1	1.93%	93.7	0.68%	1.56	2.38	1.53	0.35
2002	51.8	1.57%	92.6	0.96%	1.79	2.68	1.50	0.61
2003	55.9	3.09%	89.0	1.00%	1.59	2.50	1.57	0.32
2004	58.3	1.27%	95.0	1.93%	1.63	2.47	1.51	1.52
2005	54.3	3.75%	91.2	0.82%	1.68	2.60	1.55	0.22
2006	54.5	2.40%	95.1	1.31%	1.75	2.29	1.31	0.55
2007	44.2	5.24%	98.3	1.75%	2.22	2.89	1.30	0.33
2008	35.1	4.39%	104.6	1.08%	2.98	3.99	1.34	0.25
2009	50.0	5.79%	91.5	1.25%	1.83	2.76	1.51	0.22
Minimum	35.1	1.27%	87.8	0.68%	1.52	2.29	1.30	0.22
Average	54.2	2.89%	95.2	1.34%	1.79	2.69	1.47	0.60
Maximum	63.8	5.79%	104.6	2.47%	2.98	3.99	1.57	1.52

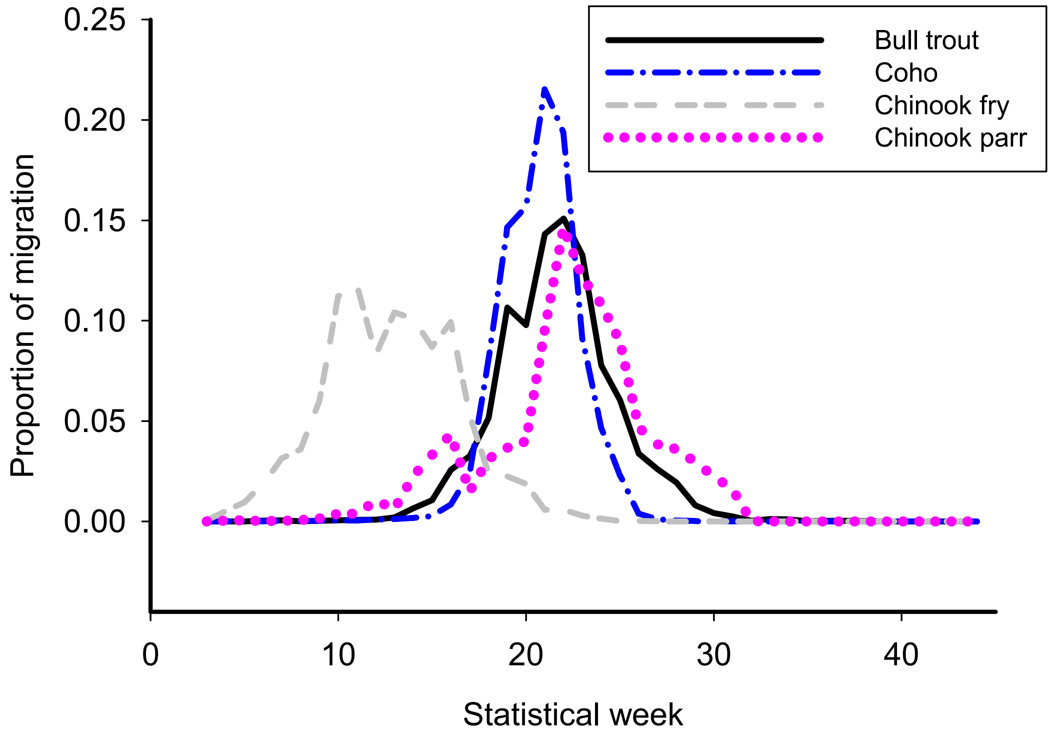

Figure 10.─Timing of juvenile salmonid downstream migrations in the Skagit River, 1990-2009. Data are average of the proportions of seasonal catch (bull trout and coho) and migration (Chinook) occurring each statistical week.

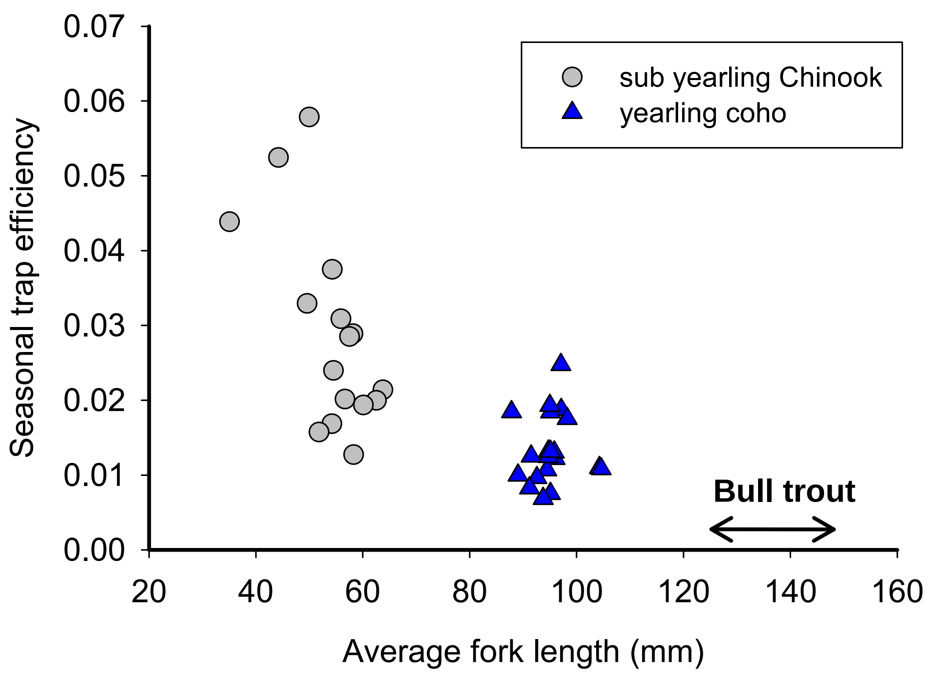

Figure 11.─Trap efficiency and body length for juvenile salmonids in the Skagit downstream trap. Data points are the average value for each year. Chinook data are for the 1994 to 2009 migration years. Coho data are for the 1990 to 2009 migration years.

