

In cooperation with PacifiCorp

# **Development of New Information to Inform Fish Passage Decisions at the Yale and Merwin Hydro Projects on the Lewis River, Washington—Final Report, 2018**



Open-File Report 2018–1190

U.S. Department of the Interior  
U.S. Geological Survey

**Front cover.** A view from the floating surface collector at Swift Dam on Swift Reservoir in the upper Lewis River, Washington.

**Back cover.** An adult *Oncorhynchus kisutch* (coho salmon) after spawning in Clear Creek in the upper Lewis River, Washington.

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By Robert Al-Chokhachy, Christopher L. Clark, Mark H. Sorel, and David A. Beauchamp

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**U.S. Department of the Interior  
U.S. Geological Survey**



## **U.S. Department of the Interior**

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## Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
micrometer ( $\mu\text{m}$ )	0.0000393701	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Area		
square meter ( $\text{m}^2$ )	0.0002471	acre
square kilometer ( $\text{km}^2$ )	247.1	acre
square meter ( $\text{m}^2$ )	10.76	square foot ( $\text{ft}^2$ )
square kilometer ( $\text{km}^2$ )	0.3861	square mile ( $\text{mi}^2$ )
Volume		
cubic meter ( $\text{m}^3$ )	6.290	barrel (petroleum, 1 barrel = 42 gal)
cubic meter ( $\text{m}^3$ )	264.2	gallon (gal)
cubic meter ( $\text{m}^3$ )	0.0002642	million gallons (Mgal)
liter (L)	61.02	cubic inch ( $\text{in}^3$ )
cubic meter ( $\text{m}^3$ )	35.31	cubic foot ( $\text{ft}^3$ )
cubic meter ( $\text{m}^3$ )	1.308	cubic yard ( $\text{yd}^3$ )
cubic meter ( $\text{m}^3$ )	0.0008107	acre-foot (acre-ft)
Flow rate		
cubic meter per second ( $\text{m}^3/\text{s}$ )	70.07	acre-foot per day (acre-ft/d)
cubic meter per second ( $\text{m}^3/\text{s}$ )	35.31	cubic foot per second ( $\text{ft}^3/\text{s}$ )
cubic meter per day ( $\text{m}^3/\text{d}$ )	264.2	gallon per day (gal/d)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t)	1.102	ton, short [2,000 lb]
metric ton (t)	0.9842	ton, long [2,240 lb]
microgram ( $\mu\text{g}$ )	0.00000003527	ounce, avoirdupois (oz)
Energy		
joule (J)	0.0000002	kilowatthour (kWh)

Temperature in degrees Celsius ( $^{\circ}\text{C}$ ) may be converted to degrees Fahrenheit ( $^{\circ}\text{F}$ ) as  $^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$ .

## Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 1983).

## Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ( $\mu\text{S}/\text{cm}$  at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter ( $\mu\text{g}/\text{L}$ ).

Results for measurements of stable isotopes of an element (with symbol E) in water, solids, and dissolved constituents commonly are expressed as the relative difference in the ratio of the number of the less abundant isotope ( $^i\text{E}$ ) to the number of the more abundant isotope of a sample with respect to a measurement standard.

Note to USGS users: Use of liter (L) as a special name for cubic decimeter ( $\text{dm}^3$ ) is restricted to the measurement of liquids and gases. No prefix other than milli should be used with liter.

## Abbreviations

AICc	Akaike Information Criteria corrected for small sample size
CHaMP	Columbia Habitat Monitoring Program
CPUE	catch-per-unit effort
CV	coefficient of variation
DFW	Department of Fish and Wildlife
EDT	Ecosystem Diagnosis and Treatment
FSC	floating surface collector
LWD	large woody debris
PIT	passive integrated transponder
PUD	public utility district
RSW	removable spillway weir
SA	surface area
SAS	smolt-to-adult survival rates
SBC	surface bypass collector
SD	standard deviation
SE	standard error
USGS	U.S. Geological Survey
UW-IACUC	University of Washington Institutional Animal Care and Use Committee
YOY	young-of-year

## Species

bluegill (*Lepomis macrochirus*)  
 brown bullheads (*Ameiurus nebulosus*)  
 bull trout (*Salvelinus confluentus*)  
 Chinook salmon (*Oncorhynchus tshawytscha*)  
 cladocerans (*Cladocera*)  
 cladoceran encased in a gelatinous shell (*Holopedium gibberum*)  
 copepods (*Copepoda*)  
 coastal cutthroat trout (*O. clarkii clarkii*)  
 coho salmon (*O. kisutch*)  
 cutthroat trout (*O. clarkii*)  
*Daphnia* (*Daphnia* spp.)  
 kokanee salmon (*O. nerka*)  
 largemouth bass (*Micropterus salmoides*)  
 mayflies (*Ephemeroptera*)  
 mountain whitefish (*Prosopium williamsoni*)  
 northern pike (*Esox lucius*)  
 northern pikeminnow (*Ptychocheilus oregonensis*)  
 Pacific salmon (*O. spp.*)  
 pumpkinseed sunfish (*L. gibbosus*)  
 rainbow trout (*O. mykiss*)  
 sculpin (*Cottus* spp.)  
 signal crayfish (*Pacifastacus leniusculus*)  
 sockeye salmon (*O. nerka*)  
 steelhead (*O. mykiss*)  
 threespine stickleback (*Gasterosteus aculeatus*)  
 tiger muskellunge (*E. lucius* x *masquinongy*)  
 tiger muskellunge (*E. masquinongy* x *lucius* or *E. lucius* x *masquinongy*)  
 westslope cutthroat trout (*O. clarkii lewisi*)



## Scientific Notation

$\chi^2$	Chi-square
dB	decibels
°	degree
°C	degrees Celsius
$df$	degrees of freedom
FL	fork length
$FL$	Frasier-Lee
>	greater than
$\geq$	greater than or equal to
<	less than
$\leq$	less than or equal to
$C_{\max}$	maximum theoretical consumption
$\%C_{\max}$	percent of maximum theoretical consumption
$r$	Pearson correlation coefficient
%	percent
$\pm$	plus or minus
$\delta^{13}\text{C}$	ratio of carbon isotopes $^{12}\text{C}$ and $^{13}\text{C}$
$\delta^{15}\text{N}$	ratio of nitrogen isotopes $^{15}\text{N}$ and $^{14}\text{N}$
$W$	weight-at-age
$\mu\text{E}$	microeinsteins
$\Phi$	apparent survival



# Development of New Information to Inform Fish Passage Decisions at the Yale and Merwin Hydro Projects on the Lewis River, Washington—Final Report, 2018

By Robert Al-Chokhachy,<sup>1</sup> Christopher L. Clark,<sup>2</sup> Mark H. Sorel,<sup>3</sup> and David A. Beauchamp<sup>1</sup>

## Executive Summary

The reintroduction of extirpated salmonids to historically occupied areas is becoming increasingly common as a conservation and recovery strategy. Often, reintroductions are implemented after the factors that originally led to species extirpation have been reduced, eliminated, or mitigated. For anadromous *Oncorhynchus* spp. (Pacific salmon) and *O. mykiss* (steelhead), addressing barriers to migration, which have been a primary factor in the decline and extirpation of many populations, has been an integral component of recovery efforts. Mitigation has included barrier removal, developing fish passage opportunities, and (or) actively trapping and hauling juvenile and adult anadromous salmonids around barriers.

With any reintroduction, there are a number of concerns regarding the ecological impact of the reintroduction efforts. Three of the main tenets to consider when assessing reintroductions are (1) the potential benefits if reintroduction is successful, (2) the biological risk through interactions of reintroduced strains with existing populations, and (3) the factors potentially limiting a successful reintroduction. This report focuses on information and data to address the second and third factors as they apply to the upper Lewis River in Washington.

The upper Lewis River historically contained wild populations of *O. tshawytscha* (Chinook salmon), *O. kisutch* (coho salmon), and steelhead. These populations were extirpated after completion of hydropower facilities on Lake Merwin in 1932, Yale Lake in 1953, and Swift Reservoir in 1958, which prevented fish from migrating to and from ocean environments. However, recent licenses issued by the Federal Energy Regulatory Commission require the installation and operation of an upstream fish passage facility at Lake Merwin and a downstream fish passage facility at Swift Reservoir. The licenses were developed in consultation with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service. The overarching goal of this fish reintroduction project is to establish viable, self-sustaining, naturally reproducing, harvestable populations of spring Chinook salmon, winter steelhead, and coho salmon at levels higher than minimum viable populations.

This report uses a combination of field data and existing information to address six key objectives related to the reintroduction in order to inform decisions about passage at the Yale Lake and Lake Merwin hydropower projects. The objectives are (1) a review of information relevant to anadromous fish reintroduction and full fish passage; (2) a habitat assessment of tributaries to Swift Reservoir, Yale Lake, and Lake Merwin; (3) a field study to assess adult potential for spawning success; (4) an assessment of juvenile production and outmigration success; (5) a Lake Merwin predator impact study; and (6) a set of studies assessing interactions between anadromous and resident fish.

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## **Chapter A. Review of Information Relevant to Anadromous Fish Reintroduction to and Fish Passage in the Lewis River, Washington**

Comparing the success of collection operations for juvenile and adult fish at different locations is challenging because of different collection designs, hydrologic conditions, and reservoir bathymetry. In general, juvenile and adult injuries and direct mortalities appear to be generally low regardless of species and location; the extent of delayed mortality, however, is less clear. Juvenile collection efficiencies are highly variable between locations and species, likely because of the inherent differences at the various locations. Fallback rates of adult Pacific salmon and steelhead in trap and haul operations are poorly studied, but available data from such operations and other hydropower facilities show that fallback rates can be moderate (up to 24 percent) but variable. The review highlights the need to continue to evaluate designs and operations that can increase the effectiveness of trap and haul operations (for example, increase the collection efficiency of juveniles) while minimizing the effects to target and nontarget taxa.

## **Chapter B. Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington**

Aside from a finite number of locations, empirical habitat data suggest little evidence that habitat quality will limit salmon and steelhead introductions. Overall, stream temperatures vary extensively within the upper Lewis River Basin, but do not appear to be a limiting factor in the near term for anadromous species. The extent of available habitat varies across reservoirs from primarily natural barriers, with particularly low amounts of habitat (8.2 kilometers) available to anadromous species in Lake Merwin.

## **Chapter C. Studies Assessing Adult Potential for Spawning Success in Yale Lake and Lake Merwin, Washington**

The ability to thoroughly evaluate spawning success in Yale Lake and Lake Merwin was constrained to a single year in Lake Merwin by low numbers of available salmon. Field results with coho salmon did show that adults use a variety of habitat types. Young-of-year coho salmon recruitment was lower than observed in Swift Reservoir based on measures of catch-per-unit effort, but size distributions of fish were similar. The lower recruitment was likely driven by the proximity of coho salmon spawning to the reservoirs and migration patterns, which were not documented herein. The robust habitat in the tributaries and spawning and recruitment patterns suggest high potential for successful spawning in Lake Merwin and Yale Lake.

## **Chapter D. Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington**

Using a combination of field methods, results suggested outmigration success may be limited by collection efficiencies. Test releases of hatchery-reared juvenile salmon suggested fish migrated relatively quickly through the reservoir environments. However, median travel time for individually tagged coho salmon and steelhead indicated movements through Swift Reservoir to



the floating surface collector at Swift Dam were 37 days and 21 days, respectively. Most salmon and steelhead were collected at the floating surface collector in the spring (April 15–June 30) and survival through the reservoir environment was high (54 percent). Among spring Chinook salmon, coho salmon, and steelhead collection efficiencies were low and did not exceed 18.7 percent. The low proportions of juvenile salmon and steelhead reaching the downstream collector suggests a considerable number of fish are likely residualizing in the reservoir environment.

## Chapter E. Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington

The population of *Ptychocheilus oregonensis* (northern pikeminnow) in Lake Merwin is extensive suggesting considerable predation on juvenile anadromous salmon and steelhead. Northern pikeminnow were increasingly piscivorous with size and diet studies suggested major prey items included pelagic and benthic fish and crayfish. The current size distribution of northern pikeminnow suggests extensive predation by large (greater than or equal to 300 millimeters) northern pikeminnow and *Esox lucius x masquinongy* (tiger muskellunge). Bioenergetics model estimates of northern pikeminnow predation on salmonids indicated the potential for 39,250 Chinook salmon smolts to be preyed upon each year. The predation during peak salmon migration (that is, April–June) was markedly lower. Predation by tiger muskellunge on northern pikeminnow would likely continue to reduce the overall predation on salmonids by northern pikeminnow.

## Chapter F. Studies Assessing Anadromous-Resident Fish Interactions in the Lewis River, Washington

A review of existing literature addressing anadromous-resident fish interactions suggests high potential for interactions given the diverse life-history patterns of resident fish such as *O. clarkii clarkii* (coastal cutthroat trout) and *Salvelinus fontinalis* (bull trout). Although some differences in thermal requirements between salmon and steelhead and resident salmonids exist, overlap in juvenile rearing (all species) and spawning of coho salmon and bull trout is likely. Bull trout predation on salmon and steelhead would be expected, given that bull trout is a top-level predator in the Pacific Northwest. While population-level effects are unknown, bull trout historically overlapped with salmon and steelhead suggesting limited implications to salmon and steelhead populations.

Field studies from Swift Reservoir show that the distribution of coastal cutthroat trout, bull trout, and coho salmon varied spatially across tributaries. Where sympatric, the results from diet studies in stream habitat indicate similar diets for juvenile coastal cutthroat trout, bull trout, and coho salmon. Coho salmon were found to superimpose on bull trout spawning redds, and the later timing of coho salmon spawning indicates a high potential for further superimposition. Diet studies indicated bull trout to be the top predator in Yale Lake and Swift Reservoir, yet there were few indications that bull trout preyed upon juvenile coho or Chinook salmon. The lack of predation on juvenile salmon may be from bull trout gape limitations and the larger size of juvenile salmon currently in Swift Reservoir. Pelagic studies illustrate that food abundance will limit the number of planktivorous fish in reservoir environment, and modeling results indicate that shifts in the amount of forage for juvenile bull trout may be detrimental to the population in the long term. The large changes in the physical template of the upper Lewis River Basin stemming from habitat alterations (for example, building of hydropower facilities, the eruption of Mount Saint Helens) means uncertainty in how anadromous reintroductions will influence native salmonids such as bull trout.



# Chapter A. Review of Information Relevant to Anadromous Fish Reintroduction to and Fish Passage in the Lewis River, Washington

## Introduction

The complex life cycle of *Oncorhynchus* spp. (Pacific salmon) predicates the need to understand fish passage at different life stages during reintroduction efforts (Anderson and others, 2014), particularly in trap and haul operations. The extirpation of populations of *O. tshawytscha* (Chinook salmon), *O. kisutch* (coho salmon), and *O. mykiss* (steelhead) after completion of hydropower facilities (Merwin Dam, Yale Dam, and Swift Dam; fig. A1) in the upper North Fork of the Lewis River predicated the need for the installation and operation of an upstream fish passage facility at Lake Merwin and a downstream fish passage facility at Swift Reservoir. This report is a complement to previous documents (PacifiCorp and Cowlitz Public Utility District [PUD], 2002) but with specific objectives of reviewing different aspects of anadromous species reintroductions above hydropower facilities, particularly where trap and haul operations are used. As such, the specific objectives of this report are to assess key attributes related to reintroductions including (1) the effects of juvenile acclimation facilities on salmon performance; (2) downstream collection efficiency and injury and survival at downstream collection facilities; (3) adult fallback, injury, and survival; and (4) collection at adult fish upstream collection facilities. Each of these attributes (for example, downstream collection efficiencies) is likely to be particularly relevant in considering the overall success and effects of the anadromous reintroductions. For example, collection efficiency, which is the proportion of fish within the zone of influence that are collected, will have profound effects on factors such as overall capacity, reservoir capacity, and anadromous-resident interactions. Thus, the direct and indirect implications of each of the attributes described in this study needs to be considered in assessing the reintroduction of anadromous salmon in each of the reservoir environments.

## Effects of Smolt Acclimation Facilities

**Rearing and release.**—Smolt acclimation facilities are commonly used to reduce stress associated with fish transport (Maule and others, 1989; Schreck and others, 1989) and for imprinting natal waters to induce adults to return to specific acclimation streams (Dittman and others, 2010). Acclimation facilities that integrate local surface-water sources also provide more natural stream temperatures, particularly where source hatcheries maintain relatively constant stream temperatures. A variety of acclimation facilities are currently being employed in anadromous species supplementation and reintroduction programs including aluminum tanks (for example, McLeod, 2008), off-channel raceways (for example, Zollman and others, 2009), and semi-natural stream channels and ponds (for example, PacifiCorp and Cowlitz PUD, 2011).

Survival within the acclimation facilities is high (typically greater than [ $>$ ] 98 percent; table A1.1 in appendix A1), excluding any disease (not covered herein). In most facilities, smolts are allowed volitional movements out of the acclimation facilities to natural systems; the time allowed for volitional release varies by systems, but typically ranges from 1–8 weeks (Cleary, 2005; Clarke and others, 2011), after which remaining smolts are often forced out of the acclimation facilities. The percentage of smolts to volitionally release from acclimation facilities can vary considerably between systems. Cleary (2005) found high (88–97 percent for all releases) volitional release of spring Chinook salmon smolts within 10 days of acclimation in the Lostine River in Oregon, which is consistent with the pattern of 100 percent volitional release for spring Chinook salmon in the Hood River, Oregon (Gerstenberger, 2009). Osborne and Rhine (1999) and Gerstenberger (2009) have reported high volitional releases ( $>$ 85 percent) for steelhead. However, Cleary and others (2006) found considerable annual variability in proportion of volitional releases of Chinook salmon during 1999–2004 with values as low as 10.9 percent, and low percentages of volitionally migrating smolts have been reported elsewhere (for example, McLean and others, 2003).

Of concern are the effects of the length of acclimation and volitional emigration as opposed to forced emigration of smolts from acclimation facilities. In a recent study, Clark and others (2012) found the amount of time spring Chinook salmon were acclimated (either 2 or 4 months) had little effect on smolt survival or stray rates, but longer acclimation (4-month acclimation from November through early March) resulted in significantly slower travel times and 27 percent higher smolt-to-adult survival rates (SAS). However, identifying the relative effects of a longer acclimation period and over-winter acclimation on parameters such as survival, stray rates, and SAS was not possible because of the limited available information.

The effects of volitional as opposed to forced release of smolts from acclimation facilities appear to be inconsistent for the different studies. In a comparison of juvenile steelhead in Washington, Gale and others (2009) found no consistent differences in survival rates or travel times of volitional and forced-migrant smolts. In contrast, Clarke and others (2011) found smolts that migrated volitionally from acclimation facilities had slower travel times and significantly higher survival rates but the higher smolt survival rate did not result in higher SAS rates for volitional migrants. The uncertainty in the effects of release strategies suggests additional research is needed with paired, experimental approaches.

*Acclimation and smolt migration patterns.*—Studies have shown inconsistent effects of acclimation on anadromous migration patterns. In a 10-year paired study, Clarke and others (2010) found travel times for acclimated summer steelhead to be 10 percent (2.9 days) longer than for fish directly released into streams. In contrast, acclimated fall Chinook salmon have demonstrated faster travel times than direct release hatchery-reared smolts (3–11 days), which more closely resembled migration patterns for naturally produced smolts (Rosenberger and others, 2013). In other studies, no consistent differences have been observed in the migration timing of direct and acclimated steelhead or Chinook salmon smolts (Fast and others, 1991; Whitesel and others, 1994; Cameron and others, 2013). Such inconsistencies highlight the need for additional studies to better understand how acclimation facilities affect travel times and the effects to long-term measures of fitness (for example, SAS).

An additional concern is the effect of acclimation facilities on residualization, which occurs when anadromous fish remain within the freshwater. When acclimated, smolts demonstrate a lower residualization rate than direct-release fish (Viola and Schuck, 1995; Hausch and Melnychuk, 2012). There continues to be uncertainty as to how residualization interferes with smolts that do not volitionally release from acclimation facilities (Hausch and Melnychuk, 2012), particularly when considering the results of Clarke and others (2011) that demonstrated more rapid travel times for smolts that did not volitionally migrate from acclimation facilities. Given the potential ecological effects of residualized smolts, additional research is needed to identify migration patterns of smolts that do not volitionally release from acclimation facilities.

*Acclimation and juvenile survival and SAS.*—Similar to other performance metrics, there is extensive variability in the influence of acclimation facilities on juvenile survival (see table A1.1 for individual estimates) and SAS. When acclimated, fall Chinook salmon smolts have higher survival rates than direct-release hatchery-reared smolts (Rosenberger and others, 2013), which is similar to the pattern for spring Chinook salmon (Fast and others, 1991; Cameron and others, 2013) and steelhead (Whitesel and others, 1994). These results contradict earlier studies with winter and summer steelhead, which found no difference in acclimated and direct-release smolt survival (Tipping, 1998; Kenaston and others, 2001; Appleby and others, 2002; Clarke and others, 2010). In contrast, Clarke and others (2010) found SAS for acclimated smolts to be >11 percent higher than observed for direct-release summer steelhead smolts, a pattern consistent in most years (6 out of the 7 years, where estimates were comparable, 2002–2010) for summer steelhead in the Umatilla River in Oregon (Cameron and others, 2013). Variability in the effects of acclimation is demonstrated in the Umatilla River, where SAS of fall Chinook salmon was lower than direct-release smolts in 4 of the 6 years that were monitored (Cameron and others, 2013).

At least some of the discrepancy between studies may be the lack of consistency in study methods. For example, Tipping (1998) found no difference in steelhead survival rates between direct release smolts and smolts allowed to rest for 24 hours. Comparing these results with longer duration acclimation practices (for example, 20–23 days; Rosenberger and others, 2013) may not be appropriate, suggesting the need for consistent experimental tests to allow for more informed comparisons.

*Acclimation and adult stray rates.*—In this study, stray rates are specifically considered for studies where direct (for example, experimental) comparisons were performed between acclimated and nonacclimated (direct release) groups. Again, results from most studies suggest moderate to high variability in stray rates. Early studies of *O. kisutch* (coho salmon), and Chinook salmon found no differences in homing rates within Lake Michigan in Illinois (Savitz and others, 1993). An experiment with spring Chinook salmon in the lower Willamette River in Oregon using net pens as acclimation facilities, yielded a mixture of results that suggest no clear pattern of the effect of acclimation on natal homing (Schroeder and Kenaston, 2005). However, Clarke and others (2010) found 42 percent lower stray rates for acclimated steelhead compared to direct-release fish. Dittman and others (2010) found that, despite homing to acclimation streams, a large portion (55.1 percent) of adult Chinook salmon spawned at distances >25 kilometers to natal sites within these streams, which was similar to the distribution observed in wild Chinook salmon. The broad distribution of spawners in the Yakima River in Washington is likely to be influenced by local spawning habitat within and proximate to acclimation facilities (Cram and others, 2013). The results of Cram and others (2013) illustrate the need to consider spatial patterns in suitable habitat when assessing stray rates to reduce uncertainty when comparing studies.

In general, comparing stray rates from different studies appears to be problematic, particularly given differences in the timing and duration of acclimation (Keefer and Caudill, 2012). Furthermore, comparison of stray rates may not be meaningful

given recent evidence of differences in stray rates among species and streams (Westley and others, 2013), suggesting the need for in situ measures of stray rates for all species.

## Smolt Collection and Injury and Survival at Downstream Collection Facilities

The focus of this section is to summarize data from existing studies on smolt collection efficiencies and survival at collection facilities.

*Smolt collection efficiency.*—A variety of collector types are used to capture downstream-migrating anadromous fish in rivers with migration barriers. Table A1 provides smolt collection efficiencies and standard deviations (SDs) by river, facility, collector type, and species. Comparisons of collection efficiencies between different projects are difficult because of the inherently different dam operations and ambient conditions. This study considers collection efficiencies as the number of migratory fish captured at a collector and summarizes results from different rivers and sites for reference.

Substantial differences in collection efficiencies were found for different species, years, and collectors. For example, estimates of collection efficiency for steelhead during the period from 1996 to 2012 varied from a low of 5.4 percent to a high of 68 percent (Serl and Morrill 2010; Serl and Heimbigner, 2013). Although general trends are consistent for different species, interannual variability may not be strongly correlated for all species (Pearson correlation coefficient [ $r$ ]=0.57; fig. A2).

At some facilities, collection efficiencies appear to be relatively consistent between species, such as at the Mayfield facility on the Cowlitz River where collection efficiencies for coho salmon, Chinook salmon, and steelhead ranged from 61.5 to 76.5 percent (table A1). At other facilities, collection efficiencies for different species differ substantially. For example, collection efficiencies using a forebay collector at Rocky Reach Dam on the Columbia River in Oregon were 17.7 percent for Chinook salmon and 47.8 percent for steelhead. There does not appear to be any consistent pattern of higher/lower collection efficiencies for the different species. For example, on the Cowlitz River, collection efficiencies for juvenile Chinook salmon (mean=21.5 percent) are half that observed for steelhead at Cowlitz Falls (mean=43.3 percent; 1996–2012), but little difference in average collection efficiencies occurs at Mayfield (the mean collection efficiency for Chinook salmon is 75 percent and for steelhead is 76.5 percent); however, the Mayfield studies were done from 1964 to 1965.

In part, the interannual differences in collection efficiencies may be a result of varying environmental conditions (for example, epilimnetic water temperatures and discharge; Kock and others, 2015). For example, Beeman and others (2016) found juvenile Chinook salmon preferred temperatures of 13–15 degrees Celsius (°C) when migrating through Cougar Reservoir in Oregon; when temperatures were higher, fish went to deeper water and were less likely to be collected. The Lewis River, Lake Merwin, Yale Lake, and Swift Reservoir all have warm (>20 °C) near-surface temperatures during the summer (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report) suggesting warmer temperatures may reduce collection, particularly if thermal barriers lead to increased residualization.

In recent years, state-of-the-art collection facilities have been constructed by hydropower entities on numerous rivers in the Pacific Northwest (for example, the Lewis River and Baker River in Washington and the Deschutes River in Oregon). However, the ability to compare collection efficiencies in different rivers is likely to require multiple years of monitoring. Early evaluations of collection efficiencies are likely to be biased because of the high interannual variability observed at many existing facilities and site-to-site differences. As such, an understanding of the factors associated with or influencing collection efficiencies (for example, variations in migration timing, in-reservoir conditions such as temperature) will be needed to establish collection-efficiency goals. That said, because the Upper Baker (Baker River) and Round Butte (Deschutes River) collectors are very similar to the floating surface collector (FSC) at the Swift Reservoir facility on the Lewis River in terms of entrance configuration, it is informative to look at how effective those two facilities are at capturing juvenile salmonid outmigrants. As shown in table A1.2, capture efficiencies for coho salmon at Upper Baker ranged from 82.6 to 99 percent (Jeanes and Verretto, 2012). At the Round Butte facility on the Deschutes River, collection efficiencies have been considerably lower for Chinook salmon (30.1–51.7 percent) and steelhead (12.4–24.2 percent, table A1.2; Hill and Quesada, 2011, 2012, 2013). However, the estimates for the surface collector at Round Butte include both hatchery-reared and wild fish. Although early results indicated no apparent difference between these groups, recent collection results suggest considerably lower collection efficiencies for naturally reared Chinook salmon and steelhead compared to hatchery-reared releases (Hill and Quesada, 2014, 2015). In addition, it is worth noting that the estimates of collection efficiencies at Round Butte include reservoir survival, a measure of downstream migrants (that is, compared to residualized fish), and collection efficiency of fish that make it to the collector. Studies at Lake Billy Chinook in Oregon indicate a large portion of the fish entering the reservoir did not make it to the surface collector at Round Butte (Hill and Quesada, 2013).

In the Lewis River, the proportion of marked to unmarked juvenile salmon collected at the FSC was relatively low through 2015. For coho salmon, the majority of data were from naturally produced juveniles (that is, subyearlings) that were tagged with passive integrated transponders (PIT) in Clear Creek (a tributary to the Muddy River in the upper Lewis River basin); other data were from hatchery-reared coho salmon juveniles that were released in 2013. To date, only 5.8 percent of the wild coho salmon



tagged in Clear Creek and 15.2 percent of the coho salmon marked in screw trap operations near the head of Swift Reservoir have been collected at the FSC. The differences in collection for coho salmon likely stem from the timing of marking, as the Clear Creek estimate includes overwinter mortality. Although data are limited, the percent of steelhead tagged at Eagle Cliff screw trap operations (on the Lewis River, immediately above the head of Swift Reservoir; see fig. D1 in chap. D of this report) and collected at the FSC is slightly higher (19 percent) than observed for coho salmon. For spring Chinook salmon, hatchery-reared smolts released into tributary streams that were PIT-tagged were included, as well as the total number of individuals released (that is, unmarked; see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report). The percent of spring Chinook salmon collected at the FSC was extremely low for fish individually PIT-tagged (yearly average for 2013–2015 was 2.2 percent) and from large releases of unmarked plants (average is 3.7 percent). Overall, the low collection rates for spring Chinook salmon are generally consistent with results from Cowlitz Falls (fig. A2; Serl and Morrill, 2010; Serl and Heimbigner, 2013). The discrepancy between the estimates of collection at the Lewis River FSC and Cowlitz Falls may be because of natural recruitment of juvenile spring Chinook salmon from residualized individuals from previous releases in the Lewis River (for example, Romer and Monzyk, 2014; Perales and others, 2015), especially as any effects of PIT-tagging large, acclimation smolts were likely minimal (Prentice and others, 1993), and high estimates of reservoir survival are common (for example, Williams and others, 2001).

Recent behavioral studies in Swift Reservoir (Beeman and others, 2016) suggest the proportion of juvenile salmon collected is likely to be increased through modifications at the FSC. In particular, results indicate that a large proportion of test-marked juvenile salmon (90 percent) move within 150 meters of the FSC. Estimates of collection efficiency (that is, the proportion of fish within the zone of influence collected at the FSC) in a 2014–2015 study (PacifiCorp and Cowlitz PUD, 2016) were relatively low (12–29 percent for coho salmon, 0 percent for spring Chinook salmon, and 16–25 percent for steelhead) but may increase substantially with different orientations of the guide nets. Ultimately, adaptively modifying efforts to capture downstream migrating salmon and steelhead will be necessary to increase collection efficiencies and consequently, the overall numbers of adult returns (for example, as documented at Cowlitz Falls; Serl and Morrill, 2010).

## Juvenile Survival Through Collection Facilities

Ample data exist to estimate survival rates for fish that go through hydropower facilities (see, for example, the Columbia Basin Fishery Agencies and Tribes Fish Passage Center webpage at <http://www.fpc.org>). However, this report is constrained to estimates of survival through collection facilities where complicating factors (for example, mortality during reservoir travel, large migration distances, and so on) are minimized. For all species, survival rates are generally high at collection facilities (mean range from 0.89 to 1; table A2). A comparison of the different types of collectors shows that survival estimates were lowest at the Bonneville Dam using the Bonneville FSC (0.86) and sampling from a barge (0.89), but mean survival at all other facilities was relatively high (>0.92; table A3). Survival estimates at forebay collectors (that is, where trap and haul activities are used on the Baker and Cowlitz Rivers) suggest mortality rates are extremely low using those collectors.

Injury rates, measured through descaling rates (>20 percent) also appear to be extremely low at collection facilities in the Pacific Northwest (table A4). Based on data in table A1.4, the average descaling rate is 2.7 percent (SD=3.0) for all species and facilities. No apparent patterns exist in average descaling rates of 2.3 percent for Chinook salmon, 1.8 percent for coho salmon, 3.6 percent for steelhead, and 0.7 percent for *O. nerka* [sockeye salmon]). Similar to survival rates, descaling rates from forebay collectors used in trap and haul operations comparable to the Upper Lewis (that is, the FSC at Swift Reservoir) were all less than (<) 1 percent.

Juvenile survival and injury rates at the FSC in the Lewis River (Swift Reservoir) have been generally consistent with rates at other structures in the Pacific Northwest. Injury rates in 2014–2015 were low for all species (0–2.4 percent), with highest injury rates for hatchery-reared spring Chinook smolts (2.4 percent; table A5; PacifiCorp and Cowlitz PUD, 2016). For the 1.1 percent of fish experiencing injuries at the FSC, descaling of >20 percent has been the most common injury to date (table A6). Survival rates were generally highest (>98.3 percent) for all smolts (Chinook salmon, *O. clarki* [coastal cutthroat trout], coho salmon, steelhead; table A4). The lowest survival rates occurred for adult steelhead (average of 85.0 percent; small sample size of 5) and adult coho salmon (average of 88.3 percent; table A5).

In addition to high survival rates through collection facilities, reduced survival through delayed mortality effects are possible. To address this concern, trap and haul facilities on the Baker and Cowlitz Rivers are currently using stress-relief ponds for smolts transported downstream of hydropower facilities. A long-term study (1998–2009) of delayed mortality by Serl and Morrill (2010) has found mortality rates to be relatively low. For example, average delayed mortality rates were <1 percent for hatchery-reared and wild steelhead, coho salmon, hatchery Chinook salmon, and coastal cutthroat trout. Mortality rates did vary between species as delayed mortality rates for wild Chinook salmon were as high as 3.58 percent. Recent tests of delayed mortality in the Cowlitz River (2008–2012) found <0.5 percent mortality for all species (Serl and Heimbigner, 2013). The short duration of stress relief used in the Cowlitz River (24–48 hours after which fish were forced out) may underestimate the effects of stress (that is, additive stress) that may not be apparent until later in downstream migration (Budy and others, 2002; Schaller

and Petrosky, 2007). Although overall mortality of fish that go through collection facilities and stress relief ponds is likely to be lower than fish that go through turbines (Keefer and others, 2012), further research and comparative studies are needed to determine site-specific mortality rates and the benefits of management actions (for example, stress relief ponds). Future studies of the effects of acclimation ponds should also consider using controls for direct comparisons of survival, as opposed to mortality assessments with just treatment groups (that is, where only acclimation ponds are used).

*Effects of downstream collection facilities on other species.*—In addition to salmon and steelhead smolts, collection facilities can collect potamodromous and other anadromous species (for example, coastal cutthroat trout), which raises concern for the effects of collection on these nontarget species. Numerous native and nonnative species, including game and nongame species, are often collected at downstream collection facilities (Portland General Electric Company [PGE], 2012; 2013) as a result of either random movements or natural, life-history movement patterns. Where evaluated, mortality estimates for nontarget species appear to be generally low for most species (<2 percent; table A7). However, higher mortality estimates were observed for *O. nerka* (kokanee salmon) with a mean of 6.5 percent (table A1.5). In general, mortality rates for nontarget species at collection facilities are expected to be considerably lower than for species that pass through turbines and or spillways (for example, Muir and others, 2001).

Injury and mortality rates at the Swift Reservoir FSC for nontarget species appear to be low (table A4). Coastal cutthroat trout fry had the lowest survival rate (52.9 percent) at the Swift Reservoir FSC, but this estimate is derived from a small sample size of 8. However, adult mortality rates for species such as *Salvelinus confluentus* (bull trout) (10 percent in 2015), which have relatively small population sizes, should be monitored to identify ways to minimize the potential negative population-level effects.

## Adult Fish Upstream Collection Facilities

The review of adult fish upstream collection facilities largely focuses on programs that use trapping and hauling methods of adults upstream of passage barriers. The use of trap and haul methods to increase the distribution of and create additional source populations for anadromous stocks has occurred for decades (for example, in the Baker and Cowlitz Rivers), and the use of this technique is currently increasing throughout the historic range of anadromous species (Vogel, 2007; Keefer and others, 2010). The report includes adult injury and survival rates, fallback rates, and upstream mortality rates for nontarget, native salmonids. Limited data currently exist for upstream capture efficiency in trap and haul projects, so they are not discussed further.

*Adult injury and survival rates.*—The collection facilities used for most trap and haul and long-term trapping facilities involves fish ladder systems where adults ascend fish ladders to separators, collectors, and so on (Zimmerman and Duke, 1993; Henning, 2010; PGE, 2013). For all species, runs (that is, life histories) and source (for example, hatchery, wild) mortalities from adult trapping and transport activities appear to be low (table A8). The majority of mortality events appear to occur during the trapping as opposed to during hauling events (Zimmerman and Duke, 1997). However, injury during hauling, as measured by descaling rates, can be substantial (Scully and Buettner, 1986). In addition, delayed mortality because of stress and (or) ambient conditions that result in prespawn mortality is rarely recorded.

The highest mortality rates from reports included herein were found for spring Chinook salmon (9.6 percent in 2000 and 6.8 percent in 1996) in the Tucannon River in Washington, and steelhead at the Mayfield facility on the Cowlitz River (6.7 percent; table A1.6). Aside from these high mortality events, average adult mortality for different species of salmon and steelhead at trapping locations was 0.4 percent; (SD=0.92 percent; table A1.6). Although mortality associated with trapping is generally low, the occurrence of anomalous events affecting mortality, including density-independent factors (for example, ambient climate conditions) and density-dependent factors (for example, crowding; U.S. Army Corps of Engineers, 2015), can result in high mortality rates.

Stress and delayed mortality from instream conditions during freshwater migration are additional possible causes of upstream mortality for anadromous species. Exposure to warm water during migration and (or) during delayed migration at tail-race areas can affect migration timing, thus indirectly exposing fish to additional stress mechanisms and reduced fitness (Keefer and Caudill, 2010). For example, excessive warming has resulted in abnormally high prespawn mortality for spring Chinook salmon (Keefer and others, 2010; Mosser and others, 2013). Caudill and others (2007) found excessive delay times associated with high mortality of adult Chinook salmon and steelhead during passage at hydropower facilities. Although the exact mechanisms contributing to the high mortality rate are not known, the results suggest the need for monitoring and evaluation of delayed migration below adult traps to determine if management alternatives are needed to reduce mortality.

An additional concern in upstream trap and haul operations is thermal shock. For bottom-releasing reservoirs with relatively cold temperatures in reaches downstream of dams, transport and release into warm epilimnetic waters of reservoirs may result in thermal shock and lead to decreased fitness (Hovda and Linley, 2000). The differences in thermal regimes between tail-race and release locations should be monitored, and where needed, release methods that avoid drastic thermal differences during the warm, stratified periods of summer (for example, release mechanisms to lower depths; PGE, 2013) should be considered.

Adult trapping studies below the dam at Lake Merwin (PacifiCorp and Cowlitz PUD, 2016) indicate that the success of adult trapping operations is generally consistent with previous studies. Operations at the Lake Merwin upstream adult trap have resulted in low injury rates (0–2.2 percent) (PacifiCorp and Cowlitz PUD, 2016). Results from this 2016 study also indicate the amount of time spent within the tailrace zone varied considerably for the different species and suggest residency time may be excessive for Chinook salmon and adult steelhead. Overall, collection efficiencies of adults were generally low (9–62 percent; (PacifiCorp and Cowlitz PUD, 2016), but the higher proportion of fish at the trap entrance (22–90 percent) suggests changes in trap designs and operations may improve collection efficiency. However, such data are preliminary and may be driven by the anomalous climatic conditions observed during the 2015 study (PacifiCorp and Cowlitz PUD, 2016), and continued studies and modifications are needed to improve collection efficiencies.

*Fallback.*—Fallback of adults during migration or transport above hydropower facilities can lead to increased stress, injury, and mortality, and considerably delayed migration times (Boggs and others, 2004). Fallback typically occurs when adults overshoot the natal spawning grounds or become disoriented (Naughton and others, 2006). How ambient conditions may contribute to fallback is poorly understood, but they likely influence fallback rates in any given year. For example, Holbrook and others (2009) found overall fallback rates for *Salmo salar* (Atlantic salmon) to range from 0.8 to 9.4 percent; however, fallback rates increased to more than 47 percent during periods of excessive stream warming (>22 °C). Understanding how conditions such as stream temperature and streamflow interact with management operations to reduce fallback warrants additional research.

Within the Pacific Northwest, we found moderate variability in fallback rates when comparing species and years (table A9; see table A1.7 for individual estimates). Overall, we found the highest fallback rates for Chinook salmon, with the highest estimates for spring Chinook salmon (mean=24.1 percent, SD=12.9 percent). The fallback estimates were markedly lower for fall Chinook salmon (mean=4.9 percent, SD=4.0) and spring–summer Chinook salmon (mean=12.4 percent, SD=8.0). Albeit limited in number of estimates (sample size of 5), fallback rates for coho salmon (mean=5.0, SD=6.7) were similar to those observed for fall Chinook salmon but with higher variability. Fallback estimates for steelhead (mean=10.0 percent, SD=7.8) were similar to those for spring and spring–summer Chinook salmon; however, in many instances, fallback estimates include kelts and thus may be biased high (Keefer and Caudill, 2010). Estimates for sockeye salmon (mean=5.9 percent, SD=4.1) were relatively low. The observed patterns indicate relatively lower fallback rates for fall spawners than for fish observed in spring and spring/summer species/runs.

Currently, few estimates of fallback are available for storage projects that utilize trap and haul methods, such as at Round Butte. Limited annual fallback rates are available from the Cowlitz facilities (Mayfield and Cowlitz Falls), and estimates are variable (table A1.7), thus rigorous comparisons between run-of-the-river projects and trap and haul are limited at this time. In Swift Reservoir, estimates of fallback are only available for adult coho salmon (hatchery) and data from 2014 (0.3 percent) and 2015 (0 percent) suggest attempted fallback (as adults are returned to the reservoir) is low. Low fallback rates are expected given that adults are released near the head of Swift Reservoir.

*Upstream mortality of nontarget salmonids.*—Estimates of mortality at upstream collection facilities for nontarget species do not appear to be common. Henning (2010) found numerous injuries to *Esox masquinongy* × *lucius* or *Esox lucius* × *masquinongy* (tiger muskellunge) but relatively low evidence of mortality. Studies with limited data for bull trout from the Pelton adult fish trap on the Deschutes River system have found no evidence of mortality (PGE, 2013), which is consistent with reports for bull trout migrating through hydropower facilities on the Columbia River (Chelan County PUD, 2012; Douglas County PUD, 2012). Studies specifically targeting handling effects for bull trout, however, have found mortality rates as high as 4 percent (PUD No. 1 of Douglas County, 2016). Little information currently exists on upstream passage effects on coastal cutthroat trout. Although survival estimates for anadromous salmon and steelhead are relatively low (table A5), additional data are needed to identify how upstream trap and haul operations may affect native salmonid survival rates.

Of particular importance for species that have narrow thermal tolerances, such as bull trout (Selong and others, 2001; McMahon and others, 2007), may be delayed migrations at upstream collection facilities and the potential for detrimental effects of thermal shock upon release into epilimnetic waters of stratified reservoirs. Temperature data from Swift Reservoir, where biweekly average temperatures during mid-July through mid-September exceeded 16 °C at depths to 9 meters (Sorel and others, 2016) suggest thermal regimes may be detrimental for species such as bull trout that are released in the epilimnion during these periods. Thermal regime monitoring may need to be integrated into the transport protocols, and alternative release strategies to avoid thermal regimes stressful to target species may need to be considered.

## Conclusion

Comparing the success of collection operations for juvenile and adult fish at different locations is challenging because of different collection designs, hydrologic conditions, and reservoir bathymetry. Juvenile and adult injuries and direct (that is, not delayed) mortalities appear to be generally low regardless of species and location, a pattern observed during the early stages of reintroduction in Swift Reservoir. Juvenile collection efficiencies appear to be highly variable between locations and species, likely because of the inherent differences at the various locations. In Swift Reservoir, the proportion of coho and Chinook salmon smolts collected at the downstream collector (that is, FSC) on Swift Reservoir appears to be relatively low compared to other collectors (table A1). Juvenile behavior near collection sites often drives such patterns (see the “Smolt collection efficiency” section in this chapter). Recent studies in Swift Reservoir suggest modifications to the netting placement are likely to substantially increase the proportion of juveniles collected, highlighting the need to continue to evaluate designs and operations that can yield substantial increases in collections of juveniles and the likely success of the reintroduction efforts.

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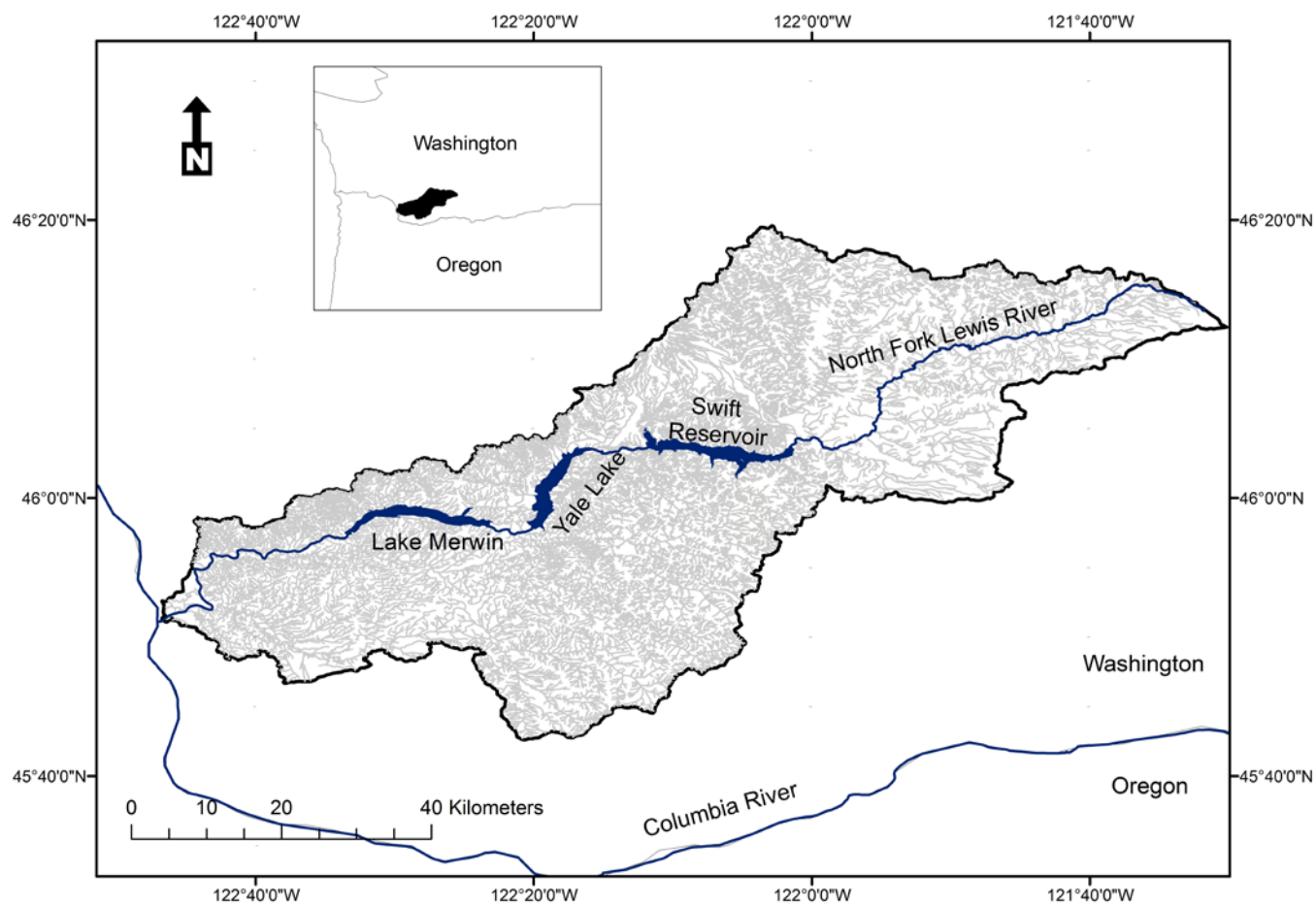
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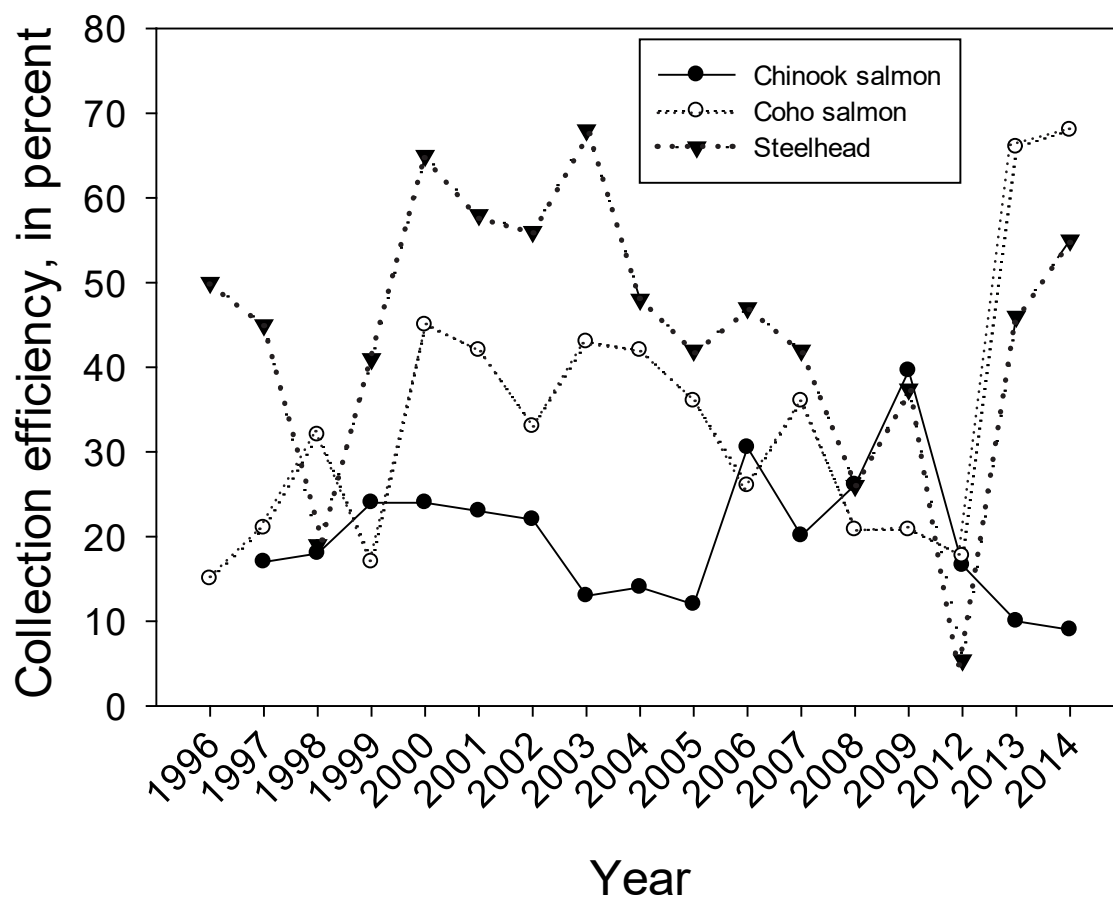
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## Figures



**Figure A1.** The North Fork of the Lewis River and the three hydropower impoundments: Lake Merwin, Yale Lake, and Swift Reservoir in the Lewis River Basin, Washington.



**Figure A2.** Interannual comparison of collection efficiencies for juvenile Chinook salmon, coho salmon, and steelhead at the Cowlitz Falls collection facility in Washington. [Data adapted from Serl and Heimbigner, 2013, and Serl and Morrill, 2010]



## Tables

**Table A1.** Smolt collection efficiencies and standard deviations by river, name of hydropower facility, collector type, species, and sample size.

[Estimates from individual studies, the years of the studies, and references for the data sources are available in table A1.2. U.S.A., United States of America; SS, Atlantic salmon; NA, not available; CO, coho salmon; OM, steelhead; CH, Chinook salmon; B2CC, second powerhouse corner collector; >, greater than; <, less than]

Facility	Collector	Species	Collection efficiency (percent)	Standard deviation	Sample size
Ariège River (France)					
Crampagna	Bypass/sluiice	SS	66.0	NA	1
Guilhot	Bypass/sluiice	SS	75.0	NA	1
Las Mijanes	Bypass/sluiice	SS	32.0	NA	1
Las Rives	Bypass/sluiice	SS	49.0	NA	1
Baker River (Washington, U.S.A)					
Lower Baker	Forebay collector—gulper	CO	22.1	13.5	21
	Floating surface collector	CO	94.0	1.6	2
Upper Baker	Forebay collector—gulper	CO	53.9	10.7	20
	Forebay collector—surface collector/enhanced gulper	CO	90.1	6.5	6
Columbia River (Oregon and Washington, U.S.A)					
Bonneville First Powerhouse	Powerhouse retrofit—prototype surface collector	OM	45.0	NA	1
		CH	43.0	NA	1
	Sluiceway	OM	54.7	10.5	3
		CH	53.4	17.1	8
Bonneville Second Powerhouse	Sluiceway—B2CC	OM	70.0	5.7	2
		CH	35.8	4.7	4
	Sluiceway—B2CC	CH	16.7	NA	1
John Day	Surface spill/surface bypass	CH	21.7	9.0	2
McNary		OM	69.0	NA	1
		CH	30.7	20.0	19
Priest Rapids	Sluiceway	OM	53.4	15.9	5
		CH	1.9	NA	1
Rocky Reach	Forebay collector	OM	47.8	21.0	6
		CH	17.7	12.1	6
	Surface spill—combined spillway	OM	21.8	5.0	4
		CH	37.5	1.2	3
The Dalles	Sluiceway	OM	9.5	6.4	2
		CH	8.5	4.4	10
Wanapum	Powerhouse retrofit	NA	0.3	0	2
	Sluiceway	CH	3.0	NA	1
	Surface spill	OM	66.9	12.1	3
		CH	17.0	9.9	2



**Table A1.** Smolt collection efficiencies and standard deviations by river, name of hydropower facility, collector type, species, and sample size.—Continued

[Estimates from individual studies, the years of the studies, and references for the data sources are available in table A1.2. U.S.A., United States of America; SS, Atlantic salmon; NA, not available; CO, coho salmon; OM, steelhead; CH, Chinook salmon; B2CC, second powerhouse corner collector; >, greater than; <, less than]

Facility	Collector	Species	Collection efficiency (percent)	Standard deviation	Sample size
Wells	Powerhouse retrofit—surface bypass units with retrofit baffle bays	CH/OM	90.4	7.0	8
Connecticut River (New Hampshire, U.S.A.)					
Bellows Falls	Bypass/sluiice	SS	94.0	NA	1
Vernon Station		SS	74.0	NA	1
Cowlitz River (Washington, U.S.A.)					
Cowlitz Falls	Forebay collector—retrofit baffle	CO	34.2	15.8	16
		OM	44.2	15.9	16
		CH	19.8	7.9	20
Mayfield	Forebay collector	CO	61.5	8.0	4
		OM	76.5	4.0	2
		CH	75.0	1.4	2
Deschutes River (Oregon, U.S.A.)					
Petlon Round Butte	Forebay collector	CH	42.7	8.7	5
		OM	16.5	4.8	5
Garonne River (France)					
Camon	Bypass/sluiice	SS	73.0	NA	1
Gave d' Aspe River (France)					
Bedous	Bypass/sluiice	SS	55.0	NA	1
Soeix	Bypass/sluiice	SS	61.0	NA	1
Gave d' Ossau River (France)					
St. Cricq	Bypass/sluiice	SS	79.0	NA	1
Gave de Pau River (France)					
Baigts	Bypass/sluiice	SS	93.0	NA	1
Castetarbe	Bypass/sluiice	SS	100.0	NA	1
Lewis River (Washington, U.S.A.)					
Swift Reservoir	Floating surface collector	CO	11.8	NA	1
		CH	0	NA	1
	Floating surface collector	OM	18.6	NA	1
Santiam River (Oregon, U.S.A.)					
Green Peter	Forebay collector—floating collection horn	CH	>80	NA	3
	Forebay collector—floating collection horn	OM	<57	NA	4
Snake River (Washington, U.S.A.)					
Ice Harbor	Sluiceway	NA	31.8	15.2	4
	Surface spill—RSW	OM	42.5	6.4	2
		CH	52.0	16.8	4

## 22 A. Review of Information Relevant to Anadromous Fish Reintroduction to and Fish Passage in the Lewis River, Wash.

**Table A1.** Smolt collection efficiencies and standard deviations by river, name of hydropower facility, collector type, species, and sample size.—Continued

[Estimates from individual studies, the years of the studies, and references for the data sources are available in table A1.2. U.S.A., United States of America; SS, Atlantic salmon; NA, not available; CO, coho salmon; OM, steelhead; CH, Chinook salmon; B2CC, second powerhouse corner collector; >, greater than; <, less than]

Facility	Collector	Species	Collection efficiency (percent)	Standard deviation	Sample size
Little Goose		OM	45.3	17.7	19
		CH	38.4	16.7	36
Lower Granite	Powerhouse retrofit—surface bypass collector	OM	22.5	6.4	2
		CH	29.0	NA	1
	Surface spill—removable spillway weir	OM	46.6	20.4	36
All		CH	37.9	20.0	53
Lower Monumental		OM	33.4	17.6	19
		CH	26.1	17.0	36
Willamette River (Oregon, U.S.A.)					
Willamette Falls	Forebay collector—inflatable rubber dam	OM	100.0	NA	1
		CH	97.3	NA	3

**Table A2.** Survival rates and standard deviations by river, smolt collection facility, species, and sample size.

[Estimates from individual studies, the years of the studies, and references for the data sources are available in table A1.3. CO, coho salmon; NA, not available; OM, steelhead; CH, Chinook salmon; SO, sockeye salmon]

Facility	Species	Survival (percent)	Standard deviation	Sample size
Baker River (Washington)				
Upper Baker	CO	100	0	4
Clackamas River (Oregon)				
North Fork	CO	100	NA	1
	OM	96	6	5
	CH	100	NA	1
	CH/CO	89	7	4
River Mill	OM	99	NA	1
	CH	99	1	2
Columbia River (Oregon and Washington)				
Bonneville	OM	87	15	30
	CH	89	11	24
Cowlitz River (Washington)				
Cowlitz Falls	CO	99	2	13
	OM	99	1	13
	CH	98	3	22
Mayfield	CO	95	0.1	11
	OM	96	0.1	9

**Table A2.** Survival rates and standard deviations by river, smolt collection facility, species, and sample size.—Continued

[Estimates from individual studies, the years of the studies, and references for the data sources are available in table A1.3. CO, coho salmon; NA, not available; OM, steelhead; CH, Chinook salmon; SO, sockeye salmon]

Facility	Species	Survival (percent)	Standard deviation	Sample size
	CH	95	4	12
Deschutes River (Oregon)				
Pelton Round Butte	OM	98	1	5
	CH	98	1	5
	SO	98	1	4
Willamette River (Oregon)				
Willamette Falls	OM	99	1	3
	CH	100	0	2

**Table A3.** Average estimates of smolt survival and standard deviations by river, collection facility, collector type, and sample size.

