DOWNSTREAM FISH PASSAGE ABOVE AND BELOW DAMS IN THE MIDDLE FORK WILLAMETTE RIVER: A MULTI-YEAR SUMMARY

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For

U.S. Army Corps of Engineers
Portland District

2010
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Preface

This report summarizes results of research activities conducted from 2003-2010 in the Middle Fork Willamette River basin. The fish collection and enumeration projects were undertaken to aid in the management and recovery of spring Chinook salmon (Oncorhynchus tshawytscha).

Peer-reviewed publication is an important priority for the staff at our respective organizations because publication provides our results to a wide audience and ensures that the work meets high scientific standards. Therefore, this report was prepared with the intention that one or more manuscripts would eventually be submitted to fisheries journals. Since this writing, two chapters have been accepted at journals and we refer the reader to those papers for the definitive references. This report includes supplementary material that was not included in the peer-reviewed versions.

Citation 1. Pending.

Citation 2. Pending.

Acknowledgements

This project was funded by the U.S. Army Corps of Engineers and many people contributed to the work. We thank C. Murphy and C. Lewellen (USACE Lookout Point office) for field help and project coordination; D. Griffith (USACE) for coordinating the joint reporting effort; the staff at the Willamette Hatchery (ODFW) for providing hatchery salmon used in trap efficiency tests; the General Maintenance and Powerhouse Staff at the Willamette Valley Project (USACE); the South Willamette Watershed district staff (ODFW); the Willamette National Forest staff (USFS); and the NOAA and ODFW staff that facilitated permitting.
Executive summary

Chapter 1: Monitoring downstream fish passage in the Middle Fork Willamette River and estimating juvenile Chinook salmon population size

Rotary screw traps were used to evaluate downstream fish passage at five sites in the Middle Fork Willamette River from 2003-2010. Three sites were downstream from dams (Lookout Point, Hills Creek, and Fall Creek dams) and two were upstream from reservoirs (North Fork Middle Fork and Fall Creek). The target population was ESA-listed juvenile spring Chinook salmon, but samples included ~12 native and ~7 non-native species.

Traps were operated for approximately 2,950 days across sites and years but deployments were opportunistic and primarily coincided with known Chinook salmon movements. A small number of screw trap efficiency tests were conducted. Efficiency varied among sites and was very low for dead Chinook salmon downstream from dams. Estimates of juvenile Chinook salmon population size varied widely among sites and years. These estimates were sensitive to assumptions regarding live and dead salmon capture efficiency and results were qualitative.

Chapter 2: Downstream fish passage in the Middle Fork Willamette River: timing, abundance, and dam-related mortality

More than 195,000 individual fish were collected across study sites and years. Samples collected upstream from reservoirs were almost exclusively native species, while those downstream from dams were often dominated by non-native species. Fish trapping rates were strongly seasonal downstream from dams where the highest passage was in November-January for most species, including Chinook salmon. High dam passage rates coincided with relatively high river discharge (and some regulating outlet and surface spill) as well as low reservoir elevations. Fish passage at dams significantly increased as reservoir elevation dropped, presumably because fish had easier access to regulating outlet and turbine passage routes. Above reservoirs, collection rates were highest in late winter through mid-summer, coincident with juvenile Chinook salmon emigration (mostly February-May). Few fish of any species were trapped at above-reservoir sites from September-January.

With all years and fish species combined, dead fish made up ≤2% of the Fall Creek and North Fork Middle Fork samples upstream from reservoirs. By comparison, minimum total mortality was 36% below Fall Creek Dam, 39% below Hills Creek Dam, and 69% below Lookout Point Dam. Mortality estimates were strongly affected by relative species abundance at each site. In general, mortality was higher for non-native species, and especially centrarchids (i.e., bluegill, crappie, and largemouth bass). Among-species mortality differences were likely a function of morphology or physiology, passage timing, and behavior. The multi-species mortality results suggest that site-specific features at each project affected mortality risks. Operational modifications, including seasonal reductions in reservoir elevation, may facilitate fish passage at the study dams.
Chapter 3: Effects of high-head dams on emigration timing and mortality of juvenile spring Chinook salmon in the Middle Fork Willamette River

A total of 13,365 juvenile Chinook salmon were trapped and measured across all sites and years, including 10,864 above reservoirs and 2,501 below dams. Salmon trapped above reservoirs were predominantly subyearlings plus small numbers of yearlings. Those trapped below dams included a variety of size and age classes. Fork length and migration timing data provided evidence for at least two – and perhaps as many as four – Chinook salmon age classes in the aggregate sample. Likely life history types included subyearling emigration, stream resident rearing followed by yearling emigration, reservoir rearing with yearling emigration, and reservoir residualizing with delayed emigration. Many of the largest salmon (> 25 cm) were collected below Lookout Point Dam and we hypothesize that some of these fish spent a year each in Hills Creek and Lookout Point reservoirs.

Annual Chinook salmon mortality estimates downstream from dams ranged from 8-59% and differed significantly among sites and years. All estimates were likely minimums because dead salmon capture efficiency was very low in several tests. At all sites, mortality was significantly higher for larger salmon, probably because they were more susceptible to injuries from shear stress, turbine blade strikes, and blunt force trauma. After correcting for salmon size effects, mortality was significantly associated with environmental (i.e., discharge) and operational conditions at dams, including regulating outlet spill, surface spill (Lookout Point only), and reservoir elevation. Total salmon mortality estimates (~14% below Fall Creek, ~25% below Lookout Point, and ~53% below Hills Creek) indicate that there were important differences in passage hazards among projects. These almost certainly included route-specific effects that were beyond the screw trap study scope.

The combined Chinook salmon life history and mortality data highlight several important issues related to effective management and recovery of these populations. Different life history types may contribute disproportionately to adult returns and a better understanding of the population-level effects of each phenotype is needed. High salmon growth rates in reservoirs may provide juvenile survival advantages, for example, but these benefits must be weighed against increased risk of dam passage mortality for larger smolts. The results also suggest that seasonal modifications to operations of the dams and reservoirs in the Middle Fork have the potential to improve downstream passage rates and survival of juvenile Chinook salmon.
CHAPTER 1

MONITORING DOWNSTREAM FISH PASSAGE IN THE MIDDLE FORK WILLAMETTE RIVER AND ESTIMATING JUVENILE CHINOOK SALMON POPULATION SIZE

Introduction

The U.S. Army Corps of Engineers (USACE) operates thirteen dams and reservoirs in the Willamette River basin, Oregon, primarily for flood risk management. The dams typically maintain reservoirs at a minimum flood control elevation in December and January, fill to a maximum elevation from February to May, maintain the maximum until September, and are drawn down back down to minimum levels by December (Sullivan and Rounds 2004; Rounds 2010).

The Middle Fork Willamette River drains the southern-most portion of the Willamette basin. Construction of three Middle Fork dams (Lookout Point, Dexter, and Hills Creek) from 1954 to 1961 inundated 43 km (27 mi) of the main stem and blocked access to 156 km (97 mi) of riverine habitats (Connolly et al. 1992; NMFS 2008). Construction of Fall Creek Dam in 1966 blocked access to additional habitat in the large Fall Creek sub-basin. The dams blocked or restricted migrations of native resident and anadromous fish species. In addition, a variety of non-native species have been introduced to riverine and reservoir habitats in the basin over the last several decades (Friesen 2005; LaVigne et al. 2008).

Based on pre-dam surveys, the area upstream from the Middle Fork and Fall Creek dams included nearly 100% of the historic spring Chinook salmon (*Oncorhynchus tshawytscha*) spawning habitat in the Middle Fork basin (Mattson 1948; Connolly et al. 1992; NMFS 2008). After dam construction, natural spring Chinook salmon production was confined to marginal spawning and rearing areas downstream from Fall Creek and Dexter dams. Spawning has been documented at these sites, but successful hatching and rearing has been very limited. Egg mortality has been near 100% and surviving fry emerge prematurely because of warm water discharged from the dams in fall and winter (Sullivan and Rounds 2004). Sampling below dams has revealed little or no natural production. Similar dam-related effects in other Willamette basin tributaries, plus degraded main stem habitat, overharvest, and other factors resulted in spring Chinook salmon and winter steelhead (*O. mykiss*) population declines and subsequent listing under the U.S. Endangered Species Act (Federal Register 1999a, 1999b).

In the 1990s, the Oregon Department of Fish and Wildlife (ODFW) began outplanting hatchery spring Chinook salmon upstream from dams on some Willamette River tributaries to provide a source of marine-derived nutrients, a prey base for native resident fish, and later to supplement natural Chinook salmon production (Beidler and Knapp 2005; McLaughlin et al. 2008; Keefer et al. 2010). Producing smolts was not originally an outplant program objective.
because there are limited or no downstream migrant passage facilities at the dams. Downstream passage routes at most of the Willamette Project dams are restricted to turbines, low-elevation regulating outlets, or (rarely) over high-head spillways. Each of these routes was assumed to present high fish mortality risks (e.g., Homolka and Downey 1991; Downey and Smith 1992). However, field observations in 1994-1997 indicated that some juvenile Chinook salmon produced in the outplant program had passed downstream successfully. A subsequent study at Cougar Dam on the South Fork McKenzie River indicated juvenile Chinook salmon passage mortality of 7% and 32% for turbine and regulating outlet routes, respectively (Taylor 2000). Downstream juvenile Chinook salmon passage has since been identified at several projects, though the mechanisms affecting passage and survival are not well understood at most dams.

In this study, screw traps were deployed at several sites in the Middle Fork Willamette River basin to survey downstream movements of native and non-native fishes, with spring Chinook salmon being the focal species. Traps were operated downstream from Lookout Point, Fall Creek, and Hills Creek dams, in Fall Creek upstream from the reservoir, and in the North Fork Middle Fork River. The North Fork enters the main stem Middle Fork downstream from Hills Creek reservoir (Figure 1.1) and is one of the main adult salmon outplant locations. The primary study objectives included:

1. estimating population size of emigrating juvenile spring Chinook salmon at each collection site (Chapter 1).

2. enumerating all species collected (Chapter 2);

3. describing the timing of downstream movement for all species (Chapter 2);

4. estimating mortality associated with dam passage for all species (Chapter 2);

5. evaluating life history characteristics of emigrating juvenile spring Chinook salmon (Chapter 3);

6. examining factors affecting spring Chinook salmon mortality associated with dam passage (Chapter 3);

6. estimating population size of emigrating juvenile spring Chinook salmon at each collection site (Chapter 4).

Methods

Trap deployment

Between 2003 and 2010, USACE personnel monitored downstream fish passage at five Middle Fork sites, including three sites downstream from dams and two sites in unimpounded upstream reaches (Figure 1.1). Fish were collected using 2.44 m (8 ft) rotary screw traps (EG Solutions, Corvallis, OR). Each trap was tethered to a channel-spanning wire rope and centered
within the thalweg. Traps located downstream from Hills Creek Dam (2003-2004), Lookout Point Dam (2007-2010), and Fall Creek Dam (2006-2009) were located 160-240 m downstream from dams. Monitoring at these sites occurred during a wide range of regulated discharge events, mostly as water passed through the powerhouse and regulating outlets but occasionally including water passed over the surface spillway (Lookout Point only). Traps located in unimpounded reaches above Fall Creek reservoir (2005-2008) and in the North Fork Middle Fork (2007-2008) were operated under a range of run-of-river conditions. Each study site had a single screw trap except two traps were operated at Lookout Point Dam starting in fall of 2009.

![Map of the Middle Fork Willamette River basin showing dam locations and sites where rotary screw traps were deployed (gray stars). Inset shows the location of the Middle Fork in the Willamette River basin.](image-url)
Fish collection

Traps were checked daily or on alternate days during times when fish moving downstream were relatively abundant and were checked less frequently (i.e., weekly) when few or no fish were moving. Traps were accessed by wading or using inflatable kayaks. Nylon mesh dipnets were used to remove fish from screw trap live boxes. Native fish were placed in a 19 L (5 gal) bucket filled with 15 L (4 gal) of river water and 2-3 mL of an anesthetic solution of 9 parts ethanol to one part clove leaf oil (Glorybee Foods, Inc., Eugene, OR); non-natives were not anesthetized. Fish of all species were enumerated. Fork length data were collected for all unmarked Chinook salmon (i.e., those without hatchery clips or other marks) and most large (i.e., non-juvenile) non-native fish. Marked Chinook salmon collected below Hills Creek Dam were also measured. Chinook salmon and other native fish were then transferred to and recovered in a 19 L bucket filled with fresh river water. All fish were released back into the river after recovery.

Collection efficiency estimates

Screw trap capture efficiency downstream from dams was estimated in a series of tests using juvenile hatchery Chinook salmon from Willamette Hatchery, and juvenile largemouth bass (Micropterus salmoides), or juvenile black crappie (Pomoxis nigromaculatus). At Fall Creek Dam in 2006, 200-400 live Chinook salmon, juvenile largemouth bass, and/or juvenile black crappie were released into the primary stilling basin on single days in February, March, November, and December. At Lookout Point Dam on seven days in 2009-2010, tests were conducted using 8,892 live and 8,800 dead juvenile hatchery Chinook salmon. Salmon were transported from the hatchery in an aerated 1,136 L (300 gal) portable tank with approximately 150 mL (5 oz) of NovAqua (Kordon LLC, Hayward, CA) to reduce stress. A subsample was euthanized using a strong mixture of MS-222. Test fish were marked using a variety of techniques, including caudal clipping and colored water dyes, with different marks on different test dates. These marks helped differentiate efficiency test fish from hatchery salmon released by ODFW into the Lookout Point reservoir. All test fish were released above Lookout Point turbine outwashes around 1700 hrs when turbines were on. Dead test fish were dumped over the edge into a single operating turbine outlet or distributed evenly across turbines when multiple units were operating. Live test fish were released in the same locations but were lowered using a rope system and released approximately 0.5 m over the water surface. A similar efficiency test was conducted at Fall Creek Dam on six days in 2009-2010 using 7,500 live and 6,250 dead juvenile hatchery Chinook salmon released into the regulating outlet channel. In all tests, fish fork lengths ranged from 9-15 cm for juvenile Chinook salmon and were < 13 cm for largemouth bass and black crappie.