Variables Influencing Anadromous Juvenile Bull Trout

Bull trout redd observations in the South Fork Sauk River have varied 100-fold over the past 20 years (Appendix C; Kraemer 2003). Redd observations in the South Fork Sauk River were not correlated with catch of anadromous juvenile bull trout (Figure 12). Of note, some of the highest catches of anadromous juveniles in the downstream trap were associated with the lowest redd observations on the South Fork Sauk. Results from recent WDFW survey areas suggest that redd observations in the South Fork Sauk River may not be correlated with other Skagit River sub basins (Appendix C; Downen 2006, Fowler 2009).

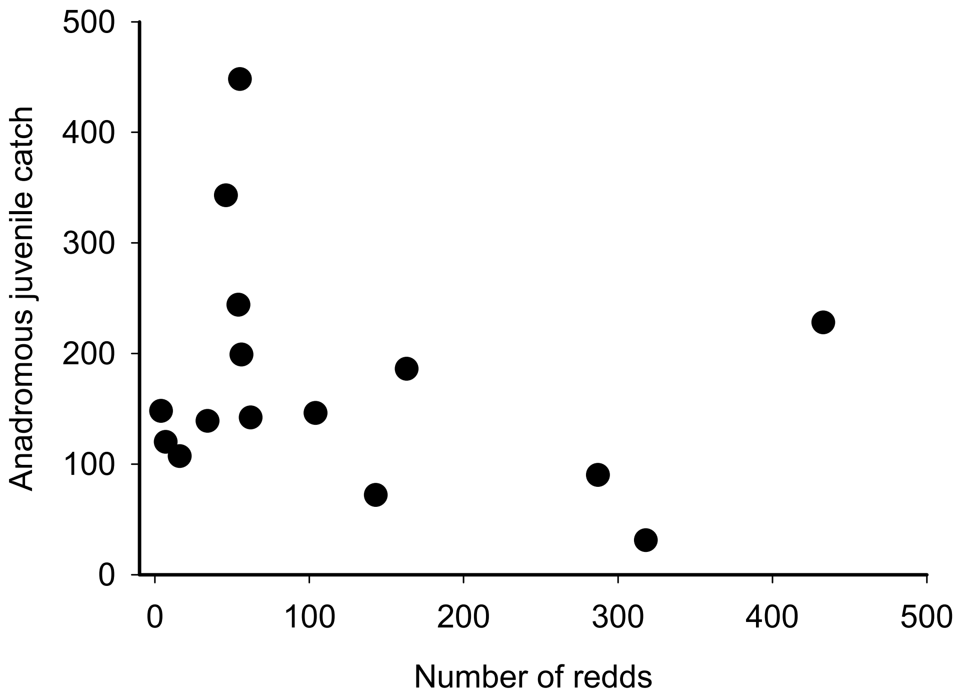

Figure 12.─Catch of anadromous juvenile bull trout in the downstream trap as a function of redd observations on the South Fork Sauk River, Skagit basin. Data points are for single brood years (1988-2006) and assume that the majority of anadromous juvenile are age-2 fish.

Maximum stream temperature of the Skagit River (near Marblemount) has ranged from 12.5 to 15ºC over the past 20 years (Appendix D). Lengths of anadromous juvenile bull trout were a negative, nonlinear function of stream temperature during the age-0 rearing year (Figure 13). The negative correlation between rearing temperature and bull trout length was greatest when maximum rearing temperatures exceeded 14ºC (Figure 13*b*). In comparison with the length data, the number of juvenile bull trout caught in the downstream trap was not a function of maximum stream temperature (Figure 13*a* and *c*).

Total returns of pink and chum salmon have ranged from 22,000 to 967,000 spawners over the past 20 years (Appendix D). Lengths of anadromous juvenile bull trout were shorter in years when both freshwater rearing years (age-0 and age-1) overlapped with low returns of pink and chum spawners than in years when these species exceeded 200,000 spawners for at least one of the bull trout rearing years (Figure 14*b, d*). When pink and chum returns over two consecutive years summed to less than 300,000, anadromous juvenile bull trout averaged between 125 and 128-mm FL. When the sum of consecutive pink and chum returns exceeded this threshold, anadromous juvenile bull trout averaged between 136 and 144-mm FL. In comparison to the length data, the number of juvenile bull trout caught in the downstream trap was not well correlated with escapements of pink and chum salmon (Figure 13*a, c*).

Total catch of sub yearling migrants (pink, chum, Chinook) has ranged 10-fold over the past 15 years (Appendix D). Neither the number or lengths of juvenile bull trout were a function of the cumulative total of sub yearling migrants (Figure 15).