[Estimates from individual studies, the years of the studies, and references for the data sources are available in table A1.3]

Facility	Collector type	Survival (percent)	Standard deviation	Sample size
Baker River (Washington)				
Upper Baker	Forebay collector—surface collector	100	0	4
Clackamas River (Oregon)				
North Fork	Forebay collector	92	7	8
	Forebay collector—v-screen collector	99	1	3
River Mill	Surface spill—spillway weir	99	1	3
Columbia River (Oregon and Washington)				
Bonneville	Bonneville floating surface collector	86	15	21
	Sampled from barge	89	12	33
Cowlitz River (Washington)				
Cowlitz Falls	Forebay collector—retrofit baffle	99	2	45
Mayfield	Louver system	97	2	5
Deschutes River (Oregon)				
Pelton Round Butte	Guidance net/skimmer	98	1	14
Willamette River (Oregon)				
Willamette Falls	Mixed	99	1	5

**Table A4.** Descaling rates and standard deviations by river, facility, species, and sample size.

[See table A1.4 for individual estimates, years, and references. PH, individual powerhouse at Bonneville Dam; CH, Chinook salmon; CO, coho salmon; OM, steelhead; NA, not available; SO, sockeye salmon]

Facility	Species	Descaling rate (percent)	Standard deviation	Sample size
Columbia River (Oregon and Washington)				
Bonneville Dam PH1	CH	3.7	2.6	30
Bonneville Dam PH2	CO	3	1.6	15
Bonneville Dam PH3	OM	6.5	4	29
Bonneville Dam PH2	CH	1.6	1.1	8
Bonneville Dam PH3	CO	1.2	0.4	4
Bonneville Dam PH4	OM	4.1	2.2	8
John Day	CH	2.6	2	12
John Day	CO	3	1.5	6
John Day	OM	4.4	2.6	12
Cowlitz River (Washington)				
Cowlitz Falls	CH	0.6	0.8	20
Cowlitz Falls	CO	0.4	1	14
Cowlitz Falls	OM	0.4	0.5	27
Mayfield	CH	4.1	NA	1
Deschutes River (Oregon)				
Fish transfer	CH	0.1	0.1	3
Fish transfer	OM	0.4	0.6	3
Fish transfer	SO	0.7	0.4	3

**Table A5.** The percent of injured fish and survival rates for different species at different life stages as measured at the floating surface collector in Swift Reservoir on the Upper Lewis River, Washington. Data from PacifiCorp and Cowlitz Public Utility District, 2016.

[NA, not available]

Species	Injured (percent)		Survival (percent)	
	2014	2015	2014	2015
Coho salmon (adult)	0	0	88.0	88.6
Coho salmon (smolt)	0.9	0.4	99.3	99.2
Coho salmon (fry)	0	0	99.8	96.9
Coho salmon (parr)	NA	0	NA	100
Chinook salmon (adult)	NA	NA	NA	NA
Chinook salmon (smolt)	2.4	2.1	98.3	97.2
Chinook salmon (parr)	NA	0	NA	0
Steelhead (adult)	0	0	82.4	87.5
Steelhead (smolt)	2.2	0.6	100	99.4
Steelhead (fry)	0	0	100	100
Steelhead (kelt)	0	0	85.7	90.3
Steelhead (parr)	NA	0	NA	100
Rainbow trout	0	0	100	100
Bull trout	0	0	100	90.0
Coastal cutthroat (smolt)	0.8	0.2	100	99.2
Coastal cutthroat (fry)	0	0	99.3	52.9
Average (percent)	0.49	0.40	96.3	93.4

**Table A6.** The type of injury by percent for all fish species for the 1.1 percent of fish injured during collection efforts at the floating surface collector in Swift Reservoir on the Upper Lewis River, Washington, in 2014 and 2015. Data from PacifiCorp and Cowlitz Public Utility District, 2016.

[>, greater than; %, percent; cm, centimeter]

Type of injury	Percent of injuries	
	2014	2015
Descaling > 20%	77.5	81.9
Hemorrhaging	4.2	8.1
Bruising > 0.5 cm diameter	14.1	5.4
Open wound (no fungus)	1.4	2.3
Gill damage	0.7	0.5
Loss of equilibrium	0.7	1.8
Fin damage (injury)	1.4	0

## 26 A. Review of Information Relevant to Anadromous Fish Reintroduction to and Fish Passage in the Lewis River, Wash.

**Table A7.** Survival rates and standard deviations for nontarget species at downstream fish collection facilities by river, facility, species, and sample size.

[See table A1.5 for years and specific references. NA, not available]

Facility	Species	Survival (percent)	Standard deviation	Sample size
Cowlitz River (Washington)				
Cowlitz Falls	Coastal cutthroat trout	99.6	0.3	13
Mayfield	Coastal cutthroat trout	99.9	NA	1
Deschutes River (Oregon)				
Round Butte	Bull trout	98.3	0.3	5
	Kokanee salmon	93.5	1.5	5
	Mountain whitefish	99.9	0.02	5
	Rainbow trout	98.6	1.2	5

**Table A8.** Average mortality rates and standard deviations during adult trap and haul operations for different species, runs (that is, spawning run type), and sources of salmon in the Pacific Northwest.

[See table A1.6 for individual estimates, years, and references. NA, not available]

Run	Source	Mortality (percent)	Standard deviation	Sample size
Chinook salmon				
Fall	Mixed	1.4	2.5	2
Fall	Wild	0.6	0.7	3
Spring	Hatchery	1.4	2.5	24
Spring	Mixed	0.7	NA	1
Spring	Wild	0.1	0.3	29
Coho salmon				
NA	Hatchery/mixed	0.3	0.2	2
NA	Wild	0.2	0.3	4
Sockeye salmon				
NA	NA	0	NA	1
Steelhead				
NA	Hatchery/mixed	1	1.7	3
NA	Wild	1.7	3.3	4

**Table A9.** Average fallback rates and standard deviations by anadromous species and runs.

[See table A1.7 for individual estimates, years, and references. NA, not available]

Run	Fallback rate (percent)	Standard deviation	Number of estimates
Chinook salmon			
Fall	4.9	4.1	21
Spring	24.1	12.9	12
Spring–summer	10.3	4.7	23
Summer	12.4	8.0	10
Coho salmon			
NA	5.0	6.7	5
Sockeye salmon			
NA	5.9	4.1	9
Steelhead			
NA	7.9	7.8	28

## Appendix A1

**Table A1.1.** Estimates of smolt survival in acclimation facilities by river, acclimation facility, year, species, run type (that is, life history), age class, acclimation facility type, and reference.

[ND, not denoted; NA, not available]

Acclimation facility	Year	Species	Run	Age (years)	Facility type	Survival (percent)	Reference
Catherine Creek (Oregon)							
Catherine Creek	2002	Chinook salmon	Spring	ND	Aluminum raceways, lined with vinyl	99.7	McLean and others, 2003
Clearwater River (Idaho)							
Big Canyon	2008	Chinook salmon	Fall	1+	Aluminum circular tanks	98.5	McLeod, 2009
Big Canyon	2008	Chinook salmon	Fall	0+	Aluminum circular tanks	99.5	McLeod, 2009
Big Canyon	2007	Chinook salmon	Fall	1+	Aluminum circular tanks	96.9	McLeod, 2008
Big Canyon	2007	Chinook salmon	Fall	0+	Aluminum circular tanks	98.7	McLeod, 2008
Big Canyon	2007	Chinook salmon	Fall	1+	Aluminum circular tanks	97.8	McLeod, 2007
Big Canyon	2007	Chinook salmon	Fall	0+	Aluminum circular tanks	98.5	McLeod, 2007
Grand Ronde River (Oregon)							
Upper Grand Ronde	2002	Chinook salmon	Spring	ND	Aluminum raceways, lined with vinyl	99.7	McLean and others, 2003
Hood River (Oregon)							
Blackberry	2008	Steelhead	Summer	ND	Polypropylene-lined tanks	99.7	Gerstenberger, 2009
Lostine River (Oregon)							
Lostine River	2007	Chinook salmon	Spring	ND	Polyvinyl chloride-lined raceways	99.9	Zollman and others, 2009
MF Hood River (Oregon)							
Parkdale	2008	Steelhead	Winter	ND	Painted concrete	99.9	Gerstenberger, 2009
Snake River (Idaho and Washington)							
Capt. John Rapids	2008	Chinook salmon	Fall	1+	In-ground, lined pond	99.8	McLeod, 2009
Capt. John Rapids	2008	Chinook salmon	Fall	0+	In-ground, lined pond	99.8	McLeod, 2009
Capt. John Rapids	2007	Chinook salmon	Fall	1+	In-ground, lined pond	99.9	McLeod, 2008
Capt. John Rapids	2007	Chinook salmon	Fall	0+	In-ground, lined pond	99.7	McLeod, 2008
Capt. John Rapids	2007	Chinook salmon	Fall	1+	In-ground, lined pond	99.1	McLeod, 2007
Capt. John Rapids	2007	Chinook salmon	Fall	0+	In-ground, lined pond	99.9	McLeod, 2007
Pittsburg Landing	2008	Chinook salmon	Fall	1+	Aluminum circular tanks	97.9	McLeod, 2009
Pittsburg Landing	2008	Chinook salmon	Fall	0+	Aluminum circular tanks	99.7	McLeod, 2009
Pittsburg Landing	2007	Chinook salmon	Fall	1+	Aluminum circular tanks	97.7	McLeod, 2008
Pittsburg Landing	2007	Chinook salmon	Fall	0+	Aluminum circular tanks	98.4	McLeod, 2008
Pittsburg Landing	2007	Chinook salmon	Fall	1+	Aluminum circular tanks	99.6	McLeod, 2007
Pittsburg Landing	2007	Chinook salmon	Fall	0+	Aluminum circular tanks	99.7	McLeod, 2007
Umatilla River (Oregon)							
Bonifer	1993	Steelhead	Summer	ND	NA	99.5	Rowan, 1994
Bonifer	1993	Steelhead	Summer	ND	NA	99.8	Rowan, 1994
Minthorn	1993	Steelhead	Summer	ND	NA	98.6	Rowan, 1994



**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Ariège River (France)					
Crampagna	Bypass/sluiice	NA	SS	66	Croze, 2008
Guilhot	Bypass/sluiice	NA	SS	70	Croze, 2008
Las Mijanes	Bypass/sluiice	NA	SS	32	Croze, 2008
Las Rives	Bypass/sluiice	NA	SS	39	Croze, 2008
Baker River (Washington, U.S.A.)					
Lower Baker	Forebay collector—gulper	1992	CO	11.3	PSE, 2012
Lower Baker	Forebay collector—gulper	1993	CO	7.8	PSE, 2012
Lower Baker	Forebay collector—gulper	1994	CO	17.6	PSE, 2012
Lower Baker	Forebay collector—gulper	1995	CO	7.2	PSE, 2012
Lower Baker	Forebay collector—gulper	1996	CO	9.2	PSE, 2012
Lower Baker	Forebay collector—gulper	1997	CO	23.1	PSE, 2012
Lower Baker	Forebay collector—gulper	1998	CO	56.8	PSE, 2012
Lower Baker	Forebay collector—gulper	1999	CO	27.2	PSE, 2012
Lower Baker	Forebay collector—gulper	2000	CO	45.2	PSE, 2012
Lower Baker	Forebay collector—gulper	2001	CO	22.9	PSE, 2012
Lower Baker	Forebay collector—gulper	2002	CO	21.9	PSE, 2012
Lower Baker	Forebay collector—gulper	2003	CO	8.2	PSE, 2012
Lower Baker	Forebay collector—gulper	2004	CO	17.3	PSE, 2012
Lower Baker	Forebay collector—gulper	2005	CO	31.6	PSE, 2012
Lower Baker	Forebay collector—gulper	2006	CO	25.4	PSE, 2012
Lower Baker	Forebay collector—gulper	2007	CO	33.5	PSE, 2012
Lower Baker	Forebay collector—gulper	2008	CO	7.8	PSE, 2012
Lower Baker	Forebay collector—gulper	2009	CO	38.5	PSE, 2012
Lower Baker	Forebay collector—gulper	2010	CO	8.3	PSE, 2012
Lower Baker	Forebay collector—gulper	2011	CO	18.2	PSE, 2012
Lower Baker	Forebay collector—gulper	2012	CO	24.5	PSE, 2012
Lower Baker	Forebay collector—gulper	2013	CO	95.1	PSE, 2015
Lower Baker	Forebay collector—gulper	2014	CO	92.8	PSE, 2015
Upper Baker	Forebay collector—gulper	1988	CO	40.9	PSE, 2012
Upper Baker	Forebay collector—gulper	1989	CO	41.8	PSE, 2012
Upper Baker	Forebay collector—gulper	1990	CO	62.7	PSE, 2012

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Upper Baker	Forebay collector—gulper	1991	CO	48.5	PSE, 2012
Upper Baker	Forebay collector—gulper	1992	CO	59.3	PSE, 2012
Upper Baker	Forebay collector—gulper	1993	CO	27.2	PSE, 2012
Upper Baker	Forebay collector—gulper	1994	CO	73.2	PSE, 2012
Upper Baker	Forebay collector—gulper	1995	CO	58.8	PSE, 2012
Upper Baker	Forebay collector—gulper	1996	CO	42.5	PSE, 2012
Upper Baker	Forebay collector—gulper	1997	CO	48.4	PSE, 2012
Upper Baker	Forebay collector—gulper	1998	CO	64	PSE, 2012
Upper Baker	Forebay collector—gulper	1999	CO	62	PSE, 2012
Upper Baker	Forebay collector—gulper	2000	CO	56.8	PSE, 2012
Upper Baker	Forebay collector—gulper	2001	CO	54.9	PSE, 2012
Upper Baker	Forebay collector—gulper	2002	CO	55.3	PSE, 2012
Upper Baker	Forebay collector—gulper	2003	CO	45.1	PSE, 2012
Upper Baker	Forebay collector—gulper	2004	CO	55.6	PSE, 2012
Upper Baker	Forebay collector—gulper	2005	CO	54.1	PSE, 2012
Upper Baker	Forebay collector—gulper	2006	CO	61.5	PSE, 2012
Upper Baker	Forebay collector—gulper	2007	CO	65.5	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector/enhanced gulper	2008	CO	92.7	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector/enhanced gulper	2009	CO	99	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector/enhanced gulper	2010	CO	NA	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector/enhanced gulper	2011	CO	82.6	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector/enhanced gulper	2013	CO	94.3	PSE, 2015
Upper Baker	Forebay collector—surface collector/enhanced gulper	2014	CO	83.3	PSE, 2015
Columbia River (Oregon and Washington, U.S.A.)					
Bonneville PH1	Powerhouse retrofit—PSC	2000	All	83	Ploskey and others, 2000, cited in USACE, 2007
Bonneville PH1	Powerhouse retrofit—PSC	2000	All	84	Ploskey and others, 2000, cited in USACE, 2007
Bonneville PH1	Sluiceway	2002	All	33	Ploskey and others, 2003

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Bonneville PH1	Sluiceway	2002	All	29	Ploskey and others, 2003
Bonneville PH1	Sluiceway	2004	All	33	Ploskey and others, 2005
Bonneville PH1	Sluiceway	2004	All	38	Ploskey and others, 2005
Bonneville PH1	Sluiceway	2005	All	37	Ploskey and others, 2006
Bonneville PH1	Sluiceway	2005	All	71	Ploskey and others, 2006
Bonneville PH1	Sluiceway	2000	CH	68	Evans and others, 2006, cited in USACE, 2007
Bonneville PH1	Sluiceway	2000	CH	29	Reagan and others, 2005
Bonneville PH1	Powerhouse retrofit—PSC	2000	CH	43	Evans and others, 2001, cited in USACE, 2007
Bonneville PH1	Sluiceway	2001	CH	70	Evans and others, 2006, cited in USACE, 2007
Bonneville PH1	Sluiceway	2001	CH	77	Reagan and others, 2005
Bonneville PH1	Sluiceway	2002	CH	48	Evans and others, 2006, cited in USACE, 2007
Bonneville PH1	Sluiceway	2002	CH	35	Reagan and others, 2005
Bonneville PH1	Sluiceway	2004	CH	47	Evans and others, 2006, cited in USACE, 2007
Bonneville PH1	Sluiceway	2004	CH	53	Reagan and others, 2005
Bonneville PH1	Sluiceway B2CC	2008	CH	16.7	FPC, 2008
Bonneville PH1	Sluiceway	2000	OM	44	Reagan and others, 2005
Bonneville PH1	Powerhouse retrofit—PSC	2000	OM	45	Evans and others, 2001, cited in USACE, 2007
Bonneville PH1	Sluiceway	2002	OM	65	Reagan and others, 2005
Bonneville PH1	Sluiceway	2004	OM	55	Reagan and others, 2005
Bonneville PH2	Sluiceway—B2CC	2004	All	31	Ploskey and others, 2005
Bonneville PH2	Sluiceway—B2CC	2004	All	40	Ploskey and others, 2005
Bonneville PH2	Sluiceway—B2CC	2005	All	32	Ploskey and others, 2006
Bonneville PH2	Sluiceway—B2CC	2005	All	44	Ploskey and others, 2006
Bonneville PH2	Sluiceway—B2CC	2004	CH	37	Evans and others, 2005, cited in USACE, 2007
Bonneville PH2	Sluiceway—B2CC	2004	CH	37	Evans and others, 2005, cited in USACE, 2007
Bonneville PH2	Sluiceway—B2CC	2005	CH	40	Evans and others, 2005, cited in USACE, 2007
Bonneville PH2	Sluiceway—B2CC	2005	CH	29	Evans and others, 2005, cited in USACE, 2007
Bonneville PH2	Sluiceway—B2CC	2004	OM	74	Reagan and others, 2005
Bonneville PH2	Sluiceway—B2CC	2005	OM	66	Reagan and others, 2005
John Day	Surface spill—surface bypass	2001	CH	28	FPC, 2001
John Day	Surface spill—surface bypass	2008	CH	15.3	FPC, 2008

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Priest Rapids	Sluiceway	1992	All	2.7	McFadden and others, 1993, cited in USACE, 2007
Priest Rapids	Sluiceway	1992	All	3.8	Ransom, 1997, cited in USACE, 2007
Priest Rapids	Sluiceway	1994	All	2.9	Ransom, 1997, cited in USACE, 2007
Priest Rapids	Sluiceway	1995	All	8.3	Ransom, 1997, cited in USACE, 2007
Priest Rapids	Sluiceway	1995	All	5.7	Ransom, 1997, cited in USACE, 2007
Priest Rapids	Sluiceway	1996	All	3.2	Ransom, 1997, cited in USACE, 2007
Priest Rapids	Sluiceway	1996	All	2.8	Ransom, 1997, cited in USACE, 2007
Priest Rapids	Sluiceway	2001	CH	1.9	Robichaud and others, 2003, cited in USACE, 2007
Priest Rapids	Sluiceway	2006	OM	39	Timko and others, 2011
Priest Rapids	Sluiceway	2007	OM	34	Timko and others, 2011
Priest Rapids	Sluiceway	2008	OM	59	Timko and others, 2011
Priest Rapids	Sluiceway	2009	OM	66	Timko and others, 2011
Priest Rapids	Sluiceway	2010	OM	69	Timko and others, 2011
Rocky Reach	Surface spill—combined spillway	1998	All	27.7	Iverson and Birmingham, 1998, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	1998	All	33.1	Iverson and Birmingham, 1998, cited in USACE, 2007
Rocky Reach	Forebay collector	2002	CH	5	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2002	CH	2	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2002	CH	23	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2002	CH	17	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2004	CH	27	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	2004	CH	38.6	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	2004	CH	37.6	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2005	CH	32	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	2005	CH	36.2	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	1999	OM	28.5	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2002	OM	27	Steig and others, 2003
Rocky Reach	Forebay collector	2002	OM	30	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2002	OM	29	Steig and others, 2007, cited in USACE, 2007

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Rocky Reach	Forebay collector	2004	OM	67	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	2004	OM	16.7	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2005	OM	68	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	2005	OM	20.1	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Surface spill—combined spillway	2005	OM	21.9	Steig and others, 2007, cited in USACE, 2007
Rocky Reach	Forebay collector	2006	OM	66	Steig and others, 2007, cited in USACE, 2007
The Dalles	Sluiceway	1999	All	13	Ploskey and others, 2001, cited in USACE, 2007
The Dalles	Sluiceway	1999	All	12	Ploskey and others, 2001, cited in USACE, 2007
The Dalles	Sluiceway	2000	All	6	Moursund and others, 2001, cited in USACE, 2007
The Dalles	Sluiceway	2000	All	7	Moursund and others, 2001, cited in USACE, 2007
The Dalles	Sluiceway	2001	All	18	Moursund and others, 2002, cited in USACE, 2007
The Dalles	Sluiceway	2001	All	5	Moursund and others, 2002, cited in USACE, 2007
The Dalles	Sluiceway	2002	All	25	Johnson and others, 2003, cited in USACE, 2007
The Dalles	Sluiceway	2002	All	11	Johnson and others, 2003, cited in USACE, 2007
The Dalles	Sluiceway	2004	All	7	Johnson and others, 2005, cited in USACE, 2007
The Dalles	Sluiceway	2004	All	4	Johnson and others, 2005, cited in USACE, 2007
The Dalles	Sluiceway	2002	CH	10	Hausman and others, 2004, Counihan and others, 2006, cited in USACE, 2007
The Dalles	Sluiceway	2003	CH	12	Hansel and others, 2004, cited in USACE, 2007
The Dalles	Sluiceway	2003	CH	17	Hansel and others, 2004, cited in USACE, 2007
The Dalles	Sluiceway	2004	CH	7	Hansel and others, 2005 and Counihan and others, 2006, cited in USACE, 2007
The Dalles	Sluiceway	2004	CH	1	Cash and others, 2005, cited in USACE, 2007
The Dalles	Sluiceway	2004	CH	7	Hansel and others, 2005, Counihan and others, 2006, cited in USACE, 2007
The Dalles	Sluiceway	2004	CH	8	Cash and others, 2005, cited in USACE, 2007
The Dalles	Sluiceway	2005	CH	4	Beeman and others, 2006a cited in USACE, 2007
The Dalles	Sluiceway	2005	CH	11	Beeman and others, 2006a cited in USACE, 2007
The Dalles	Sluiceway	2002	OM	14	Hausman and others, 2004, cited in USACE, 2007
The Dalles	Sluiceway	2004	OM	5	Cash and others, 2005, cited in USACE, 2007
Wanapum	Sluiceway	1989	All	8.6	Ransom, 1997, cited in USACE, 2007

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Wanapum	Sluiceway	1990	All	5.7	Ransom, 1997, cited in USACE, 2007
Wanapum	Sluiceway	1991	All	4.2	Ransom, 1997, cited in USACE, 2007
Wanapum	Sluiceway	1994	All	5.8	Ransom, 1997, cited in USACE, 2007
Wanapum	Sluiceway	1995	All	10	Ransom, 1997, cited in USACE, 2007
Wanapum	Sluiceway	1995	All	9.9	Ransom, 1997, cited in USACE, 2007
Wanapum	Sluiceway	1996	All	3	Ransom, 1997, cited in USACE, 2007
Wanapum	Sluiceway	1996	All	3.7	Ransom, 1997, cited in USACE, 2007
Wanapum	Powerhouse retrofit	1996	All	0.3	Kumagai and others, 1997, cited in USACE, 2007
Wanapum	Powerhouse retrofit	1997	All	0.3	Kumagai and others, 1997, cited in USACE, 2007
Wanapum	Sluiceway	1996	CH	3	Robichaud and others, 2003, cited in USACE, 2007
Wanapum	Surface spill	2002	CH	10	Robichaud and others, 2003, cited in USACE, 2007
Wanapum	Surface spill	2004	CH	24	USACE, 2007
Wanapum	Surface spill	2008	OM	53.5	Timko and others, 2010
Wanapum	Surface spill	2009	OM	70.2	Timko and others, 2010
Wanapum	Surface spill	2010	OM	77	Timko and others, 2011
Wells	Powerhouse retrofit—surface bypass units with retrofit baffle bays	1990	CH, OM	84.3	Skalski and others, 1996
Wells	Powerhouse retrofit—surface bypass units with retrofit baffle bays	1990	CH, OM	76.5	Skalski and others, 1996
Wells	Powerhouse retrofit—surface bypass units with retrofit baffle bays	1991	CH, OM	95	Skalski and others, 1996
Wells	Powerhouse retrofit—surface bypass units with retrofit baffle bays	1991	CH, OM	97	Skalski and others, 1996
Wells	Powerhouse retrofit—surface bypass units with retrofit baffle bays	1992	CH, OM	89	Skalski and others, 1996
Wells	Powerhouse retrofit—surface bypass units with retrofit baffle bays	1992	CH, OM	93.4	Skalski and others, 1996
Connecticut River (New Hampshire, U.S.A.)					
Bellows Falls	Bypass/sluice	NA	SS	94	Hanson, 1999
Vernon Station	Bypass/sluice	NA	SS	74	Hanson, 1999

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Cowlitz River (Washington, U.S.A.)					
Cowlitz Falls	Forebay collector—retrofit baffle	1997	CH	17	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1998	CH	18	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1999	CH	24	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2000	CH	24	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2001	CH	23	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2002	CH	22	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2003	CH	13	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2004	CH	14	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2005	CH	12	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2006	CH	30.5	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2007	CH	20.1	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2008	CH	26.1	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2009	CH	39.6	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2012	CH	16.6	Serl and Heimbigner, 2013
Cowlitz Falls	Forebay collector—retrofit baffle	1996	CO	15	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1997	CO	21	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1998	CO	32	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1999	CO	17	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2000	CO	45	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2001	CO	42	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2002	CO	33	Serl and Morrill, 2010



**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Cowlitz Falls	Forebay collector—retrofit baffle	2003	CO	43	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2004	CO	42	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2005	CO	36	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2006	CO	26	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2007	CO	36	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2008	CO	20.8	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2009	CO	20.8	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2012	CO	17.7	Serl and Heimbigner, 2013
Cowlitz Falls	Forebay collector—retrofit baffle	1996	OM	50	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1997	OM	45	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1998	OM	19	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1999	OM	41	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2000	OM	65	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2001	OM	58	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2002	OM	56	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2003	OM	68	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2004	OM	48	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2005	OM	42	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2006	OM	47	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2007	OM	42	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2008	OM	26	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2009	OM	37.4	Serl and Morrill, 2010

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Cowlitz Falls	Forebay collector—retrofit baffle	2012	OM	5.4	Serl and Heimbigner, 2013
Mayfield	Forebay collector	1964	CH	76	USACE, 2007
Mayfield	Forebay collector	1965	CH	74	USACE, 2007
Mayfield	Forebay collector	1964	CO	50	USACE, 2007
Mayfield	Forebay collector	1965	CO	62	USACE, 2007
Mayfield	Forebay collector	2001	CO	67	USACE, 2007
Mayfield	Forebay collector	2012	CO	67	Serl and Heimbigner, 2013
Mayfield	Forebay collector	1964	OM	73.6	USACE, 2007
Mayfield	Forebay collector	1965	OM	79.3	USACE, 2007
Deschutes River (Oregon, U.S.A.)					
Round Butte	Forebay collector—double –V screen	2010	CH	46.9	Hill and Quesada, 2011
Round Butte	Forebay collector—double –V screen	2011	CH	51.7	Hill and Quesada, 2012
Round Butte	Forebay collector—double –V screen	2012	CH	46.9	Hill and Quesada, 2013
Round Butte	Forebay collector—double –V screen	2013	CH	30.1	Hill and Quesada, 2014
Round Butte	Forebay collector—double –V screen	2014	CH	37.7	Hill and Quesada, 2015
Round Butte	Forebay collector—double –V screen	2010	OM	17.4	Hill and Quesada, 2011
Round Butte	Forebay collector—double –V screen	2011	OM	24.2	Hill and Quesada, 2012
Round Butte	Forebay collector—double –V screen	2012	OM	16	Hill and Quesada, 2013
Round Butte	Forebay collector—double –V screen	2013	OM	12.7	Hill and Quesada, 2014
Round Butte	Forebay collector—double –V screen	2014	OM	12.4	Hill and Quesada, 2015
Garonne (France)					
Camon	Bypass/sluiice	NA	SS	73	Travade and Larinier 2006
Gave d' Aspe (France)					
Bedous	Bypass/sluiice	NA	SS	55	Travade and Larinier 2006
Soeix	Bypass/sluiice	NA	SS	61	Travade and Larinier 2006
Gave d' Ossau (France)					
St. Cricq	Bypass/sluiice	NA	SS	79	Travade and Larinier 2006

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Gave de Pau (France)					
Baigts	Bypass/sluiice	NA	SS	93	Travade and Larinier 2006
Castetarbe	Bypass/sluiice	NA	SS	100	Travade and Larinier 2006
Lewis River (Washington, U.S.A.)					
Swift Reservoir	Floating surface collector	2015	CO	11.8	PacifiCorp and Cowlitz PUD, 2016
Swift Reservoir	Floating surface collector	2015	CH	0	PacifiCorp and Cowlitz PUD, 2016
Swift Reservoir	Floating surface collector	2015	OM	18.6	PacifiCorp and Cowlitz PUD, 2016
Santiam River (Oregon, U.S.A.)					
Green Peter	Forebay collector—Floating collection horn	NA	CH	>80	AECOM, 2010
Green Peter	Forebay collector—Floating collection horn	4 years in the late 1960s	OM	<57	AECOM, 2010
Snake River (Idaho, Oregon, and Washington, U.S.A.)					
Ice Harbor	Sluiceway	1982	All	13	Johnson and others, 1982, cited in USACE, 2007
Ice Harbor	Sluiceway	1983	All	30	Johnson and others, 1982, cited in USACE, 2007
Ice Harbor	Sluiceway	1986	All	50	Sullivan and others, 1986, cited in USACE, 2007
Ice Harbor	Sluiceway	1987	All	34	Ransom and Ouellette, 1988, cited in USACE, 2007
Ice Harbor	Surface Spill—RSW	2005	All	28	USACE, 2007
Ice Harbor	Surface Spill—RSW	2005	All	38	USACE, 2007
Ice Harbor	Surface Spill—RSW	2005	CH	60	USACE, 2007
Ice Harbor	Surface Spill—RSW	2005	CH	29	Axel and others, 2006, cited in USACE, 2007
Ice Harbor	Surface Spill—RSW	2006	CH	68	USACE, 2007
Ice Harbor	Surface Spill—RSW	2006	CH	51	USACE, 2007
Ice Harbor	Surface Spill—RSW	2005	OM	47	Axel and others, 2006, cited in USACE, 2007
Ice Harbor	Surface Spill—RSW	2006	OM	38	USACE, 2007
Lower Granite	Powerhouse retrofit—SBC	2000	All	43	Anglea and others, 2001, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2002	All	65	USACE, 2007
Lower Granite	Surface Spill—RSW	2005	All	31	Dawson and others, 2006, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2005	All	25	Dawson and others, 2006, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	1998	CH	49	FPC, 2001
Lower Granite	Surface Spill—RSW	1998	CH	49	FPC, 2001

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Lower Granite	Surface Spill—RSW	1999	CH	26	FPC, 2001
Lower Granite	Surface Spill—RSW	1999	CH	26	FPC, 2001
Lower Granite	Surface Spill—RSW	2000	CH	38	FPC, 2001
Lower Granite	Surface Spill—RSW	2000	CH	38	FPC, 2001
Lower Granite	Surface Spill—RSW	2000	CH	38	FPC, 2001
Lower Granite	Surface Spill—RSW	2000	CH	55	FPC, 2001
Lower Granite	Powerhouse retrofit—SBC	2000	CH	29	Plumb and others, 2002, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2001	CH	79	FPC, 2001
Lower Granite	Surface Spill—RSW	2001	CH	75	FPC, 2006
Lower Granite	Surface Spill—RSW	2001	CH	82	FPC, 2006
Lower Granite	Surface Spill—RSW	2001	CH	60	FPC, 2001
Lower Granite	Surface Spill—RSW	2002	CH	22	FPC, 2006
Lower Granite	Surface Spill—RSW	2002	CH	22	FPC, 2006
Lower Granite	Surface Spill—RSW	2002	CH	60	FPC, 2002
Lower Granite	Surface Spill—RSW	2002	CH	56	Plumb and others, 2003, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2003	CH	32	FPC, 2008
Lower Granite	Surface Spill—RSW	2003	CH	42	FPC, 2006
Lower Granite	Surface Spill—RSW	2003	CH	49	FPC, 2004
Lower Granite	Surface Spill—RSW	2003	CH	58	Plumb and others, 2004, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2004	CH	55	FPC, 2008
Lower Granite	Surface Spill—RSW	2004	CH	61	FPC, 2006
Lower Granite	Surface Spill—RSW	2005	CH	72	FPC, 2008
Lower Granite	Surface Spill—RSW	2005	CH	76	FPC, 2008
Lower Granite	Surface Spill—RSW	2005	CH	35	FPC, 2006
Lower Granite	Surface Spill—RSW	2005	CH	69	USACE, 2007
Lower Granite	Surface Spill—RSW	2005	CH	37	USACE, 2007
Lower Granite	Surface Spill—RSW	2006	CH	24	FPC, 2011
Lower Granite	Surface Spill—RSW	2006	CH	32	FPC, 2011
Lower Granite	Surface Spill—RSW	2006	CH	16	FPC, 2006
Lower Granite	Surface Spill—RSW	2006	CH	16	FPC, 2006
Lower Granite	Surface Spill—RSW	2006	CH	58	USACE, 2007
Lower Granite	Surface Spill—RSW	2006	CH	30	USACE, 2007

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Lower Granite	Surface Spill—RSW	2007	CH	25	FPC, 2011
Lower Granite	Surface Spill—RSW	2007	CH	32	FPC, 2011
Lower Granite	Surface Spill—RSW	2007	CH	13	FPC, 2007
Lower Granite	Surface Spill—RSW	2007	CH	9	FPC, 2007
Lower Granite	Surface Spill—RSW	2008	CH	37	FPC, 2011
Lower Granite	Surface Spill—RSW	2008	CH	38	FPC, 2011
Lower Granite	Surface Spill—RSW	2008	CH	14	FPC, 2008
Lower Granite	Surface Spill—RSW	2008	CH	16	FPC, 2008
Lower Granite	Surface Spill—RSW	2009	CH	32	FPC, 2011
Lower Granite	Surface Spill—RSW	2009	CH	45	FPC, 2011
Lower Granite	Surface Spill—RSW	2009	CH	17	FPC, 2009
Lower Granite	Surface Spill—RSW	2009	CH	15	FPC, 2009
Lower Granite	Surface Spill—RSW	2010	CH	17	FPC, 2011
Lower Granite	Surface Spill—RSW	2010	CH	26	FPC, 2011
Lower Granite	Surface Spill—RSW	2010	CH	15	FPC, 2010
Lower Granite	Surface Spill—RSW	2010	CH	11	FPC, 2010
Lower Granite	Surface Spill—RSW	2011	CH	34	FPC, 2011
Lower Granite	Surface Spill—RSW	2011	CH	42	FPC, 2011
Lower Granite	Surface Spill—RSW	2011	CH	19	FPC, 2011
Lower Granite	Surface Spill—RSW	2011	CH	17	FPC, 2011
Lower Granite	Surface Spill—RSW	1998	OM	59	FPC, 2001
Lower Granite	Surface Spill—RSW	1998	OM	59	FPC, 2001
Lower Granite	Surface Spill—RSW	1999	OM	36	FPC, 2003
Lower Granite	Surface Spill—RSW	1999	OM	37	FPC, 2001
Lower Granite	Surface Spill—RSW	1999	OM	31	FPC, 2001
Lower Granite	Surface Spill—RSW	2000	OM	59	FPC, 2006
Lower Granite	Surface Spill—RSW	2000	OM	63	FPC, 2002
Lower Granite	Surface Spill—RSW	2000	OM	53	FPC, 2002
Lower Granite	Powerhouse retrofit—SBC	2000	OM	27	Plumb and others, 2002, cited in USACE, 2007
Lower Granite	Powerhouse retrofit—SBC	2000	OM	18	Plumb and others, 2002, cited in USACE, 2007

**Table A1.2.** Estimates of collection efficiency by river, facility, collection method, year, species, and reference.—Continued

[NA, not available; SS, Atlantic salmon; U.S.A., United States of America; CO, coho salmon; PSE, Puget Sound Energy; PH, powerhouse; PSC, prototype surface collector; USACE, U.S. Army Corps of Engineers; CH, Chinook salmon; FPC, Fish Passage Center; OM, steelhead; B2CC, second power house corner collector; PUD, Public Utility District; >, greater than; <, less than; RSW, removable spillway weir; SBC, surface bypass collector]

Facility	Method	Year	Species	Collection efficiency (percent)	Reference
Lower Granite	Surface Spill—RSW	2001	OM	89	FPC, 2006
Lower Granite	Surface Spill—RSW	2001	OM	91	FPC, 2002
Lower Granite	Surface Spill—RSW	2001	OM	87	FPC, 2002
Lower Granite	Surface Spill—RSW	2002	OM	24	FPC, 2006
Lower Granite	Surface Spill—RSW	2002	OM	23	FPC, 2002
Lower Granite	Surface Spill—RSW	2002	OM	27	FPC, 2002
Lower Granite	Surface Spill—RSW	2002	OM	61	Plumb and others, 2003, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2002	OM	62	Plumb and others, 2003, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2003	OM	32	FPC, 2008
Lower Granite	Surface Spill—RSW	2003	OM	67	Plumb and others, 2004, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2003	OM	69	Plumb and others, 2004, cited in USACE, 2007
Lower Granite	Surface Spill—RSW	2004	OM	73	FPC, 2008
Lower Granite	Surface Spill—RSW	2005	OM	68	FPC, 2008
Lower Granite	Surface Spill—RSW	2005	OM	49	USACE, 2007
Lower Granite	Surface Spill—RSW	2005	OM	41	USACE, 2007
Lower Granite	Surface Spill—RSW	2006	OM	35	FPC, 2011
Lower Granite	Surface Spill—RSW	2006	OM	37	FPC, 2011
Lower Granite	Surface Spill—RSW	2006	OM	27	USACE, 2007
Lower Granite	Surface Spill—RSW	2007	OM	22	FPC, 2011
Lower Granite	Surface Spill—RSW	2007	OM	24	FPC, 2011
Lower Granite	Surface Spill—RSW	2008	OM	28	FPC, 2011
Lower Granite	Surface Spill—RSW	2008	OM	35	FPC, 2011
Lower Granite	Surface Spill—RSW	2009	OM	44	FPC, 2011
Lower Granite	Surface Spill—RSW	2009	OM	46	FPC, 2011
Lower Granite	Surface Spill—RSW	2010	OM	19	FPC, 2011
Lower Granite	Surface Spill—RSW	2010	OM	22	FPC, 2011
Lower Granite	Surface Spill—RSW	2011	OM	38	FPC, 2011
Lower Granite	Surface Spill—RSW	2011	OM	41	FPC, 2011

**Table A1.3.** Estimates of survival through collectors by river, facility, collection method, year, species, origin, and reference.

[CO, coho salmon; Mixed, hatchery and wild; OM, steelhead; CH, Chinook salmon; H, hatchery, NA, not available; W, wild; FPC, Fish Passage Center; PGE, Portland General Electric Company]

Facility	Collection method	Year	Species	Origin	Survival (percent)	Reference
Baker River (Washington)						
Upper Baker	Forebay collector—surface collector	2011	CO	Mixed	100	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector	2010	CO	Mixed	100	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector	2009	CO	Mixed	100	Jeanes and Verretto, 2012
Upper Baker	Forebay collector—surface collector	2008	CO	Mixed	100	Jeanes and Verretto, 2012
Clackamas River (Oregon)						
North Fork	Forebay collector	2001	OM	Mixed	86	Heisey and others, 2002
North Fork	Forebay collector	2001	OM	Mixed	97	Heisey and others, 2002
North Fork	Forebay collector	2001	OM	Mixed	98	Heisey and others, 2002
North Fork	Forebay collector	2001	OM	Mixed	99	Heisey and others, 2002
North Fork	Forebay collector	2001	CH/CO	Mixed	80	Heisey and others, 2002
North Fork	Forebay collector	2001	CH/CO	Mixed	87	Heisey and others, 2002
North Fork	Forebay collector	2001	CH/CO	Mixed	95	Heisey and others, 2002
North Fork	Forebay collector	2001	CH/CO	Mixed	95	Heisey and others, 2002
River Mill	Surface spill—spillway weir	2004	OM	Mixed	99	Karchesky and others, 2008
River Mill	Surface spill—spillway weir	2004	CH	Mixed	98	Karchesky and others, 2008
River Mill	Surface spill—spillway weir	2004	CH	Mixed	99	Karchesky and others, 2008
Columbia River (Oregon and Washington)						
Bonneville	Bonneville floating surface collector	2003	OM	H	44	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	49	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	58	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	69	Clemens and others, 2009
Bonneville	Sampled from barge	2002	OM	H	74	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	79	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2002	OM	H	81	Clemens and others, 2009
Bonneville	Sampled from barge	2002	OM	H	83	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2002	OM	H	85	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	86	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2002	OM	H	87	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	89	Clemens and others, 2009



**Table A1.3.** Estimates of survival through collectors by river, facility, collection method, year, species, origin, and reference.—Continued

[CO, coho salmon; Mixed, hatchery and wild; OM, steelhead; CH, Chinook salmon; H, hatchery, NA, not available; W, wild; FPC, Fish Passage Center; PGE, Portland General Electric Company]

Facility	Collection method	Year	Species	Origin	Survival (percent)	Reference
Bonneville	Sampled from barge	2003	OM	H	89	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	91	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	93	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	94	Clemens and others, 2009
Bonneville	Sampled from barge	2002	OM	H	95	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	95	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	95	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	96	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	96	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	96	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	96	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	98	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	98	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	100	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	100	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	100	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	OM	H	100	Clemens and others, 2009
Bonneville	Sampled from barge	2003	OM	H	100	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	66	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	CH	Mixed	72	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	73	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	73	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	77	Clemens and others, 2009
Bonneville	Sampled from barge	2003	CH	Mixed	78	Clemens and others, 2009
Bonneville	Sampled from barge	2003	CH	Mixed	87	Clemens and others, 2009
Bonneville	Sampled from barge	2003	CH	Mixed	87	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	CH	Mixed	87	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	88	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	90	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	CH	Mixed	91	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	92	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	92	Clemens and others, 2009

**Table A1.3.** Estimates of survival through collectors by river, facility, collection method, year, species, origin, and reference.—Continued

[CO, coho salmon; Mixed, hatchery and wild; OM, steelhead; CH, Chinook salmon; H, hatchery, NA, not available; W, wild; FPC, Fish Passage Center; PGE, Portland General Electric Company]

Facility	Collection method	Year	Species	Origin	Survival (percent)	Reference
Bonneville	Bonneville floating surface collector	2003	CH	Mixed	96	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	98	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	CH	Mixed	99	Clemens and others, 2009
Bonneville	Sampled from barge	2003	CH	Mixed	100	Clemens and others, 2009
Bonneville	Bonneville floating surface collector	2003	CH	Mixed	100	Clemens and others, 2009
Bonneville	Sampled from barge	2003	CH	Mixed	100	Clemens and others, 2009
Bonneville	Sampled from barge	2003	CH	Mixed	100	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	100	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	100	Clemens and others, 2009
Bonneville	Sampled from barge	2004	CH	H	100	Clemens and others, 2009
Collected at Lower Granite Dam	NA	2010	CH	Mixed	98	McMichael and others, 2011
Cowlitz River (Washington)						
Cowlitz Falls	Forebay collector—retrofit baffle	1997	CO	H	93	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1998	CO	H	98	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1999	CO	H	98	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2008	CO	H	98	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2002	CO	H	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2006	CO	H	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2007	CO	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2000	CO	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2001	CO	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2003	CO	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2004	CO	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2005	CO	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2009	CO	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2012	CO	H	100	Serl and Heimbigner, 2013

**Table A1.3.** Estimates of survival through collectors by river, facility, collection method, year, species, origin, and reference.—Continued

[CO, coho salmon; Mixed, hatchery and wild; OM, steelhead; CH, Chinook salmon; H, hatchery; NA, not available; W, wild; FPC, Fish Passage Center; PGE, Portland General Electric Company]

Facility	Collection method	Year	Species	Origin	Survival (percent)	Reference
Cowlitz Falls	Forebay collector—retrofit baffle	1997	OM	Mixed	95	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2008	OM	Mixed	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1998	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1999	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2012	OM	W	100	Serl and Heimbigner, 2013
Cowlitz Falls	Forebay collector—retrofit baffle	2007	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2006	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2000	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2002	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2005	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2009	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2001	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2003	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2004	OM	Mixed	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1997	CH	H	88	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1998	CH	H	95	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2001	CH	H	97	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2005	CH	W	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2007	CH	W	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2005	CH	H	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2003	CH	H	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	1999	CH	H	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2000	CH	H	99	Serl and Morrill, 2010

**Table A1.3.** Estimates of survival through collectors by river, facility, collection method, year, species, origin, and reference.—Continued

[CO, coho salmon; Mixed, hatchery and wild; OM, steelhead; CH, Chinook salmon; H, hatchery, NA, not available; W, wild; FPC, Fish Passage Center; PGE, Portland General Electric Company]

Facility	Collection method	Year	Species	Origin	Survival (percent)	Reference
Cowlitz Falls	Forebay collector—retrofit baffle	2008	CH	W	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2004	CH	H	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2006	CH	W	99	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2002	CH	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2006	CH	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2007	CH	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2008	CH	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2004	CH	W	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2009	CH	H	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2009	CH	W	100	Serl and Morrill, 2010
Cowlitz Falls	Forebay collector—retrofit baffle	2012	CH	W	100	Serl and Heimbigner, 2013
Mayfield	Louver system	2008	CO	W	96	FPC, 2011
Mayfield	Louver system	2009	CO	W	98	Henning, 2010
Mayfield	Louver system	2009	OM	Mixed	99	Henning, 2010
Mayfield	Louver system	2009	CH	W	95	Henning, 2010
Deschutes River (Oregon)						
Pelton Round Butte	Guidance net/skimmer	2010	OM	H	98	PGE, 2011
Pelton Round Butte	Guidance net/skimmer	2010	CH	H	98	PGE, 2012
Pelton Round Butte	Guidance net/skimmer	2010	SO	H	98	PGE, 2012
Pelton Round Butte	Guidance net/skimmer	2011	SO	H	97	PGE, 2012
Pelton Round Butte	Guidance net/skimmer	2011	CH	H	99	PGE, 2012
Pelton Round Butte	Guidance net/skimmer	2011	OM	H	99	PGE, 2012
Pelton Round Butte	Guidance net/skimmer	2012	SO	H	97	PGE, 2012
Pelton Round Butte	Guidance net/skimmer	2012	CH	H	98	PGE, 2012
Pelton Round Butte	Guidance net/skimmer	2012	OM	H	99	PGE, 2012

**Table A1.3.** Estimates of survival through collectors by river, facility, collection method, year, species, origin, and reference.—Continued

[CO, coho salmon; Mixed, hatchery and wild; OM, steelhead; CH, Chinook salmon; H, hatchery, NA, not available; W, wild; FPC, Fish Passage Center; PGE, Portland General Electric Company]

Facility	Collection method	Year	Species	Origin	Survival (percent)	Reference
Pelton Round Butte	Guidance net/skimmer	2013	CH	Mixed	98	PGE, 2014
Pelton Round Butte	Guidance net/skimmer	2013	OM	Mixed	99	PGE, 2014
Pelton Round Butte	Guidance net/skimmer	2013	SO	H	98	PGE, 2014
Pelton Round Butte	Guidance net/skimmer	2014	CH	Mixed	98	PGE, 2015
Pelton Round Butte	Guidance net/skimmer	2014	OM	Mixed	99	PGE, 2015
<b>Clackamas River (Oregon)</b>						
River Mill	Surface spill—spillway weir	2004	OM	Mixed	99	Karchesky and others, 2008
River Mill	Surface spill—spillway weir	2004	CH	Mixed	98	Karchesky and others, 2008
River Mill	Surface spill—spillway weir	2004	CH	Mixed	99	Karchesky and others, 2008
<b>Willamette River (Oregon)</b>						
Willamette Falls	From hatchery	2008	OM	H	98	Karchesky, 2008
Willamette Falls	From hatchery	2008	OM	H	99	Karchesky and others, 2008
Willamette Falls	From hatchery	2008	OM	H	100	Karchesky and others, 2008
Willamette Falls	From hatchery	2008	CH	H	100	Karchesky and others, 2008
Willamette Falls	From hatchery	2008	CH	H	100	Karchesky and others, 2008

**Table A1.4.** Descaling estimates by river, facility, type of collector, year, species, and reference.

[CH, Chinook salmon; PH, power house; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon]

Facility	Collector	Year	Species	Age	Descaling rates (percent)	Reference
<b>Columbia River (Oregon and Washington)</b>						
John Day	Juvenile bypass	1998	CH	1+	6.1	Martinson and others, 2004
John Day	Juvenile bypass	1999	CH	1+	6.2	Martinson and others, 2004
John Day	Juvenile bypass	2000	CH	1+	2.4	Martinson and others, 2004
John Day	Juvenile bypass	2001	CH	1+	1.7	Martinson and others, 2004
John Day	Juvenile bypass	2002	CH	1+	3.1	Martinson and others, 2004
John Day	Juvenile bypass	2003	CH	1+	4.6	Martinson and others, 2004
John Day	Juvenile bypass	1998	CH	0+	2.2	Martinson and others, 2004
John Day	Juvenile bypass	1999	CH	0+	0.9	Martinson and others, 2004
John Day	Juvenile bypass	2000	CH	0+	0.6	Martinson and others, 2004
John Day	Juvenile bypass	2001	CH	0+	0.9	Martinson and others, 2004
John Day	Juvenile bypass	2002	CH	0+	1	Martinson and others, 2004

**Table A1.4.** Descaling estimates by river, facility, type of collector, year, species, and reference.—Continued

[CH, Chinook salmon; PH, power house; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon]

Facility	Collector	Year	Species	Age	Descaling rates (percent)	Reference
John Day	Juvenile bypass	2003	CH	0+	0.9	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2000	CH	1+	3.3	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2001	CH	1+	1.8	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2002	CH	1+	2.4	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2003	CH	1+	2.8	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2000	CH	0+	0.5	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2001	CH	0+	0.6	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2002	CH	0+	0.4	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2003	CH	0+	0.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1989	CH	0+	4.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1990	CH	0+	7	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1991	CH	0+	9.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1992	CH	0+	4.6	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1993	CH	0+	3.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1994	CH	0+	2.6	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1995	CH	0+	6.7	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1996	CH	0+	5.1	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1997	CH	0+	4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1998	CH	0+	4.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1999	CH	0+	3.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2000	CH	0+	9.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2001	CH	0+	1.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2002	CH	0+	7.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2003	CH	0+	7.7	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1989	CH	1+	2.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1990	CH	1+	2.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1991	CH	1+	2.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1992	CH	1+	2.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1993	CH	1+	1.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1994	CH	1+	0.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1995	CH	1+	1.1	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1996	CH	1+	0.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1997	CH	1+	1.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1998	CH	1+	1.6	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1999	CH	1+	1	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2000	CH	1+	3.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2001	CH	1+	0.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2002	CH	1+	3.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2003	CH	1+	2.6	Martinson and others, 2004
John Day	Juvenile bypass	1998	CO	NA	5.6	Martinson and others, 2004

**Table A1.4.** Descaling estimates by river, facility, type of collector, year, species, and reference.—Continued

[CH, Chinook salmon; PH, power house; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon]

Facility	Collector	Year	Species	Age	Descaling rates (percent)	Reference
John Day	Juvenile bypass	1999	CO	NA	3.7	Martinson and others, 2004
John Day	Juvenile bypass	2000	CO	NA	1.4	Martinson and others, 2004
John Day	Juvenile bypass	2001	CO	NA	1.6	Martinson and others, 2004
John Day	Juvenile bypass	2002	CO	NA	3.1	Martinson and others, 2004
John Day	Juvenile bypass	2003	CO	NA	2.6	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2000	CO	NA	1.6	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2001	CO	NA	0.7	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2002	CO	NA	1.1	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2003	CO	NA	1.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1989	CO	NA	3.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1990	CO	NA	5.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1991	CO	NA	4.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1992	CO	NA	6.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1993	CO	NA	2.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1994	CO	NA	1.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1995	CO	NA	2.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1996	CO	NA	2.5	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1997	CO	NA	2.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1998	CO	NA	2.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1999	CO	NA	1.1	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2000	CO	NA	4.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2001	CO	NA	0.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2002	CO	NA	2.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2003	CO	NA	2.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1989	OM	NA	4.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1990	OM	NA	6	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1991	OM	NA	7	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1992	OM	NA	6.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1993	OM	NA	2.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1994	OM	NA	2.7	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1995	OM	NA	2.6	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1996	OM	NA	2.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1997	OM	NA	1	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1998	OM	NA	2.2	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1999	OM	NA	1.1	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2000	OM	NA	7.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2001	OM	NA	0	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2002	OM	NA	7.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2003	OM	NA	4.4	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1990	OM	NA	14.9	Martinson and others, 2004



**Table A1.4.** Descaling estimates by river, facility, type of collector, year, species, and reference.—Continued

[CH, Chinook salmon; PH, power house; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon]

Facility	Collector	Year	Species	Age	Descaling rates (percent)	Reference
Bonneville Dam PH1	Juvenile bypass	1991	OM	NA	8.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1992	OM	NA	12.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1993	OM	NA	8.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1994	OM	NA	7.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1995	OM	NA	10.6	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1996	OM	NA	7.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1997	OM	NA	6.8	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1998	OM	NA	6.3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	1999	OM	NA	3	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2000	OM	NA	12.6	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2001	OM	NA	12	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2002	OM	NA	12.9	Martinson and others, 2004
Bonneville Dam PH1	Juvenile bypass	2003	OM	NA	7.5	Martinson and others, 2004
John Day	Juvenile bypass	1998	OM	NA	1.6	Martinson and others, 2004
John Day	Juvenile bypass	1999	OM	NA	1.9	Martinson and others, 2004
John Day	Juvenile bypass	2000	OM	NA	1.8	Martinson and others, 2004
John Day	Juvenile bypass	2001	OM	NA	1.4	Martinson and others, 2004
John Day	Juvenile bypass	2002	OM	NA	2.8	Martinson and others, 2004
John Day	Juvenile bypass	2003	OM	NA	3.3	Martinson and others, 2004
John Day	Juvenile bypass	1998	OM	NA	7.2	Martinson and others, 2004
John Day	Juvenile bypass	1999	OM	NA	6.1	Martinson and others, 2004
John Day	Juvenile bypass	2000	OM	NA	5.6	Martinson and others, 2004
John Day	Juvenile bypass	2001	OM	NA	4.7	Martinson and others, 2004
John Day	Juvenile bypass	2002	OM	NA	7.2	Martinson and others, 2004
John Day	Juvenile bypass	2003	OM	NA	8.7	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2000	OM	NA	1.1	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2001	OM	NA	2	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2002	OM	NA	3.2	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2003	OM	NA	2.9	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2000	OM	NA	5	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2001	OM	NA	4.7	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2002	OM	NA	6.5	Martinson and others, 2004
Bonneville Dam PH2	Juvenile bypass	2003	OM	NA	7.5	Martinson and others, 2004
Cowlitz River (Washington)						
Mayfield		2009	CH	NA	4.1	Henning, 2010
Cowlitz Falls Fish Facility		2004	CH	NA	0.18	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2005	CH	NA	0.18	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2006	CH	NA	0.07	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2007	CH	NA	0.29	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2008	CH	NA	0.53	Serl and Morrill, 2010

**Table A1.4.** Descaling estimates by river, facility, type of collector, year, species, and reference.—Continued

[CH, Chinook salmon; PH, power house; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon]

Facility	Collector	Year	Species	Age	Descaling rates (percent)	Reference
Cowlitz Falls Fish Facility		2009	CH	NA	0.7	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1997	CH	NA	2.43	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1998	CH	NA	0.05	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1999	CH	NA	0.08	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2000	CH	NA	0.07	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2001	CH	NA	0.39	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2002	CH	NA	0.17	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2003	CH	NA	0.86	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2004	CH	NA	2.87	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2005	CH	NA	0.43	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2006	CH	NA	0.18	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2007	CH	NA	0.1	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2008	CH	NA	0.33	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2009	CH	NA	1.06	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2012	CH	NA	0.7	Serl and Heimbigner, 2013
Cowlitz Falls Fish Facility		1997	CO	NA	0.61	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1998	CO	NA	0.02	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1999	CO	NA	0.13	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2000	CO	NA	0.02	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2001	CO	NA	0.16	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2002	CO	NA	0.11	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2003	CO	NA	0.14	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2004	CO	NA	3.66	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2005	CO	NA	0.06	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2006	CO	NA	0.03	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2007	CO	NA	0.05	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2008	CO	NA	0.09	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2009	CO	NA	0.19	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2012	CO	NA	0.5	Serl and Heimbigner, 2013
Cowlitz Falls Fish Facility		1997	OM	NA	0.91	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1998	OM	NA	0.62	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1999	OM	NA	0.14	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2000	OM	NA	0.01	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2001	OM	NA	0.04	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2002	OM	NA	0.03	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2003	OM	NA	0.13	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2004	OM	NA	1.37	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2005	OM	NA	0.13	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2006	OM	NA	0.09	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2007	OM	NA	0.17	Serl and Morrill, 2010

**Table A1.4.** Descaling estimates by river, facility, type of collector, year, species, and reference.—Continued

[CH, Chinook salmon; PH, power house; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon]

Facility	Collector	Year	Species	Age	Descaling rates (percent)	Reference
Cowlitz Falls Fish Facility		2008	OM	NA	0.19	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2009	OM	NA	0.27	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1997	OM	NA	2.34	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1998	OM	NA	0.62	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		1999	OM	NA	0.1	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2000	OM	NA	0	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2001	OM	NA	0.03	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2002	OM	NA	0.02	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2003	OM	NA	0.31	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2004	OM	NA	0.97	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2005	OM	NA	0.07	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2006	OM	NA	0.09	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2007	OM	NA	0.23	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2008	OM	NA	0.21	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2009	OM	NA	0.16	Serl and Morrill, 2010
Cowlitz Falls Fish Facility		2012	OM	NA	0.7	Serl and Heimbigner, 2013
Deschutes River (Oregon)						
Round Butte		2011	CH	NA	0	PGE, 2013
Round Butte		2012	CH	NA	0.1	PGE, 2013
Round Butte		2013	CH	NA	0.28	PGE, 2014
Round Butte		2011	OM	NA	0	PGE, 2013
Round Butte		2012	OM	NA	0.02	PGE, 2013
Round Butte		2014	OM	NA	1.06	PGE, 2015
Round Butte		2011	SO	NA	0.3	PGE, 2013
Round Butte		2012	SO	NA	NA	PGE, 2013
Round Butte		2012	SO	NA	0.79	PGE, 2014
Round Butte		2014	SO	NA	0.98	PGE, 2015

**Table A1.5.** Mortality estimates for nontarget species at downstream fish collection facilities by river, facility, year, species, and reference.

