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FINAL REPORT
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Prepared for the U.S. Army Corps of Engineers
Portland District, Portland, Oregon
Under a Related Services Agreement
with the U.S. Department of Energy
Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

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Executive Summary

Acoustic telemetry proved to be a very effective method for determining how juvenile salmonids use the areas at the mouth of the Columbia River (MCR). Data collected with acoustic telemetry were used to determine the daily and seasonal behavior of yearling and subyearling Chinook salmon and steelhead in the areas where the U.S. Army Corps of Engineers (USACE) conducts channel maintenance and jetty repairs. This project took advantage of the release of 3,119 juvenile salmonids that were each surgically implanted with a microacoustic transmitter (0.63 g in air, 0.39 g in water) and released near Bonneville Dam or at the Astoria Bridge in other USACE-funded projects. Detection arrays were located near West Sand Island (‘primary array’) and on the Columbia River Bar (‘secondary array’).

Subyearling Chinook salmon were more likely to enter the areas near the North Jetty than yearling Chinook salmon or steelhead. The cross-channel distribution of these groups was variable, but steelhead and yearling Chinook salmon generally were distributed more toward the navigation channel than the jetty. Subyearling Chinook salmon were more often detected in close proximity to the North Jetty than were yearling Chinook salmon or steelhead.

Yearling Chinook salmon and steelhead typically had shorter travel times and passed through the area around the MCR in a more directed manner than subyearling Chinook salmon. Mean travel times from release near Bonneville Dam to the MCR (~140 river miles) were generally between 3 and 4 days (mean = 3.5 days) for yearling Chinook salmon and steelhead. These larger fish also tended to spend less time (9 to 24 minutes) in the MCR detection area than the smaller subyearling Chinook salmon (mean = 160 minutes). Subyearling Chinook salmon took significantly longer to reach the primary array from Bonneville Dam (mean = 4.5 days) and they tended to exhibit less directed movements and remain in the area for longer periods than yearling Chinook salmon and steelhead. Steelhead released at Skamania Landing (~135 miles upstream of the MCR) were more likely to be detected during daylight hours in the MCR area than were their counterparts released at night on an ebbing tide at the Astoria Bridge. In general, the time of day when fish released near Bonneville Dam arrived in the MCR area was variable within and among release groups, and likely was more dependent on tide than daylight. The highest number of detections of fish implanted with microacoustic transmitters occurred during ebb tide conditions.

Due to the rapid travel times and short residence times of yearling Chinook salmon and steelhead in the MCR area, channel and jetty maintenance and repair activities there would not be expected to adversely impact these emigrating fishes. Subyearling Chinook salmon moved slower and remained in the MCR area longer, but their estimated residence (exposure) time (4.6 days) was less than in a previous study that reported no effect on the osmoregulatory abilities of juvenile salmon exposed to dredge sediments and high turbidity for a 9-day period.

Acknowledgments

Many hours on uneven seas were spent to collect the information presented in this report. Gary Dennis, Pacific Northwest National Laboratory (PNNL)-Sequim, the able skipper, was instrumental in getting the crew and gear in and out of the water safely. Kate Deters, Rich Brown, Scott Titzler, Mark Weiland, and Ian Welch, all from PNNL-Richland, helped rig the equipment and get it deployed, serviced, and recovered. Lynn McComas, National Oceanographic and Atmospheric Administration Fisheries, worked very hard to get the cabled system deployed and operational and provided PNNL with the data collected by that system. Rich Brown, Kenneth Ham, Abby Capetillo, John Stephenson, Ratna Saripalli, Craig Allwardt, and Eric Robinson assisted greatly in the processing of data and/or preparation of the report. Walter Pearson provided helpful information relevant to dredging impacts. Carolyn Schneider and Mark Siiploa, U.S. Army Corps of Engineers, provided helpful comments and references during the report preparation.

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1.0 Introduction

Safe operation of the navigation channel for vessel traffic across the Columbia River Bar where the river enters the Pacific Ocean requires periodic dredging and maintenance. In addition, the jetties at the mouth of the Columbia River (MCR) also need periodic repair. Work in these areas has the potential to impact endangered fish species that may migrate through or rear in that area. In response to concerns that channel maintenance and/or jetty repair might impact Endangered Species Act-listed juvenile salmonids on their seaward migration, during the spring and summer of 2005, the Pacific Northwest National Laboratory (PNNL) undertook a study for the Portland District of the U.S. Army Corps of Engineers (USACE) using acoustic telemetry to document the general behavior of juvenile salmonids in the MCR area.

The primary goal of this study was to document the use and general behavior of juvenile salmonids using acoustic telemetry in the MCR area during the spring and summer of 2005, with focus on usage of potential habitat near the navigation channel and north jetty where repair/maintenance work was scheduled for 2005.

Specifically, the objectives were to:

1. Describe species and age class specific general distribution, residence times, and movement patterns of subyearling and yearling Chinook salmon and steelhead bearing Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic microtransmitters as recoverable from detections on receivers in the MCR area.

2. Detail two-dimensional movement patterns for juvenile fish bearing acoustic micro-transmitters in a designated area of interest using time series of position data obtained from a two-dimensional tracking baseline of autonomous nodes.

3. Assess the relationships between fish distribution, residence times, movement patterns, and environmental conditions, such as river discharge, daylight, and tide for subyearling and yearling Chinook salmon and steelhead.

4. Summarize acquired data using Geographic Information System-related methods to visually show the movement patterns and usage of regions of interest by acoustic telemetry fish.

2.0 Methods

This project relied heavily on ongoing USACE studies to estimate the survival of subyearling and yearling Chinook salmon and steelhead smolts to ocean entry from release below Bonneville Dam, especially Project EST-P-02-01, the Estuary Survival Study. This leverage included observations of use of the region near the north jetty and Clatsop Spit by fish implanted with microacoustic transmitters that survive from release at Bonneville Dam to detection arrays in the estuary deployed immediately upstream and in the immediate vicinity of the jetty. In addition, for purposes of the MCR study, behavioral observations were extracted from data acquired for the survival study.

2.1 Transmitter Implantation

The microacoustic transmitters (Figure 2.1) used in 2005 weighed 0.63 g in air and had a residual mass of <0.39 g in fresh water. The transmitters each emitted a unique 31-bit coded pulse every 4.2 to 4.9 seconds at a frequency of 416.7 kHz and had a battery life of ~30 days after activation.

Figure 2.1. Microacoustic Transmitter used in Juvenile Chinook Salmon and Steelhead in 2005. The copper wires were removed during transmitter activation, which occurred prior to surgical implantation.

All fish detected in this study were surgically implanted with microacoustic transmitters at Bonneville Dam. Methods similar to Anglea et al. (2004) and Brown et al. (2005) were used to surgically implant transmitters. The Chinook salmon (both yearlings and subyearlings) were captured as run-of-the-river fish in the Bonneville Second Powerhouse (B2) bypass at the Juvenile Fish Facility and were implanted and released (following a minimum of 12 hours of recovery) into the bypass outside this same facility. The juvenile steelhead were Snake River-origin hatchery steelhead that were collected from fish transport barges by lift netting between John Day and Bonneville dams. These fish were implanted in a National Oceanographic and Atmospheric Administration (NOAA) tagging trailer located near the upstream side of the navigation locks on the Oregon side of Bonneville Dam. As detailed below, some of these fish were released at Skamania Landing downstream of Bonneville Dam and some were transported by boat to the Astoria Bridge and released there during hours of darkness that coincided with an outgoing tide.

In 2005, a total of 3,119 fish were implanted and released for two different USACE-funded studies (Table 2.1). Between May 4 and June 1, 2005, 894 yearling Chinook salmon were implanted and then released at the B2 Juvenile Bypass Facility. An additional 1,220 subyearling Chinook salmon were implanted and released at the same facility between June 18 and July 16, 2005. Between May 6 and 22, 2005, 1,005 Snake River hatchery-origin steelhead smolts were implanted and released at Skamania Landing below Bonneville Dam (N=640) and at Astoria Bridge (N=365).

Table 2.1. Steelhead (STL), Yearling Chinook Salmon (SPC), and Subyearling Chinook Salmon (FC) Released in the Columbia River in 2005 that were Implanted with Microacoustic Transmitters. The related USACE-funded projects are shown for each release group.

Project	Species	Release Date	Release Location	Live Fish Released
Alternate Barge	STL	5/6/2005	Astoria	90
Alternate Barge	STL	5/6/2005	Skamania Landing	160
Alternate Barge	STL	5/16/2005	Astoria	95
Alternate Barge	STL	5/16/2005	Skamania Landing	160
Alternate Barge	STL	5/19/2005	Astoria	90
Alternate Barge	STL	5/19/2005	Skamania Landing	160
Alternate Barge	STL	5/22/2005	Astoria	90
Alternate Barge	STL	5/22/2005	Skamania Landing	160
JSATS	SPC	5/4/2005	Bonneville	245
JSATS	SPC	5/15/2005	Bonneville	243
JSATS	SPC	5/24/2005	Bonneville	161
JSATS	SPC	6/1/2005	Bonneville	245
JSATS	FC	6/18/05	Bonneville	240
JSATS	FC	6/25/05	Bonneville	245
JSATS	FC	7/2/05	Bonneville	245
JSATS	FC	7/9/05	Bonneville	245
JSATS	FC	7/16/05	Bonneville	245
Total	STL			1005
	SPC			894
	FC			1220
Grand Total				3119

2.2 Receiving Arrays

A total of 42 receiving nodes (Figure 2.2), arranged in primary and secondary arrays, were deployed to detect and record the presence of passing fish bearing the microacoustic transmitters. The primary array was deployed at river mile 5.6 and consisted of large stationary cabled receivers deployed by NOAA Fisheries and an ocean engineering firm. The secondary array, located at about river mile 2 was composed of autonomous receiving nodes. Autonomous nodes included on-board power (30-day battery life) and data storage (256 MB Compact Flash). The autonomous nodes were attached to 150-lb anchors with bungee moorings. The moorings were 12 ft long and attached the acoustic release (InterOcean Systems, Inc., San Diego, CA; model 111) to the anchor. The acoustic releases had a tag line canister filled with 150 ft of 3/16-in.-diameter Samson line, which allowed the nodes to surface when the acoustic release was activated. The lead from the acoustic release to the autonomous node was 3 ft long and was made of 3/8-in.-diameter Samson Tenex line with a clear Samthane coating. The node was attached to the line by a bridle made of vinyl-coated 3/32-in. stainless steel cable that was terminated in stainless steel thimbles on the node end and in a milled UHMW plastic swivel block on the rope lead end. All rope leads were terminated with a braided splice around a 3/8-in. SeaDog nylon thimble and were professionally tied-up (by a vendor for West Marine). From the node bridle to the surface ran a 3/8-in.-diameter Samson Tenex line with a subsurface buoy (yellow, Spongex CB6, 10 lbs, 10 oz of buoyancy, 6 in. in diameter and 14 in. long) placed ~18 ft above the node. Three additional yellow CB6 buoys were placed on the line at the surface. The length of the rigging was designed to be approximately two times the depth at each deployment location at high tide. Figure 2.2 shows several autonomous nodes in the process of rigging with the associated radio buoys prior to deployment.