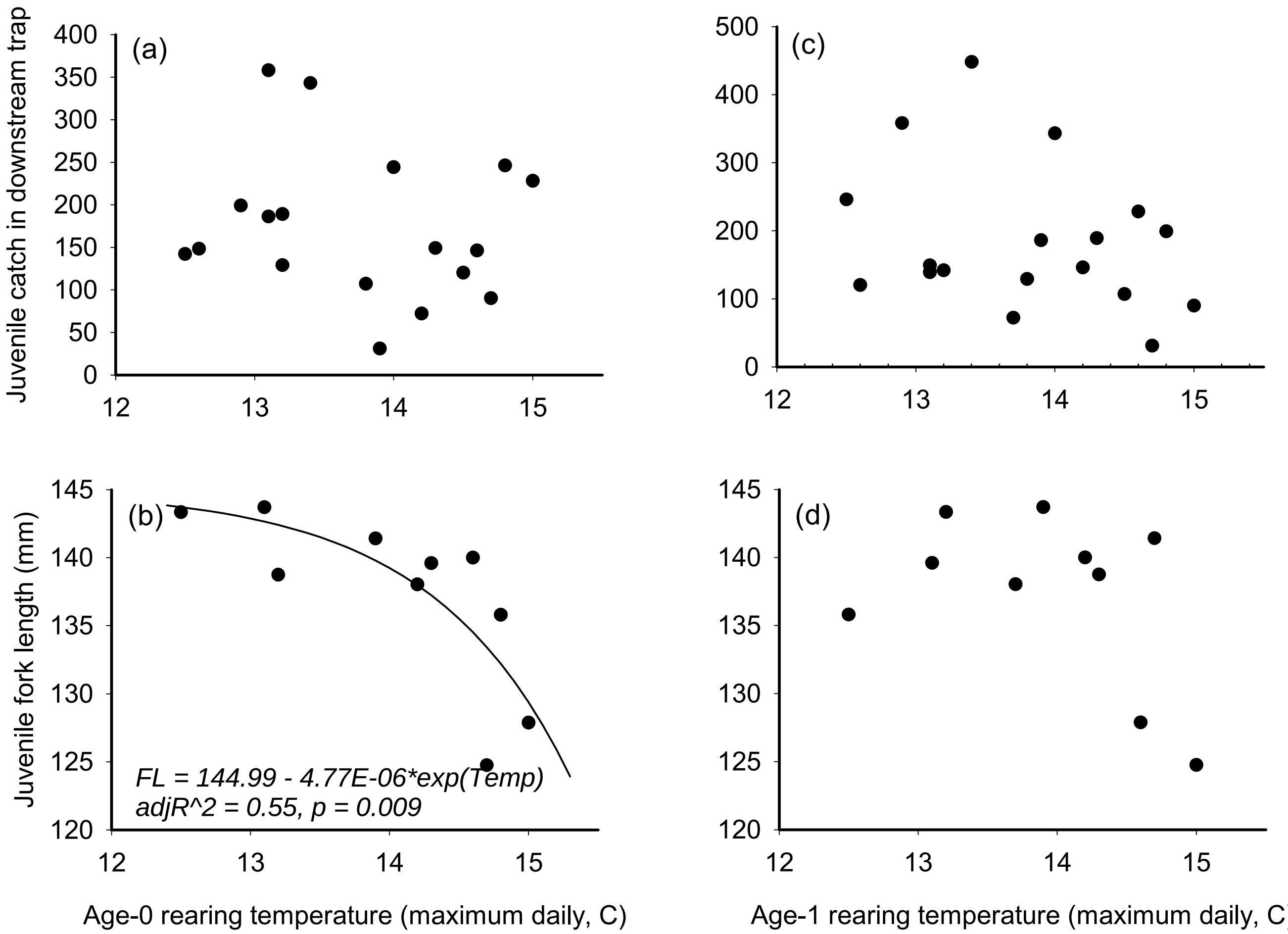

Figure 13.—Abundance and length of anadromous juvenile bull trout in the Skagit River as a function of maximum stream temperature during the age-0 (*a, b*) and the age-1 rearing periods (*c, d*). Juveniles were enumerated (1990-2009) and measured (2000-2009) at the Skagit River downstream trap. Maximum stream temperature was measured at the Marblemount USGS gage (#12181000). Each data point represents a single year.