[PGE, Portland General Electric Company]

Facility	Year	Species	Mortality (percent)	Reference
Cowlitz River (Washington)				
Cowlitz Falls Fish Facility	1997	Coastal cutthroat trout	1.5	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	1998	Coastal cutthroat trout	0.54	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	1999	Coastal cutthroat trout	0.38	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2000	Coastal cutthroat trout	0.28	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2001	Coastal cutthroat trout	0.28	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2002	Coastal cutthroat trout	0.1	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2003	Coastal cutthroat trout	0.08	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2004	Coastal cutthroat trout	0.14	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2005	Coastal cutthroat trout	0.39	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2006	Coastal cutthroat trout	0.14	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2007	Coastal cutthroat trout	0.14	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2008	Coastal cutthroat trout	0	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2009	Coastal cutthroat trout	0.71	Serl and Morrill, 2010
Cowlitz Falls Fish Facility	2012	Coastal cutthroat trout	0	Serl and Heimbigner, 2013
Mayfield Dam	2009	Coastal cutthroat trout	0.09	Henning, 2010
Deschutes River (Oregon)				
Round Butte	2010	Bull trout	1.4	PGE, 2011
Round Butte	2010	Kokanee salmon	6.9	PGE, 2011
Round Butte	2010	Rainbow trout	2.1	PGE, 2011
Round Butte	2010	Mountain whitefish	0	PGE, 2011
Round Butte	2011	Bull trout	1.98	PGE, 2012
Round Butte	2011	Kokanee salmon	9.1	PGE, 2012
Round Butte	2011	Rainbow trout	2	PGE, 2012
Round Butte	2011	Mountain whitefish	0.04	PGE, 2012
Round Butte	2012	Bull trout	1.7	PGE, 2013
Round Butte	2012	Kokanee salmon	9.7	PGE, 2013
Round Butte	2012	Rainbow trout	0	PGE, 2013
Round Butte	2012	Mountain. whitefish	0	PGE, 2013
Round Butte	2013	Bull trout	0.4	PGE, 2014
Round Butte	2013	Kokanee salmon	2.9	PGE, 2014
Round Butte	2013	Rainbow trout	0	PGE, 2014
Round Butte	2013	Mountain. whitefish	0	PGE, 2014
Round Butte	2014	Bull trout	0.7	PGE, 2015
Round Butte	2014	Kokanee salmon	4.0	PGE, 2015
Round Butte	2014	Rainbow trout	0	PGE, 2015
Round Butte	2014	Mountain whitefish	0	PGE, 2015

**Table A1.6.** Estimates of adult mortality during trap and haul operations for different species by river, facility, year, species, run, source, and references.

[CH, Chinook salmon; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon; TFH, Tucannon Fish Hatchery]

Facility	Year	Species	Run	Source	Mortality (percent)	Reference
Cowlitz River (Washington)						
Mayfield	2009	CH	Fall	Mixed	1.6	Henning, 2010
Mayfield	2009	CO	NA	Hatchery	0.3	Henning, 2010
Mayfield	2009	CO	NA	Wild	0.6	Henning, 2010
Mayfield	2009	OM	NA	Wild	6.7	Henning, 2010
Mayfield	2009	OM	NA	Hatchery	3	Henning, 2010
Deschutes River (Oregon)						
Pelton Trap	2012	CH	Spring	Wild	0	PGE, 2013
Pelton Trap	2012	OM	NA	Wild	0	PGE, 2013
Pelton Trap	2012	SO	NA	Wild	0	PGE, 2013
South Fork Mackenzie River (Oregon)						
Cougar Reservoir	2010	CH	Spring	Mixed	0	Zymonas and Hogansen, 2013
Cougar Reservoir	2011	CH	Spring	Mixed	0.8	Zymonas and Hogansen, 2013
Tucannon River (Washington)						
TFH	1986	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1987	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1988	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1989	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1990	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1991	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1992	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1993	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1994	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1995	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1996	CH	Spring	Wild	1.3	Gallinat and Ross, 2012
TFH	1997	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1998	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1999	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2000	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2001	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2002	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2003	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2004	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2005	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2006	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2007	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2008	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2009	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2010	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	2011	CH	Spring	Wild	0	Gallinat and Ross, 2012
TFH	1988	CH	Spring	Hatchery	0	Gallinat and Ross, 2012

**Table A1.6.** Estimates of adult mortality during trap and haul operations for different species by river, facility, year, species, run, source, and references.—Continued

[CH, Chinook salmon; CO, coho salmon; NA, not available; OM, steelhead; PGE, Portland General Electric Company; SO, sockeye salmon; TFH, Tucannon Fish Hatchery]

Facility	Year	Species	Run	Source	Mortality (percent)	Reference
TFH	1989	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	1990	CH	Spring	Hatchery	0.5	Gallinat and Ross, 2012
TFH	1991	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	1992	CH	Spring	Hatchery	1	Gallinat and Ross, 2012
TFH	1993	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	1994	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	1995	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	1996	CH	Spring	Hatchery	6.8	Gallinat and Ross, 2012
TFH	1997	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	1998	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	1999	CH	Spring	Hatchery	0.7	Gallinat and Ross, 2012
TFH	2000	CH	Spring	Hatchery	9.6	Gallinat and Ross, 2012
TFH	2001	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	2002	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	2003	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	2004	CH	Spring	Hatchery	0	Gallinat and Ross, 2012
TFH	2005	CH	Spring	Hatchery	2.6	Gallinat and Ross, 2012
TFH	2006	CH	Spring	Hatchery	3.8	Gallinat and Ross, 2012
TFH	2007	CH	Spring	Hatchery	5.4	Gallinat and Ross, 2012
TFH	2008	CH	Spring	Hatchery	0.3	Gallinat and Ross, 2012
TFH	2009	CH	Spring	Hatchery	0.8	Gallinat and Ross, 2012
TFH	2010	CH	Spring	Hatchery	1.1	Gallinat and Ross, 2012
TFH	2011	CH	Spring	Hatchery	1.6	Gallinat and Ross, 2012
Umatilla River (Oregon)						
Threemile	1993	CH	Spring	Wild	0.7	Zimmerman and Duke, 1993
Threemile	1993	CH	Fall	Wild	0	Zimmerman and Duke, 1993
Threemile	1995	CH	Spring	Wild	0.8	Zimmerman and Duke, 1995
Threemile	1996	CH	Spring	Wild	0.4	Zimmerman and Duke, 1996
Threemile	1995	CH	Fall	Wild	0	Zimmerman and Duke, 1995
Threemile	1996	CH	Fall	Wild	0	Zimmerman and Duke, 1996
Threemile	1997	CH	Fall	Mixed	0	Zimmerman and Duke, 1997
Threemile	1997	CH	Spring	Mixed	0.7	Zimmerman and Duke, 1997
Threemile	1993	CO	NA	Wild	0	Zimmerman and Duke, 1993
Threemile	1995	CO	NA	Wild	0	Zimmerman and Duke, 1995
Threemile	1996	CO	NA	Wild	0	Zimmerman and Duke, 1996
Threemile	1993	OM	NA	Wild	0.1	Zimmerman and Duke, 1993
Threemile	1995	OM	NA	Wild	0	Zimmerman and Duke, 1995
Threemile	1996	OM	NA	Mixed	0	Zimmerman and Duke, 1996
Threemile	1997	OM	NA	Mixed	0	Zimmerman and Duke, 1997
Threemile	1997	OM	NA	Mixed	0	Zimmerman and Duke, 1997



**Table A1.7.** Fallback rates over dam facilities for adult anadromous species by river, dam, year, species, run, and reference.

[CH, Chinook salmon; NA, not available; CO, coho salmon; SO, sockeye salmon; OM, steelhead]

Dam	Year	Species	Run	Fallback (percent)	Reference
Columbia River (Oregon and Washington)					
Bonneville	1996	CH	Spring–summer	13.8	Boggs and others, 2004
Bonneville	1997	CH	Spring–summer	14.6	Boggs and others, 2004
Bonneville	1998	CH	Spring–summer	11.2	Boggs and others, 2004
Bonneville	2000	CH	Spring–summer	13	Boggs and others, 2004
Bonneville	2001	CH	Spring–summer	4.1	Boggs and others, 2004
Bonneville	1996	CH	Spring–summer	16.4	Bjornn and others, 2000
Bonneville	1997	CH	Spring–summer	19.9	Bjornn and others, 2000
Bonneville	1998	CH	Spring–summer	15.9	Bjornn and others, 2000
Bonneville	1996	CH	Fall	NA	Boggs and others, 2004
Bonneville	1997	CH	Fall	NA	Boggs and others, 2004
Bonneville	1998	CH	Fall	3.5	Boggs and others, 2004
Bonneville	2000	CH	Fall	3.9	Boggs and others, 2004
Bonneville	2001	CH	Fall	4.8	Boggs and others, 2004
The Dalles	1996	CH	Spring–summer	13.3	Boggs and others, 2004
The Dalles	1997	CH	Spring–summer	14.4	Boggs and others, 2004
The Dalles	1998	CH	Spring–summer	11.5	Boggs and others, 2004
The Dalles	2000	CH	Spring–summer	9.6	Boggs and others, 2004
The Dalles	2001	CH	Spring–summer	5.5	Boggs and others, 2004
The Dalles	1996	CH	Fall	NA	Boggs and others, 2004
The Dalles	1997	CH	Fall	NA	Boggs and others, 2004
The Dalles	1998	CH	Fall	10.2	Boggs and others, 2004
The Dalles	2000	CH	Fall	8.5	Boggs and others, 2004
The Dalles	2001	CH	Fall	6.9	Boggs and others, 2004
John Day	1996	CH	Spring–summer	11.9	Boggs and others, 2004
John Day	1997	CH	Spring–summer	9.9	Boggs and others, 2004
John Day	1998	CH	Spring–summer	10.6	Boggs and others, 2004
John Day	2000	CH	Spring–summer	6.0	Boggs and others, 2004
John Day	2001	CH	Spring–summer	3.0	Boggs and others, 2004
John Day	1996	CH	Fall	NA	Boggs and others, 2004
John Day	1997	CH	Fall	NA	Boggs and others, 2004
John Day	1998	CH	Fall	3.7	Boggs and others, 2004
John Day	2000	CH	Fall	2.6	Boggs and others, 2004
John Day	2001	CH	Fall	2.6	Boggs and others, 2004
McNary	1996	CH	Spring–summer	9.3	Boggs and others, 2004
McNary	1997	CH	Spring–summer	8.0	Boggs and others, 2004
McNary	1998	CH	Spring–summer	9.2	Boggs and others, 2004
McNary	2000	CH	Spring–summer	4.3	Boggs and others, 2004
McNary	2001	CH	Spring–summer	1.4	Boggs and others, 2004
McNary	1998	CH	Fall	2.1	Boggs and others, 2004
McNary	2000	CH	Fall	2.0	Boggs and others, 2004
McNary	2001	CH	Fall	3.5	Boggs and others, 2004
McNary	1996	CH	Spring	22.6	Keefer and others, 2004

**Table A1.7.** Fallback rates over dam facilities for adult anadromous species by river, dam, year, species, run, and reference.—Continued

[CH, Chinook salmon; NA, not available; CO, coho salmon; SO, sockeye salmon; OM, steelhead]

Dam	Year	Species	Run	Fallback (percent)	Reference
McNary	1997	CH	Spring	27.5	Keefer and others, 2004
McNary	1998	CH	Spring	19.6	Keefer and others, 2004
McNary	2000	CH	Spring	20.9	Keefer and others, 2004
McNary	2001	CH	Spring	7.6	Keefer and others, 2004
Lower Granite	1996	CH	Spring	35.5	Keefer and others, 2004
Lower Granite	1997	CH	Spring	36.4	Keefer and others, 2004
Lower Granite	1998	CH	Spring	28.3	Keefer and others, 2004
Lower Granite	2000	CH	Spring	35.4	Keefer and others, 2004
Lower Granite	2001	CH	Spring	10.4	Keefer and others, 2004
McNary	1996	CH	Summer	10.7	Keefer and others, 2004
McNary	1997	CH	Summer	13.8	Keefer and others, 2004
McNary	1998	CH	Summer	10.6	Keefer and others, 2004
McNary	2000	CH	Summer	8.5	Keefer and others, 2004
McNary	2001	CH	Summer	0.6	Keefer and others, 2004
Lower Granite	1996	CH	Summer	22.2	Keefer and others, 2004
Lower Granite	1997	CH	Summer	12.5	Keefer and others, 2004
Lower Granite	1998	CH	Summer	25.7	Keefer and others, 2004
Lower Granite	2000	CH	Summer	17.4	Keefer and others, 2004
Lower Granite	2001	CH	Summer	2	Keefer and others, 2004
Bonneville	1998	CH	Fall	4.2	Bjornn and others, 2000
McNary	1996	CH	Fall	NA	Keefer and others, 2004
McNary	1997	CH	Fall	NA	Keefer and others, 2004
McNary	1998	CH	Fall	1.7	Keefer and others, 2004
McNary	2000	CH	Fall	3.8	Keefer and others, 2004
McNary	2001	CH	Fall	3.7	Keefer and others, 2004
Lower Granite	1996	CH	Fall	NA	Keefer and others, 2004
Lower Granite	1997	CH	Fall	NA	Keefer and others, 2004
Lower Granite	1998	CH	Fall	0	Keefer and others, 2004
Lower Granite	2000	CH	Fall	5.9	Keefer and others, 2004
Lower Granite	2001	CH	Fall	16.7	Keefer and others, 2004
Wells	2004	CO	NA	3.3	Murdoch and others, 2005
Wanapum	2004	CO	NA	16.7	Murdoch and others, 2005
Bonneville	1997	SO	NA	11.4	Naughton and others, 2006
The Dalles	1997	SO	NA	4.9	Naughton and others, 2006
John Day	1997	SO	NA	3.6	Naughton and others, 2006
McNary	1997	SO	NA	2	Naughton and others, 2006
Priest Rapids	1997	SO	NA	4.2	Naughton and others, 2006
Wanapum	1997	SO	NA	4	Naughton and others, 2006
Rock Island	1997	SO	NA	1.9	Naughton and others, 2006
Rocky Reach	1997	SO	NA	7.1	Naughton and others, 2006
Bonneville	1998	SO	-	13.7	Bjornn and others, 2000
Bonneville	1996	OM	NA	4.9	Boggs and others, 2004
Bonneville	1997	OM	NA	9.1	Boggs and others, 2004
Bonneville	2000	OM	NA	6.9	Boggs and others, 2004

**Table A1.7.** Fallback rates over dam facilities for adult anadromous species by river, dam, year, species, run, and reference.—Continued

[CH, Chinook salmon; NA, not available; CO, coho salmon; SO, sockeye salmon; OM, steelhead]

Dam	Year	Species	Run	Fallback (percent)	Reference
Bonneville	2001	OM	NA	4.3	Boggs and others, 2004
The Dalles	1996	OM	NA	6	Boggs and others, 2004
The Dalles	1997	OM	NA	6.6	Boggs and others, 2004
The Dalles	2000	OM	NA	6.3	Boggs and others, 2004
The Dalles	2001	OM	NA	6.1	Boggs and others, 2004
John Day	1996	OM	NA	10.1	Boggs and others, 2004
John Day	1997	OM	NA	7.9	Boggs and others, 2004
John Day	2000	OM	NA	4.3	Boggs and others, 2004
John Day	2001	OM	NA	5.3	Boggs and others, 2004
McNary	1996	OM	NA	7.4	Boggs and others, 2004
McNary	1997	OM	NA	10.7	Boggs and others, 2004
McNary	2000	OM	NA	9.8	Boggs and others, 2004
McNary	2001	OM	NA	7.1	Boggs and others, 2004
Bonneville	1996	OM	NA	5.2	Bjornn and others, 2000
Bonneville	1997	OM	NA	9.9	Bjornn and others, 2000
McNary	1996	OM	Spring	9.3	Keefer and others, 2004
McNary	1997	OM	Spring	7.8	Keefer and others, 2004
McNary	1998	OM	Spring	NA	Keefer and others, 2004
McNary	2000	OM	Spring	8.8	Keefer and others, 2004
McNary	2001	OM	Spring	4.8	Keefer and others, 2004
Lower Granite	1996	OM	Spring	12.1	Keefer and others, 2004
Lower Granite	1997	OM	Spring	14.7	Keefer and others, 2004
Lower Granite	1998	OM	Spring	NA	Keefer and others, 2004
Lower Granite	2000	OM	Spring	16.9	Keefer and others, 2004
Lower Granite	2001	OM	Spring	16.2	Keefer and others, 2004
Cowlitz River (Washington)					
Mayfield	2009	CH	Fall	12.0	Henning, 2010
Cowlitz Falls	2012	CH	Spring	0.7	Serl and Heimbigner, 2013
Mayfield	2009	CO	NA	3.3	Henning, 2010
Mayfield	2009	CO	NA	1.5	Henning, 2010
Mayfield	2009	OM	NA	30.8	Henning, 2010
Mayfield	2009	OM	NA	38.7	Henning, 2010
Cowlitz Falls	2012	OM	NA	2.0	Serl and Heimbigner, 2013
North Santiam River (Oregon)					
Bennett Dams	2003	CH	Spring	1.2	Schroeder and others, 2007
Bennett Dams	2005	CH	NA	2.9	Schroeder and others, 2006
Umatilla River (Oregon)					
Threemile	1994–1995	CO	NA	0	Zimmerman and Duke, 1995
Threemile	1994–1995	CH	Spring	43.8	Zimmerman and Duke, 1995
Threemile	1994–1995	CH	Fall	0	Zimmerman and Duke, 1995
Threemile	1994–1995	OM	NA	1.3	Zimmerman and Duke, 1995



# Chapter B. Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington

## Introduction

Habitat portrays an important role in determining the distribution and abundance of biota in stream ecosystems (Minshall and others, 1983; Schlosser, 1991). For anadromous *Oncorhynchus* spp. (Pacific salmon) and *O. mykiss* (steelhead), freshwater habitat is strongly associated with fish growth and survival (for example, Tappel and Bjornn, 1983; Quinn and Peterson, 1996; Sommer and others, 2001), distribution (for example, Nickelson and others, 1992; Torgersen and others, 1999), and abundance (for example, Fausch and Northcote, 1992; Solazzi and others, 2000). Indeed, understanding the amount and quality of habitat is an important part of Pacific salmon reintroductions (Anderson and others, 2014).

In the upper Lewis River, characterizing the status and extent of habitat available to anadromous salmon and steelhead in tributary streams is needed for robust assessments of the reintroduction potential. From 2013 through 2015, we assessed the available habitat of tributaries to Swift Reservoir, Yale Lake, and Lake Merwin (fig. B1). In Swift Reservoir, assessments were targeted towards updating habitat information where recent surveys (within the last decade) were not available and (or) in tributaries where *O. kisutch* (coho salmon) have been observed during recent reintroductions. In tributaries to Lake Merwin and Yale Lake, we conducted surveys to quantify the extent and status of available habitat for potential reintroductions. Information regarding the extent and quality of habitat was subsequently integrated with the Ecosystem Diagnosis and Treatment (EDT) method (Lestelle and others, 1996) for species-specific estimates of production potential in the Swift Reservoir, Yale Lake, and Lake Merwin basins.

## Methods

### Survey Streams

Survey locations varied based on data needs to inform anadromous species reintroductions and data limitations identified by regional biologists and existing data collected by U.S. Department of Agriculture Forest Service biologists in tributaries to Swift Reservoir. Our habitat surveys included Chickoon Creek; Clear Creek; Curly Creek; Cussed Hollow Creek; Diamond Creek; the upper Lewis River (upstream of Little Creek to the lower Lewis River Falls); Little Creek; Range Creek; S15 and S20 (tributaries to Swift Reservoir); Spencer Creek; M1 (tributary to Muddy River); upper Clearwater Creek; Pepper Creek; and P1, P3, and P7 (tributaries to Pine Creek) (fig. B2). Curly Creek was found to be dry and was not surveyed. We inventoried all streams with at least 25 meters (m) of available habitat in (1) Lake Merwin including Brooks Creek, Buncombe Hollow Creek, Cape Horn Creek, Indian George Creek, Jim Creek, lower Speelyai Creek, and Rock Creek; and (2) Yale Lake including Cougar Creek, Dog Creek, North fork of Siouxon Creek, Ole Creek, Panamaker Creek, Siouxon Creek, Speelyai Creek, Swift Bypass Channel, and west tributary of Speelyai Creek (fig. B3). All surveys were conducted in 2014 and 2015. Given that Rain Creek was dry at the confluence with Ole Creek, except during extremely high discharge events, we did not sample this tributary. In addition, no habitat data were collected from Rock Creek, as the habitat was influenced by the reservoir elevation.

### Habitat Quality

During late July and early August 2014, we conducted continuous habitat surveys from each tributary mouth to the upstream migration barrier. Features were considered barriers based on changes in elevation or continued high-gradient stretches that likely impede salmon passage and the habitat features below the barrier (in the sense of Washington State Department of Fish and Wildlife, 2007). We used a census sampling design to collect continuous habitat data for a comprehensive assessment of habitat and to minimize bias in assessments from site-to-site variability (Urquhart and others, 1998; Larsen and others, 2004; Anlauf and others, 2011). To ensure consistency with regional approaches, we conducted our surveys using protocols derived from the Columbia Habitat Monitoring Program (CHaMP, 2013) that are currently employed in anadromous salmon

and steelhead research and monitoring in the Columbia River Basin. To allow for rapid continuous surveys, our approach was a modification from the original CHaMP 2013 method (for example, Blanchard, 2015). We georeferenced each habitat unit and the data associated with that unit using handheld global positioning devices while conducting our surveys.

*Reach length.*—We established reach lengths in each stream using an average measure of bankfull width. We determined the minimum reach length for each stream by taking the average bankfull width of the first 10 habitat units (table B1) and multiplying it by 20 (Kershner and others, 2004; CHaMP, 2013). The first habitat unit boundary encountered after this minimum length served as the start of the next reach length.

*Habitat unit classification.*—We identified habitat units using a two-tiered hierarchical system (Hawkins and others, 1993). Tier I units were distinguished by gradient, relative stream velocity, and turbulence and included three classes: fast-water turbulent, fast-water nonturbulent, and slow-water pool. Tier I fast-water turbulent units were further subdivided into Tier II classes. These subclasses were differentiated by hydraulic properties and included riffles, rapids, cascades, and falls. Tier I slow-water pools were further subdivided into Tier II classes based on the primary process that formed the unit and included scour pool, plunge pool, dam pool, beaver pool, and off-channel pool. Tier I fast-water nonturbulent units were referred to as glides.

During each sampling event, we evaluated stream physical habitat attributes that are important for anadromous salmon and steelhead. We georeferenced each habitat unit and estimated (1) unit dimensions consisting of wetted and bankfull width and length, (2) the total number of pieces of large woody debris (LWD) exceeding 10 centimeters (cm) in diameter and 1 meter in length, (3) percent substrate composition of each size class to the nearest 5 percent, (4) percent fine sediment in pool tails, and (5) riparian condition according to Blair and others (2008).

*Habitat unit dimensions.*—We measured wetted and bankfull widths at two transects located approximately at one-third and two-thirds total unit length and unit length from bottom to top (Hankin and Reeves, 1988) using a laser range finder. We recorded three depth measurements spaced equidistantly across each transect for a total of six depth measurements, which we averaged for each unit.

We used the individual measurements from transects for an estimate of average wetted and bankfull width and depth for each habitat unit. Additionally, we calculated the surface area of each habitat unit through estimates of average width and unit length. Computing estimates of surface area enabled us to quantify the total surface area for each stream and the proportional surface area for any type of habitat unit.

For all pools, we also calculated the residual pool depth as a measure of pool volume (Lisle, 1987). We calculated the residual pool depth in each unit by taking the difference between the pool tail depth, located at pool tail crest, and the maximum depth (Kershner and others, 2004). We identified the pool crest visually as the point at which there is a break or transition in stream channel slope.

*Large woody debris (LWD).*—The importance of stream habitat diversity is undeniable for aquatic biota (Lonzarich and Quinn, 1995). Structural elements (for example, woody debris) often control geomorphic processes (Abbe and Montgomery, 2003; Montgomery and others, 2003) and can benefit salmonid communities (Cederholm and others, 1997; Johnson and others, 2005). We enumerated all LWD equal to or greater than ( $\geq$ ) 1 meter within the bankfull channel; we further delineated pieces based on diameter as either *large* (diameter  $>50$  cm) or *small* (10 cm–50 cm). If the stem was cracked or broken, it was treated as one piece if any portions were still connected. If the piece was broken completely and both pieces met the minimum size criteria, then they were both counted. Where pieces extended outside of the bankfull prism (area between and below bankfull width and height, respectively), we only considered the portions of pieces within the prism. If a piece extended across multiple habitat unit boundaries, we considered these as separate pieces in our counts for each unit but only where the criteria for LWD were met.

We summarized LWD by obtaining reach-based estimates of pieces per unit surface area (count divided by average width multiplied by reach length) for both size categories. This approach enabled us to estimate the LWD density of each size category separately as well as a sum across the large and small categories for a total estimate of LWD density for a given reach.

*Substrate composition.*—We classified surface sediment composition using a two-tiered visual estimation approach (Buffington and Montgomery, 1999) to quantify the dominant and subdominant size classes of substrate in habitat units. First, we estimated the extent of each habitat unit (to the nearest 5 percent) with different sediment characteristics. We modified the size class categories from Lane (1947) and Church and others (1987), which were generally consistent with the CHaMP protocol, and included exposed bedrock surface, boulder ( $>256$  millimeters [mm]), large cobbles (127.1–256 mm), small cobbles (64.1–127 mm), gravel (2–64 mm), and fines (less than 2 mm).

Next, we used this information to quantify the dominant and subdominant sediment characteristics of each habitat unit (Buffington and Montgomery, 1999). Given concerns of bias for visual sediment estimates (for example, McHugh and Budy, 2005), we also conducted systematic pebble counts (Wolman, 1954) at transects in the first 10 habitat units of each stream. We placed transects at approximately one-half the total habitat length, and we selected particles at 10 equally spaced sampling points spanning the width of the wetted channel. Substrate particles were selected while turning eyes away and extending finger down and picking up the first particle touched at the tip of the surveyor's boot (Wolman, 1954; Kondolf, 2000) and measuring the b-axis of each particle (Kershner and others, 2004). We then regressed the sediment data from the ocular estimates against the sediment measurement from the pebble counts to quantify observer error and bias in the ocular estimates. The resulting regression equation ( $R^2=0.51$ ) was then used to correct all ocular estimates of substrate across streams.



For all pool units, we also quantified the substrate characteristics of pool tailouts for measures of the quality of salmonid spawning habitat (McHugh and Budy, 2005). We visually identified pool tailouts as 20 percent of the channel unit upstream of the pool tail crest. Pool tailouts were not measured individually for width or length. The surface area of a pool tailout was estimated to be on average 20 percent of the surface area of the pool per EDT instructions. We estimated the proportion of fine sediment within each pool tailout using the same two-tiered visual estimation approach as used in the unit substrate surveys. To ensure accurate summaries of pool tail fines at the reach scale, we used a weighted approach. The weighted average of percent fines over pool tails within a reach, with weights proportional to the surface area of each pool tail, were summed to obtain a reach-based estimate of percent fines in pool tails.

*Riparian function.*—Riparian forests exert strong controls on stream microclimates (Gregory and others, 1991; Caissie, 2006), in-channel morphology (Bilby and Ward, 1991; Montgomery and others, 1995), nutrient cycling (McClain and others, 2003), and water quality (Gilliam, 1994; Naiman and Decamps, 1997). We evaluated the riparian condition and assigned a riparian index rating for each habitat unit. We adopted an index rating from Blair and others (2008) ranging from 0 (no anthropogenic alterations with strong linkages to floodplain) to 4 (complete severing of floodplain stream linkages). Given the differences in channel unit lengths, we used a weighted approach for estimates of riparian condition at the reach scale. We first calculated the proportion of the total surface area within the channel unit relative to the total surface area of the reach and then multiplied the weighting proportion by the riparian condition rating of the channel unit. These weighted riparian condition ratings were then summed to the reach scale and rounded to the nearest whole number.

In addition to habitat characteristics, we also quantified attributes that drive habitat forming processes and water quality. At the stream level, we measured (1) stream gradient, (2) ambient stream temperature, (3) stage discharge relationships, and (4) dissolved oxygen, which are described next.

*Longitudinal gradient survey.*—Gradient profiles were collected for each tributary using a Trimble GeoXH 6000 that is capable of collecting high-resolution elevation data (10 cm). Before each gradient survey, we surveyed an established reference location with constant x, y, and z coordinates to use as a survey control station. This reference was Yale Lake monument (monument ID 6791; latitude 46.02615, longitude -122.31809; Washington State Department of Transportation; <http://www.wsdot.wa.gov/monument/>). We used the reference survey data to obtain estimates of bias and accuracy. By incorporating reference surveys estimates, we were able to evaluate and correct for potential bias in our elevation data. Our reference surveys deviated slightly from the control station (average=0.72 cm, standard deviation=0.41).

We analyzed the longitudinal gradient data in ArcGIS® to obtain estimates at the reach scale. We snapped the reach boundaries for each stream to the gradient profile and calculated gradient as the difference between reach boundary elevations divided by the length (that is, rise divided by run). Because of the timing of habitat data collection, gradient data were only collected in tributaries to Lake Merwin and Yale Lake.

*Temperature and discharge.*—Given the importance of streamflow and thermal profiles in driving fundamental biological processes (for example, Brett, 1971), we collected stream temperature and discharge data in each survey stream in 2013 and 2014. Where discharge data were not available from existing monitoring stations, we quantified stage discharge relationships for estimates of summer and early autumn hydrologic regimes (June–October). We installed pressure transducers (Solinst Levelogger model 3001) near the mouth of each stream and collected hourly measurements of the stage (that is, river height). In addition, we installed a barometric pressure logger to control for basin-specific changes in barometric pressure from ambient weather that can influence stage measurements. During the period of deployment (that is, June–October in 2013 and 2014), we measured discharge at least three times per stream to establish stream-specific, stage-discharge relationships.

Each pressure transducer also recorded stream temperatures, and we placed additional temperature loggers at the upstream barrier in all study streams to measure ambient stream temperature profiles. All temperature loggers were tested and calibrated before deployment (Dunham and others, 2005). Each year (2013–2014), stream temperature was collected in each study stream from June 1 through the October 31. Temperature data were collected at 1-hour intervals using Onset Tidbit v2 (ranges from -20 to 50 degrees Celsius [°C], accuracy  $\pm 0.53$  °C from 0 to 50 °C), and Onset HOBO Pendant (range -20 to 70 °C, accuracy  $\pm 0.2$  °C from 0 to 50 °C) data loggers. Data loggers were housed in white PVC housing to avoid bias from direct solar radiation (in the sense of Isaak and Horan, 2011).

For both the upstream and downstream temperature logging devices, we calculated the mean temperature for each day. We then averaged these two numbers to get an overall daily temperature and then calculated the mean and range from these numbers from June through October. Temperature and streamflow information was only collected in tributaries to Lake Merwin and Yale Lake because of the timing of habitat data collection.

*Dissolved oxygen.*—We measured dissolved oxygen during habitat sampling (August 14–31) using a YSI multimeter model (Pro 2030). Measurements were taken in fast-moving water at the top and bottom of each study stream. We summarized dissolved oxygen at the reach level by correcting for lapse change, which we estimated by differencing our top and bottom measurements then dividing by total length of the stream. This provided a per-meter rate of change that could then be multiplied by each reach length and added to the previous reach-based estimate of dissolved oxygen. Because of the timing of habitat data collection, dissolved oxygen data were only collected in tributaries to Lake Merwin and Yale Lake.



## Results and Discussion

### Extent of Tributary Habitat in Lake Merwin and Yale Lake

Surveys of available habitat indicated a total of 36.2 kilometers (km) of available habitat in tributaries to Yale Lake and Lake Merwin (tables B1, B2; fig. B3). The majority (28.0 km) were in tributaries to Yale Lake with Siouxon Creek (and tributary; total=6.4 km), Speelyai Creek (and tributaries; total=7.5 km), Swift Bypass Channel (4.9 km), and Cougar Creek (2.7 km) having the majority of available habitat. Within Lake Merwin, Brooks Creek (including a tributary to Brooks Creek [B1]; 4.1 km) and Indian George Creek (1.5 km) contain the most available habitat. Brooks Creek (10,318 square meters [ $m^2$ ]) in Lake Merwin and Cougar Creek (35,565  $m^2$ ), Siouxon Creek (96,753  $m^2$ ), Speelyai Creek (45,346  $m^2$ ), and the Swift Bypass Channel (119,180  $m^2$ ) in Yale Lake contained the most amount of habitat based on surface area in Yale Lake (table B3). Tributaries to Swift Reservoir (>700,000  $m^2$ ) clearly contained the most amount of tributary habitat among the three reservoirs, particularly when compared to Lake Merwin (27,389  $m^2$ ). The amount of habitat available is a strong predictor of salmon population sizes (Isaak and others, 2007), as density dependence limits freshwater survival (Jonsson and others, 1998; Milner and others, 2003; Walters and others, 2013). The small amounts of existing habitat likely controlling salmon production (that is, smolts) combined with extensive predation potential (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report) suggest available habitat may limit the likelihood of developing self-sustaining populations within Lake Merwin (McElhany and others, 2000; Nickelson, 2000; Anderson and others, 2014).

### Habitat Quality

The onset of early snow during the fall of 2015 prevented the completion of surveys in M1 (tributary to Muddy River) and the upper Clearwater Creek. Where surveys were completed, our data suggest the complexity of stream habitat based on stream habitat type and depth varied considerably across streams (tables B4, B5). LWD is an important driver of juvenile salmon distribution and abundance (Rosenfeld and others, 2000; Roni and Quinn, 2001). On average, tributaries to Lake Merwin contain the highest densities of LWD, and tributaries to Swift Reservoir contain the lowest densities (table B6). Much of these differences, however, were attributed to sizes of LWD present as the density of small LWD (diameter 10–50 cm) was substantially greater than large LWD (diameter >50 cm) across all streams (table B6). We observed the highest densities of LWD in Cape Horn, Jim, and lower Speelyai Creeks in Lake Merwin and Dog, North Fork Siouxon, Ole, and Panamaker Creeks in Yale Lake.

We found little evidence of sediment limitations in most tributaries that were evaluated, regardless of reservoir. Fine sediment values in pool tails were low in the most streams except for Little Creek and Pepper Creek (Swift Reservoir; table B6), both of which exceeded tolerant levels for salmonids (Bryce and others, 2010). These patterns were generally consistent with data from fast-water habitat (riffles, glides, cascades) where gravel, cobble, and boulders composed the majority of streambed substrate (table B7). Together, these results indicate that sediment is unlikely limiting salmonid populations in the upper Lewis River Basin (Tappel and Bjornn, 1983; McHugh and others, 2004).

Average temperatures differed across tributaries, and the differences across years varied by stream (tables B8, B9). The largest range of temperatures occurred during August (range 2013–2014=6.8–17.0 °C). During 2013 and 2014, we found generally consistent temperatures during June and July, but September and October 2014 temperatures were dramatically warmer than 2013 temperatures in all streams except Cougar Creek. Average summer (July–August 2014) temperatures in Buncombe Hollow, Dog, Siouxon, and Speelyai Creeks were generally higher than preferred juvenile rearing temperatures for coho and Chinook salmon (Oregon Department of Environmental Quality, 1995). While empirical summer stream temperature data were not available for tributaries to Swift Reservoir at the time of this field study, recent estimates of average August stream temperature from the U.S. Department of Agriculture Forest Service NorWeST stream temperature model (<http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html>; Isaak and others, 2010) suggest excessively warm temperatures are unlikely to impede salmon or steelhead (fig. B4). As expected, measures of dissolved oxygen were largely correlated with observed temperatures in tributaries to Lake Merwin and Yale Lake (table B10).

Riparian conditions and stream gradients varied substantially across tributaries (table B11). Aside from Cougar Creek and the Swift Bypass Channel, average stream gradients in all tributaries exceeded 2 percent with the highest gradients (about 10 percent) in tributaries to Speelyai Creek. Overall, we found little evidence of excessive alteration in riparian conditions in most tributaries (tables B8, B9). However, moderate-to-high riparian degradation was found in lower Speelyai Creek in Lake Merwin; Dog Creek, Brooks Creek, and Swift Bypass Channel in Yale Lake; and Little Creek, P7, and S20 in Swift Reservoir. Stream riparia represent an important part of aquatic ecosystems in terms of controlling sediment inputs and geomorphology (Barling and Moore, 1994; Naiman and others, 2005). Riparian vegetation is also a key factor influencing terrestrial prey inputs, which are often a substantial component of juvenile salmon diets (Wipfli, 1997, 2005). Furthermore, riparian vegetation also serves as major contributors of LWD and in limiting solar inputs and stream warming (Caissie, 2006). Ultimately, the importance of riparia suggests the need to consider restoration actions as a means for increasing the overall capacity for anadromous species. Quantifying the effectiveness of such actions may be an important step in prioritizing and directing restoration efforts (Roni and others, 2012).

## Conclusions

Empirical habitat data suggest little evidence that habitat quality will limit anadromous salmon and steelhead reintroductions. Evidence of habitat degradation appears to be location specific and includes sediment degradation (for example, fine sediment in Little Creek, tables B6 and B7), some thermal constraints during the summer months in tributaries to Lake Merwin and Yale Lake, and riparian degradation. The data collected herein and other available data from State and Federal agencies can be used to specifically identify factors limiting salmonids and to help target further studies to quantify potential effectiveness of restoration.

The extent of available habitat is likely to be a major factor limiting anadromous salmonids in Lake Merwin. The observed habitat limitations appear to be largely natural (that is, natural geologic features), suggesting that opportunities to enhance the capacity in Lake Merwin are minimal. The relatively small amount of habitat may also influence habitat use and emigration patterns for juvenile salmon, as juveniles more proximate to large water bodies can exhibit earlier emigration (see “Studies Assessing Adult Potential for Spawning Success in Yale Lake and Lake Merwin, Washington,” chap. C of this report) and suggests limited potential for establishing and maintaining viable populations of anadromous fishes in Lake Merwin. Ultimately, assessing the potential for viable populations will require consideration not only of habitat availability but also biotic interactions between anadromous fishes and extant species (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report).

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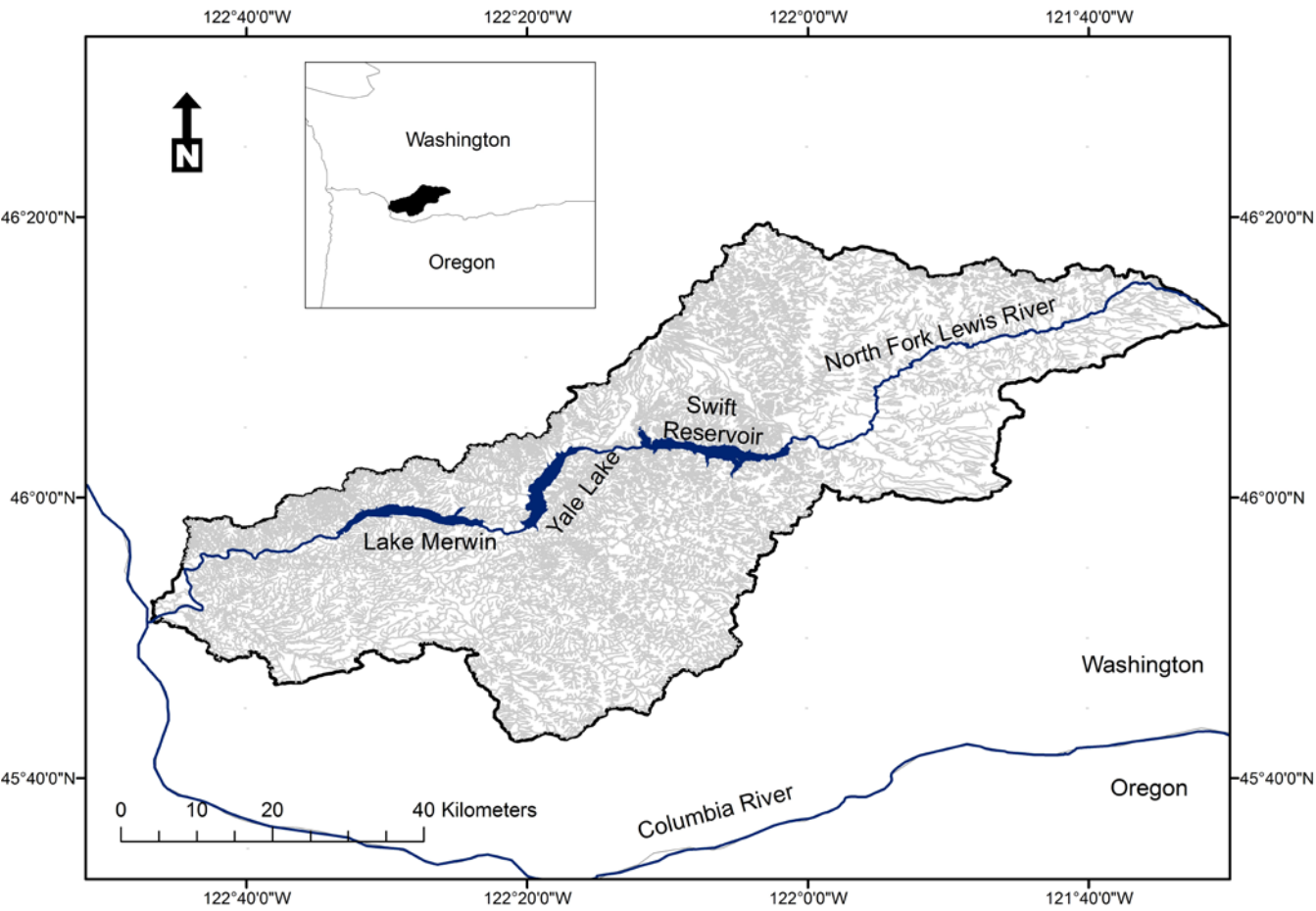
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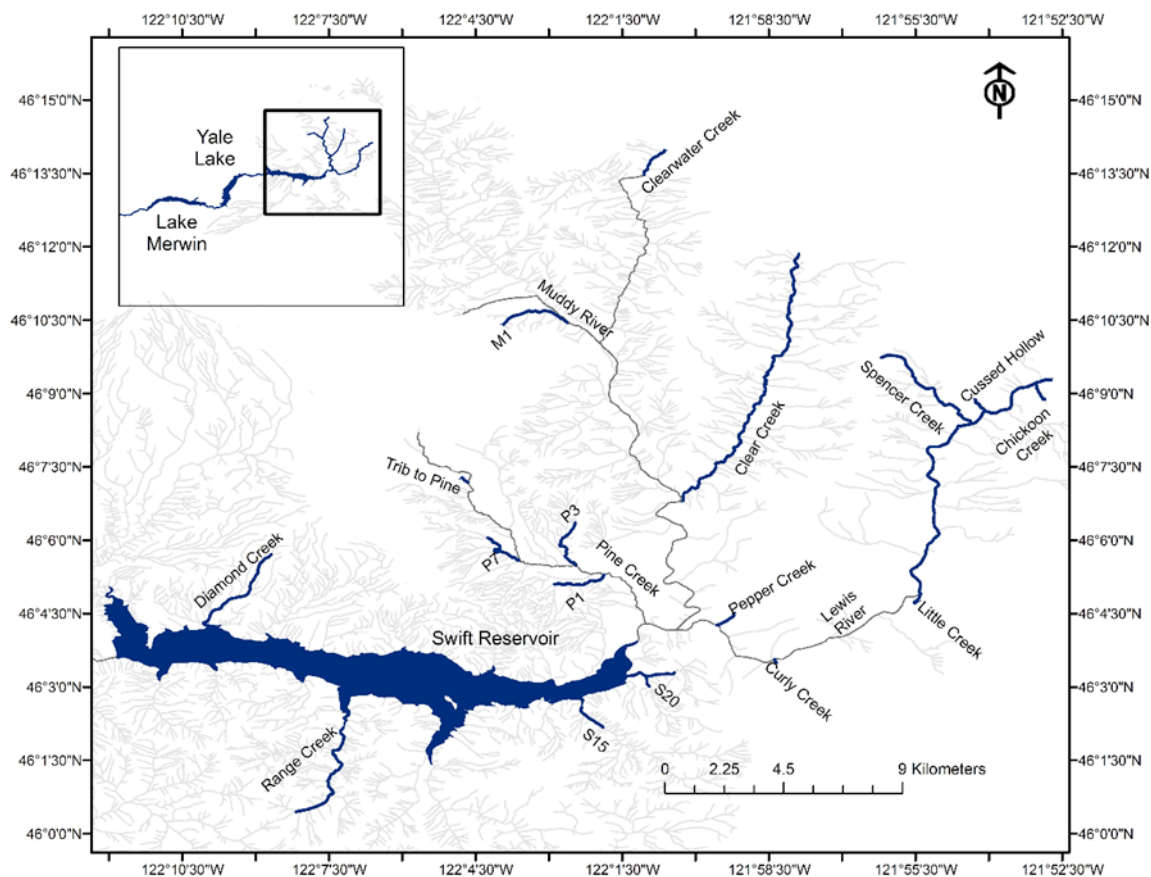
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Figures

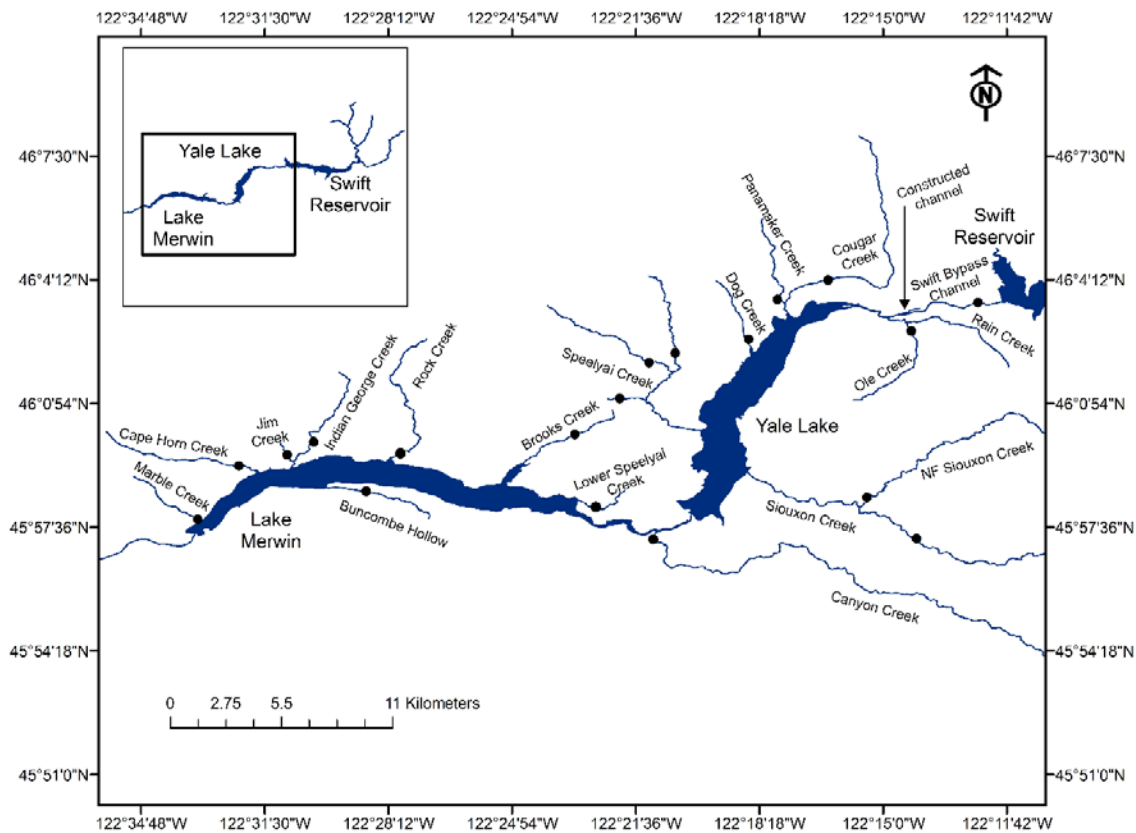


**Figure B1.** The North Fork of the Lewis River and the three hydropower impoundments: Lake Merwin, Yale Lake, and Swift Reservoir in the Lewis River Basin, Washington.

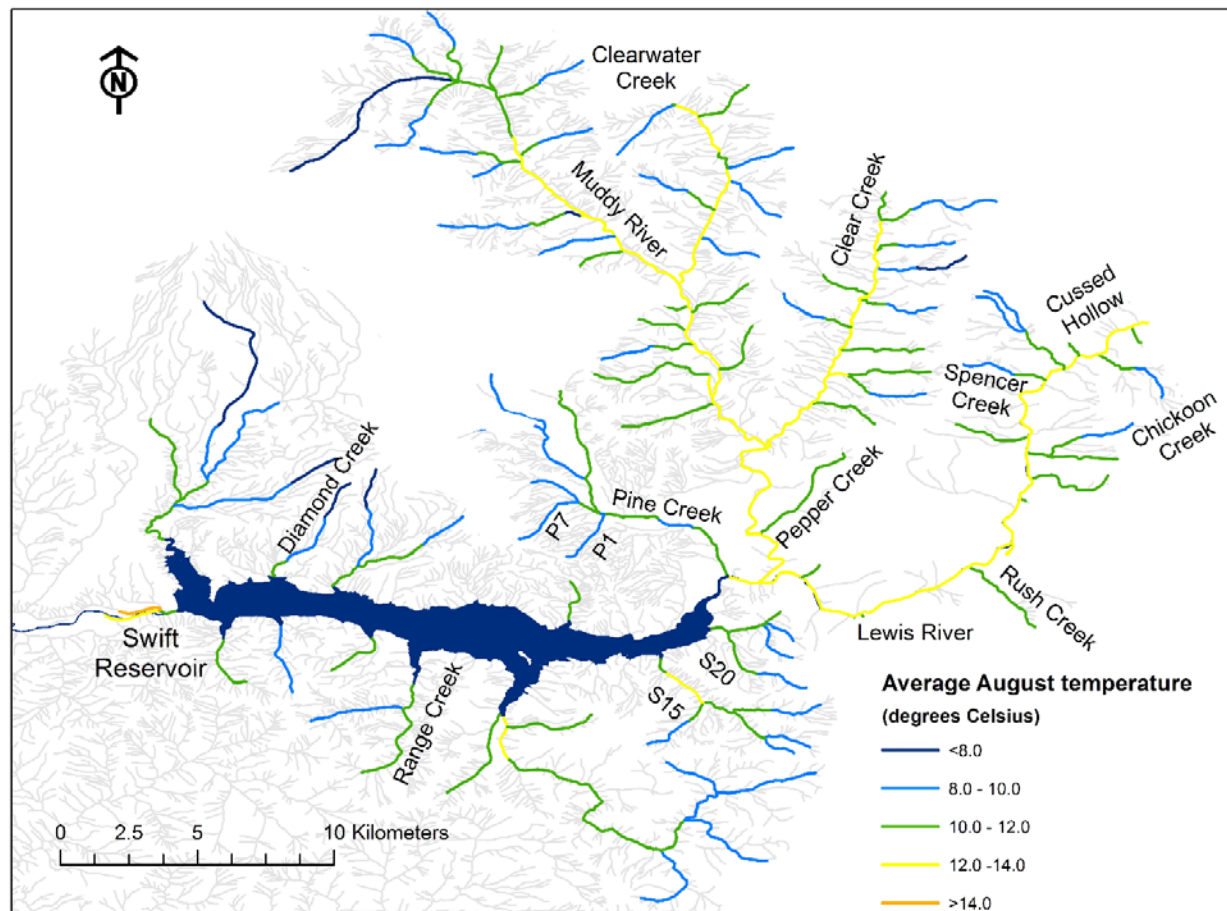


**Figure B2.** Upper Lewis River tributaries, Washington, where updated habitat data were needed (as noted by the thick blue lines) for assessments of anadromous salmon reintroductions. (trib., tributary; M1, tributary to Muddy River; P1, P3, and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir)





**Figure B3.** Stream habitat potentially available to anadromous salmon (blue) from upstream barriers (black circles) in tributaries to Yale Lake and Lake Merwin, Washington. (NF, north fork)



**Figure B4.** Predicted average August stream temperatures in degrees Celsius ( $^{\circ}\text{C}$ ) from the NorWeST (<http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html>; Isaak and others, 2010) stream temperature model for tributaries to Swift Reservoir, Washington. (P3 is not shown on the map because no estimates from the NorWeST stream temperature model were available. P1 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir)

## Tables

**Table B1.** The total stream length surveyed, average bankfull width (standard deviation [SD] in parentheses), wetted width (SD in parentheses), and number of sample reaches (n) in each tributary stream to Swift Reservoir, Washington, during surveys in 2015.

[The number of sample reaches corresponds to all subsequent tables. Curly Creek contained no streamflow below the falls at the time of the survey, and a barrier to upstream passage was identified at the mouth of P1—as such no data were collected in these tributaries. km, kilometer; m, meter; NA, not available; P1, P3, and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir]

Stream	Length (km)	Bankfull width (m)	Wetted width (m)	n
Chickoon Creek	0.5	8.2 (0.5)	3.2 (0.4)	3
Clear Creek	4.7	38 (11.5)	18.6 (4.9)	19
Curly Creek	NA	NA	NA	NA
Cussed Hollow Creek	0.5	8.5 (0.8)	3.3 (0.3)	3
Diamond Creek	0.4	7.1 (1.7)	4.4 (0.5)	3
Little Creek	0.8	6.6 (2.8)	4.4 (1.7)	7
P1 creek	NA	NA	NA	NA
P3 creek	1.3	6.2 (0.5)	5 (1.3)	2
P7 creek	NA	10.5 (2.6)	6.9 (1)	8
Pepper Creek	0.2	8.6 (2.2)	5.2 (1)	21
Range Creek	0.9	12.4 (2.8)	9.2 (0.9)	3
S15	1.4	9.8 (1.1)	6.8 (0.4)	6
S20	1.2	7.9 (1.8)	4.8 (1)	6
Spencer Creek	0.9	8.8 (0.6)	5.1 (0.9)	5
Upper Lewis River	11.4	35.8 (5.7)	21.7 (2.9)	11

**Table B2.** The total stream length, average bankfull width (standard deviation [SD] in parentheses), wetted width (SD in parentheses), and number of sample reaches (n) in each tributary stream to Lake Merwin and Yale Lake, Washington, during surveys in 2014.