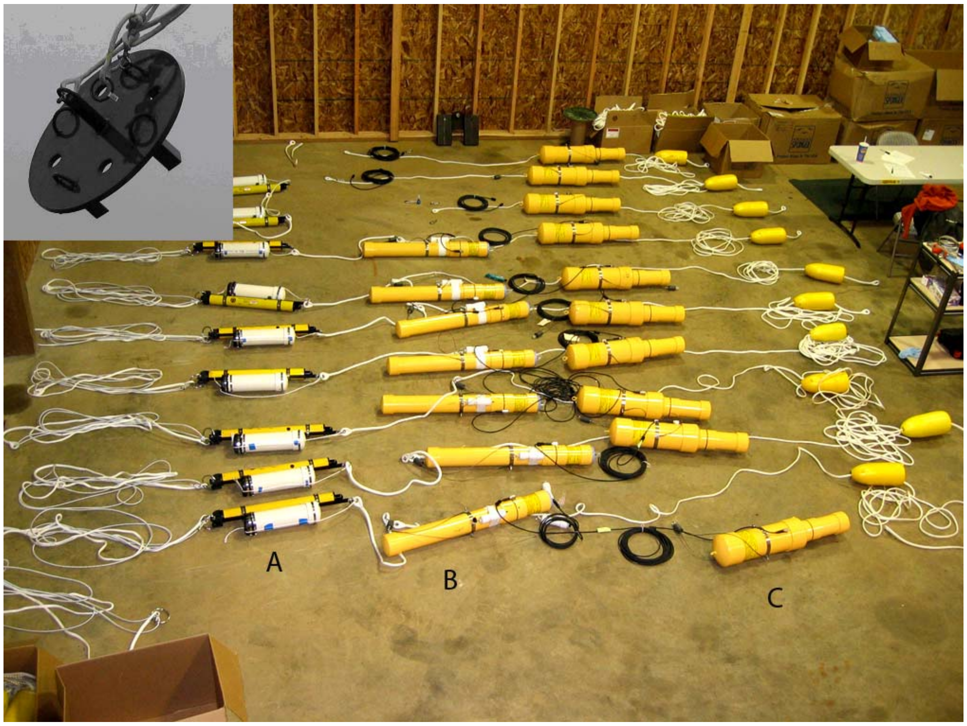

Figure 2.2. Autonomous Nodes in the Process of Rigging for Deployment on the Columbia River Bar. The 150-lb anchor (inset) was attached to the leads at the left of the photo below the acoustic release (A), the autonomous node (B), and the radio buoy (C).

Some nodes (N=14) were deployed with a radio communication system buoy attached. The radio system was deployed as a feasibility effort to transmit data to researchers in near real-time and to send Global Positioning System (GPS)-derived time signals out to the nodes to synchronize the clocks within the autonomous nodes (Figure 2.3). These nodes used a Freewave radio inside a custom buoy that was linked to the autonomous node by an RS-232 cable. The RS-232 cable was attached to the mooring rope by cable ties and electrical tape. The nodes transmitted to a base station that was located in the Lewis and Clark Interpretive Center (at the top of Cape Disappointment).

The cabled nodes were deployed in the primary array near West Sand Island (Figures 2.4 and 2.5). The primary array was originally deployed in two sections. The cabled node portion of the primary array consisted of 19 nodes on the West Sand Island portion and 3 nodes on the Clatsop Spit portion. All nodes on the primary array were linked to shore stations by underwater cable. The secondary detection array, on the Columbia Bar, consisted of 29 autonomous nodes. There were 8 autonomous nodes deployed on the Oregon side of the navigation channel and 21 autonomous nodes on the Washington side of the navigation channel on the secondary array. An additional array of 13 autonomous nodes was deployed on April 26, 2005, on the Washington side of the navigation channel on the primary array near Sand Island due to the failure of the cabled primary detection array in that area. This 'temporary primary array' remained in place until July 8, ~2 weeks after the cabled primary array had been repaired and returned to service.

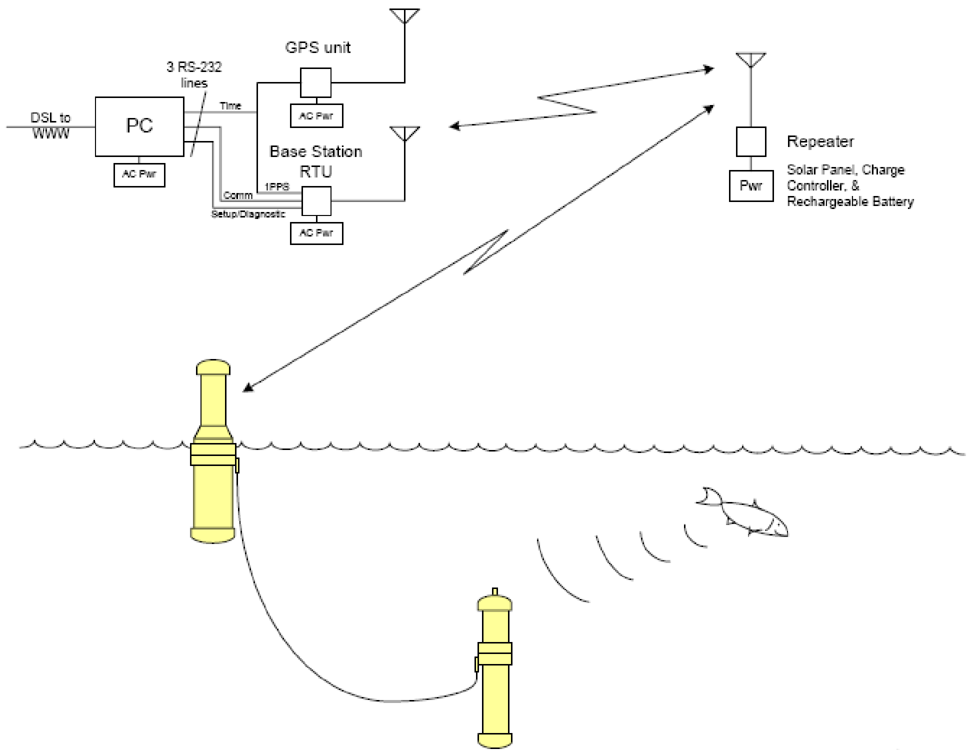

Figure 2.3. Block Diagram of the Radio Communication System Tested on the Columbia River Bar in Spring 2005

Figure 2.4 shows the location of the primary (right) and secondary (left) arrays which were located 3.6 mi apart. Figure 2.5 shows the deployment pattern for autonomous nodes on the Columbia River Bar during the first portion of the study (A: April 4 to June 9, 2005) and during the second portion of the study after the three nodes were moved out of the North Jetty disposal site (B: June 9 to August 17, 2005).

2.3 Data Processing and Analyses

Data collected by the autonomous nodes were recorded as text files on Compact Flash cards. These text files were transferred to a laptop computer when the nodes were serviced during the season or when recovered at the end of the season. Physical data were written to file every 15 seconds. Physical data recorded included date, time, pressure, water temperature, tilt, and battery voltage. Detections of transmitters were recorded in real time as they were received. They were written to media with TagID (individual code of transmitter), time stamp, RSSI (receive signal strength indicator), and RxThreshold (a

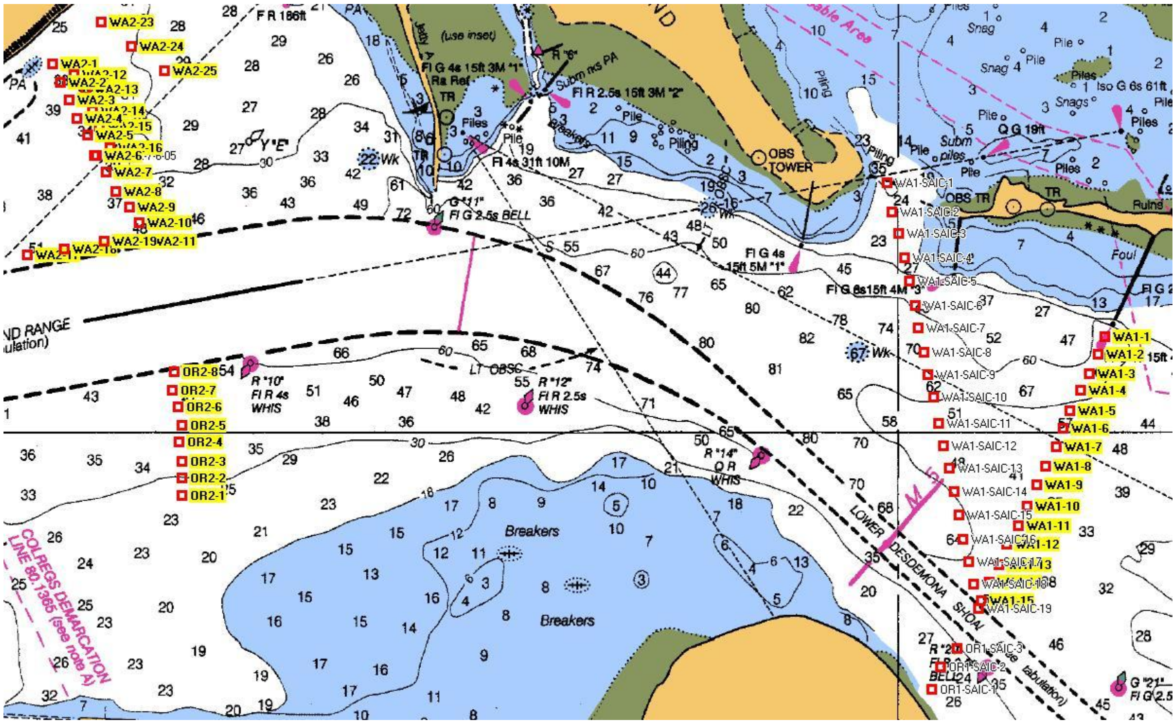

Figure 2.4. Location of Acoustic Receiving Nodes within the Study Area near the Mouth of the Columbia River, April – August 2005. The markers identified by yellow highlighting indicate autonomous node deployment locations, while the red squares with black text and no yellow highlighting were locations where cabled nodes were deployed.

calculated measure of noise). Data files from all nodes were coded with the node location and stored in a database that was developed specifically for storing and processing acoustic telemetry data (TagViz©). To filter out 'false positives' (i.e., detections of TagIDs that did not meet criteria to be considered a valid detection), a post-processing program was implemented. The program included a sequence of steps as follows:

1. Comparing each detection to a list of tags that were released so only tags that were released were retained in the database.

2. Comparing the detection date to the release date so only tags detected after they were released were retained in the database.

3. Analyzing the RSSI/RxThreshold (essentially signal to noise ratio) so only detections that had an RSSI that was 0.75 times higher than the RxThreshold were kept.

4. Analyzing the time spacing between detections was analyzed so only the detections with the correct time spacing were retained in the valid detection file.