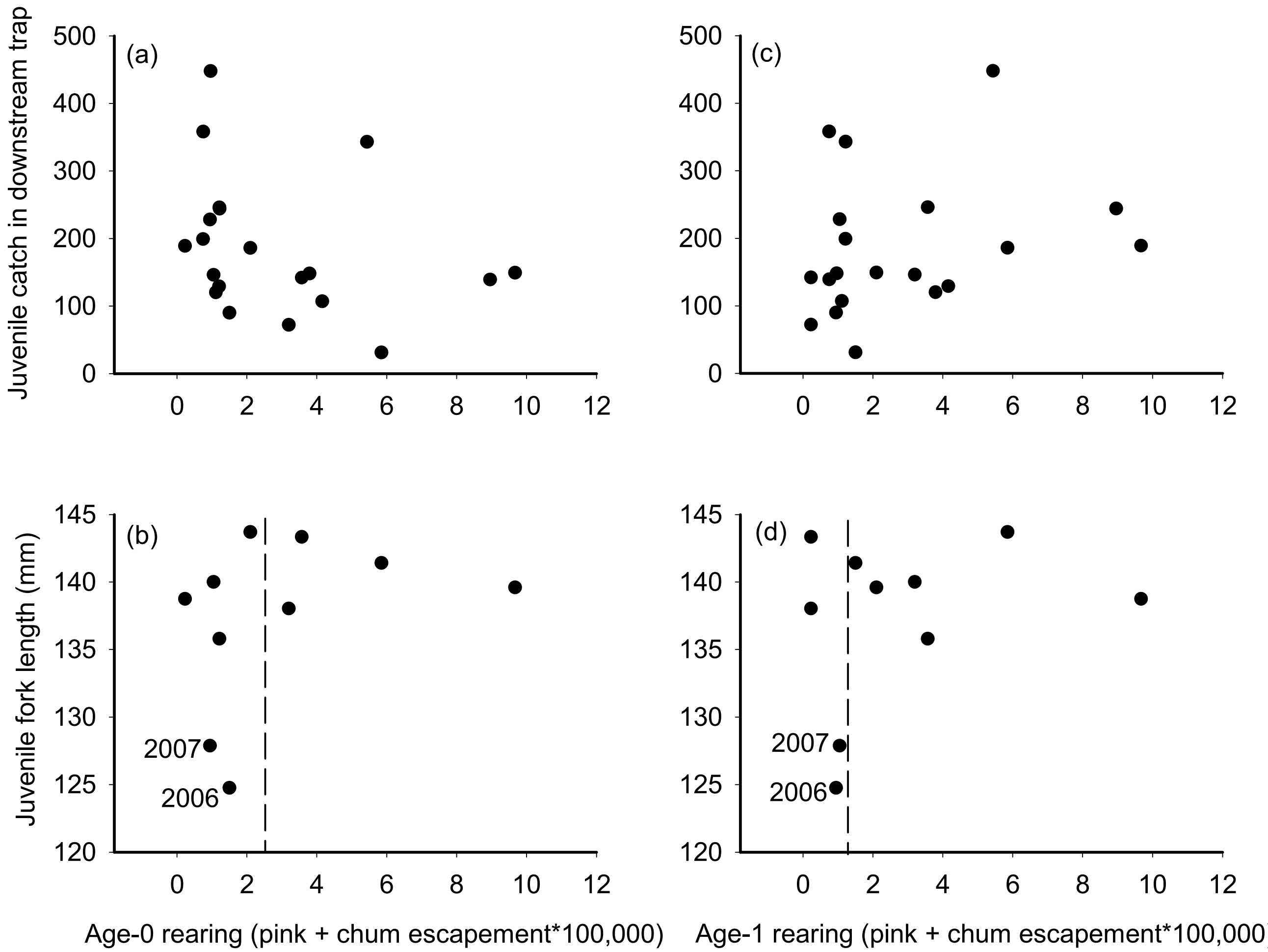

Figure 14.─Abundance and length of anadromous juvenile bull trout in the Skagit River as a function of pink and chum escapements during the age-0 (*a, b*) and the age-1 rearing periods (*c, d*). Juvenile catch are 1990-2009 migration years and lengths are 2000-2009 migration years. Each data point represents a single year. The 2006 and 2007 migration years correspond to two consecutive low escapements of pink and chum salmon.

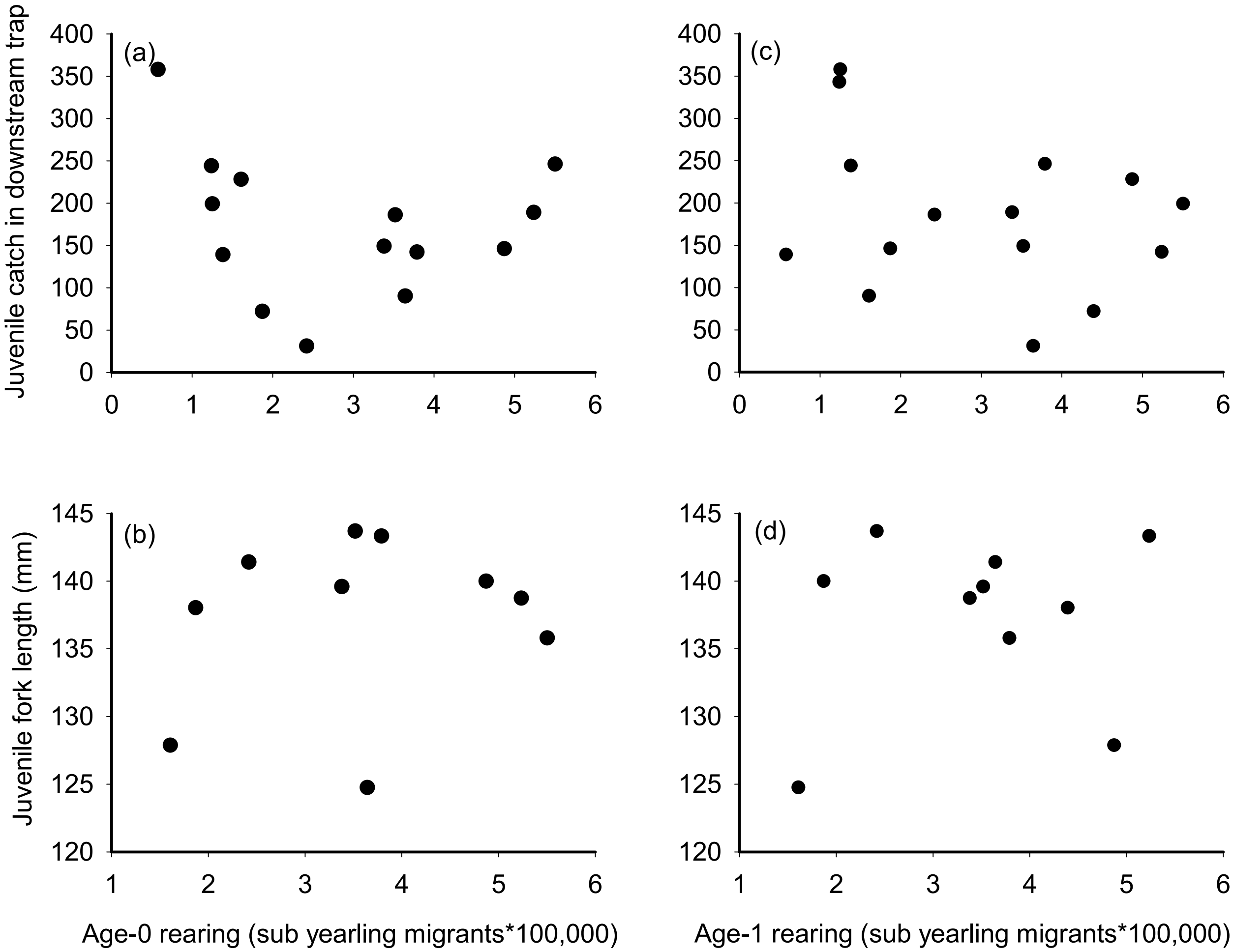

Figure 15.—Abundance and length of anadromous juvenile bull trout in the Skagit River as a function of sub yearling catch (pink, chum, Chinook) in the downstream trap. Sub yearling catch corresponds to age-0 (*a, b*) and age-1 freshwater rearing periods (*c, d*) of bull trout. Each data point represents a single year.