Predation from gulls (Larus spp.), bald eagles (Haliaeetus leucocephalus), osprey (Pandion haliaetus), and double-crested cormorants (Phalacrocorax auritus) was observed upon release of test fish at Lookout Point Dam. However, predation rates were considered low and unlikely to significantly affect efficiency results. As the study progressed, it was determined that river otters (Lontra canadensis) and cormorants could predate on fish inside the rotary screw trap liveboxes. It is unknown whether these predators preferred live or dead fish or how large an effect the predation had on efficiency estimates.
Capture efficiency tests were also conducted at the screw traps in unimpounded reaches, using live hatchery Chinook salmon fry. In 2005, 528 salmon were released approximately 50-100 m upstream from the Fall Creek screw trap. In 2007, 830 salmon were released approximately 400 m upstream from the North Fork Middle Fork River screw trap.

Capture efficiencies at all sites were calculated by dividing the number of fish recaptured in screw traps by the number of fish released. The Lookout Point tests were run during several discharge configurations that lasted for a minimum of 12 h following fish release to ensure that all test fish had passed the trap site. Most recapture events occurred on the day of release, though some fish were trapped up to several days post release.

**Chinook salmon population estimates**

Trap efficiency tests were conducted only intermittently and with single size/age classes of all species. In addition, tests were conducted over a narrow range of river discharge and dam operations at each site. For these reasons, using trap efficiency estimates to generate population estimates of the populations passing the screw trap sites should be done with caution.

We used two basic approaches to estimate population. The first was based on the regression model relationships between discharge and live fish trap efficiency at each site (see Figure 1.4). This modeling approach had two potentially important limitations: 1) dead fish capture efficiencies were excluded because they were considered unreliable; and 2) it was unknown if the regression model was appropriate for discharge or other operational conditions beyond those encountered during tests. The second approach was to estimate population size using capture efficiencies that ranged from 0.25-3.00% below Fall Creek and Lookout Point dams, 2.00-14.00% in Fall Creek, and 0.50-1.00% in the North Fork. These values were selected to capture the range of point estimates were intended to provide a range of reasonable values.

**Results and Discussion**

**Trap operations**

Screw traps were operated for approximately 2,950 days at the five study sites from 2003-2010 (Figure 1.2). Days of operation, with all years combined, were 521 d at the upstream Fall Creek site, 889 d at the site downstream from Fall Creek Dam, 357 d in the North Fork Middle Fork, 469 d downstream from Hills Creek Dam, and 715 d downstream from Lookout Point Dam. The total at Lookout Point Dam included 136 d when two traps were operated in 2009-2010.
Screw trap operations were not equally distributed across months at any study site (Figure 1.3). The North Fork and upper Fall Creek traps were primarily run in late winter and spring. The largest trapping effort at Fall Creek Dam was in October-January plus April, whereas low flow precluded trapping occurred in July. Trapping at Lookout Point Dam was concentrated from October-March, with limited effort in mid-summer months. In contrast, trapping was relatively evenly distributed across months at Hills Creek Dam, though with an emphasis in September-December (Figure 1.3).
In general, the timing of screw trap operations was selected to maximize collection of juvenile spring Chinook salmon, and there was less effort to collect other species. Deployments were also constricted by trap and personnel availability and high or low flow conditions. Sampling was not constant within years and collection years differed among study sites. Therefore, results presented in Chapters 2-4 should be interpreted cautiously. For example, direct comparisons of collected samples among sites is not recommended because environmental conditions differed among years, year-class strength likely differed among years (i.e., for Chinook salmon), and emigration timing did not consistently coincide with dates of trap operation. In most cases, comparisons among sites should be qualitative. Where appropriate in subsequent chapters, sample analyses have been weighted to account for trapping effort.

**Collection efficiency and Chinook salmon population estimates**

*Fall Creek Dam* – In 2006, two days of screw trap tests using live juvenile Chinook salmon released at Fall Creek Dam had efficiency estimates of 1.75% and 0.00% (Table 1.1.). No dead Chinook salmon were trapped in any Fall Creek Dam test. These results were consistent with efficiency tests in 2009-2010 that had larger sample sizes and more release dates. Live Chinook salmon capture efficiencies in the 2009-2010 tests ranged from 0.00-2.40% (Table 1.1). In a simple linear regression, trap efficiency at Fall Creek Dam was significantly ($P = 0.011$) positively correlated with total project outflow. Capture rates were near zero when outflow was $< 10 \text{ m}^3\text{s}^{-1}$ and increased as outflow increased (Figure 1.4). This relationship may have reflected higher water velocity in the constricted channel downstream from the dam at higher discharge, and perhaps reduced trap avoidance by salmon.
Table 1.1. Results of screw trap efficiency tests conducted downstream from Fall Creek Dam (FCD) and Lookout Point Dam (LPD) in 2006 and 2009-2010.

<table>
<thead>
<tr>
<th>Dam</th>
<th>Year</th>
<th>Month</th>
<th>discharge</th>
<th>Species</th>
<th>n</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCD</td>
<td>2006</td>
<td>February</td>
<td>57 m³ s⁻¹</td>
<td>Chinook salmon</td>
<td>400</td>
<td>1.75%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March</td>
<td>~9 m³ s⁻¹</td>
<td>Chinook salmon</td>
<td>287</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>November</td>
<td>~34 m³ s⁻¹</td>
<td>Largemouth bass/Black crappie</td>
<td>200</td>
<td>7.00%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>December</td>
<td>32 m³ s⁻¹</td>
<td>Black crappie</td>
<td>300</td>
<td>6.00%</td>
</tr>
<tr>
<td>FCD</td>
<td>2009</td>
<td>November</td>
<td>19 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>1.28%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>28 m³ s⁻¹</td>
<td>Chinook salmon (dead)</td>
<td>1,250</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>1.36%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>December</td>
<td>6 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>0.08%</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>January</td>
<td>49 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>1.76%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>0.00%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chinook salmon (dead)</td>
<td>1,250</td>
<td>0.00%</td>
</tr>
<tr>
<td>LPD</td>
<td>2009</td>
<td>November</td>
<td>112 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>1.20%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>108 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,337</td>
<td>1.87%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>December</td>
<td>100 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,300</td>
<td>0.08%</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>January</td>
<td>164 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>1.04%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>53 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>83 m³ s⁻¹</td>
<td>Chinook salmon (live)</td>
<td>1,250</td>
<td>0.72%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chinook salmon (dead)</td>
<td>1,250</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

Using the regression model of capture efficiency for live Chinook salmon below Fall Creek Dam (Figure 1.4), estimated population size during trap operations ranged from 9,960 in 2008 to 17,321 in 2006 (Table 1.2). These were probable underestimates in all years because dead salmon trap efficiencies were near zero in all tests. Using an estimated capture efficiency of 0.25% for live and dead salmon combined the population estimates ranged from 67,200 to 159,200 fish annually. These are likely maximums during trap operation periods. Additional estimates based on projected live+dead capture efficiencies are provided in Table 1.2.

Trap efficiency estimates for the largemouth bass and black crappie released at Fall Creek Dam in November and December 2006 were 6.00% and 7.00%, respectively (Table 1.1). Total outflow during these tests was 32–34 m³ s⁻¹. It was not clear why these species were trapped at higher rates than juvenile Chinook salmon. However, among-species differences in screw trap
capture efficiency are common (e.g., Kennen et al. 1994; Thedinga et al. 1994). It is possible that behavioral differences, such as more passive downstream movement by bass and crappie or surface orientation, affected trapping likelihood.

Figure 1.4. Screw trap collection efficiency for live hatchery spring Chinook salmon downstream from Fall Creek (●) and Lookout Point (○) dams in relation to total outflow (m$^3$ s$^{-1}$) in 2009-2010. Each point represents a single release date. Regression lines are natural-log (ln) scale: Fall Creek Dam trap $r^2 = 0.83, P = 0.011$; Lookout Point Dam trap $r^2 = 0.62, P = 0.036$. Squares (■) represent estimates from live salmon released on two dates at Fall Creek Dam in 2006 (not included in regression).

**Lookout Point Dam** – Results from Chinook salmon trap efficiency tests at Lookout Point Dam in 2009-2010 were consistent with results at Fall Creek Dam. Efficiencies ranged from 0.00% to 1.87% for live salmon and from 0.00–0.08% for dead salmon (Table 1.1). Live salmon trap efficiency was significantly positively correlated ($P = 0.036$) with total discharge, with very low efficiency (< 0.10%) at the lowest discharge levels (Figure 1.4). The efficiency estimates for Lookout Point Dam were for the combined two traps operated side by side.

Near-zero trap efficiency for dead juvenile Chinook salmon at both Fall Creek and Lookout Point dams presents some challenges for evaluating samples collected during normal trapping operations (see Chapter 3). More specifically, lower trap efficiency for dead fish would mean that using the raw trap data to estimate mortality rates or population size would need additional adjustments. For example, the raw proportion of dead Chinook salmon in a sample would tend to be an underestimate of total mortality because live fish are more likely than dead fish to be trapped. Similarly, estimates of the size of the population passing a dam would tend to be underestimates.
Table 1.2. Total numbers of unmarked juvenile Chinook salmon estimated to have passed Fall Creek and Lookout Point dams in each monitoring year. “Modeled” collection efficiency estimates used regressions from live salmon tests conducted during a range of discharge conditions in 2009-2010 (see Figure 1.4). Percentage efficiency estimates are provided to present a range of possible estimates that incorporate uncertainty about dead fish collection efficiency downstream from dams and span the range of point estimates at sites upstream from reservoirs (see Table 1.3). Note that all estimates are only for time periods that traps were operated (see Figure 1.2).

<table>
<thead>
<tr>
<th>Site</th>
<th>Collection efficiency estimate</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Creek Dam</td>
<td>Modeled</td>
<td>17,321</td>
<td>14,829</td>
<td>9,960</td>
<td>10,046</td>
</tr>
<tr>
<td></td>
<td>0.25%</td>
<td>159,200</td>
<td>116,800</td>
<td>67,200</td>
<td>69,600</td>
</tr>
<tr>
<td></td>
<td>0.50%</td>
<td>79,600</td>
<td>58,400</td>
<td>33,600</td>
<td>34,800</td>
</tr>
<tr>
<td></td>
<td>1.00%</td>
<td>39,800</td>
<td>29,200</td>
<td>16,800</td>
<td>17,400</td>
</tr>
<tr>
<td></td>
<td>2.00%</td>
<td>19,900</td>
<td>14,600</td>
<td>8,400</td>
<td>8,700</td>
</tr>
<tr>
<td></td>
<td>3.00%</td>
<td>13,267</td>
<td>9,733</td>
<td>5,600</td>
<td>5,800</td>
</tr>
<tr>
<td></td>
<td>2007^1</td>
<td>2008^1</td>
<td>2009</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Lookout Point Dam</td>
<td>Modeled</td>
<td>5,832</td>
<td>21,583</td>
<td>8,621</td>
<td>13,129</td>
</tr>
<tr>
<td></td>
<td>0.25%</td>
<td>16,000</td>
<td>144,800</td>
<td>36,800</td>
<td>83,200</td>
</tr>
<tr>
<td></td>
<td>0.50%</td>
<td>8,000</td>
<td>72,400</td>
<td>18,400</td>
<td>41,600</td>
</tr>
<tr>
<td></td>
<td>1.00%</td>
<td>4,000</td>
<td>36,200</td>
<td>9,200</td>
<td>20,800</td>
</tr>
<tr>
<td></td>
<td>2.00%</td>
<td>2,000</td>
<td>18,100</td>
<td>4,600</td>
<td>10,400</td>
</tr>
<tr>
<td></td>
<td>3.00%</td>
<td>1,333</td>
<td>12,067</td>
<td>3,067</td>
<td>6,933</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Fall Creek^2</td>
<td>2.00%</td>
<td>339,650</td>
<td>13,500</td>
<td>107,650</td>
<td>2,150</td>
</tr>
<tr>
<td></td>
<td>6.00%</td>
<td>113,217</td>
<td>4,500</td>
<td>35,883</td>
<td>717</td>
</tr>
<tr>
<td></td>
<td>10.00%</td>
<td>67,930</td>
<td>2,700</td>
<td>21,530</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>14.00%</td>
<td>48,521</td>
<td>1,929</td>
<td>15,379</td>
<td>307</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>2008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Fork</td>
<td>0.50%</td>
<td>237,800</td>
<td>85,400</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.75%</td>
<td>158,533</td>
<td>56,933</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00%</td>
<td>118,900</td>
<td>42,700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^1 Estimates multiplied by 2 because only one trap was deployed whereas efficiency estimates were for two traps

Using the regression model of capture efficiency for live Chinook salmon below Lookout Point Dam (Figure 1.4), estimated population size during trap operations ranged from 5,832 in 2005 to 21,583 in 2006 (Table 1.2). These were probable underestimates in all years because dead salmon trap efficiencies were near zero in all tests. Using an estimated capture efficiency of 0.25% for live and dead salmon combined the population estimates ranged from 16,000 to 144,800 fish annually. These are likely maximums during trap operation periods.