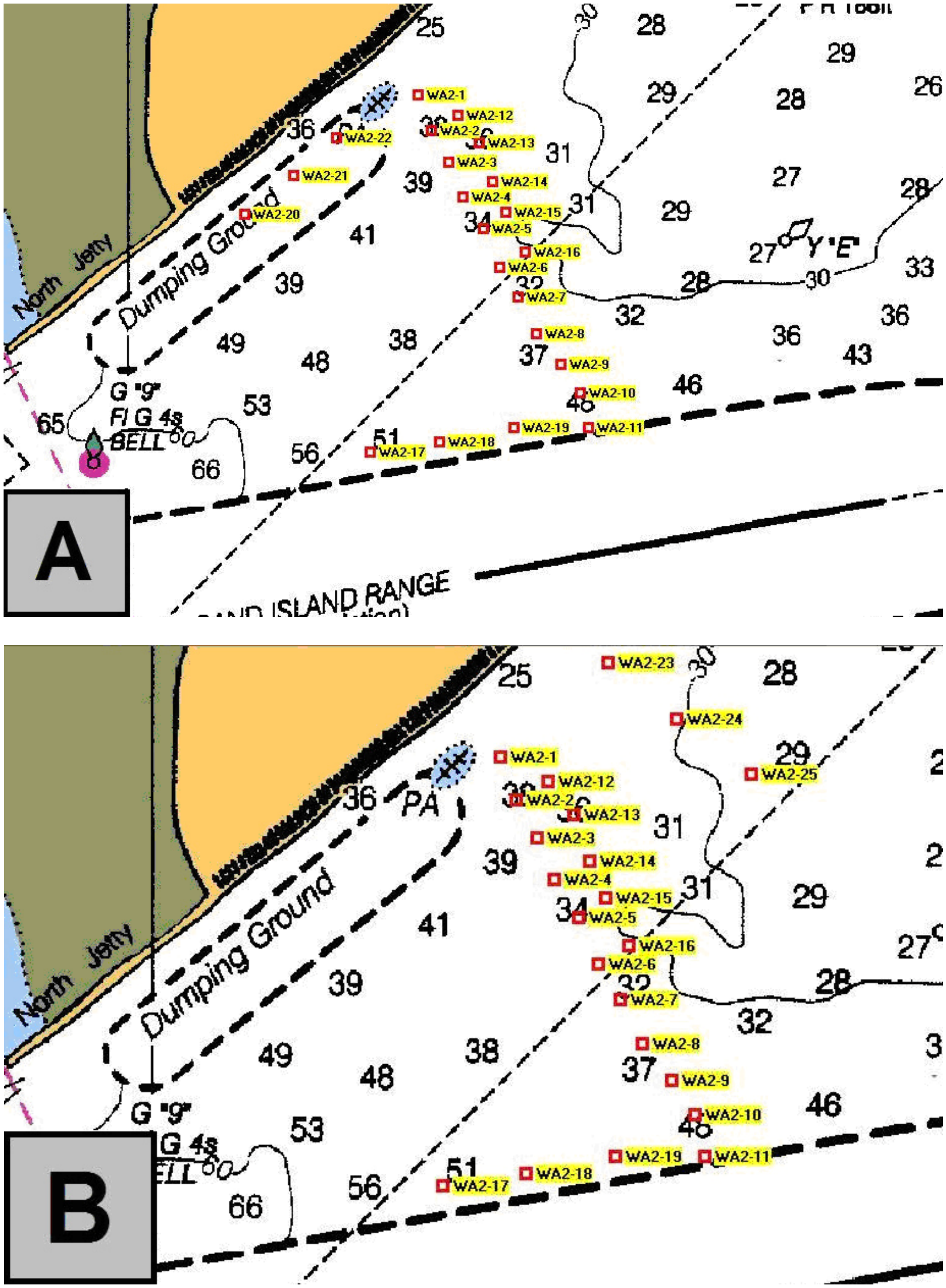

Figure 2.5. The Location of Autonomous Nodes within the Washington Portion of the Secondary Array at the Mouth of the Columbia River. Panel A shows autonomous node placements on the secondary array between April 4 and June 9, 2005. Panel B shows autonomous node placements from June 9 to August 17, 2005.

Once the valid detection file was created, the detection histories of release groups were analyzed to determine the cross-channel distribution of each species/stock, arrival and departure times, residence times, and movement patterns of steelhead, yearling Chinook salmon, and subyearling Chinook salmon in the MCR area, as well as the area 3.6 mi upstream where the primary array was located. To determine cross-channel distribution, the database was queried to get a count of distinct tags that were observed at each node location for each species and release group. To evaluate arrival and departure times, the database was queried for the first and last time a fish was observed within the secondary array and the locations of those observations. To simplify the visualization of these locations, the Washington side of the secondary array was divided into four parts: north, south, North Jetty disposal site, and triangle. The nodes in the 'triangle' were only present for the later fall Chinook releases. A count of fish for each hour (independent of day) was then plotted for each of the three species/stocks and five areas. Residence time was calculated by finding the difference between the times of the first and last observations on the secondary array. Analysis of movement patterns was completed by assigning fish to the aforementioned location categories based on the sequence of observations. To provide an indication of how fish moved through the last few miles of the Columbia River Estuary, movement directedness was examined. Directedness was determined as follows: if a fish was observed first on the primary array and then on the secondary array, or if it was observed on several nodes within the secondary array moving in a seaward direction (i.e., on the nodes along the navigation channel or along the North Jetty), then its movement was considered to be directed. Conversely, if a fish was observed first on the secondary array and then on the primary array (or if it appeared to move back and forth between arrays or within an array), then its movement was considered to be 'not directed.' Data were not considered in the analysis of directedness if the fish was only observed on one array, or on fewer than three nodes within the secondary array.

3.0 Results

A total of 1,401 of the 3,119 fish implanted with microacoustic transmitters (45%) were detected on the arrays near the MCR in 2005. The following sections provide information on the general behavior of these juvenile salmon and steelhead as they passed through the last few miles of the Columbia River Estuary and entered the Pacific Ocean. Specific sections present detailed information on the cross-channel distribution, residence time, and movement patterns of fish implanted for this and other studies.

3.1 Distribution

Based on the counts of individual Chinook salmon detected across the secondary array at the Columbia River Bar, yearling Chinook salmon tended to be distributed across the entire channel, with a slightly higher proportion along the Oregon side of the navigation channel (Figure 3.1). One release of yearling Chinook salmon (May 12) was more oriented toward the navigation channel than the others. Later releases of yearling Chinook salmon appeared to make more use of the area near the North Jetty than yearling Chinook salmon that were released earlier in the season. Steelhead were generally detected in higher numbers close to the navigation channel (Figures 3.2 and 3.3). However, some steelhead from both release locations were detected along the North Jetty. Subyearling Chinook salmon were distributed widely across the Columbia River Bar, however those released earlier (June 18, 2005) were detected in higher numbers in the ‘triangle’ area between the North Jetty and Cape Disappointment (Figure 3.4).

3.2 Residence Time

Subyearling Chinook salmon spent significantly more time in the area at the MCR than yearling Chinook salmon or steelhead. It appears that yearling Chinook salmon and steelhead moved through this area at a higher rate than subyearling Chinook salmon. Yearling Chinook salmon and steelhead migrating seaward were generally detected for periods less than 30 minutes (Figure 3.5; Table 3.1). Subyearling Chinook salmon were detected in our arrays at the MCR for longer periods, with release group means between 72 and 202 minutes. This is not the total time that these fish spent in the area between the jetties – as the detection area around the nodes covered an area about 200 yds wide along the lines (~1 mi) where the nodes were deployed. However, this metric is useful for inferring the relative residence times of the various groups of fish. Time of arrival was examined to provide increased understanding of the time of day when juvenile salmonids might be in the MCR areas where channel maintenance or jetty repair might be occurring. Yearling Chinook salmon first arrived in the area around the secondary array at all hours of the day, but showed slight trends toward early morning. On the Oregon portion of the secondary array near Clatsop Spit, two of the release groups showed the largest numbers of fish arriving in that area in the early morning hours, while the other two release groups had higher counts in the early evening (Figure 3.6). On the secondary array on the Washington side of the navigation channel, yearling Chinook salmon were typically first detected during early morning hours (Figure 3.6). Only four yearling Chinook salmon were first detected in the North Jetty disposal site along the North Jetty and three of four arrived in the early morning.

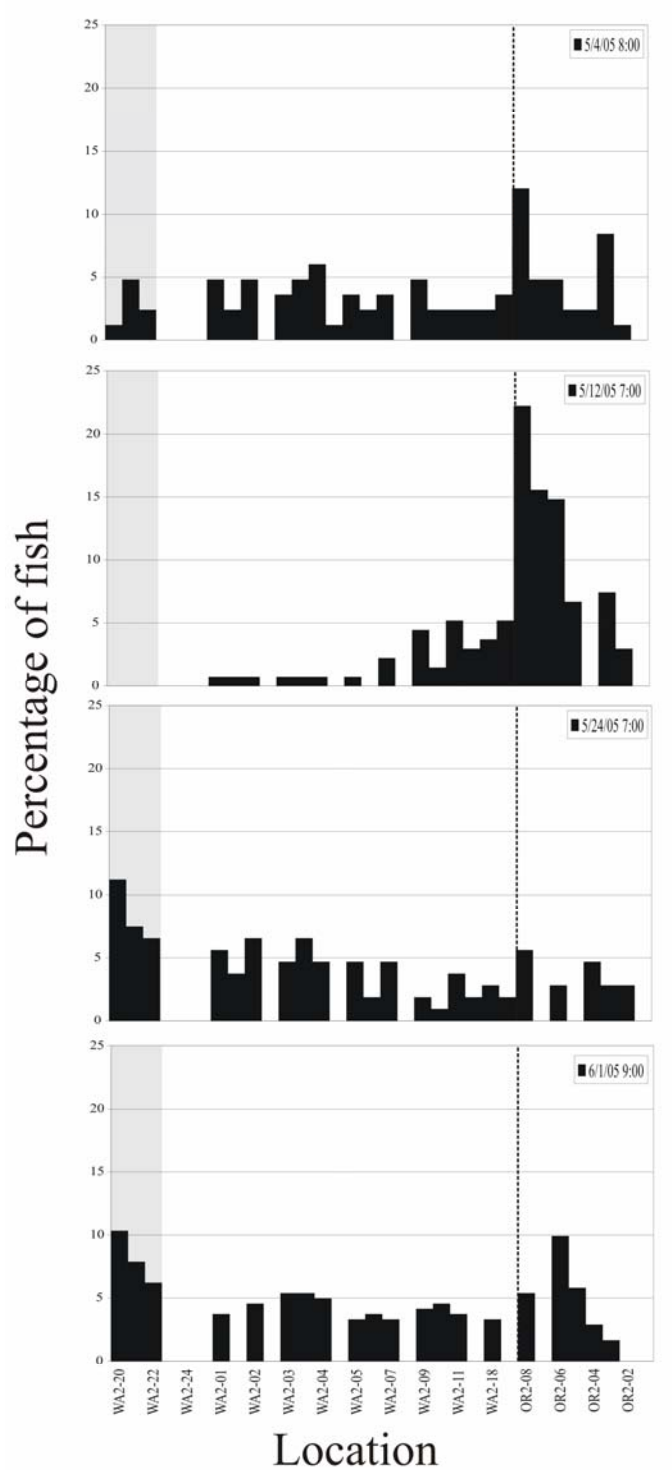

Figure 3.1. Cross-Channel Distribution of Yearling Chinook Salmon on the Columbia River Bar during Spring and Summer 2005. The shaded locations on the left of the figure are in the 'North Jetty disposal site' near the North Jetty, the navigation channel is denoted by the dashed line, and Clatsop Spit is to the far right edge of the figure. Please refer to Figures 2.4 and 2.5 for specific node locations.