[The number of sample reaches corresponds to all subsequent tables. km, kilometer; m, meter; NA, not available]

Stream	Length (km)	Bankfull width (m)	Wetted width (m)	n
Lake Merwin				
Brooks Creek	4.1	7.7 (2.8)	3.3 (0.6)	17
Buncombe Hollow Creek	1.1	5.6 (2.0)	2.9 (0.2)	9
Cape Horn Creek	0.5	13.4 (0.6)	6.0 (0.6)	2
Indian George Creek	1.5	10.2 (1.5)	3.9 (0.2)	7
Jim Creek	0.5	12.3 (0)	5.29 (0)	2
Lower Speelyai Creek	0.3	16.6 (0)	6.5 (0)	1
Rock Creek	0.2	NA	NA	NA
<b>Total</b>	<b>8.2</b>			<b>38</b>
Yale Lake				
Cougar Creek	3.9	16.1 (4.3)	8.1 (1.7)	8
Dog Creek	0.3	15.9 (0)	5.6 (0)	1
North fork of Siouxon Creek	0.7	24.7 (0.4)	14.5 (0.1)	2
Ole Creek	1.7	13.8 (2.0)	5.7 (0.4)	6

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**Table B2.** The total stream length, average bankfull width (standard deviation [SD] in parentheses), wetted width (SD in parentheses), and number of sample reaches (n) in each tributary stream to Lake Merwin and Yale Lake, Washington, during surveys in 2014.—Continued

[The number of sample reaches corresponds to all subsequent tables. km, kilometer; m, meter; NA, not available]

Stream	Length (km)	Bankfull width (m)	Wetted width (m)	n
Panamaker Creek	0.4	10.7 (0.7)	4.5 (1.0)	2
Siouxon Creek	6.1	28.4 (5.0)	15.6 (3.0)	8
Speelyai Creek	6.0	17.3 (14.4)	7.1 (1.8)	23
Swift Bypass Channel	6.5	20.8 (6.1)	16.2 (5.6)	11
West Fork Speelyai Creek	1.3	13.3 (1.6)	6.0 (0.5)	5
West tributary of Speelyai Creek	1.1	9.9 (1.9)	5.4 (0.6)	5
<b>Total</b>	<b>28.0</b>			<b>71</b>

**Table B3.** The total surface area (SA) by reach and the average SA (standard deviation in parentheses) in pool habitat, pool tailouts (that is, spawning habitat), and glides in each tributary stream to Swift Reservoir in 2015 and Lake Merwin and Yale Lake, Washington in 2014.

[In Swift Reservoir, not all tributary habitat was sampled (see table B1); m<sup>2</sup>, square meter; P3 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir]

Stream	Reach SA (m <sup>2</sup> )	Pool SA (m <sup>2</sup> )	Pool tailout SA (m <sup>2</sup> )	Glide SA (m <sup>2</sup> )
Swift Reservoir				
Chickoon Creek	4,280	369 (89)	74 (18)	10 (8)
Clear Creek	184,831	3,359 (2,221)	672 (444)	13 (17)
Cussed Hollow Creek	4,159	434 (141)	87 (28)	18 (7)
Diamond Creek	3,367	126 (71)	25 (14)	0 (0)
Little Creek	5,130	136 (139)	27 (28)	37 (22)
P3 creek	2,100	37 (53)	7 (11)	2 (3)
P7 creek	19,040	350 (99)	70 (20)	4 (7)
Pepper Creek	31,937	233 (263)	47 (53)	1 (2)
Range Creek	11,326	634 (131)	127 (26)	0 (0)
S15 creek	14,112	306 (105)	61 (21)	0 (0)
S20 creek	8,941	176 (202)	35 (40)	0 (0)
Spencer Creek	8,518	177 (123)	35 (25)	2 (2)
Upper Lewis River	407,313	11,530 (5,542)	2,306 (1,108)	33 (18)
Lake Merwin				
Brooks Creek	10,318	90 (40)	18 (8)	69 (53)
Buncombe Hollow Creek	3,373	119 (114)	24 (23)	7 (10)
Cape Horn Creek	3,103	530 (13)	38 (3)	65 (65)
Indian George Creek	6,165	142 (57)	74 (11)	64 (48)
Jim Creek	2,692	604 (89)	46 (18)	90 (26)
Lower Speelyai Creek	1,738	120 (0)	45 (0)	414 (0)

**Table B3.** The total surface area (SA) by reach and the average SA (standard deviation in parentheses) in pool habitat, pool tailouts (that is, spawning habitat), and glides in each tributary stream to Swift Reservoir in 2015 and Lake Merwin and Yale Lake, Washington in 2014.—Continued

[In Swift Reservoir, not all tributary habitat was sampled (see table B1); m<sup>2</sup>, square meter; P3 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir]

Stream	Reach SA (m <sup>2</sup> )	Pool SA (m <sup>2</sup> )	Pool tailout SA (m <sup>2</sup> )	Glide SA (m <sup>2</sup> )
Yale Lake				
Cougar Creek	35,565	319 (327)	64 (65)	444 (425)
Dog Creek	1,647	386 (0)	77 (0)	27 (0)
North fork of Siouxon Creek	9,688	1,147 (473)	229 (95)	0 (0)
Ole Creek	9,975	495 (175)	99 (35)	361 (318)
Panamaker Creek	1,866	285 (161)	57 (32)	120 (120)
Siouxon Creek	96,753	3,452 (1,622)	690 (324)	1,052 (729)
Speelyai Creek	45,346	329 (198)	66 (40)	299 (349)
Swift Bypass Channel	119,180	2,683 (2815)	537 (563)	4,823 (2,981)
West Fork Speelyai Creek	8,392	168 (58)	34 (12)	24 (38)
West tributary of Speelyai Creek	6,208	299 (98)	60 (20)	0 (0)

**Table B4.** Average depth (standard deviation [SD] in parentheses) for nonpool habitat and residual pool depth (SD in parentheses) for pools by habitat type and stream in each tributary stream to Swift Reservoir, Washington, from surveys in 2015.

[m, meter; NA, not available; P3 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir]

Stream	Average depth (m)				Residual pool depth (m)			
	Cascade	Glide	Rapid	Riffle	Beaver pool	Dam pool	Plunge pool	Scour pool
Swift Reservoir								
Chickoon Creek	0.17 (NA)	0.19 (0.05)	0.15 (0.02)	NA	NA	NA	0.56 (0.31)	0.46 (0.14)
Clear Creek	0.16 (NA)	0.62 (0.18)	0.52 (0.13)	0.46 (0.14)	NA	1.36 (0.61)	1.35 (NA)	0.99 (0.26)
Cussed Hollow Creek	0.25 (0.16)	0.18 (0.03)	0.24 (0.05)	0.16 (0.06)	NA	NA	0.69 (0.44)	0.35 (0.11)
Diamond Creek	0.36 (0.11)	0.51 (NA)	0.28 (0.08)	0.21 (NA)	NA	NA	0.61 (0.12)	0.38 (0.14)
Little Creek	0.3 (0.11)	0.48 (0.11)	0.27 (0.09)	0.21 (0.06)	NA	0.59 (0.24)	NA	0.5 (0.12)
P3 creek	0.46 (0.04)	0.48 (NA)	0.44 (NA)	0.39 (NA)	NA	NA	NA	0.23 (NA)
P7 creek	0.48 (0.1)	0.5 (0.04)	0.42 (0.07)	0.39 (0.08)	NA	0.8 (0.28)	0.99 (0.69)	0.82 (0.41)
Pepper Creek	0.37 (0.09)	0.54 (0.01)	0.35 (0.06)	0.34 (0.06)	NA	0.59 (0.38)	0.55 (0.3)	0.51 (0.11)
Range Creek	0.48 (0.03)	NA	0.49 (0.06)	0.33 (NA)	NA	NA	0.49 (0.09)	0 (0)
S15 creek	0.44 (0.09)	NA	0.4 (0.17)	0.31 (NA)	NA	NA	0.71 (0.02)	0.65 (0.19)
S20 creek	0.32 (0.05)	0.36 (NA)	0.33 (0.06)	0.32 (0.06)	NA	NA	NA	0.41 (0.08)
Spencer Creek	0.4 (0.09)	0.44 (0.16)	0.42 (0.04)	0.41 (NA)	NA	NA	0.4 (0.07)	0.5 (0.07)
Upper Lewis River	0.57 (0.07)	0.61 (0.13)	0.47 (0.11)	0.43 (0.07)	NA	NA	1.3 (0.91)	1.45 (0.33)

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**Table B5.** Average depth (standard deviation [SD] in parentheses) for nonpool habitat and residual pool depth (SD in parentheses) for pools by habitat type and stream in each tributary stream to Lake Merwin and Yale Lake, Washington, from surveys in 2014.

[m, meter; NA, not available]

Stream	Average depth (m)				Residual pool depth (m)			
	Cascade	Glide	Rapid	Riffle	Beaver pool	Dam pool	Plunge pool	Scour pool
Lake Merwin								
Brooks Creek.	0.15 (0.07)	0.2 (0.46)	0.12 (0.04)	0.10 (0.03)	0.21 (0.01)	0.24 (0.08)	0.96 (4.47)	0.26 (0.10)
Buncombe Hollow Creek	0.10 (0.02)	0.19 (0.01)	0.13 (0.07)	0.10 (0.04)	0	0.29 (0.16)	0.33 (0.27)	0.29 (0.11)
Cape Horn Creek	0.30 (0.03)	0.24 (NA)	0.22 (0.05)	0.21 (NA)	0	0	0.61 (0.28)	0.43 (0.17)
Indian George Creek	0.18 (0.06)	0.16 (0.03)	0.16 (0.04)	0.12 (0.07)	0	0.28 (NA)	0.55 (0.51)	0.32 (0.12)
Jim Creek	0.22 (0.05)	0.2 (0.03)	0.17 (0.08)	0.13 (0.02)	0	0.33 (0.21)	0.33 (0.28)	0.50 (0.37)
Lower Speelyai Creek	0.19 (0.05)	0.17 (0.05)	0.13 (0.01)	0.18 (NA)	0	0	0.22 (0.04)	0.26 (0.05)
Yale Lake								
Cougar Creek	0	0.45 (0.15)	0.54 (1.12)	0.23 (0.08)	0	0.58 (0.41)	0.87 (0.55)	0.68 (0.30)
Dog Creek	0.17 (0.04)	0.20 (NA)	0.18 (0.02)	0.13 (NA)	0	0	1.54 (1.79)	0.36 (0.14)
North fork of Siouxon Creek	0.43 (0.08)	0	0.26 (0.07)	0	0	0	1.04 (0.28)	0
Ole Creek	0.20 (0.05)	0.28 (0.31)	0.16 (0.05)	0.10 (0.02)	0	0	0.72 (1.0)	0.53 (0.33)
Panamaker Creek	0.20 (0.09)	0.20 (0.01)	0.20 (0.06)	0	0	0	1.15 (0.89)	0.51 (0.41)
Siouxon Creek	0.67 (0.25)	0.52 (0.1)	0.42 (0.1)	0.34 (0.1)	0	0	0.56 (10.08)	1.44 (1.37)
Speelyai Creek	0.26 (0.06)	0.39 (0.54)	0.27 (0.32)	0.24 (0.07)	0	0.98 (NA)	0.53 (0.48)	0.70 (0.54)
Swift Bypass Channel	0 (0.25)	0.67 (0)	0.48 (0.18)	0.28 (0.15)	1.37 (1.06)	0.49 (0.31)	0.69 (0.40)	0.70 (0.69)
West Fork Speelyai Creek	0.26 (0.06)	0	0.24 (0.04)	0	0	0	1.07 (1.93)	0
West tributary of Speelyai Creek	0.22 (0.06)	0.24 (0.05)	0.51 (1.25)	0.16 (0.03)	0	0	0.53 (0.33)	0.38 (0.25)

**Table B6.** The average (standard deviation in parentheses) density (count multiplied by bankfull width divided by reach length as per Ecosystem Diagnosis and Treatment) of large woody debris (LWD) delineated by large (large: diameter greater than 50 centimeters [cm]) and small (small: diameter less than [ $<$ ] 10 to  $<$ 50 cm) pieces, and percent surface fines in pool tailouts in each tributary stream to Swift Reservoir in 2014 and Lake Merwin and Yale Lake in 2014 in Washington.

[% , percent; NA, not available; P3 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir]

Stream	LWD density (large)	LWD density (small)	% fines in tailout
Swift Reservoir			
Chickoon Creek	0.22 (0.09)	0.55 (0.24)	7.0 (12.2)
Clear Creek	0.45 (0.23)	0.67 (0.36)	11.2 (16.5)
Cussed Hollow Creek	0.53 (0.24)	0.46 (0.06)	10.6 (13.6)
Diamond Creek	0.17 (0.08)	0.18 (0.03)	12.1 (17.7)
Little Creek	0.16 (0.1)	0.28 (0.19)	48.7 (31.4)
P3 creek	0 (0)	0 (0)	68.5 (NA)
P7 creek	0.15 (0.1)	0.2 (0.11)	3.1 (6.1)
Pepper Creek	0.2 (0.16)	0.3 (0.25)	28.4 (23.5)
Range Creek	0.26 (0.14)	0.22 (0.1)	0 (0)

**Table B6.** The average (standard deviation in parentheses) density (count multiplied by bankfull width divided by reach length as per Ecosystem Diagnosis and Treatment) of large woody debris (LWD) delineated by large (large: diameter greater than 50 centimeters [cm]) and small (small: diameter less than [ $<$ ] 10 to  $<$ 50 cm) pieces, and percent surface fines in pool tailouts in each tributary stream to Swift Reservoir in 2014 and Lake Merwin and Yale Lake in 2014 in Washington.—Continued

[%, percent; NA, not available; P3 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir]

Stream	LWD density (large)	LWD density (small)	% fines in tailout
S15 creek	0.09 (0.06)	0.16 (0.09)	0 (0)
S20 creek	0.15 (0.05)	0.19 (0.1)	3.1 (3.5)
Spencer Creek	0.23 (0.08)	0.25 (0.08)	5.3 (9.0)
Upper Lewis River	0.33 (0.09)	0.38 (0.13)	0.6 (1.5)
Lake Merwin			
Brooks Creek	0.15 (0.09)	0.79 (0.56)	5.4 (5.3)
Buncombe Hollow Creek	0.02 (0.03)	0.07 (0.07)	12.3 (13.3)
Cape Horn Creek	0.31 (0.09)	1.91 (0.18)	2.0 (0.5)
Indian George Creek	0.17 (0.06)	0.96 (0.36)	2.5 (1.5)
Jim Creek	0.41 (0.07)	2.13 (0.01)	0.6 (0.0)
Lower Speelyai Creek	0.40 (0)	1.59 (0)	4.9 (0)
Yale Lake			
Cougar Creek	0.22 (0.18)	0.42 (0.32)	0.2 (0.4)
Dog Creek	0.10 (0)	2.97 (0)	1.0 (0)
North fork of Siouxon Creek	0.39 (0.22)	1.05 (0.57)	2.3 (2.3)
Ole Creek	0.16 (0.17)	0.99 (1.09)	0.2 (0.4)
Panamaker Creek	0.40 (0.20)	1.68 (0.12)	5.2 (4.0)
Siouxon Creek	0.16 (0.08)	0.43 (0.19)	0.3 (0.6)
Speelyai Creek	0.17 (0.34)	0.40 (0.54)	3.8 (9.9)
Swift Bypass Channel	0.03 (0.08)	0.12 (0.12)	0 (0)
West Fork Speelyai Creek	0.22 (0.18)	0.44 (0.26)	2.0 (3.0)
West tributary of Speelyai Creek	0.11 (0.09)	0.35 (0.31)	1.2 (1.7)



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**Table B7.** Percent of substrate estimated as bedrock, boulder (greater than 256 millimeters [mm]), large cobbles (127.1–256 mm), small cobbles (64.1–127 mm), gravel (2–64 mm), and fines (less than 2 mm) in fast-water habitat (riffles, glides, cascades) in tributaries to Reservoir in 2015 and Lake Merwin and Yale Lake in 2014 in Washington.

[P3 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir]

Stream	Bedrock	Boulder	Cobble	Gravel	Fines
Swift Reservoir					
Chickoon Creek	31.4	11.8	48.3	8	0.5
Clear Creek	0	4	60.4	28.1	5.7
Cussed Hollow Creek	24.9	12.7	45.2	10.4	2.1
Diamond Creek	0	36.4	46.3	17.2	0
Little Creek	0	0	24.5	21.7	53.7
P3 creek	0	50	22	16	12
P7 creek	0	18.4	53.5	24.2	2
Pepper Creek	6	9.2	52	28.3	3.2
Range Creek	2.5	49.3	28.9	14.5	0
S15 creek	7.8	60.9	28.6	2.7	0
S20 creek	0	23.7	73.8	1.8	0.7
Spencer Creek	5.9	30.6	56.5	7	0
Upper Lewis River	6.2	17.8	60.7	14.5	0.6
Lake Merwin					
Brooks Creek	0.5	7.4	25.9	57.7	7.4
Buncombe Hollow Creek	38.2	0	22	33.1	6.6
Cape Horn Creek	27.4	15.4	31.1	19.8	6.4
Indian George Creek	5.1	5.9	43.7	42.4	1.8
Jim Creek	20.4	13.5	22.1	37.7	5.9
Lower Speelyai Creek	0	6.4	15.5	53.6	15.5
Yale Lake					
Cougar Creek	0	0.9	34.4	52.7	3.5
Dog Creek	0	23.6	31.8	35.5	9.1
North fork of Siouxon Creek	16.7	58.3	13.3	11.7	0
Ole Creek	0	14	52.7	32.3	1
Panamaker Creek	10	12.4	57.1	20	0
Siouxon Creek	13.3	46.1	33.3	7.2	0
Speelyai Creek	4.7	38	40.8	11.3	0.6
Swift Bypass Channel	0.4	26.7	57	10.8	4.2
West Fork Speelyai Creek	2	59.5	30.6	7.9	0
West tributary of Speelyai Creek	0.5	34.7	48.1	15.4	0.1

**Table B8.** The average and range of stream temperatures by month from July through October 2013 for Clear Creek (Swift Reservoir) and in each tributary stream to Lake Merwin and Yale Lake in Washington in 2014.

[The logger and data for Siouxon Creek and Cape Horn Creeks were lost during the high flow event during September. avg., average; NA, not available]

Stream	July <sup>1</sup>		August		September		October	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Lake Merwin								
Brooks Creek	13.0	10.6–15.5	13.0	11.4–15.1	12.6	10.1–15.3	9.5	7.7–11.2
Buncombe Hollow	16.3	14.2–18.7	16.4	14.2–18.4	14.7	11.3–17.6	10.2	8.3–11.6
Indian George	14.3	11.5–16.5	15.2	13.5–16.7	13.8	9.7–16.7	9.0	7.4–10.6
Jim Creek	13.8	11.2–15.7	14.6	12.9–15.8	13.4	10.0–16.0	9.1	7.4–10.4
Yale Lake								
Cougar Creek	6.8	6.2–7.9	6.8	6.4–7.9	6.8	6.2–8.1	6.8	6.5–7.2
Dog Creek	13.0	10.5–14.9	17.0	12.9–23.3	14.6	9.1–20.5	9.3	8.2–10.7
Ole Creek	13.8	11.6–15.8	14.8	13.2–16.0	13.2	8.9–15.6	8.4	7.5–9.3
Panamaker Creek	12.8	10.5–14.9	14.0	12.2–16.5	NA	NA	NA	NA
Speelyai Creek	15.3	11.6–19.2	16.2	13.6–19.5	13.7	9–18.5	8.7	7.1–10.4
Swift Reservoir								
Clear Creek	14.0	10.7–17.8	14.5	12.6–17.9	13.1	7.6–17.2	7.3	6.1–8.9

<sup>1</sup>July values include period from July 10–July 31.**Table B9.** The average and range of stream temperatures by month from June through October for Clear Creek (Swift Reservoir) and in each tributary stream to Lake Merwin and Yale Lake in 2014 in Washington.

[avg., average; NA, not available]

Stream	June		July		August		September		October	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Lake Merwin										
Brooks Creek	16.5	9.8–21.9	13.8	12.4–19.4	13.8	12.8–14.8	12.4	11.9–13.3	11.6	10.4–12.5
Buncombe Hollow Creek	13.7	11.4–15.1	17.0	14.9–19.1	17.5	15.6–19.0	14.8	13.5–16.2	12.6	11.4–14.0
Cape Horn Creek	11.2	9.5–12.4	14.2	12.4–15.8	14.9	13.5–16.2	12.9	11.7–14.2	11.3	9.7–13.0
Indian George Creek	11.7	9.8–13.1	15.1	13.1–16.7	16.0	14.7–17.1	14.0	12.9–15.2	11.8	9.9–13.7
Jim Creek	11.8	10.1–13.0	14.9	13.1–16.4	15.6	14.3–16.6	13.6	12.6–14.7	12.3	10.2–13.9
Lower Speelyai Creek	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Yale Lake										
Cougar Creek	7.0	6.5–7.7	7.3	7.1–7.7	7.4	7.1–7.6	7.0	6.7–7.2	7.2	6.6–8.4
Dog Creek	9.9	9.2–10.7	12.7	11.2–14.1	16.5	14.1–19.8	15.1	12.8–18.2	11.7	9.2–15.7
North fork of Siouxon Creek	10.7	9.0–12.1	13.8	11.4–15.6	15.3	14.1–16.3	13.3	12.4–14.0	12.3	10.9–14.0
Ole Creek	10.7	9.6–11.7	13.4	11.5–14.7	14.7	13.6–15.4	12.9	11.8–13.7	11.1	9.0–12.6
Panamaker Creek	10.6	9.4–11.7	12.7	11.1–13.9	14.4	13.7–14.9	14.8	12.9–17.8	11.5	8.7–15.2
Siouxon Creek	11.4	9.4–13.2	15.4	12.4–17.7	16.9	14.9–18.6	14.0	12.5–15.2	12.3	10.9–14.0
Speelyai Creek	11.6	9.6–13.3	15.0	12.8–17.0	16.8	15.0–17.8	14.6	13.1–15.6	11.6	9.1–14.0
Swift Bypass Channel	10.5	9.5–11.8	12.3	11.0–13.1	13.4	12.4–14.3	13.3	12.4–14.0	12.1	10.3–13.2
West Fork Speelyai Creek	10.8	9.0–12.1	13.6	11.6–15.3	15.0	13.4–15.9	13.0	11.7–14.4	10.8	8.7–13.0
West tributary of Speelyai Creek	11.3	9.1–12.8	14.4	12.3–16.4	15.5	13.9–16.9	13.3	12.1–14.6	12.2	10.6–14.0
Swift Reservoir										
Clear Creek	10.4	8.1–14.4	14.4	10.1–19.1	15.6	13.2–19.3	13.5	10.8–16.7	10.7	6.8–14.8

## 78 B. Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington

**Table B10.** The average (standard deviation in parentheses) measures of dissolved oxygen, reach gradient, and riparian function in each tributary stream to Lake Merwin and Yale Lake, Washington, in 2014.

[ml/l, milliliter per liter; %, percent; NA, not available]

Stream	Dissolved oxygen (ml/l)	Gradient (%)	Riparian function
Lake Merwin			
Brooks Creek	9.84 (0.26)	4.4 (2.4)	2.7 (0.7)
Buncombe Hollow Creek	8.50 (0.92)	3.2 (1.8)	1.6 (1.5)
Cape Horn Creek	9.54 (0.15)	5.2 (0.9)	0.1 (0.1)
Indian George Creek	9.65 (0.02)	5.7 (1.8)	0.9 (1.3)
Jim Creek	9.24 (0.05)	4.7 (1.1)	0 (0)
Lower Speelyai Creek	9.89 (0)	2.8 (0)	4 (NA)
Yale Lake			
Cougar Creek	12.29 (0.04)	1.6 (0.9)	1.1 (1.6)
Dog Creek	8.83 (0)	4.9 (0)	2.8 (NA)
North fork of Siouxon Creek	9.75 (0.08)	7.0 (2.7)	1.8 (0)
Ole Creek	9.46 (0.25)	2.0 (1.7)	0.9 (1.1)
Panamaker Creek	9.80 (0.16)	NA	0 (0)
Siouxon Creek	9.73 (0.06)	2.1 (2.3)	0.1 (0.2)
Speelyai Creek	9.56 (0.36)	6.2 (4.4)	0.9 (1.4)
Swift Bypass Channel	NA	0.7 (0.5)	2.1 (0.2)
West Fork Speelyai Creek	9.68 (0.05)	10.7 (2.5)	0 (0)
West tributary of Speelyai Creek	9.86 (0.03)	9.0 (5.6)	0 (0)

**Table B11.** The average (standard deviation in parentheses) measures of riparian function in sampled tributary stream to Swift Reservoir, Washington, in 2015.

[P3 and P7, tributaries to Pine Creek; S15 and S20, tributaries to Swift Reservoir; NA, not available]

Stream	Riparian condition
Chickoon Creek	0 (0)
Clear Creek	0.5 (0.9)
Cussed Hollow Creek	0 (0)
Diamond Creek	1.0 (0.4)
Little Creek	2.3 (1.2)
P3 creek	1 (NA)
P7 creek	2.0 (0.7)
Pepper Creek	0.2 (0.6)
Range Creek	1.2 (1.1)
S15 creek	1 (NA)
S20 creek	2 (NA)
Spencer Creek	0 (0)
Upper Lewis River	0.1 (0.3)

# Chapter C. Studies Assessing Adult Potential for Spawning Success in Yale Lake and Lake Merwin, Washington

## Introduction

Understanding the ability of reintroduced anadromous species to successfully reproduce in the tributaries to Yale Lake and Lake Merwin (fig. C1) is an essential component of a reintroduction program. Under current management plans, anadromous adults will be released into the reservoir systems, and with this, there remains considerable uncertainty in how these fish will disperse and utilize available stream habitat. We introduced a set of adult *Oncorhynchus kisutch* (coho salmon) into Lake Merwin (based on availability of surplus salmon) in the fall of 2014 to evaluate tributary use and potential for recruitment.

## Methods

### Field Sampling

*Spawning surveys.*—During 2014, we assessed the adult potential for spawning success in tributaries to Lake Merwin using a test release of adult coho salmon. On September 23, 2014, a set of 280 adults was released into the reservoir near Cresap Bay Campground. Beginning in the second week of October, which is the approximate start of coho salmon spawning observed in the Lewis River upstream of Merwin Dam (see “Studies Assessing Anadromous-Resident Fish Interactions in the Lewis River, Washington,” chap. F of this report), and continuing through the first week of November, we tracked the adult spawning locations using biweekly redd and carcass surveys in each of the tributaries. Spawning surveys were continuous and included all habitats available in each tributary. During each survey, we georeferenced the occurrence of spawning activity and delineated observations into three categories: (1) carcasses, (2) observed redds, and (3) staging. We considered fish as “staging” where no redd was clearly observed near fish, and we did not delineate staging fish based on the presence of female only, male only, or male/female pairings.

*Juvenile recruitment.*—In the late spring and early summer of 2015, we conducted electrofishing and snorkel surveys in Cape Horn Creek, Jim Creek, Indian George Creek, and Brooks Creek to verify successful spawning. We sampled all the existing habitat in Cape Horn Creek, Jim Creek, and Indian George Creek using snorkel surveys. In Brooks Creek, we sampled continuously until at least 50 individuals were captured using a backpack electrofisher for an estimate of catch-per-unit effort (CPUE) in fish per second and measured the fork lengths of all individuals captured. We contrasted the capture information with field results for juvenile coho salmon in Clear Creek, a tributary in the Swift Basin, where reintroduction efforts have been ongoing since 2012 (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report). We used the size comparisons with Clear Creek as a measure of successful recruitment given the observed production of juvenile coho salmon in Clear Creek.

## Results and Discussion

*Spawning surveys.*—We observed coho salmon spawning activity during surveys in Cape Horn Creek, Jim Creek, Indian George Creek, and Brooks Creek (fig. C2). Spawning activities were observed up to the existing barriers in Cape Horn Creek and Jim Creek but only partially upstream in Indian George Creek and Brooks Creek. No spawning activity was observed in Buncombe Hollow Creek. However, use of existing tributaries is likely to vary considerably given the lack of natal homing in the test fish used in this study (Quinn, 1993; Candy and Beacham, 2000).

*Juvenile recruitment.*—During 2015 sampling surveys, no juvenile coho salmon were observed in Jim Creek and Indian George Creek, but low densities of coho salmon were observed in Cape Horn Creek and in Brooks Creek. For example, in Brooks Creek we sampled 1.2 kilometers to capture a total of 50 juvenile coho salmon. The size distribution of coho salmon in Brooks Creek was generally similar to that observed in Clear Creek (Swift Reservoir; fig. C3), suggesting that rearing conditions are suitable. Densities of juvenile coho salmon in Brooks Creek were relatively low (CPUE=0.008 fish per second) when compared to Clear Creek (average CPUE=0.039 fish per second; range=0.012–0.066; fig. C4), particularly given the low densities observed in Clear Creek in 2015 (see “Studies Assessing Anadromous-Resident Fish Interactions in the Lewis River, Washington” chap. F of this report) and the likely higher capture probabilities associated with stream size.

Habitat can be a factor limiting juvenile recruitment (Jensen and others, 2009), yet research suggests that coho salmon can use a variety of habitats, albeit to varying densities (Anlauf-Dunn and others, 2014). Habitat conditions in tributaries to Lake Merwin and Yale Lake are generally robust with relatively high large woody debris densities (see “Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington,” chap. B of this report) and minimal indications of excessive levels of fine sediment (table C1; Bryce and others, 2008). In some tributaries, however (for example, Siouxon Creek; table C2), a considerable amount of existing substrate may be too large for coho salmon spawning (Kondolf, 2000; Mull and Wilzbach, 2007). The large substrate is likely from the ambient geology and the high stream power, which is driven by precipitation patterns and high gradients observed in many tributaries (table B10 in “Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington,” chap. B of this report).

The low densities of juvenile coho salmon observed in tributary surveys in Lake Merwin, however, do not necessarily indicate that habitat is limiting juvenile production. For example, the observed low densities of juvenile coho salmon may also be a function of the location of observed redds, which were all within 1.15 kilometers of Lake Merwin (fig. C2), and the limited amount of existing habitat. Downstream emigration of coho salmon fry can be common in streams with limited habitat and locations proximate to larger water bodies (Roni and others, 2012; Rebenack and others, 2015). Coho salmon emigration at the fry stage appears to be relatively common in Swift Reservoir, as over 18 percent of the coho salmon captured at the floating surface collector in 2015 were fry. As such, the low densities of juvenile coho salmon may not be strong indicators of spawning capacity, as recruitment patterns can be complex, particularly given the variety of factors that can influence juvenile coho salmon life-history expressions (for example, Pess and others, 2011).

## Conclusions

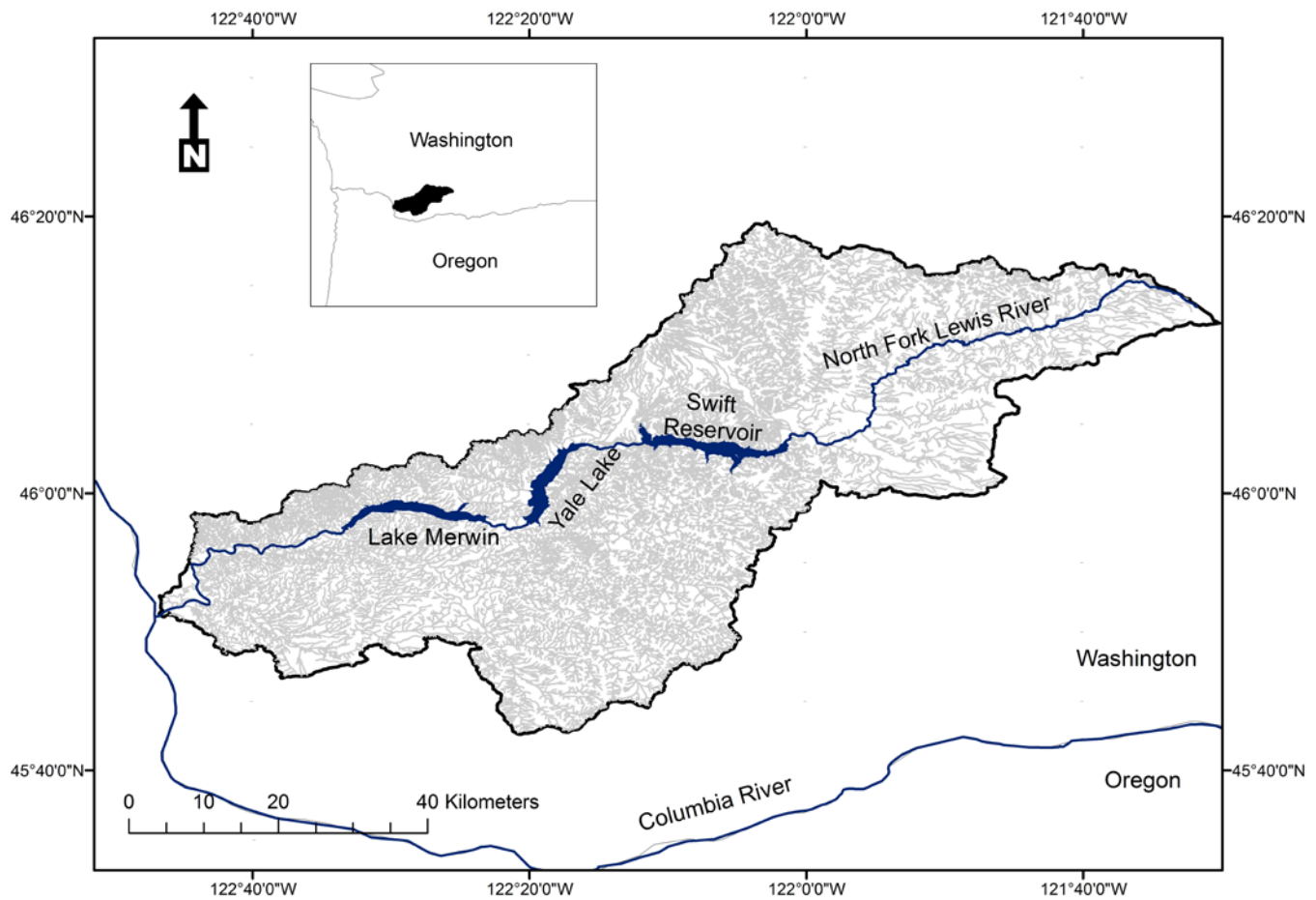
The lack of surplus coho salmon adults to mimic potential reintroduction scenarios somewhat hindered our ability to understand patterns of spawning behavior and the likely consequences of such patterns (that is, recruitment). However, coho salmon can utilize a variety of habitats, a pattern demonstrated in the variability of habitats and tributaries utilized by adult coho salmon in Swift Reservoir (see “Studies Assessing Anadromous-Resident Fish Interactions in the Lewis River, Washington” chap. F of this report). Furthermore, the colonization of tributaries that are spatially distant within the reservoir indicates that finding and accessing habitat is unlikely a limiting factor. For example, although adult coho salmon are released in the upper two-thirds of Swift Reservoir, redd count data from the first 3 years of reintroduction indicate individuals have been found spawning more than 10 kilometers downstream of the release site. Together, these results suggest coho salmon adults will be capable of finding and accessing a range of habitats in tributaries to Lake Merwin and Yale Lake.

Understanding juvenile salmon and steelhead recruitment patterns can be challenging given the variety of life-history expressions demonstrated by different species. Ultimately, the distribution of spawning coupled with the extent and condition of tributary habitat may lead to increased use of reservoir habitat by juveniles—particularly if progeny of redds proximate to the reservoir migrate earlier and have extended rearing in the reservoir environment. Longer periods of rearing in the reservoir environments may have profound influences on the potential predation of juvenile salmon by existing predators (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report) and the seasonal carrying capacity of the reservoirs based on forage base (see “Studies Assessing Anadromous-Resident Fish Interactions in the Lewis River, Washington,” chap. F of this report).

## References

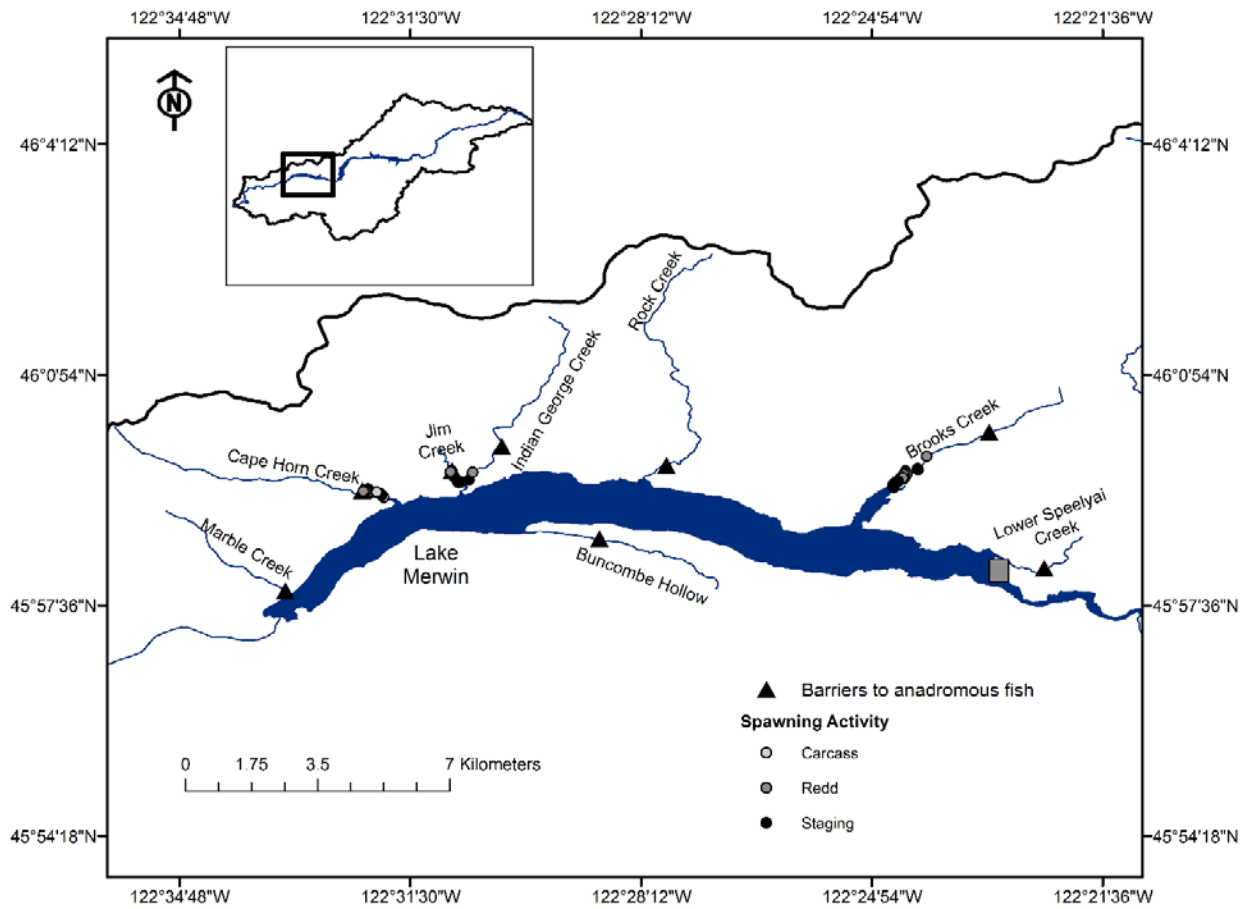
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## Figures

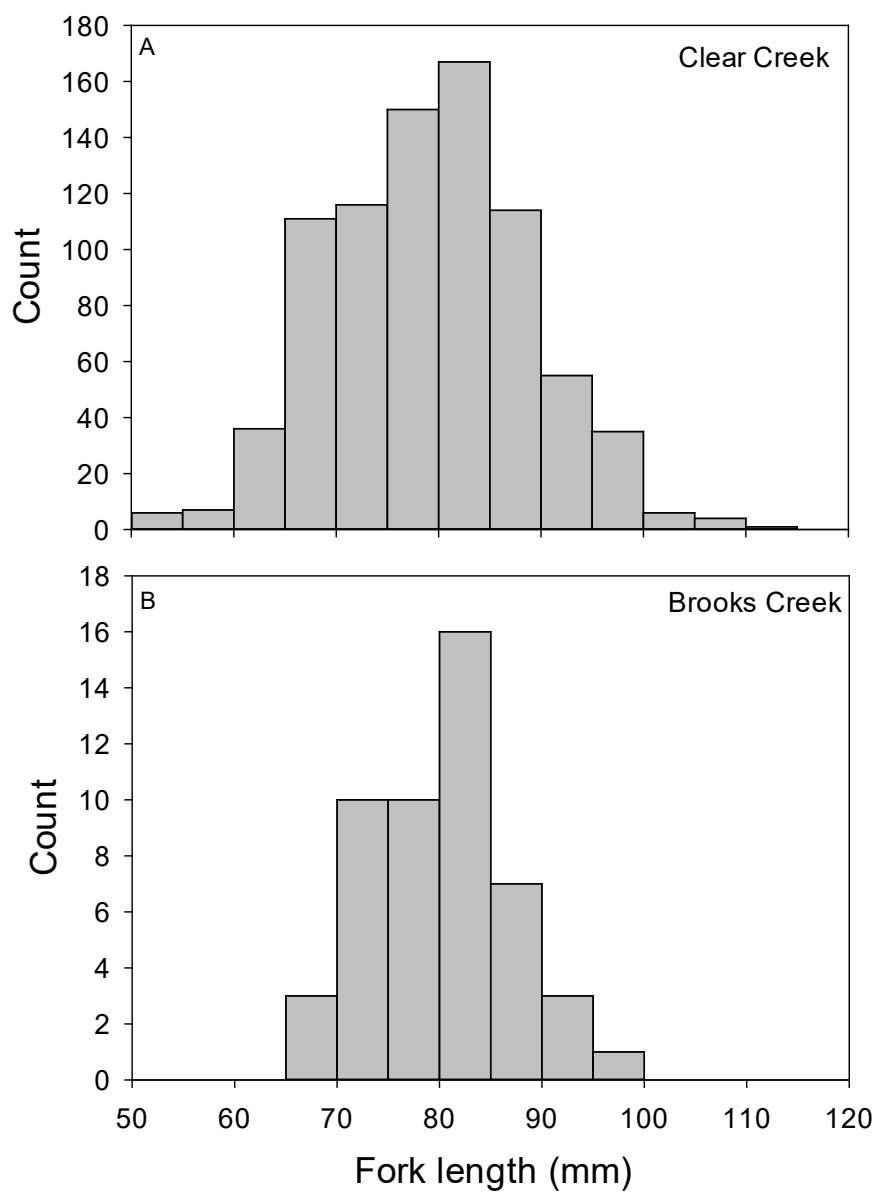


**Figure C1.** The North Fork of the Lewis River and the three hydropower impoundments: Lake Merwin, Yale Lake, and Swift Reservoir in the Lewis River Basin, Washington.

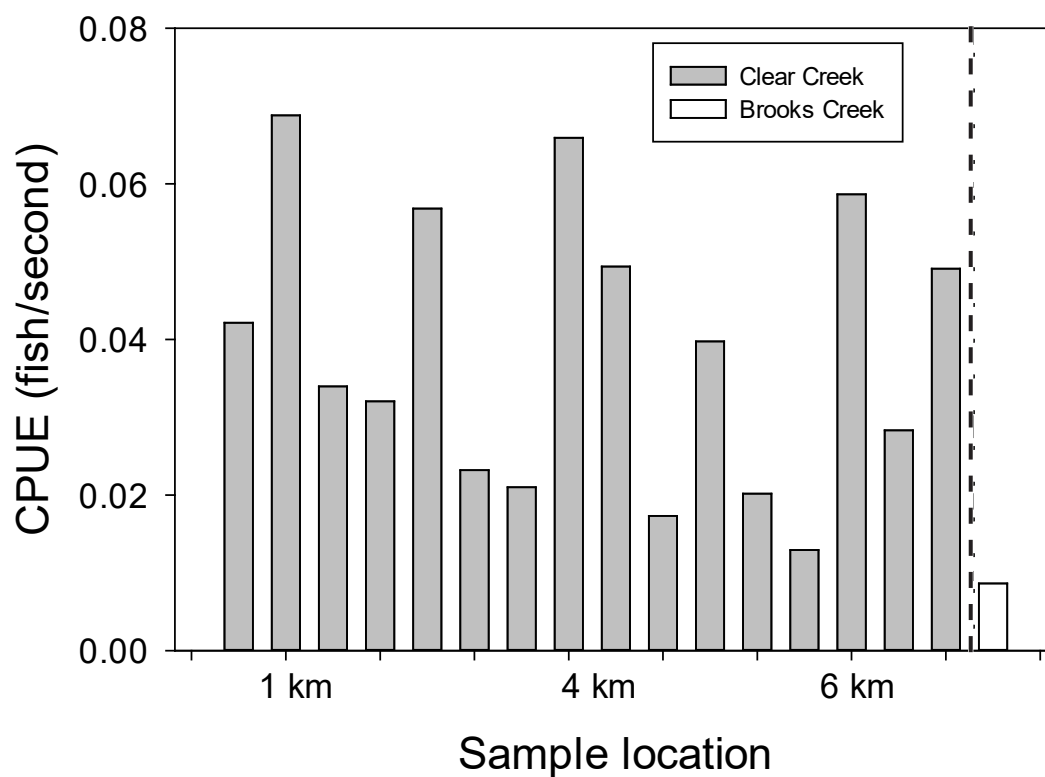




**Figure C2.** The location of the coho salmon release site (gray square), existing barriers to anadromous species (black triangles), and spawning activity including observed carcass locations (hollow circles), adults observed staging (gray circles), and redds (black circles) during 2015 fall spawning surveys in Lake Merwin tributaries. The inset map shows the location of Lake Merwin study area in relation to the Lewis River Basin, Washington.



**Figure C3.** Length frequency histograms for juvenile coho salmon from early summer electrofishing surveys in 2013–2015 for *A*, Clear Creek (Swift Reservoir) and in 2015 for *B*, Brooks Creek demonstrating generally consistent sizes. mm, millimeter.



**Figure C4.** Catch-per-unit-effort (CPUE) in fish per second estimates from Brooks Creek (hollow; Lake Merwin) and sample reaches from Clear Creek (gray; Swift Reservoir) from 2015. Data from Clear Creek are organized from the most downstream (far left, near mouth of Clear Creek) upstream to the barrier based on systematic surveys (greater than 7 kilometers [km] total), with approximate distances upstream noted on x-axis.

## Tables

**Table C1.** Field estimates from 2014 surveys of the percent of fine sediment (less than 6 millimeters) in pool tailouts in available tributary habitat in Lake Merwin and Yale Lake, Washington (see “Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington,” chap. B of this report).

[%, percent]

Stream	% fines in pool tailouts
Lake Merwin	
Brooks Creek	5.4 (5.3)
Buncombe Hollow Creek	12.3 (13.3)
Cape Horn Creek	2.0 (0.5)
Indian George Creek	2.5 (1.5)
Jim Creek	0.6 (0)
Lower Speelyai Creek	4.9 (0)
Yale Lake	
Cougar Creek	0.2 (0.4)
Dog Creek	1.0 (0)
North fork of Siouxon Creek	2.3 (2.3)
Ole Creek	0.2 (0.4)
Panamaker Creek	5.2 (4.0)
Siouxon Creek	0.3 (0.6)
Speelyai Creek	3.8 (9.9)
Swift Bypass Channel	0 (0)
West Fork Speelyai Creek	2.0 (3.0)
West tributary of Speelyai Creek	1.2 (1.7)

**Table C2.** Percent of substrate estimated as bedrock, boulder (greater than 256 millimeters [mm]), large cobbles (127.1–256 mm), small cobbles (64.1–127 mm), gravel (2–64 mm), and fines (less than 2 mm) in fast-water habitat (riffles, glides, cascades) from 2014 field surveys in tributaries to Lake Merwin and Yale Lake, Washington (see “Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington,” chap. B of this report).

Stream	Bedrock	Boulder	Cobble	Gravel	Fines
Lake Merwin					
Brooks Creek	0.5	7.4	25.9	57.7	7.4
Buncombe Hollow Creek	38.2	0	22	33.1	6.6
Cape Horn Creek	27.4	15.4	31.1	19.8	6.4
Indian George Creek	5.1	5.9	43.7	42.4	1.8
Jim Creek	20.4	13.5	22.1	37.7	5.9
Lower Speelyai Creek	0	6.4	15.5	53.6	15.5
Yale Lake					
Cougar Creek	0	0.9	34.4	52.7	3.5
Dog Creek	0	23.6	31.8	35.5	9.1
North Fork of Siouxon Creek	16.7	58.3	13.3	11.7	0
Ole Creek	0	14	52.7	32.3	1
Panamaker Creek	10	12.4	57.1	20	0
Siouxon Creek	13.3	46.1	33.3	7.2	0
Speelyai Creek	4.7	38	40.8	11.3	0.6
Swift Bypass Channel	0.4	26.7	57	10.8	4.2
West Fork Speelyai Creek	2	59.5	30.6	7.9	0
West Tributary of Speelyai Creek	0.5	34.7	48.1	15.4	0.1

# Chapter D. Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington

## Introduction

Given the differences in habitat and resident fish in Lake Merwin, Yale Lake, and Swift Reservoir, Washington (fig. D1), an important step of the Lewis River anadromous *Oncorhynchus* spp. (Pacific salmon) and *O. mykiss* (steelhead) reintroduction is to evaluate the survival and behavior of smolts in both stream and reservoir environments. Furthermore, understanding the timing of anadromous species outmigration to reservoirs, particularly as it relates to ambient conditions (for example, streamflow), will provide critical insight into the strength of these factors relative to intraannual cycles (that is, seasons). Because of the lack of anadromous fish currently present in Yale Lake and Lake Merwin, it was necessary to thoroughly evaluate these patterns by assessments in Swift Reservoir in combination with data collected from test smolts in Yale Lake. Integrating the information from ongoing data collection regarding outmigration timing, travel times within reservoirs, and results understanding of potential predation effects (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report, and community interactions and capacity (see “Studies Assessing Adult Potential for Spawning Success in Yale Lake and Lake Merwin, Washington,” chap. C of this report) allows for a more comprehensive assessment of the factors that may be limiting successful reintroductions.

## Methods

To meet our objectives, we used a combination of field studies involving wild (naturally produced) and hatchery-reared salmon in the stream and reservoir habitat in the upper Lewis River Basin. We combined the data from our empirical field studies with additional data from the Washington Department of Fish and Wildlife (DFW) and PacifiCorp biologists for a more comprehensive assessment of juvenile salmon and steelhead production and outmigration.

## Stream Habitat

*Sampling of wild *O. kisutch* (coho salmon).*—In 2013, we initiated mark-recapture methods in Clear Creek, a tributary to the Muddy River, to understand juvenile production and outmigration success. We selected Clear Creek as a focal study stream because of its current population of wild coho salmon, the potential for the installment of a passive instream antenna, and identification as a location for juvenile, acclimation spring *O. tshawytscha* (Chinook salmon) releases each year. In late August 2013, we installed a pass-by passive integrated transponder (PIT) tag antenna system with Biomark biologists on Clear Creek (latitude 46.11818, longitude -121.9995, in decimal degrees), approximately 0.75 kilometers (km) upstream from the confluence with Muddy Creek. The antenna spanned the entire stream channel, and the reader was able to detect fish tagged with both half duplex and full duplex that passed by the antenna. At the antenna site, we also installed a pressure transducer for real-time, continuous measurements of streamflow (that is, stage) and stream temperature and a modem to allow for cellular connection to the system for real-time information gathering. All equipment was powered by solar panels installed adjacent to the site, and all PIT-tag data, antenna and receiver diagnostics, streamflow, and stream temperature can be remotely accessed.

The initial study area in Clear Creek encompassed 11.7 km from the confluence with Muddy Creek upstream to the first known upstream barrier. We used a systematic sampling design with reach lengths of a minimum of 250 meters (m) and a minimum target of 33 percent sampling rate for 2013. Reach lengths varied, however, as we began each reach at a pool tail and continued sampling until the first pool beyond 250 m. We contracted our study area in 2014 by restricting our efforts to reaches that were above the Biomark PIT-tag antenna system to allow for detection of fish moving downstream past the antennas. This

resulted in a study area of approximately 10.5 km, which we maintained in 2015. We continued using a systematic sampling design with reach lengths of a minimum of 250 m and a minimum target of 33 percent sampling rate (fig. D2). Reach lengths varied, however, as we began each reach at a pool tail and continued sampling until the first pool beyond 250 m. In 2014 and 2015, we only surveyed those reaches above our PIT-tag antenna.

During 2013, we used a variety of sampling techniques to capture fish including backpack electrofishing, minnow traps, seining, and herding fish with a snorkeler into a seine. After evaluating the variety of sampling techniques used in 2013, we determined backpack electrofishing to be the most efficient technique, and this method was used exclusively during 2014–2015. Each year, all sampling occurred during the summer and early fall, and when captured, we sedated fish using the anesthetic AQUI-S (approximately 1.5 milliliters to 8 liters of water) and recorded weights and lengths (fork length). We marked all salmonids greater than 80 millimeters (mm) with a 12-mm full duplex PIT-tag in the dorsal sinus. Upon completion of marking, we placed fish in recovery pens within the sample reach; after equilibrium was fully regained, we returned fish to the sample reach. We spatially referenced each marked fish with a specific sampling reach to allow for analyses of spatial and temporal movement patterns.

We used the individual PIT-tag information in combination with recapture information at the fixed PIT-tag antenna to quantify spatial patterns of outmigration and potential factors affecting outmigration. In addition to our sampling data, we summarized information from individual fish PIT-tagged by Washington DFW and PacifiCorp biologists at a rotary screw trap located just upstream from the head of the reservoir at a pool (that is, Eagle Cliff; fig. D2). We integrated mark and recapture information from Clear Creek and the rotary screw trap with recaptures at the floating surface collector (FSC) on Swift Reservoir to estimate timing of outmigration and reservoir rearing and the proportion of fish marked collected at the FSC (that is, collection efficiency).

Ultimately integrating data from individual marking and recapture events will allow for robust estimates of production to the collector in Swift Reservoir. We computed initial survival estimates for wild coho salmon during the tributary phase using individual mark-recapture information including marking, antenna recapture events, and recaptures at the FSC in Swift Reservoir. We used a Cormack-Jolly-Seber mark-recapture model, which is commonly used for anadromous species survival estimates (Achord and others, 2007; Brakensiek and Hankin, 2007). We estimated apparent survival ( $\Phi$ ) for fish marked in tributaries in 2013 and 2014, but we did not include fish marked in 2015 as outmigration and rearing continued in 2016. With only three sampling events (marking, antenna recaptures, and FSC), we were unable to estimate capture probability at the FSC and estimate survival in the reservoir environment. To overcome this hurdle, we used the proportion of fish marked at the rotary screw trap that were collected at the FSC (0.15; see “Wild coho salmon outmigration patterns” in the “Results and Discussion” section of this chapter) as the recapture probability at the FSC (fixed) with the modeling analysis. We consider this estimate to be appropriate as the rotary screw trap is located proximate to the reservoir (fig. D2), providing a more accurate estimate of recapture through the reservoir environment.

*Acclimation Chinook salmon and coho salmon.*—Hatchery-reared acclimation salmon remain an important part of the reintroduction efforts in the upper Lewis River. Starting in 2013, a portion of acclimation smolts have been PIT-tagged (table D1), providing information on outmigration patterns and success. Only in 2013 were hatchery-reared coho salmon and spring Chinook salmon released in Swift Reservoir tributaries, and only spring Chinook salmon were released in subsequent years. Most of the fish have been yearlings released during spring (45,000 in 2014 and 109,666 in 2015); however, an October release of 48,000 juvenile spring Chinook salmon (also yearlings) occurred in 2015. We used date of release, Clear Creek antenna recapture information, and date at which fish are captured at the FSC to estimate residence time and timing of outmigration from tributaries, travel times across the reservoir to the collector, and proportion of individuals reaching the collector.

## Reservoir Habitat

To evaluate smolt movement behavior and migration timing through Yale Lake and to locate smolt aggregations in the forebay to guide the siting of a future smolt collector, coho salmon smolt movements were assessed before, during, and after a test release using a hydroacoustic system. A total of 5,000 hatchery-reared coho salmon smolts were released into Yale Lake at Yale Park (middle of reservoir; fig. D3) on April 8, 2014, at 09:50 (24-hour).

*Hydroacoustic surveys of 2014 smolt test release in Yale Lake.*—The hydroacoustics system used for all surveys consisted of two multiplexed split-beam 200 kilohertz transducers towed in sidelooking (12.8 degrees [°] full beam angle) and downlooking (6.8° full beam angle) orientations. The transducers were connected to a Biosonics DE-6000 scientific echo sounder with the following data acquisition parameters: bottom threshold=70 m, ping rate=2–3 pulses per second, pulse width=0.3 millisecond, and target strength detection threshold=−65 decibels (dB). Surveys consisted of transects extending the length of the east and west banks and along the center axis of the reservoir, as well as a zig-zag transect going between banks through the forebay and within the lower quarter of the reservoir. We divided transects running the length of the reservoir into five distinct analysis regions based on minutes of latitude (fig. D3). These divisions were designed to obtain finer spatial resolution in fish distribution

yet maintain enough sampling power within each spatial unit to obtain reliable estimates of fish densities. Most transects were surveyed during daylight, but some regions of the reservoir were surveyed during dusk (defined as 1 hour after sunset) and at night. Light levels (lux and microeinsteins:  $[uE] \cdot s^{-1} \cdot m^{-2}$ ) were recorded at the start, end, and periodically throughout each transect. Light intensity is important, as fish like *Oncorhynchus nerka* (kokanee salmon), the primary pelagic planktivore in Yale Lake, often exhibit diel vertical migrations, and their distribution is highly sensitive to time of day and light conditions (for example, Eggers, 1978).

Prerelease surveys were conducted in Yale Lake to establish the background distribution and density of resident fish targets on April 7, 2014, and on the morning of April 8, 2014. The daylight part of the survey conducted on April 7, 2014 consisted of transects along both banks and a zig-zag transect near the dam (table D2, fig. D3). Also, on April 7, 2014, a survey of the middle axis was conducted at dusk, and a second zig-zag transect was conducted at night. A short transect along the middle axis was conducted before the release on the morning of April 8, 2014, to examine the daytime distribution of fish, and these daylight surveys were used in place of the dusk surveys for comparison with postrelease transects conducted in these areas during daylight.