Fall Creek and North Fork sites – Live Chinook salmon trap efficiency at the Fall Creek site upstream from Fall Creek Dam in 2005 ranged from 3.91% to 12.50% (Table 1.3). There was relatively little difference in discharge among the three test dates (range = 1.5–1.7 m^3 s^-1), but efficiency did decrease with increasing discharge. This negative relationship is not unusual in
screw trap evaluations because, in most channels, proportionately less flow passes through a trap as total discharge increases (e.g., Kennan et al. 1994). We estimated total population size at the Fall Creek site using capture efficiencies ranging from 2-14% (Table 1.2). At the lowest trap efficiency, population estimates ranged from 2,150 in 2008 to 339,650 in 2005. Estimates at the highest efficiency ranged from 307 to 48,521. As at the dams, these estimates were limited to days of trap operation.

Efficiency estimates for live Chinook salmon at the North Fork trap were 0.69% and 0.75% on the two 2007 release dates (Table 1.3). We estimated total population size at the North Fork site using capture efficiencies ranging from 0.50-0.75% (Table 1.2). At the lowest trap efficiency, population estimates were 237,800 in 2007 and 85,400 in 2008. Estimates at the highest efficiency were 118,900 in 2007 and 42,700 in 2008.

### Table 1.3. Results of screw trap efficiency tests conducted at the Fall Creek (FC) and North Fork Middle Fork River (NF) sites in 2005 and 2007.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Year</th>
<th>Month</th>
<th>Total discharge</th>
<th>Species</th>
<th>$n$</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC</td>
<td>2005</td>
<td>February</td>
<td>~1.6 m$^3$s$^{-1}$</td>
<td>Chinook salmon</td>
<td>200</td>
<td>6.50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March</td>
<td>~1.5 m$^3$s$^{-1}$</td>
<td>Chinook salmon</td>
<td>200</td>
<td>12.50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March</td>
<td>~1.7 m$^3$s$^{-1}$</td>
<td>Chinook salmon</td>
<td>128</td>
<td>3.91%</td>
</tr>
<tr>
<td>NF</td>
<td>2007</td>
<td>February</td>
<td>n/a</td>
<td>Chinook salmon</td>
<td>400</td>
<td>0.75%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March</td>
<td>n/a</td>
<td>Chinook salmon</td>
<td>430</td>
<td>0.69%</td>
</tr>
</tbody>
</table>

All of the population estimates described above and presented in Table 1.2 should be considered more qualitative than quantitative. There were several critical uncertainties associated with these calculations. They include: 1) imprecision regarding dead salmon capture efficiencies downstream from dams; 2) limitations associated with the small size of salmon used in tests compared to the wide size range of the salmon collected, especially downstream from dams; and 3) efficiency testing was conducted only during late fall and winter (below dams) or in late winter-early spring (above dams). Ideally, tests would be conducted using fish that were representative in size and migration timing to those in the general population (Volkhardt et al. 2007). We also emphasize that the estimates in Table 1.2 are limited to the time periods that traps were operated. In almost all cases, annual estimates would be higher. However, we are reluctant to extrapolate to non-trapping periods, especially given the uncertainties described above.
References


CHAPTER 2

DOWNSTREAM FISH PASSAGE AT DAMS AND IN TRIBUTARIES OF THE MIDDLE FORK WILLAMETTE RIVER: TIMING, ABUNDANCE, AND MORTALITY

Introduction

High-head, flood-control dams in the Willamette River basin present a variety of fish passage challenges. Most of the dams are located in secondary tributaries and were constructed without fish facilities for either upstream or downstream passage (Myers et al. 2006; NMFS 2008). Consequently, native fish movements associated with seasonal habitat use and life history requirements can be severely restricted. Anadromous species, including spring Chinook salmon (*Oncorhynchus tshawytscha*), winter steelhead (*O. mykiss*), and Pacific lamprey (*Lampetra tridentata*) are among the most impacted species because dams block adult access to historic spawning areas (Myers et al. 2006; Keefer and Caudill 2010) and affect the timing and survival of outmigrating juveniles (Taylor 2000; NMFS 2008). The dams also affect the movements and distributions of non-native species in the basin. Dams can prevent upstream range expansion of non-natives, but robust non-native populations in reservoirs often provide a source for downstream expansion. As potential predators and competitors, non-natives can affect the ecological dynamics of downstream native fish communities (e.g., Schultz et al. 2003).

In this study, we examined downstream fish passage in the Middle Fork Willamette River basin. Fish were collected at two sites upstream from reservoirs, in areas with relatively intact native fish assemblages, and downstream from three high-head dams (Fall Creek, Hills Creek, and Lookout Point dams) whose reservoirs support a mix of native and non-native species. Passage routes at the dams were via turbines, spillways, and low-elevation regulating outlets. Each of these routes has been associated with fish mortality. Mortality and injury risks from turbine passage have been well-documented at many other dams, and include shear stress, blade strikes, cavitation injuries, and rapid pressure changes (e.g., Navarro et al. 1996; Coutant and Whitney 2000; Mathur et al. 2000; Čada 2001; Čada et al. 2006; Ferguson et al. 2008; Deng et al. 2010). Spillway passage is generally considered more benign than turbine passage, although spillway height, plunge pool configuration, and other features result in a variety of injuries and direct and delayed mortality (e.g., Muir et al. 2001; Schilt 2007; Williams 2008). There have been few studies associated with regulating outlet passage, but reported mortality rates for fish passing this route at other Willamette basin dams have been in the 30-70% range (e.g., Homolka and Downey 1991; Taylor 2000; ODFW 2004).

The relative availability and use of each passage route at Middle Fork Willamette basin dams depends on operational and environmental conditions. Use of both turbine and regulating outlet routes is linked to reservoir elevation and depth to the water intake sites. Elevations can vary by 40 meters or more at these flood control projects in the course of a year (see Appendix). Surface-oriented species, including emigrating salmonid smolts (e.g., Johnson et al. 2005; Johnson and Dauble 2006), primarily use these routes when reservoir elevation is low and
sounding depths are substantially reduced. Fish use of Willamette dam spillways is mostly restricted to flood events. These events do not necessarily occur when juvenile salmonids are physiologically prepared to emigrate (i.e., spill can occur prior to smoltification). However, spill at the Willamette dams has been associated with entrainment of large numbers of surface-oriented species plus passively-drifting and pelagic species, including larval and juvenile non-natives like crappie (*Pomoxis* spp.) and bluegill (*Lepomis macrochirus*).

There were three primary objectives for the multi-species portion of this study. The first was to use screw traps to enumerate all native and non-native fishes collected at sites upstream from Middle Fork reservoirs and downstream from dams. The second was to summarize the timing of downstream movement for all species and to assess factors associated with these movements. The third was to estimate species-specific mortality and to evaluate potential operational and environmental factors affecting mortality rates. The emphasis in the mortality component was for samples collected downstream from dams.

**Methods**

**Fish collection**

Fish were collected in rotary screw traps at five sites in the Middle Fork Willamette River between 2003 and 2010 (see Figure 1.1). Traps were deployed downstream from Fall Creek Dam (2006-2009), Hills Creek Dam (2003-2004), and Lookout Point Dam (2007-2010) and in unimpounded reaches above Fall Creek reservoir (2005-2008) and in the North Fork Middle Fork (2007-2008). Each study site had a single 2.44 m (8 ft) trap, except two traps were operated below Lookout Point Dam starting in fall of 2009.

Traps were checked daily or on alternate days during times when fish moving downstream were relatively abundant and were checked less frequently (i.e, weekly) when few or no fish were moving. Native fish were placed in a 19 L (5 gal) bucket filled with 15 L (4 gal) of river water and 2-3 mL of an anesthetic solution of 9 parts ethanol to 1 part clove leaf oil (Glorybee Foods, Inc., Eugene, OR); non-natives were not anesthetized. Fish of all species were enumerated. Fork length data were collected for all unmarked Chinook salmon (i.e., those without hatchery clips or other marks), marked salmon below Hills Creek Dam, and most large (i.e., non-juvenile) non-native fish. All anesthetized fish recovered in a 19 L bucket filled with fresh river water and were then released back into the river. Non-native fish were immediately released after enumeration.

**Dam configurations**

The configurations and operations of the three study dams differ in important ways for fish passage evaluations. Lookout Point Dam (~1,023 m long, 84 m high) is operated as a power peaking facility, with water primarily released through three Francis turbines, but occasionally through the five spillway gates or four regulating outlets. The minimum and maximum Lookout Point reservoir elevations are ~251 m and 285 m, respectively. Hills Creek Dam (~655 m long, 93 m high) is primarily a flood control project that has two Francis turbines and two spillway
gates and two regulating outlets. Reservoir elevations range from 441 m (minimum) to 470 m (maximum). Fall Creek Dam (~1,023 m long, 55 m high) is a flood control project with no power generation and two spillways, two regulating outlets, and three ‘fish horns’ that provide water seasonally. Reservoir elevations range from 205 m (minimum) to 254 m (maximum). Storage volumes for the three reservoirs are 562.2 million m$^3$ (455,800 acre-ft) for Lookout Point, 438.5 million m$^3$ (355,500 acre-ft) for Hills Creek, and 154.2 million m$^3$ (125,000 acre-ft) for Fall Creek.

**Data analyses**

Trapping effort was not consistent among sites, among years, or within year at individual sites (see Chapter 1). Therefore, capture rates (fish per trap per day = fish/d) were used to evaluate emigration timing patterns and the effects of river environment and dam operations on collection of all species. In the samples collected downstream from dams, we used linear regression (Zar 1999) to test for associations between fish collection rates and both reservoir elevation and total river discharge. In these models, elevation was binned by 1.52 m (5 ft) intervals and discharge was binned by 10 m$^3$.s$^{-1}$ intervals. Days of trap operations in each bin was used as a weighting term for the discharge models to reduce the influence of outliers with limited fish passage. We evaluated the combined effects of discharge and elevation on trapping rates using a stratified quartile analysis (see below).

Fish mortality was defined as the proportion (or percentage) of fish collected in screw traps that were dead. This probably underestimated the proportion of dead fish passing the trap sites because trap efficiency was lower for dead than live Chinook salmon in all efficiency tests conducted downstream from Lookout Point and Fall Creek dams (see Table 1.1). There were no similar tests at the other trap sites or with other species, but we expect that dead fish capture efficiency mechanisms would be reasonably consistent across locations. The magnitude of this bias was unknown and presumably varied with discharge volume and current velocity at each site (e.g., Johnson and Rayton 2007) and with fish size and species (e.g., Thedinga et al. 1994).

We evaluated the effects of dam operations and river environment on fish mortality downstream from the three dams by calculating mortality for groups of fish in stratified combinations of reservoir elevation and river discharge. In this analysis, quartile values (25$^{th}$, 50$^{th}$, and 75$^{th}$ percentiles) of elevation and discharge at each site were used to create a 4×4 matrix of conditions during trap operations. Total fish mortality was calculated for each of the resulting 16 combinations and we tested for differences among strata using general linear models (GLM; SAS 2000). In the models, reservoir elevation and discharge quartiles were the predictor variables and the weighting term was either number of days in each strata or number of fish in each strata to account for disproportionate representation. Mortality during spill and no-spill conditions at Lookout Point and Hills Creek dams was calculated separately in the elevation×discharge strata where spill occurred. Effects of spill in these strata were evaluated using Pearson’s χ$^2$ tests (Zar 1999).
Results

Collection summary

A total of 195,772 fish were collected at the five screw trap sites in 2,950 days of trap operations (total trap rate = 66 fish/d). Trap rates at individual sites were: 51 fish/d (Fall Creek Dam), 4 fish/d (Hills Creek Dam), 171 fish/d (Lookout Point Dam), 23 fish/d (Fall Creek), and 5 fish/d (North Fork). Ten native and six non-native species were collected downstream from the dams (Table 2.1), whereas essentially no non-native and 12 native species were collected at the sites upstream from reservoirs (Table 2.2).

Annual samples downstream from Fall Creek Dam were dominated (95.3-98.0%) by non-native species, especially juvenile black crappie (*Pomoxis nigromaculatus*) and juvenile bluegill (*Lepomis macrochirus*). In contrast, annual samples below Hills Creek Dam included a majority (59.0-78.7%) of native species and juvenile Chinook salmon were the most abundant species in both 2003 (70.7%) and 2004 (34.3%). The next-most abundant Hills Creek natives were largescale sucker (*Catostomus machrocheilus*, 2.6-10.3%) and sculpin (*Cottus* spp., 1.5-6.9%), and the most abundant non-natives were white crappie (*Pomoxis annularis*, 9.7-19.8%), bullhead (*Ameiurus* spp., 1.8-15.6%), and black crappie (*Pomoxis nigromaculatus* 0.9-5.8%). The samples below Lookout Point Dam were very different among years, with ≥ 98.9% white crappie (almost all juveniles) in 2007-2008, while Chinook salmon most abundant in 2009 (77.2%) and 2010 (88.6%).