Discussion

Anadromy of Juvenile Bull Trout in the Skagit River

Catch of juvenile bull trout in the Skagit River trap varied 14-fold between 1990 and 2009. Over this period, all juvenile char caught in the Skagit River trap were assumed to be bull trout and not Dolly Varden. This assumption was based on the known distribution of anadromous forms of Dolly Varden (50º to 71º N) versus bull trout (46º to 56º N) in the northwest Pacific (Goetz et al. 2004). In the Skagit River basin, all genetic samples of char below Ross Dam have been bull trout (Leary and Allendorf 1997, Goetz et al. 2004), although Dolly Varden are observed in the tributaries of Diablo Lake, Ross Lake, and the Skagit River drainage in British Columbia (E. Connor, Seattle City light, personal communication).

A uni-modal pattern to the outmigration was observed each year with peak migration occurring in mid to late May. Movements were primarily nocturnal, a result also observed for coho smolts in this system (Seiler et al. 1997). Downstream movement was minimal to none in January and February and in September and October. A similar seasonality of bull trout catch has been observed in the estuary monitoring program. Sampling in the Skagit delta occurs between February and August and bull trout caught in these surveys have a similar seasonality and length distribution to the freshwater juvenile trap (Beamer and Henderson 2004). Downstream movement during November and December is unknown as the freshwater juvenile trap has never operated during these months. However, sampling in Skagit Bay, "downstream" from the delta, occurs year round and has demonstrated a smaller peak of large bull trout (up to 750 mm FL) in the month of December (Beamer and Henderson 2004). These fish may represent an additional emigration period from the river (i.e., November and December) or seasonal use of Skagit Bay habitat by anadromous bull trout that emigrated in a previous year. Together the downstream trap and estuary monitoring data support the existence of an anadromous bull trout life history strategy in the Skagit River. Therefore, we assume that bull trout caught in the downstream trap are migrating to salt water (i.e., anadromous life history) rather than rearing in the lower Skagit River (i.e., fluvial life history).

Juvenile anadromy observed in the Skagit River contrasts with that observed in the Hoh River. The Hoh River drains from the west side of the Olympic Mountains and historically produced more bull trout that any other coastal Washington watershed (Mongillo 1993). Movements of juvenile and adult bull trout in this system were studied through acoustic tagging and otolith microchemistry (Brenkman and Corbett 2005, Brenkman et al. 2007). Juvenile bull trout tagged during the fall of 2004 were observed to undergo seaward migration between September and December 2004 (Brenkman et al. 2007). No ocean migrations were observed in January 2005 although transmitters continued to function through this time period. Hoh River juvenile migrants were older (3 to 4 years) and larger (243 to 360-mm FL) than the Skagit River fish (Kraemer 2003, Brenkman et al. 2007), suggesting that anadromous life histories differ between these two systems. A caveat to this conclusion is the lack of information on movements of smaller juvenile bull trout in the Hoh River. At the time that the acoustic study was conducted, both the size of tagged fish and the timing of the tag implementation were constrained by opportunistic sampling (S. Brenkman, Olympic National Park, personal communication). Further study of smaller bull trout tagged in the January to March time frame in the Hoh River or study of bull trout tagged in the September to December time frame in the Skagit River would provide a more direct comparison between watersheds.

Catch and Abundance of Anadromous Juvenile Bull Trout

Although estimations of total abundance of anadromous juvenile bull trout are desirable for stock assessment, the results of such an assessment will only be as useful as the data used. After evaluating available information, we conclude that estimations of total juvenile bull trout abundance are not defensible because existing data violated two of the assumptions necessary for this estimation.

In order to make an abundance estimate, catch of juvenile migrants in the downstream trap must be expanded by their capture rates (i.e., trap efficiency). Trap efficiency data were available for two species representing two different size classes – Chinook (average 54-mm FL) and coho (average 95-mm FL). Between 1990 and 2009, capture rates of coho smolts in the Skagit downstream trap has been 0.60 times the capture rate of juvenile Chinook. If bull trout capture rates are assumed to be 0.73 times the capture rate of coho smolts, total abundance of anadromous juvenile bull trout would range between 5,200 and 37,600 migrants (average = 19,600 migrants). This adjustment assumes that the coho to Chinook size ratio (1.79) explains the different in capture rates (0.60 coho per Chinook) between these species and that bull trout capture rate can be estimated based on a comparable conversion of the bull trout to coho size ratio (ratio = 1.47; 0.73 = 0.6*1.79/1.47). These estimates are slightly lower than the calculations of Lowery (2009) from the same data (N = 14,000 to 49,000 migrants). However, both estimates rely on the unlikely assumption that trap efficiency is a linear function of body size. The ratio of coho to Chinook trap efficiencies has varied among years and this variation can not be explained by body size. Capture rates of bull trout and coho smolts are also likely to be impacted by fish behavior. Bull trout have a benthic orientation (Pratt 1992) and a preference for deeper water than coho (Beecher et al. 2002, Beamer and Henderson 2004). Differences in swimming depth may result in lower capture rates of bull trout than coho because the distance between the river bottom and the downstream trap is in continual flux in response to changing flows. In addition, capture rates of the largest juvenile bull trout are unknown because they are entirely missed by the downstream trap. For these reasons, estimates of bull trout capture rates would be pure speculation at this point and the total abundance estimates provided above are likely to be biased low.