The boat launch at Yale Park and surrounding areas was surveyed while fish were being released to directly assess the target strengths of smolts as registered by the hydroacoustic survey system. Numerous direct sightings of the released smolts swimming through water while being sampled by the sidelooking transducer were linked to specific locations on the corresponding echograms (fig. D4). Postrelease surveys were conducted along the same tracks as the prerelease surveys, along both banks, the center axis, and in a zig-zag pattern within the forebay and lower quarter of the reservoir. We surveyed transects following the smolt release on April 8, 2014, during daylight beginning at 13:58 (24-hour time) and concluding at 17:06 (table D2). We surveyed an additional zig-zag transect in the lower quarter of the reservoir from 20:31 to 21:01 to examine the density of fish near the dam at night.

A third survey was conducted on April 9, 2014, the day after the smolts were released. All regions were surveyed during daylight beginning at 07:25 and concluding at 10:43 (table D3). An additional transect was conducted at dusk along the middle-axis in Region 4 (middle to upper reservoir) from 19:28 to 19:47 to qualitatively examine whether smolts had left the vicinity of the release site. Lastly, we surveyed the same zig-zag transect within the lower quarter of the reservoir during the night from 20:45 to 21:18 to assess whether smolts shifted to lower regions of the reservoir or were aggregated near the dam.

All echograms were visually examined, and regions of background noise and nonfish targets were excluded from the analysis. Standard echo counting techniques (Beauchamp and others, 1997, 2009) with EchoView 5.4 software (Myriax Pty. Ltd.) were used to evaluate depth specific densities of fish targets. Targets measured by the sidelooking transducer were used to estimate fish density within the upper 5–20 m of the water column over a range of 0–40 m from the survey vessel. Target strength frequency histograms were examined for groups of smolts sampled during the release at the boat launch to determine the range of target strengths corresponding to the smolts as seen by the sidelooking transducer. Fish densities were calculated for targets with strengths within the range determined for the smolts (–55 to –43 dB) on the sidelooker. Water depths were too shallow to effectively sample smolts during the release with the downlooking transducer. Therefore, we used the average fork length of test released coho salmon smolts in 2013 (data were unavailable for 2014) to determine the likely range of target strengths expected on the downlooking transducer based on the fish length-to-target strength relation of Love (1977). The average fork length of test released Coho in 2013 was 127 mm ( $n=663$ , ranged 84–178 mm,  $SD=10.3$  mm), so densities were calculated for targets with strengths equivalent of 75–175 mm total length fish (–42 to –49 dB). Echograms from both the sidelooking and downlooking transducers were visually examined for aggregations of smolt-sized targets, especially within the vicinity of the forebay.

Without real-time direct fish sampling during these hydroacoustic surveys to ground truth observed fish targets, or telemetry data from individually tracked coho salmon smolts, the interpretation of these data were limited to only qualitative descriptions of how smolt-sized fish targets are distributed in the reservoir across time and space. Any noticeable increase in the density of smolt-sized targets within different regions or depths after their release would only be suggestive that coho salmon smolts are occupying or moving through those areas.

## Results and Discussion

By combining empirical field data in both stream and reservoir habitat, our results illustrate clear patterns of relatively rapid movement within the reservoir environment, high reservoir survival, but generally low collection efficiencies of juvenile anadromous salmon and steelhead at the FSC. We consider our results in the context of previous studies in the Pacific Northwest and potential limitations of our results.



## Stream Habitat

*Wild coho salmon juveniles.*—Our sampling intensity varied across years to achieve different project objectives. During 2013 and 2014, we sampled primarily in late August and early September, but in 2015 we sampled all reaches in mid-summer (July) and in late September and early October to provide additional recapture information for growth and survival. During 2013, we sampled a total of 20 reaches on Clear Creek for a total of 5.42 km, and in 2014, we sampled 17 reaches totaling 4.65 km. During 2015, we sampled a similar number of reaches and length of stream that were collected in 2014 but with two sampling collections, our sample length of stream was doubled (9.3 km). Within the sample reaches, we PIT-tagged 357 individual coho salmon in 2013, 883 individuals in 2014, and 780 individuals in 2015. Thus, with double effort in 2015, catch rate for wild coho salmon was roughly half those observed in 2014.

The average size of wild coho salmon captured differed across years and seasons. The average size of coho salmon captured in 2013 (average=88.5 mm; standard deviation [SD]=8.3) was nearly 10 mm larger than fish captured in 2014 (average=79.6 mm; SD=8.1; fig. D5). The different timing of sampling during 2015 (that is, July and late September) led to shifts in size of sampled coho salmon, as fish captured during July (78.2 mm, SD=11.8) were smaller than those fish captured during late September (average=85.1, SD=13.0). The number of coho salmon captured by reach varied considerably within and across years, and juvenile coho salmon were captured as high as 7.0 km upstream from the confluence with the Muddy River (fig. D6).

*Wild coho salmon outmigration patterns.*—An important part of the reintroduction of coho salmon is to understand the diversity and overall patterns of outmigration and rearing. Through December 31, 2015, antenna recapture data suggest considerable differences in migration of wild coho salmon across years. In 2013, most marked fish emigrated during September (fig. D7), which coincided with a large precipitation event. On the contrary, fish marked in 2014 demonstrated diffused outmigration throughout much of the winter with the peak outmigration during April–June 2015. Across years, however, our results are generally similar to previous studies (Bennett and others, 2011; Pess and others, 2011) as we found the largest numbers of fish emigrating during the fall and late spring (figs. D6, D7). Overall, the two-season outmigration pattern and differences across years suggests use of screw trap methods to monitor outmigration should consider sampling during both spring and fall.

Across both years, most fish emigrating in early fall were marked in the downstream reaches (fig. D8). Nearly identical to Pess and others, (2011), we found no outmigration from mid-May (year day 140) through early August (year day 212; fig. D8), perhaps a result of low streamflow patterns typical during this period and avoidance of shallow riffle habitat. Coho salmon emigrating during the period of October 1 through May displayed a wider range of location of origin (that is, tagging). In contrast to Pess and others (2011), however, we observed no clear trends in outmigration date when considering coho salmon size (not shown).

Considering individual PIT-tag data and PIT-tag antenna, and screw trap data along with the FSC data provides insight into the rearing behavior of juvenile coho salmon in the upper Lewis River. Individual marking data in Clear Creek suggest coho salmon reside in Swift Reservoir for nearly 4 months, with the median number of days between emigrating from Clear Creek and collecting at the FSC as 121 days (range=21–347 days). These outmigration patterns are substantially longer than patterns observed for coho salmon PIT-tagged at the Eagle Cliff Screw Trap (median reservoir travel time=37 days, range=8–391). The observed differences in reservoir rearing are largely driven by the variability in the timing of outmigration from Clear Creek, as fish emigrate throughout much of the year, and the sampling duration of screw trap information (spring and early summer).

We find general consistent patterns of timing of juvenile coho salmon to the FSC across data sources. The majority (93 percent) of wild (fig. D9A) and hatchery-reared (fig. D9B) coho salmon PIT-tagged in Clear Creek and collected at the FSC have occurred during the spring (April 15–June 30). This timing of outmigration to the collector is consistent with total counts of coho salmon smolts at the FSC (fig. D10) and from individuals marked at the Eagle Creek screw trap (2013–2014; fig. D11). The predominant outmigration through spring is consistent with coho salmon outmigration patterns elsewhere in the Pacific Northwest (Miller and Sadro 2003; Pess and others, 2011; Rebenack and others, 2015).

Collection rates at the FSC of juvenile coho salmon have been relatively low (see “Review of Information Relevant to Anadromous Fish Reintroduction to and Fish Passage in the Lewis River, Washington,” chap. A of this report) across all data sources. Overall, relatively few (3.4 percent) of the PIT-tagged wild coho salmon (2,020 individuals; 2013–2015) from Clear Creek have reached the FSC through December 31, 2015. However, the percent of coho salmon PIT-tagged at a rotary screw trap (Eagle Cliff; latitude 46.0654, longitude -122.01998, in decimal degrees) that were successfully collected at the FSC during 2014 and 2015 was considerably higher (15.2 percent; table D3). Such differences are likely a result of the timing of marking, as fish in Clear Creek are marked during late September, while fish marked at the Eagle Cliff screw trap occurred during late spring, nearly 7 months later. The timing of sampling coupled with overwinter survival rates, which can be less than 50 percent (Ford and Lonzarich, 2000), likely explain the different collection rates at the FSC.

*Juvenile coho salmon survival.*—Initial estimates of coho salmon survival from mark-recapture analysis (2013 and 2014 data only) suggest apparent survival is high ( $\Phi=0.54$ , 0.48–0.61). The high summer and early fall survival is consistent with recent apparent survival estimates (Brakensiek and Hankin, 2007). However, we were unable to delineate time periods (Clear Creek survival compared to reservoir survival) at the time of this report because of data limitations. Updated apparent survival estimates will be possible after fish marked in 2015 have emigrated.

*Acclimation Chinook salmon and coho salmon.*—Outmigration patterns for spring Chinook salmon include a relatively rapid downstream movement from release sites and a reservoir rearing period found to be longer and more variable than observed for coho salmon. As outlined in “Studies Assessing Adult Potential for Spawning Success in Yale Lake and Lake Merwin, Washington,” chap. C of this report, the majority (60 percent) of acclimation spring Chinook salmon emigrated from Clear Creek within the first 7 days after release and 98 percent within 60 days. For acclimation Chinook salmon released in Clear Creek, we found the median residence time in Swift Reservoir, which we calculated as the time since emigrating from Clear Creek, as 70 days (range=5–320; fig. D12A). However, nearly 30 percent of the spring Chinook salmon resided in Swift Reservoir for more than 170 days (fig. D12B). When considering all PIT-tagged spring Chinook salmon, there has been a bimodal distribution of the total time since release to the FSC with an initial, substantially larger peak at 75 days after release and a second, smaller peak at approximately 9 months after release (fig. D13). The interannual variability in outmigration is not uncommon and may be linked with hydrologic regimes (Romer and others, 2014). The observed rearing times in Swift Reservoir are considerably shorter than found in Willamette Valley reservoirs (Oregon) where spring Chinook salmon appear to spend 5–7 months in reservoir environments (Romer and others, 2014). Such differences, however, are likely driven by size at outmigration into the reservoir environment as spring Chinook salmon in the Willamette Valley reservoirs enter the reservoir at size typically less than 100 mm, which are considerably smaller than the hatchery-reared acclimation spring Chinook salmon in Swift Reservoir (greater than 120 mm). Extended use of reservoir environments for rearing is common in anadromous juveniles (Hegg and others, 2013; Bourret and others, 2014) and can result in pronounced growth. The median days between initial release and collection at the FSC were generally consistent across release locations for 2013 (Clear Creek=67 days, Crab Creek=57 days, Muddy River=75 days; fig. D14), but we observed considerable differences in the median travel time in 2014 for Clear Creek (259 days). Travel times during 2015 were consistent with 2013 for Clear Creek (69 days) and Crab Creek (70 days). The differences in reservoir rearing time are largely driven by fish released in 2014, which demonstrated considerably more variability than releases during 2013 and 2015 (fig. D15).

Overall, the proportion of juvenile salmon collected as the FSC has been relatively low across species and years. Nearly 14 percent of the hatchery-reared juvenile coho salmon released in Clear Creek in 2013 successfully emigrated to the FSC. However, only 1.4 percent (2013), 2 percent (2014), and 1.7 percent (2015) of the acclimation spring Chinook salmon (PIT-tagged) have successfully emigrated to the FSC (fall 2015 release not included). Based on the total number of spring Chinook salmon released in the spring 2014 (45,000), spring 2015 (109,666), and fall 2015 (48,000), we estimate that as of December 31, 2015, 3.7 percent of the acclimation spring Chinook salmon have been collected at the FSC. Although still low, this is markedly higher than inferences from PIT-tags. Given the likely minimal effects of PIT-tagging on large, acclimation smolts (Prentice and others, 1993) and high estimates of reservoir survival (for example, Williams and others, 2001), the discrepancy between estimates of the proportion of salmon collected at the FSC may be due to the increased number of juvenile spring Chinook salmon because of natural recruitment from residualized individuals from previous releases (for example, Romer and Monzyk, 2014; Perales and others, 2015).

*Steelhead outmigration.*—Because of the relatively low numbers of wild steelhead present in Swift Reservoir tributaries, no targeted field studies were conducted to assess outmigration success. However, information from screw trap data suggest median travel time for steelhead juveniles (21 days, range=1–342) was considerably lower than coho salmon (see “Wild coho salmon outmigration patterns” in the “Results and Discussion” section of this chapter). Albeit small sample sizes (table D3), we find a higher proportion of marked steelhead (18.7 percent) than either coho or spring Chinook salmon juveniles, a pattern requiring additional monitoring.

## Reservoir Habitat

Targets identified in hydroacoustic surveys in Yale Lake were predominantly moving downstream after initial release. Smolt-sized targets were found to be using open water (mid-channel) with some skew toward the west bank, the same side as the release. The densities of “smolt-like” targets detected in the surface-oriented sidelooking data and downlooking data were approximately equal.

*Density of smolt-sized targets from sidelooking hydroacoustic surveys.*—We used sidelooking hydroacoustic surveys to estimate fish densities in the upper portions of the water column (Gangl and Whaley, 2004). When compared to the prerelease surveys in Yale Lake, densities of surface-oriented, smolt-sized targets increased in the afternoon following the morning test release of coho salmon smolts on April 8, 2014. Specifically, the densities of smolt-sized targets increased in the lower half of the reservoir (Regions 1–3) along the west bank (fig. D16). Densities also increased by a factor of nine along the middle axis in the region closest to the dam (Region 1) and in the zig-zig transect in the lower quarter of the reservoir by a factor of 13 during daylight and by a factor of 3 at night. Densities on the day after the release increased relative to prerelease densities in Regions 2 and 3 along the west bank. Densities also increased relative to prerelease in the lower quarter zig-zig transects during both daylight and night.

On the day following release, densities of surface-oriented smolt-sized targets were similar or slightly higher than the previous day along the west bank in Regions 3 and 2 but were generally lower in the middle axis and other regions of the west bank with no notable pattern on the east bank (fig. D17). Densities estimated from the zig-zig transect in the lower quarter of the reservoir declined by 68 percent during the daylight survey, and the night zig-zag transect remained at similar levels to the day of the release. Aggregations of smolt-sized targets were observed on hydroacoustic echograms on the day after the release near the boat launch in Region 4 during the daylight survey and the additional dusk survey, although the densities in this area did not increase. Aggregations were also observed near Yale Dam during daylight on the day following the release, with the appearance of higher concentrations along the west shoreline in Region 1, directly in front of Saddle Dam, and directly in front of the spillway (fig. D4). Similar patterns were observed in echograms from nighttime near the dam on the day after the release.

Densities of smolt-sized targets from the sidelooking hydroacoustic surveys largely provide inference for the upper 20 m of the reservoir and suggest relatively rapid downstream movements through Yale Lake. Our results from Yale Lake are consistent with previous efforts in Swift Reservoir, where acoustically tagged coho salmon smolts were detected most commonly in the upper portions of the water column near Swift Dam (PacifiCorp and Cowlitz Public Utility District [PUD], 2004).

*Density of smolt-sized targets from downlooking hydroacoustic surveys.*—In contrast to sidelooking surveys, we employed downlooking hydroacoustic surveys to evaluate fish densities deeper than 20 m (that is, the portion of the water column not effectively sampled during sidelooking surveys). Densities of deeper coho salmon smolt-sized targets detected by the downlooking transducer increased during daylight surveys in the afternoon on the day of the release, compared to the prerelease surveys in different depths and regions. Densities increased from 0 to approximately 0.5 targets/1,000 cubic meters along the east bank in Regions 4 and 5 (fig. D18). We observed an increase of coho salmon smolt-sized targets by a factor of 24 in Region 2 at 50–60 m depths along the west bank. Densities also increased along the middle axis in the region closest to the dam (Region 1) by 210 percent at 20–30 m; 202 percent at 30–40 m; 251 percent at 40–50 m; and by a factor of 6 at 50–60 m. The lower quarter zig-zag transect increased by 134 percent at 30–40 m in the daylight survey, and by 115 percent in the night survey; however, densities in most other depths decreased in the zig-zag transects (fig. D19).

Densities on the day after the release increased relative to the prerelease in Regions 1 and 2 along the middle axis at depths below 30 m, at 10–40 m in Region 3 along the west bank, and at 40–50 m in Region 2 along the east bank (fig. D18). Coho salmon smolt densities also increased at 30–40 m depths in the lower quarter zig-zag transect during daylight (fig. D16).

Densities on the day after the release changed relative to the afternoon and night of the day of release in several regions as well. We observed an increase in densities in Region 3 along the west bank from 0 to 1.3 targets/1,000 cubic meters at 30–40 m, and Region 2 along the west bank increased by a factor of 4 at 30–40 m (fig. D18). We observed a 135 percent increase at 30–40 m in Region 1 along the middle axis, as well as a 145 percent increase at 40–50 m in this area. The lower quarter zig-zag transects during daylight increased by 153 percent at 20–30 m, 127 percent at 30–40 m, and 184 percent at 50–60 m (fig. D19). In contrast, densities decreased by approximately 50 percent in most depths in the lower quarter zig-zag transects at night. Visual observation of aggregations of smolt-sized targets detected in Region 4 near the boat launch and increases in densities in Regions 4 and 5 along the east bank suggest that a portion of the smolts remained in the upper reservoir until at least the day following the release.

The results from monitoring Yale Lake indicate that coho salmon smolts have a relatively short migration time through the reservoir, a pattern similar to previous studies (PacifiCorp and Cowlitz PUD, 2001). The increase in densities of smolt-sized targets in lower regions on the day of the release suggests that smolts were capable of transiting the lower half of Yale Lake in less than a day. A portion of the test release smolts likely moved down reservoir along the west bank (the bank where they were released) immediately upon release, based on the increased densities of smolt-sized targets. It appears many smolts were able to reach the dam and distributed to the middle axis in Region 1 and the east bank in Region 2 within 12 hours of being released. Further increases in densities along the west bank and lower reservoir regions on the day following the release suggest that smolts continued to migrate down the reservoir. Smolts appeared to migrate to the lower quarter of the reservoir where they were detected on the sidelooker in both postrelease surveys during night.

The findings of this study (approximately 7 km per day) are consistent with the results of radio telemetry tracking of coho salmon smolts in Swift Reservoir, which found that more than half of tagged fish released in the upper reservoir were detected at the dam within 4 days, and the greatest number of detections by time interval was for the period of 1–2 days after release (5.2 km per day [PacifiCorp and Cowlitz PUD, 2001]). However, we acknowledge that migration rates can vary across species and reservoirs with minimal river effect (Miller and others, 2004). Most detections in mobile surveys were along the shore where they were released, generally near river inlets, in coves, and near woody debris.

Detections on the antenna array at Swift Dam revealed that virtually all smolts approached the intake structure in the upper 13.8 m of the water column, typically from the north side at first and then resided on the south side (PacifiCorp and Cowlitz PUD, 2001). However, the depth of reservoir used by juvenile Chinook salmon can vary considerably by season based on thermal regimes (Beeman and Maule, 2006; Kock and others, 2015; Beeman and others, 2016), suggesting the need to integrate information on the outmigration timing through Swift Reservoir. Results from telemetry of Chinook salmon smolts revealed that they also approached the intake in the upper 13.8 m of the water column, with a mean travel time of 5.5 days from release at

Eagle Cliff Park to detection at the project intake (PacifiCorp and Cowlitz PUD, 2002). These results indicate that the densities observed by the sidelooking transducer may be more important for identifying smolt distribution than densities observed by the downlooking transducer.

We acknowledge several limitations to the hydroacoustic survey analyses. Several environmental conditions potentially biased our results or limited our ability to interpret results within the context of smolt movement through the reservoir. The prerelease survey along the middle axis in Regions 3–5 represented crepuscular fish densities, whereas the postrelease surveys represent daylight densities, making direct comparison difficult. The propensity of kokanee salmon to migrate vertically across the diel sequence likely added some variability into our results, particularly during dusk and night periods, which could have masked the signal of the relatively small release of 5,000 test smolts. Furthermore, noise from wind and rain, as well as the tops of standing timber masked the signal of fish targets for portions of the sidelooking data.

Despite these limitations, our results are consistent with other studies indicating use of relatively shallow habitats in reservoirs (Durkin and others, 1970; Dilley, 1994). Concomitantly, our data from hydroacoustic surveys in Yale Lake with coho salmon, findings from previous radiotelemetry studies with Chinook salmon in Swift Reservoir (PacifiCorp and Cowlitz PUD, 2002), and other studies (for example, Aitken and others, 1996) suggest reservoir travel times to be relatively rapid. Furthermore, we have consistently found considerably longer residence times for wild coho salmon and acclimation spring Chinook salmon in the Swift Reservoir than observed in test releases. Indeed, recent studies in Swift Reservoir (PacifiCorp and Cowlitz PUD, 2017) illustrated that a large portion of test-tagged juvenile salmon emigrated within 150 m of the zone of influence of the FSC but that most fish were not collected resulting in low collection efficiencies. Synthesizing our data with these previous studies suggest difficulties of fish “finding” the FSC, a pattern supported by studies elsewhere (Beeman and others, 2016).

We also acknowledge that collection efficiencies may be affected by summer thermal regimes within the reservoir. During the summer months, epilimnetic temperatures in Swift Reservoir can exceed 18 degrees Celsius. The effect of temperature on juvenile salmon behavior (Tiffan and others, 2009) and collection in trap and haul operations (Beeman and others, 2016) suggest temperatures during July through early September in Swift Reservoir may act as a thermal barrier during these months. However, the relative short duration of warm surface temperatures is unlikely to disproportionately explain the low collection rates of juvenile salmon in Swift Reservoir. Together, these results highlight the need to consider alternative measures to enhance collection at the FSC, particularly as delays in capture at the FSC may affect juvenile mortality (for example, Buchanan and others, 2009) and the lack of understanding of the effects of residualized populations of coho salmon and Chinook salmon on recovery efforts (Romer and Monzyk, 2014).

## Conclusions

Together, our results suggest outmigration success appears to be limited by collection at the FSC. A critical next step in enhancing the reintroduction success will be to identify those factors affecting delays and overall capture rates of outmigrating juvenile salmon and steelhead. Such information may be particularly important as the proportion of juvenile fish collected at the FSC (across species and data sources-PIT-tags, screw trap, and so on) is generally low when compared to data from similar trap and haul operations (see “Review of Information Relevant to Anadromous Fish Reintroduction to and Fish Passage in the Lewis River, Washington,” chap. A of this report). Furthermore, low proportions of juvenile salmon collected at the FSC are likely to have profound effects on community interactions and the overall capacity to support rearing in the reservoir environment (see “Studies Assessing Adult Potential for Spawning Success in Yale Lake and Lake Merwin, Washington,” chap. C of this report).

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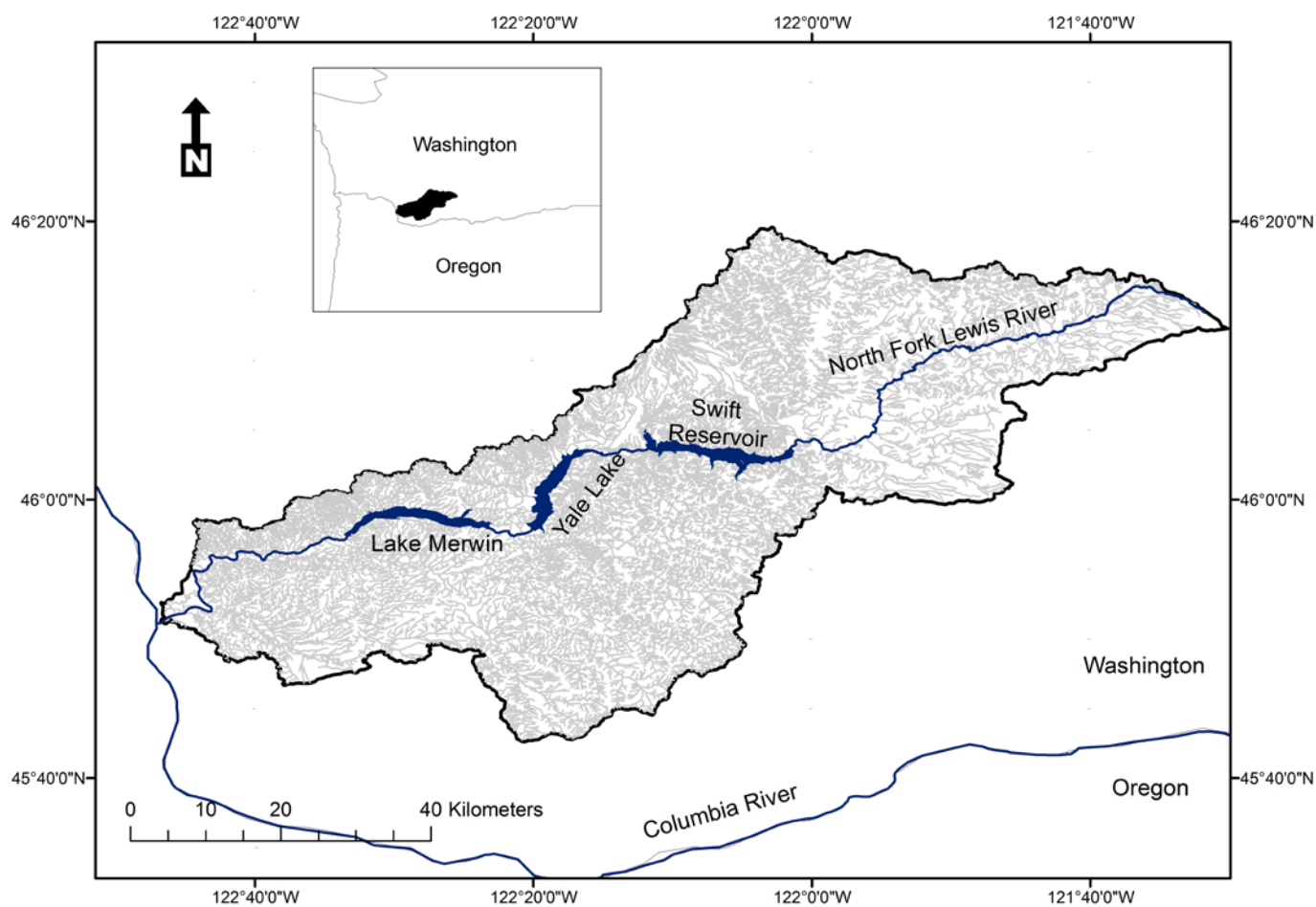
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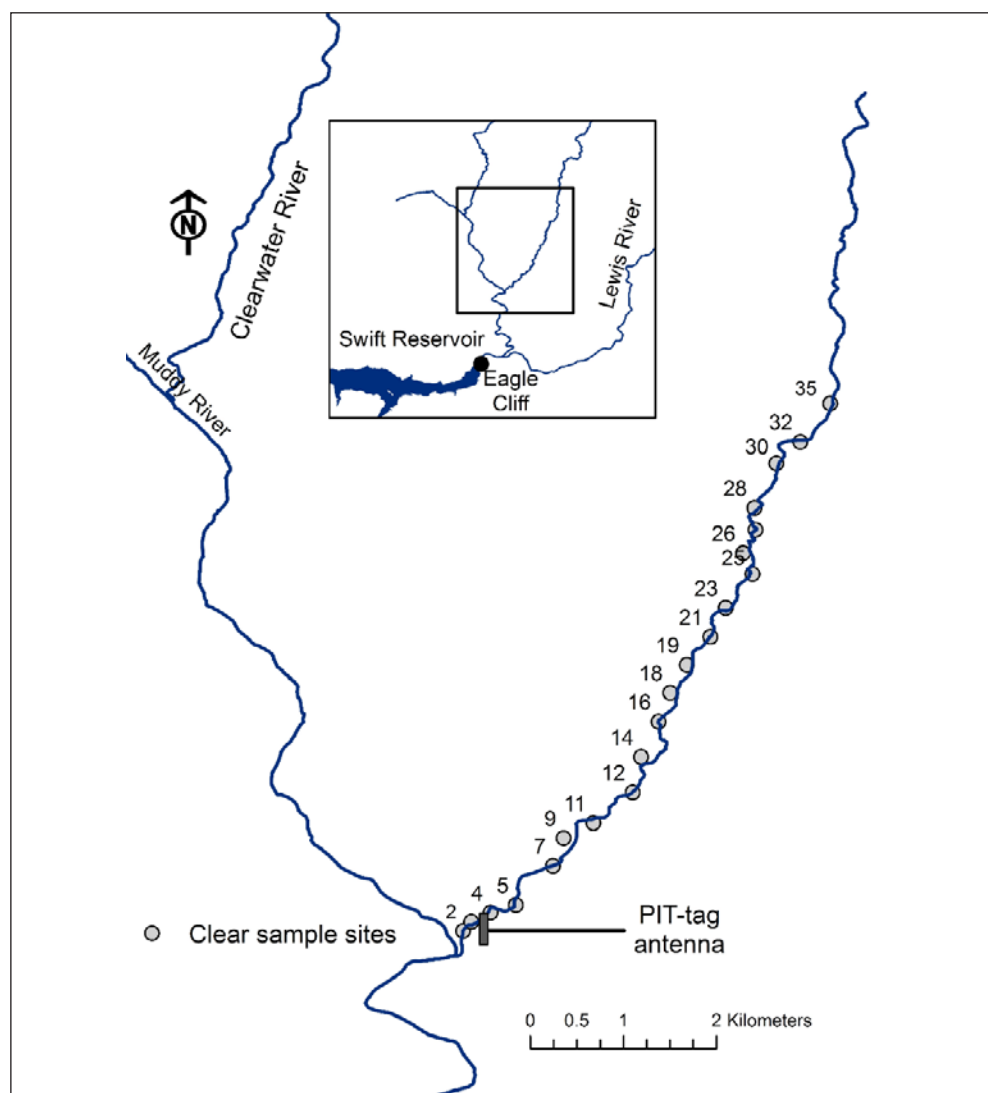
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## Figures

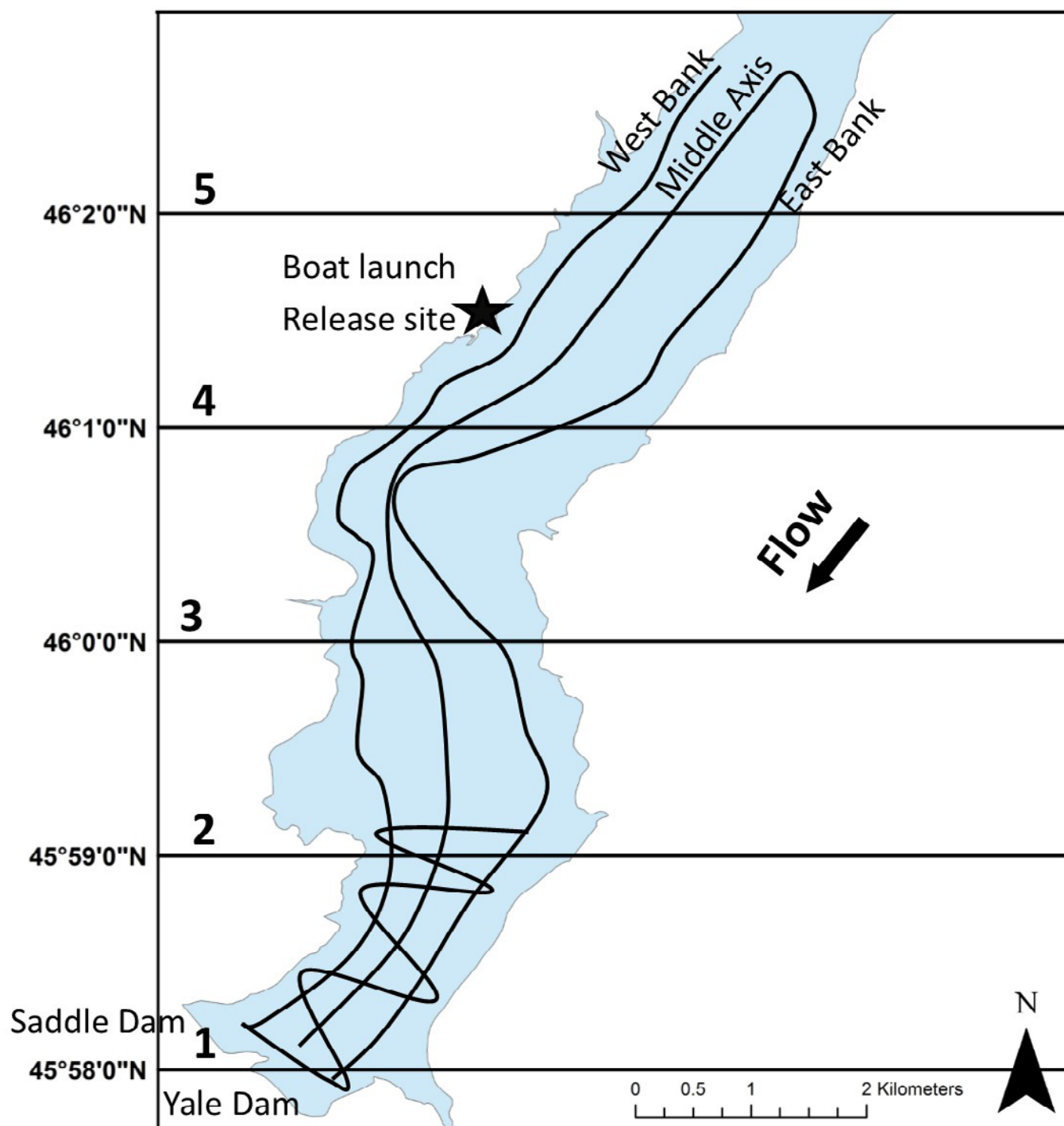


**Figure D1.** Study area map. The North Fork of the Lewis River and the three hydropower impoundments: Lake Merwin, Yale Lake, and Swift Reservoir in the Lewis River Basin, Washington.

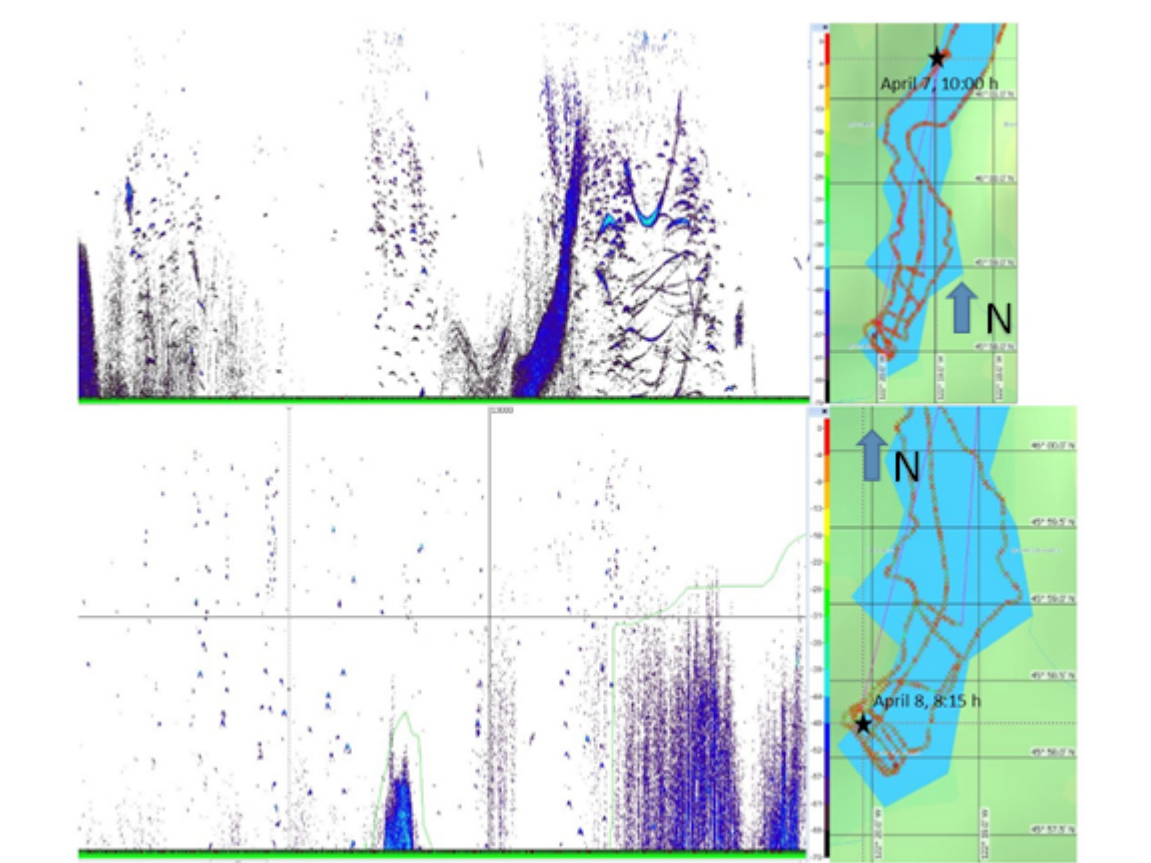




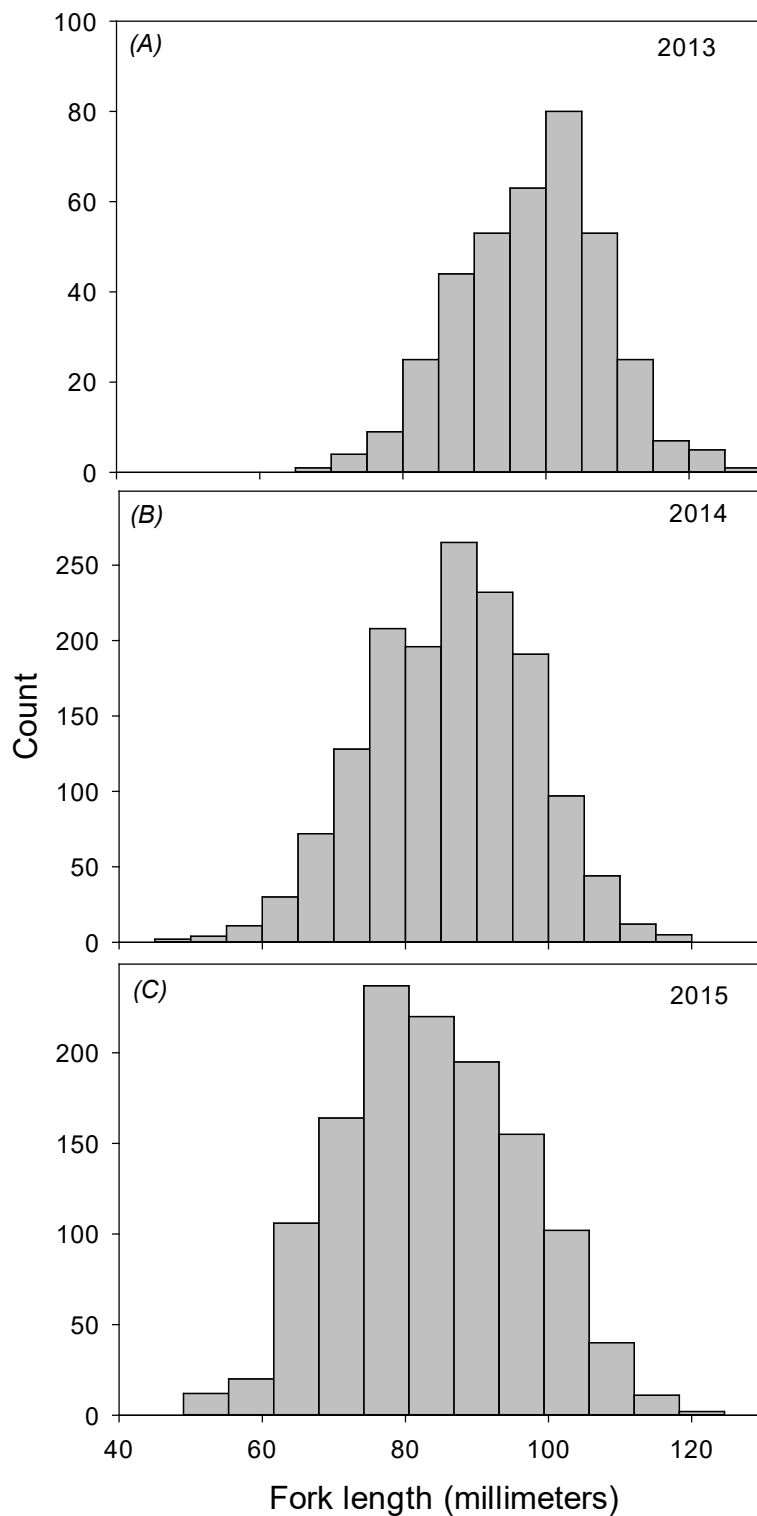
**Figure D2.** Sample reaches (light gray circles) used in the systematic sampling design for passive integrated transponder (PIT)-tagging coho salmon in Clear Creek (2013–2015) with location of the PIT-tag antenna (gray box). Inset map shows the location of the sampling area in relation to Swift Reservoir, Washington, and the location of Eagle Cliff where the rotary screw trap was operated (black circle).



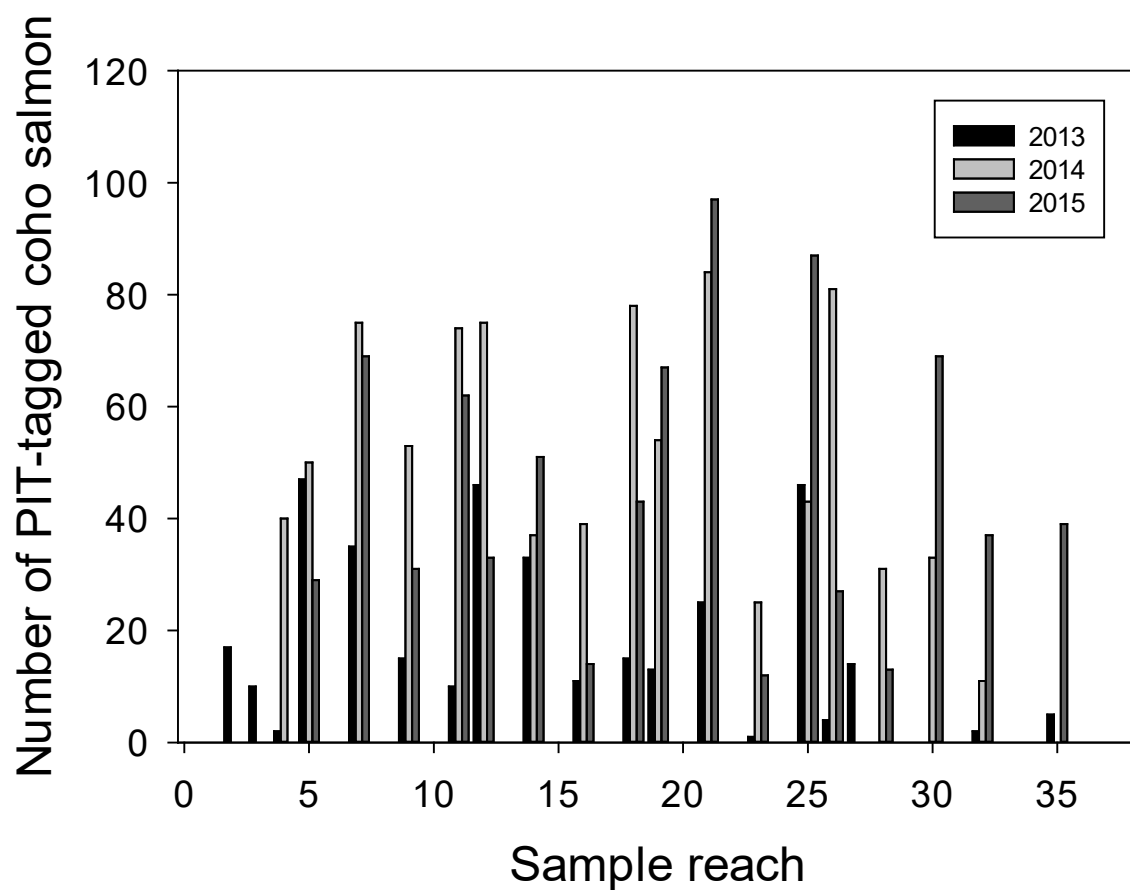
**Figure D3.** Yale Lake, Washington, with labeled regions that were used to evaluate densities of coho salmon smolt-sized targets in hydroacoustic surveys (black lines) and the release location of smolts (star; Yale Park). Region 1 contained all parts of the reservoir below 45° 59'N. Hydroacoustic survey transects were replicated for the prerelease, day of release, and day after release surveys.



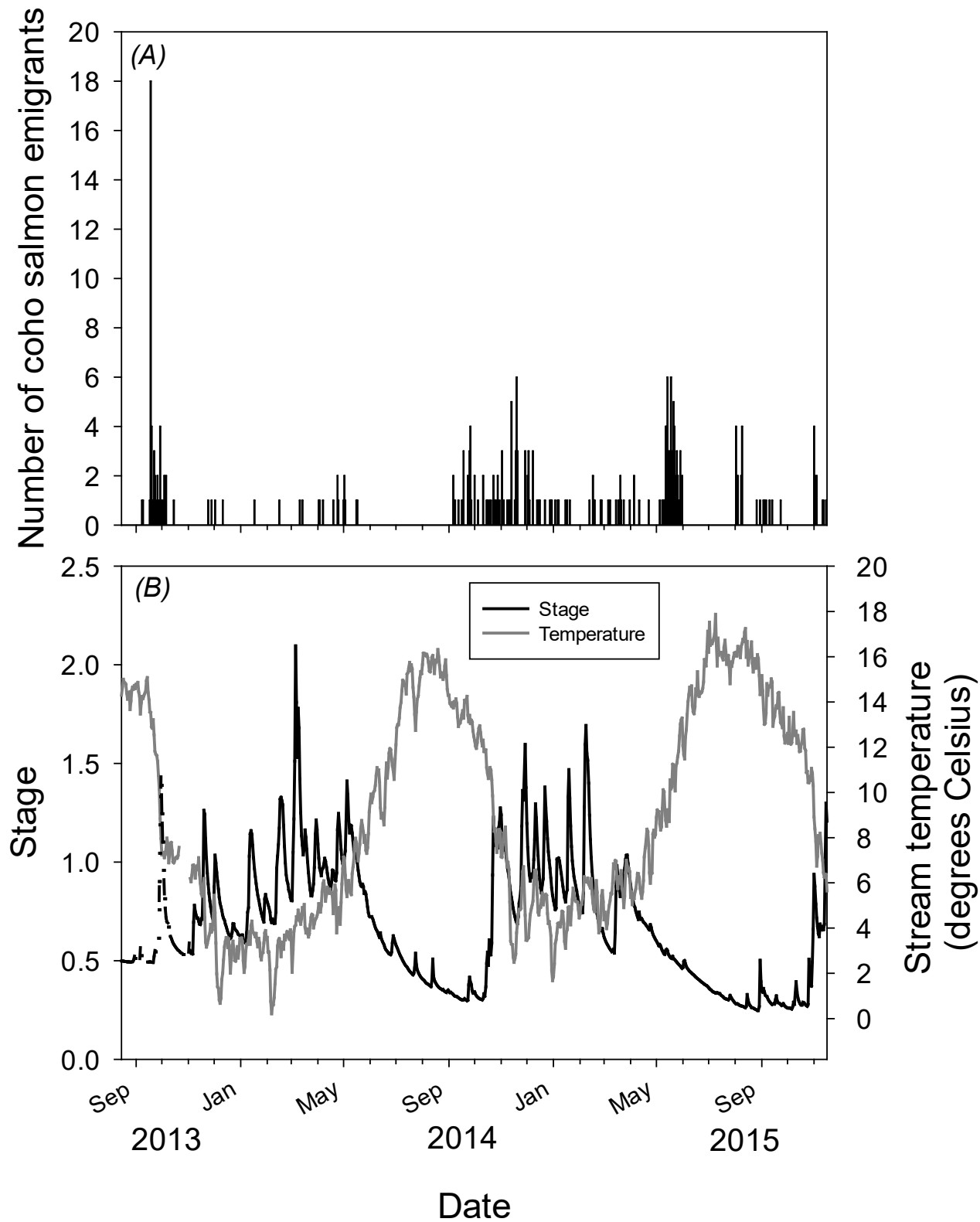
**Figure D4.** Echograms from the sidelooking transducer showing smolt-sized targets in Yale Lake, Washington. Top panel shows the boat launch while fish were being released, and the bottom panel shows an aggregation of smolt-sized targets seen along the west side of Yale Dam in a zig-zag transect.



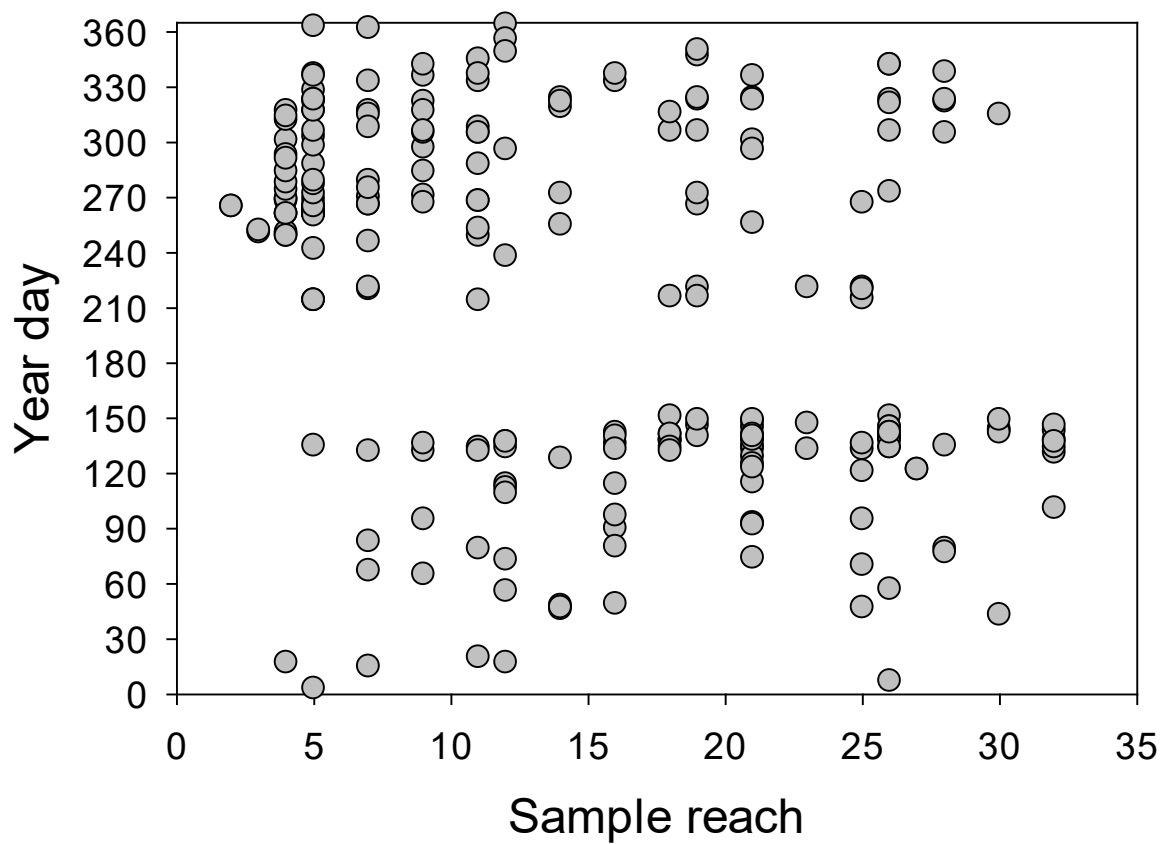
**Figure D5.** Length frequency of coho salmon captured in Clear Creek, Washington, during surveys in *A*, 2013, *B*, 2014, and *C*, 2015 (combined sampling from summer and fall surveys).



**Figure D6.** The number of passive integrated transponder (PIT)-tagged coho salmon by reach in 2013 (black), 2014 (light gray), and 2015 (dark gray). Refer to fig. D2 for location of sample sites, but sites progress from downstream to upstream (left to right).

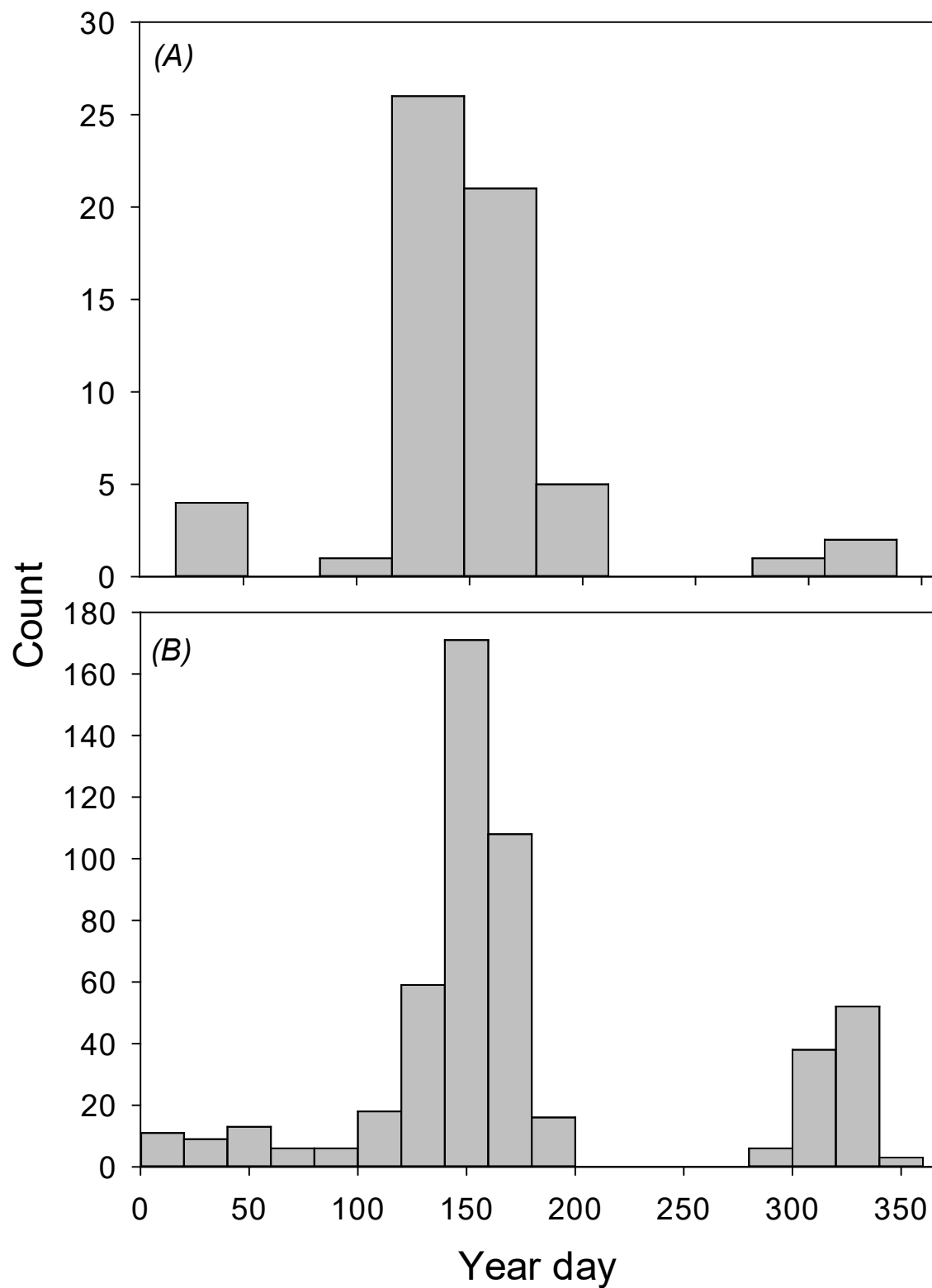


**Figure D7.** A, Outmigration timing of passive integrated transponder (PIT)-tagged wild coho salmon downstream past the fixed antennas on Clear Creek, Washington. B, Average daily hydrologic stage (black line) and stream temperature at the Clear Creek antennas (2013–2015). Note: the dashed line is estimated from correlations with the Muddy River U.S. Geological Survey gaging station as the pressure transducer in Clear Creek was not initially operational.