The most abundant species in all annual Fall Creek samples was Chinook salmon (44.3-92.2%), followed by rainbow trout, speckled dace, or unidentified dace species (Table 2.2). The Chinook salmon were primarily subyearlings with a small component of yearling fish (see Chapter 3). The North Fork samples were predominated by Chinook salmon (90.6-94.1%).
Table 2.1. Summary of fish collected in rotary screw traps downstream from Hills Creek, Fall Creek, and Lookout Point dams, 2003-2010. Most centrarchids and all Chinook salmon were juveniles.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Fall Creek</th>
<th></th>
<th>Hills Creek</th>
<th></th>
<th>Lookout Point</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Largescale sucker</td>
<td><em>Catostomus macrocheilus</em></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>28</td>
<td>66</td>
<td>3</td>
</tr>
<tr>
<td>Sculpin spp.</td>
<td><em>Cottus</em> spp.</td>
<td>3</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>16</td>
<td>44</td>
</tr>
<tr>
<td>Western brook lamprey</td>
<td><em>Lampetra richardsoni</em></td>
<td>12</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal cutthroat trout</td>
<td><em>Oncorhynchus clarkii clarkii</em></td>
<td>9</td>
<td>2</td>
<td>9</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td><em>Oncorhynchus mykiss</em></td>
<td>37</td>
<td>5</td>
<td>6</td>
<td>22</td>
<td>6</td>
<td>27</td>
</tr>
<tr>
<td>Chinook salmon (wild) (hatchery)</td>
<td><em>Oncorhynchus tshawytscha</em></td>
<td>398</td>
<td>292</td>
<td>168</td>
<td>174</td>
<td>760</td>
<td>220</td>
</tr>
<tr>
<td>Salmonid fry</td>
<td><em>Oncorhynchus</em> spp.</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern pikeminnow</td>
<td><em>Ptychocheilus oregonensis</em></td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td>Longnose dace</td>
<td><em>Rhinichthys cataractae</em></td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Speckled dace</td>
<td><em>Rhinichthys osculus</em></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redside shiner</td>
<td><em>Richardsonius balteatus</em></td>
<td>1</td>
<td>42</td>
<td>5</td>
<td>1</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Bullhead spp.</td>
<td><em>Ameiurus</em> spp.</td>
<td>48</td>
<td>31</td>
<td>30</td>
<td>23</td>
<td>19</td>
<td>100</td>
</tr>
<tr>
<td>Bluegill</td>
<td><em>Lepomis macrochirus</em></td>
<td>243</td>
<td>7658</td>
<td>4934</td>
<td>325</td>
<td>35</td>
<td>28</td>
</tr>
<tr>
<td>Largemouth bass</td>
<td><em>Micropterus salmoides</em></td>
<td>3490</td>
<td>205</td>
<td>1189</td>
<td>1295</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>White crappie</td>
<td><em>Pomoxis annularis</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>104</td>
<td>127</td>
</tr>
<tr>
<td>Black crappie</td>
<td><em>Pomoxis nigromaculatus</em></td>
<td>9376</td>
<td>7043</td>
<td>4071</td>
<td>3493</td>
<td>62</td>
<td>6</td>
</tr>
<tr>
<td>Walleye</td>
<td><em>Sander vitreus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>13731</strong></td>
<td><strong>15672</strong></td>
<td><strong>10429</strong></td>
<td><strong>5345</strong></td>
<td><strong>1075</strong></td>
<td><strong>641</strong></td>
</tr>
</tbody>
</table>

1 1 cutthroat-rainbow hybrid
Table 2.2. Summary of fish collected in rotary screw traps in Fall Creek upstream from Fall Creek reservoir and in the North Fork Middle Fork Willamette River, 2005-2008. Chinook salmon were all juveniles.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Fall Creek 2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>North Fork 2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largescale sucker</td>
<td><em>Catostomus macrocheilus</em></td>
<td>13</td>
<td>10</td>
<td>25</td>
<td>5</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Sculpin spp.</td>
<td><em>Cottus</em> spp.</td>
<td>17</td>
<td>15</td>
<td>32</td>
<td>15</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Western brook lamprey</td>
<td><em>Lampeira richardsoni</em></td>
<td>20</td>
<td>23</td>
<td>17</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Coastal cutthroat trout</td>
<td><em>Oncorhynchus clarkii clarkii</em></td>
<td>12</td>
<td>15</td>
<td>32</td>
<td>15</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Rainbow trout</td>
<td><em>Oncorhynchus mykiss</em></td>
<td>132</td>
<td>151</td>
<td>360</td>
<td>16</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Chinook salmon (wild)</td>
<td><em>Oncorhynchus tshawytscha</em></td>
<td>6793</td>
<td>270</td>
<td>2153</td>
<td>43</td>
<td>1189</td>
<td>427</td>
</tr>
<tr>
<td>Salmonid fry</td>
<td><em>Oncorhynchus</em> spp.</td>
<td>44</td>
<td>20</td>
<td>8</td>
<td></td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Mountain whitefish</td>
<td><em>Prosopium williamsoni</em></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern pikeminnow</td>
<td><em>Ptychocheilus oregonensis</em></td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Longnose dace</td>
<td><em>Rhinichthys cataractae</em></td>
<td></td>
<td>45</td>
<td>314</td>
<td>8</td>
<td>42</td>
<td>13</td>
</tr>
<tr>
<td>Speckled dace</td>
<td><em>Rhinichthys osculus</em></td>
<td>71</td>
<td>947</td>
<td>8</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Dace spp.</td>
<td><em>Rhinichthys</em> spp.</td>
<td>334</td>
<td>3</td>
<td></td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redside shiner</td>
<td><em>Richardsonius balteatus</em></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brook trout</td>
<td><em>Salvelinus fontinalis</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7366</td>
<td>609</td>
<td>3913</td>
<td>89</td>
<td>1313</td>
<td>454</td>
</tr>
</tbody>
</table>
**Downstream passage timing**

Downstream from dams, fish trapping rates (fish/d) followed strong seasonal patterns (Figure 2.1). Maximum trapping rates were 102-567 fish/d in January, November and December below both Fall Creek and Lookout Point dams. Rates were 10-100 fish/d downstream from Fall Creek (February, March, October), Hills Creek (December), and Lookout Point (February, October) dams. Collection rate nadirs at these sites occurred from June-August. Upstream from reservoirs, trapping rates were less seasonally variable. In Fall Creek, the highest rates were 51-74 fish/d (March) and 51 fish/d (February), and were 12-17 fish/d in May, June, and October (Figure 2.1). In the North Fork, the highest rates were 14 fish/d (May) and 9 fish/d (March).

![Graph showing fish trapping rates](image)

Figure 2.1. Numbers of fish collected in rotary screw traps per day (log scale) in Fall Creek upstream from the reservoir (■), in the North Fork Middle Fork (●), and at Fall Creek (●), Lookout Point (●), and Hills Creek (○) dams, all years combined. Results are not weighted by trapping effort.

Passage timing distributions varied among species at each trap site. In Fall Creek, Chinook salmon were trapped at the highest rates in February and March. Largescale suckers and speckled dace (*Rhinichthys osculus*) collection rates were highest in May, western brook lamprey (*Lampetra richardsoni*) and cutthroat trout (*O. clarkii*) rates were highest in April, and longnose dace (*R. cataractae*) and sculpin (*Cottus* spp.) rates were highest in June (Figure 2.2). Although
the Fall Creek trap ran for parts of October-December, almost no fish were captured in those months. In the North Fork, trapping rates were highest for Chinook salmon and rainbow trout in May, for sculpins and longnose dace in June, and for unidentified dace species in August (Figure 2.3). Few fish of any species were trapped in September-February.

Figure 2.2. Relative monthly abundance and passage timing of all species collected in the screw trap upstream from Fall Creek reservoir, 2005-2008. Circle size was scaled by multiplying the monthly proportion of the total sample (each species separately) by the monthly proportion of trapping effort. Black squares represent proportion of trapping effort. Note: symbol size should not be compared across species and symbols representing may not be visible for months with very small numbers of a species.

Downstream from Fall Creek Dam, trapping rates for cutthroat trout, rainbow trout (*O. mykiss*), Chinook salmon, northern pikeminnow (*Ptychocheilus oregonensis*), bullhead (*Ameiurus* spp.), bluegill, and largemouth bass were all highest in November (Figure 2.4). Rates were highest in December for sculpins and black crappie, in June for western brook lamprey, and in October for redside shiner (*Richardsonius balteatus*). Very few fish were trapped in February-March or August-September. Collection rates below Hills Creek Dam were consistently highest in the fall and early winter for both native and non-native species (Figure 2.5). Rates were highest in September for largescale sucker and bullhead, in October for redside shiner and dace, in November for black crappie, bluegill, and largemouth bass, and in December for the three salmonids and white crappie. Peak collection rates below Lookout Point Dam (Figure 2.6) were in November or January for all species except sculpin (December). Although the trap was operated, very few fish were collected in September, February, or April-June.
Figure 2.3. Relative monthly abundance and passage timing of all species collected in the screw trap in the North Fork Middle Fork, 2007-2008. Circle size was scaled by multiplying the monthly proportion of the total sample (each species separately) by the monthly proportion of trapping effort. Black squares represent proportion of trapping effort. Note: symbol size should not be compared across species and symbols representing may not be visible for months with very small numbers of a species.

Figure 2.4. Relative monthly abundance and passage timing of all species collected in the screw trap downstream from Fall Creek Dam, 2006-2009. Circle size was scaled by multiplying the monthly proportion of the total sample (each species separately) by the monthly proportion of trapping effort. Open circles are for native species, gray circles are for non-native species, and black squares represent proportion of trapping effort. Note: symbol size should not be compared across species and symbols representing may not be visible for months with very small numbers of a species.
Figure 2.5. Relative monthly abundance and passage timing of all species collected in the screw trap downstream from Hills Creek Dam, 2003-2004. Circle size was scaled by multiplying the monthly proportion of the total sample (each species separately) by the monthly proportion of trapping effort. Open circles are for native species, gray circles are for non-native species, and black squares represent proportion of trapping effort. Note: symbol size should not be compared across species and symbols representing may not be visible for months with very small numbers of a species.

Figure 2.6. Relative monthly abundance and passage timing of all species collected in the screw trap downstream from Lookout Point Dam, 2007-2010. Circle size was scaled by multiplying the monthly proportion of the total sample (each species separately) by the monthly proportion of trapping effort. Open circles are for native species, gray circles are for non-native species, and black squares represent proportion of trapping effort. Note: symbol size should not be compared across species and symbols representing may not be visible for months with very small numbers of a species.
Factors affecting dam passage

Fish trapping rates (all species combined) downstream from dams rapidly increased as reservoir elevation decreased (Figure 2.7). Rates at the lowest reservoir elevations were an order of magnitude higher than at the highest elevations below all three dams. Linear regressions using log-transformed trapping rates and 1.52-m (5 ft) elevation intervals were significant ($P < 0.05$, $0.50 \leq r^2 \leq 0.83$) at each site. Trapping rates were also positively associated with total river discharge at each site (Figure 2.8), but discharge explained less variability than reservoir elevation ($0.09 \leq r^2 \leq 0.63$).

Figure 2.7. Numbers of fish collected in rotary screw traps per day (log scale) in relation to reservoir elevation at Fall Creek (●), Lookout Point (●), and Hills Creek (○) dams, all years combined. Elevation was binned in 1.52 m (5 ft) increments. Linear regression results: Fall Creek Dam, log(Fish/day) = -0.076(elev) + 19.087, $r^2 = 0.83$; Lookout Point Dam, log(Fish/day) = -0.096(elev) + 25.805, $r^2 = 0.50$; Hills Creek Dam, log(Fish/day) = -0.059(elev) + 27.089, $r^2 = 0.78$. Bins with zero fish trapped are not shown because log 0 is undefined.

The elevation×discharge quartile analysis indicated that trapping rates were highest below Fall Creek Dam when reservoir elevation was in the 1st (lowest) quartile and decreased in each subsequent elevation quartile (Figure 2.9). Discharge effects appeared to be secondary, but there was a tendency for higher catch rates at higher discharge within elevation strata. Below Hills Creek Dam, the elevation effect was not as strong as below Fall Creek Dam, but there was a similar effect of higher catch rates at higher discharge within elevation strata (Figure 2.10). Regulating outlet (RO) spill occurred at Hills Creek Dam on some days when discharge was in
the third and fourth quartiles. Relatively large proportions of the total catch rate in these strata were on days with RO spill, suggesting that fish may disproportionately pass the dam via the spillway when the route is available. Below Lookout Point Dam, the highest trapping rates were in the 1st and 2nd elevation quartiles at the higher discharge levels (Figure 2.11). Rates were far lower in the 3rd and 4th elevation quartiles, except when there was high discharge and accompanying RO spill. There was also a single surface spill event at Lookout Point Dam.

![Graph showing fish trapped per day in relation to total river discharge](image)

Figure 2.8. Numbers of fish collected in rotary screw traps per day (log scale) in relation to total river discharge (Q) at Fall Creek (●), Lookout Point (●), and Hills Creek (○) dams, all years combined. Discharge was binned in 10 m$^3$/s increments. Weighted linear regression results: Fall Creek Dam, log(Fish/day) = 1.495(Q) + 19.764, $r^2 = 0.57$; Lookout Point Dam, log(Fish/day) = 2.392(Q) - 22.909, $r^2 = 0.09$; Hills Creek Dam, log(Fish/day) = 0.179(Q) - 1.802, $r^2 = 0.63$. Bins with zero fish trapped are not shown because log 0 is undefined.
Figure 2.9. Numbers of fish collected in rotary screw traps per day (log scale) downstream from Fall Creek Dam in relation to reservoir elevation and total river discharge. Rates were calculated for each combination of elevation and discharge quartiles. White circles are number of days.

Figure 2.10. Numbers of fish collected in rotary screw traps per day (log scale) downstream from Hills Creek Dam in relation to reservoir elevation and total river discharge. Rates were calculated for each combination of elevation and discharge quartiles. Hashed portions of bars represent the portion during days with regulating outlet spill. White circles are number of days.
Figure 2.11. Numbers of fish collected in rotary screw traps per day (log scale) downstream from Lookout Point Dam in relation to reservoir elevation and total river discharge. Rates were calculated for each combination of elevation and discharge quartiles. Hashed portions of bars represent the portion during days with regulating outlet or surface spill. White circles are number of days.