We recommend that downstream trap catches be used as an index of abundance of anadromous juvenile bull trout with some qualifications. The positive correlation between downstream trap and delta catch per unit effort was promising in this regard. However, outliers need to be understood in order substantiate conclusions based on this correlation. Outliers in the downstream trap versus delta catch correlation may have occurred in years when a high proportion of large bull trout migrants were not detected in the downstream trap. Of the three outlier years, an assessment of size bias was only possible for 2005. In this year, bull trout longer than 176-mm FL were not detected in the downstream trap. According to delta collections from this year, undetected fish (proportion of fish > 176-mm FL) represented 31% of the total juvenile migrants.

The impact of size bias on the use of downstream trap catches should be particularly sensitive to the percentage of migrants that are not detected. Size bias in the downstream trap could be assessed for five years – 2000, 2001, 2003, 2004, and 2005. Of these years, 2005 had a much higher proportion of migrants (31% of tidal delta samples) in the size range not captured in the downstream trap. This proportion of undetected fish was much higher than other years (3-5% as described below). In 2000, scale back-calculations suggested that just 3% of the total bull trout migrants were longer than bull trout captured in the downstream trap (maximum 195-mm FL). In 2001, scale back-calculations suggested that just 5% of the total bull trout migrants were longer than bull trout captured in the downstream trap (maximum 205-mm FL). In 2003, tidal delta sampling suggested that just 5% of the total bull trout migrants were longer than bull trout captured in the downstream trap (maximum 270-mm FL). In 2004, tidal delta collections suggested that all bull trout migrants were within the size range captured in the downstream trap (maximum 240-mm FL). Based on these comparisons, one would expect the 2005 downstream catch to be a poor proxy for total abundance, a conclusion supported by the outlier position of this data point on the downstream trap versus delta catch correlation.

Environmental Contributions to Bull Trout Anadromy

Environmental contributions to anadromous juvenile bull trout were interpreted based on the assumption that the majority of migrants were age-2 fish. This assumption was supported by several pieces of evidence. Analysis of scales from anadromous spawners indicated that most fish reared in freshwater for two years prior to saltwater entry (Kraemer 2003). By itself, this result may be questionable as char scales are notoriously difficult to read (L. Campbell, WDFW, personal communication). However, lengths observed in the downstream trap are consistent with literature values for age-2 bull trout (Rieman and McIntyre 1993, McPhail and Baxter 1996). Furthermore, otoliths collected from in-river Skagit collections of bull trout found age-2 fish to be ~140-mm FL, compared to ~100-mm FL for age-1 fish and ~300-mm FL for age-3 fish (Lowery 2009). Based on this assumption, environmental variables were assigned to the age-0 and age-1 rearing periods.

Body lengths of anadromous juvenile bull trout were predicted by a combination of rearing temperature and spawner carcasses. Maximum stream temperatures in our dataset ranged between 12.5 and 15.0ºC. Lengths of anadromous juvenile bull trout decreased as maximum age-0 rearing temperatures increased. This result is consistent with laboratory observations that peak growth of juvenile bull trout occurs around 13ºC (Selong et al. 2001) and field observations that bull trout occurrence probabilities can be predicted by maximum stream temperature (Rieman and Chandler 1999, Dunham et al. 2003). The rearing temperatures used in this report should be considered an indicator for more specific stream temperatures within the Skagit basin. The Marblemount stream gage was selected because time series temperature data were not available from specific tributaries where juveniles are known to rear. Anadromous juvenile bull trout were also shorter when both age-0 and age-1 rearing periods experienced less than 200,000 pink and chum spawners than when at least one rearing year exceeding this escapement level. Smaller body sizes may result from reduced juvenile feeding on either the carcasses or salmon eggs, both important nutrient sources have for juvenile bull trout (Lowery 2009). Juvenile lengths were not a function of salmonid fry, indicating that this variable may not limit anadromous bull trout growth in the Skagit River. Together, these results indicate that chronically low escapements of pink and chum salmon combined with high stream temperatures have the potential to limit early growth of anadromous bull trout in the Skagit River.

Catch of juvenile bull trout was not correlated with any of the environmental variables examined. This result was not surprising given the complexity of juvenile life history strategies expressed by Skagit bull trout. Environmental variables known to influence bull trout survival will only be detectable as catch of anadromous juvenile fish if each life history strategy is a constant proportion from year to year. Although low temperatures or high food availability should improve in-stream survival, the mechanisms by which these variables influence the anadromous component of the brood year are unknown. Furthermore, anadromous life history may be a facultative characteristic for the bull trout. For example, Brenkman and colleague (2007) observed that anadromous offspring came from both anadromous and resident females, and Kraemer (2003) concluded that some bull trout shifted among resident, fluvial, and anadromous life histories over the course of their life.

Catch of anadromous juvenile bull trout were also uncorrelated with spawner abundances in the South Fork Sauk. The South Fork Sauk data were selected because this is the only long-term data set available for the Skagit River. Other index reaches were added to WDFW surveys beginning in 2001 (Downen 2006, Fowler 2009). The lack of correlation between juveniles and spawners was difficult to interpret for several reasons. First, South Fork Sauk data may or may not be representative of all Skagit bull trout populations. To this end, expanded WDFW survey reaches in the past eight years should improve understanding of whether population dynamics are synchronized among populations. Second, the contributions of different spawning populations to the anadromous life history strategy are unknown. South Fork Sauk spawners may or may not be contributing to the anadromous juveniles. A genetic baseline is currently being developed for spawning populations (M. Small, WDFW, personal communication) and will allow for stock-specific contributions to be evaluated in the future. Third, as discussed above, the proportion of juveniles that become anadromous are unknown as are the mechanisms that influence the expression of anadromy. If the proportion of anadromous fish varies substantially from year to year, spawner abundance may not be correlated with juvenile anadromous fish at all.