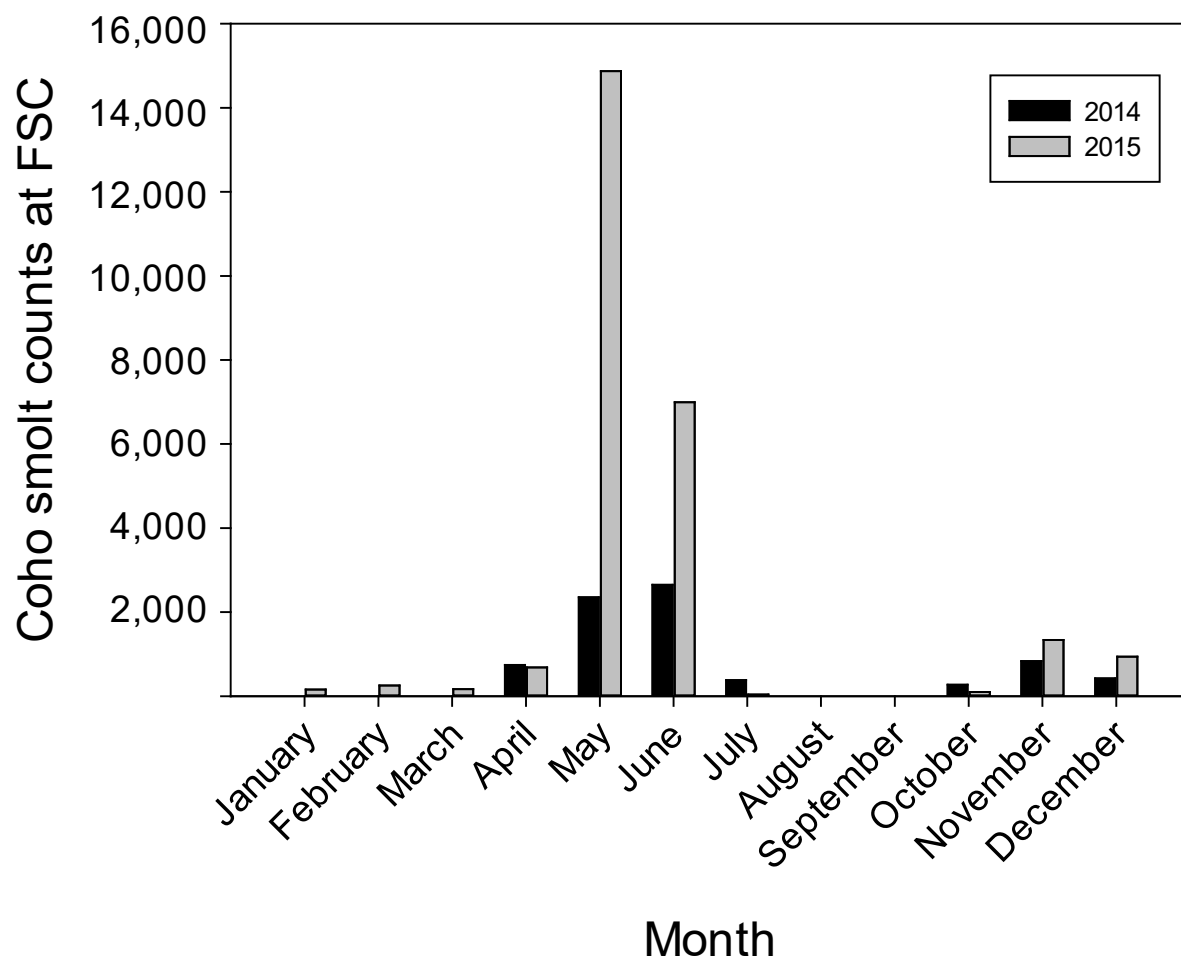


**Figure D8.** Julian day of outmigration (1=January 1, 365=December 31) past the fixed passive integrated transponder (PIT)-tag antenna for wild coho salmon marked with PIT-tags in different sampling reaches. Note the increasing reach number corresponds to distance from river mouth (see fig. D2).

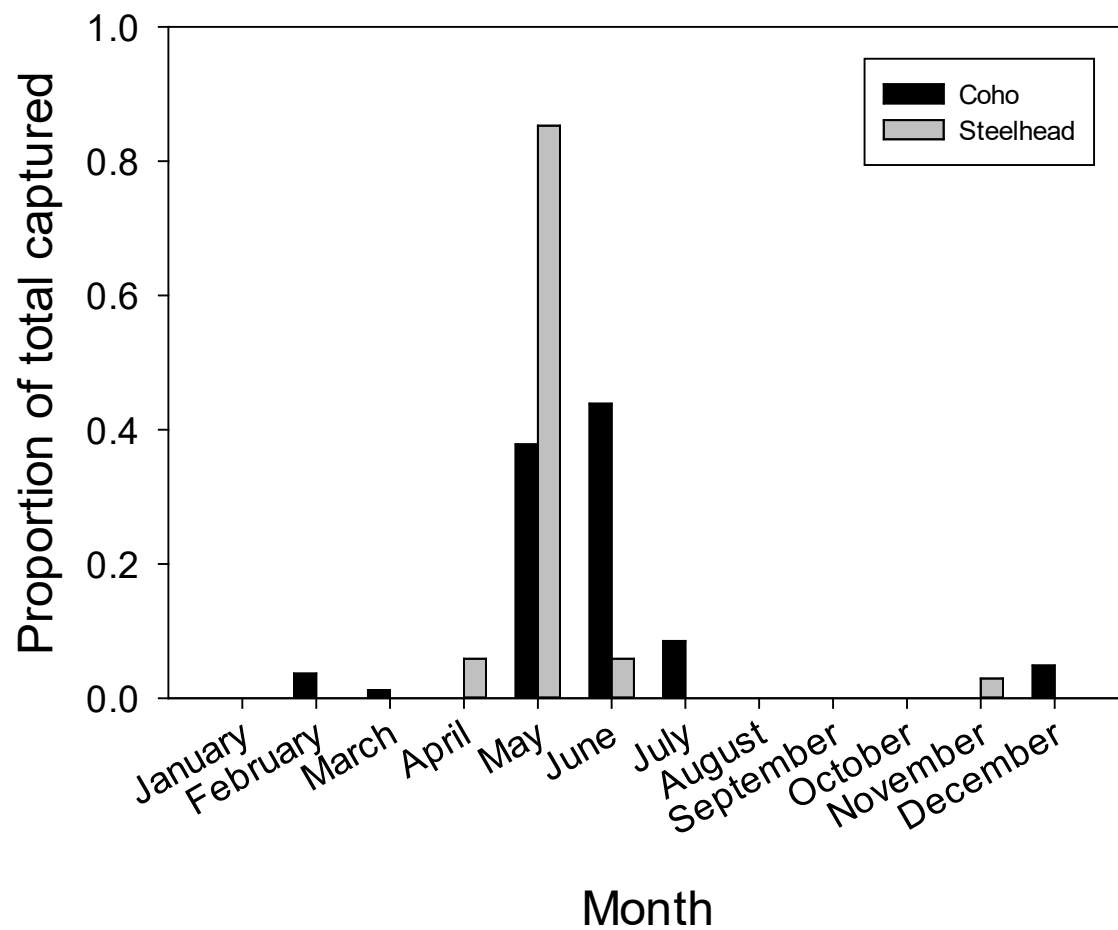




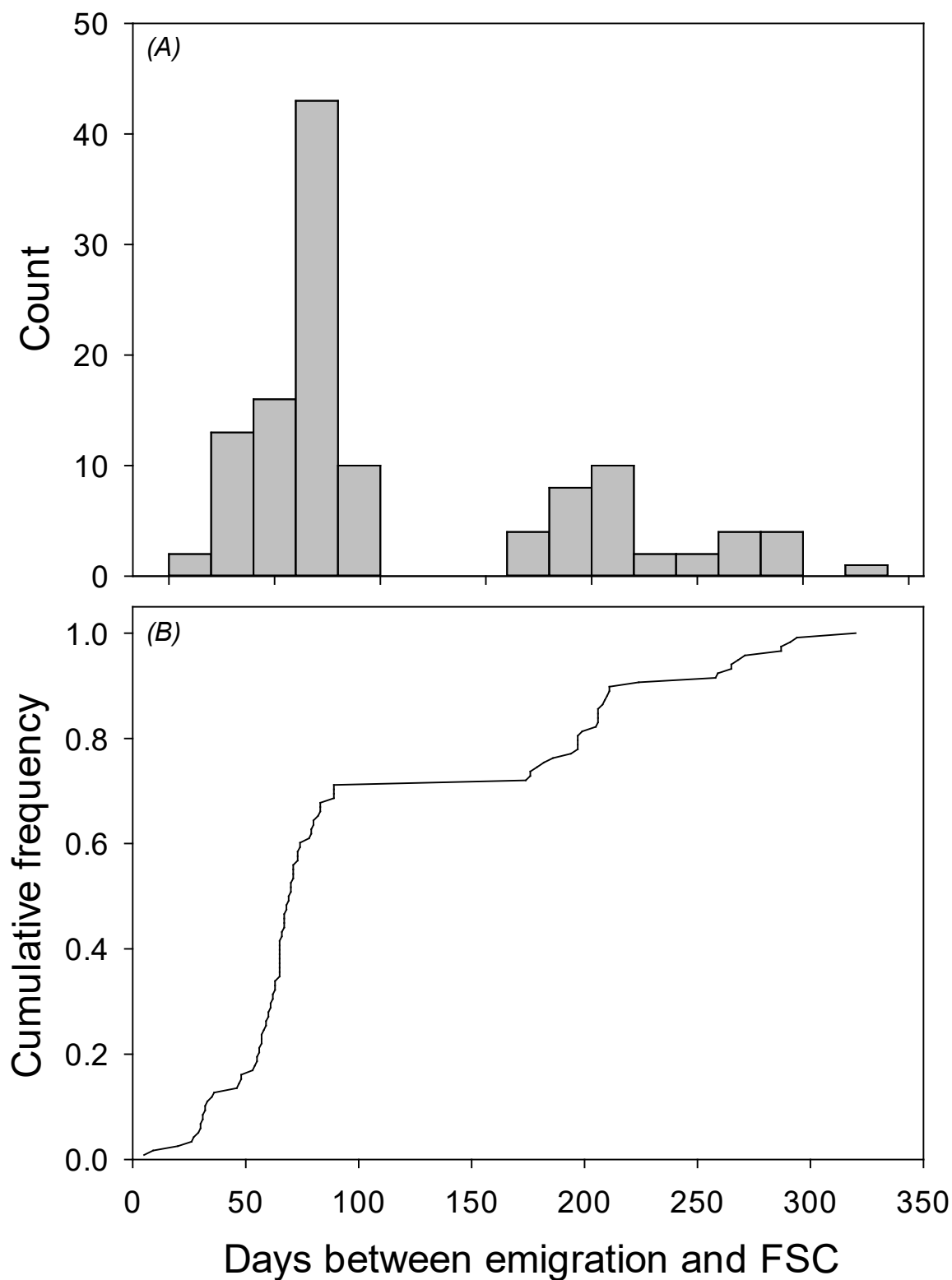
**Figure D9.** Year day that *A*, passive integrated transponder-tagged individual wild coho salmon (2013–2015) and *B*, hatchery-reared coho salmon (2013 only) juveniles were collected at the floating surface collector in Swift Reservoir, Washington.



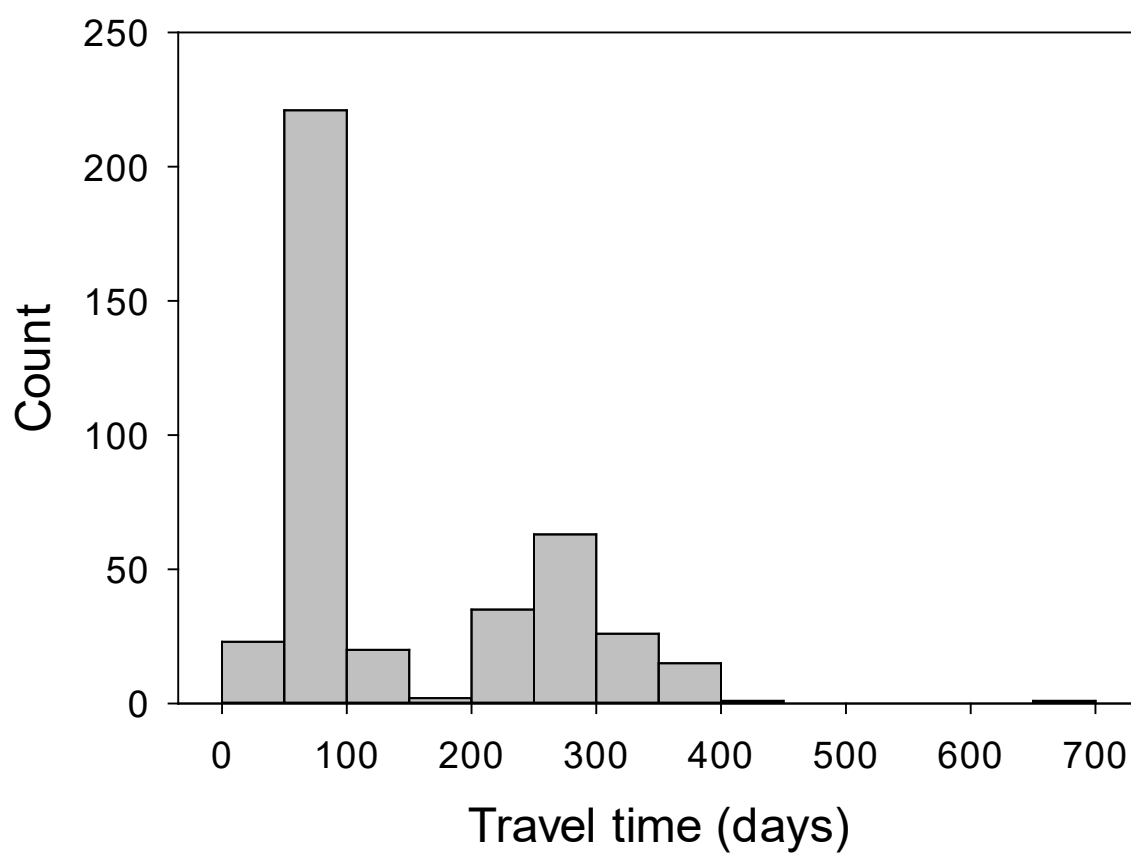
**Figure D10.** Total coho salmon smolt counts by month for 2014 (black) and 2015 (gray) at the floating surface collector (FSC) in Swift Reservoir, Lewis River, Washington.



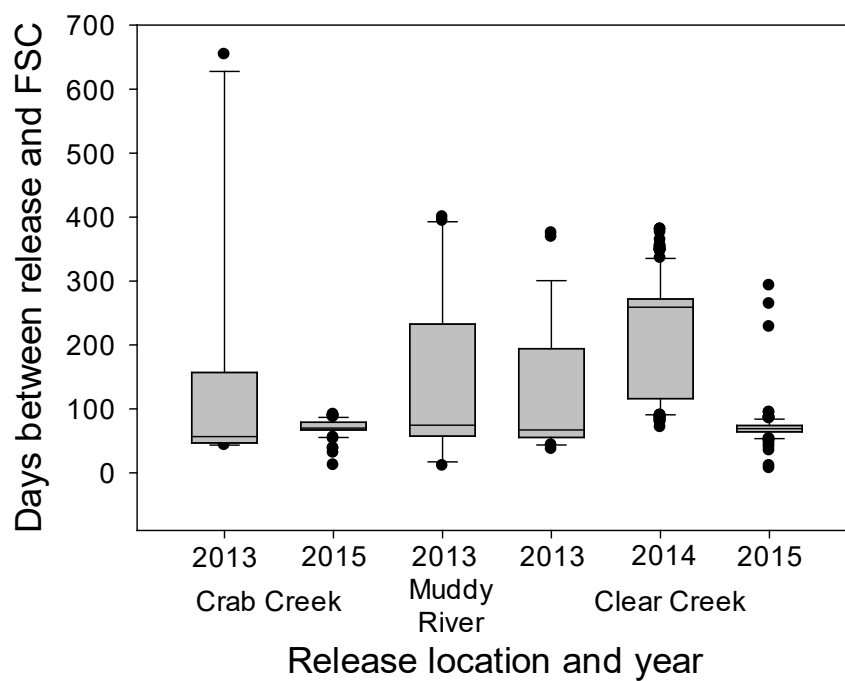
**Figure D11.** Proportion of coho salmon (black) and steelhead (gray) passive integrated transponder-tagged at the Eagle Cliff Screw trap collected at the floating surface collector by month.



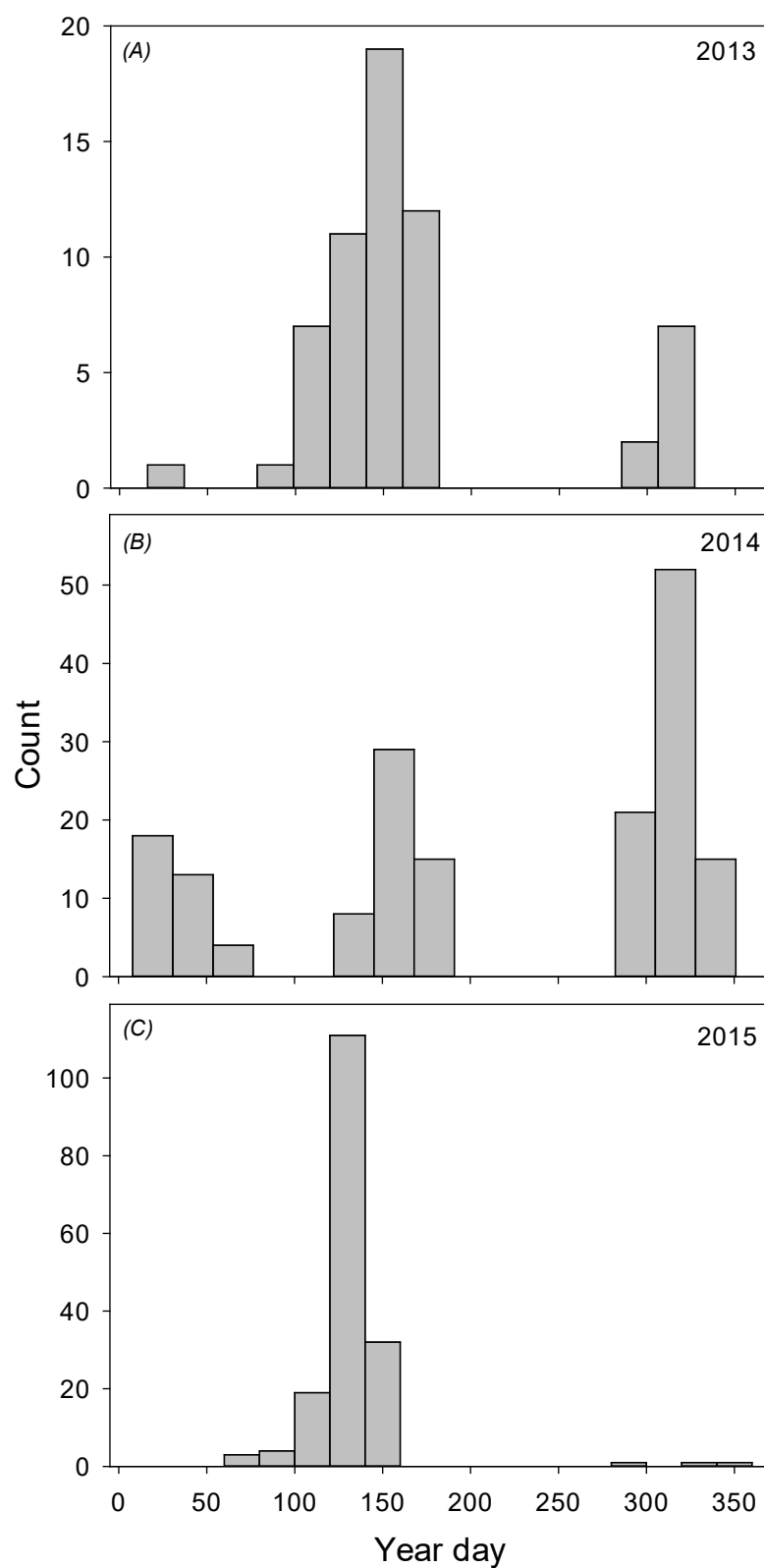
**Figure D12.** A frequency distribution *A*, and a cumulative frequency *B*, of the number of days passive integrated transponder (PIT)-tagged spring Chinook salmon (acclimation) spent between outmigration past the fixed PIT-tag antenna on Clear Creek (likely in Swift Reservoir) and collection at the floating surface collector (FSC) in Swift Reservoir, Washington (2013–2015).



**Figure D13.** Total travel time for acclimation spring Chinook salmon (passive integrated transponder-tagged) from release in tributaries (Crab Creek, Muddy River, Clear Creek) to the floating surface collector in Swift Reservoir, Washington (2013–2015).

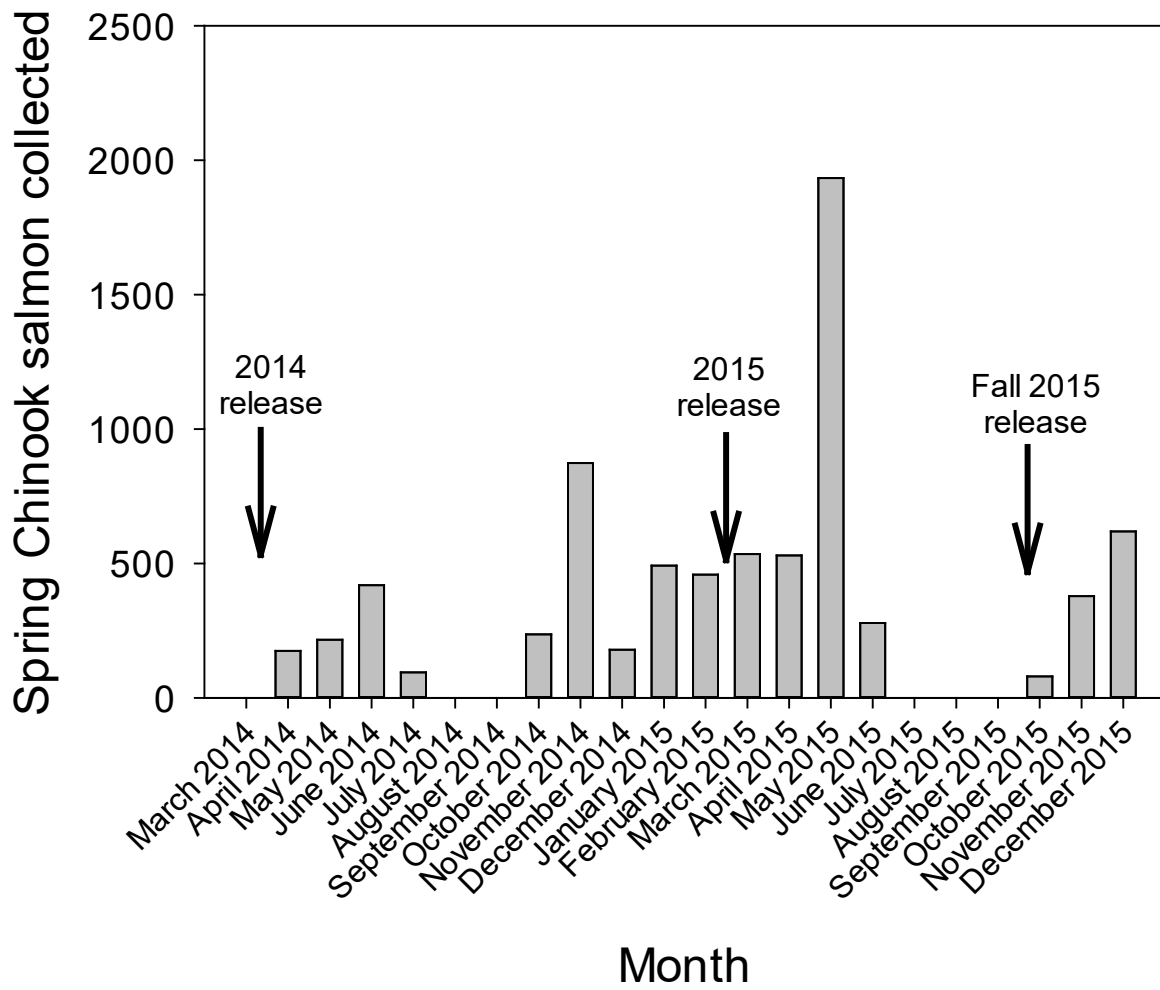


**Figure D14.** Total number of days between release and collection at the floating surface collector (FSC) in Swift Reservoir for acclimation spring Chinook salmon (passive integrated transponder-tagged only) across different release locations and years. Note: multiple years of releases were only available for Clear Creek and Crab Creek, Washington, and the 2015 data are incomplete.

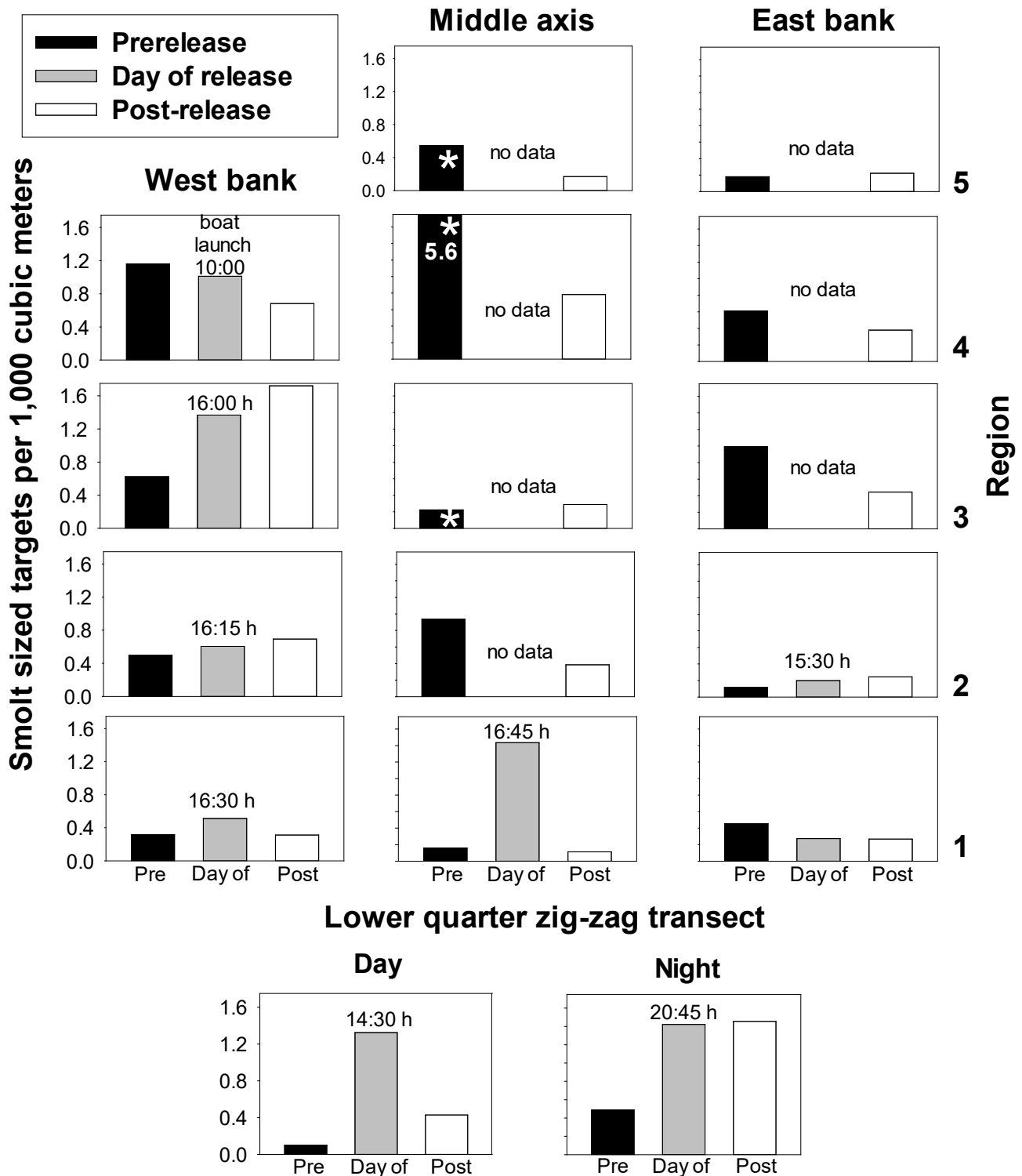


**Figure D15.** Year day that acclimation spring Chinook salmon released in *A*, 2013, *B*, 2014, and *C*, 2015 were captured at the floating surface collector in Swift Reservoir, Washington.

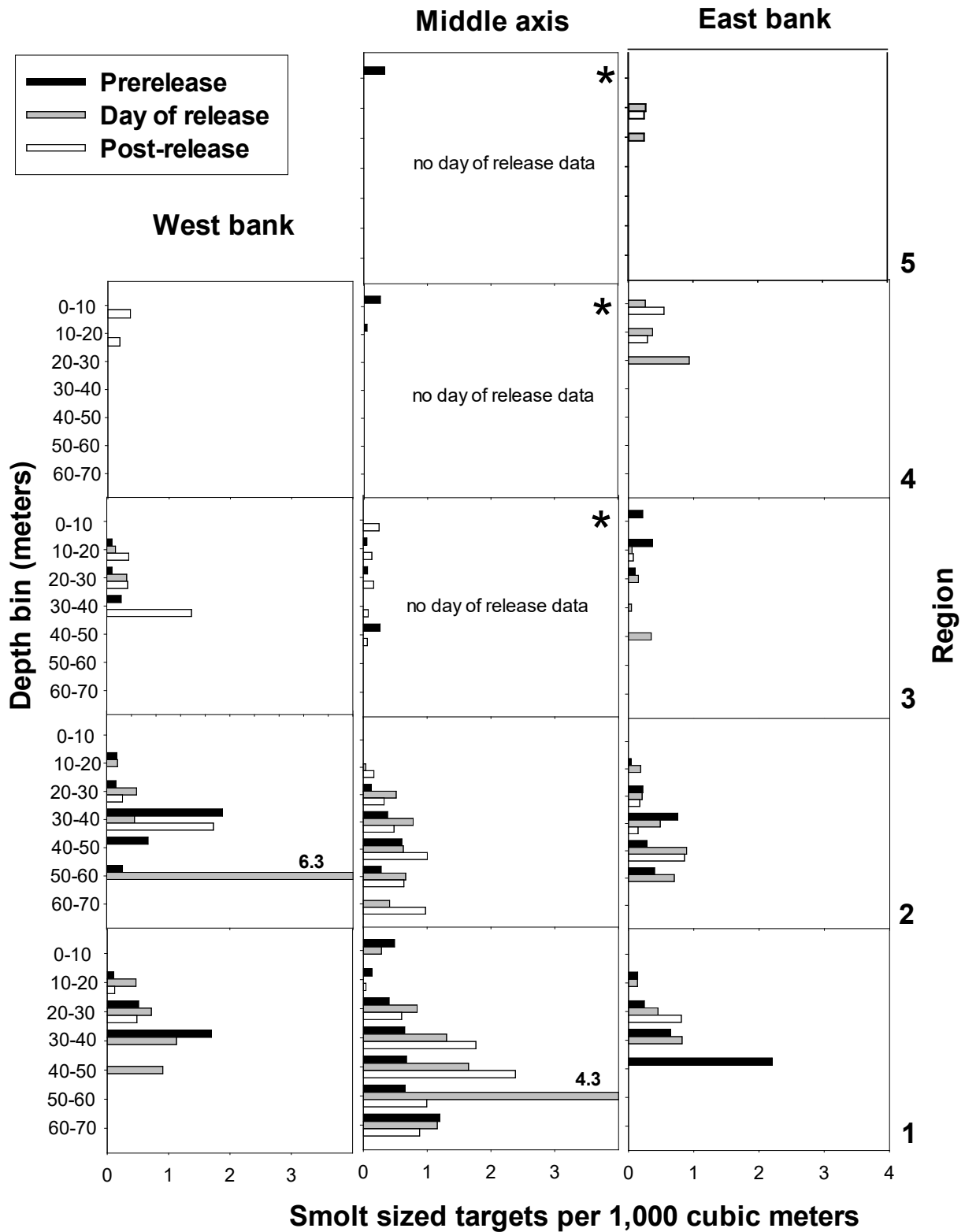




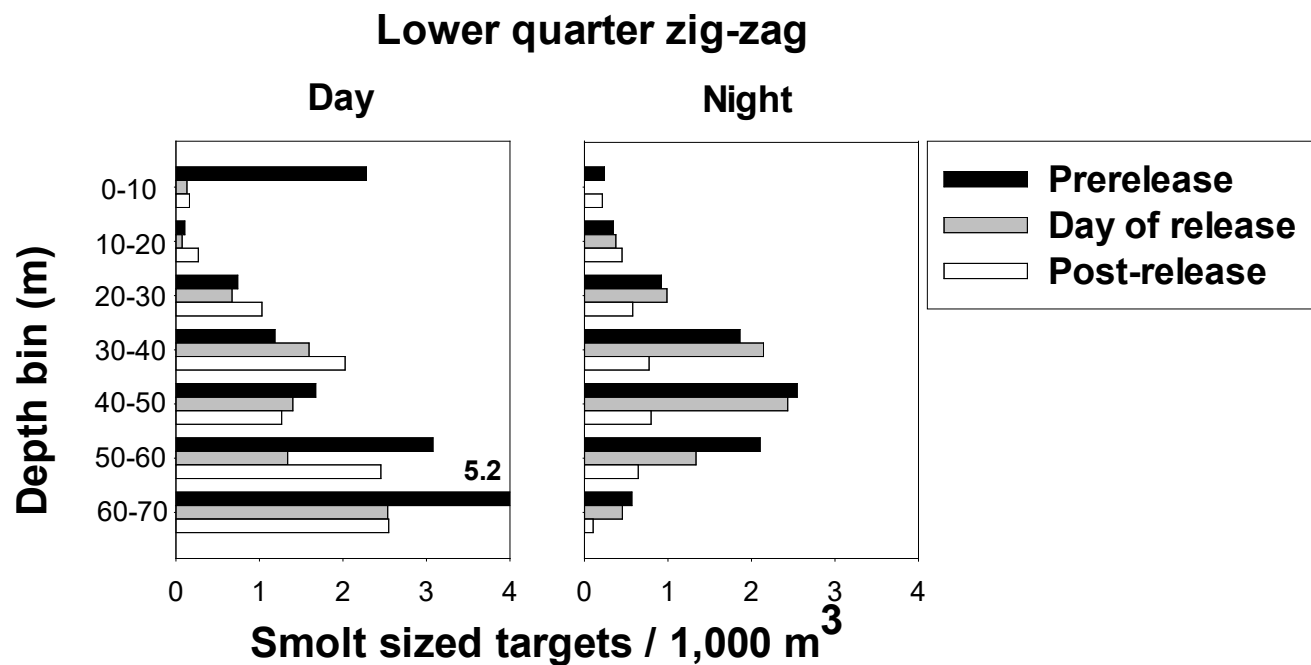
**Figure D16.** The total number of spring Chinook salmon collected at the floating surface collector in Swift Reservoir, Washington, from a 2014 spring release (45,000 individuals), 2015 spring release (109,666 individuals), and a fall 2015 release (48,000 individuals).



**Figure D17.** Coho salmon smolt sized targets per 1,000 cubic meters ( $m^3$ ) observed by the sidelooking transducer in Yale Lake, Washington, prerelease (pre), the day of release (day of), and postrelease (post) of 5,000 test smolts. Panels are arranged in columns from west (left), mid-axis (center) and east (right) transects (labeled on top), and rows based on upper to lower regions in the reservoir (Region 1 closest to the dam). The lower quarter zig-zag transect panels represent densities estimated from a series of zig-zag transects within the lower quarter of the reservoir. Bars with an asterisk represent prerelease surveys conducted during dusk, while all other surveys were conducted under daylight unless otherwise noted (24-hour time). (h, hour)



**Figure D18.** Smolt-sized targets per 1,000 cubic meters ( $m^3$ ) observed by the downlooking transducer in 10-meter (m) depth bins in Yale Lake, Washington, prerelease (pre), the day of release (day of), and postrelease (post) of 5,000 test smolts. Panels are arranged in columns based on transects (labeled on top), and rows based on regions (labeled at lower right of row). Lower numbered regions are lower in the reservoir (that is closer to the dam). Panels with an asterisk represent prerelease surveys conducted during dusk, while all other surveys were conducted under daylight.



**Figure D19.** Coho salmon smolt-sized targets per 1,000 (m<sup>3</sup>) observed by the downlooking transducer in 10-meter (m) depth bins during zig-zag transects conducted in the lower quarter of Yale Lake, Washington, prerelease, day of release, and postrelease of 5,000 coho salmon smolts at Yale Park. Surveys were conducted during daylight (left panel) and night (right panel) surveys (no crepuscular survey conducted).

## Tables

**Table D1.** Number of passive integrated transponder-tagged acclimation coho salmon and spring Chinook salmon released by location and year in the Lewis River upstream from Swift Dam, Washington, 2013–2015. Note: the dashes (—) indicate no releases occurred.

Year	Species	Clear Creek	Crab Creek	Muddy River
2013	Chinook salmon	1,750	750	1,750
	Coho salmon	—	—	2,000
2014	Chinook salmon	<sup>1</sup> 7,576	—	—
2015	Chinook salmon	3,400	3,300	3,300

<sup>1</sup>Includes fish from Muddy River as acclimation ponds at the Muddy River site were unusable.

**Table D2.** Hydroacoustic transects conducted in 2014 to evaluate coho salmon smolt movement and distribution in Yale Lake, Washington, including release status (that is, prerelease, during, or postrelease), date, location, start and end times, and diel period.

Release status	Date	Transect	Start time (24-hour)	End time (24-hour)	Period
Prerelease	April 7, 2014	West bank	16:28	17:00	Daylight
		Zig-zag	17:00	17:35	Daylight
		East bank	17:40	18:40	Daylight
		Middle axis	18:47	19:50	Dusk
		Zig-zag	20:33	22:03	Nighttime
Prerelease	April 8, 2014	Middle axis	9:21	9:40	Daylight
Release	April 8, 2014	Boat launch	9:50	10:10	Daylight
Postrelease	April 8, 2014	Zig-zag	13:58	14:35	Daylight
		East bank	14:35	15:35	Daylight
		West bank	15:35	16:40	Daylight
		Middle axis	16:41	17:06	Daylight
		Zig-zag	20:31	21:01	Nighttime
Postrelease	April 9, 2014	West bank	7:25	8:18	Daylight
		Zig-zag	8:18	8:36	Daylight
		East bank	8:37	9:39	Daylight
		Middle axis	9:40	10:43	Daylight
		Middle axis	19:28	19:47	Dusk
		Zig-zag	20:45	21:18	Nighttime

**Table D3.** Total numbers of spring Chinook salmon, coho salmon, and juvenile steelhead passive integrated transponder-tagged by year at the screw trap at Eagle Cliff on the Lewis River at the head of Swift Reservoir, Washington, and the percent (%) of fish collected (across years) at the floating surface collector (FSC), 2014–2015.

Species	Year emigrated		% collected at FSC
	2014	2015	
Chinook salmon	276	38	0.3
Coho salmon	147	394	15.2
Steelhead	60	122	18.7



# Chapter E. Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington

## Introduction

*Ptychocheilus oregonensis* (northern pikeminnow) were identified as an abundant predator of juvenile salmon in Lake Merwin, Washington, in the 1950s and 1960s, during an experiment to determine if the reservoir could be used to rear juvenile hatchery-reared *Oncorhynchus kisutch* (coho salmon) (Hamilton and others, 1970). The abundance of predatory-sized northern pikeminnow (greater than or equal to  $\geq$  200 millimeters [mm]) was estimated around 350,000 in 1961; however, the population has not since been assessed. Additionally, the Washington Department of Fish and Wildlife began stocking approximately 1,000 *Esox masquinongy* x *E. lucius* (tiger muskellunge) annually beginning in 1995 to limit the population of northern pikeminnow, but the efficacy of this program has not been formally evaluated. Here, we evaluate the contemporary abundance, diet, growth, and temporal-spatial distribution of northern pikeminnow, *O. nerka* (kokanee salmon), and tiger muskellunge to gauge how northern pikeminnow might affect populations of reintroduced anadromous salmonids. To achieve this objective, we characterized the temporal-spatial dimensions of the thermal environment, food supply, and the distribution, size, age, and diet of key predators and prey, and mapped the overall trophic structure of the food web through stable isotope analysis for 2013–2014. We then used these empirical data to inform bioenergetics simulations to estimate the seasonal and size-specific consumption rates and predation impact of northern pikeminnow on salmonids and alternative prey fish species (Beauchamp and others, 1997).

## Methods

### Site Description

Lake Merwin, a waterbody impounded by the Merwin Dam on the Lewis River, southeastern Washington, is approximately 23.3 kilometers (km) long (PacifiCorp and Cowlitz Public Utility District [PUD], 2004) with a maximum depth of 73 meters (m) and a mean depth of 31 m (Sorel and others, 2016). It is oligotrophic, with a mean secchi depth of roughly 5 m and total phosphorus of less than ( $<$ ) 0.02 milligram per liter (mg/l) (PacifiCorp and Cowlitz PUD, 2004) (table E1). Stream habitat surveys in the Lake Merwin basin (see “Habitat Assessment of Tributaries to Swift Reservoir, Yale Lake, and Lake Merwin, Washington” chap. B of this report) suggest that there is a total of 8.2 km of anadromous salmonid habitat available in tributaries to Lake Merwin (Al-Chokhachy and others, 2014).

The fish assemblage in Lake Merwin consists of a large population of northern pikeminnow, *Catostomus macrocheilus* (largescale suckers), and moderate to small populations of kokanee salmon, *O. clarkii* (cutthroat trout), *O. mykiss* (rainbow trout), *Cottus* spp. (sculpin), *Lepomis gibbosus* (pumpkinseed sunfish), coho salmon, *O. tshawytscha* (Chinook salmon), *Salvelinus confluentus* (bull trout), tiger muskellunge, and *Micropterus salmoides* (largemouth bass) (table E2). The kokanee salmon population is supplemented with approximately 45,000 hatchery-reared fingerlings in October of each year and 48,000 yearlings in spring (PacifiCorp and Cowlitz PUD, 2014). Natural production of kokanee salmon from tributaries of Lake Merwin is likely minimal. However, recruitment from Yale Lake (directly upstream of Lake Merwin) is probably the primary source of recruitment of naturally produced kokanee salmon (PacifiCorp and Cowlitz PUD, 2004). Large (300–600 mm) hatchery-reared rainbow trout are stocked periodically, as available, to provide fishing opportunities, and juvenile coho salmon and Chinook salmon are also present through spill from Yale Lake.



## Approach

We characterized the temporal-spatial dimensions of the thermal environment, and the abundance, distribution, size- and age-structure, and diet of northern pikeminnow and tiger muskellunge in Lake Merwin. We examined the food web structure of Lake Merwin through stable isotope analysis and higher resolution data on seasonal and size-specific diet composition by these piscivores to identify potential prey of piscivorous fishes and examine their ontogenetic shifts in predatory behavior. These data informed bioenergetics model simulations constructed to estimate the seasonal and size-specific consumption rates and predation impact of northern pikeminnow on resident salmonids and alternative prey fish species, and of tiger muskellunge on northern pikeminnow and salmonids. We used the results from the bioenergetics simulations to infer the likely predation impact by northern pikeminnow on reintroduced anadromous salmonids under different scenarios regarding rearing in versus migrating through the reservoir by subyearling and yearling fish. We also used the results of the bioenergetics simulations to evaluate the cannibalism of smaller northern pikeminnow and predation of northern pikeminnow by tiger muskellunge.

## Fish Sampling

Fish were systematically sampled in June, late July, and November of 2013 to obtain biological samples, seasonal fish distribution data, and population size structure. Paired small mesh (2.5, 3.2, 3.8, 5.1, 6.4, and 7.6 centimeter [cm] stretched mesh) and large mesh (8.9, 10.2, 11.4, 12.7, and 15.2 cm stretched mesh) sinking gill nets were fished perpendicular to shore for approximately 24 hours. Nets were set at a minimum of three sites around the reservoir per season and were fished in three depth strata: 1–15 m; 16–30 m; and greater than (>) 30 m deep to approximate the depths above, within, and below the thermocline during peak summer stratification. In addition to systematic gillnetting in 2013, samples were gathered opportunistically by gill nets targeting northern pikeminnow as part of the mark-recapture study and other approaches including the use of Merwin traps (Hamilton and others, 1970; Lynch 1993), angling, dip net, minnow trap, angler surveys, and snorkeler hand collection in 2013 and 2014.

We identified and counted fish by species and recorded a subset of fork lengths to the nearest millimeter and body mass to the nearest gram. Living fish were either released or euthanized according to the University of Washington Institutional Animal Care and Use Committee (UW-IACUC; <http://oaw.washington.edu/>) protocol #3286-21. Stomachs, scales from the preferred region, fin tissue, and some whole bodies were collected, placed on ice in the field, and later frozen for preservation and analysis.

*Northern pikeminnow mark-recapture.*—Northern pikeminnow of 200 mm or more were tagged with 2.54-cm numbered Floy tags. In 2013, we captured fish for tagging using short-term gill nets (5.1, 6.4, and 7.6 cm stretched mesh) set nearshore for 30 minutes to 2 hours. Catch rates were greatest at dusk on the north side of the reservoir around Indian George Creek and Speelyai Bay (fig. E1), so we preferentially netted in these areas at dusk. Our initial goal was to tag and release 2,000–5,000 marked fish in one season; however, difficulty in capturing sufficient numbers necessitated an extended tagging period over two years: June–August 2013 through May–July 2014. In 2014, we exclusively used Merwin traps to capture fish for tagging (number of samples [n]=4 locations; fig. E2). Northern pikeminnow were anesthetized in Tricaine Methanesulfonate (MS-222) buffered with baking soda and tagged.

A total of 98 tagged northern pikeminnow were held in net pens for 48 hours to evaluate short-term tagging mortality and tag retention. No tag loss and approximately 10 percent mortality was observed in the holding trials. However, lacerations and evisceration observed on the carcasses of mortalities and the presence of otters and piscivorous birds in the area suggested that these fish may have been predated upon rather than injured in the capture and tagging process. Therefore, short-term tagging mortality was assumed negligible.

Northern pikeminnow were captured and examined for tags in August and September 2014 with small mesh (5.1, 6.4, 7.6 cm stretched mesh) and large mesh (8.9, 10.2, 11.4, 12.7, and 15.2 cm stretched mesh) gill nets set methodically around the perimeter of the reservoir and soaked for approximately 24 hours. We assumed that fish captured and tagged during their spawning migration in June 2014 had redistributed throughout the reservoir by August. All captured individuals were measured for fork length and examined for tags, and a subset were weighed. Another subset of stomach samples (including some bycatch) were frozen for analysis. Additional individuals were captured by a separate investigator from Meridian Environmental Inc. using an electrofishing boat in the inlet to the reservoir during August 2014.

We explored multiple models and ad-hoc approaches to estimate the abundance of northern pikeminnow  $\geq 200$  mm, given potential biases that emerged during the recapture phase of the study. First, the sizes of recaptured fish were biased toward  $\geq 300$  mm individuals, which was likely the result of greater natural mortality and gill net selectivity against 200–299 mm fish (Beamesderfer and Rieman, 1988). Therefore, we estimated the abundance of the 200–299 mm population of northern pikeminnow and the population of the 300 mm separately. Second, the majority of tags were recovered within the upper quadrant of the reservoir, where most were initially released, suggesting that tagged fish were not randomly mixed with the rest of the

population. Consequently, we estimated abundance in the upper quadrant of the reservoir alone, in addition to our analysis of the entire reservoir. We divided the reservoir into quadrants based on geographic features such as points and bends (fig. E2), then proportionally expanded estimates from the upper quadrant (quadrant 1; fig. E2) to the remaining quadrants based on relative catch-per-unit effort (CPUE) in gill nets and the shoreline length of each quadrant.

Ultimately, the least biased and most precise abundance estimate used the Chapman estimator (Chapman, 1948; Seber, 1982) for northern pikeminnow  $\geq 300$  mm in the upper quadrant of the reservoir, expanded based on length and CPUE in the other quadrants of the reservoir. We used just the upper quadrant of the reservoir for our estimate because four of six recovered tags were captured in this quadrant. All six recovered tags occurred within the same quadrant where they were released, suggesting considerable site fidelity for this size class. The Chapman estimator was used because mortality was expected to be negligible for these large individuals during this study.

We estimated the abundance of the smaller 200–299 mm northern pikeminnow using the POPAN formulation of the Jolly-Seber model in the program MARK (White and Burnham, 1999), based on encounters from the entire reservoir. We used the POPAN estimator because we expected significant mortality for these smaller fish over the 13-month study. We used a fixed annual survival rate (39.7 percent) based on a catch-curve analysis (Miranda and Bettoli, 2007) with the most support based on Akaike Information Criteria corrected for small sample size (AICc) (AICc=138.4, table E3). We used data from the entire reservoir because one of the seven recovered tags was recovered on the other side of the reservoir from where it was released. This suggested that tagged fish of this size class had mixed between regions.

*Northern pikeminnow size distribution.*—The length frequency distribution of northern pikeminnow captured in gill nets was adjusted for effort by mesh size, size-dependent encounter probability (Spangler and Collins, 1992), and gill-net size-selectivity (Hansen and others, 1997) to estimate an unbiased size distribution. Only catches from mesh sizes 5.1 cm (2-inch stretch mesh) and above were used, as these meshes contributed the majority of the effort and catch of fish  $\geq 200$  mm. We only adjusted catches from Merwin traps for the probability of encounter, as these large nets allow for equal retention of fish across a wide range of sizes. The adjusted length distribution from the Merwin traps were averaged with those from gill nets, and separate size distributions were created for male and female northern pikeminnow to account for sex-specific differences in growth and survival. Chi-square ( $\chi^2$ ) tests were used to compare the adjusted and unadjusted length distributions to examine the degree of size selection by each gear type. We also compared length distributions between this study and the 1958–1963 study (Hamilton and others, 1970) using gill-net data from similar mesh sizes and Merwin traps set in similar areas to test whether the size structure of northern pikeminnow had changed and thus changed predation risk to juvenile salmonids. Length frequency data from both study periods were adjusted for gear selectivity.

*Tiger muskellunge survival and abundance.*—Using stocking records and a catch-curve analysis, we constructed an age-structured population estimate. Records of the number, size, and release dates of tiger muskellunge in Lake Merwin from 1995 to 2013 were provided by the Washington Department of Fish and Wildlife. Since 2004, fish have been reared at Ringold Springs Hatchery at a constant water temperature of approximately 16 degrees Celsius ( $^{\circ}\text{C}$ ) (Sorel and others, 2016), and an average of 1,340 fish (range=500–2,220) have been stocked at age-1 year in April–June. The large size at which tiger muskellunge are stocked (range=14–348 mm, mean=302 mm, standard error=12.1 mm), and the cool surface water temperatures and seemingly abundant forage base of small northern pikeminnow in spring suggest that stocking mortality is negligible.

Annual survival for tiger muskellunge at 1–10 years old (the range of ages observed) was estimated with a catch-curve analysis and is likely a function of natural and overwinter mortality. To estimate annual survival, we used cleithra-based ages and the observed size distribution to estimate a population age structure. We then used a catch-curve analysis (Miranda and Bettoli, 2007) to estimate an annual survival rate based on the estimated age-structure of the population. We estimated annual survival to be 71 percent for fish ages 1–10 years in Lake Merwin. The minimum size for legal retention of tiger muskellunge in Lake Merwin was above the maximum size observed in field efforts; therefore, the majority of angling was likely catch-and-release. Postrelease survival has been observed to be very high (approaching 100 percent) in Canadian rivers using a variety of handling procedures (Landsman and others, 2011). Thus, we assumed fishing pressure does not significantly reduce survival rates.

*Bioenergetics model inputs.*—Bioenergetics models are energy balance equations that operate on a daily time-step and estimate the feeding rate (percent of maximum theoretical consumption; percent  $C_{\text{max}}$ ) and the consumption rate (grams of prey/day) needed to achieve the growth observed by different age classes of consumers over the time interval of the simulations. These estimates depend on the energy densities of predators and prey and species-specific parameters that describe the temperature-dependent and allometric effects of body mass on consumption, metabolism, and waste (Hanson and others, 1997). We collected field data on thermal experience (daily temperature experienced by the consumer), seasonal diet composition, and growth to construct a set of model inputs specific to northern pikeminnow and tiger muskellunge in Lake Merwin.

*Thermal experience and depth distribution.*—Seasonal thermal experience of different size classes of northern pikeminnow and tiger muskellunge were estimated using thermal profiles and depth-distribution patterns inferred from catches in gill and trap nets (table E4; Beauchamp and others, 2007). Temperature profiles were recorded monthly from April to November at 1-m intervals from the surface to 30 m and every 2 m thereafter down to 60 m at two limnology stations located at one-third and two-thirds of the length of the reservoir (fig. E1). Depth-specific measurements were averaged between stations in each

month. Temperature profiles recorded by PacifiCorp in November 1999, January 2000, and March 2000 in the lower half of the reservoir were used to fill data gaps and complete the characterization of the seasonal thermal regime for periods outside of our monthly sampling (April to November, 2013 and 2014; Sorel and others, 2016). Relative catch at different depths in different seasons was then used to calculate the average daily thermal experience for each species and size class of consumer.

*Stable isotope analysis.*—Stable isotopes provide an integrative signal of diet over several months to a year, providing a valuable complement to and corroboration for stomach content analysis. We used stable isotopes to identify the length at which northern pikeminnow transition to piscivory in order to delineate size classes for calculating diet composition and thermal experience. We examined delta c 13 ( $\delta^{13}\text{C}$ , ratio of carbon isotopes  $^{12}\text{C}$  and  $^{13}\text{C}$ ) and delta n 15 ( $\delta^{15}\text{N}$ , ratio of nitrogen isotopes  $^{15}\text{N}$  and  $^{14}\text{N}$ ) for a range of sizes of northern pikeminnow and tiger muskellunge and representative samples of benthic invertebrates, terrestrial insects, zooplankton, zooplanktivores, pelagic- and benthic-feeding fishes, and piscivores (Vander Zanden and Rasmussen, 1999; McIntyre and others, 2006). Fin tissue from fish, muscle tissue from clams and crayfish, and whole bodies of insects were placed on ice in the field and then frozen within 12 hours for storage. Samples were dried at 60 °C for 48 hours and homogenized with mortar and pestle, and 0.4–0.6 milligrams of material were weighed in aluminum capsules for analysis. Isotope samples were analyzed by the University of Washington IsoLab using a Costech Elemental Analyzer, Conflo III, MAT253 for continuous flow-based measurement of solid organic material. The reference material was Vienna Pee Dee belemnite for carbon and atmospheric nitrogen for nitrogen.

*Diet composition and energy density of prey.*—We analyzed the seasonal diets for different sizes of northern pikeminnow and tiger muskellunge as inputs for the bioenergetics model. Stomach contents were identified under a dissecting microscope to species for prey fish and to order for invertebrates. Lengths of prey fish were measured or reconstructed from diagnostic bones (Hansel and others, 1988). We calculated diet proportions by blotted wet weight (Chipps and Garvey, 2007) for two size classes of northern pikeminnow (200–299 mm and  $\geq 300$  mm), the breakpoint reflecting a transition to piscivory based on  $\delta^{15}\text{N}$  signatures. One set of seasonal diet proportions was calculated for all sizes of tiger muskellunge given their similarity in diet across sizes and the limited number of non-empty stomachs obtained. The energy densities of prey items were taken from literature values (table E5).

*Age and growth of Northern pikeminnow.*—We measured the age and growth of northern pikeminnow from scales to obtain annual growth increments for different age-classes in the bioenergetics model (table E6). Opercles were also analyzed for a subset of individuals to corroborate the scale-based ages. Scales were measured along a transect 20 degrees (°) off the scale's anterior-posterior axis from the center of the focus out to the edge of each annulus and additionally to the margin of the scale using a dissecting microscope with a digital camera and Image Pro analysis software. Fork length-at-age was back-calculated using the Fraser-Lee (*FL*) method with a biological intercept of zero (*FL* Range: 34–560 mm,  $n=101$ , coefficient of determination [ $R^2$ ]=0.97,  $P<0.001$ ; Isely and Grabowski, 2007). Growth in length was characterized by a von Bertalanffy growth function fit to length-at-age data using the back-calculated length at final annulus for each fish (von Bertalanffy, 1938). A likelihood ratio test using the “vblrt” function in the fish methods package in R (Nelson, 2014) indicated that a sex-specific von Bertalanffy growth model described the length-at-age data significantly better than a single model for both sexes where ( $\chi^2=12.88$ , degrees of freedom [ $df$ ]=3,  $P<0.005$ ). The greatest scale-based age observed was 14 years (431 mm male, and 542 mm female). While scales often underestimate ages of northern pikeminnow  $>350$  mm (Takata and others, 2007), our analysis of opercles helped reduce this bias by identifying older annuli on  $>350$  mm fish. The von Bertalanffy growth parameters fit for females ( $n=34$ ) were  $L_{\infty}=786.64$  mm,  $K=0.0665$ , and  $t_0=-2.0139$  ( $n=34$ ). Corresponding parameters for the male model ( $n=38$ ) were  $L_{\infty}=689.23$ ,  $K=0.0599$ , and  $t_0=-3.0117$  (see fig. E3), where  $L_{\infty}$  is the asymptotic average length,  $K$  is the growth rate coefficient, and  $t_0$  is the age when average length is zero.

Fork length-at-age was converted to weight-at-age ( $W$ ) using length-weight relationships developed for northern pikeminnow in Lake Merwin. Separate relationships were developed for individuals  $<300$  mm and  $\geq 300$  mm due to the inability of a single power function to fit length and weight measurements over the entire range of *FL*'s observed. The *FL* to  $W$  relationship for northern pikeminnow  $<300$  mm was ( $n=2,941$ , range: 34–299 mm;  $R^2=0.972$ ,  $P<0.001$ ):

$$W=0.000012 \times FL^{2.979} \quad (\text{E1})$$

The *FL* to  $W$  relationship for individuals  $\geq 300$  mm was ( $n=354$ , range: 300–574 mm;  $R^2=0.974$ ,  $P<0.001$ ):

$$W=0.0000015 \times FL^{3.348} \quad (\text{E2})$$

Spawning losses were calculated separately for each sex by subtracting the average gonadosomatic index ( $100 \times \text{gonad mass/body mass}$ ) of spent from ripe fish in the spring. Spawning losses were then phased in over two age classes for bioenergetics model simulations to represent an increase in the proportion of mature fish. Spawning losses were 3.9 percent of body mass for males age 3–14 years, 6 percent for age 3 females, and 8.9 percent for age 4–14 years females.