Fish mortality

With all years and species combined, dead fish made up ≤ 2% of the Fall Creek and North Fork trap samples upstream from reservoirs. By comparison, total mortality was 36% below Fall Creek Dam, 39% below Hills Creek Dam, and 69% below Lookout Point Dam. Total mortality estimates were strongly affected by the species composition at each site. For example, relatively high total mortality below Lookout Point Dam was influenced by high mortality (70%) for the numerically dominant juvenile white crappie (Table 2.3). Similarly, the total mortality estimate below Fall Creek Dam was strongly influenced by juvenile black crappie mortality (42%).

In general, mortality downstream from dams was higher for non-native – and especially for centrarchids – than for native species (Table 2.3). Total mortality was 32-49% for bluegill and black crappie, 70% for white crappie (Lookout Point only), and 18-23% for largemouth bass. Among native species, mortality was consistently highest for Chinook salmon, with rates of 14-54% for unmarked salmon and 36-53% for marked salmon (for additional Chinook salmon details see Chapter 3). Annual mortality estimates for individual species (Figure 2.12) showed some among-year variability, but estimates were generally clustered and patterns were similar to those for total mortality. (Note: a small portion of the fish captured below dams may have been resident fish.)
Table 2.3. Estimated percent mortality (n) for all species collected in rotary screw traps at each study site, all years combined. Data from the Fall Creek trap upstream from the reservoir are for 2006-2008 only.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Fall Creek</th>
<th>Hills Creek</th>
<th>Lookout Point</th>
<th>Fall Creek</th>
<th>North Fork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largescale sucker</td>
<td><em>Catostomus macrocheilus</em></td>
<td>0% (2)</td>
<td>n/a (71)</td>
<td>38% (13)</td>
<td>0% (67)</td>
<td>20% (5)</td>
</tr>
<tr>
<td>Sculpin spp.</td>
<td><em>Cottus</em> spp.</td>
<td>0% (13)</td>
<td>n/a (23)</td>
<td>11% (38)</td>
<td>5% (40)</td>
<td>28% (18)</td>
</tr>
<tr>
<td>Western brook lamprey</td>
<td><em>Lampetra richardsoni</em></td>
<td>n/a (7)</td>
<td>n/a (7)</td>
<td>0% (1)</td>
<td>33% (6)</td>
<td>6% (17)</td>
</tr>
<tr>
<td>Coastal cutthroat trout</td>
<td><em>Oncorhynchus clarkii clarkii</em></td>
<td>0% (24)</td>
<td>n/a (11)</td>
<td>0% (1)</td>
<td>1% (511)</td>
<td>6% (17)</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td><em>Oncorhynchus mykiss</em></td>
<td>10% (70)</td>
<td>n/a (33)</td>
<td>17% (6)</td>
<td>1% (511)</td>
<td>6% (17)</td>
</tr>
<tr>
<td>Chinook salmon (wild)</td>
<td><em>Oncorhynchus tshawytscha</em></td>
<td>14% (1032)</td>
<td>54% (550)</td>
<td>23% (632)</td>
<td>&lt;1% (2432)</td>
<td>1% (1616)</td>
</tr>
<tr>
<td>(hatchery)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmonid fry</td>
<td><em>Oncorhynchus</em> spp.</td>
<td>0% (2)</td>
<td>n/a (2)</td>
<td>0% (3)</td>
<td>0% (28)</td>
<td>0% (8)</td>
</tr>
<tr>
<td>Northern pikeminnow</td>
<td><em>Pycthocheilus oregonensis</em></td>
<td>0% (12)</td>
<td>8% (91)</td>
<td>0% (359)</td>
<td>0% (3)</td>
<td>0% (3)</td>
</tr>
<tr>
<td>Longnose dace</td>
<td><em>Rhinichthys cataractae</em></td>
<td>0% (4)</td>
<td>n/a (7)</td>
<td>0% (55)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speckled dace</td>
<td><em>Rhinichthys osculus</em></td>
<td>0% (2)</td>
<td>n/a (1)</td>
<td>&lt;1% (1018)</td>
<td>0% (5)</td>
<td></td>
</tr>
<tr>
<td>Redside shiner</td>
<td><em>Richardsonius balteatus</em></td>
<td>2% (49)</td>
<td>n/a (13)</td>
<td>0% (3)</td>
<td>0% (3)</td>
<td></td>
</tr>
<tr>
<td>Brook trout</td>
<td><em>Salvelinus fontinalis</em></td>
<td>2% (132)</td>
<td>n/a (119)</td>
<td>0% (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bullhead spp.</td>
<td><em>Ameiurus</em> spp.</td>
<td>32% (5502)</td>
<td>43% (63)</td>
<td>49% (73)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bluegill</td>
<td><em>Lepomis macrochirus</em></td>
<td>19% (6179)</td>
<td>18% (11)</td>
<td>23% (47)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Largemouth bass</td>
<td><em>Micropterus salmoides</em></td>
<td>42% (23983)</td>
<td>35% (68)</td>
<td>100% (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White crappie</td>
<td><em>Pomoxis annularis</em></td>
<td>70% (132813)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black crappie</td>
<td><em>Pomoxis nigromaculatus</em></td>
<td>35% (68)</td>
<td>100% (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walleye</td>
<td><em>Sander vitreus</em></td>
<td>60% (10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Cutthroat-rainbow hybrid
Figure 2.12. Annual mortality for individual species caught in screw traps downstream from Fall Creek (●), Lookout Point (●), and Hills Creek (○) dams. Includes only species-years with ≥ 10 fish.

Relationships between total mortality downstream from dams and environmental conditions at the dams were complex. In the elevation×discharge quartile analysis, total mortality downstream from Fall Creek Dam was highest when elevation and discharge were each in the 2nd quartile (Figure 2.13), but only 2% of the total sample was collected under these conditions. The next-highest mortality estimate was when elevation was in the 2nd quartile and discharge was in the highest quartile; 16% of the sample was collected under these conditions. In the GLM results, reservoir elevation was significant (F = 4.5, P = 0.035) in the model weighted by number of fish/strata, with higher mortality at lower elevation. Neither elevation nor discharge was significant (P > 0.05) in the model weighted by number of days/strata.

Downstream from Hills Creek Dam, the highest mortality rates were in the lowest elevation quartile when discharge was in the 3rd and 4th quartiles (Figure 2.14). These conditions were associated with high fish collection rates (13% and 32%, respectively). Total mortality was also associated with RO spill, particularly when discharge was high and reservoir elevation was in the lowest two quartiles. There was a general pattern of decreasing mortality as elevation dropped (Figure 2.14). In the GLM results, reservoir elevation was significant (6.4 ≤ F ≤ 11.4, 0.002 ≤ P ≤ 0.013) in both models, with higher mortality at lower elevation. Discharge was significant (F = 0.65, P = 0.012) in the fish-weighted model, but not in the day-weighted model (F = 2.9, P = 0.096). In both models, mortality was higher in higher discharge strata. Five strata had fish pass during RO spill (Figure 2.14). Mortality was significantly (P = 0.010) higher during RO spill (37.6%) than during non-spill (9.5%) in the strata where elevation was in the 2nd quartile and discharge was in the 4th quartile. However, the RO outlet channel was downstream from the screw trap site, so increased mortality during spill was not clearly associated with RO passage.
Figure 2.13. Estimated mortality of fish collected in rotary screw traps downstream from Fall Creek Dam in relation to reservoir elevation and total river discharge. Proportions dead were calculated for each combination of elevation and discharge quartiles. White circles are proportion of total fish.

Figure 2.14. Estimated mortality of fish collected in rotary screw traps downstream from Hills Creek Dam in relation to reservoir elevation and total river discharge. Proportions dead were calculated for each combination of elevation and discharge quartiles. Hashed portions of bars represent the proportion that passed during days with regulating outlet spill. White circles are proportion of total fish.
Total mortality downstream from Lookout Point Dam was quite variable among elevation×discharge strata (Figure 2.15). Most fish were collected in the 1st and 2nd elevation quartiles, and mortality tended to be highest in these strata when discharge was relatively high. In the GLM results, mortality was significantly ($F = 3.9, P = 0.050$) higher at lower reservoir elevation in the model weighted by number of fish/strata. Three strata had fish pass during RO or surface spill (Figure 2.15). In the strata with elevation in the 2nd quartile and discharge in the 4th quartile, mortality was significantly ($P < 0.001$) lower during spill (39.3%) than during non-spill (70.8%). That pattern was reversed when both variables were in the 4th quartile: mortality was higher during spill (73.0%) than non-spill (25.0%) conditions ($P < 0.001$). Sample sizes were very limited in the remaining strata. Overall, mortality patterns below Lookout Point Dam were driven by white crappie mortality (see Chapter 3 for more detailed analyses of Chinook salmon mortality).

**Discussion**

**Downstream passage**

The multi-species results indicate that fish communities and fish movements in the Middle Fork Willamette River basin vary along spatial and temporal scales, and that dam and reservoir operations systematically affect the timing and rate of downstream passage. A clear spatial gradient was that non-native species were increasingly abundant as habitats changed from...
Riverine at upstream sites to reservoir-influenced at downstream sites. In both the Fall Creek and the main Middle Fork basins, samples upstream from reservoirs were almost exclusively native species. In contrast, juvenile non-natives predominated at the two most downstream collection sites (below Lookout Point and Fall Creek dams), with >95% non-native individuals in six of eight annual samples. Below Hills Creek Dam, a spatially intermediate site, samples included a relatively even mix of natives and non-natives. There were at least two important temporal patterns. First, fish collection rates below dams were highest from late fall to late winter when reservoir elevations were low and fish access to downstream passage routes (i.e., turbine and regulating outlet intakes) was relatively high (Taylor 2000). Second, collection rates upstream from reservoirs were highest in early spring through early summer, coincident with the emigration of subyearling juvenile Chinook salmon and with probable post-spawn dispersal by suckers, dace, and sculpins (e.g., Robinson et al. 1998; Schmetterling and McEvoy 2000).

The passage timing results highlight the mismatch between seasonal operations of the flood control projects and the life history requirements for several Middle Fork native species. The most obvious example was that juvenile Chinook salmon entered reservoirs as pools were rapidly filling in early spring through early summer. Increasing depth to turbine and regulating outlet intakes during this time likely prevented downstream passage for many salmon subyearlings and especially for yearling smolts that would have continued outmigrating had routes been more accessible. Much of the downstream movement by resident native fish at the upstream sites also occurred during this period, and operations presumably prevented seasonal dispersal by these species. The Middle Fork flood control operations present a much different set of fish passage challenges than the run-of-river operations at Columbia and Snake River dams, where reservoir elevations remain relatively stable and surface passage routes like spillways and bypass systems are usually available (e.g., Williams et al. 2005; Schilt 2007; Wertheimer 2007). Providing surface or other downstream passage routes at dams when Middle Fork reservoirs are high could partially restore some life history functionality in this system.

Although we did not monitor specific passage routes at the dams, most presumably passed through regulating outlets or turbines. However, the results suggest that some fish passed via surface spill at Lookout Point dam during a May high-discharge event. Surface-oriented migrants often congregate in dam forebays when downstream passage routes are limited (Snelling and Schreck 1994; Venditti et al. 2000; Johnson et al. 2005) and these aggregations can be entrained over the spillway when the route is opened (e.g., Paller et al. 2006). It is also likely that fish were entrained in turbine and regulating outlet intakes at higher rates during high-discharge events when more units were operated, reservoir and forebay water velocities increased, and intake entrainment fields were larger (e.g., Coutant and Whitney 2000; Nestler et al. 2008). A better understanding of vertical and horizontal fish distributions and behaviors in the forebays of the Middle Fork dams will be needed as fish collection or fish guidance strategies are developed.

One of the major uncertainties in the multi-species evaluation was the distinction between active (i.e., volitional) fish movement past the dams versus passive movement. In either case, the composition and relative abundance of fishes collected in screw traps were almost certainly not in proportion to the available population in the reservoirs upstream (e.g., Navarro and McCauley 1993; Sorenson et al. 1998). The motivation for active downstream passage
presumably ranged from high for individuals of anadromous species that were physiologically-ready to migrate (e.g., Healey 1991), to very low for non-native lentic species like crappies and bluegills. The likelihood of dam passage was likely also linked to among-species differences in behavior, such as swimming ability or diel vertical migrations (e.g., Shoup et al. 2004), and to differences in their propensity for littoral versus pelagic distributions in the reservoirs (e.g., Lewis 1968; Paller et al. 2006).

**Fish mortality**

Fish mortality varied significantly among species, among collection sites, and among years at individual sites. With all species and years combined, the percentages of dead fish in the traps were low (≤ 2%) at the two upriver sites and were moderate to high downstream from dams (36-69%), clearly implicating dam passage as a significant mortality source. Mortality was typically higher for non-native species, and especially for centrarchids, but rates also exceeded 20% for Chinook salmon in many annual samples. In general, total mortality estimates at each site were sensitive to the rates for the most abundant species and therefore comparisons among sites may be more meaningful for individual species rather than for the aggregates. Although site-specific features at each project likely affected mortality rates, the broad-scale results suggest that morphological, physiological, and/or behavioral differences among species affected fish susceptibility to direct and delayed mortality below dams. Such effects have been described elsewhere for a variety of species (e.g., Stokesbury and Dadswell 1991; Budy et al. 2002; Gibson and Myers 2002; Navarro et al. 2006). Evidence for morphological effects include the far higher passage-related mortality for large versus small Chinook salmon (see Chapter 3) and very high mortality rates for the relatively delicate young-of-the-year centrarchids.

