Evaluation of the Relationship Among Time of Ocean Entry, Physical and Biological Characteristics of the Estuary and Plume Environment, and Adult Return Rates, 2003

William D. Muir, Robert L. Emmett, and Regan A. McNatt

Report of research by

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
2725 Montlake Boulevard East
Seattle, WA 98112

to

Portland District
U.S. Army Corps of Engineers
P.O. Box 2946
Portland, OR 97208-2946
Contract W66QKZ20374368

June 2004

EXECUTIVE SUMMARY

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

During 2003, the second year of releases, six groups of yearling spring chinook salmon were transferred from Willamette Hatchery to net pens in Blind Slough in the Columbia River estuary, reared for 14 days, and released at 10-day intervals from 9 April through 27 May. Size and smolt development (gill Na^{+}-K^{+} ATPase activity) at release were similar among groups. Mortality at Willamette Hatchery and in Blind Slough was higher than usual for all groups, although no causative viral, bacterial, or parasitic agents were identified. Coded-wire-tags will be recovered from adults beginning in 2004 from the Blind Slough terminal gill net fishery.

Smolt-to-adult return rates for serially released groups of coded-wire tagged spring chinook salmon will be integrated with information collected from ongoing studies funded by Bonneville Power Administration (BPA) and others characterizing the physical and biological conditions of the estuary and plume environment. By enhancing our understanding of the linkages between ocean entry and the physical and biological estuarine and ocean conditions that the smolts encounter, we might improve SARs for some stocks by manipulating transportation tactics or hatchery release dates.

CONTENTS

INTRODUCTION

The effects on survival of salmon of short- and long-term fluctuations in oceanographic and climatic conditions have received increased attention in the Pacific Northwest 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 appear to be critical in determining overall salmonid year-class strength. This is based on the relationship between returns of jack salmon after only a few months at sea and numbers of adults returning from the same brood class in later years, and ocean purse-seine catches of salmonids in June that 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 and 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 at a variety of scales (Francis et al. 1998; 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 (Marsh et al. 2000). 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. Characterization of the conditions that smolts encounter in the estuary and nearshore ocean and of SARs on a temporal basis should allow us to identify which estuarine or ocean biological/physical conditions 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 if the delayed mortality or “D” observed for transported fish is in part due to a difference in ocean entry timing between transported and inriver fish.

Conditions that might vary in the estuary and nearshore ocean and affect salmonid survival include the abundance of predators (birds, fish, and marine mammals), alternative prey for those predators (northern anchovy, Pacific herring, Pacific sardine, 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 documented in recent years (Emmett and Brodeur 2000).

This National Marine Fisheries Service (NMFS) 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. 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 periods of release,

3) determine the level of physiological development and disease status of smolts at release,

4) correlate SARs with environmental conditions, and

5) identify potential indicators (biotic, abiotic, or a combination of both) of salmonid marine survival that could be used to improve management actions.

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 the fall of 2002, about 150,000 spring chinook salmon (Willamette stock) were obtained from Oregon Department of Fish and Wildlife (ODFW), divided into six groups of about 25,000 fish each, and reared at Willamette Hatchery in separate raceways (two groups per divided raceway). Each of the six groups were coded-wire tagged (CWT) with a different tag code (Table 1). A sample of about 500 fish from each release group was examined at the hatchery in early April to determine CWT retention and adipose fin removal rates. About 2,000 fish in each group were also tagged with passive integrated transponder (PIT) tags (Prentice et al. 1990) to account for avian predation by Caspian terns (*Sterna* c*aspia*) and double-crested cormorants (*Phalacrocorax auritas*) nesting on East Sand Island (River Kilometer, RKm 8) in the Columbia River estuary (Ryan et al. 2001; Table 2). Raceways were periodically swept with a magnet to collect shed PIT tags, and all mortalities were scanned for PIT tags to determine final PIT tag release numbers. Feeding rate was adjusted so that each group would be similar in size at release, with a target size of 140-150 mm.