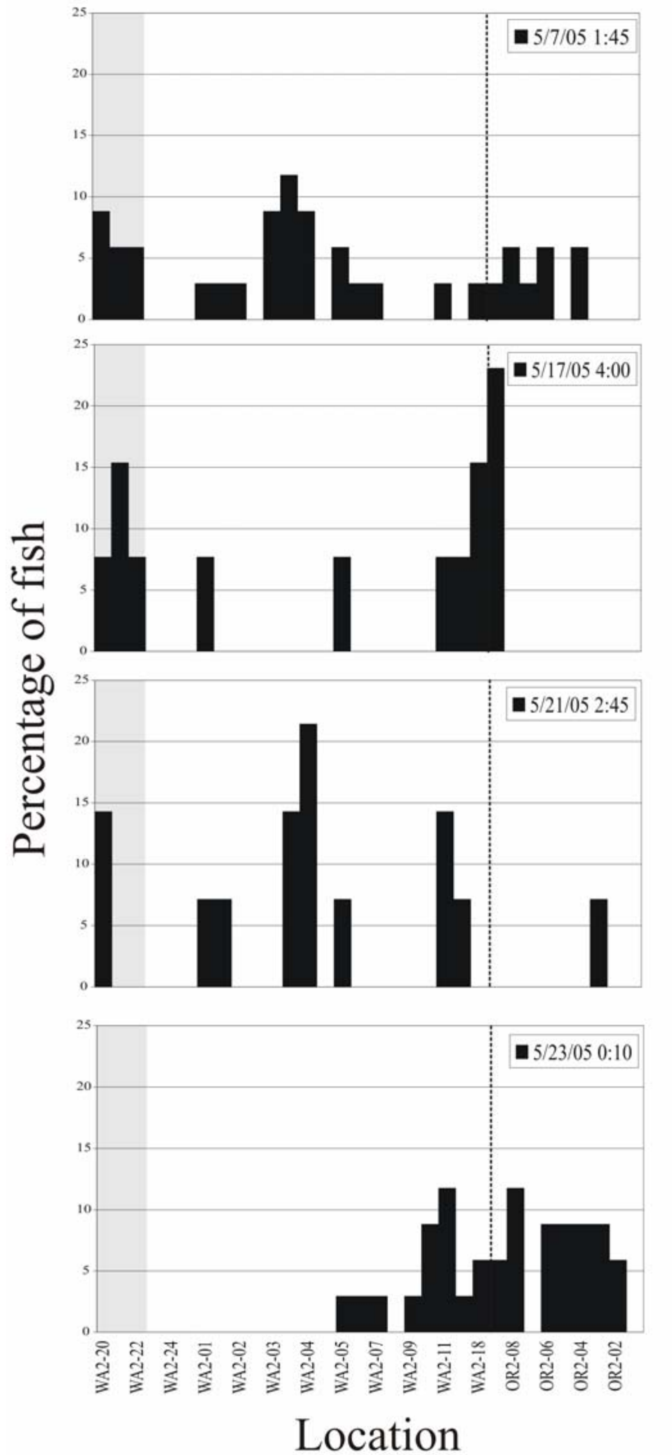

Figure 3.2. Cross-Channel Distribution of Steelhead Released at Skamania Landing on the Columbia River Bar during Spring 2005. The shaded locations on the left of the figure are in the 'North Jetty disposal site' near the North Jetty, the navigation channel is denoted by the dashed line, and Clatsop Spit is to the far right edge of the figure. Please refer to Figures 2.4 and 2.5 for specific node locations.

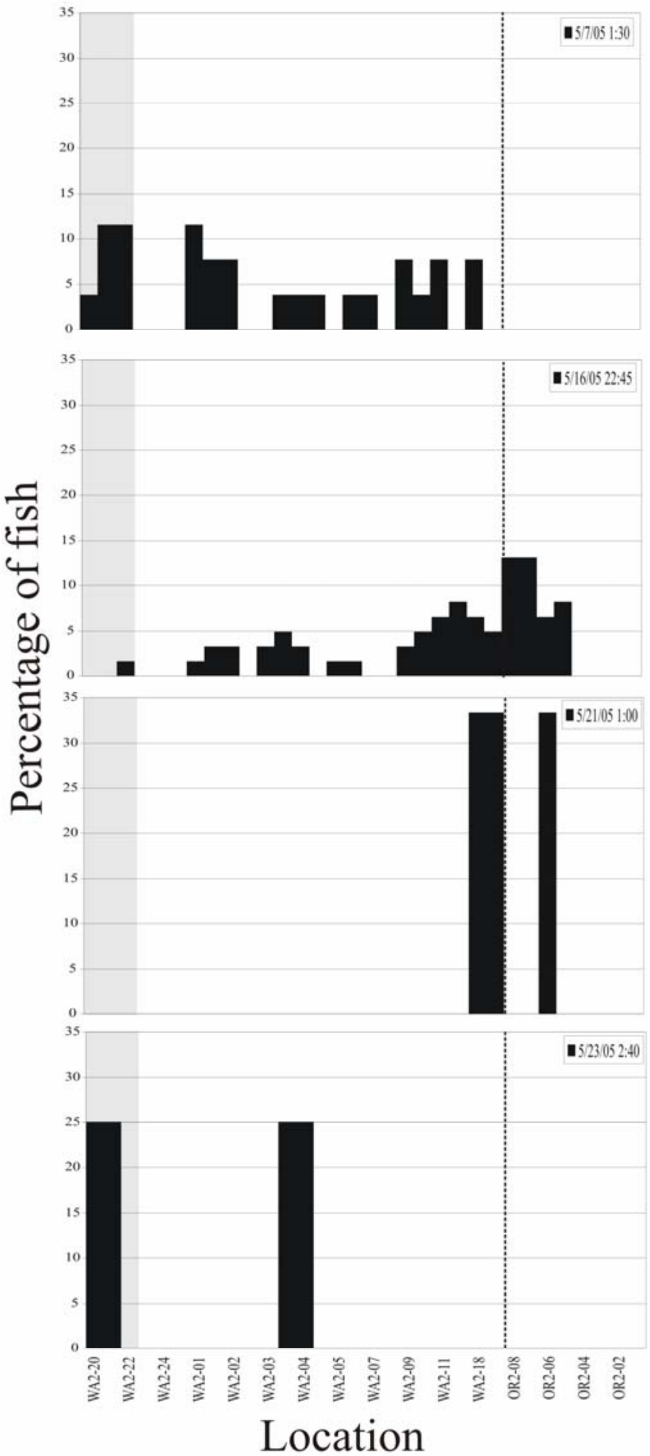

Figure 3.3. Cross-Channel Distribution of Steelhead Released at the Astoria Bridge on the Columbia River Bar during Spring 2005. The shaded locations on the left of the figure are in the 'North Jetty disposal site' near the North Jetty, the navigation channel is denoted by the dashed line, and Clatsop Spit is to the far right edge of the figure. Please refer to Figures 2.4 and 2.5 for specific node locations.

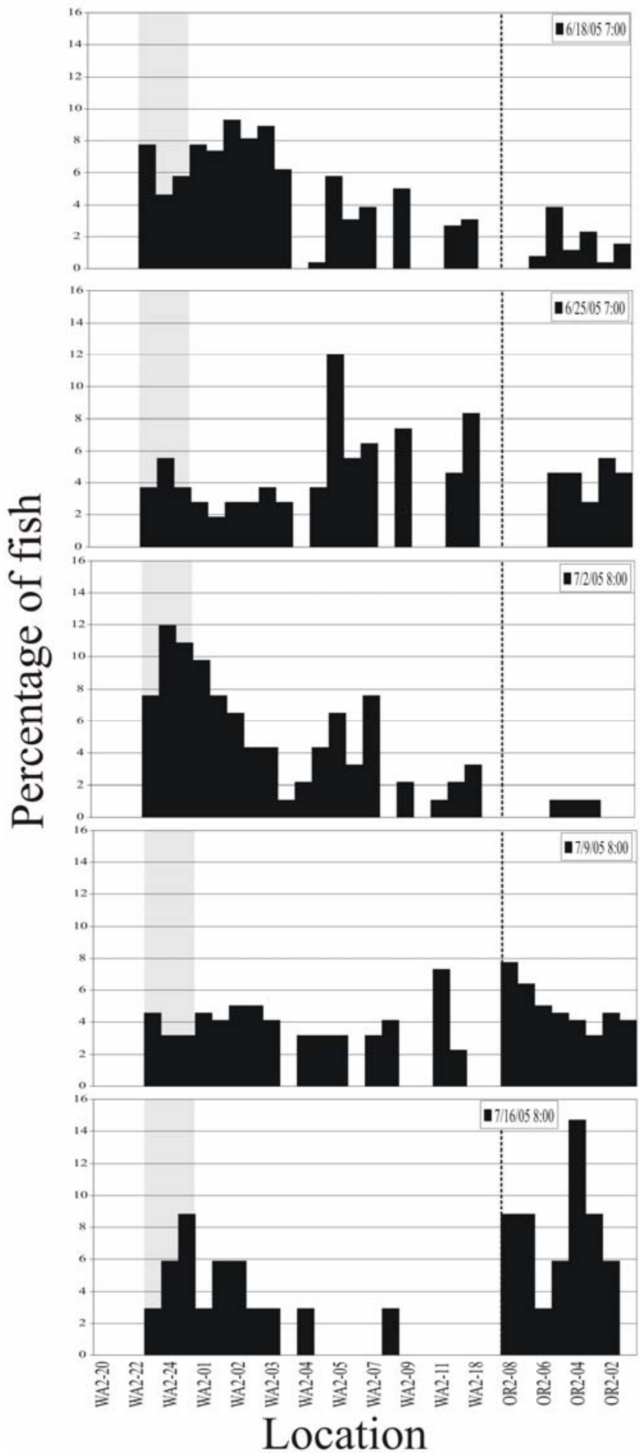

Figure 3.4. Cross-Channel Distribution of Subyearling Chinook Salmon on the Columbia River Bar during Spring and Summer 2005. The shaded locations near the left of the figure are near in the 'triangle' area near the North Jetty, the navigation channel is denoted by the dashed line, and Clatsop Spit is to the far right edge of the figure. Please refer to Figures 2.4 and 2.5 for specific node locations.

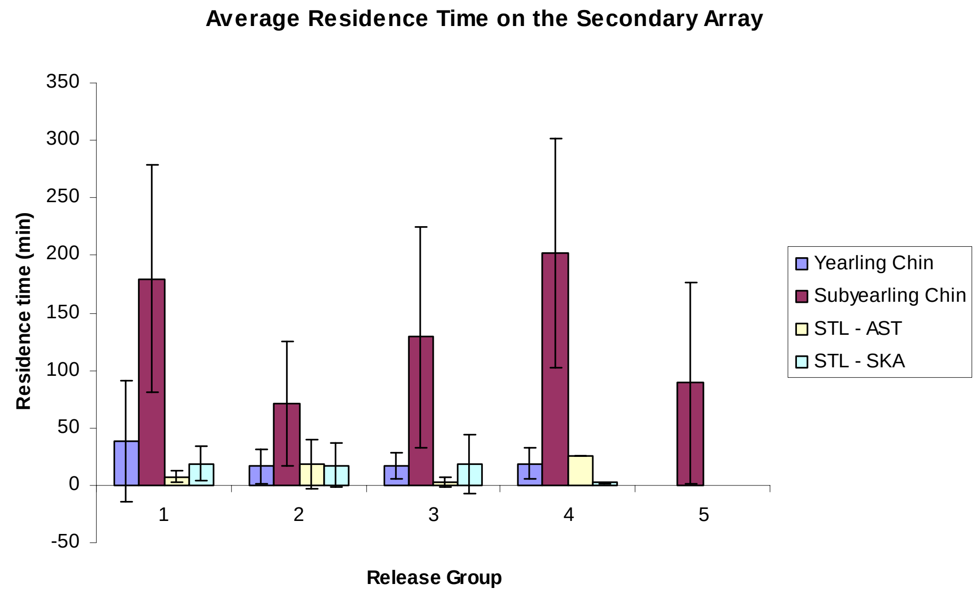

Figure 3.5. Residence Time (minutes; mean time between the first and last detections of individual fish) of Yearling and Subyearling Chinook Salmon and Steelhead in the Detection Area at the Mouth of the Columbia River. Error bars indicate ±1.96 standard errors.

Table 3.1. Travel Time (days and decimal days) and Movement Summary Information for Detections of Juvenile Yearling and Subyearling Chinook Salmon and Steelhead Implanted with Microacoustic Transmitters in Spring and Summer 2005 near the Mouth of the Columbia River. Note: summary average travel times are for all fish of each species group, not an average of the release group averages.