*Age and growth of tiger muskellunge.*—Annual growth increments for bioenergetics simulations of tiger muskellunge consumption were determined with age-to-length and weight-length relationships (table E7). Age was determined using standard cleithra aging procedures for a parent species, northern pike (*E. lucius* of tiger muskellunge [Euchner, 1988]). Fish are routinely implanted with blank wire tags in various locations on their bodies that indicated their brood year, and a number of individuals were aged based on the location of these tags to corroborate cleithra-based ages. We used the proportional linear relationship derived for the other parent species, muskellunge (*E. masquinongy*) (Harrison and Hadley, 1979) to estimate total length at age.

$$TL_i = (TL - 1.41) \times (CL_i / CL) + 1.41 \quad (E3)$$

where

$TL$  is total length at age  $i$ , and

$TL_i$  is back calculated based on measurements from the origin of the cleithra to each annuli ( $CL_i$ ), the origin to edge of the cleithra ( $CL$ ), and  $TL$  is the total length at capture.

A von Bertalanffy growth curve was fit to total length at age ( $K=0.389$ ,  $L_\infty=1023.9$ ,  $t_0=0.00$ ). Total Length ( $TL$ , mm) was converted to  $FL$  with the relationship  $FL=0.959 \times (TL) - 0.654$  (Gayzusuzl and others, 2006). Fork length-at-age was then converted to weight-at-age with the equation ( $n=62$ , range: 324–975 mm,  $R^2=0.988$ ,  $P<0.001$ )

$$W=0.00000037 \times FL^{3.479} \quad (E4)$$

*Bioenergetics modeling simulations of seasonal predation.*—The Wisconsin bioenergetics model (Hanson and others, 1997) parameterized for northern pikeminnow (Petersen and Ward, 1999) was used to estimate seasonal consumption demand. The bioenergetics model fit the daily per-capita consumption, starting April 1, needed to satisfy the observed growth of an average northern pikeminnow from each age class and sex over an annual cycle. Age-frequency distributions within each size class were developed from the unbiased size distribution estimated above and an age-length key (Isely and Grabowski, 2007). Per-capita consumption demand was expanded to separate age-structured populations of 1,000 northern pikeminnow of the 200–299 mm and  $\geq 300$  mm size classes, assuming an even sex ratio. We then used estimates of consumption of resident salmonids to gauge potential predation on reintroduced anadromous salmonids under different reservoir use scenarios (for example, rearing in versus migrating through the reservoir).

*Estimating predation on reintroduced salmon.*—In order to estimate maximum potential predation on reintroduced anadromous salmonids, we assumed that all observed predation on resident kokanee salmon would switch to anadromous fish once they were reintroduced. Thus the monthly biomass of kokanee salmon that was consumed from April 1 to March 30 based on bioenergetics simulations was divided by the estimated monthly weight of an age-0 (that is, during the year after fish emerged) Chinook salmon that adopted a year-round reservoir rearing strategy to estimate how many individuals could be lost to predation. We divided northern pikeminnow monthly consumption of salmonid biomass by the monthly mass of individual age-0 stream-type Chinook salmon estimated using a bioenergetics simulation. For the bioenergetics simulation of age-0 Chinook salmon growth in the reservoir, we assumed that kokanee salmon and subyearling stream-type Chinook salmon used similar depth distributions during thermally stratified periods and would therefore share similar thermal experiences in reservoirs. This assumption, based on observations of Chinook salmon in North Fork Reservoir on the Clackamas River, Oregon (Lowery and Beauchamp, 2010), also suggests similar overlap with predatory northern pikeminnow, supporting our use of kokanee salmon as a surrogate to estimate predation on juvenile anadromous salmonids. For the bioenergetics simulation of age-0 Chinook salmon in the reservoir, we assumed a diet of zooplankton and insects, and a feeding rate of 93 percent  $C_{max}$ , as informed by observations of age-1 Chinook salmon smolts that residualized in Swift Reservoir (also on the North Fork of the Lewis River) following releases in 2013. Information on the diet and feeding rate of age-0 Chinook salmon in Swift Reservoir was not available. Fish in this simulation grew from 0.36 grams (g) (35 mm) on April 1 to 45 g (155 mm) on November 15, after which their mass was held constant through March 30 to simulate reduced prey supply and growth during winter. The mass that smolts achieved in this simulation was similar to the upper end of the length distribution of smolts outmigrating from the Columbia River that survived at least 30 days in the marine environment (Tomaro and others, 2012). We also simulated the magnitude of predation on reservoir-rearing Chinook salmon that achieved a mass of only 18 g (about 120 mm), at the lower end of the length distribution of smolts that survived at least 30 days in the marine environment (Tomaro and others, 2012). A different predation scenario was used to simulate potential predation on age-1 smolts migrating through Lake Merwin.

Some juvenile stream-type Chinook salmon smolts might only use the reservoir as a migration corridor after rearing in tributaries. Therefore, we estimated potential predation on smolts traversing the reservoir to evaluate the effect of northern pikeminnow on their survival during the spring outmigration period. As before, our estimate of population-level consumption demand of kokanee salmon by northern pikeminnow was divided by the mass of individual stream-type Chinook salmon. However, to estimate predation on smolts, we restricted the simulation to April through June, spanning the months for peak outmigration as indicated from field efforts in Swift Reservoir (see “Assessment of Juvenile Fish Production and Outmigration Success



on the Lewis River, Washington,” chap. D of this report). We used the same potential average smolt sizes (18 and 45 g), which were held constant for the 3-month simulations. Unlike in the reservoirs on the mainstem Columbia River, there is no tailrace area in Lake Merwin where disoriented salmon smolts would concentrate and provide easy access for northern pikeminnow (for example, Rieman and others, 1991), so we did not simulate northern pikeminnow feeding at an elevated rate in response to a smolt outmigration.

Our estimates of predation on age-0 or age-1 Chinook salmon represent the maximum potential predation on either age class because the same population-level consumption by northern pikeminnow was used to estimate losses in both scenarios. However, we expect that this overall consumption rate of salmonids by northern pikeminnow would be partitioned among the two age classes of anadromous salmonids as well as resident salmonids, so the realized predation should be lower than our estimates.

We calculated predation rates for size-structured population units of 1,000 predators for each of the two size classes of northern pikeminnow rather than for the entire populations, given the uncertainty surrounding our population abundance estimates. Our predation estimates contain all the major variability related to seasonal and size-specific diet, consumption rates, and relative abundance of each size/age class. These estimates of predation by size-structured units of 1,000 predators can be multiplied by however many thousands of predators of that size range are in the population (or however many might be prescribed in different predation scenarios) to generate full population-level predation estimates.

*Estimating predation by tiger muskellunge on northern pikeminnow.*—Thermal experience, size-specific diet composition, and growth estimates were used as inputs in a bioenergetics model (Bevelhimer and others, 1985) to determine annual consumption rates for each age class of tiger muskellunge. Individual consumption demands were then expanded by the respective abundance estimates of each age-class to determine the total consumption by the population.

We used the biomass of northern pikeminnow consumed by tiger muskellunge estimated with bioenergetics combined with the lengths of northern pikeminnow found in stomachs to estimate the number and size distribution of prey consumed by the predator population. For age-1 and age 2–10 predator size classes, we converted the lengths of northern pikeminnow found in tiger muskellunge diets to masses with a weight-length regression. We then used the masses of individual prey fish and the estimates of consumption demand to calculate how many of each size class of northern pikeminnow were consumed by each size class of tiger muskellunge.

## Results and Discussion

### Seasonal Distribution and Thermal Experience of Northern Pikeminnow

Thermal stratification in Lake Merwin began in May and peaked in August in 2014; rapid destratification occurred during October and the water column became isothermal in November of that year (fig. E4). The epilimnion encompassed the upper 8 m of the water column, the metalimnion ranged from roughly 8–18 m, and the hypolimnion was approximately 18 m and deeper. Epilimnetic temperatures began at 14–16 °C in May and peaked at 22–24 °C in August and July 2014. The hypolimnion warmed from 5–6 °C in April to 15–18 °C in October 2014.

The depth-distribution of northern pikeminnow varied by season. Most northern pikeminnow and especially those  $\geq 300$  mm occupied warmer surface waters nearshore in 0–15 m depths during thermally stratified periods in June–September but were deeper during isothermal conditions in November (figs. E1, E4). The CPUE of the larger fish was significantly higher in 0–15 m depths (4.8 fish/net) than deeper (0.3 fish/net) in spring–summer (two-sided t-test:  $df=18$ ,  $t=5.11$ ,  $P<0.001$ ). This pattern reversed as the reservoir became isothermal in November, and CPUE was higher in 16–30 m depths (5.7 fish/net) than in 0–15 m (1.5 fish/net), although this difference was not significant (two-sided t-test:  $t=1.89$ ,  $df=3$ ,  $P=0.155$ ). The CPUE of northern pikeminnow 200–299 mm was also significantly higher at 0–15 m depths (24.3 fish/net), but a sizeable number also occupied 15–30 m (13.4 fish/net) during stratification (two-sided t-test:  $df=14$ ,  $t=3.42$ ,  $P=0.004$ ). Northern pikeminnow 200–299 mm exhibited the same distribution pattern as fish  $\geq 300$  mm in November, and their CPUE in 16–30 m depths (15 fish/net) was also not significantly higher than in 0–15 m (10.4 fish/net) (two-sided t-test:  $df=3$ ,  $t=0.65$ ,  $P=0.561$ ). Tiger muskellunge remained in the epilimnion in spring–fall similarly to large northern pikeminnow.

The density of northern pikeminnow was greater in the lower half of the reservoir (quadrants 3–4) in summer based on CPUE (fig. E5). Although not significant, the CPUE of northern pikeminnow  $\geq 300$  mm in gill nets was greater in the lower half (6 fish/net) than the upper half of the reservoir (3.1 fish/net) during the recapture phase of the mark-recapture study in August–September 2014 (two-sided t-test;  $df=6$ ,  $t=2.08$ ,  $P=0.083$ ). The CPUE of 200–299 mm northern pikeminnow during this recapture effort was also significantly higher in the lower half of the reservoir (27.1 fish/net) than the upper half (17.8 fish/net; two-sided t-test;  $df=58$ ,  $t=2.79$ ,  $P=0.007$ ). This pattern suggests that northern pikeminnow redistributed to the lower half of the reservoir by August after spawning in Canyon Creek (at the top of the reservoir; fig. E2), or a segment also spawned near tributaries in the lower reservoir as also observed by Hamilton and others, (1970).

## Bioenergetics Inputs and Model Simulations

**Stable isotopes.**—Northern pikeminnow became increasingly piscivorous and reliant on benthically derived energy with increasing size (table E8, fig. E6). The trophic position of medium-sized northern pikeminnow (200–299 mm) suggested that they fed primarily on a mix of pelagic and benthic invertebrates and increasing proportions of benthic fish or *Pacifastacus leniusculus* (signal crayfish) (figs. E6, E7). The isotopic signatures for large northern pikeminnow  $\geq 300$  mm suggested that they consumed a combination of pelagic and benthic fish and signal crayfish.

Stable isotope analysis suggested that tiger muskellunge fed on a mix of pelagically and benthic-littorally derived carbon and increased in trophic level steadily throughout their lives (fig. E6). Tiger muskellunge increased by nearly one trophic level ( $\sim 3.4$  per thousand increase in  $\delta^{15}\text{N}$ ) (Minagawa and Wada, 1984; Hussey and others, 2014) over the range of 450–1,050 mm *FL* (figs. E6, E7). Thus stable isotopes suggest that tiger muskellunge initially consumed invertebrate-feeding fish but progressed to consuming partially-piscivorous fish as they grew.

**Stomach content analysis.**—Northern pikeminnow exhibited seasonal and ontogenetic shifts in diet composition, with an increasing reliance on prey fish at larger sizes, in agreement with the stable isotope patterns (table E8). The spring and summer of 2013–2014 diets of 200–299 mm northern pikeminnow contained 72–88 percent zooplankton and smaller proportions of sculpins, signal crayfish, insects, and plant matter, but no salmonids were detected (table E9). Diets of the  $\geq 300$  mm northern pikeminnow contained primarily fish and signal crayfish. During spring, signal crayfish (45 percent) and smaller northern pikeminnow (43 percent) were the predominant prey, indicating a high proportion of cannibalism. During summer, signal crayfish still represented 51 percent of the diet, but northern pikeminnow declined to 19 percent, whereas sculpins (9 percent) and kokanee salmon (14 percent) increased. The diet proportions of sculpins (14 percent) and kokanee salmon (28 percent) continued increasing during fall, while signal crayfish (29 percent) and smaller northern pikeminnow (10 percent) declined.

The maximum *FL* of prey fish consumed increased with the *FL* of northern pikeminnow (fig. E8). Kokanee salmon were the largest prey fish consumed by northern pikeminnow and occasionally exceeded 50 percent of the predator's *FL* when reconstructed from diagnostic bones. Four 100–150 mm kokanee salmon were found in the guts of 300–399 mm northern pikeminnow. Six 200–325 mm kokanee salmon were observed in  $\geq 400$  mm northern pikeminnow. As prey, the average *FL* of northern pikeminnow eaten by 300–399 mm cannibals was 143 mm (range: 143–144,  $n=2$ ) and 164 mm for  $\geq 400$  mm predators (range: 101–252 mm,  $n=10$ ).

The diet composition of tiger muskellunge remained relatively constant from spring through fall 2014 (table E10) and was corroborated by stable isotopes (table E8). Northern pikeminnow were the largest component (65–80 percent of diet across seasons) followed by largescale suckers (10–25 percent), while kokanee salmon, pumpkinseed sunfish, signal crayfish, and aquatic insects represented smaller proportions (table E5). Only one salmonid (*FL*=451 mm) was found in a tiger muskellunge's stomach, a 920 mm fish captured in September 2014 when kokanee salmon were using the littoral zone as a spawning-migration corridor. Tiger muskellunge consumed a wide size range of northern pikeminnow (57–394 mm) (fig. E9). The majority of prey fish were approximately 40 percent of their consumers' fork lengths, but a significant number of northern pikeminnow were also  $< 20$  percent of the predators' lengths. Age-1 tiger muskellunge (*FL* $>300$  mm) began feeding on northern pikeminnow that were  $\geq 200$  mm. The mean fork length of northern pikeminnow consumed was not significantly different between age-1 (152 plus or minus  $\pm$  49 mm [mean $\pm$ standard deviation]) and ages 2–10 tiger muskellunge (195 $\pm$ 97 mm) (t-test:  $DF=19$ ,  $T=-1.354$ ,  $P=0.192$ ). The mean fork length of northern pikeminnow consumed was also not significantly different among spring (181 $\pm$ 76 mm), summer (182 $\pm$ 92 mm), and fall (163 $\pm$ 81 mm) (one-factor analysis of variance [ANOVA]:  $F=0.087$ ,  $P=0.917$ ,  $df=21$ ).

**Size distribution.**—The length frequency distributions of male and female northern pikeminnow were skewed toward smaller (200–299 mm) individuals and exhibited a decrease in modal *FL* from 1958–1963 to 2013–2014 (fig. E10). Fish 200–299 mm made up 83 percent of the population of  $\geq 200$  mm northern pikeminnow in the present study. The adjusted length distribution was significantly different than the unadjusted distribution for fish captured in gill nets ( $\chi^2=336$ ,  $df=224$ ,  $P=0.003$ ), but not in Merwin traps ( $\chi^2=456$ ,  $df=418$ ,  $P=0.097$ ), suggesting that the degree of selectivity was greater for gill nets (fig. E11). Males in the present study were significantly smaller on average than in the historic study ( $\chi^2=192$ ,  $df=80$ ,  $P<0.001$ ) as were females ( $\chi^2=336$ ,  $df=224$ ,  $P<0.001$ ), whereas the current female size structure was significantly larger than males. The contemporary size distribution of northern pikeminnow is likely driven by predation by large northern pikeminnow and tiger muskellunge (Baker and others, 2015) on smaller northern pikeminnow (see the “Population-level consumption demand” sections in this chapter).

**Mark recapture.**—Estimates of northern pikeminnow abundance (table E3) were imprecise due to the relatively few recaptures ( $< 1$  percent). It was difficult to estimate the abundance of fish because they were only vulnerable to capture in certain locations and exhibited considerable site fidelity, eliminating much of the mixing of marked and unmarked fish necessary for accurate estimation in this type of study design. The estimate of the fully piscivorous  $\geq 300$  mm northern pikeminnow was 11,240 fish (95 percent confidence interval [CI]: 3,730–39,880), and 544,259 (95 percent CI: 190,609–1,554,062) 200–299 mm northern pikeminnow. This abundance estimate of smaller northern pikeminnow was roughly 50 times greater than the abundance of

$\geq 300$  mm fish whereas the observed size distribution of the population suggests that this ratio should be only approximately six times greater. This disagreement suggests some bias in the estimates of the population size distribution or abundance.

*Tiger Muskellunge abundance.*—The population abundance of tiger muskellunge based on the 71 percent annual survival rate was 5,488 fish. We expanded individual consumption demands by the population abundance estimate as well as calculating predation by a size-structured population of 1,000 tiger muskellunge for comparison with northern pikeminnow.

*Population-level consumption demand of northern pikeminnow.*—Our estimates of consumption varied by month, a pattern consistent with previous studies of northern pikeminnow predation rates (Rieman and others, 1991). Total monthly consumption demand by northern pikeminnow on salmonids and other fish was highly influenced by the size structure and abundance of the population, as well as the thermal regime, which influenced metabolic rates and seasonal diet compositions. Overall consumption started low in spring and increased as the water warmed. The greatest consumption of fish biomass was estimated in October, when relatively warm water allowed a high metabolic rate, and predators ate a higher proportion of fish (fig. E9). Consumption demand was very low in winter when water temperature limited metabolic rates. The feeding rate of the 200–299 mm northern pikeminnow was 55–65 percent  $C_{\max}$ , but declined to 22–25 percent  $C_{\max}$  for the  $\geq 300$  mm size class (table E6). Consumption by a size-structured population of 1,000 northern pikeminnow 200–299 mm over the entire year totaled 1,069 kilogram (kg) of zooplankton (peak=August), 382 kg of plant matter (peak=August), and 159 kg of sculpins (peak=October) (fig. E12). Consumption by 1,000  $\geq 300$  mm fish over the entire year totaled 1,118 kg of crayfish (peak=August), 557 kg of northern pikeminnow (peak=June), and 384 kg of salmonids (peak=October).

Dividing monthly consumption demand of salmonids by the mass of an age-0 stream-type Chinook salmon in the corresponding month and summing across months provided an estimate of 39,250 Chinook salmon consumed from April 1 to March 31 (peak September) by a size-structured population of 1,000 northern pikeminnow  $\geq 300$  mm, if the salmon reached 18 g by November, and 16,022 fish if they reached a mass of 45 g by November (fig. E13). Our estimates of potential predation on age-1 Chinook salmon smolts was considerably less than on age-0's.

Consumption of salmonids by a size-structured population of 1,000 large northern pikeminnow during peak months of smolt outmigration in April–June was only 17 kg (fig. E12). This biomass was equivalent to 969 salmon smolts weighing 18 g each, or 388 smolts weighing 45 g each. These numerical estimates of smolt consumption were driven in large part by the lack of salmonids observed in northern pikeminnow diets during spring, and low overall consumption rates due to cold water in the spring months. Cannibalism on smaller northern pikeminnow by 1,000 predators  $\geq 300$  mm was 557 kg (fig. E12). Using the length distribution of cannibalized individuals and a length-weight regression, we estimated that this was equivalent to 1,862 fish of 200–299 mm and 9,311 northern pikeminnow  $< 200$  mm. The observed cannibalism on smaller northern pikeminnow likely reduces the overall predation pressure on salmonids.

In lieu of our estimates of salmonid consumption, we acknowledge that salmonid consumption may vary as a function of migration timing and reservoir thermal regimes (Vigg and others, 1991; Petersen and Kitchell, 2001). In Swift Reservoir, hatchery-reared spring Chinook salmon smolts rapidly emigrate to the reservoir environment (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report) and the median rearing time in the reservoir is approximately 2 months, but considerable variability in rearing time is possible (for example, Romer and others, 2014). For coho salmon, rearing in the reservoir environment has been approximately 4 months (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report). Despite the longer period of rearing for coho salmon smolts, estimates of predation by month suggest predation on spring Chinook salmon is likely to be higher given the overlap in distribution during the periods of relatively high predation (for example, spring–early summer). Further, the fact that nearly 30 percent of Chinook salmon are rearing in the reservoir for more than 9 months suggest the exposure to northern pikeminnow predation may be relatively high. However, rearing in reservoirs can be highly variable for juvenile salmon (Vendetti and others, 2000; Smith and others, 2003), which can affect the predicted patterns of predation.

*Population-level consumption demand of tiger muskellunge.*—We estimated that 29,069 northern pikeminnow  $\geq 300$  mm, 142,508 of 200–299 mm, and 247,736 of  $< 200$  mm were consumed by the population of tiger muskellunge (ranged 316–970 mm) over the course of a year (fig. E14). The equivalent consumption by a size-structured population unit of 1,000 tiger muskellunge was 5,296 northern pikeminnow  $\geq 300$  mm, 25,967 of 200–299 mm, and 45,141 of  $< 200$  mm (table E7). The numerical estimate of northern pikeminnow  $\geq 300$  mm consumed was based on a single observation of a 394 mm northern pikeminnow in one tiger muskellunge's stomach, which could have been an anomaly that skewed our data due to our relatively small sample size of prey fish examined. Despite this limitation, the predation of smaller northern pikeminnow by tiger muskellunge likely further reduces the overall predation of juvenile salmonids.



## Conclusions

We found large northern pikeminnow represent a substantial predation threat to anadromous smolts in Lake Merwin. Our simulations indicated that yearly consumption by a population of 1,000 large northern pikeminnow would be approximately 16,000–40,000 age-0 spring Chinook salmon rearing in the reservoir based on their current feeding rate, consumption of resident salmonids, and the size distribution of the population. Concomitantly, our predation studies suggest the overall northern pikeminnow predation on salmonids was considerably reduced due to predation on smaller northern pikeminnow by larger conspecifics and tiger muskellunge.

Continued monitoring of reservoir rearing as efficiencies improve at juvenile collection facilities (for example, floating surface collector on Swift Reservoir) will ultimately provide further insight into the likelihood of predation for fish with varying periods of reservoir rearing. Ultimately, considering such predation rates in the context of robust productivity measures can provide key insights into the ramifications of different predation levels on long-term persistence of reintroduced anadromous species into Lake Merwin.

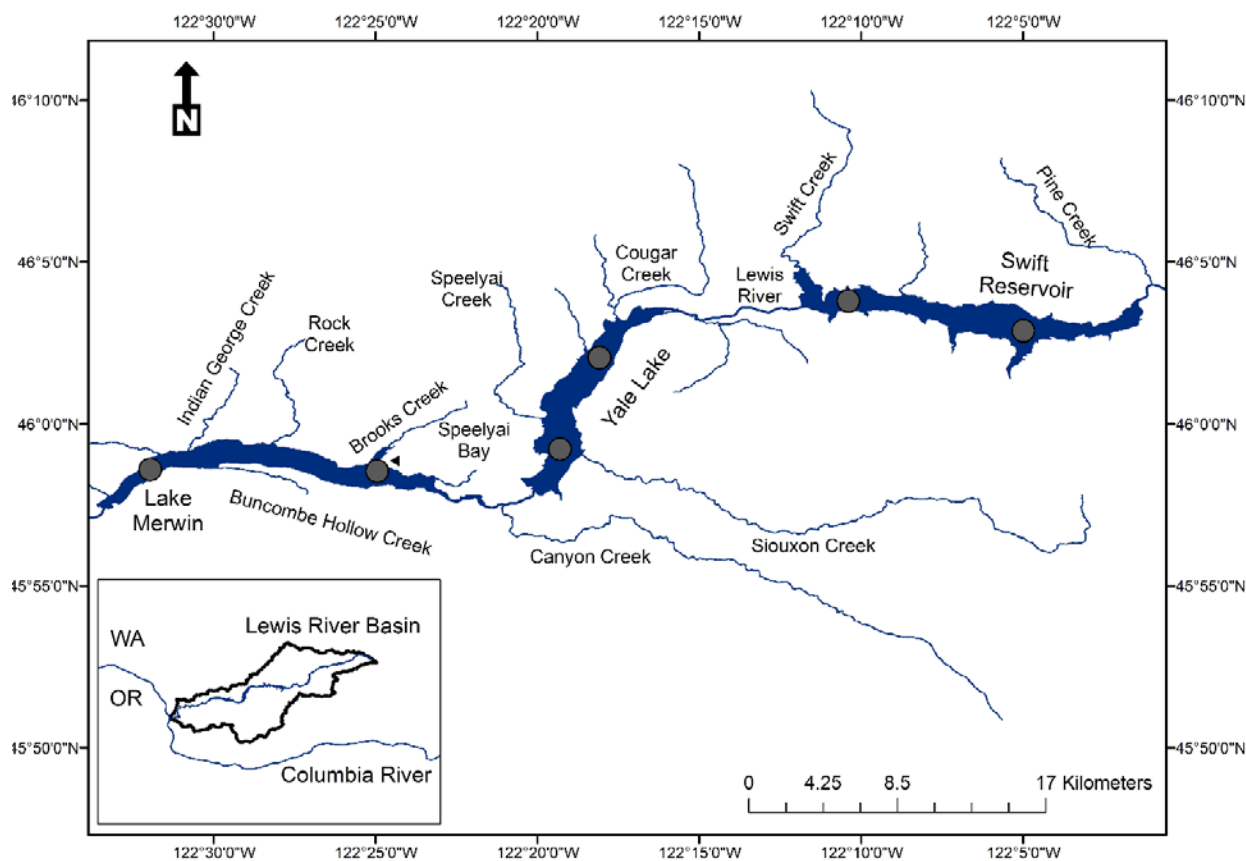
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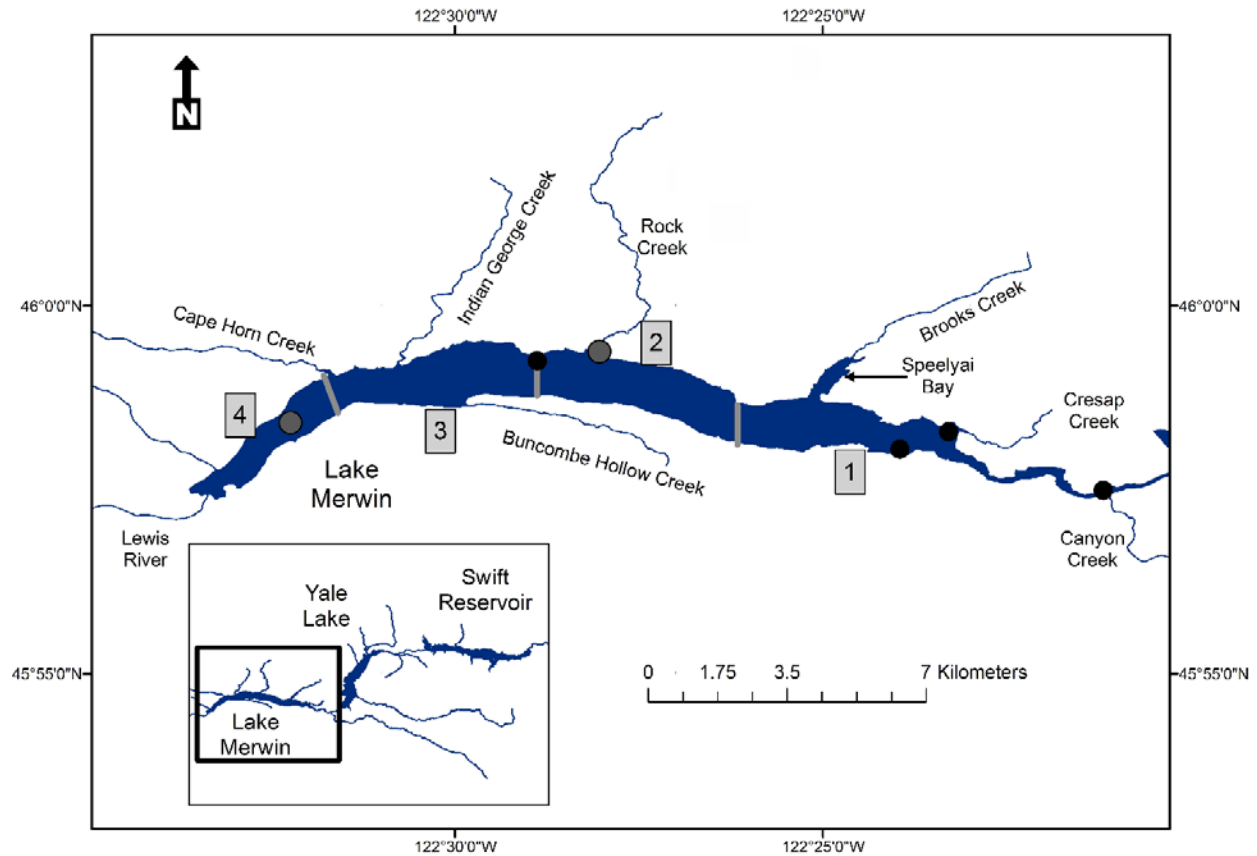
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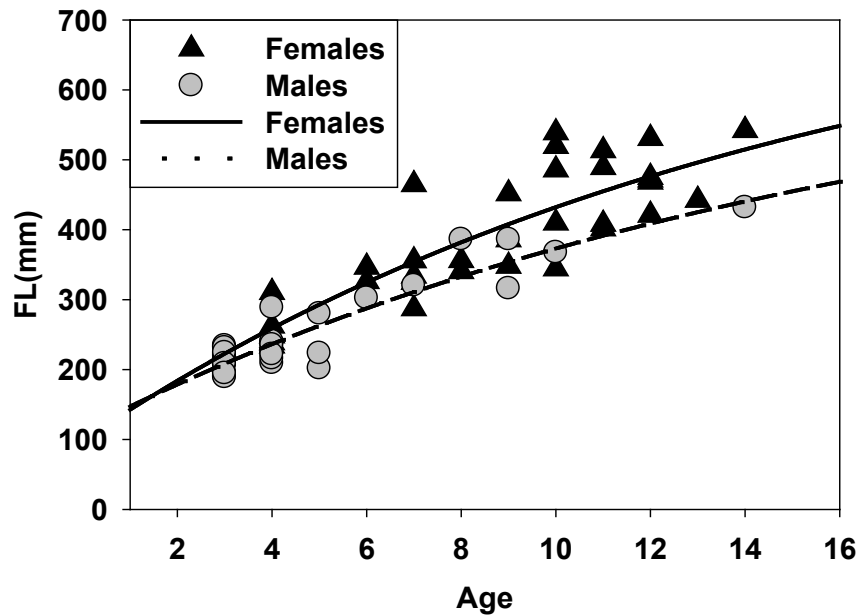
## Figures



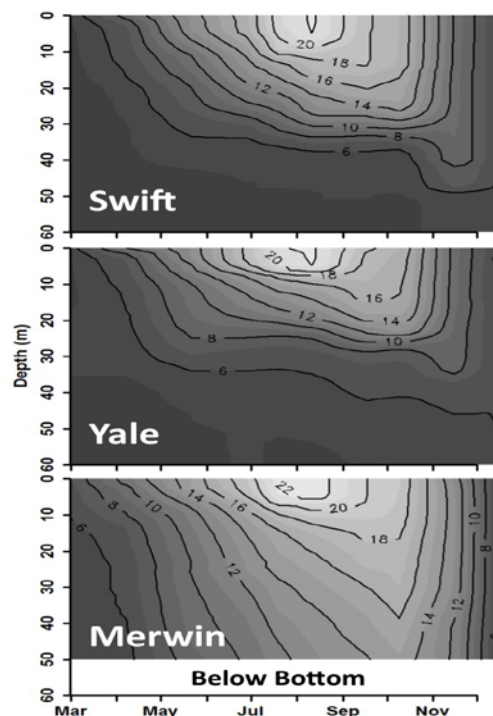
**Figure E1.** Study area map showing the reservoirs in the North Fork of the Lewis River, Washington, illustrating the location of limnology stations (gray circles) where temperature and zooplankton were sampled. Inset shows the location of the reservoirs and the Lewis River Basin in relation to the Columbia River in Washington (WA) and Oregon (OR).



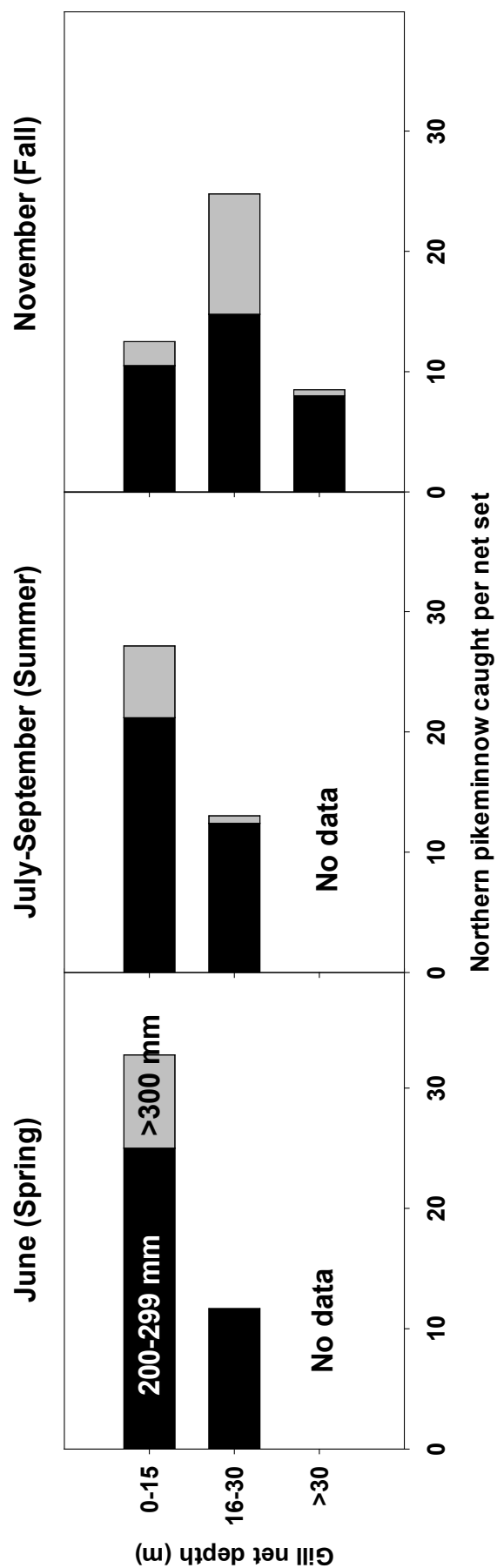
**Figure E2.** Limnological stations (gray circles) and Merwin trap locations (black circles) within Lake Merwin, Washington, with numbers categorizing the different quadrants. The reservoir was divided into quadrants based on geographic features such as points and bends and the quadrants are delineated by the light gray lines. Inset shows location of the Lake Merwin study area (in box) in the upper Lewis River.



**Figure E3.** Length at age in years and von Bertalanffy growth curves for male (gray circles, dashed line) and female (black triangles, solid line) *Ptychocheilus oregonensis* (northern pikeminnow) in Lake Merwin, Washington for years 2013–2014. (FL, fork length; mm, millimeter)

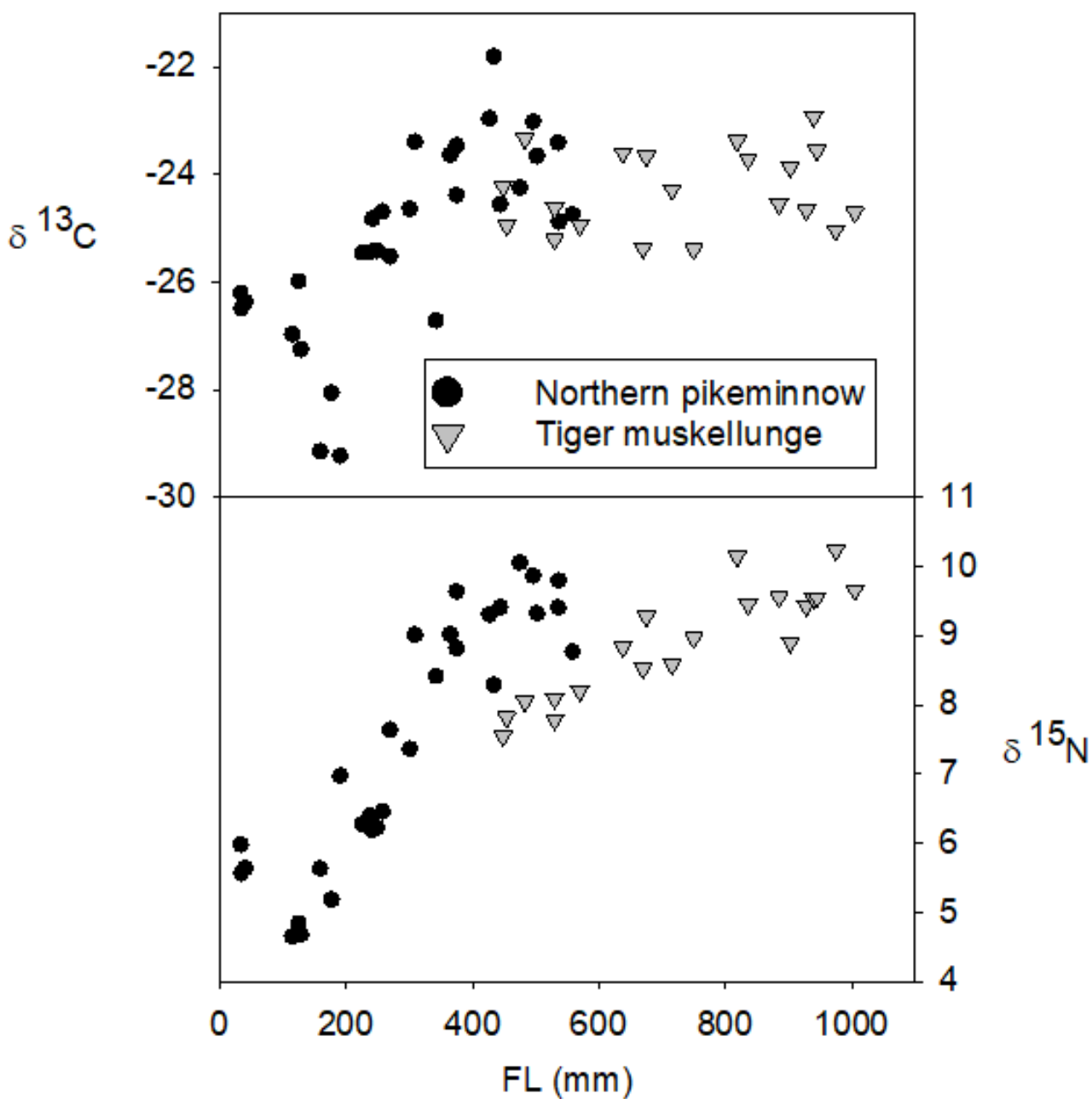


**Figure E4.** Isoclines of average water temperature (in degrees Celsius) from two stations one-third and two-thirds along the length of Swift Reservoir and Lake Merwin during April–October 2014, and November 2014 in Yale Lake, Washington. In Swift Reservoir, a profile from November 1999 and a partial profile from November 2013 were combined, and profiles inferred from tailrace temperatures from February and December 2013 were incorporated to fill out the seasonal thermal regime. Supplementary profiles from the lower half of Yale Lake from December 1997 and February 1998, and a composite of a November 1999 and a partial profile from November 2013, and January and March 2000 from the lower half of Lake Merwin were also included. (m, meter)

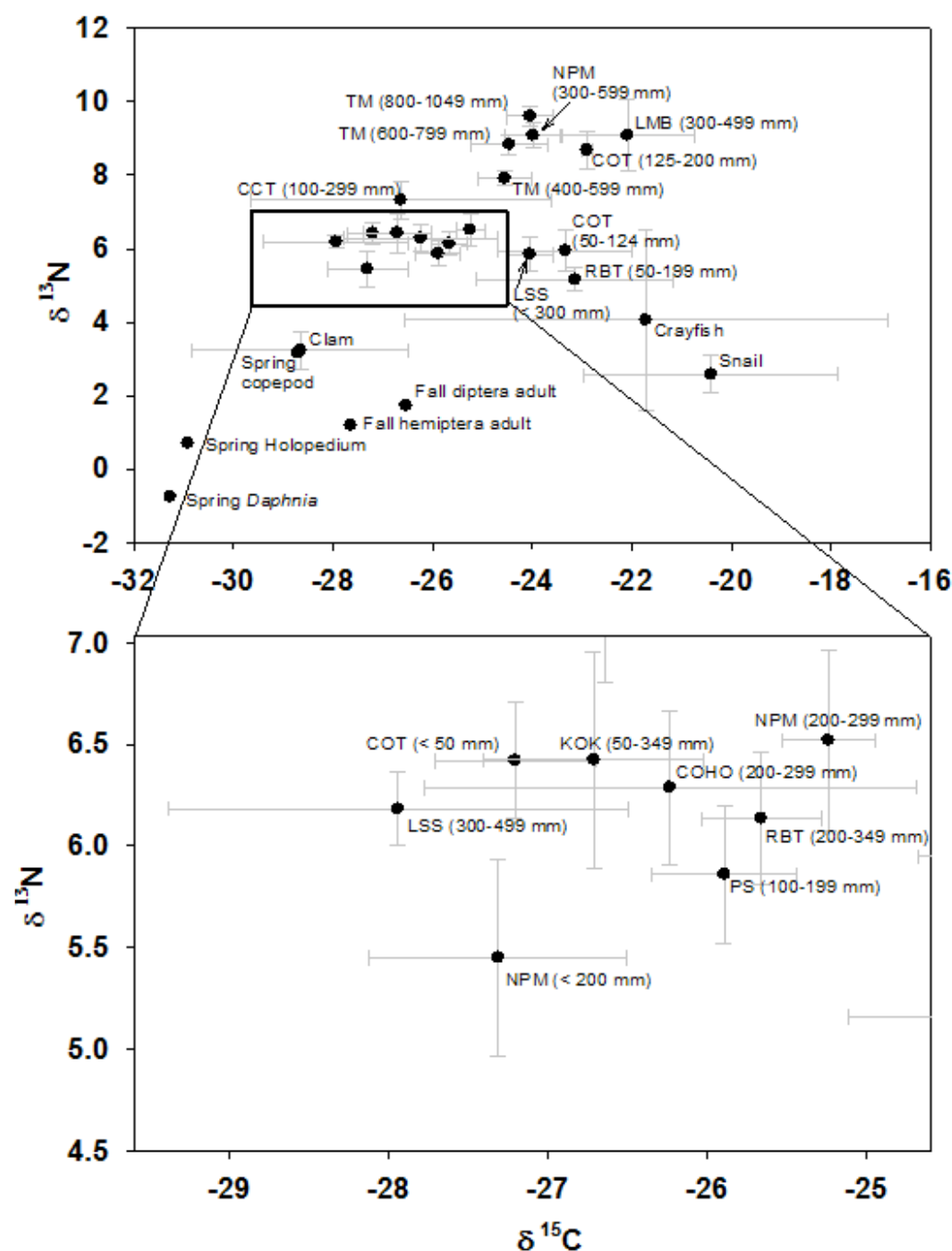


**Figure E5.** Catch-per-unit-effort for *Ptychocheilus oregonensis* (northern pikeminnow) greater than or equal to 200 mm caught in sinking horizontal gill nets by depth and season in Lake Merwin, Washington, in 2013 and 2014. (m, meter; mm, millimeter; >, greater than)

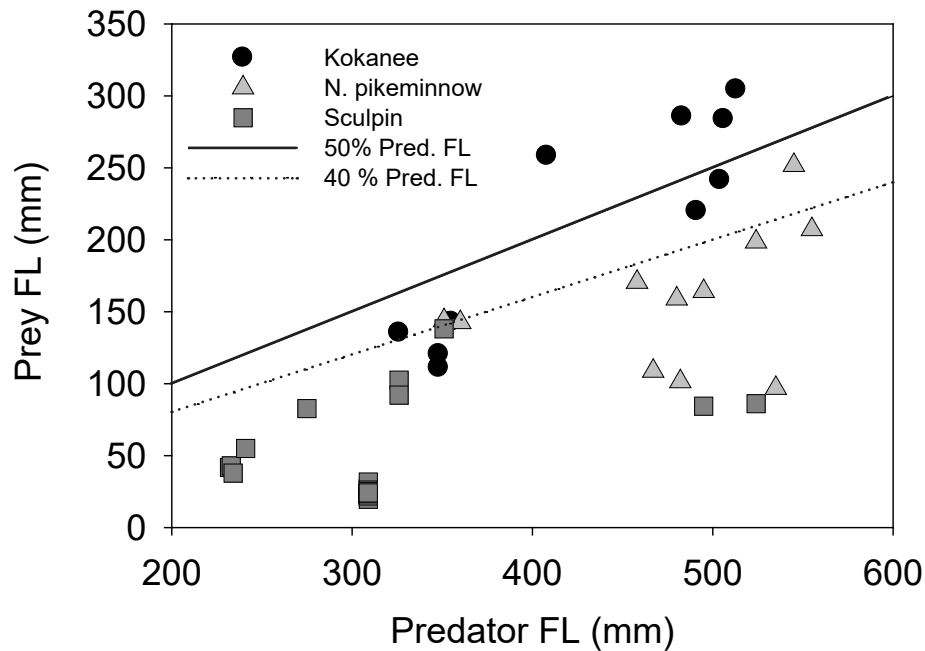




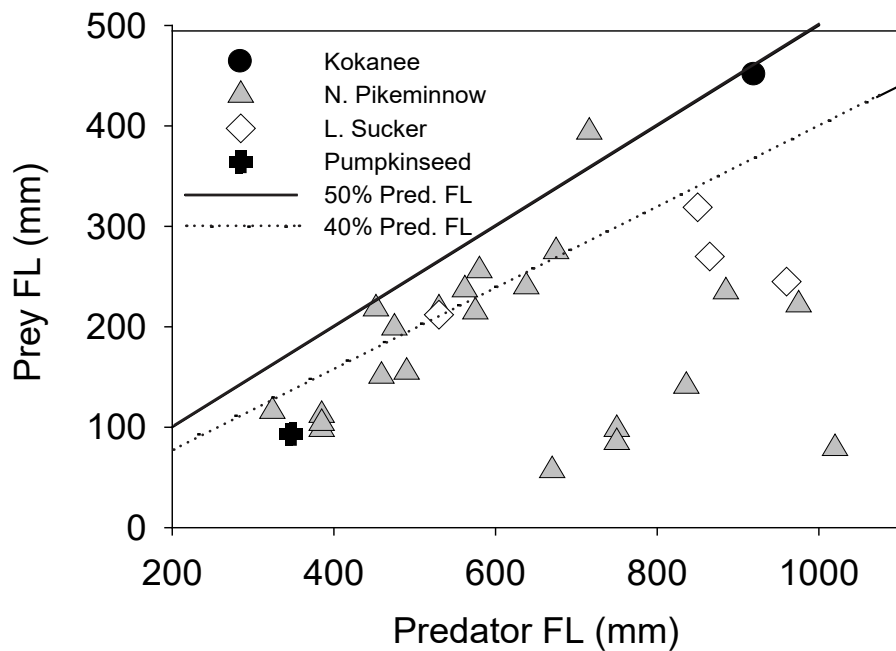
**Figure E6.** Stable isotope values of individual *Ptychocheilus oregonensis* (northern pikeminnow) and *Esox lucius x masquinong* (tiger muskellunge) as a function of fork length, Lake Merwin, Washington, for 2013–2014. ( $\delta^{13}\text{C}$ ; delta c 13, ratio of carbon isotopes  $^{12}\text{C}$  and  $^{13}\text{C}$ ;  $\delta^{15}\text{N}$ , delta n 15, ratio of nitrogen isotopes  $^{15}\text{N}$  and  $^{14}\text{N}$ ; FL, fork length; mm, millimeter)



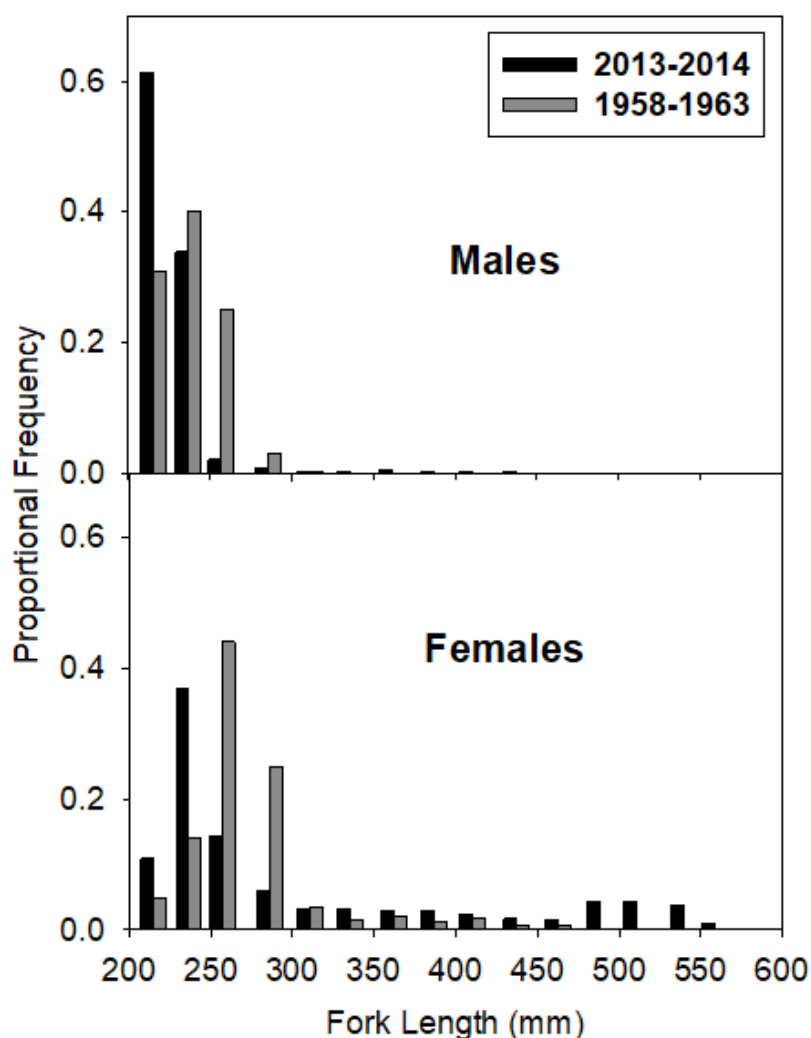
**Figure E7.** Average  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  signatures (error bars=2 standard errors) for organisms sampled in Lake Merwin, Washington, in 2013–2014. ( $\delta^{13}\text{C}$ ; delta c 13, ratio of carbon isotopes  $^{12}\text{C}$  and  $^{13}\text{C}$ ; NPM, *Ptychocheilus oregonensis* [northern pikeminnow]; TM, *Esox lucius x masquinongy* [tiger muskellunge]; LMB, *Micropterus salmoides* [largemouth bass]; COT, *Cottus* spp. [sculpin]; CCT, *Oncorhynchus clarkii* [coastal cutthroat trout]; RBT, *Oncorhynchus mykiss* [rainbow trout]; LSS, *Catostomus macrocheilus* [large-scale sucker]; crayfish, *Pacifastacus leniusculus* [signal crayfish]; <, less than; mm, millimeter; KOK, *Oncorhynchus nerka* [kokanee salmon]; COHO, *Oncorhynchus kisutch* [coho Salmon]; PS, *Lepomis gibbosus* [pumpkinseed sunfish];  $\delta^{15}\text{N}$ , delta n 15, ratio of nitrogen isotopes  $^{15}\text{N}$  and  $^{14}\text{N}$ )



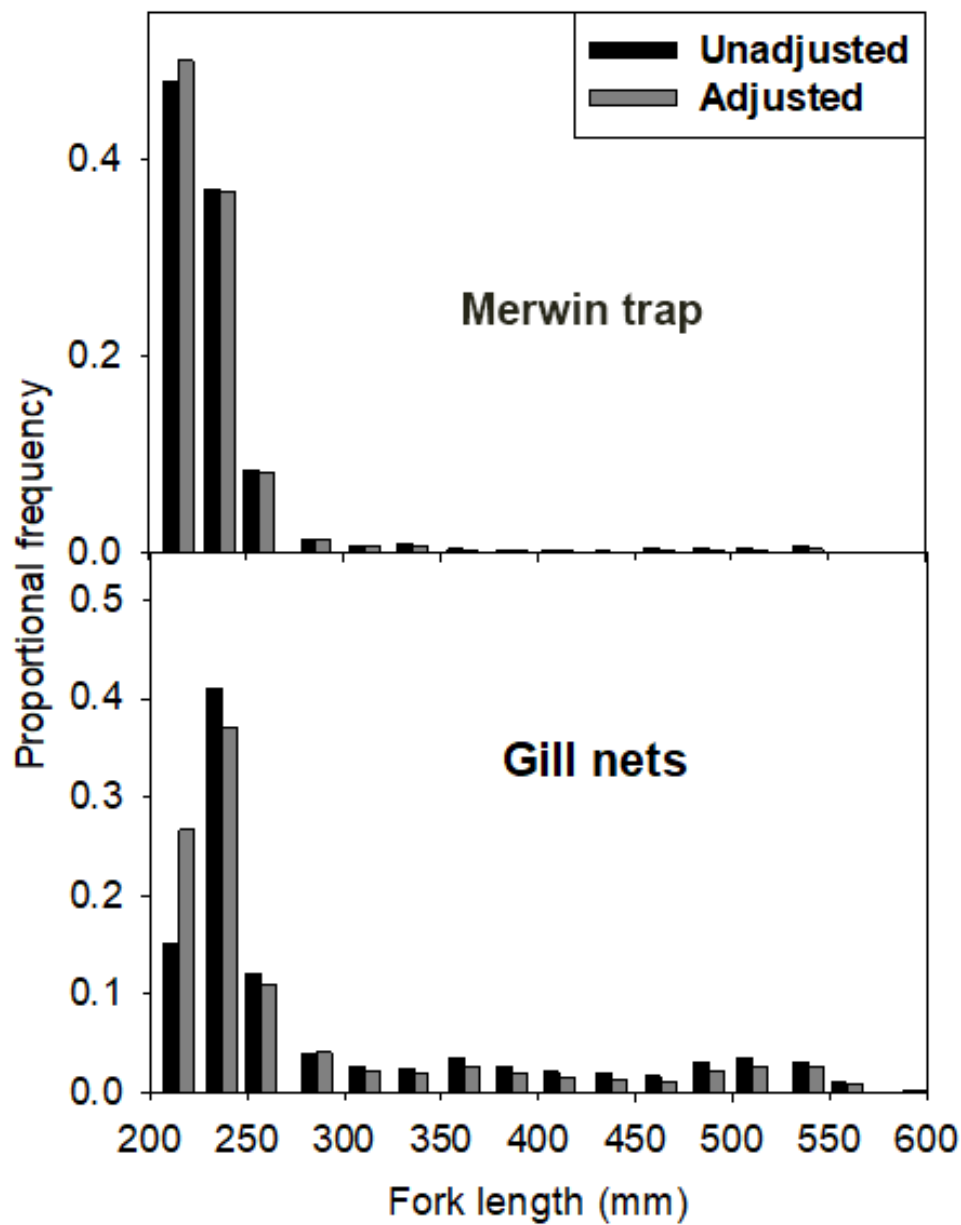
**Figure E8.** The relationship between *Ptychocheilus oregonensis* (northern pikeminnow) fork length and prey fish fork length for 2013–2014, Lake Merwin, Washington. (FL, fork length; mm, millimeter; Kokanee, *Oncorhynchus nerka* [kokanee salmon]; sculpin, *Cottus* spp. [signal crayfish]; %, percent; Pred., predator)



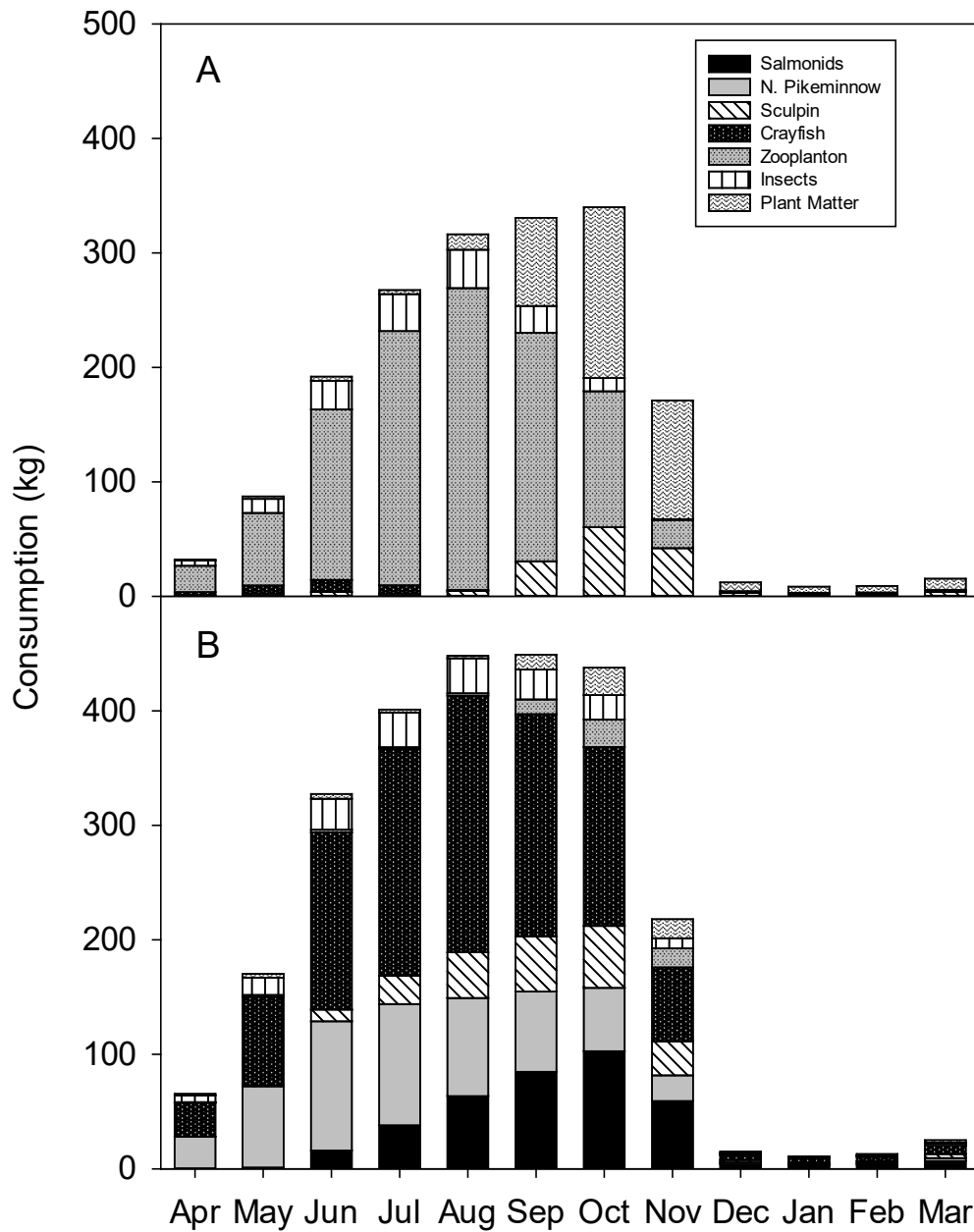
**Figure E9.** The relationship between *Esox lucius x masquinongy* (tiger muskellunge's) fork length and prey fish's fork length for 2013–2014, Lake Merwin, Washington. (Kokanee, *Oncorhynchus nerka* [kokanee salmon]; N. Pikeminnow, *Ptychocheilus oregonensis* [northern pikeminnow]; L. Sucker, *Catostomus macrocheilus* [largescale suckers]; Pumpkinseed, *Lepomis gibbosus* [pumpkinseed sunfish]; mm, millimeter; %, percent; FL, fork length)



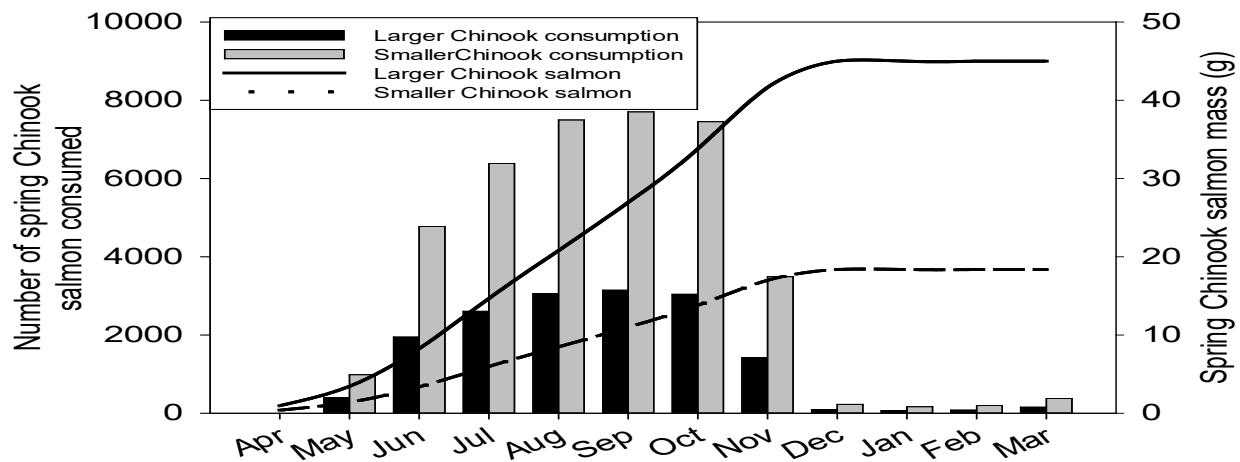
**Figure E10.** Length frequency distributions of male and female *Ptychocheilus oregonensis* (northern pikeminnow) captured in gill nets and traps in Lake Merwin, Washington, between 2013–2014 and 1958–1963 (Hamilton and others, 1970). The contemporary gill netting included larger mesh sizes than the historical data, which were included in the 2013–2014 distribution to best characterize the size distribution of the population. Efforts were made to standardize the length frequencies by including only fish captured in similar areas. (FL, fork length, mm, millimeters)



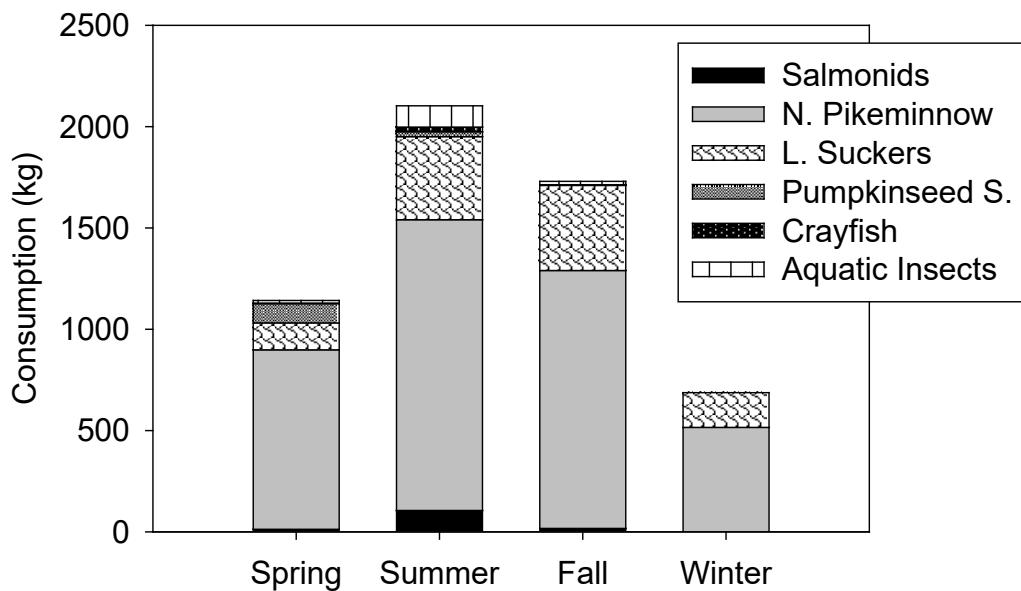
**Figure E11.** Length frequency histograms from raw catch data and data adjusted for size selectivity, Lake Merwin, Washington, from 2013–2014. The top panel shows Merwin trap data which was adjusted for size-selective encounter rate only, and the bottom panel shows gill net data that was adjusted for size selectivity of gill-net mesh sizes as well as encounter rate. Adjusted and unadjusted size distributions were not statistically significant for both gear types. (FL, fork length, mm, millimeters)



**Figure E12.** Estimates from bioenergetics simulations of monthly biomass of prey consumed by size-structured populations of 1,000 *Ptychocheilus oregonensis* (northern pikeminnow): A, 200–299 millimeters (mm) and B, greater than or equal to 300 mm, Lake Merwin, Washington. (kg, kilogram; sculpin, *Cottus* species; Crayfish, *Pacifastacus leniusculus* [signal crayfish])



**Figure E13.** Estimate of potential number of subyearling spring *Oncorhynchus tshawytscha* (Chinook salmon) that could be consumed monthly by a size-structured population unit of 1,000 large *Ptychocheilus oregonensis* (northern pikeminnow), and the expected monthly masses of reservoir-rearing subyearling Chinook salmon (shown as lines and secondary y-axis), Lake Merwin, Washington, for year(s). (g, gram)



**Figure E14.** Estimates from bioenergetics simulations of seasonal biomass of prey consumed by an age-structured population of 5,488 *Esox lucius x masquinongy* (tiger muskellunge), Lake Merwin, Washington. (kg, kilogram; L. Suckers, *Catostomus macrocheilus* [largescale suckers]; Pumpkinseed S., *Lepomis gibbosus* [pumpkinseed sunfish]; Crayfish, *Pacifastacus leniusculus* [signal crayfish])



## Tables

**Table E1.** Limnological and morphometric characteristics of Lake Merwin, Washington (PacifiCorp and Cowlitz Public Utility District, 2004; Sorel and others, 2016).

