Evaluation of the Relationship Among Time of Ocean Entry, Physical and Biological Characteristics of the Estuary and Plume Environment, and Adult Return Rates, 2005-2006

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EXECUTIVE SUMMARY

This study examines the relationship between smolt-to-adult return rates (SARs) for spring Chinook salmon and the time of ocean entry in relation to physical and biological characteristics of the estuary and nearshore ocean plume environment. Study fish, originally from Willamette Hatchery, were transferred and reared by the Clatsop Economic Development Committee Fisheries Project and released in the lower Columbia River.

In 2005, the fourth year of releases for this project, six groups of coded-wire tagged (CWT) yearling spring Chinook salmon were transferred from Willamette Hatchery to net-pens in Blind Slough in the Columbia River estuary. Fish were reared for 14 d and released at 10-day intervals from 6 April through 23 May. Size and smolt development (gill Na^+-K^- ATPase activity) at release were similar among groups. In 2005, all release groups had chronic levels of bacterial kidney disease while at Willamette Hatchery, and signs of the disease increased in severity while fish were in the net-pens. Mortality increased for fish in the net-pens for the last two release groups as water temperatures in Blind Slough increased to more than 13°C.

In 2006, the fifth and final year of releases, six groups of CWT yearling Chinook salmon were transferred from Willamette Hatchery in the fall of 2005 to Leaburg Hatchery for rearing. The fish were then transferred from Leaburg Hatchery to net-pens in Blind Slough, reared for 14 d and released at 10-day intervals from 6 April through 24 May. Size and smolt development (gill Na^+-K^- ATPase activity) at release were similar among groups. Fish were very healthy in 2006, likely a result of the cooler water available for rearing at Leaburg Hatchery. Mortalities in the net-pens were low for all release groups.

Coded-wire-tags from 2005 releases will be recovered from adults returning in 2007 and 2008, and from 2006 releases in 2008 and 2009, primarily from the Blind Slough terminal gill net fishery. The 2002 project releases provided an estimated catch of 1,388 adults to the 2004 Blind Slough gill net and other local fisheries, 515 adults were caught in 2005 fisheries, and 31 6-year-old fish were caught in 2006 fisheries for a total of 1,934 adults from 2002 releases. SARs for the 2002 releases ranged from 0.60 to 1.78%. The estimated catch of 4- and 5-year-old fish from 2003 project releases totaled only 33 adults, with few additional returns of 6-year-old fish expected in 2007. A total of 62 4-year-old adults from 2004 releases were captured in Blind Slough in 2006; additional adults are expected in 2007 and 2008.

SARs for the serially released groups of spring Chinook salmon (when complete) will be integrated with information collected from ongoing studies funded by the Bonneville Power Administration (BPA) and others, characterizing the physical and biological conditions of the Columbia River estuary and plume. By enhancing our understanding of the linkages between ocean entry, the physical and biological estuarine and ocean conditions that the smolts encounter, and SARs, the information may provide a rationale for manipulating transportation tactics or hatchery release dates to improve SARs for some salmon stocks.

CONTENTS

INTRODUCTION

The effects of short- and long-term fluctuations in oceanographic and climatic conditions on survival of Pacific Northwest salmon have received increased attention as salmon runs have declined (NRC 1996; Emmett and Schiewe 1997; Logerwell et al. 2003; Williams et al. 2000). Growth and survival of salmonids in their first days and months at sea appears critical in determining overall salmonid year-class strength. Year class strength is evidenced by the relationship between returns of jack salmon, which spend less than one year at sea, and numbers of adults returning from the same brood class in later years. Ocean purse-seine catches of salmonids in June may also indicate year-class strength, since they correlate well with jack and adult returns (Percy 1992).

The Columbia River estuary has been significantly altered by human development (Sherwood et al. 1990; Weitkamp 1994), with seasonal flow patterns altered by dam construction, while salmonid habitat changed as a result of dredging, diking, and urbanization. Exotic species introductions and large-scale salmonid hatchery programs have radically changed the species mix in the Columbia River estuary. Furthermore, ocean conditions appear to vary significantly both spatially and temporally on a variety of scales (Francis et al. 1998; Mantua et al. 1997; Welch et al. 2000). The relative importance of these factors to juvenile salmon survival is not well understood.

Increasing our understanding of variations in estuarine and nearshore ocean environments, and the role these variations play in salmonid survival, could provide management options to increase adult returns. Smolt-to-adult-return (SAR) rates for PIT-tagged smolts that are collected and transported vary greatly within years (Muir et al. 2006; Williams et al. 2005). Past studies have documented little mortality during actual transport, and recent studies using juvenile radio tags have indicated rapid migration and high survival to the Columbia River estuary after release (Schreck and Stahl 1998). Recent studies of smolt survival during downstream migration through Snake and Columbia River reservoirs and dams have also shown little variation in survival within or between years (Muir et al. 2001; Williams et al. 2001). Therefore, changes in direct survival during migration through fresh water do not appear to explain observed changes in SARs for groups of fish within or between years.