Species/Stock	Release Location	Release Date	Average Travel Time (days) - release to primary array	Average Travel Ttime (days) - primary array to secondary array	Average Residence Time (secondary array, minutes)	(N)	% directed	(N)
Yearling Chin	Bonneville	5/4/2005 8:00	6.61	0.10	38.58	23	75.0	12
Yearling Chin	Bonneville	5/12/2005 7:00	2.86	0.09	16.80	15	92.9	14
Yearling Chin	Bonneville	5/24/2005 7:00	3.11	0.12	16.94	30	94.4	18
Yearling Chin	Bonneville	6/1/2005 9:00	2.93	0.05	18.53	64	89.8	49
	Spring Chinook Summary		3.50	0.09	22.71	132	89.2	93
Subyearling Chin	Bonneville	6/18/2005 7:00	5.21	0.25	179.66	80	28.0	75
Subyearling Chin	Bonneville	6/25/2005 7:00	3.91	0.02	71.55	38	43.8	32
Subyearling Chin	Bonneville	7/2/2005 8:00	4.18	-0.03	128.96	31	20.7	29
Subyearling Chin	Bonneville	7/9/2005 8:00	4.31	0.17	202.01	45	36.6	41
Subyearling Chin	Bonneville	7/16/2005 8:00	3.60	0.46	88.89	4	100.0	3
	Fall Chinook Summary		4.49	0.17	134.22	198	32.8	180
Steelhead	Astoria	5/7/2005 1:30	0.15	0.04	7.65	10	100.0	7
Steelhead	Astoria	5/16/2005 22:45	0.18	0.04	18.46	12	75.0	12
Steelhead	Astoria	5/21/2005 1:00			2.91	1	100.0	1
Steelhead	Astoria	5/23/2005 2:40	0.08	0.27	24.90	1	100.0	1
		Astoria Summary	0.18	0.11	13.48	24	85.7	21
Steelhead	Skamania Landing	5/7/2005 1:45	3.53	0.10	18.49	10	80.0	5
Steelhead	Skamania Landing	5/17/2005 4:00	2.55	0.02	17.43	6	100.0	6
Steelhead	Skamania Landing	5/21/2005 2:45	2.60	0.12	18.26	8	83.3	5
Steelhead	Skamania Landing	5/23/2005 0:10	2.77	0.76	2.37	9	100.0	5
		Skamania Summary	2.90	0.25	14.14	33	91.3	21
	Steelhead Summary			0.19	13.81	57	90.5	42

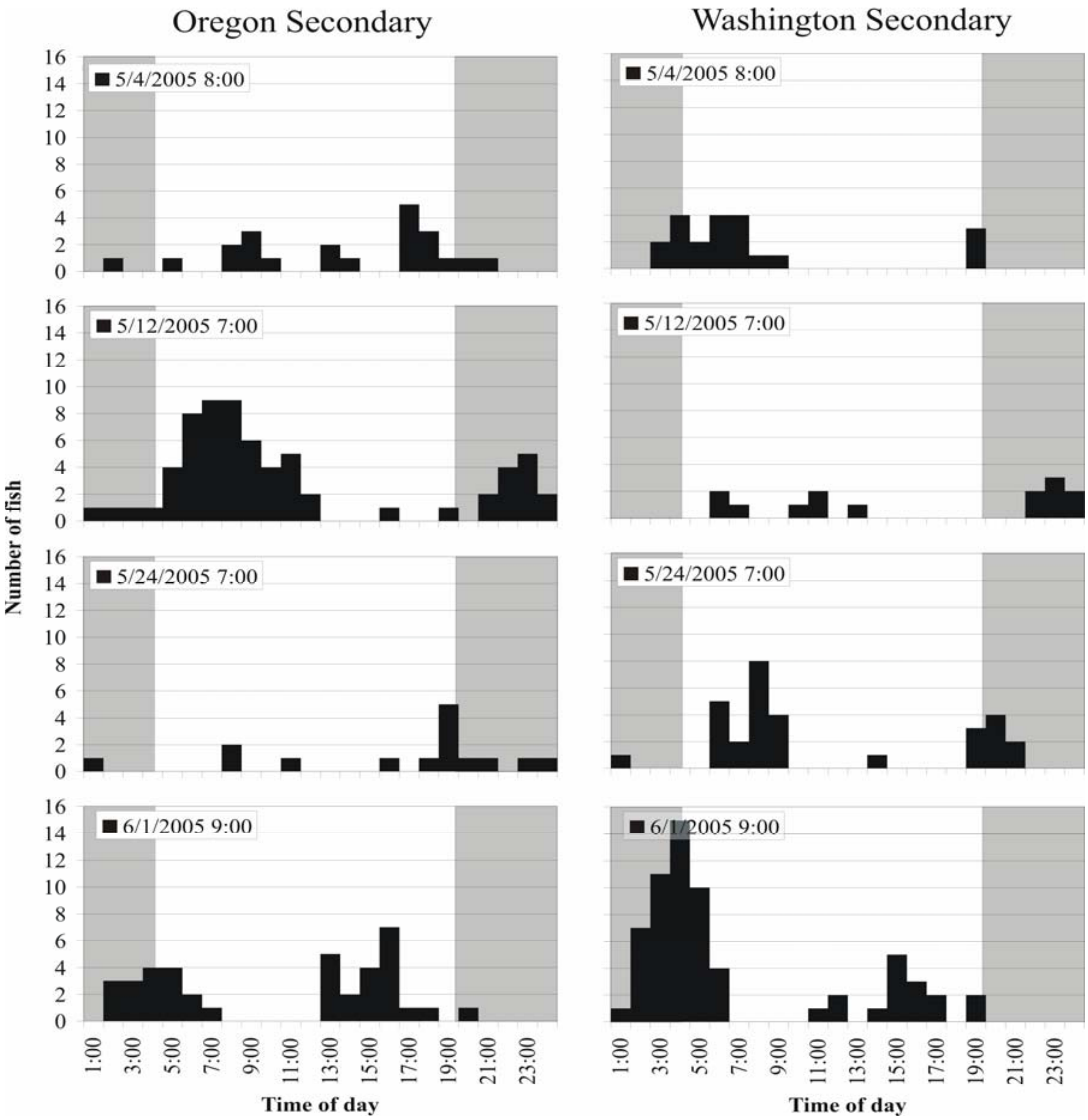

Figure 3.6. Time of Arrival of Yearling Chinook Salmon Implanted with Microacoustic Transmitters and Released below Bonneville Dam, then Detected on the Oregon Secondary Array near Clatsop Spit (left) and the Washington Secondary Array near the North Jetty (right) at the Mouth of the Columbia River. The time and date when implanted fish were released is shown in the figure legend. Shaded areas represent periods of darkness.

Subyearling Chinook salmon arrived at the secondary array on the Oregon side of the navigation channel during all hours, but were generally first detected during daylight hours (Figure 3.7). On the Washington side of the navigation channel, the subyearling Chinook salmon were first detected throughout the day, with greater numbers in the early morning hours for two of the five release groups (Figure 3.7).

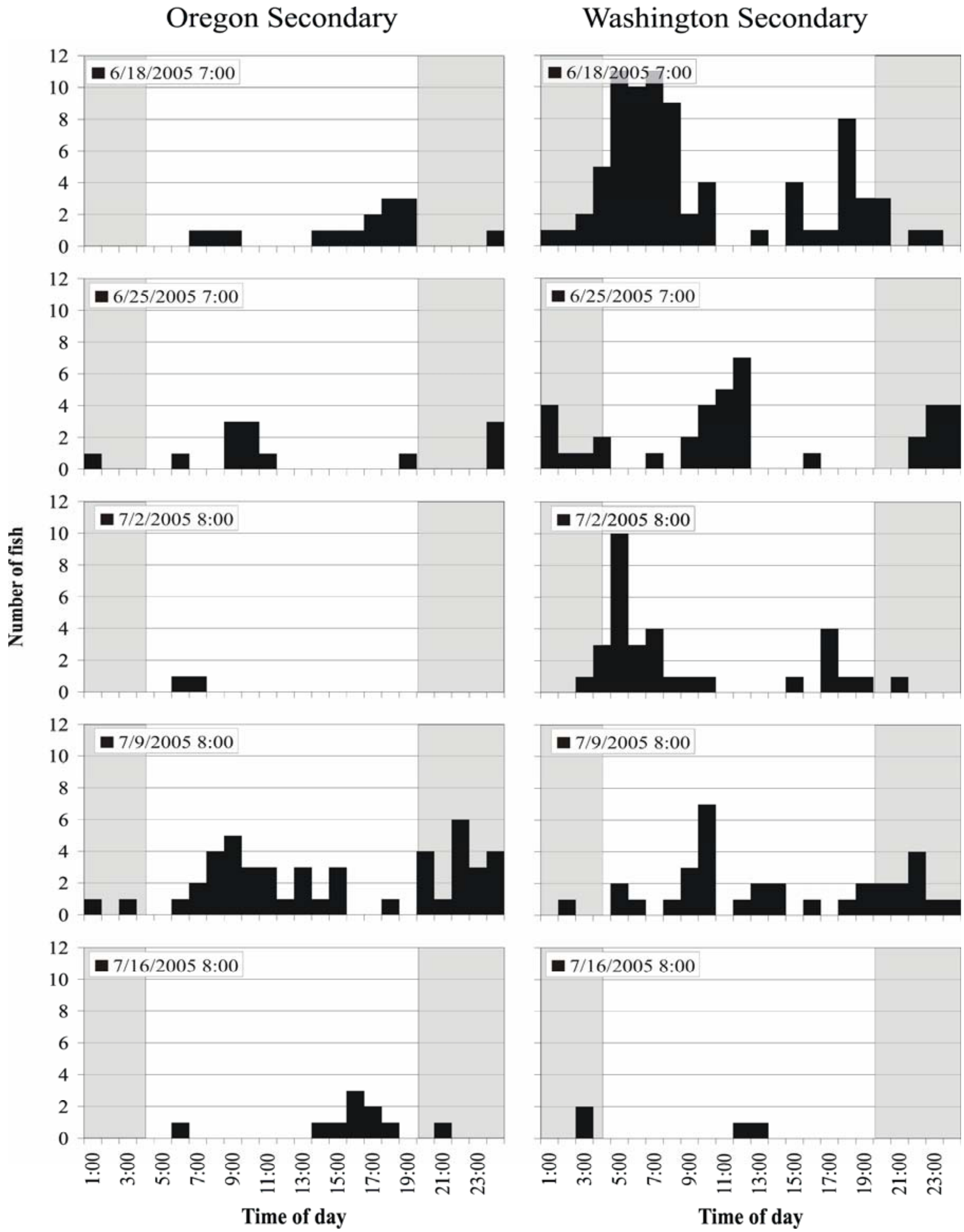

Figure 3.7. Time of Arrival of Subyearling Chinook Salmon Implanted with Microacoustic Transmitters and Released below Bonneville Dam, then Detected on the Oregon Secondary Array near Clatsop Spit (left) and the Washington Secondary Array near the North Jetty (right) at the Mouth of the Columbia River. The time and date when implanted fish were released is shown in the figure legend. Shaded areas represent periods of darkness.

There was no obvious pattern in the time of arrival of steelhead on the different areas of the secondary array, with the exception of the difference in time of arrival between steelhead that were released at Skamania Landing versus those released at the Astoria Bridge. Steelhead detections were fewer than for Chinook salmon, possibly due to their tendency to emigrate in the navigation channel. On the Oregon side of the navigation channel, the steelhead released at the Astoria Bridge were first detected during late night and early morning hours shortly after they were released (Figure 3.8). Conversely, steelhead released at the Skamania Landing were first detected primarily during daylight and evening hours (Figure 3.9). Similar relationships between the time of arrival and release location were apparent for detections on the Washington secondary array.