Mortality estimates below dams were likely minimums for many species. For example, Chinook salmon mortality was almost certainly underestimated given substantially lower trap efficiency for dead versus live salmon (see Chapter 1). Confidence in mortality estimates for other species was lower than for Chinook salmon because no efficiency tests were conducted for several of the most abundant species (i.e., white crappie, bluegill) or for dead fish of species other than Chinook salmon. Calculating confidence intervals around mortality point estimates for all species will require efficiency testing over a wider range of size classes and operational conditions at each site (e.g., Volkhardt et al. 2007).

Due to logistical constraints, we did not estimate trap-related mortality or differentiate between direct (i.e., acute) versus delayed mortality. However, based on the very low salmon mortality estimates at the sites above reservoirs and in other screw trap studies (e.g., Chaput and Jones 2004; Scace et al. 2007; Music et al. 2010), we think that trap-related salmon mortality was also low (< 5%) at the below-dam sites in this study. Trap-related mortality for other species was unknown, but may have been relatively higher for lentic species like weak-swimming juvenile centrarchids. The latter were collected at high densities during peak passage periods and may have been susceptible to impingement or injury in holding boxes. Downstream from dams, a portion of the dead fish probably died in the traps from injuries sustained during dam passage (i.e., delayed mortality). This component was not measured because intervals between trap checks varied seasonally and among sites. Furthermore, no fish were held after
capture to directly assess post-capture delayed effects (e.g., Deng et al. 2010). Such effects have accounted for a large portion of total dam-related mortality in several studies (e.g., Kostecki et al. 1987; Dubois and Gloss 1993; Ferguson et al. 2006). We expect that overall mortality associated with Middle Fork dam passage would probably be higher than the estimates presented here if delayed effects and low dead-fish trap efficiency were accounted for. Future mortality studies at the Middle Fork dams should address route-specific mortality rates. Ideally, such studies would use mark-recapture approaches or position screw traps or other capture devices directly below specific passage routes.

References


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ODFW. 2004. Hatchery and genetic management plan: North Santiam River spring Chinook. ODFW, Salem, OR.


CHAPTER 3

EFFECTS OF HIGH-HEAD DAMS ON EMIGRATION TIMING AND MORTALITY OF JUVENILE SPRING CHINOOK SALMON IN THE MIDDLE FORK WILLAMETTE RIVER

Introduction

Construction and operation of hydropower dams have contributed to major population declines and local extirpations of anadromous salmonids (*Oncorhynchus* spp.) along the western Pacific Rim (Raymond 1988; Nehlsen et al. 1991; National Research Council 1996). In response, many salmon and steelhead populations have been listed as threatened or endangered under the U.S. Endangered Species Act (Good et al. 2005). The listings prompted a variety of large-scale research and mitigation projects, including hatchery programs (ISAB 2002; Brannon et al. 2004), habitat restoration (Roni et al. 2002), and structural and operational changes at dams to improve fish passage (Williams et al. 2005; Ferguson et al. 2008). The vast majority of the fish passage research has been in the Columbia and Snake rivers and has focused on both reducing juvenile salmonid mortality in turbines (Coutant and Whitney 2000; Čada 2001) and guiding outmigrating fish towards more benign passage routes such as spillways and bypass systems (Ferguson et al. 1998; Muir et al. 2001; Johnson et al. 2005; Zabel et al. 2008).

Main stem Columbia and Snake River dams are operated as run-of-river projects, where reservoir elevations remain relatively stable and surface fish passage routes like spillways and bypass systems are available for most juvenile emigrants (Williams et al. 2005; NMFS 2008a). The run-of-river model is in stark contrast to the flood control operations typical at high-head dams in Oregon’s Willamette River basin. Reservoirs in the major Willamette basin tributaries are drawn down in late fall to provide storage for winter and spring flood runoff and then are refilled from winter to early summer. The large seasonal fluctuations in reservoir elevation (i.e., often > 10’s of meters) limit downstream passage options for threatened juvenile spring (stream-type) Chinook salmon (*O. tshawytscha*) and winter steelhead (*O. mykiss*). Most of the Willamette dams were constructed without fish passage facilities for downstream migrants (Myers et al. 2006; NMFS 2008b), and the screening and bypass systems used at Columbia and Snake River dams would be difficult to deploy at the flood-control Willamette dams. Surface passage options (i.e., spillways) are very limited because tainter gates are rarely operated at most of the dams. Consequently, juvenile salmonids and other fish pass Willamette dams primarily via hydroelectric turbines or deep-water regulating outlets, each of which present significant injury and mortality risks (Homolka and Downey 1991; Taylor 2000; ODFW 2004; Deng et al. 2010).

Seasonal operations at the Willamette dams are poorly matched to the life history schedule and behaviors of outmigrating juvenile salmonids. For example, yearling spring Chinook salmon typically smolt in spring (Groot and Margolis 1991), a time when the Willamette reservoirs are rapidly filling, surface spill is restricted, and the depth to turbine and regulating outlets can be
prohibitively deep. Surface-oriented juvenile outmigrants may have difficulty finding and using the deep water routes at this important migration stage (e.g., Venditti et al. 2000; Johnson and Dauble 2006). Subyearling spring Chinook salmon also actively migrate in the Willamette system (Schroeder and Kenaston 2004; Friesen et al. 2007). Subyearlings exit spawning tributaries and enter high-order tributary or main stem habitats from winter through fall, with the earliest outmigrants entering reservoirs when they are at seasonal low elevations. Opportunities to pass dams via through regulating outlets may be relatively high for some of these early emigrants. However, downstream passage is increasingly restricted for subyearlings that enter reservoirs in spring, summer, and fall. A portion of both the subyearling and yearling populations that enter Willamette reservoirs are thought to fail to pass downstream during their typical outmigration window. These fish may residualize in reservoirs for up to a year (or more) before resuming outmigration.

Several of the Willamette basin dams have no upstream fish passage facilities and adult Chinook salmon and steelhead did not spawn in their historic habitats for several decades (Myers et al. 2006). In recent years, however, surplus hatchery and some naturally-produced Chinook salmon have been outplanted upstream from impassable dams in the North Santiam, South Santiam, McKenzie, and Middle Fork Willamette River basins in an effort to supplement natural production and provide a prey base for native fish (Biedler and Knapp 2005; Schroeder et al. 2007; Keefer et al. 2010). The outplant program has produced increasing numbers of juveniles, but little is known about their life history, migration ecology, or downstream survival past the dams.

There were four primary objectives for the Chinook salmon portion of this study. These included: (1) to enumerate naturally-produced salmon at sites above reservoirs and below dams; (2) to summarize the timing of downstream salmon passage and to assess factors associated with these movements; (3) to use salmon fork length and migration timing data to make some preliminary inferences about the life history characteristics of the Middle Fork population; and (4) to estimate salmon mortality and evaluate potential operational and environmental factors affecting mortality rates. The emphasis in the mortality component was for samples collected downstream from dams.

**Methods**

**Salmon collection**

Juvenile spring Chinook salmon were collected in rotary screw traps at five sites in the Middle Fork Willamette River between 2003 and 2010 (see Figure 1.1). Traps were deployed downstream from Fall Creek Dam (2006-2009), Hills Creek Dam (2003-2004), and Lookout Point Dam (2007-2010) and in unimpounded reaches above Fall Creek reservoir (2005-2008) and in the North Fork Middle Fork (2007-2008). Each study site had a single 2.44 m (8 ft) trap, except two traps were operated below Lookout Point Dam starting in fall of 2009.

Traps were checked daily or on alternate days during times when fish moving downstream. Chinook salmon were placed in a 19 L (5 gal) bucket filled with 15 L (4 gal) of river water and
2-3 mL of an anesthetic solution of 9 parts ethanol to 1 part clove leaf oil (Glorybee Foods, Inc., Eugene, OR). Fork lengths of all unmarked (presumed wild-origin) salmon were measured, except on days when large numbers of similarly-sized salmon were collected. In these cases, size was estimated to the nearest 1-cm. Salmon with hatchery marks (i.e., fin clips, brands, dyes) were not measured and were excluded from all analyses in this chapter. The single exception was that marked fish were measured below Hills Creek Dam in 2003-2004. The size distribution and migration timing of the Hills Creek hatchery group were comparable to those for unmarked fish and the two groups were pooled for most analyses. Differences are noted in Results where significant. All Chinook salmon recovered in a 19 L bucket filled with fresh river water and were then released back into the river.

**Data analyses**

Life history summaries for the Chinook salmon samples at each trap site were inferred from fork length and timing data. These evaluations were mostly qualitative because no scale or otolith data were collected and because information about Chinook salmon growth rates in Middle Fork reservoirs is only available from historic studies (e.g., Smith 1976). Recent juvenile age data from scale analysis by ODFW (Lisa Borgerson, unpublished data) were used to help infer basic life history designations. Size differences among groups of salmon size were assessed using analysis of variance (ANOVA).

Trapping effort was not consistent among sites, among years, or within year at individual sites (see Chapter 1). Therefore, capture rates (Chinook salmon per trap per day) were used to evaluate emigration timing patterns and effects of river environment and dam operations. In the samples collected downstream from dams, we used weighted linear regression (Zar 1999) to test for associations between Chinook salmon catch rates and both reservoir elevation and total river discharge. In these models, elevation was binned by 1.52 m (5 ft) intervals and river discharge was binned by 10 m$^3$s$^{-1}$ intervals. Days of trap operations in each bin was used as the weighting term.

Chinook salmon mortality was defined as the proportion (or percentage) of salmon collected in screw traps that were dead. This almost certainly underestimated the proportion of dead fish passing the trap sites because trap efficiency was lower for dead than live salmon in all efficiency tests conducted downstream from Lookout Point and Fall Creek dams (see Table 1.1). There were no similar tests at the other trap sites, but we expect that dead salmon capture efficiency mechanisms would be consistent across locations. The magnitude of this bias was unknown and presumably varied with discharge volume and current velocity at each site (e.g., Johnson and Rayton 2007) and with fish size (e.g., Thedinga et al. 1994).

We evaluated salmon mortality downstream from the three dams using weighted linear regression models similar to those described above for trapping rates, but weighted by numbers of salmon in each elevation, discharge, or fork length bin. We also used a series of univariate and multivariate logistic regression models to estimate mortality probabilities using individual fish data (Allison 1999). Predictor variables in the logistic models included salmon fork length, reservoir elevation, river discharge, and several interaction terms that were identified as
potentially influential in exploratory analyses (see Results). We used an information theoretic approach to compare 15 logistic regression models for each of the three below-dam trap samples. The models were ranked using Akaike’s information criteria (AIC) and were evaluated with respect to ΔAIC, the change in AIC relative to the most parsimonious model (Burnham and Anderson 2002). Regulating outlet spill occurred at Lookout Point and Hills Creek dams in most years, primarily during peak winter discharge events (see Appendix 1). We did not include regulating outlet spill in the logistic model comparisons because of strong associations between spill and total discharge. Instead, salmon mortality during spill and non-spill periods at Lookout Point and Hills Creek dams was compared using Pearson’s χ² tests. We emphasize that this modeling exercise was not intended to be predictive, but rather was conducted to identify gross-scale patterns and generate hypotheses.

Results

Collection summary

A total of 13,365 juvenile Chinook salmon were trapped and measured across all sites and years, with the majority (69%, n = 9,273) trapped in Fall Creek (Table 3.1). Marked fish were measured only below Hills Creek Dam in 2003-2004, when 398 fish had hatchery marks and 550 had no marks. The remainder of the sample was unmarked and presumed wild origin. With all years combined, trapping rates were 17.9 fish/d in Fall Creek, 1.2 fish/d below Fall Creek Dam, 4.5 fish/d in the North Fork, 2.0 fish/d below Hills Creek Dam, and 0.7 fish/d below Lookout Point Dam. The number of salmon collected varied among years by an order of magnitude in Fall Creek and below Lookout Point Dam and varied by a factor of 2.4–4.4 at the North Fork, Fall Creek Dam, and Hills Creek Dam sites. Among-year variability was due, at least in part, to differences in the timing and duration of trap operations (see Figure 1.2).

Table 3.1. Annual and total numbers of juvenile Chinook salmon collected in screw traps and the numbers trapped per day of operation, 2003-2010.

<table>
<thead>
<tr>
<th>Trap</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>Total</th>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall Creek</td>
<td>-</td>
<td>-</td>
<td>6831</td>
<td>273</td>
<td>2126</td>
<td>43</td>
<td>-</td>
<td>-</td>
<td>9273</td>
</tr>
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<td>293</td>
<td>162</td>
<td>174</td>
<td>-</td>
<td>1025</td>
</tr>
<tr>
<td>North Fork</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1192</td>
<td>399</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>177</td>
<td>-</td>
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<td>948</td>
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<td>-</td>
<td>20</td>
<td>190</td>
<td>110</td>
<td>208</td>
<td>528</td>
</tr>
</tbody>
</table>

Salmon collected per day

<table>
<thead>
<tr>
<th>Trap</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
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<tbody>
<tr>
<td>Fall Creek</td>
<td>-</td>
<td>-</td>
<td>48.1</td>
<td>1.3</td>
<td>18.2</td>
<td>0.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fall Creek Dam</td>
<td>-</td>
<td>-</td>
<td>1.9</td>
<td>1.1</td>
<td>0.7</td>
<td>0.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>North Fork</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.9</td>
<td>3.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hills Creek Dam</td>
<td>6.9</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lookout Point Dam</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
<td>0.6</td>
<td>0.4</td>
<td>2.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>
The timing of Chinook salmon downstream movements differed among trap sites (Figure 3.1). Salmon were collected primarily from February to June in traps upstream from reservoirs and mostly from November to January in traps downstream from dams. Catch rates were highest in February (49 fish/d) and March (74 fish/d) in Fall Creek and in March-May (9-13 fish/d) in the North Fork. Below the dams, catch rates in November-January ranged from 2-4 fish/d below Fall Creek Dam, 2-12 fish/d below Hills Creek Dam, and ~1-4 fish/d below Lookout Point Dam. A May, 2008 spill event at Lookout Point Dam was associated with a catch rate of 1.2 fish/d for the month.