The ability to characterize the conditions that smolts encounter in the estuary and nearshore ocean, combined with evaluation of SARs on a temporal basis, should allow us to identify estuarine or ocean biological/physical conditions that are correlated with high or low levels of salmon ocean survival. Managers can potentially use this information to determine optimal times for hatchery releases, or whether to transport smolts from collector dams or allow them to migrate naturally to synchronize their arrival to the estuary and nearshore ocean during optimal conditions. Furthermore, information from this study may help to determine whether *D*, the delayed mortality observed in transported fish, is due in part to a difference in ocean entry timing between transported and in-river fish, as hypothesized by Muir et al. (2006) and Williams et al. (2005).

Conditions that might vary in the estuary and nearshore ocean to affect salmonid survival include changes in turbidity, the abundance of predators (birds, fish, and marine mammals), alternative prey for those predators (northern anchovy *Engraulis mordax*, Pacific herring *Clupea pallas*, Pacific sardine *Sardinops sagax*, and euphausiids), and the salmonids' own prey (optimally allowing smolts to grow rapidly, reducing their vulnerability to predators). Dramatic changes in predator and baitfish populations off the coast of Oregon and Washington have been observed in recent years (Emmett 2006; Emmett and Brodeur 2000; Emmett et al. 2001).

This study examines the relationships among time of salmonid ocean entry, physical and biological characteristics of the Columbia River estuary and nearshore plume environment, and SARs for yearling Chinook salmon *Oncorhynchus tshawytscha*. The objectives are to:

1) estimate SARs of serially released yearling Chinook salmon through the spring migration period,
2) characterize variations in the physical and biological conditions in the Columbia River estuary and nearshore ocean environment during release periods,
3) determine the level of physiological development and disease status of smolts at release,
4) correlate SARs with environmental conditions at release, and
5) identify potential indicators (biotic, abiotic, or a combination of both) of salmonid marine survival that could be used by management to improve SARs.

In addition, the results from this study will provide valuable information to the Clatsop Economic Development Committee Fisheries Project (CEDC) to assess potential release strategies to maximize SARs.

METHODS

In fall 2004, about 160,000 spring Chinook salmon (Willamette stock) were obtained from Oregon Department of Fish and Wildlife (ODFW) and divided into 6 groups of about 27,000 fish each. Fish were reared at Willamette Hatchery in separate raceways (2 groups per divided raceway). In fall 2005, about 170,000 spring Chinook salmon (Willamette stock) were divided into 6 groups of about 28,000 fish each and reared at Leaburg Hatchery in separate raceways (after rearing to the fingerling stage at Willamette Hatchery). In both years, each of the 6 groups were coded-wire tagged (CWT) with a different tag code (Table 1), and feeding rates were adjusted so that each group attained a similar size at release (target size of 140-150 mm.)

Table 1. Release dates, coded-wire-tag codes, percent with CWT, and percent with adipose fin clip for Willamette stock yearling spring Chinook salmon released into Blind Slough in 2005 and 2006

Release date	Tag code	Percent with CWT	Percent with adipose clip
2005			
6 April	094055	96.2	99.5
15 April	094056	94.6	100.0
25 April	094057	97.0	100.0
4 May	094058	99.0	100.0
13 May	094060	98.0	100.0
23 May	094059	99.5	100.0
2006			
6 April	094254	96.5	99.3
17 April	094253	98.2	99.3
27 April	094258	95.6	99.8
5 May	094255	97.4	99.7
16 May	094256	97.7	100.0
24 May	094257	95.4	99.2

In 2005 and 2006, individual groups of yearling Chinook salmon were transported by truck (5,000 gal) to net-pens located in Blind Slough in the lower Columbia River (Figure 1). Fish were transported every 10 d from late March through mid-May in both years. The net-pens, owned and operated by the CEDC, were 6.1 m wide by 6.1 m long by 2.4 m deep. The facility has relatively high return rates, and the lower Columbia River terminal fishery is heavily monitored to recover CWTs. Furthermore, mortality associated with migration through fresh water is minimized for these fish because CEDC facilities are located in the Columbia River estuary.

Smolts were sampled prior to release to determine their level of physiological development and health. Gill Na^{+}-K^{-} ATPase activity was measured on the date of arrival in Blind Slough and 14 days later at release. Gill filaments were trimmed from the gill arches of 15 fish on each sample date, placed into microcentrifuge tubes containing sucrose, ethylenediamine, and imidazole (SEI), and immediately frozen on dry ice. Gill Na^{+}-K^{-} activity was determined according to the method of McCormick (1993). Fish health was inspected monthly and just prior to transport to Blind Slough from each raceway by an Oregon State University pathologist. Health evaluations included enzyme-linked immunosorbent assay (ELISA) for bacterial kidney disease (Pascho et al. 1991).