3.3 Movement Patterns

As they emigrated from the Columbia River and into the Pacific Ocean, steelhead and yearling Chinook salmon tended to move more rapidly and with fewer departures from a direct course than subyearling Chinook salmon. Mean travel times from the B2 Juvenile Bypass Facility outfall to the primary array averaged 3.50 days for yearling Chinook salmon, and they generally decreased as the season progressed (Table 3.1). Subyearling Chinook salmon took an average of 4.49 days to migrate from the same point of release near Bonneville Dam to the primary array and also exhibited shorter travel times later in the season. There was a statistically significant difference between travel times of yearling and subyearling Chinook salmon ($P < 0.01$).

Similar to Chinook salmon release groups, steelhead also showed a general trend toward more rapid emigration rates later in the season. Steelhead were released in two different locations. Steelhead released at the Astoria Bridge were detected very soon after release (0.14 days = 3.4 hours) at the primary array, which was located ~8 mi downstream of the release point. These groups of steelhead were intentionally released on the beginning of an ebb tide during hours of darkness in an attempt to increase the probability that they would migrate past the piscivorous bird foraging areas near East Sand Island (adjacent to the primary array). Groups of steelhead that were released farther upstream, at Skamania Landing (below Bonneville Dam), had a mean travel time of 2.9 days.

Movement patterns of yearling Chinook salmon (mean = 89% directed) and steelhead (means = 86% and 91% directed) near the MCR were generally directed from the Columbia River and into the Pacific Ocean (Figure 3.10; Table 3.2). Conversely, subyearling Chinook salmon (mean = 33% directed) were detected on multiple receiving nodes in a sequence that did not indicate they were on a directed migration path out into the Pacific Ocean. The exception to this is the final release of subyearling Chinook salmon (all directed), which shows directed movement. However, there were very few detections (N=3) of this release group on the secondary array. There did not appear to be a clear relationship between river discharge and travel time in the fish detected in this study. Mean daily discharge at Bonneville Dam increased rapidly between May 1 and May 19 and then declined steeply through about June 17, after which the discharge was fairly stable with a slow decline (Figure 3.11). Travel times generally decreased (i.e., the fish were moving faster) later in the season, even though the discharge was decreasing (Table 2.1).

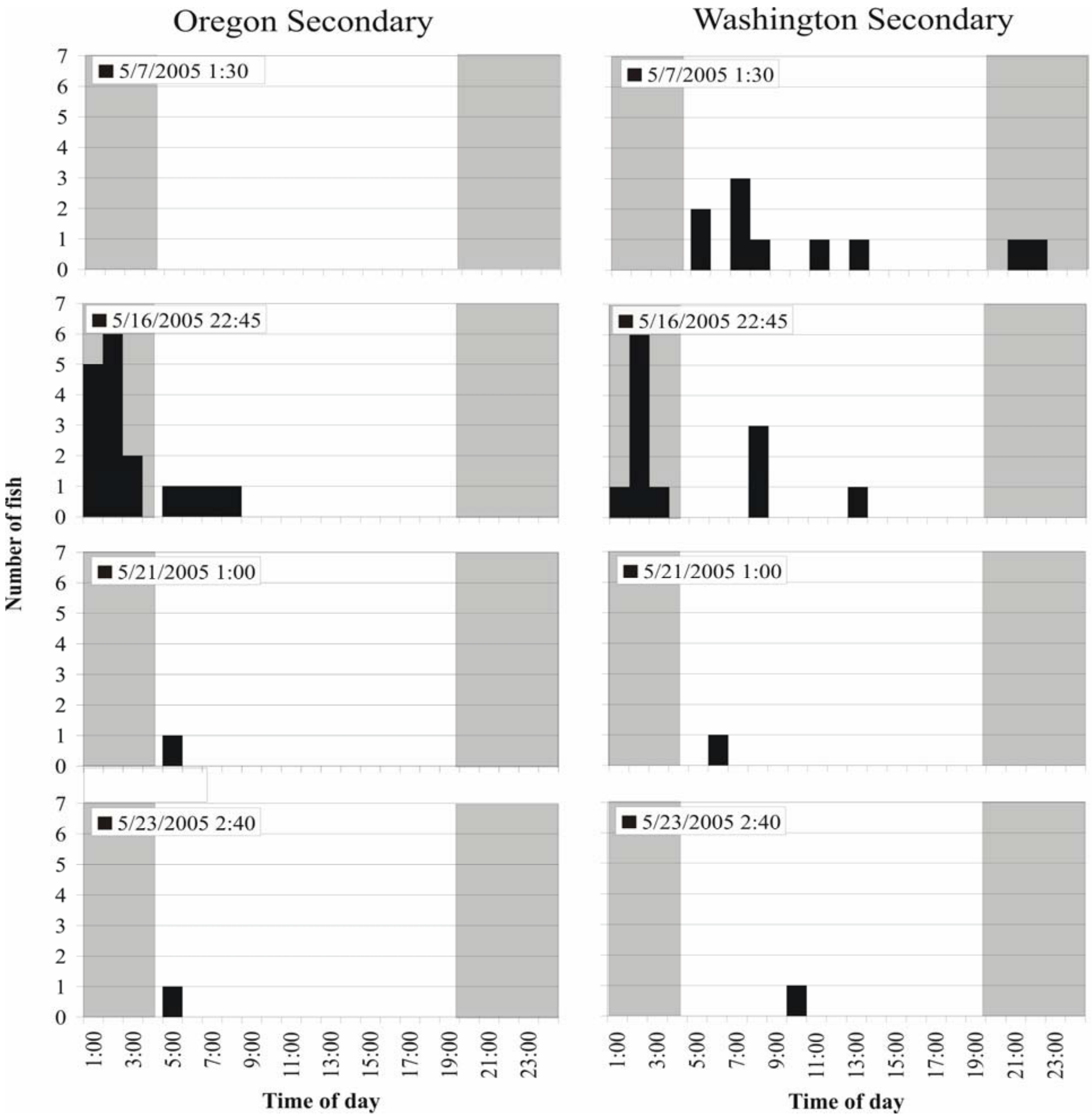

Figure 3.8. Time of Arrival of Steelhead Implanted with Microacoustic Transmitters and Released at the Astoria Bridge, then Detected on the Oregon Secondary Array near Clatsop Spit (left) and the Washington Secondary Array near the North Jetty (right) at the Mouth of the Columbia River. The time and date when implanted fish were released is shown in the figure legend. Shaded areas represent periods of darkness.

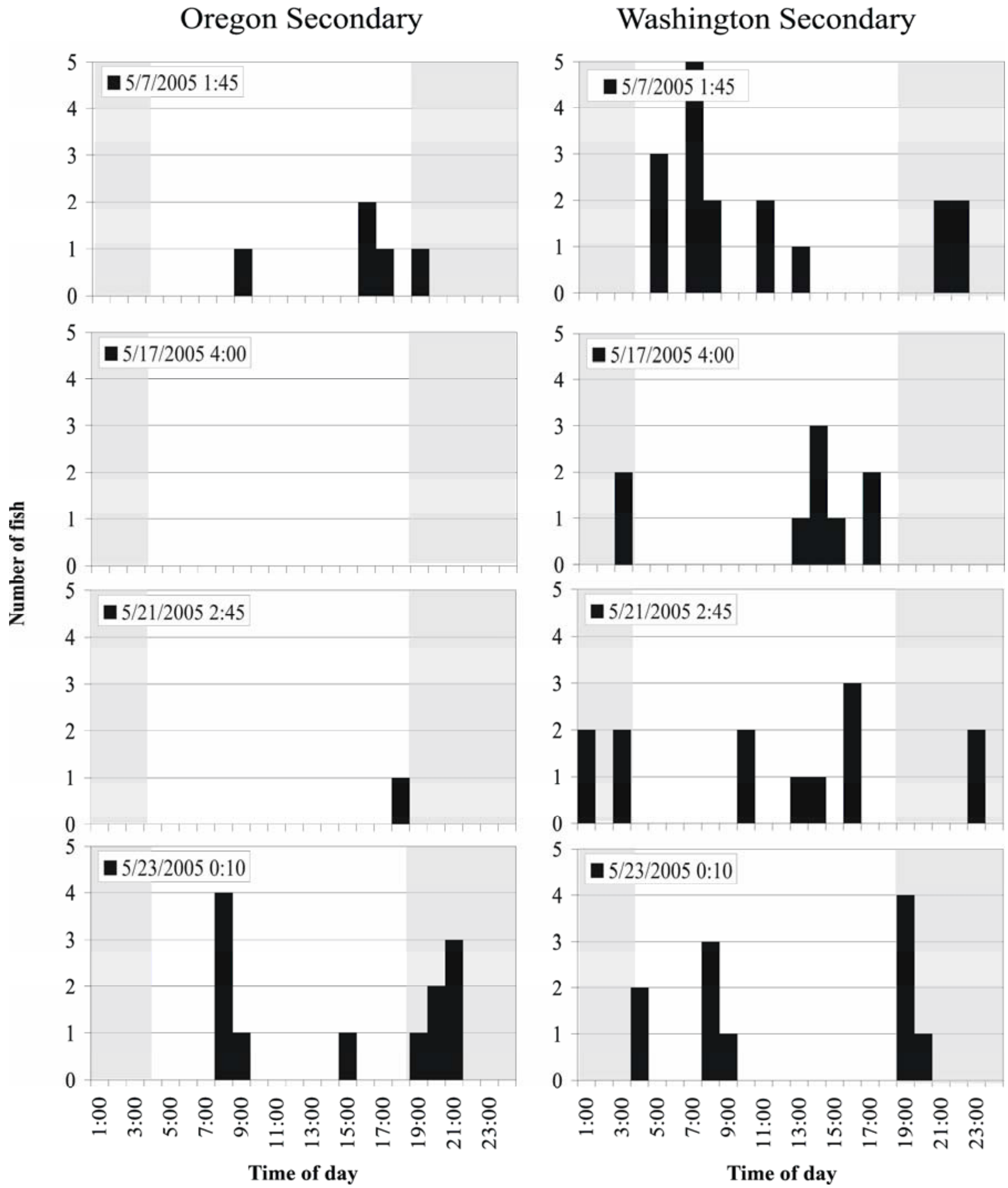

Figure 3.9. Time of Arrival of Steelhead Implanted with Microacoustic Transmitters and Released at Skamania Landing, then Detected on the Oregon Secondary Array near Clatsop Spit (left) and the Washington Secondary Array near the North Jetty (right) at the Mouth of the Columbia River. The time and date when implanted fish were released is shown in the figure legend. Shaded areas represent periods of darkness.