Figure 3.1. Numbers of Chinook salmon trapped per day of trap operation for each month with all years combined. Note different y-axis scales.

Chinook salmon trapping rates downstream from dams significantly \(0.19 \leq r^2 \leq 0.48, P < 0.05\) increased as reservoir elevation decreased (Figure 3.2). Below Fall Creek Dam, some
salmon were trapped at most reservoir elevations but the highest trapping rates were 5.3-5.6 fish/d at elevations between 220 and 230 m. Below Hills Creek Dam, the highest trapping rates were 10.9 (~444 m), 5.0 (~447 m) and 3.9 (~443 m) fish/d with very few fish trapped when elevation was higher. Below Lookout Point Dam, the highest trapping rate (2.3 fish/d) was at ~255 m elevation and almost no salmon were trapped at elevations > 260 m. An exception was that 0.8 fish/d was caught at ~281 m elevation during the May 2008 spill event. Trapping rates also significantly (0.73 ≤ r² ≤ 0.81) increased as total river discharge increased below Fall Creek (P = 0.006) and Lookout Point (P < 0.001) dams, but not below Hills Creek Dam (r² = 0.55, P = 0.260; Figure 3.3). In most cases, high discharge coincided with low reservoir elevation in winter.

Figure 3.2. Numbers of Chinook salmon collected in rotary screw traps per day in relation to reservoir elevation at Fall Creek (●), Lookout Point (●), and Hills Creek (○) dams, all years combined. Elevation was binned in 1.52 m (5 ft) increments. Weighted linear regression results: Fall Creek Dam, (Fish/day) = -0.082(elev) + 20.569, r² = 0.48; Lookout Point Dam, (Fish/day) = -0.030(elev) + 8.675, r² = 0.19; Hills Creek Dam, (Fish/day) = -0.232(elev) + 107.552, r² = 0.47.
Life history summary

Salmon trapped upstream from reservoirs were predominantly subyearlings plus small numbers of yearling fish, while those trapped below dams included a variety of size and age classes (Figure 3.4). Across sites and years, Chinook salmon fork lengths ranged from 2-38 cm (grand mean = 6.1 cm, SD = 6.1 cm; Figure 3.4). On average, salmon were smallest in Fall Creek (mean = 3.4 cm, SD = 1.1 cm, range = 2-15 cm) and the North Fork (mean = 4.8 cm, SD = 2.3 cm, range = 3-14 cm). Salmon trapped below dams were largest, on average, below Hills Creek Dam (mean = 20.0 cm, SD = 3.9 cm, range = 7-32 cm), followed by Lookout Point Dam (mean = 15.6 cm, SD = 6.0 cm, range = 3-38 cm) and Fall Creek Dam (mean = 14.6 cm, SD = 8.2 cm, range = 3-29 cm).

Mean salmon fork lengths differed significantly among sites (ANOVA F = 10.264.2, P < 0.001), with all pairwise comparisons significant (P < 0.05) in post hoc Tukey’s tests. Mean lengths also differed significantly among years at Fall Creek, North Fork, Fall Creek Dam, and Hills Creek Dam traps (49.0 ≤ F ≤ 183.7, P < 0.001) but not at Lookout Point Dam (F = 2.1, P = 0.094). When the fork length data were stratified by month, differences among the five sites were significant (14.5 ≤ F ≤ 1743.7, P < 0.001) for all months except July and September, when few salmon were collected.
Subyearlings in the 2-5 cm range made up > 96% of the Fall Creek sample and > 78% of the North Fork sample (Figures 3.4 and 3.5). Fish in this size class were first trapped in December in Fall Creek and in January in the North Fork and some were present until early summer at both sites (Figure 3.5). However, a group of 8-12 cm fish was trapped in late winter at both sites, indicating that some salmon spent additional months rearing near spawning areas before moving downstream (Figure 3.5). In addition, small percentages of the Fall Creek (~1%) and North Fork (~6%) fish collected in winter and early spring were in the 9-15 cm range and were presumed yearlings.

The Fall Creek Dam sample was more complex, with three modes in the fork length distribution (Figure 3.4). About 31% were subyearlings in the 2-5 cm size range trapped in
December-February (Figure 3.5). About 10% were in the 9-15 cm range, and most of these were trapped in November-February and were presumed yearlings. The remaining 59% of the sample was in the 16-29 cm range and ages of these fish were uncertain.

No small (2-5 cm) subyearlings were collected below Hills Creek Dam and the size distribution was bimodal (Figure 3.4). About 10% of the sample was fish in the 8-15 cm range and 90% was in the 16-32 cm range. As at Fall Creek Dam, the age of these samples was unknown. The 8-15 cm group collected in November-February (Figure 3.5) was presumably yearlings. Marked salmon captured below Hills Creek Dam were significantly (ANOVA F = 39.2, P < 0.001) larger (mean = 20.9 cm, SD = 2.3 cm, n = 398) than unmarked salmon (mean = 19.3 cm, SD = 4.7 cm, n = 550)

The size distribution at Lookout Point Dam was approximately bimodal, but included a right-skewed tail and possible third mode at ~26 cm (Figure 3.4). Less than 1% of the sample was small (2-5 cm) subyearlings, 54% was fish in the 8-15 cm range, 38% was in the 16-25 cm range, and 8% was in the 26-38 cm range. Most salmon were trapped between November and February and size classes were well-mixed in each month (Figure 3.5). The group of salmon that passed during the May 2008 spill event also spanned size classes and included several of the largest salmon collected in the study. As in samples below Fall Creek and Hills Creek dams, age classes in the Lookout Point Dam sample were unknown but probably included a mix of yearling and older fish.
Figure 3.5. Individual spring Chinook salmon fork length by screw trap capture date, all years combined. (Note: many data points are obscured, particularly in the smallest size class.) Data in the bottom right panel, shown for comparison, are monthly mean spring Chinook salmon fork lengths for subyearlings reared in Fall Creek reservoir (1966-1975, ○), caught emigrating from Fall Creek reservoir (1970-1974, ○), and reared at the Willamette Hatchery (1972 and 1974, ○); data are from Smith (1976).
Salmon mortality

The percentage of Chinook salmon that was dead inside screw traps varied significantly among sites ($\chi^2 = 4675.0, P < 0.001$, all years combined). Mortality was relatively low at sites upstream from reservoirs (annual rates $= 0.0$-1.9%) and high at sites downstream from dams (annual rates $= 7.8$-58.8%; Table 3.2). When only sites below dams were compared, total mortality differed significantly ($\chi^2 = 24.4, P < 0.001$) among Hills Creek (53.2%), Lookout Point (25.2%), and Fall Creek (13.8%) dam samples. There was also significant among-year variability in mortality in samples from Fall Creek ($\chi^2 = 18.4, P < 0.001$), Fall Creek Dam ($\chi^2 = 24.4, P < 0.001$), and Hills Creek Dam ($\chi^2 = 2.7, P = 0.0983$), but not from North Fork ($\chi^2 = 3.6, P = 0.057$) or Lookout Point Dam ($\chi^2 = 5.1, P = 0.168$).

Table 3.2. Annual and total percentages of juvenile Chinook salmon collected in screw traps that were dead, 2003-2010. See Table 3.1 for sample sizes.

<table>
<thead>
<tr>
<th>Trap</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Creek</td>
<td></td>
<td></td>
<td>0.2</td>
<td></td>
<td>1.5</td>
<td>0.1</td>
<td>0.0</td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Fall Creek Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.8</td>
<td>15.4</td>
<td>22.8</td>
<td>16.1</td>
<td>13.8</td>
</tr>
<tr>
<td>North Fork</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.9</td>
<td>0.5</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Hills Creek Dam</td>
<td>51.9</td>
<td>58.8</td>
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<td>15.0</td>
<td>30.0</td>
<td>20.0</td>
<td>24.5</td>
<td>25.2</td>
</tr>
</tbody>
</table>

Chinook salmon mortality was positively associated with fish fork length at all trap sites (Figure 3.6). Weighted linear regression models explained 23-63% of the variability in mortality at the two sites upstream from reservoirs and 35-80% of the variability at the sites downstream from dams ($P < 0.005$ except Fall Creek $P = 0.079$). Univariate logistic regression models were also significant ($P < 0.001$) for each site. Odds ratios were 1.402 (95% CI = 1.219-1.612) in Fall Creek and 1.729 (1.474-2.030) in North Fork models, indicating a substantial increase in the likelihood of mortality for larger fish in those samples. Odds ratios were 1.074 (1.046-1.103) in models for Fall Creek Dam, 1.140 (1.098-1.183) Hills Creek Dam, and 1.188 (1.144-1.235) Lookout Point Dam, indicating a 7-18% increase in mortality for each 1-cm increase in fork length. Results below Hills Creek Dam were not significant for marked salmon (odds ratio $= 1.085, 95\%$ CI $= 0.992$-1.186, $P = 0.076$) but were for unmarked fish (odds ratio $= 1.162, 95\%$ CI $= 1.114$-1.212, $P < 0.001$). The latter result reflected, in part, the narrower size range for marked fish.

Downstream from dams, Chinook salmon mortality was associated with reservoir elevation and river discharge in addition to fish size. Univariate logistic regression models using the environmental variables were significant ($P < 0.05$) in most cases, but the direction of the effects differed among sites. For example, mortality increased with increasing reservoir elevation above Hills Creek and Lookout Point dams, but decreased as elevation increased above Fall Creek Dam. Similarly, mortality decreased as discharge increased below Fall Creek and Hills Creek dams, but the opposite was true below Lookout Point Dam. In exploratory multivariate analyses, there were interactive effects among reservoir elevation, river discharge, and salmon fork length variables. The interactions were related to likely among-year environmental variability, to
salmon of different size classes passing at different seasons (see Figure 3.5), and differences in the operational conditions and passage route availability encountered by fish.

Figure 3.6. Percentages of dead Chinook salmon collected in rotary screw traps in relation to fish fork length at Fall Creek (○) and the North Fork (●) (top panel) and at Fall Creek (●), Lookout Point (●), and Hills Creek (○) dams (bottom panel), all years combined. Weighted (by numbers of salmon in each 1-cm length interval) linear regression results: Fall Creek, mortality = 0.003(length) - 0.007, \( r^2 = 0.23 \); North Fork, mortality = 0.012(length) - 0.043, \( r^2 = 0.63 \); Fall Creek Dam, mortality = 0.007(length) + 0.034, \( r^2 = 0.35 \); Lookout Point Dam, mortality = 0.031(length) - 0.226, \( r^2 = 0.80 \); Hills Creek Dam, mortality = 0.030(length) - 0.070, \( r^2 = 0.68 \).

The multi-model logistic regression comparisons indicated that a combination of salmon fork length, reservoir elevation, and discharge variables affected salmon mortality below each dam (Table 3.3). In the Fall Creek Dam comparison, five models had support with \( \Delta AIC \leq 2.0 \) (Table 3.3). The most parsimonious model included the two interaction terms (fork length \( \times \) reservoir elevation and fork length \( \times \) river discharge) and each was significant \( (P < 0.001) \). In this model, the probability of mortality increased with salmon size and generally decreased as both reservoir elevation and river discharge decreased, although some of the lowest estimates were at intermediate elevations (Figures 3.7 and 3.8). The four other models with statistical support included a mix of river discharge, reservoir elevation, and interaction terms in addition to fork
length (Table 3.3). Notably, univariate models (i.e., fork length only, discharge only, elevation only) had no statistical support compared to multivariate models.

Table 3.3. Selection statistics for logistic regression models of juvenile Chinook salmon mortality for fish captured in screw traps downstream from Fall Creek, Hills Creek, and Lookout Point dams. FL = Chinook salmon fork length, RE = reservoir elevation, RD = total river discharge. Bold text indicates most parsimonious models and shading indicates support with ΔAIC ≤ 2.0.

<table>
<thead>
<tr>
<th>Model</th>
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<th></th>
<th></th>
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<th>Hills Creek Dam</th>
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Three models had support in the Hills Creek Dam comparison, and the model with fork length ($P < 0.0001$) and fork length×reservoir elevation ($P < 0.0001$) variables was most parsimonious (Table 3.3). In this model the lowest probability of mortality was for the smallest fish and when reservoir elevation was lowest (Figure 3.9). Mortality probabilities > 90% were predicted for salmon with fork length > ~22 cm that passed when elevation was ≥ ~447 m. (Note: marked and unmarked fish were included to maximize sample size.)