While in the net-pens, fish were fed Oregon Moist Pellet[1] 5 d/week to satiation. Mortalities were removed from the net-pens and counted. At the time of release, about 500 fish from each group were individually measured, and small groups were weighed and counted to determine size at release. Scale samples were taken from a subsample of juveniles at release (30/release group) to determine the relationship between scale radius length and juvenile length using methods similar to those of Fisher and Percy (2005) and Moss et al. (2005). Using this relationship, scales from future returning adults will be measured to determine their length at release for evidence of size-selective mortality.

Environmental conditions within the estuary and nearshore ocean environment, both biotic and abiotic, are being characterized for each release time, primarily by utilizing data from existing Columbia River estuary and ocean studies. Physical conditions being characterized during ocean and estuary studies include water temperature, salinity, and current at various depths using anchored buoys in the Columbia River estuary and plume (Oregon Graduate Institute Study, unpublished data).

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

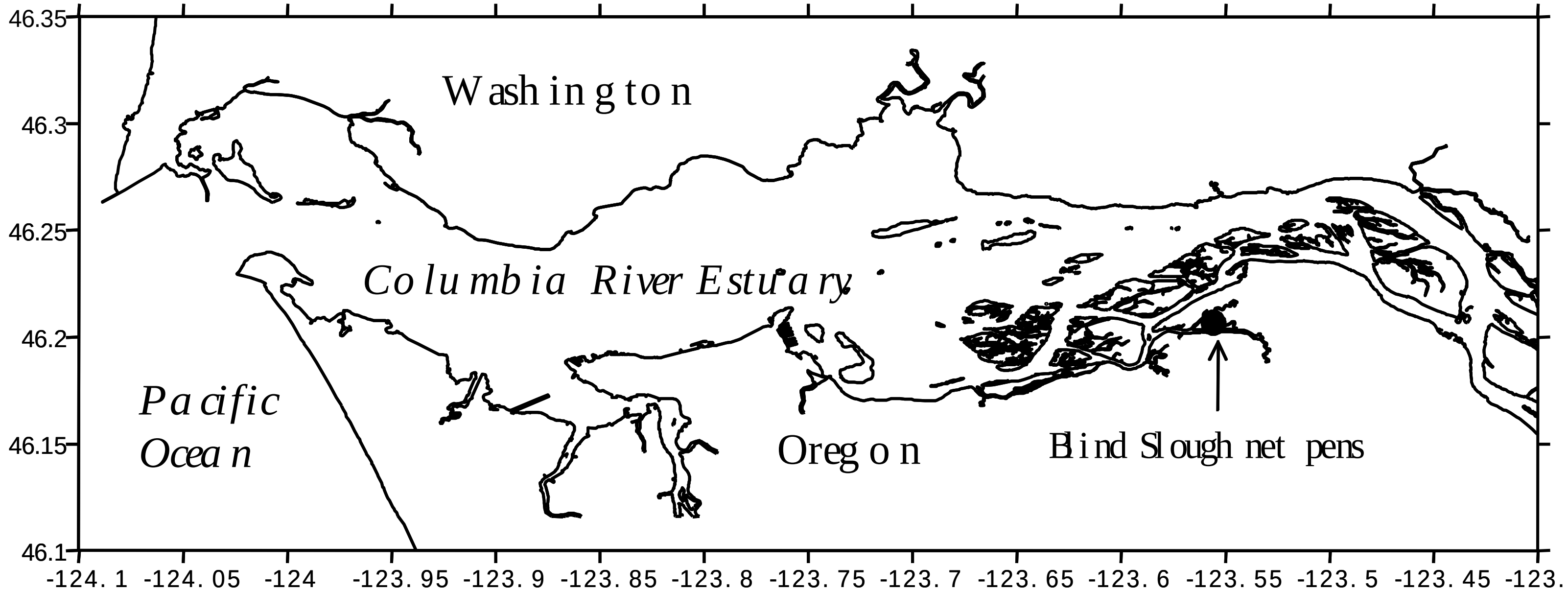

Figure 1. Study area showing location of Blind Slough net-pens in the upper Columbia River estuary where Willamette and Leaburg Hatchery yearling spring Chinook salmon were acclimated and released in 2005 and 2006.

Populations of salmonid predators (Pacific hake *Merluccius productus*, Pacific mackerel *Scomber japonicus*, and jack mackerel *Trachurus symmetricus*), along with the abundance of alternative prey for those predators and for salmonids (northern anchovy, Pacific herring, Pacific sardine), are being sampled by surface trawl in the Columbia River plume at about 10-d intervals. Our releases were timed to coincide with that sampling effort. The use of satellite imagery data to characterize physical conditions in the nearshore ocean environment will also be evaluated.

Complete adult returns from our serial releases will be evaluated and correlated with biotic and abiotic conditions smolts encountered in the Columbia River estuary and nearshore ocean. Adult returns to Blind Slough are expected according to release year, as shown below.