Every 10 days from late March through the end of May 2003, individual groups of fish were transported by truck (5,000 gal) to net pens located in Blind Slough in the lower Columbia River (Fig. 1). The net pens, owned and operated by the CEDC, were 6.1-m wide by 6.1-m long by 2.4-m deep. Using the CEDC facilities reduced the number of hatchery fish needed to evaluate adult returns because the facility has high return rates and the terminal lower Columbia River fishery is heavily monitored to recover CWTs. Furthermore, the mortality associated with migration through fresh water is minimized because the 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 for each group. Gill filaments were trimmed from the gill arch from 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, including an ELISA for bacterial kidney disease (Pascho et al. 1991), for each raceway by an Oregon State University pathologist.

Table 1. Release dates, coded-wire-tag codes, percent tag loss (or with no adipose fin clip), and sample sizes for Willamette Hatchery yearling spring chinook salmon released into Blind Slough in 2003.

Release date	Tag code	Percent tag loss	Sample size
9 April	093619	4.0	522
18 April	093622	2.6	509
28 April	093620	1.2	502
7 May	093623	2.5	512
16 May	093621	2.1	513
27 May	093624	2.7	515

Table 2. Yearling spring chinook salmon release dates, number of PIT tags shed in raceways, PIT-tag mortalities, and total numbers with PIT tags released into Blind Slough in 2003.

Release date	Number PIT-tagged	Number of shed tags and mortalities	Number with PIT tags released
9 April	2,000	430	1,570
18 April	2,000	168	1,832
28 April	2,000	199	1,801
7 May	2,000	237	1,763
16 May	2,000	344	1,656
27 May	2,001	427	1,574