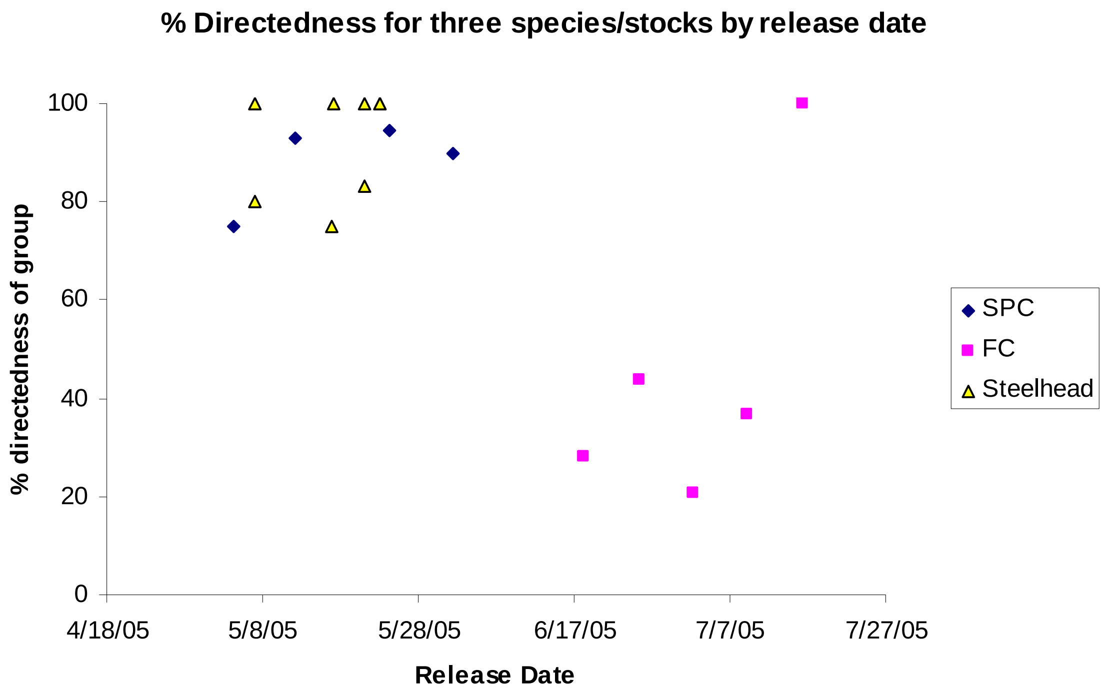

Figure 3.10. Movement Pattern Summary Information for Yearling (SPC) and Subyearling (FC) Chinook Salmon and Steelhead Implanted with Microacoustic Transmitters during Spring and Summer 2005. Percent directedness was determined by the pattern of detections on the primary and secondary arrays near the mouth of the Columbia River. Specific methods are detailed in Section 2.3.

Table 3.2. Mean Residence Time (minutes) and Travel Time (days) of Steelhead Released at Astoria (STL-AST) and Skamania Landing (STL-SKA), and Yearling (SPC) and Subyearling (FC) Chinook Salmon Released near Bonneville Dam during Different Discharge Conditions in Spring and Summer 2005

			Residence time (minutes)				Travel Time (days)			
Start Date	End date	Condition	STL-AST	STL-SKA	SPC	FC	STL-AST	STL-SKA	SPC	FC
26-Apr	19-May	Rising	15.6	16.3	24.4	ND	0.2	3.4	4.0	ND
20-May	17-Jun	Falling	10.2	8.7	18.0	ND	0.3	2.9	2.9	ND
18-Jun	17-Aug	Stable/slow decline	ND	ND	ND	159.7	ND	ND	ND	4.8

The largest number of detections tends to occur on ebbing tides and the first few (i.e., ‘fastest’) fish from each group typically pass on an ebbing tide. Groups of yearling Chinook salmon implanted with microacoustic transmitters generally passed by the secondary array at the MCR within a fairly short period (2 to 4 days). Figure 3.12 shows the number of detections of yearling Chinook salmon versus date and tidal stage. With the exception of the first release group (May 4), release groups of yearling Chinook salmon generally passed the secondary array within relatively few tidal exchanges. Figure 3.13 shows a more detailed look at the timing of detections of two of the release groups of yearling Chinook salmon on the secondary array.

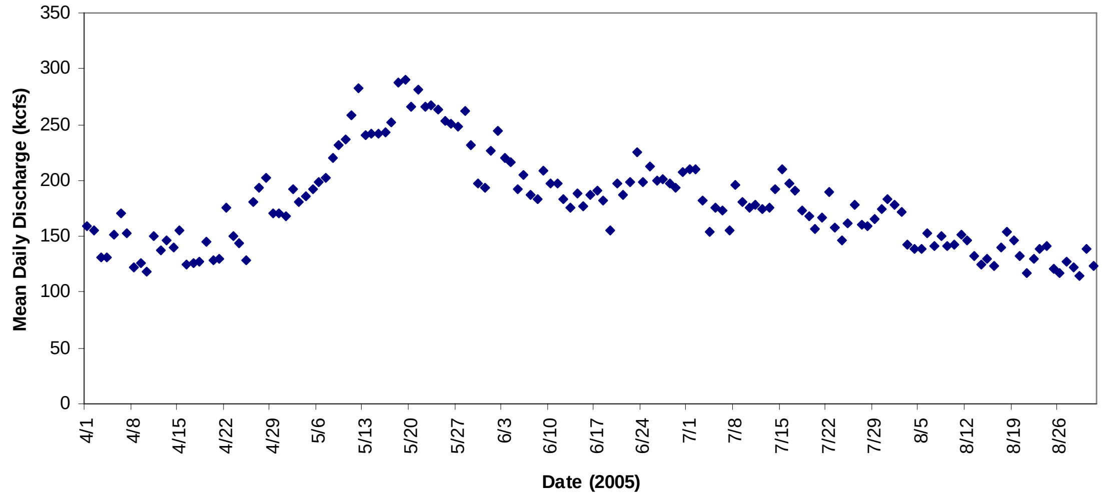

Figure 3.11. Mean Daily Discharge (thousand cubic feet per second) of the Columbia River at Bonneville Dam in Spring and Summer 2005

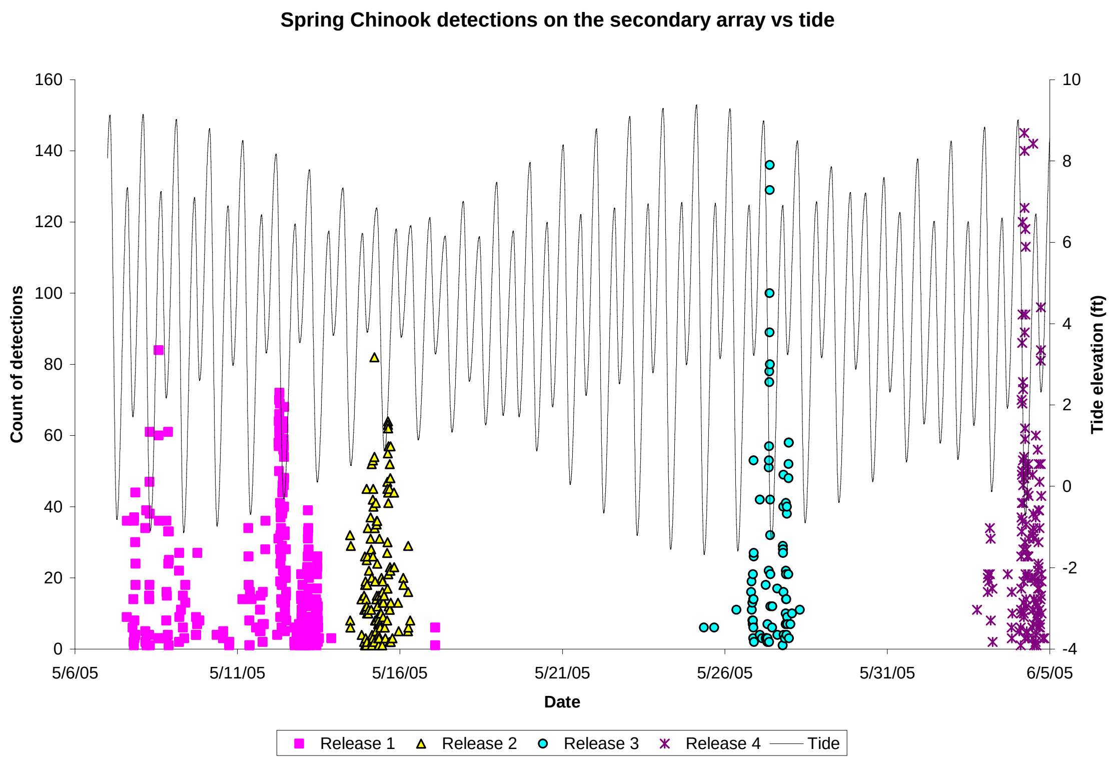

Figure 3.12. Count of Individual Detections of Implanted Yearling Chinook Salmon on the Secondary Array and Tidal Stage at the Mouth of the Columbia River during Spring 2005 versus Date

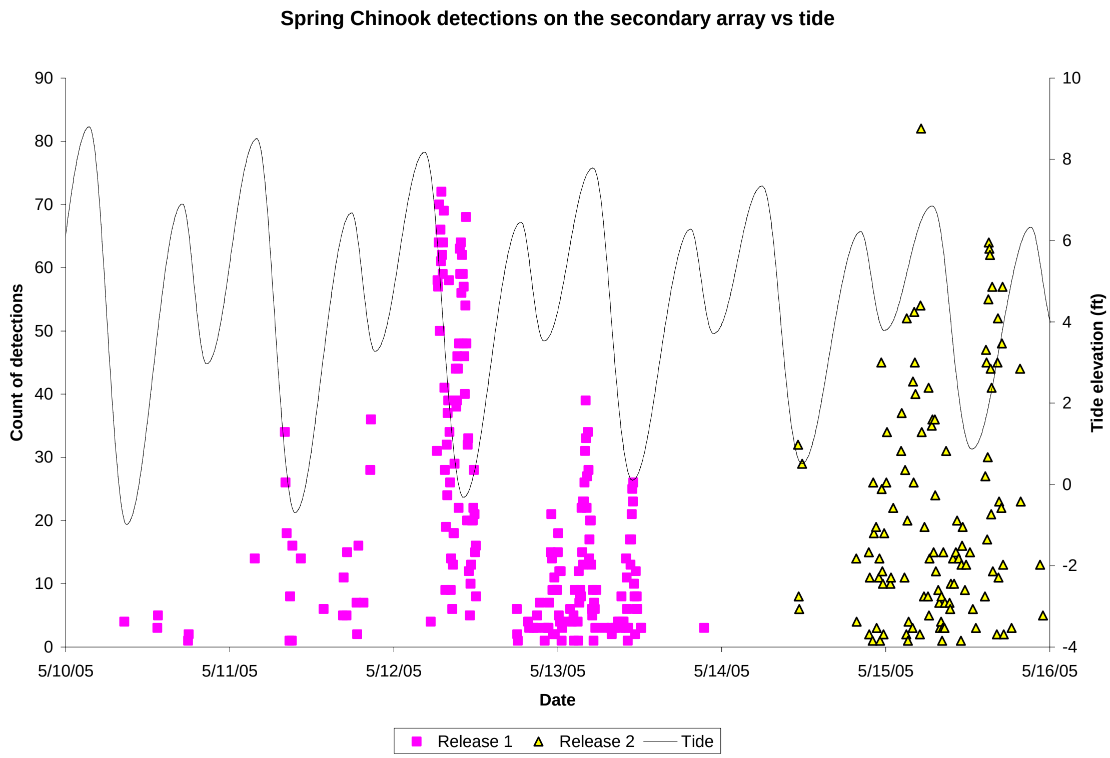

Figure 3.13. Count of Individual Detections of Yearling Chinook Salmon from the First (May 4) and Second (May 12) Releases on the Secondary Array and Tidal Stage at the Mouth of the Columbia River during Spring 2005 versus Date

Subyearling Chinook salmon are also generally detected in larger numbers on ebbing tides. One interesting thing in the timing of arrival of the subyearling Chinook salmon is that more hits are detected for a longer period after the bulk of a release group passes (Figure 3.14). It is possible that some of the detections that occur much later than the group's mean arrival date are due to detections of transmitters in subyearling Chinook salmon that had been eaten by predators that regularly visited the areas around our detection arrays. Subyearling Chinook salmon also tended to pass the secondary array during ebb tides, however, a particular release group might pass over the course of more consecutive days than the yearling Chinook salmon (Figure 3.15).