Smolt release year	Adult return years
2002	2004-2006
2003	2005-2007
2004	2006-2008
2005	2007-2009
2006	2008-2010

Adult returns to the lower Columbia River terminal gill net fishery are monitored at a sample rate of about 50% by ODFW, and returns to other local fisheries are also monitored. Adult return rates of PIT-tagged spring/summer Chinook salmon passing Bonneville Dam or transported and released below Bonneville Dam will be compared to those of CEDC adults with similar ocean entry times. Because of the complexity of the marine environment, it is anticipated that multiple years of study will be required to confidently correlate salmonid smolt survival with specific environmental conditions in the estuary and nearshore ocean.

RESULTS AND DISCUSSION

Fish Released in 2005

In 2005, 6 groups of from 23,051 to 25,646 yearling spring Chinook salmon were released into Blind Slough at 10-day intervals between 6 April and 23 May (Tables 2-3). These fish were tagged with a CWT; the groups of fish released with both CWTs and adipose fin clips ranged from 22,597 to 24,552 (Table 3). Our goal of keeping fish length constant among release groups was largely achieved, with mean length per group ranging from 140 to 147 mm FL at release (Figure 2; Table 3).

Table 2. Transport dates from Willamette (2005) and Leaburg (2006) Hatcheries, release dates and times into Blind Slough, and Blind Slough water temperature on arrival and at release.

Transport date	Release date	Release time	Water temperature on arrival (°C)	Water temperature at release (°C)
2005				
23 March	6 April	1330	8.9	8.3
1 April	15 April	1300	8.3	8.3
13 April	25 April	1300	8.3	12.2
20 April	4 May	1400	10.0	13.9
29 April	13 May	1230	12.2	13.3
10 May	23 May	1300	13.9	13.9
2006				
23 March	6 April	1630	6.7	9.4
4 April	17 April	1400	9.4	8.9
14 April	27 April	1500	10.0	12.8
20 April	5 May	1430	8.9	12.8
2 May	16 May	1330	12.2	15.0
10 May	24 May	1330	13.3	15.6

While at Willamette Hatchery prior to release, chronic levels of BKD were found in all 2005 release groups, although mortalities while at the hatchery were low. Mortality during the 14-day acclimation period in Blind Slough net-pens ranged from 0.64 to 6.73% per group (Table 3). Numerous fish showing signs of BKD were observed in the last two release groups, and these groups had the highest mortality.

Table 3. Yearling spring Chinook salmon release dates, mean fork length (mm) and number/lb at release, percent mortality in net-pens, total numbers released, and numbers with coded-wire-tags (CWT) and adipose clips released into Blind Slough in 2005 and 2006 .

Release date	Fork length (s.e.)	Number of fish/lb	Percent mortality	Number of fish released	Number with CWT and ad clip released
2005					
6 April	140 (0.6)	15.6	0.64	25,646	24,552
15 April	142 (0.6)	14.2	0.71	25,344	23,964
25 April	140 (0.6)	16.0	1.28	25,182	24,437
4 May	146 (0.6)	14.0	2.98	24,747	24,502
13 May	147 (0.6)	13.6	6.73	23,051	22,597
23 May	147 (0.6)	13.7	6.66	23,115	23,001
2006					
6 April	133 (0.5)	17.2	0.21	28,099	27,117
17 April	136 (0.5)	17.5	0.32	27.440	26,952
27 April	139 (0.5)	15.7	0.12	27,459	26,256
5 May	142 (0.6)	14.3	0.21	27,831	27,107
16 May	144 (0.6)	17.2	0.22	27,493	26,857
24 May	141 (0.5)	15.9	0.27	25,851	24,657