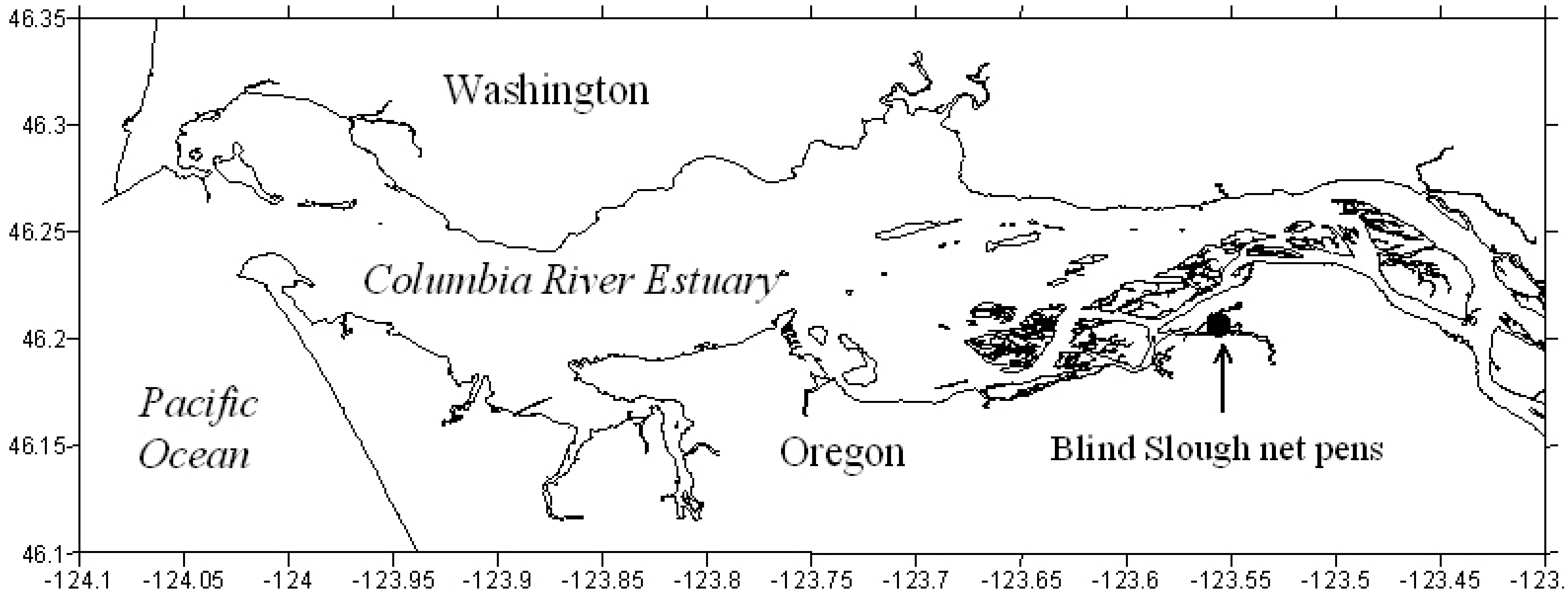

Figure 1. Study area showing location of Blind Slough net pens in the upper Columbia River estuary where Willamette Hatchery yearling spring chinook salmon were acclimated and released during 2003.

While in the net pens, fish were fed Oregon Moist Pellet, 5 days/week to satiation. Mortalities were removed from the net pen, counted, and scanned for PIT tags. At the time of release, about 500 fish from each group were individually measured and small groups weighed and counted to determine size at release.

Environmental conditions within the estuary and nearshore ocean environment, both biotic and abiotic, will be characterized during each salmonid release-time, primarily by utilizing data from existing Columbia River estuary and plume studies. Existing studies monitor physical conditions including water temperature, salinity, and current at various depths using anchored buoys in the Columbia River estuary and plume (Oregon Graduate Institute Study, unpublished data). The populations of salmonid predators (Pacific hake, Pacific mackerel, jack mackerel) 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-day intervals. Our releases were timed to coincide with that sampling effort.

PIT-tag codes from our releases will be recovered in an ongoing study to collect tag information on Rice and East Sand Island to determine losses of PIT-tagged fish from avian predation (Ryan et al. 2001). Our releases will add important information to this study because they will be made at regular intervals with fish of known physiological and disease status. Our release groups will be the only PIT-tag releases in the Columbia River estuary made at regular intervals over the nesting season of piscivorus birds. This release schedule will provide data for an estimate of vulnerability to predation through time to compare with salmonids migrating from above Bonneville Dam.

Adult returns from serial releases will be evaluated and correlated with the biotic and abiotic conditions smolts encountered in the Columbia River estuary and nearshore ocean environment. Adults from 2003 releases will return to Blind Slough beginning in 2005 and will be complete for 2003 releases in 2006. Adult returns will be monitored in the terminal gill net fishery at about a 75% sample rate in the lower Columbia River fishery by ODFW. Adult return rates of PIT-tagged spring/summer chinook salmon passing Bonneville Dam or transported and released below Bonneville Dam will also be compared to the CEDC adults with similar time of ocean entry. 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 estuary/near-shore ocean environmental conditions.

RESULTS AND DISCUSSION

During 2003, six groups of about 20,000 CWT (with 2,000 PIT-tagged and CWT/group) spring chinook salmon were released into Blind Slough at 10-day intervals between 9 April and 27 May (Tables 2-4). Because of relatively high losses at Willamette Hatchery and while in the net pens, final release numbers of fish with CWTs and adipose clips ranged from 17,768 to 21,772 fish/release group (Table 4). Our goal of keeping size constant among release groups was largely achieved, with mean size per group ranging from 136 to 142 mm at release (Fig. 2; Table 4).

Mortality for fish was chronic and higher than normal for all groups while at Willamette Hatchery in 2003. During examinations at the hatchery, fish with crooked backs, dark coloration (some with light colored patches on the sides), pale gills, and pale livers were observed. However, no viral, bacterial, or parasitic agents were identified. Toxic exposure was suspected as the causative agent, but testing of water, feed, and rearing environment were negative for toxins. Losses continued after transfer to Blind Slough net pens with mortality during the 14-day acclimation period ranging from 1.6 to 7.1% per group (Table 4).