Future Direction

Bull trout are a diverse species with multiple and specific habitat requirements. An ecosystem approach will be required for successful conservation and management of this species. Such an approach will require an accurate understanding of which habitats are important for bull trout growth and survival as well as which migratory corridors that connect critical habitats (Rieman and McIntyre 1993). Understanding the anadromous life history strategy will help to conserve this unique component of the Coastal-Puget Sound bull trout DPS. This report provides a comprehensive interpretation of anadromous juvenile bull trout in the Skagit River. However, further work is needed to resolve issues raised by the results of this report.

- Source populations for anadromous juvenile bull trout should be identified based on genetic analysis of individuals captured in the downstream trap and in estuary collections. This analysis should soon be possible due to the development of a genetic baseline distinguishing parental populations (M. Small, WDFW, personal communication). Results would identify the populations with the highest contributions to the unique anadromous life history form.
- Movement and age structure of juvenile bull trout using estuary and near shore habitats should be summarized with respect to saltwater entry described in this report. This analysis is possible based on currently collected information in the estuary monitoring program conducted by the Skagit River System Cooperative. Results would identify the estuary residency period and the relative importance of this habitat for anadromous bull trout growth and survival.
- Direct collection of age data from the Skagit downstream trap and estuary collections is needed to validate assumed age-structure. A technique for aging based on fin ray cross sections is currently being investigated by WDFW and may be useful for this purpose. Alternately, otolith recoveries from in-river sport fisheries would validate age at ocean entry. Results would be the most direct validation of assumptions used for analysis of environmental variables in this report.

The facultative versus obligatory nature of the different life history strategies remains a key question related to bull trout recovery. Should all four strategies by expressed in a healthy coastal system? Results from the Hoh River indicate that a parent with a resident life history can give rise to a migrant offspring (Brenkman et al. 2007); however, the relative contributions of each life history form to the subsequent generations are unknown. In the Skagit River, these data could be acquired by analysis of otoliths harvested from sport fishery catches. Results would demonstrate the relative fitness of each life history form and help to model the contributions of life history diversity to long-term persistence of bull trout populations in a watershed.

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APPENDIX A

Total catch of juvenile bull trout by statistical week in Skagit River juvenile trap

Appendix A.─Total catch of juvenile bull trout by statistical week in the Skagit River downstream trap, 1990-2009. Zero values indicate no catch during trap operation. Empty cells are prior to or after the trapping season.

Statistical week	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
3									0	0
4									0	0
5									0	0
6									0	0
7								0	0	0
8								0	1	0
9								1	0	0
10								1	0	0
11								0	0	0
12								0	0	0
13						9		0	0	1
14						5		2	1	0
15	0	5	0	0	0	2	1	1	0	1
16	4	6	0	1	2	11	12	3	1	2
17	3	5	6	1	45	8	3	17	2	3
18	1	13	4	1	41	12	15	15	19	2
19	39	5	20	6	51	8	16	19	164	9
20	22	11	23	10	58	43	19	10	48	3
21	25	19	19	60	64	65	20	23	40	6
22	3	11	20	37	58	45	10	13	19	42
23	12	11	6	29	36	27	48	6	21	62
24	19	12	10	3	43	29	27	8	10	17
25	1	9	12		17	22	25	0	4	25
26					21	22	14	9	10	13
27					12	23	13	3	5	6
28						4	17	0	3	3
29						7	4	0	4	2
30						1		1	1	0
31								1	2	2
32								0	1	0
33								3	1	0
34								3	0	0
35								0	1	0
36								1	0	0
37								1	0	0
38										
39										
40										
41										
42										
43										
44										0
Total	**129**	**107**	**120**	**148**	**448**	**343**	**244**	**141**	**358**	**199**

Appendix A (continued).

Statistical week	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
3	0	0	0	0				0	0	
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	2	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	1	0	0	0	0	0	0	0
11	0	0	1	0	0	0	0	1	1	0
12	0	1	0	0	1	0	0	1	0	0
13	0	0	0	0	1	0	0	1	0	0
14	0	0	3	8	1	0	1	3	0	0
15	0	0	7	2	6	0	0	14	0	0
16	5	0	22	0	10	2	0	7	0	1
17	9	0	10	0	8	1	1	1	0	5
18	10	28	6	0	14	3	1	9	2	0
19	12	13	8	2	37	5	3	19	1	4
20	22	25	11	4	20	3	6	38	2	5
21	47	24	23	6	20	7	1	39	25	0
22	47	18	32	40	13	6	12	28	61	9
23	26	6	28	37	25	2	20	10	17	23
24	18	7	14	12	8	1	8	14	9	12
25	10	12	9	16	2	1	15	13	15	2
26	13	1	3	7	7	0	5	7	5	5
27	5	3	7	7	10	0	7	7	1	1
28	8	2	4	5	2	0	7	12	2	2
29	4	0	0	0	0	0	2	2	4	2
30	3	2	0	2	0	0	0	2	1	1
31	4	0	0	1	1	0	0			0
32	1						0			
33	0									
34	0									
35										
36										
37										
38										
39	0									
40										
41										
42	0									
43										
44	0									
Total	**246**	**142**	**189**	**149**	**186**	**31**	**90**	**228**	**146**	**72**

APPENDIX B

Lengths of juvenile bull trout upon salt-water entry estimated from three sampling methods in the Skagit River

Appendix B.─Fork lengths (mm) of juvenile bull trout upon salt-water entry estimated from three sampling methods in the Skagit River, 1994-2009. Sampling methods are catch in the downstream trap at Mt Vernon (juvenile trap), back-calculated lengths from scales of spawners (scale back-calculations), and catch in fyke nets in the Skagit delta (delta blind channel).