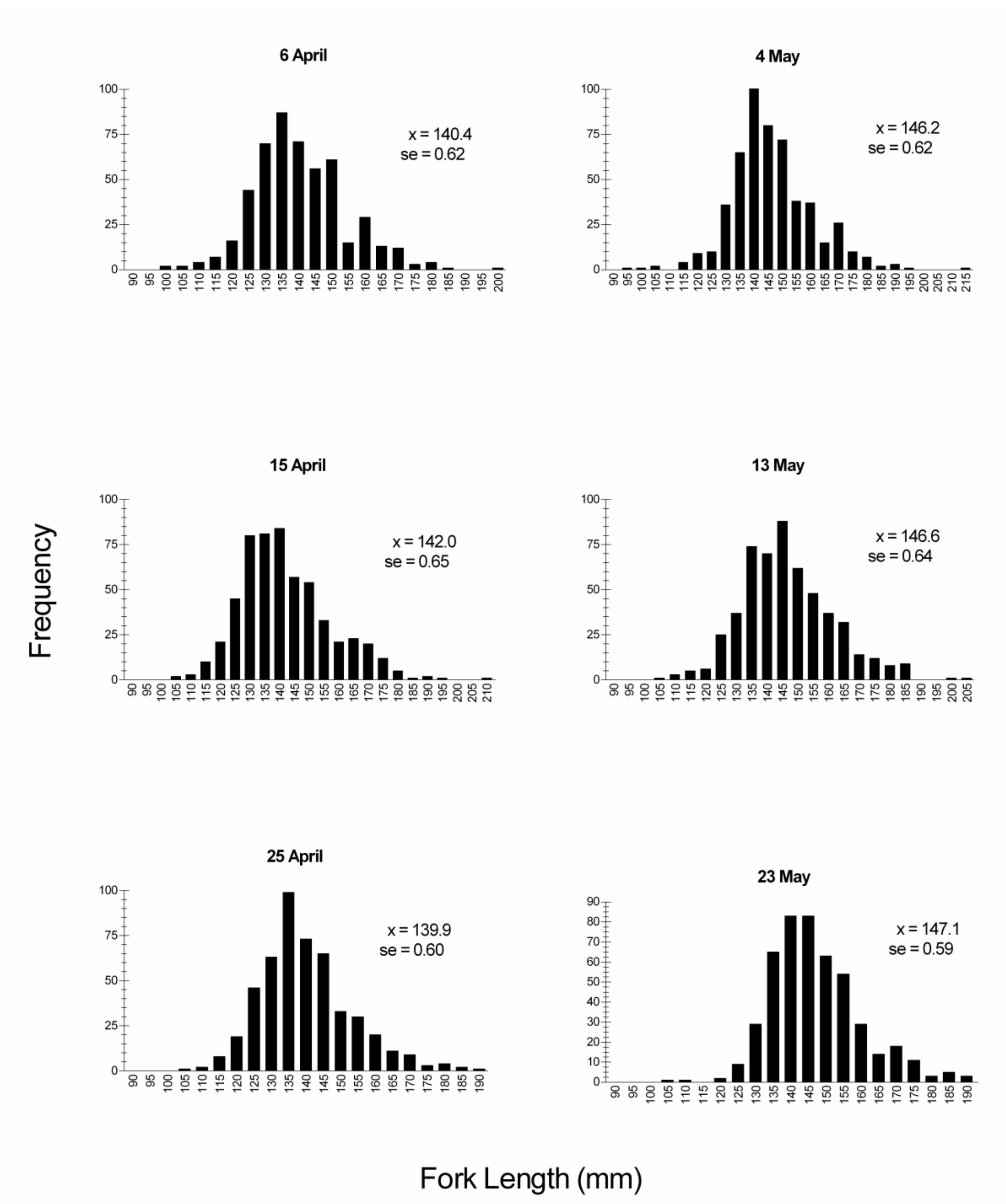

Figure 2. Length frequency (with mean and standard error) of Willamette stock yearling spring Chinook salmon at release from net-pens into Blind Slough during 2005.

Gill Na^{+}-K^{-} ATPase activity followed a typical development pattern for yearling spring Chinook salmon, peaking in mid-May (Figure 3). Acclimation in the Blind Slough net-pens appeared to stimulate gill ATPase activity in all release groups except the last one, similar to past years in Blind Slough (Muir et al. 2004a,b, 2005). Water temperatures in Blind Slough were higher than at Willamette Hatchery and likely stimulated gill ATPase development, but were perhaps too high for the last release group (13.9°C). All groups had sufficiently elevated gill ATPase levels at release to enter seawater.

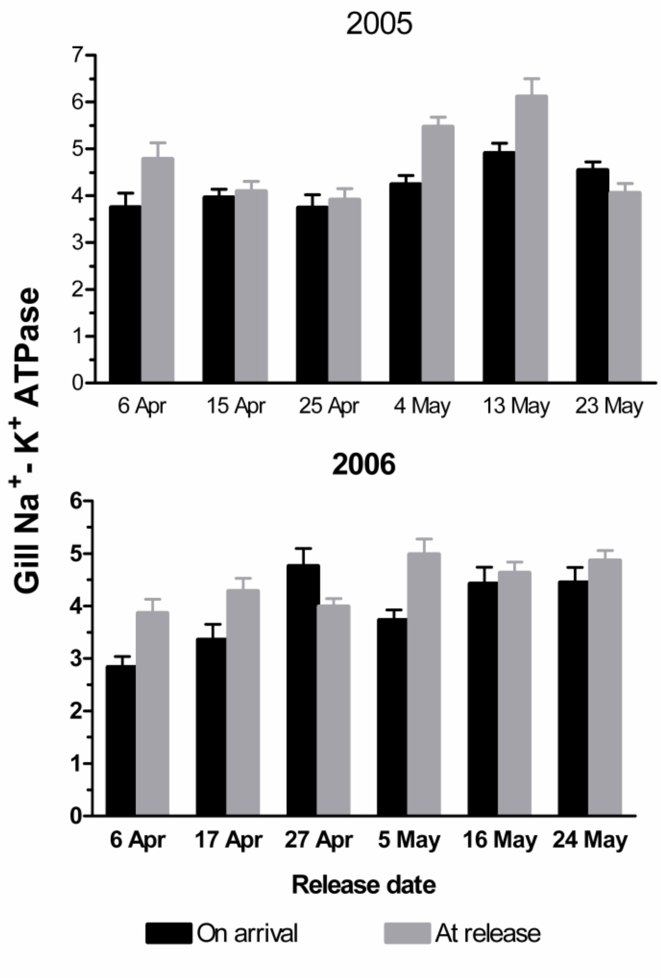

Figure 3. Mean gill Na^{+}- K^{+} ATPase activity μmol Pi · mg · $Prot^{-1}$ · h^{-1} (with standard error) for Willamette stock yearling Chinook salmon on arrival at net-pens and release 14 d later into Blind Slough, 2005 and 2006.