Gill Na^+-K^+ ATPase activity followed a normal development pattern for yearling spring chinook salmon, peaking in late April to mid-May with a slight decline by the end of May (Fig. 3). Acclimation in the net pens in Blind Slough appeared to stimulate gill ATPase activity in all but the last release group. Water temperatures were higher in Blind Slough than at Willamette Hatchery and could have stimulated development, but were perhaps too warm for the last release group, which exhibited a slight decline in gill ATPase activity level. However, all groups had sufficiently high gill ATPase levels at release to enter seawater.

Over the period of the releases, water temperature in the Columbia River (measured at Beaver Terminal, Rkm 87) increased steadily from 9.6 to 14.3°C. Turbidity and discharge varied slightly among releases, with turbidity ranging from 7 to 14 nephelometric turbidity units (NTU) and discharge ranging from 279 to 316 kcfs (Fig. 4). Additional information on physical and biological characteristics of the estuary and nearshore ocean plume environment will be entered into a database during the winter of 2003/2004 to correlate with future SARs. The first adult returns from 2002 releases will be from the Blind Slough terminal gill net fishery in 2004 and will be complete in 2005. Adults from 2003 releases will return in 2005 and 2006.

Table 3. Transport dates from Willamette Hatchery, release dates and times into Blind Slough, and Blind Slough water temperature on arrival and at release during 2003.

Transport dates	Release dates	Release time	Water temperature on arrival (°C)	Water temperature at release (°C)
25 March	9 April	1300	7.8	8.3
4 April	18 April	1400	8.3	10.0
14 April	28 April	1300	9.4	10.6
23 April	7 May	1300	9.4	12.2
2 May	16 May	1230	12.2	12.8
13 May	27 May	1300	13.3	16.1

Table 4. 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 2003.

Release date	Fork length (s.e.)	Number/lb	Percent mortality	Number of fish released	Number with CWT and ad clip released
9 April	135.7 (0.76)	16.4	1.63*	18,508	17,768
18 April	138.6 (0.57)	15.8	5.05	22,353	21,772
28 April	139.2 (0.69)	15.6	4.69	21,236	20,981
7 May	138.0 (0.77)	16.5	7.11	20,801	20,281
16 May	139.7 (0.69)	16.6	2.24	20,158	19,735
27 May	141.8 (0.72)	14.7	1.22	20,319	19,770

* 4,918 mortalities during transport from hatchery not included.