Migration	Juvenile trap					Scale back-calculations					Delta blind channel[1]				
year	*n*	Mean	St.Dev.	Min.	Max.	*n*	Mean	St.Dev.	Min.	Max.	*n*	Mean	St.Dev.	Min.	Max.
1994						2	85.5	1.5	84	87					
1995						1	141.0	0.0	141	141					
1996						5	127.6	16.9	101	149					
1997						10	153.6	26.3	105	198					
1998						22	150.0	35.4	73	233					
1999						26	142.7	38.7	74	242					
2000	245	135.8	17.0	90	195	34	146.3	28.2	79	209					
2001	133	143.3	19.5	104	205	20	165.3	28.0	115	225					
2002	4	138.8	29.2	91	170						26	193.2	64.8	115	350
2003	140	139.6	19.6	100	270						21	163.6	60.9	110	400
2004	190	143.7	23.0	102	240						11	148.1	28.6	103	202
2005	32	141.4	16.4	115	176						13	160.2	31.5	105	211
2006	90	124.8	16.9	90	176						8	148.4	32.2	111	215
2007	233	127.9	14.6	98	176										
2008	135	140.0	16.9	105	210										
2009	77	138.0	24.4	106	290										

[1] Length data for delta blind channel collections were provided by the Skagit River Systems Cooperative (E. Beamer, personal communication). Summary of these data is limited to February to June sampling windows to avoid confounding length measures with growth in the estuary.

APPENDIX C

Bull trout redd observations in five survey reaches of the Skagit River basin

Appendix C.—Bull trout redd observations in five survey reaches of the Skagit basin. Skagit bull trout surveys are conducted by WDFW Region 4 and compiled here from three WDFW reports (Kraemer 2003, Downen 2006, Fowler 2009). Empty cells exist for years when no survey was conducted.

Year	SF Sauk Index	Bacon	Illabot	Downey	Cascade & SF Cascade	Source
1988	16					Kraemer 2003
1989	7					Kraemer 2003
1990	4					Kraemer 2003
1991	55					Kraemer 2003
1992	46					Kraemer 2003
1993	54					Kraemer 2003
1994	34					Kraemer 2003
1995						Kraemer 2003
1996	56					Kraemer 2003
1997						Kraemer 2003
1998	62					Kraemer 2003
1999						Kraemer 2003
2000						Kraemer 2003
2001	163					Kraemer 2003
2002	318	155	333	0		Downen 2006
2003	287	75	319	32		Downen 2006
2004	433	111	305	0		Downen 2006
2005	104	101	131	158		Downen 2006
2006	143	59	NA	193	434	Fowler 2009
2007	110	86	NA	172	344	Fowler 2009
2008	208	84	NA	197	333	Fowler 2009
2009	77	21	NA	103	91	Fowler 2009

APPENDIX D

Environmental variables associated with age-0 and age-1 rearing of anadromous juvenile bull trout

Appendix D.─Environmental variables associated with age-0 and age-1 rearing of anadromous juvenile bull trout. Data set assumes that majority of anadromous juveniles are age-2 migrants.

	Age-0 Rearing Variables				Age-1 Rearing Variables				Age-2 Migrants	
Year	Max Daily Temp (C)[1]	Pink + Chum Escapement[2]	Sub Yearling Catch[3]	Year	Max Daily Temp (C)[1]	Pink + Chum Escapement[2]	Sub Yearling Catch[3]	Year	Catch	Fork Length (mm)
1988	13.2	119,791		1989	13.8	415,226		1990	129	
1989	13.8	415,226		1990	14.5	110,567		1991	107	
1990	14.5	110,567		1991	12.6	378,967		1992	120	
1991	12.6	378,967		1992		95,940		1993	148	
1992		95,940		1993	13.4	542,950		1994	448	
1993	13.4	542,950		1994	14.0	121,775	123,752	1995	343	
1994	14.0	121,775	123,752	1995		895,470	138,266	1996	244	
1995		895,470	138,266	1996	13.1	74,474	57,787	1997	139	
1996	13.1	74,474	57,787	1997	12.9	74,308	125,010	1998	358	
1997	12.9	74,308	125,010	1998	14.8	120,875	550,215	1999	199	
1998	14.8	120,875	550,215	1999	12.5	356,712	378,981	2000	246	135.9
1999	12.5	356,712	378,981	2000	13.2	22,321	523,625	2001	142	143.3
2000	13.2	22,321	523,625	2001	14.3	967,041	338,016	2002	189	138.8
2001	14.3	967,041	338,016	2002	13.1	209,478	351,880	2003	149	160.2
2002	13.1	209,478	351,880	2003	13.9	584,709	241,876	2004	186	155.1
2003	13.9	584,709	241,876	2004	14.7	149,700	364,267	2005	31	141.4
2004	14.7	149,700	364,267	2005	15.0	94,000	160,777	2006	90	124.8
2005	15.0	94,000	160,777	2006	14.6	104,483	487,191	2007	228	127.9
2006	14.6	104,483	487,191	2007	14.2	319,450	187,103	2008	146	140.0
2007	14.2	319,450	187,103	2008	13.7	22,274	439,245	2009	72	138.0

[1] Data source: USGS stream gage #12181000 on Skagit River near Marblemount, Washington

[2]Data source: WDFW Salmon Abundance and Stock Inventory database, http://wdfw.wa.gov/mapping/salmonscape/index.html

[3]Sub yearling catch is the sum of chum, pink and Chinook sub yearlings caught in the downstream trap.