At Lookout Point Dam, the full model was most parsimonious, and no other models had statistical support (all ΔAIC ≥ 9.2; Table 3.3). Each of five terms was significant: fork length ($P = 0.0037$), reservoir elevation ($P = 0.0005$), river discharge ($P = 0.0116$), fork length×reservoir elevation ($P = 0.0043$), and fork length×river discharge ($P = 0.0012$). There was a relatively strong size effect, with much higher probability of mortality for larger fish, increasing mortality at higher reservoir elevation, and modest increases in mortality with increasing river discharge (Figures 3.10 and 3.11). Thirteen percent (71/528) of the Lookout Point sample was collected during a May 2008 surface spill event when reservoir elevation was ~281 m (Figure 3.10). The most parsimonious model with these fish excluded had fork length ($P = 0.777$), river discharge ($P = 0.028$), and fork length×river discharge ($P = 0.003$). In this model, the probability of mortality was highest for large fish that passed during high discharge, while mortality probability for fish in the smallest size classes decreased as discharge increased (Figure 3.12).
Figure 3.7. Bubble plot showing the relationship between Fall Creek reservoir elevation, Chinook salmon fork length, and the probability of salmon mortality as predicted from the logistic regression model: mortality = (fork length x reservoir elevation) + (fork length x river discharge). Larger bubbles indicate higher mortality probability.

Figure 3.8. Bubble plot showing the relationship between river discharge at Fall Creek Dam, Chinook salmon fork length, and the probability of salmon mortality as predicted from the logistic regression model: mortality = (fork length x reservoir elevation) + (fork length x river discharge). Larger bubbles indicate higher mortality probability.
Figure 3.9. Bubble plot showing the relationship between Hills Creek reservoir elevation, Chinook salmon fork length, and the probability of salmon mortality as predicted from the logistic regression model: mortality = fork length + (fork length\times reservoir elevation). Larger bubbles indicate higher mortality probability.

Figure 3.10. Bubble plot showing the relationship between Lookout Point reservoir elevation, Chinook salmon fork length, and the probability of salmon mortality as predicted from the logistic regression model: mortality = fork length + reservoir elevation + river discharge + (fork length\times reservoir elevation) + (fork length\times river discharge). Larger bubbles indicate higher mortality probability.
Figure 3.11. Bubble plot showing the relationship between river discharge at Lookout Point Dam, Chinook salmon fork length, and the probability of salmon mortality as predicted from the logistic regression model: mortality = fork length + reservoir elevation + river discharge + (fork length\times reservoir elevation) + (fork length\times river discharge). Larger bubbles indicate higher mortality probability.

Figure 3.12. Bubble plot showing the relationship between river discharge at Lookout Point Dam, Chinook salmon fork length, and the probability of salmon mortality as predicted from the logistic regression model: mortality = fork length + river discharge + (fork length\times river discharge). Larger bubbles indicate higher mortality probability. Salmon that passed during a May 2008 surface spill event were excluded (compare to Figure 3.11.).
Effects of regulating outlet and surface spill. – Regulating outlet spill occurred on about 19% of the days that the screw trap was operated downstream from Hills Creek Dam. However, the RO outlet channel was downstream from the screw trap site, so it was not possible to directly assess the effects of RO passage on mortality. We did test whether the high-discharge conditions associated with RO operation was associated with mortality for fish that passed via turbines. A total of 437 Chinook salmon were trapped during RO spill events below Hills Creek Dam, and mortality for this group was 51.5%, not significantly different ($\chi^2 = 0.9$, $P = 0.339$) than for salmon collected during no-spill conditions (54.6%, $n = 511$). However, salmon collected during RO spill were significantly (ANOVA $F = 8.6$, $P = 0.003$) smaller ($mean = 19.6$ cm, $SD = 4.7$ cm) than those collected during no-spill ($mean = 20.3$ cm, $SD = 3.1$ cm). In a logistic model with mortality as the dependent variable and RO spill (yes, no) and fork length as predictor variables, mortality was higher for larger fish ($\chi^2 = 47.3$, $P < 0.001$) and spill was not significant ($\chi^2 = 0.1$, $P = 0.756$). Proportions of marked and unmarked salmon were similar (45-47%) in RO spill and no-spill samples.

At Lookout Point Dam, RO and/or surface spill occurred on about 3% of the days that one or both screw traps were operated. A total of 254 Chinook salmon were trapped during spill events in January (2009, 2010) and May (2008). Mortality for this group was 35.4%, significantly ($\chi^2 = 27.3$, $P < 0.001$) higher than for salmon collected during no-spill conditions (15.7%, $n = 274$). Unlike at Hills Creek Dam, salmon collected during Lookout Point spill were significantly ($F = 19.9$, $P < 0.001$) larger ($mean = 16.8$, $SD = 6.2$ cm) than those collected during no-spill ($mean = 14.5$ cm, $SD = 5.7$ cm). In the logistic model, both terms were significant, with higher mortality for larger fish ($\chi^2 = 69.2$, $P < 0.001$) and during spill ($\chi^2 = 14.9$, $P < 0.001$).

Discussion

Life history and downstream passage

The screw trap samples provide several insights into the life history and migration ecology of juvenile Chinook salmon in the Middle Fork Willamette River. Perhaps most importantly, the results demonstrate that dam and reservoir operations clearly affect the rate and timing of Chinook salmon passage at the downstream sites. These effects alter the basic life history timetable of salmon in the basin and lead to varying levels of migration delay and reservoir entrapment. There was compelling evidence that many subyearlings and some yearling fish rear and possibly residualize in the reservoirs, with currently unknown effects on growth and survival. There was also considerable variability in downstream passage patterns among sites, among years, and among salmon age classes, suggesting that environmental conditions and dam-specific features or operations affected salmon behavior and passage.

Salmon collection rates below dams were highest from late fall to late winter when reservoir elevations were low and fish access to downstream passage routes (i.e., turbine and regulating outlet intakes) was relatively high. Most of the regulating outlet spill at Lookout Point and Hills Creek dams also occurred during this winter period, and circumstantial evidence suggested that many salmon may have passed via these routes. In contrast, collection rates upstream from reservoirs were highest in early spring through early summer, coincident with the emigration of
subyearling and, to a much lesser extent, yearling juvenile Chinook salmon from spawning areas. These fish entered reservoirs as pools were rapidly filling. Increasing depth to turbine and regulating outlet intakes during this time likely prevented downstream passage for many fish. Blocked downstream routes may be especially consequential for yearling smolts that would almost certainly have continued outmigrating had routes been more accessible.

The fork length data provided evidence for at least two – and possibly as many as four – Chinook salmon age classes in the aggregate sample. Above dams, samples were predominated by small subyearlings (2-5 cm) that likely emigrated from spawning areas within weeks to several months after emergence. This subyearling behavior is relatively common among spring Chinook salmon in the Willamette River basin (Friesen et al. 2005, 2007) and in some other stream-type Chinook salmon populations where growth opportunities improve downstream from spawning tributaries (e.g., Connor et al. 2001). Much smaller percentages of the above-reservoir samples were presumed yearling fish that had likely begun smoltification in preparation for rapid emigration to the ocean (Wedemeyer et al. 1980; Quinn 2005). There appeared to be yearling-sized fish moving downstream at several different times of the year, indicating either differential growth rates in reservoirs versus spawning streams or possible plasticity in smoltification timing (e.g., Beckman et al. 2003).

The life histories of the samples collected downstream from dams were more complex. There were small numbers of small subyearling fish in some years and ~10-50% of the annual samples were likely yearlings in the 8-15 cm size class. These fish either reared in reservoirs as subyearlings or entered reservoirs as yearlings and passed through with limited reservoir residency. In previous studies, subyearling salmon that reared in Fall Creek reservoir and in the North Fork reservoir on the Clackamas River averaged between 11 and 17 cm by late fall (Smith 1976; Cramer et al. 1996). We were therefore less certain about the age of relatively large juveniles in the 20-38 cm range. Some of these fish may have been yearlings, or possibly even subyearlings, that grew very rapidly in the reservoirs (e.g., Cramer et al. 1996; Connor and Burge 2003). Others were likely two-year-old and possibly three-year-old fish that residualized in the reservoirs after failing to pass when they were physiologically ready to migrate. The largest salmon were collected downstream from Lookout Point Dam, and some of these may have been two- or three-year old fish that spent a year each in the Hills Creek and Lookout Point reservoirs.

The combined migration timing and fork length data suggest that several life history strategies may be expressed by Middle Fork Chinook salmon in response to prevailing river and reservoir conditions. These include subyearling emigration, stream resident rearing followed by yearling emigration, reservoir rearing with yearling emigration, and likely reservoir residualizing (e.g., Dilley and Wunderlich 1993; Connor et al. 2005). Quantifying the incidence of these strategies will require tagging studies or aging studies using either otoliths or scales (e.g., Kennedy et al. 2002; Fisher and Pearcy 2005; Volk et al. 2010). A preliminary scale analysis using fish collected in Lookout Point reservoir and in other Willamette River basin reservoirs has shown that some scales have two annuli, indicating reservoir residualizing, while others show likely reservoir rearing followed by winter outmigration (Lisa Borgersen, ODFW, personal communication). The survival costs and benefits of the various strategies are currently unknown in the study system. Time spent in reservoirs may confer some competitive advantages, including larger size during outmigration (e.g., Zabel and Achord 2004; Monzyk et al. 2009), but
such benefits must be weighed against increased dam passage mortality risk for larger fish, migration delay, and mismatches between physiological readiness and migration opportunity.

**Salmon mortality**

Annual Chinook salmon mortality rates downstream from dams ranged from 8-59%, and differed significantly among sites and years. Mortality was almost certainly underestimated given substantially lower trap efficiency for dead versus live salmon (see Chapter 1). We also did not estimate trap-related mortality or differentiate between direct (i.e., acute) versus delayed mortality. However, based on the very low salmon mortality estimates at the sites above reservoirs (< 2%) and in other screw trap studies (e.g., Chaput and Jones 2004; Scace et al. 2007; Music et al. 2010), we think that trap-related salmon mortality was also low (< 5%) at the below-dam sites in this study. Downstream from dams, a portion of the dead fish probably died in the traps from injuries sustained during dam passage (i.e., delayed mortality). This component was difficult to measure, although the mechanism of injury (i.e., blunt trauma, decapitation, etc.) was obvious in many dead fish. Furthermore, no fish were held after capture to directly assess post-capture delayed effects (e.g., Deng et al. 2010). Such effects have accounted for a large portion of total dam-related mortality in several studies (e.g., Kostecki et al. 1987; Dubois and Gloss 1993; Ferguson et al. 2006). For these reasons, we expect that total Chinook salmon mortality associated with Middle Fork dam passage was higher than the estimates presented here.

Salmon size was a consistent predictor of mortality across sites, but especially downstream from dams. In all cases, mortality was significantly higher for larger fish (i.e., for yearlings and older age classes). Below dams, this suggests that larger fish were more susceptible to lethal or sub-lethal injuries from shear stress, cavitation, turbine blade strikes, rapid pressure changes, or blunt force trauma than were smaller individuals. Many of the dead salmon had injuries consistent with one or several of these mechanisms (i.e., decapitation, swim bladder ruptures, contusions, descaling), and it is likely that the types of injuries varied with passage route and operational conditions (e.g., Coutant and Whitney 2000; Čada 2001; Ferguson et al. 2008; Deng et al. 2010).

Although salmon size was clearly important, operational and environmental variables were also significant predictors of mortality. The multi-model comparison indicated that these effects were complex, in part because there were significant interaction effects and because salmon size varied non-randomly through each year. For example, salmon of different size classes passed each dam during different seasons and therefore encountered different operational conditions. The analysis was further confounded by uncertainty about which passage routes (i.e., the spillway at Lookout Point Dam vs. turbine vs. regulating outlet) salmon used. Despite these limitations, some patterns emerged. Below Lookout Point Dam, mortality was higher when discharge and reservoir elevation were high and when spill was occurring, even after accounting for salmon size effects. Mortality below Hills Creek Dam was also higher when reservoir elevation was high. The elevation effects may indicate that passing through turbines or regulating outlets when the intakes were at greater depth increased some injury types (i.e., related to pressure). The discharge and spill effects at Lookout Point Dam may indicate relatively high hazard for fish passing via the regulating outlets or over the spillway. Some of these patterns were reversed at Fall Creek Dam, with lower mortality when elevation and
discharge were higher. It is possible that regulating outlets were opened wider during these operations, and there were possible interaction effects with salmon size and passage timing.

There have been few route-specific juvenile salmon survival studies at the Willamette dams. In part, this is because there were few or no juveniles produced upstream from many of the projects. However, if juvenile production becomes a priority in the adult outplant programs, there will be a need to partition route-specific and operation-specific injury and mortality rates at the dams (e.g., Bickford and Skalski 2000; Budy et al. 2002; Mathur et al. 2000). Such differentiation was not possible with the current dataset. Total Chinook salmon mortality estimates for all passage routes combined (14% at Fall Creek, 25% at Lookout Point, and 53% at Hills Creek) suggest that there are important differences among projects. This may reflect either a difference in the proportions of fish using each route (i.e., the proportion that passed via turbines at each dam) or differences in the hazards associated with individual routes. Previous small-scale studies at Hills Creek and Fall Creek dams and at Cougar Dam on the McKenzie River have shown mortality rates for salmon that pass via regulating outlets and turbines range up to 70% (Downey and Smith 1990; Homolka and Downey 1991; Taylor 2000; ODFW 2004 and citations therein). Mortality studies initiated in 2009-2010 will help refine our understanding of the mechanisms affecting mortality for fish passing via the various routes at Willamette Project dams.

References


NMFS. 2008b. 2008 Willamette Project Biological Opinion. NMFS.


***************************************************************************************
Appendix Figures

Appendix Figure 1. Fall Creek Dam reservoir elevation and total discharge.
Appendix Figure 2. Hills Creek Dam reservoir elevation, total discharge, and regulating outlet spill.
Appendix Figure 3. Lookout Point Dam reservoir elevation, total discharge, and regulating outlet plus spillway spill.