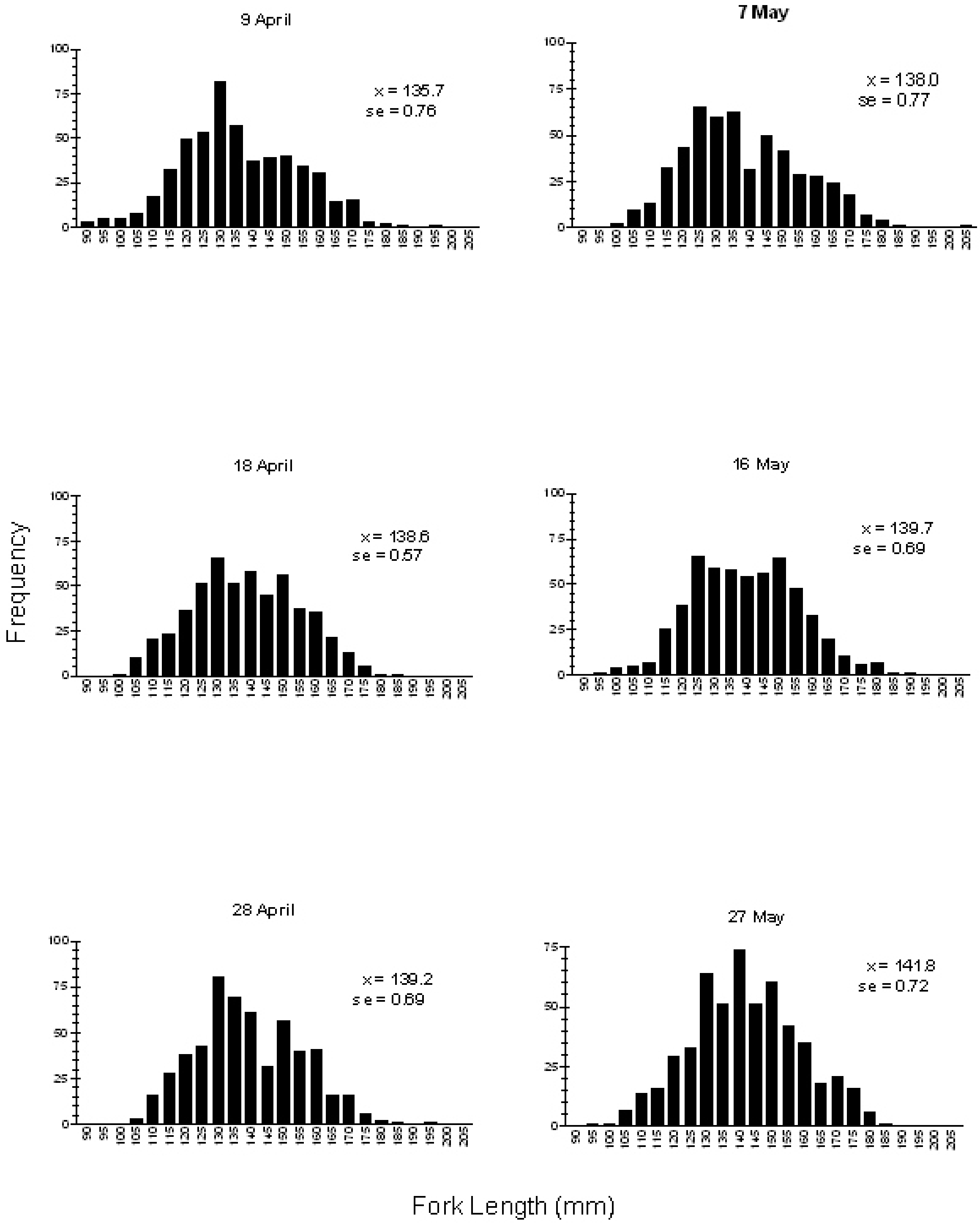

Figure 2. Length frequency (with mean and standard error) of Willamette Hatchery yearling spring chinook salmon at release from net pens into Blind Slough during 2003.