Water temperatures in the Columbia River (measured at Beaver Terminal, rkm 87) increased steadily from 8.9 to 13.7°C over the period of releases. Turbidity and flows varied among releases, with turbidity ranging from 6.8 to 12.3 (FNU) and flows ranging from 186 to 359 kcfs (Figure 4).

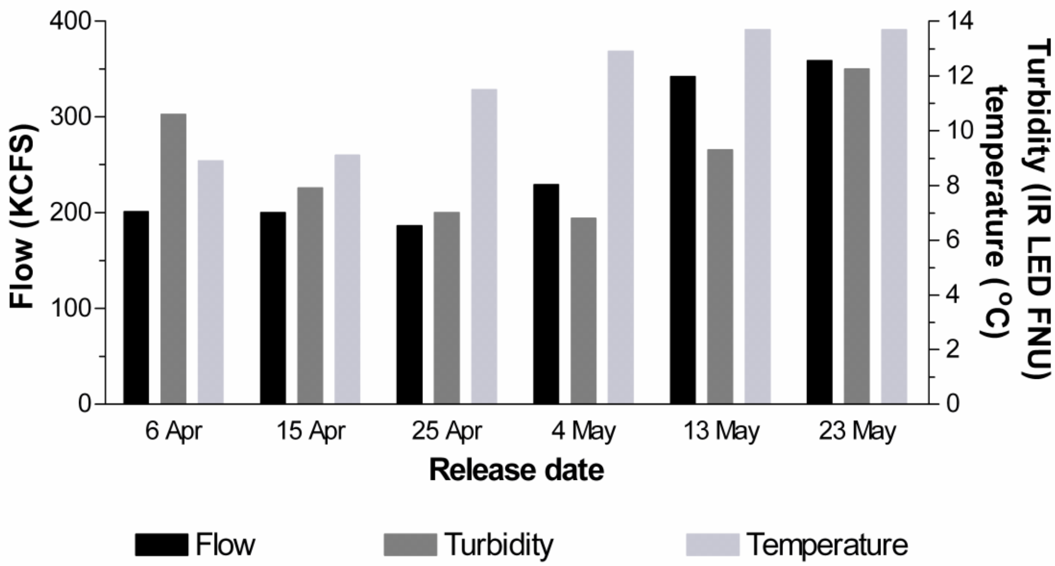

Figure 4. Flow (kcfs), turbidity (IR LED FNU), and water temperature (°C) measured at Beaver Terminal on each release date for Willamette Hatchery yearling spring Chinook salmon from net-pens in Blind Slough during 2005.

Fish Released in 2006

In 2006, 6 groups of from 25,851 to 28,099 CWT yearling spring Chinook salmon were released into Blind Slough at 10-d intervals between 6 April and 24 May (Tables 2-3). Numbers of fish released with CWTs and adipose clips ranged from 24,657 to 27,117 (Table 3). Our goal of keeping fish length constant among release groups was largely achieved, with mean length per group ranging from 133 to 144 mm FL at release (Figure 5; Table 3).