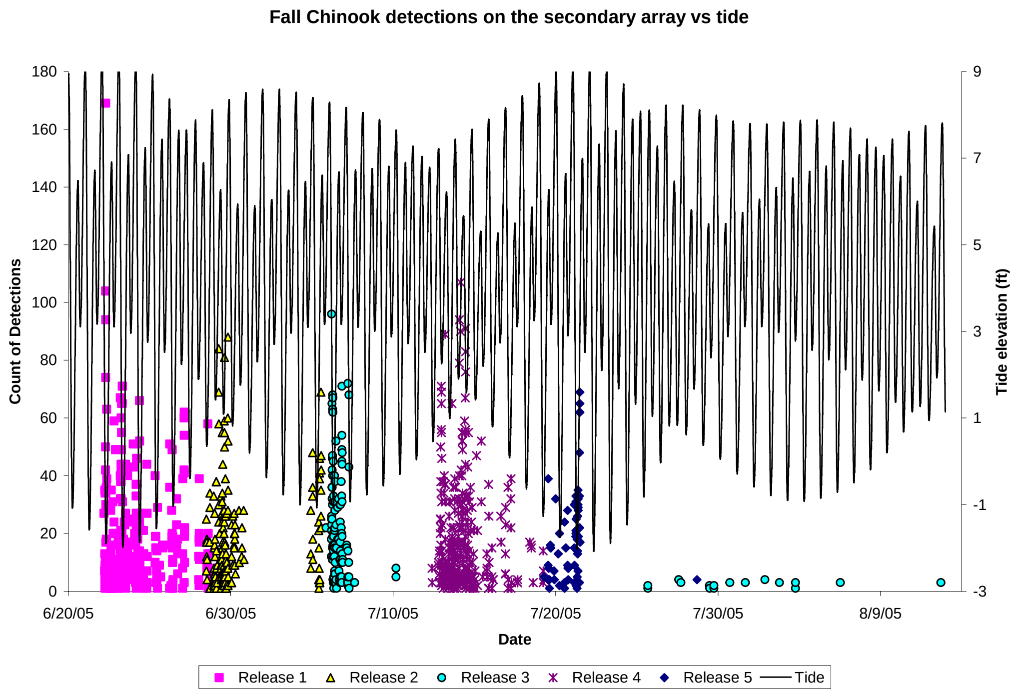

Figure 3.14. Count of Individual Detections of Implanted Subyearling Chinook Salmon on the Secondary Array and Tidal Stage at the Mouth of the Columbia River during Spring 2005 versus Date

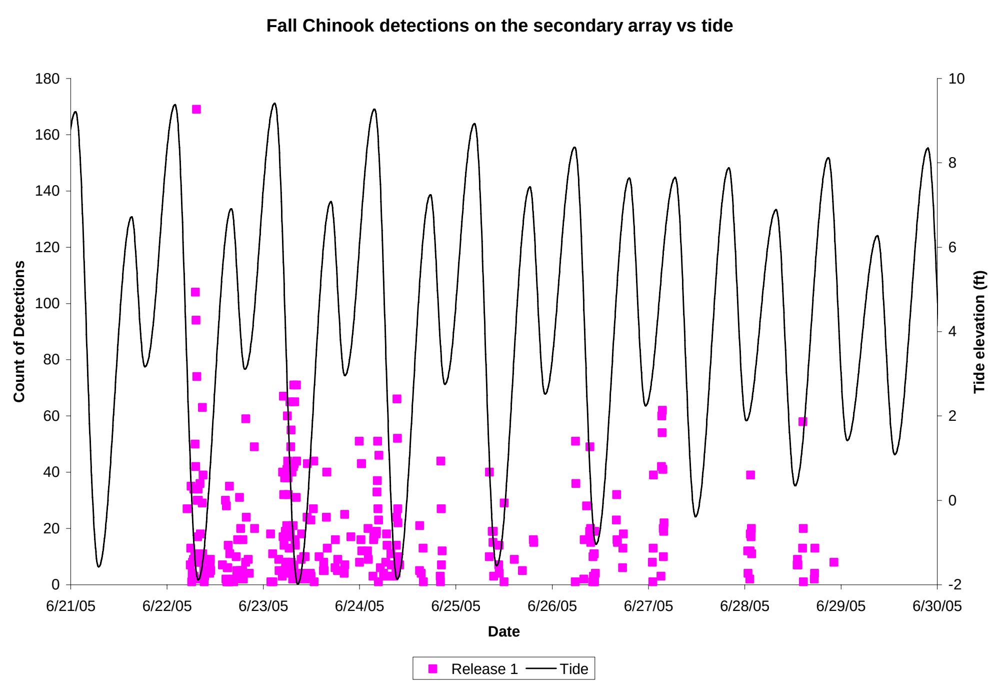

Figure 3.15. Count of Individual Detections of the First Release (June 18) of Implanted Subyearling Chinook Salmon on the Secondary Array and Tidal Stage at the Mouth of the Columbia River during Spring 2005 versus Date

4.0 Discussion

Juvenile salmon emigrating from the Columbia River into the Pacific Ocean must necessarily pass through the MCR where the USACE performs channel maintenance (dredging) and jetty repair. The manner in which these juvenile salmonids interact with the environment in this area will influence the probability that these fish may be impacted by work activities related to channel maintenance and/or jetty repair. If emigrating fish spend a long period of time adjusting to the sea water, for example, and remain in close proximity of the North Jetty, then repair activities taking place on the jetty and waters surrounding the jetty might be expected to influence the residence time or movement patterns of these migrating fish. If, on the other hand, these fish spend little time in the MCR area and exhibit clearly directed movements from the fresh to sea water environments, impacts from maintenance and repair activities should be minimal.

In 2005, over 3,000 yearling and subyearling Chinook salmon and steelhead implanted with micro-acoustic transmitters were released in the lower Columbia River and subsequently detected on receiving arrays placed at river mile 5.6 and on the Columbia River Bar at river mile 2.0. Yearling Chinook salmon and steelhead tended to arrive at the MCR within only a few days of release below Bonneville Dam (~145 mi upstream). Upon reaching the MCR area, these yearling Chinook salmon and steelhead usually moved quickly out to sea. The yearling Chinook salmon and steelhead were typically detected on the primary array and then shortly thereafter (usually within a few hours) on the secondary array, which was located 3.6 mi downstream on the Columbia River Bar. These fish were seldom detected on multiple receivers within the secondary array, indicating they passed directly from the river environment into the sea. Subyearling Chinook salmon implanted with the microacoustic transmitters, however, did not follow the same detection patterns as the older and larger smolts. Subyearling Chinook salmon took significantly longer to get to, and spent more time around, the MCR area and their movements were less directed than those of yearling fish. Subyearling Chinook salmon residence times within the detection areas at the MCR (estimated ~70 ac) were about 15 to 20 times longer than the larger yearling Chinook salmon and steelhead.

Fish that emigrate quickly from the river and into the sea would be expected to be less susceptible to impacts from channel maintenance and jetty repairs. The depth of migration may also influence susceptibility to impacts resulting from these maintenance activities. The steelhead are thought to migrate nearer the surface than Chinook salmon, therefore steelhead might be more susceptible to impacts from surface-oriented disturbances related to channel maintenance or jetty repair. Past research has shown that avian predation rates are generally highest on steelhead and lower, but still significant, on yearling Chinook salmon (Collis et al. 2001; Ryan et al. 2003). However, data from this and other studies (Schreck et al. 2005) show that steelhead tend to migrate near the navigation channel and move from fresh to salt water rather rapidly. This rapid emigration rate and location in an area where surface disturbances are minimal during channel maintenance and jetty repair would be expected to minimize the probability that emigrating steelhead would be exposed to these activities for more than a few minutes. Similarly, yearling Chinook salmon detected in this study showed directed movements and are thought to migrate deeper in the water column than steelhead (Collis et al. 2001; Ryan et al. 2003). The combination of the yearling Chinook salmon's directed emigration, rapid travel times, and deeper position in the water column would be expected to result in a low probability of impact due to channel maintenance or jetty repair activities.

Subyearling Chinook salmon movements were less directed and their residence times were longer than for yearling Chinook salmon and steelhead. The residence times as measured in the current study were on the order of a few hours. However, the overall area considered in these calculations was ~200 yds of river length and nearly the width of the river between the jetties. The estimated area of detection was about 70 ac. The area of the MCR from the jetty ends to Cape Disappointment (approximately the lower 2 river miles) is about 2,600 ac. Even if the area that was sampled was only 2.7 % of the MCR area that could be influenced by channel maintenance or jetty repair activities, then residence time could be extrapolated from ~3 hours to ~110 hours (4.6 days) in the area that could possibly be affected. Of course, this assumes that the residence times in the examined areas were representative of the larger area. This extrapolated, albeit crudely, estimate of residence time of 4.6 days in the larger MCR area is very similar to the overall average of travel time (average = 4.49 days) for subyearling Chinook salmon migrating from near Bonneville Dam to the MCR area, a distance of ~140 river miles.

There is a reasonably large body of published literature on the effects of dredging and construction activities on the reproductive and early rearing success of anadromous salmonids (e.g., Beechie et al. 1994; Arnekleiv and Roenning 1997; Harvey and Lisle 1999). There is substantially less on the potential effects of dredging on emigrating salmonid smolts. One exception is a report by Kehoe (1983), which showed that bioassays with juvenile coho salmon (*O. kisutch*) exposed to simulated suspended sediment loads contaminated with heavy metals for 9 days did not impair the osmoregulatory ability of the test fish. In light of these results and with mean exposure times expected to be more on the order of hours to a maximum of a few days in the Columbia River mouth, it is expected that the impacts of channel maintenance on emigrating smolts would be negligible. Further, the sediment in the navigation channel at the MCR has shown very low heavy metal levels, primarily due to the fact that it is typically sand with few fines as it is dredged regularly (USACE 2000). For example, in June 1990, 98.6% of the sediment samples from this area were comprised of sand and 1.4% were fines with a mean grain size of 0.26 mm. The heavy metals have typically been found in the fines portion of these types of sediment samples. Finally, construction activities that occur along the jetties would be expected to have little if any impact on the emigrating salmonids, as the fish are either moving out rather rapidly, as in the case of the yearling Chinook salmon and steelhead, or are not in the area for much more than 1 day. In the Willamette River near Portland, Oregon, Ward et al. (1994) used radio telemetry to track migrating juvenile salmonids and found that development activities along the waterfront did not affect their behavior, migration rate, or spatial distribution.

Direct effects of juvenile salmonids being entrained by a dredge would be expected to result in a high mortality rate (Dutta 1976). However, surveys of fishes entrained in dredging activities at the MCR by Pearson et al. (2005) found that no salmonids were entrained in the 643 samples from 214 loads of dredge sediment sampled during the summer of 2002. In the MCR and in nearby Gray’s Harbor, the majority of fish entrained by dredges were sand lance (*Ammodytes hexapterus*) and other benthic species such as Pacific staghorn sculpin (*Leptocottus armatus*) and Pacific sanddab (*Citharichthys sordidus*) (McGraw and Armstrong 1990; Pearson et al. 2005). Only one salmonid was detected in their entrainment samples in the Gray’s Harbor study and it was a chum salmon (*O. keta*) fry.

Based on the results of the current study and a review of the relevant literature, it appears unlikely that dredging and jetty repair activities at the MCR in the June to September time period would impact emigrating juvenile salmon and steelhead smolts.

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