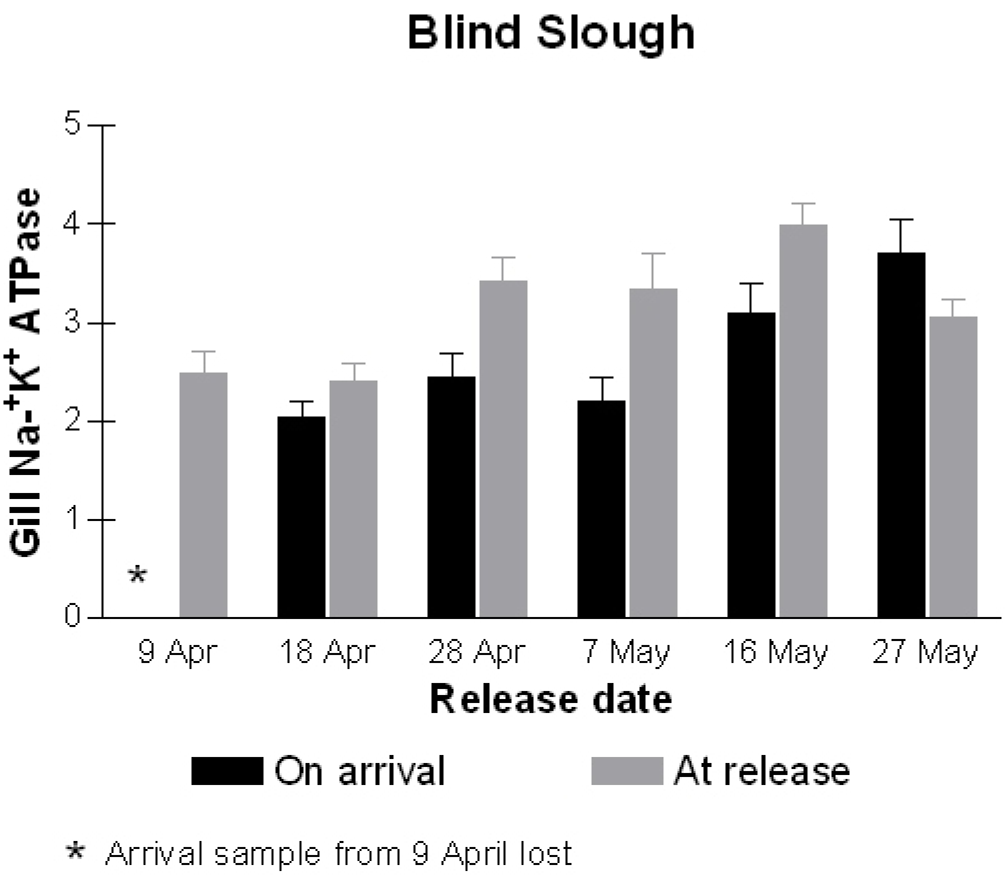

Figure 3. Mean gill Na^+-K^+ ATPase activity in *u*mol Pi · mg $Prot^{-1}$ · h^{-1} (with standard error) for Willamette Hatchery yearling spring chinook salmon on arrival and at release from net pens 14 days later into Blind Slough during 2003.

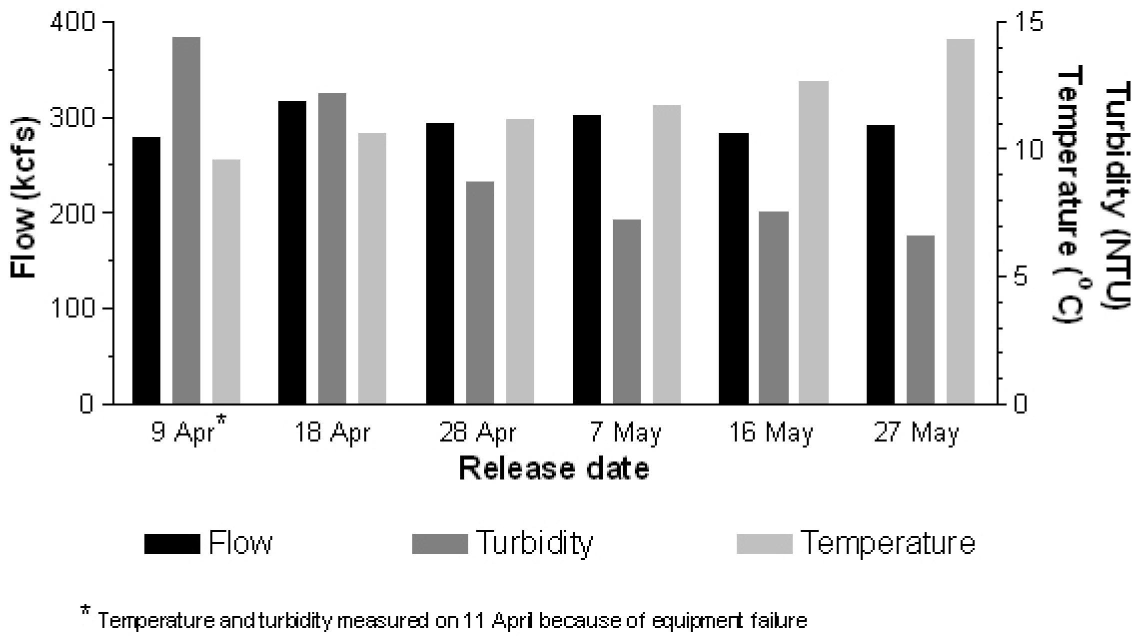

Figure 4. Flow (kcfs), turbidity (NTU), and water temperature (°C) measured at Beaver Terminal on each release date for Willamette Hatchery yearling spring chinook salmon from net pens in Blind Slough during 2003.