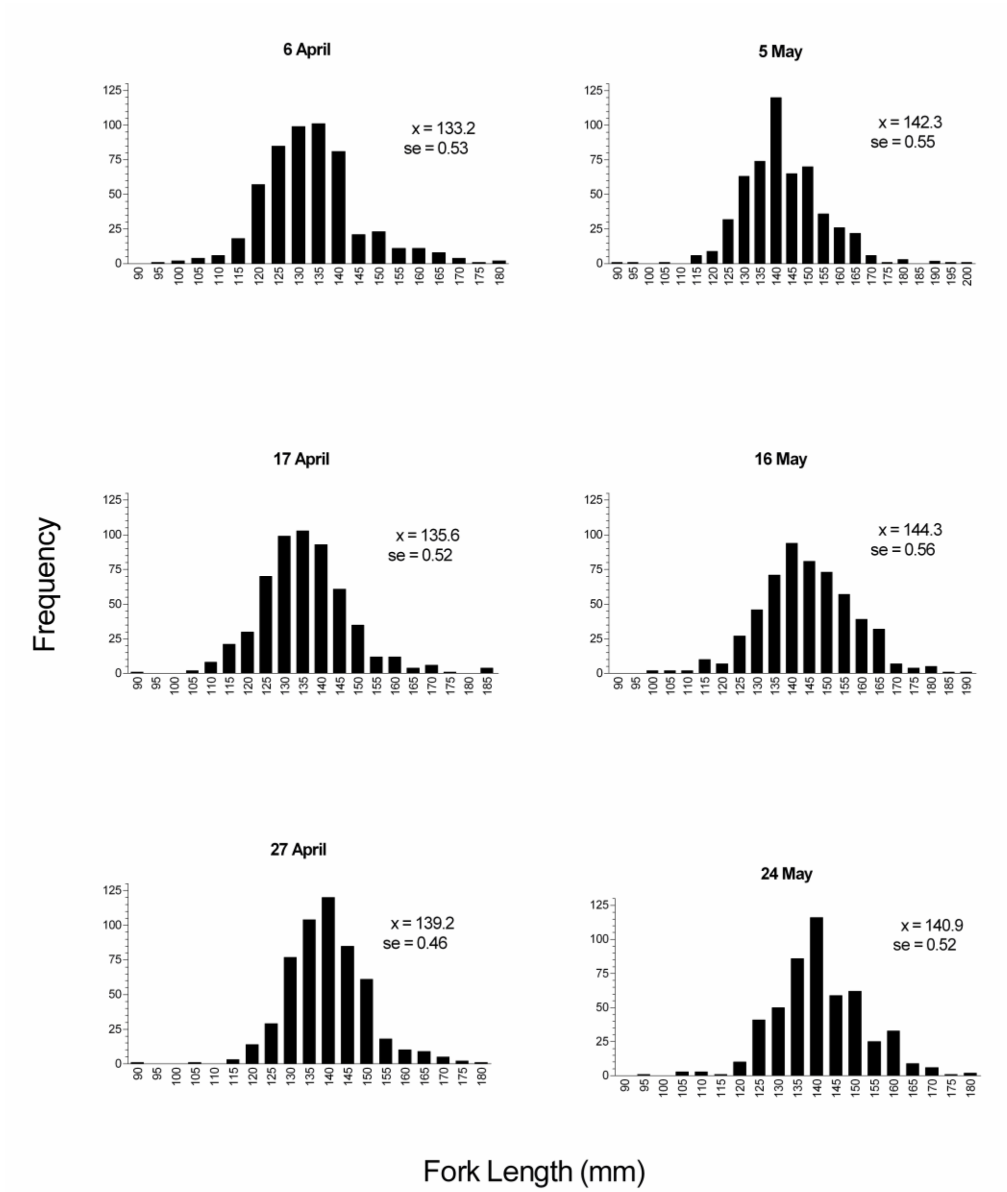

Figure 5. Length frequency (with mean and standard error) of Willamette stock yearling spring Chinook salmon at release from net-pens into Blind Slough during 2006.

Fish were very healthy during 2006, likely a result of their being reared at Leaburg Hatchery (with its cooler water) than at Willamette Hatchery, where fish for this study were reared for the first 4 years of releases. No disease was found during fish health screenings while at the hatchery or in the net-pens. Mortality during the 14-d acclimation period in Blind slough net-pens ranged from 0.12 to 0.32% per group (Table 3).

Gill Na^{+}-K^{-} ATPase activity peaked in early May (Figure 3). Acclimation in the Blind Slough net-pens appeared to stimulate gill ATPase activity in all release groups except the third one, similar to past years in Blind Slough (Muir et al. 2004a,b, 2005). All groups had sufficiently elevated gill ATPase levels at release to enter seawater.

During 2006 releases, water temperatures in the Columbia River (measured at Camas, Rkm 190) over the period of the releases increased steadily from 8.7 to 14.9°C. Flows varied among releases, ranging from 276 to 389 kcfs (Figure 6). Additional information on physical and biological characteristics of the estuary and nearshore ocean plume environment has been entered into a database to correlate with future SARs.

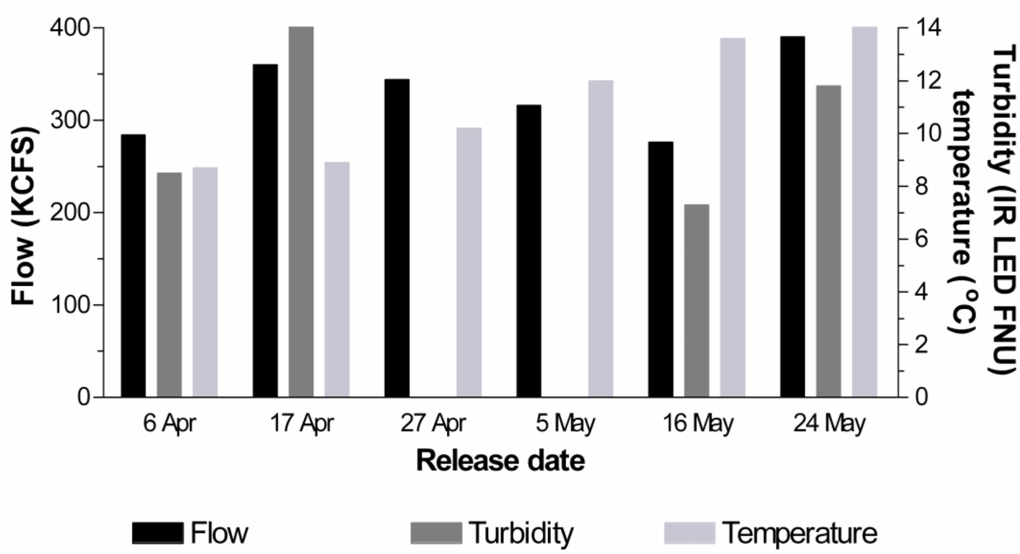

Figure 6. Flow (kcfs) and water temperature (°C) measured at Camas and turbidity (IR LED FNU) measured at Beaver Terminal on each release date for Willamette Hatchery yearling spring Chinook salmon from net-pens in Blind Slough during 2006.

Adult Returns

Adult returns to the Blind Slough terminal gill net and other fisheries from 2002 releases began in 2004 and were completed in 2006. Adult return rates (expanded for tag loss and sample rate) to the Blind Slough gill net and other fisheries were estimated at 1,388 4-year-old fish in 2004, 515 5-year-old fish in 2005, and 31 6-year-old fish in 2006. Thus a total of 1,934 adults returned from the 2002 releases (Table 4). For the 6 groups released in 2002, SARs ranged from 0.60 to 1.78%.

For fish released in 2003, the estimated catch was only 26 4-year-old adults in 2005 and 7 5-year-old adults captured in 2006 fisheries for a total of 33 adults to date (Table 5). SARs for fish released in 2003 were low for all groups, ranging from zero to 0.05%.

Table 4. Smolt-to-adult returns (SARs) of coded-wire-tagged spring Chinook salmon (expanded for sample rate and tag loss) from Blind Slough releases in 2002. Adult returns were primarily from the Blind Slough terminal gill net fishery.

Release date (2002)	4-year-old fish	5-year-old fish	6-year-old fish	Total	SAR
10 Apr	223	72	1	296	1.19
19 Apr	284	52	4	340	1.42
30 Apr	240	117	6	363	1.50
10 May	238	126	5	369	1.51
20 May	303	107	10	420	1.78
30 May	100	41	5	146	0.60
Totals	1,388	515	31	1,934	

Table 5. Smolt-to-adult returns (SARs) of coded-wire-tagged spring Chinook salmon (expanded for sample rate and tag loss) from Blind Slough releases in 2003. Only adult returns from the Blind Slough terminal gillnet fishery are shown.

Release date (2003)	4-year-old fish	5-year-old fish	6-year-old fish[a]	Total[b]	SAR
9 Apr	3	1		4	0.02
18 Apr	8	1		9	0.04
28 Apr	8	3		11	0.05
7 May	7	0		7	0.03
16 May	0	2		2	0.01
27 May	0	0		0	0.00
Totals	26	7		33	

[a] Six-year-old fish will return in 2007

[b] Through 2006

A total of 62 4-year-old adults from 2004 releases were captured in Blind Slough in 2006, with additional adults expected in 2007 and 2008 (Table 6).

Eight PIT-tagged adults from 2002 releases were detected passing Bonneville Dam in 2004. Expanding this number for the non-PIT-tagged population, an estimated 57 adults passed Bonneville Dam from our 2002 releases. No PIT-tagged adults from our releases were detected at Columbia River dams in 2005 or 2006. Fish were acclimated in Blind Slough net-pens for 10 d in 2002 and 14 d in 2003 through 2006.

Table 6. Smolt-to-adult returns (SAR) of coded-wire-tagged spring Chinook salmon (expanded for sample rate and tag loss) from Blind Slough releases in 2004. Only adult returns from the Blind Slough terminal gillnet fishery are shown.

Release date (2004)	4-year-old fish	5-year-old fish[a]	6-year-old fish[b]	Total[c]	SAR
8 Apr	17				0.10
16 Apr	27				0.10
26 Apr	10				0.04
6 May	2				0.01
20 May	6				0.03
27 May	0				0.00
Totals	62				

a 5-year-old fish will return in 2007

b 6-year-old fish will return in 2008

c Through 2006

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We thank Dave Rogers (ODFW) for securing fish for this study; Gary Yeager and staff (ODFW) at Willamette Hatchery and Tim Wright and staff at Leaburg Hatchery for rearing the fish; Antonio Amandi (Oregon State University) for disease sampling; Allan Dietrichs, Tod Jones, and staff (CEDC) for the use of net-pens and feeding the fish in Blind Slough; Jimmy Watts, Jeff Whisler, and John North (ODFW) for providing coded-wire-tag data; William Ryan, (NMFS) for fish transport; and Brian Beckman and Kathy Cooper (NMFS) for analyzing gill ATPase samples.

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