ACKNOWLEDGMENTS

We thank Dave Rogers (ODFW) for securing fish for this study; Gary Yeager and staff (ODFW) for rearing the fish at Willamette Hatchery; 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; William Ryan, Brad Ryan, Kennith McIntyre, Yvonne McIntyre, Douglas Marsh, Gordon Axel, and Neil Paasch (NMFS) for PIT-tagging and fish transport; and Brian Beckman, Paul Parkins, and Kathy Cooper (NMFS) for analyzing gill ATPase samples.

REFERENCES

Emmett, R. L., and R. D. Brodeur. 2000. Recent changes in the pelagic nekton community off Oregon and Washington in relation to some physical oceanographic conditions. North Pacific Anadromous Fish Commission Bulletin 2:11-20.

Emmett, R. L., and M. H. Schiewe (eds). 1997. Estuarine and ocean survival of Northeastern Pacific Salmon: Proceedings of the Workshop. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC 29:1-313.

Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fisheries Oceanography 7:1-21.

Logerwell, E. A., N. Mantua, P. W. Lawson, R. C. Francis, and V. N. Agostini. 2003. Tracking environmental processes in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. Fisheries Oceanography 12(6):554-568.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2000. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1998. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District.

McCormick, S. D. 1993. Methods for nonlethal gill biopsy and measurement of Na^+-K+ ATPase activity. Canadian Journal of Fisheries and Aquatic Sciences 50:656-658.

Muir, W. D., S. G. Smith, J. G. Williams, E. E. Hockersmith, and J. R. Skalski. 2001. Survival estimates for migrant yearling chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and Columbia Rivers, 1993-1998. North American Journal of Fisheries Management 21:269-282.

NRC (National Research Council). 1996. Upstream-salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C, 452 p.

Pascho, R. J., D. G. Elliot, and J. M.. Streufert. 1991. Brood stock segregation of spring chinook salmon by use of the enzyme-linked immunosorbent assay (ELISA) and the fluorescent antibody technique (FAT) affects the prevalence and levels of *Renibacterium salmoninarum* infection in progeny. Diseases of Aquatic Organisms 12:25-40.

Percy, W. G. 1992. Ocean ecology of North Pacific salmon. Washington Sea Grant Program, University of Washington Press, Seattle, WA, 179 p.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Ryan, B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorus bird colonies in the Columbia River Basin. North American Journal of Fisheries Management 21:149-153.

Schreck, C. B., and T. P. Stahl. 1998. Evaluation of migration and survival of juvenile salmonids following transportation. Report to the U.S. Army Corps of Engineers, Walla Walla, District. (Available from Oregon Cooperative Fish and Wildlife Research Unit, 104 Nash Hall, Oregon State Univ., Corvallis, OR 97331-3803.)

Sherwood, C. R., D. A. Jay, R. B. Harvey, P. Hamilton, and C. A. Simenstad. 1990. Historical changes in the Columbia River estuary. Progress in Oceanography 25:299-352.

Weitkamp, L. A. 1994. A review of the effects of dams on the Columbia River estuarine environment, with special reference to salmonids. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Welch, D. W., B. R. Ward, B. D. Smith, and J. P. Eveson. 2000. Temporal and spatial responses of British Columbia steelhead (*Oncorhynchus mykiss*) populations to ocean climate shifts. Fisheries Oceanography 9:17-32.

Williams, J. G., S. G. Smith, and W. D. Muir. 2001. Survival estimates for downstream migrant yearling juvenile salmonids through the Snake and Columbia Rivers hydropower system, 1966-1980 and 1993-1999. North American Journal of Fisheries Management 21:310-317.

Williams, R. N., and eleven coauthors. 2000. Return to the river. Restoration of salmonid fishes in the Columbia River ecosystem. Northwest Power Planning Council Document 2000-12. NWPPC, Portland, Oregon. (Available online at www.nwppc.org/library/return/2000-12.htm February 2004.)