[km<sup>2</sup>, square kilometer; km, kilometer; m, meter; ~, approximately; mg/L, milligram per liter; <, less than; °C, degree Celsius; msl, mean sea level]

Attribute	Estimate
Surface area (km <sup>2</sup> )	15.7
Length (km)	23.3
Mean depth (m)	31
Maximum depth (m)	73
Mean Secchi depth transparency (m)	~5
Water residence time (days)	118.4
Total phosphorus (mg/L)	<.02
Trophic status	Oligotrophic
Months stratified	April–Sept.
Depth of thermocline (m)	~8
Ice cover	None
Range of surface temps (°C)	23–5
Maximum surface elevation (m msl)	73

**Table E2.** Relative abundance of fish species present in Lake Merwin, Washington, based on field sampling.

Common name	Scientific name	Relative abundance
Kokanee salmon	<i>Oncorhynchus nerka</i>	High*
Rainbow/steelhead trout	<i>Oncorhynchus mykiss</i>	Moderate*
Bull trout	<i>Salvelinus confluentus</i>	Rare
Cutthroat trout	<i>Oncorhynchus clarkii</i>	Rare
Juvenile coho salmon	<i>Oncorhynchus kisutch</i>	Rare*
Juvenile Chinook salmon	<i>Oncorhynchus tshawytscha</i>	Rare*
Northern pikeminnow	<i>Ptychocheilus oregonensis</i>	High
Largescale suckers	<i>Catostomus macrocheilus</i>	High
Sculpin	<i>Cottus</i> spp.	High
Threespine stickleback	<i>Gasterosteus aculeatus</i>	Rare
Tiger muskellunge	<i>Esox lucius</i> x <i>masquinongy</i>	Moderate*
Pumpkinseed sunfish	<i>Lepomis gibbosus</i>	High
Largemouth bass	<i>Micropterus salmoides</i>	Rare

\*Hatchery supplemented population.

**Table E3.** Abundance estimates of *Ptychocheilus oregonensis* (northern pikeminnow) by size class in Lake Merwin, Washington for 2013.

[%; percent; AICc, Akaike Information Criteria corrected for small sample size;  $\hat{N}$ , abundance estimate; PJS, POPAN formulation of the Jolly-Seber model; Y, yes; N, no; LP, Chapman estimator for the Lincoln-Peterson model; NA, not applicable]

Region	Model	Fixed survival	Survival (%)	AIC <sub>c</sub>	$\hat{N}$	Expansion	Expanded $\hat{N}$	Lower 95%	Upper 95%
Less than 200									
Whole	PJS	Y	73.2	225.0	400,090	1.0	400,090	218,667	732,039
Whole	PJS	N	34.4	225.5	311,754	1.0	311,754	92,582	1,049,770
Whole	LP	Y	NA	NA	367,119	1.0	367,119	205,405	682,972
Upper quarter	PJS	N	13.6	180.1	101,082	5.5	559,003	109,973	2,841,476
Upper quarter	PJS	Y	73.2	181.5	179,574	5.5	993,077	567,608	1,737,469
Upper quarter	LP	Y	NA	NA	147,548	5.5	815,966	419,394	1,684,744
<b>Average</b>							<b>574,502</b>	<b>268,938</b>	<b>1,454,745</b>
200–299									
Whole	PJS	Y	39.7	138.4	544,259	1.0	<sup>1</sup> 544,259	190,609	1,554,062
Whole	PJS	N	12.5	143.2	322,748	1.0	322,748	50,872	2,047,624
Whole	LP	Y	NA	NA	518,795	1.0	518,795	232,607	1,061,451
Upper quarter	PJS	N	NA	110.2	10,458	6.3	66,381	55,742	79,050
Upper quarter	PJS	Y	39.7	126.7	250,101	6.3	1,587,446	746,217	3,377,012
Upper quarter	LP	Y	NA	NA	178,794	6.3	1,134,846	475,760	3,076,582
<b>Average</b>							<b>695,746</b>	<b>291,968</b>	<b>1,865,964</b>
Greater than or equal to 300									
Whole	PJS	N	20.3	85.7	1,499	1.0	1,499	639	3,517
Whole	PJS	Y	85.1	86.3	2,590	1.0	2,590	945	7,102
Whole	LP	Y	NA	NA	5,894	1.0	5,894	2,448	15,828
Upper quarter	PJS	N	8.7	66.7	713	3.5	2,530	1,304	4,909
Upper quarter	PJS	Y	85.1	72.6	1,482	3.5	5,261	1,850	14,962
Upper quarter	LP	Y			3,100	3.5	<sup>1</sup> 11,002	3,728	39,878
<b>Average</b>							<b>4,796</b>	<b>1,819</b>	<b>14,366</b>

<sup>1</sup>Best estimate.

**Table E4.** Thermal experiences of *Ptychocheilus oregonensis* (northern pikeminnow) and *Esox lucius x masquinongy* (tiger muskellunge) in Lake Merwin, Washington.

[°C, degree Celsius; mm, millimeter; ≥, greater than or equal to]

Date	Simulation day	Thermal experience (°C)		
		200–299 mm	≥300 mm	Tiger muskellunge
1-April	1	7.7	8.3	8.3
15-May	45	11.5	12.3	12.3
30-June	89	15.6	16.7	16.7
19-July	109	17.8	19.1	19.1
15-August	135	18.8	20.1	20.1
18-September	168	18.6	19.3	19.3
10-October	190	17.5	17.6	17.6
18-November	228	12.5	12.7	12.7
15-December	255	5.8	5.8	5.8
1-January	270	5.5	5.5	5.5
1-March	330	6	6.3	6.3
31-March	365	7.7	8.3	8.3

**Table E5.** Energy density (joules/gram) of prey items of *Ptychocheilus oregonensis* (northern pikeminnow) and *Esox lucius x masquinongy* (tiger muskellunge) in Lake Merwin, Washington.[ZOOP, zooplankton; TERR, terrestrial insects; Inverts, aquatic invertebrates; Sal, salmonids; COT, *Cottus* spp.(sculpin); NPM, northern pikeminnow; LSS, *Catostomus macrocheilus* (largescale sucker), PUM, *Lepomis gibbosus* (pumpkinseed sunfish); CRAY, *Pacifastacus leniusculus* (signal crayfish); Plant, miscellaneous vegetation]

Day	ZOOP	TERR	Inverts	Sal	COT	NPM	LSS	PUM	CRAY	Plant
1	1950 <sup>a</sup>	5000	3400 <sup>b</sup>	5200	4305 <sup>c</sup>	6703 <sup>d</sup>	3641	4186	3318 <sup>c</sup>	1435
365	1950	5000	3400	5200	4305	6703	3641	4186	3318	1435

<sup>a</sup>Sorel and others, 2016.<sup>b</sup>Hansen and others, 1997.<sup>c</sup>Mazur, 2004.<sup>d</sup>Petersen and Ward, 1999.

**Table E6.** Bioenergetics inputs of growth and spawning losses and output of percent maximum consumption and total *Oncorhynchus nerka* (Kokanee salmon), *Ptychocheilus oregonensis* (northern pikeminnow), *Cottus* spp. (sculpins); and *Pacifastacus leniusculus* (signal crayfish) annual consumption by individual male and female northern pikeminnow age 3–14 years, Lake Merwin, Washington. Spawning losses were 3.9 percent of body mass for males age 3–14 years, 6 percent for females age 3 years, and 8.9 percent for females age 4–14 years.

[mm, millimeter; g, gram; %, percent; %C<sub>max</sub>, percent maximum consumption]

Age (years)	Initial fork length (mm)	Initial weight (g)	Final weight (g)	%C <sub>max</sub>	Annual consumption (g)				
					Total	Kokanee	Northern pikeminnow	Sculpins	Signal crayfish
Males									
3	208	94	137	60	1,290	0	0	90	21
4	236	137	188	57	1,622	0	0	116	26
5	263	188	258	57	2,060	0	0	144	34
6	288	258	335	55	2,480	0	0	182	42
7	311	335	421	25	1,481	0	0	215	640
8	333	421	515	24	1,708	223	316	126	739
9	354	515	617	23	1,939	256	366	144	839
10	373	617	724	23	2,170	289	417	163	940
11	392	724	837	23	2,401	323	468	182	1,041
12	409	837	954	22	2,630	356	519	201	1,140
13	425	954	1,075	22	2,856	389	570	219	1,239
14	440	1,075	1,197	22	3,078	421	620	238	1,336
Females									
3	223	115	180	62	1,602	0	0	107	25
4	259	180	259	60	2,107	0	0	146	34
5	293	259	387	28	1,456	0	0	189	625
6	325	387	518	26	1,784	224	305	126	768
7	354	518	667	25	2,139	271	379	152	923
8	382	667	831	25	2,504	322	457	181	1,082
9	408	831	1,009	24	2,873	375	537	211	1,243
10	432	1,009	1,198	23	3,244	428	619	241	1,404
11	455	1,198	1,396	23	3,614	482	701	272	1,565
12	476	1,396	1,601	23	3,978	535	783	302	1,724
13	496	1,601	1,811	22	4,337	587	864	331	1,880
14	515	1,811	2,025	22	4,687	639	944	360	2,033

**Table E7.** Bioenergetics inputs of growth-at-age and outputs of percent maximum consumption (%C<sub>max</sub>), total consumption, and growth efficiency by individual *Esox lucius x masquinongy* (tiger muskellunge) aged 1–10 years, Lake Merwin, Washington.[mm, millimeter; g, gram; %C<sub>max</sub>, percent maximum consumption; %, percent]

Age (years)	Initial fork length (mm)	Initial weight (g)	Final weight (g)	Growth (g)	%C <sub>max</sub>	Total consumption (g)	Growth efficiency (%)
1	316	184	1,116	932	48.85	2,213	42.13
2	531	1,116	2,592	1,475	40.28	4,772	30.92
3	676	2,592	4,159	1,568	35.74	7,049	22.24
4	774	4,159	5,545	1,385	33.01	8,798	15.74
5	841	5,545	6,652	1,107	31.29	10,060	11.01
6	886	6,652	7,486	834	30.18	10,944	7.62
7	917	7,486	8,092	606	29.44	11,553	5.24
8	938	8,092	8,521	430	28.95	11,971	3.59
9	952	8,521	8,821	300	28.62	12,255	2.45
10	961	8,821	9,029	208	28.40	12,448	1.67

**Table E8.** Mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  stable isotope values for fish and invertebrates sampled in the Lake Merwin, Yale Lake, and Swift Reservoir of the Lewis River, Washington, by location and size class for years 2013–2014.

[mm, millimeter; n, number of samples;  $\delta^{15}\text{N}$ , delta n 15, ratio of nitrogen isotopes  $^{15}\text{N}$  and  $^{14}\text{N}$ ;  $\delta^{13}\text{C}$ , delta c 13, ratio of carbon isotopes  $^{12}\text{C}$  and  $^{13}\text{C}$ ; PS, pumpkinseed sunfish (*Lepomis gibbosus*); NA, not applicable; Coho, *Oncorhynchus kisutch* (coho salmon); sculpin, *Cottus* spp.; <, less than; CCT, *O. clarkii* (coastal cutthroat trout); RBT, *Os. mykiss* (rainbow trout); kokanee, *O. nerka* (kokanee salmon); LMB, *Micropterus salmoides* (largemouth bass); LSS, *Catostomus macrocheilus* (largescale sucker); NPM, *Ptychocheilus oregonensis* (northern pikeminnow); tiger muskie, *Esox lucius x masquinongy* (tiger muskellunge); SB, *Gasterosteus aculeatus* (threespine stickleback)]

Species	Size Class (mm)	n	Mean $\delta^{15}\text{N}$	Minimum $\delta^{15}\text{N}$	Maximum $\delta^{15}\text{N}$	Mean $\delta^{13}\text{C}$	Minimum $\delta^{13}\text{C}$	Maximum $\delta^{13}\text{C}$
Lake Merwin								
PS	100–199	3	5.860	5.637	6.201	–25.895	–26.350	–25.592
Clam	NA	4	3.231	2.607	3.848	–28.656	–30.751	–25.627
Coho	200–299	4	6.288	5.888	6.723	–26.236	–27.546	–24.334
Copepods	NA	1	3.160	3.160	3.160	–28.711	–28.711	–28.711
Sculpin	<100	9	6.112	5.307	6.685	–25.386	–27.959	–21.971
	100–199	3	8.068	6.839	8.946	–23.354	–24.257	–22.855
Crayfish	NA	2	4.054	2.801	5.306	–21.718	–24.198	–19.238
CCT	100–299	3	7.318	7.037	7.844	–26.639	–29.092	–23.817
<i>Daphnia</i>	0	1	–0.758	–0.758	–0.758	–31.270	–31.270	–31.270
Diptera	0	1	1.726	1.726	1.726	–26.537	–26.537	–26.537
Hemiptera	0	1	1.194	1.194	1.194	–27.648	–27.648	–27.648
Holopedium	0	1	0.695	0.695	0.695	–30.916	–30.916	–30.916
RBT	<299	7	5.605	4.992	6.489	–24.342	–26.121	–22.133
	300–399	7	9.186	6.544	10.757	–20.956	–26.262	–17.692
	500–699	6	13.081	12.329	13.656	–17.658	–18.230	–17.177
Kokanee	<399	9	6.423	5.232	7.573	–26.713	–28.186	–25.062
LMB	300–499	2	9.084	8.585	9.582	–22.085	–22.768	–21.402

**Table E8.** Mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  stable isotope values for fish and invertebrates sampled in the Lake Merwin, Yale Lake, and Swift Reservoir of the Lewis River, Washington, by location and size class for years 2013–2014.—Continued

[mm, millimeter; n, number of samples;  $\delta^{15}\text{N}$ , delta n 15, ratio of nitrogen isotopes  $^{15}\text{N}$  and  $^{14}\text{N}$ ;  $\delta^{13}\text{C}$ , delta c 13, ratio of carbon isotopes  $^{12}\text{C}$  and  $^{13}\text{C}$ ; PS, pumpkinseed sunfish (*Lepomis gibbosus*); NA, not applicable; Coho, *Oncorhynchus kisutch* (coho salmon); sculpin, *Cottus* spp.; <, less than; CCT, *O. clarkii* (coastal cutthroat trout); RBT, *O. mykiss* (rainbow trout); kokanee, *O. nerka* (kokanee salmon); LMB, *Micropterus salmoides* (largemouth bass); LSS, *Catostomus macrocheilus* (largescale sucker); NPM, *Ptychocheilus oregonensis* (northern pikeminnow); tiger muskie, *Esox lucius x masquinongy* (tiger muskellunge); SB, *Gasterosteus aculeatus* (threespine stickleback)]

Species	Size class (mm)	n	Mean $\delta^{15}\text{N}$	Minimum $\delta^{15}\text{N}$	Maximum $\delta^{15}\text{N}$	Mean $\delta^{13}\text{C}$	Minimum $\delta^{13}\text{C}$	Maximum $\delta^{13}\text{C}$
LSS	<200	4	5.841	5.415	6.286	-24.051	-24.763	-23.791
	300–499	5	6.182	5.849	6.380	-27.943	-29.670	-25.710
NPM	<200	9	5.451	4.639	6.963	-27.315	-29.245	-26.005
	200–299	6	6.519	6.179	7.626	-25.242	-25.543	-24.708
	300–399	5	8.640	7.353	9.627	-24.584	-26.729	-23.479
	400–599	9	9.348	8.278	10.048	-23.714	-24.899	-21.826
Snail	NA	4	2.576	1.993	3.135	-20.409	-22.691	-16.770
Tiger muskie	400–799	11	8.333	7.546	9.275	-24.513	-25.396	-23.345
	800–1099	9	9.608	8.902	10.236	-24.048	-25.041	-22.930
Yale Lake								
Bull trout	300–399	2	7.923	7.913	7.933	-24.729	-26.582	-22.876
	400–799	11	9.385	8.844	10.164	-24.682	-27.557	-22.203
Copepods	NA	1	3.684	3.684	3.684	-31.088	-31.088	-31.088
Sculpin	<100	5	6.189	5.285	7.603	-25.036	-28.558	-21.887
	100–199	1	7.057	7.057	7.057	-22.094	-22.094	-22.094
Crayfish	NA	2	3.037	2.568	3.507	-23.325	-26.952	-19.697
CCT	200–399	7	7.499	5.706	8.549	-24.756	-27.164	-22.960
<i>Daphnia</i>	NA	2	0.463	-0.126	1.053	-31.221	-31.654	-30.789
Holopedium	NA	1	0.872	0.872	0.872	-31.094	-31.094	-31.094
Plankton	NA	1	1.034	1.034	1.034	-26.575	-26.575	-26.575
Kokanee	<299	13	6.266	5.460	6.897	-30.441	-33.570	-27.435
LSS	200	4	4.664	4.148	5.021	-21.376	-24.634	-19.008
	300	5	6.128	5.707	6.956	-26.099	-27.727	-24.416
NPM	<200	8	4.753	4.207	5.263	-26.657	-29.247	-25.138
	200–299	6	6.304	5.640	6.988	-25.143	-25.543	-24.682
	300–399	6	8.083	7.431	9.427	-23.124	-26.712	-21.698
	400–599	4	8.564	7.962	9.356	-24.831	-26.950	-21.637
RBT	200	4	6.095	5.182	7.708	-24.074	-26.922	-19.334
SB	<100	5	6.334	4.580	7.355	-28.276	-30.050	-26.715
Swift Reservoir								
Bull trout	100–299	4	8.618	7.146	11.898	-23.433	-24.877	-22.047
	300–699	16	10.417	8.664	11.846	-24.100	-27.718	-21.579
Caddisfly	NA	1	-0.297	-0.297	-0.297	-24.516	-24.516	-24.516
Chinook	100–299	7	5.504	4.817	7.126	-26.201	-27.380	
Coho	<200	8	5.405	4.398	6.721	-25.534	-27.146	-23.786
	200–299	5	6.454	5.441	7.224	-26.336	-26.931	-25.486

**Table E8.** Mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  stable isotope values for fish and invertebrates sampled in the Lake Merwin, Yale Lake, and Swift Reservoir of the Lewis River, Washington, by location and size class for years 2013–2014.—Continued

[mm, millimeter; n, number of samples;  $\delta^{15}\text{N}$ , delta n 15, ratio of nitrogen isotopes  $^{15}\text{N}$  and  $^{14}\text{N}$ ;  $\delta^{13}\text{C}$ , delta c 13, ratio of carbon isotopes  $^{12}\text{C}$  and  $^{13}\text{C}$ ; PS, pumpkinseed sunfish (*Lepomis gibbosus*); NA, not applicable; Coho, *Oncorhynchus kisutch* (coho salmon); sculpin, *Cottus* spp.; <, less than; CCT, *O. clarkii* (coastal cutthroat trout); RBT, *O. mykiss* (rainbow trout); kokanee, *O. nerka* (kokanee salmon); LMB, *Micropterus salmoides* (largemouth bass); LSS, *Catostomus macrocheilus* (largescale sucker); NPM, *Ptychocheilus oregonensis* (northern pikeminnow); tiger muskie, *Esox lucius x masquinongy* (tiger muskellunge); SB, *Gasterosteus aculeatus* (threespine stickleback)]

Species	Size class (mm)	n	Mean $\delta^{15}\text{N}$	Minimum $\delta^{15}\text{N}$	Maximum $\delta^{15}\text{N}$	Mean $\delta^{13}\text{C}$	Minimum $\delta^{13}\text{C}$	Maximum $\delta^{13}\text{C}$
Copepods	NA	1	3.675	3.675	3.675	-29.048	-29.048	-29.048
Sculpin	<100	5	4.856	3.796	7.048	-25.573	-29.037	-22.757
	100–199	3	6.243	4.360	8.016	-25.588	-27.891	-23.361
Crayfish	NA	4	3.911	3.118	5.608	-23.728	-25.457	-22.432
CTT	200–399	11	7.045	5.832	8.201	-24.368	-25.813	-22.616
<i>Daphnia</i>	NA	1	0.708	0.708	0.708	-28.709	-28.709	-28.709
RBT	100–199	5	4.924	2.845	6.378	-24.982	-25.904	-23.550
	200–299	9	6.236	5.120	8.003	-25.191	-27.289	-23.040
	300–399	11	7.595	5.245	11.187	-23.379	-27.230	-19.048
	500–599	3	11.410	10.194	12.211	-18.278	-20.058	-17.073
LSS	<500	8	4.584	3.563	6.652	-24.382	-25.928	-22.315
Snails	NA	1	2.415	2.415	2.415	-23.750	-23.750	-23.750
MWF	200–399	4	5.387	4.921	5.844	-21.953	-22.420	-20.770
SB	400	1	7.498	7.498	7.498	-20.548	-20.548	-20.548

**Table E9.** Diet proportions of two size classes of *Ptychocheilus oregonensis* (northern pikeminnow) (200–299 millimeters [mm] and greater than [>] 300 mm) in Lake Merwin, Washington, for the years 2013–2014.

[n, sample size; ZOOP, zooplankton; Inverts, aquatic invertebrates; KOK, *Oncorhynchus nerka* (kokanee salmon); COT, *Cottus*, spp. (sculpin); NPM, *Ptychocheilus oregonensis* (northern pikeminnow); CRAY, *Pacifastacus leniusculus* (signal crayfish); Plant, miscellaneous vegetation]

Day	Season	n	Diet proportions							
			ZOOP	Terrestrial insects	Inverts	KOK	COT	NPM	CRAY	Plant
200–299 millimeters										
45	Spring	23	0.72	0.05	0.10	0	0.03	0	0.09	0.03
135	Summer	9	0.88	0	0.11	0	0	0	0	0.01
225	Fall	12	0.12	0	0	0	0.26	0	0	0.63
>300 millimeters										
45	Spring	11	0.01	0	0.09	0	0	0.43	0.45	0.02
135	Summer	29	0	0	0.07	0.14	0.09	0.19	0.51	0
225	Fall	26	0.08	0.04	0	0.28	0.14	0.10	0.29	0.08



**Table E10.** Diet proportions of tiger muskellunge including *Ptychocheilus oregonensis* (northern pikeminnow) in Lake Merwin, Washington, for years 2013–2014.

[n, sample size; FL, fork length; mm, millimeter; NPM, northern pikeminnow; LSS, *Catostomus macrocheilus* (largescale suckers), PKS, *Lepomis gibbosus* (pumpkinseed sunfish); KOK, *Oncorhynchus nerka* (kokanee); Inverts, aquatic macroinvertebrates]

Season	n	FL range (mm)	Diet proportions				
			NPM	LSS	PKS	KOK	Inverts.
Spring	10	300–975	0.80	0.10	0.10	0	0
Summer	15	375–1,025	0.65	0.20	0	0.07	0.08
Fall	4	525–850	0.75	0.25	0	0	0

# Chapter F. Studies Assessing Anadromous-Resident Fish Interactions in the Lewis River, Washington

## Introduction

Understanding interspecific interactions and likely risks of such interactions is considered an important part of anadromous salmon reintroductions (Anderson and others, 2014). The goal of this report is to assess the effects of anadromous fish reintroduction on resident species, and, conversely, assess the effects of resident fish on the reintroduced anadromous fish. Juvenile anadromous salmonids will utilize tributary habitat and reservoirs as migratory corridors and rearing habitats to varying degrees. Therefore, the magnitude and duration of interactions with resident species will vary among anadromous salmonids. Although *Salvelinus confluentus* (bull trout), *Oncorhynchus kisutch* (coho salmon), *O. mykiss* (steelhead), *O. tshawytscha* (Chinook salmon), and *O. clarki* (coastal cutthroat trout) all historically occurred sympatrically in the upper part of the Lewis River in Washington (for example, Lowery and Beauchamp, 2015), the physical template has changed dramatically since anadromous species were abundant in the upper Lewis River.

This report focuses on evaluating interactions between newly reintroduced salmon and resident fish in tributary and reservoir environments. To address this objective, we specifically evaluated the distribution, behavior, and community interactions of anadromous salmon and resident fish at different life stages. Within the reservoir environment, we also assessed the forage base and capacity of reservoirs to support juvenile salmon. Since reintroduction of anadromous salmonids is already underway in Swift Reservoir on the Lewis River, we focused most of these efforts in the Swift Reservoir and its tributaries. Our specific objectives included (1) conducting a review of the existing literature and potential community-level interactions among reintroduced anadromous species and native and nonnative taxa and (2) conducting a suite of field studies in the upper Lewis River (a) assessing the distributional overlap between coho salmon and bull trout at different life stages and environments, (b) quantifying the extent of diet overlap between resident fish and anadromous species in tributary and reservoir habitats and potential shifts since reintroduction was initiated, (c) determining the forage capacity of the reservoir environments, and (d) integrating field results into a modeling framework to assess the potential effects of anadromous reintroductions on extant bull trout populations. We present the results of objective 1 first and follow with field studies and field results.

## Literature Review and Potential Community-Level Interactions

### Review of Anadromous-Resident Interactions

This review focused on the effects of anadromous reintroductions on native bull trout and coastal cutthroat trout but did not cover interactions between hatchery and wild fish of anadromous species, which have been extensively studied. Given a report describing habitat use and the overlap between anadromous species and resident trout (PacifiCorp and Cowlitz Public Utility District [PUD], 2002), we constrained our synthesis to new information describing niche overlap, the known effects of anadromous species on coastal cutthroat trout and bull trout from empirical studies, information describing known effects of native taxa (bull trout, coastal cutthroat trout) on anadromous reintroductions, and predation by nonnative predators and management considerations.

### Effects of Anadromous Reintroductions on Native Species

*Distributional overlap.*—Overlap in distribution of bull trout and juvenile Chinook salmon, coho salmon, steelhead, and coastal cutthroat trout is likely to be dictated by thermal requirements, local habitat quality, and life-history expressions and vary across life-stage and species. The fact that both coastal cutthroat trout and bull trout can exhibit complex life histories with

movements from headwaters to reservoir environments suggests the potential for overlap with anadromous species within the upper Lewis River. Indeed, overlap between coastal cutthroat trout with coho salmon (for example, Glova, 1987; Trotter, 1989; Sabo and Pauley, 1997; Pess and others, 2011) and steelhead (for example, Trotter, 1989; Slaney and others, 1996; Heath and others, 2010) is extensive and well established in the literature. Bull trout overlap with Chinook salmon, steelhead, and coho salmon has also been demonstrated, particularly in headwater streams and reservoirs (for example, Thurrow and others, 1997; Taylor and others, 1999; Lowery, 2009; Schoby and Keeley, 2011; Portland General Electric Company, 2013).

Formal assessments of overlap during anadromous species supplementation programs in the Yakima River Basin in Washington have found considerable overlap between spring Chinook salmon, steelhead, and coastal cutthroat trout, but limited overlap with bull trout (Pearsons and Temple, 2007). The greatest amount of overlap found by Pearsons and Temple (2007) occurred in mainstem reaches with mixed results for smaller tributaries. Interestingly, the changes in distributional overlap have not occurred during large increases in abundance of anadromous stocks. Within the Yakima River Basin, however, supplementation release sites were specifically targeted to minimize impacts to nontarget taxa (Pearsons, 2008, 2010).

Where native bull trout distributions are proximate to supplementation sites, distributional overlap may be considerably higher, particularly during later phases of reintroductions and where supplementation fish demonstrate large upstream movements (McMichael and Pearsons, 2001). The extent of distributional overlap is also likely to be affected by native trout life-history strategies, abundance, distribution, and thermal and habitat characteristics of the basins (that is, are habitat conditions suitable for overlap?). In the Lewis River, upstream of Swift Reservoir, overlap in distribution has been observed between wild (that is, naturally produced) juvenile coho salmon and juvenile bull trout (see distributional overlap parts of the “Results and Discussion” section of this report). Although, densities of juvenile coho salmon are currently relatively low, recent diet studies indicate considerable overlap in trophic level and likely forage resources (see “Food web and community interactions” in this chapter).

*Overlap in thermal requirements.*—The importance of temperature in determining seasonal species distribution patterns and mediating interspecific interactions has been well documented (for example, Fausch, 1989; Wenger and others, 2011). When compared, the temperatures needed for maximum growth of bull trout are considerably lower than for juvenile Chinook salmon, coho salmon, and steelhead (the maximum is unknown for coastal cutthroat trout). However, the range for optimum growth is relatively similar (little information on thermal suitability for coastal cutthroat trout currently exists; table F1) with considerable opportunities for overlap. Ultimately, information regarding the thermal suitability from lab studies and those observed in different portions of species ranges (Spina, 2007) may not be appropriate to determine in situ thermal preferences for the upper Lewis River. Interspecific interactions may shift the thermal ranges used by individual species (for example, Hutchinson, 1978). In addition, it is unclear to what extent there is local variation in species thermal tolerances (meaning, Eliason and others, 2011).

*Overlap in spawning habitat for fall spawners.*—Overlap in spawning habitat can be substantial for bull trout, coho salmon, and Chinook salmon, all spawn during the late summer to early autumn. Across their native range, bull trout typically spawn from August through late October (Fraley and Shepard, 1989; Rieman and McIntyre, 1993; Howell and Sankovich, 2012). In the upper Lewis River Basin, bull trout spawning in Cougar Creek and Pine Creek and tributaries has been documented as early as the end of July through late October (PacifiCorp and Cowlitz PUD, 2002). Recent redd data (2012–2015) suggest that bull trout spawning in Swift Reservoir tributaries typically ends in mid-October (see “Redd superimposition” in this chapter). Based on information in the Lewis River below Merwin Dam, spring Chinook salmon typically spawn during September and October; fall Chinook salmon spawn during mid-October through early November; and coho salmon spawn during mid-October through early December (PacifiCorp and Cowlitz PUD, 2002), typically after bull trout. During the first 3 years of coho salmon reintroduction above Swift Dam (2012–2015), redd surveys indicate that most spawning occurred between early October and late November.

Of greatest concern during the fall spawning period is the risk of redd superimposition. Superimposition by coho salmon on top of bull trout has been documented in tributaries to Swift Reservoir (see “Redd superimposition” in this chapter). Superimposition is likely to be most pronounced as densities of Chinook and coho salmon increase and saturate habitat. Recent survey information suggests the later timing of coho salmon spawning and the fact that coho salmon spawn in smaller streams more similar to those where bull trout spawn than do Chinook salmon suggest a higher likelihood of coho salmon superimposition on bull trout redds. Where the species are naturally sympatric (that is, wild populations; Lowery and Beauchamp, 2015), superimposition is likely to be substantially lower (that is, minimizing contemporary competitive interactions; Connell, 1980) than during reintroduction phases when hatchery-reared individuals that lack natal homing are released (Quinn, 1993).

Coho and Chinook salmon and bull trout are all generally considered to spawn in pool-tail/riffle-crest habitat (Kondolf, 2000), but spawning generally extends to areas with high intragravel flows. These intragravel flows include both upwelling (positive vertical hydraulic gradient) and downwelling (negative vertical hydraulic gradient), and use of both types of intragravel flows has been observed for bull trout (Baxter and McPhail, 1999; Baxter and Hauer, 2000; Bean, 2012), Chinook salmon (Vronskii and Leman, 1991; Geist and Dauble, 1998), and coho salmon (Mull and Wilzbach, 2007). The selection of areas with positive or negative hydraulic gradients is likely to allow for the exchange between subsurface and surface flows (Baxter and Hauer, 2000) or to moderate temperatures.

Like most salmonids, high levels of fine sediment can have detrimental effects on egg survival (Tappel and Bjornn, 1983), and spawning gravel is an additional habitat metric that may facilitate overlap between the three species. Although some overlap

is likely across each of the species, substrate use for spawning Chinook salmon (mean=47 millimeters [mm]; range=1–175 mm; as reviewed in Kondolf, 2000) is considerably larger than observed for bull trout (mean=29 mm; range=3–58 mm; as reviewed in Baxter and McPhail, 1996) and coho salmon (mean=20 mm; range=5–35 mm; as reviewed in Kondolf, 2000; Mull, 2005). The similarity in spawning substrate used by bull trout and coho salmon further suggests a high potential for overlap during the spawning period, particularly when densities are high.

The current understanding of Chinook salmon, coho salmon, and bull trout spawning periods in the upper Lewis River suggests redd depth may also be an important factor in considering interspecific interactions. Redd depths are typically shallower for bull trout (mean=16.5 centimeters [cm], mean range=11–17 cm; Weeber and others, 2010) than reported for Chinook salmon (mean=28.4 cm, mean range=24.2–43.9 cm; DeVries, 1997), and coho salmon (mean range=21.1 cm, mean range=12.3–31.6 cm; DeVries, 1997; Mull, 2005). Deeper redds from anadromous species are likely to have the greatest superimposition impacts on bull trout redds where anadromous species spawn later than bull trout (Weeber and others, 2010). Monitoring the potential for superimposition is warranted in the upper Lewis River, particularly if Chinook and coho salmon spawning extends to the core bull trout spawning areas (for example, Pine Creek and its tributaries).

*Population-level effects.*—The effects of anadromous reintroductions on native bull trout and coastal cutthroat trout populations are relatively limited, so other native salmonids need to be considered for this review. Riley and others (2004) found no significant effects of Chinook and coho salmon supplementation releases on rainbow trout and coastal cutthroat trout fry densities. In a review of existing studies, Naman and Sharpe (2012) found hatchery-reared predation of native fish to be relatively low. At an individual level, predation of fry may be relatively low, but population-level predation may be high, particularly where large supplementation releases occur and considerable overlap in distribution occurs with fry rearing (Naman and Sharpe, 2012; Tabor and others, 2012).

Additional concerns exist surrounding the competitive interactions between coastal cutthroat trout and juvenile coho salmon. Some competition studies have shown that coho salmon exhibit dominance over juvenile coastal cutthroat trout (Sabo and Pauley, 1997) often resulting in displacement of coastal cutthroat trout (Glova, 1987). However, these results are not consistent across studies (Kiffney and others, 2009), and the effects of interspecific competition has not been documented to have fitness or population-level effects for coastal cutthroat trout (Kiffney and others, 2009; Pess and others, 2011).

Early research in headwater streams in the Yakima River Basin, however, suggested large increases in wild Chinook salmon abundance did not lead to significant changes in rainbow trout growth, abundance, and biomass (McMichael and Pearsons, 1998). Long-term assessments, however, found hatchery-reared Chinook salmon supplementation has led to significant declines in rainbow trout abundance, which is likely attributable to the cumulative effects of increases in both hatchery supplementation and increases in wild Chinook salmon abundance (that is, replacement; Pearsons and Temple, 2010). Continued monitoring in the Yakima River, however, has found differential results, as mean abundance of coastal cutthroat trout and *Prosopium williamsoni* (mountain whitefish) increased during hatchery supplementation (Temple and Pearsons, 2012). Although Temple and Pearsons (2012) continued to find significant decreases in rainbow trout size structure during supplementation (that is, similar to Pearsons and Temple, 2010), the authors did not find evidence that supplementation caused such patterns.

The effects of reintroductions can also have genetic consequences for closely related steelhead and coastal cutthroat trout. Of particular concern is the effect of residualized hatchery-reared steelhead (that is, fish that remain as residents), which typically is greater than (>) 5 percent but can approach levels as high as 17 percent (Hausch and Melnychuk, 2012). Residualized steelhead can make relatively long upstream movements (>12 kilometers [km]; McMichael and Pearsons, 2001). The presence of residualized steelhead can also lead to significantly reduced growth in wild rainbow trout (McMichael and others, 1997). The presence of steelhead residuals is likely to lead to erosion of reproductive barriers with native coastal cutthroat trout (Docker and others, 2003) and increase hybridization levels above that observed in wild populations (for example, Ostberg and others, 2004; Heath and others, 2010). Although relatively close to the Pacific Ocean, the presence of reservoir habitat may lead to increased residualization in the upper Lewis River (Hausch and Melnychuk, 2012), suggesting the need to develop monitoring programs to account for the extent of residualization and potential hybridization.

In general, detecting the effects of anadromous reintroductions on bull trout and coastal cutthroat trout populations is likely to be challenging (Ham and Pearsons, 2000; Weber and Fausch, 2003). The difficulties of detecting changes in abundance of salmonids (Ham and Pearsons, 2000) and relating these changes to reintroduction actions (for example, Temple and Pearsons, 2012) suggests the need to consider multiple metrics to quantify the effects of management actions. Given that the effects to resident trout species may differ within and across streams (Kiffney and others, 2009), caution should be urged in extrapolating results where data are limited. Furthermore, in many cases, the effects may either be unknown or cumulative, which can be challenging to identify (Pearsons, 2008). Ultimately implementing an approach as outlined in Pearsons (2002 and 2010), with long-term monitoring sites (for example, Temple and Pearsons, 2012) and adaptive management practices, is likely to provide feedback to managers on how to limit negative effects on native taxa.

## Effects of Native Species on Anadromous Reintroductions

The occurrence of native bull trout, coastal cutthroat trout, and *Ptychocheilus oregonensis* (northern pikeminnow) in the upper Lewis River highlights the need for consideration of the effects these native fish have on anadromous reintroductions. This review specifically focuses on predation effects on anadromous stocks.

**Coastal cutthroat trout.**—Although generally not considered a top predator, coastal cutthroat trout predation on juvenile anadromous species can be substantial (Gregory and Levings, 1996). In an extensive diet study in the lower Cedar River in Washington, juvenile Chinook salmon represented up to 30 percent of winter/spring diets for juveniles/small adult coastal cutthroat trout (Tabor and others, 2012). Although diets consisted primarily of aquatic insects during the summer, when year-round predation was linked with population estimates, Tabor and others (2012) found annual predation to be 66,000 Chinook salmon in a given year. Although seemingly high, these predation rates appear to be relatively consistent with coho salmon predation of *O. nerka* (sockeye salmon) in the lower Cedar River, suggesting relatively high predation rates on newly emerged salmon is common even among anadromous salmon species. Despite high predation estimates, mortality during emergence is likely to be naturally high, and no studies have evaluated predation effects on adult salmon returns or smolt-to-adult survival. Given the relatively ubiquitous distribution of coastal cutthroat trout in the upper Lewis River, there is a potential for predation of anadromous fry/parr (for example, Tabor and others, 2012); however, densities of coastal cutthroat trout from field sampling in the upper Lewis River are relatively low, suggesting limited population-level effects.

**Bull trout.**—Across the Pacific Northwest, bull trout are one of the top native freshwater predators. Bull trout are considered to be highly piscivorous, particularly with increasing size (Rieman and McIntyre, 1993; Wilhelm and others, 1999; Beauchamp and Van Tassell, 2001; Lowery and Beauchamp, 2015). When comparing bull trout diets among studies, the proportion of fish in bull trout diets averaged 44.7 percent (range=01–100 percent; table F2). When considering only large bull trout (that is, where size is identified including adults, >500 grams, and >300 mm), the mean proportion of fish in diets increased to 68.2 percent (range=22–100 percent). Where sympatric with *O. nerka* (kokanee) in reservoir/lake systems, kokanee tend to be the dominant prey (Clarke and others, 2005; Guy and others, 2011; Hill and others, 2014); this pattern is consistent (albeit limited-time series) in Lake Billy Chinook in Oregon where no identified Chinook salmon juveniles were found in bull trout diets during spring or fall sampling events (Hill and others, 2014). Few studies have evaluated bull trout predation on anadromous species within fluvial systems. Lowery (2009) found consistent predation of anadromous smolts but considerable variability in the extent of predation of any prey species (coho salmon, Chinook salmon, and steelhead) within and across seasons/years. Lowery and Beauchamp (2015) also found substantial differences in the proportion of predation across tributary and mainstem habitat for bull trout 96–300 mm. Budy and others (2012) found bull trout diets in the Sout Fork Walla Walla River in Oregon varied across years (2002–2012), with *Oncorhynchus* spp. (Chinook salmon, steelhead, and rainbow trout) making up anywhere between 0 percent and >95 percent of diets. Ultimately, these studies suggest bull trout are opportunistic feeders in fluvial environments.

A recent expert panel found bull trout impacts to anadromous populations in a fluvial population (Clackamas River in Oregon) to be predominantly characterized as moderately low to none (Marcot and others, 2012). Although predation impacts to kokanee salmon can be relatively high in fluvial environments (Beauchamp and Van Tassell, 2001), there remains considerable uncertainty of predation effects on coho salmon, Chinook salmon, and steelhead. There is a relatively high potential for bull trout predation of anadromous smolts within mainstem Lewis River (Lowery and Beauchamp, 2015), in reservoirs where thermal conditions are suitable, and in tributary streams where overlap occurs. Increases in fish abundance and distribution through the reintroduction process may increase the extent of predation. Within reservoir systems, predation will likely be dictated by thermal profiles, smolt migration timing and routes, smolt delays at collection facilities, and abundance of bull trout. Ultimately, monitoring bull trout and anadromous species distribution, abundance, and diet patterns will be needed to accurately understand bull trout predation effects.

## Effects of Native and Nonnative Salmonid Predators to Reintroduction Efforts

Considerable populations of native and nonnative predators exist within the upper Lewis River Basin as a result of fisheries management objectives and native species distributions. Within the upper Lewis River Basin, the main native predator is the northern pikeminnow. Nonnative predators include *Esox masquinongy* × *lucius* or *Esox lucius* × *masquinongy* (tiger muskellunge), *Lepomis macrochirus* (bluegill), *Micropterus salmoides* (largemouth bass), and *Ameiurus nebulosus* (brown bullheads).

Given the extensive review of the effects of nonnative species on anadromous species (PacifiCorp and Cowlitz PUD, 2002), this review only included new literature related to existing native and nonnative predators within the upper Lewis River Basin. Of particular concern in the upper Lewis River Basin is the uncertainty of predation rates of tiger muskellunge, the relative strength of predation of largemouth bass, and the need for potential management actions to control native and nonnative predators.

**Tiger muskellunge.**—Data related to tiger muskellunge predation on salmonids continues to be rare in the literature (see PacifiCorp and Cowlitz PUD, 2002), raising the need to consider diet data for closely related *Esox lucius* (northern pike). Recent diet studies have indicated considerably higher northern pike predation of salmonids than observed in Schmetterling (2001). In Alaska, Sepulveda and others (2013) found the extent of predation to vary based on suitable habitat. In streams with high



overlap in distribution (suitable thermal and physical habitat) for both salmon and northern pike, salmonids were the dominant prey across sample sites and spring and summer months (48–70 percent diet mass). In an adjacent stream, with habitat only suitable for salmon and northern pike in the lower reaches, the proportion of salmonids in diets was relatively high (31 percent) in the suitable lower reaches but no salmon were found in northern pike diets in reaches with unsuitable habitat. Interestingly, Sepulveda and others (2013) found no correlation in the proportion of Chinook or coho salmon in diets with increasing size of northern pike (range=25–100 cm). Northern pike predation across size classes suggests relatively high predation potential for similar predators like tiger muskellunge on salmon at the population level.

Other studies have also found considerable northern pike predation on salmonids (Muhlfeld and others, 2008; Spens and Ball, 2008). In Montana, Muhlfeld and others (2008) observed northern pike consuming a mixture of soft-rayed and bony-rayed fish. Northern pike diets varied across seasons with predation on bull trout and *O. clarkii lewisi* (westslope cutthroat trout) to be relatively high during winter and spring, and their proportion of diet was >50 percent during the spring months. Summer predation was minimal, likely because of thermal segregation of the species. Northern pike predation on salmonids was generally higher for large fish (>600 mm), but some predation did occur for smaller fish with apparently greater selection of westslope cutthroat trout over bull trout at smaller size classes, suggesting that size classes affect predation levels. These recent results suggest salmonids are extremely vulnerable to northern pike (Haught and von Hippel, 2011) and that predation on salmonids from species with similar life histories and morphologies such as tiger muskellunge, is likely to be high in the upper Lewis River. Although field estimates from Lake Merwin suggest salmonid predation by tiger muskellunge is relatively low (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report), such patterns may change considerably if the density and distribution of coho salmon, Chinook salmon, and steelhead increases substantially during and after reintroduction. However, given the potential for tiger muskellunge to be long-lived (>8 years; Schmuck and Petersen, 2006), total predation estimates will require extensive diet data, which can vary across individuals (PacifiCorp and Cowlitz PUD, 2002), and population estimates across size classes.

*Other nonnatives.*—Empirical data continue to be relatively limited for predation of juvenile salmon and steelhead by brown bullheads and largemouth bass. Where formally evaluated, brown bullhead predation potential appears to be low (Tabor and others, 2004), which is consistent with other studies in the Pacific Northwest (Bonar, and others 2005; Gray, 2005), suggesting population-level effects are limited. Largemouth bass are considered to be a relatively warm-water fish, but predation on juvenile salmonids suggests this species has relatively high predation potential (Bonar, and others 2005). In Lake Washington in Washington, Tabor and others (2004) found salmonids in the diets of largemouth bass ranging from 100 to >300 mm in length. Although diet varied, salmonids made up approximately 50 percent of small (100–199 mm) largemouth bass diets in some habitats (for example, a shipping canal). Given the relative abundance of smaller-sized largemouth bass, population-level predation may be an additional limitation to reintroduction efforts where present (for example, Karchesky and Bennett, 1999). Such results highlight the need for in situ studies of largemouth bass predation, and indicate a potential for competition effects between juvenile bass and juvenile salmonids (Gray, 2005).

*Management considerations.*—Given the relative abundance of northern pikeminnow and the presence of additional nonnative predators in the upper Lewis River, there continues to be concern about the need for management actions to control predation and enhance recovery efforts. Management efforts to control populations of predators have been in place for decades on the Columbia River (Beamesderfer and others, 1996; Porter, 2012). The effects of predator controls, however, are complex (Harvey and Kareiva, 2005; Carey and others, 2012). During 22 years, more than 2 million northern pikeminnow have been removed from the Columbia River in Oregon and Washington under the Columbia River Northern Sport Reward Fishery Program, but there appears to be no apparent trends in annual harvest and catch-per-unit-effort appears to be increasing (Porter, 2012), raising questions regarding the population-level impacts of the management efforts. However, within certain reservoirs (for example, John Day Reservoir in Oregon), populations of northern pikeminnow are decreasing as a result of management actions, but nonnative populations of *Sander vitreus* (walleye) have increased.

Management actions in the Columbia River have met target goals of reducing predator numbers, but there is uncertainty as to how these actions have affected overall salmon survival rates (Beamesderfer and others, 1996). The challenges associated with management actions also stem from the potential indirect effects that management actions for one population may have on sympatric predator populations (Harvey and Kareiva, 2005) or compensatory mechanisms within the source population (Beamesderfer and others, 1996). Prior to implementing management actions to control native and nonnative predator populations, considerable data related to species distribution, abundance, and community interactions (for example, food web) are needed to avoid unintended consequences and improve the efficiency of management actions (if needed). Ultimately, with ample data, scenario modeling should be completed (for example, Harvey and Kareiva, 2005) and an adaptive management framework should be established with iterative analyses of monitoring and evaluation data.

## Field Studies and Methods

### Stream Habitat

During 2014, we continued studies to quantify interactions between resident and anadromous species in the study area. Given that reintroductions have not occurred in Lake Merwin and Yale Lake in Washington, efforts were largely focused in tributaries to Swift Reservoir.

*Distributional overlap.*—We quantified the distributional overlap of bull trout and juvenile coho salmon using snorkel surveys each year. During 2013–2014, we focused efforts on Pine Creek and P8, a tributary to Pine Creek because the creek's tributaries are considered to contain the highest densities of bull trout in the Swift Basin. Snorkeling studies can substantially underestimate the abundance of bull trout, particularly during daytime studies (Thurrow and others, 2006). However, we selected daytime snorkeling surveys because bull trout commonly use Pine Creek and P8, and we needed to quantify juvenile coho salmon distribution, which is unlikely to have pronounced diel bias. To assess the distribution of both species, we used a systematic sampling approach (random start), as both species are likely clumped in distribution (for example, Al-Chokhachy and others, 2009, fig. 4). Reach lengths varied by stream, with reaches of at least 200 meters (m) used in Pine Creek and 150 m used in P8. We partitioned the entire study area into reaches and sampled every third reach from the random start for an approximate annual sample rate of 33 percent. From 2013–2015, we systematically sampled adjacent reaches to effectively sample the entire study area during the duration of this study. Each year, we conducted all surveys during late August and early September.

In 2015, we expanded our snorkel surveys both spatially and temporally. In addition to Pine Creek and P8, we also included Rush Creek, a tributary considered to be a historical stronghold for bull trout in the Swift Basin, and P3, a tributary to Pine Creek, within the known distribution of bull trout. In Rush Creek, we sampled two reaches at least 250 m long and systematically spaced within the first kilometer of stream habitat. Given the relatively short amount of habitat available in P3, we sampled all of the existing habitat (400 m). For all four tributaries (Pine Creek, P8, P3, and Rush Creek), we conducted two sets of surveys including an early survey (mid-June through mid-July) and a late survey (mid–late August).

During snorkel surveys, two individuals progressed upstream (except at P3, where only one individual conducted the surveys because of the narrow channel width, mean=1.7 m), remaining relatively parallel to each other; all side channels and channel units were included in each survey. All fish were recorded, placed into 50-mm categories, and reported to a third individual on the streambank. Snorkelers carried flashlights to improve visibility in shaded areas and in sections with large amounts of woody debris.

In addition to overlap with bull trout, we considered the potential interactions between acclimation juvenile Chinook and wild coho salmon in Clear Creek, a tributary in the upper Lewis River. Specifically, we evaluated the spatial and temporal overlap of acclimation for juvenile Chinook salmon using tagging location data and emigration patterns, based on recapture events at the fixed antennae on Clear Creek, of tagged coho salmon (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report) and passive integrated transponder (PIT)-tagged acclimation Chinook salmon. The data on migration timing will help also identify “residence” time of acclimation Chinook salmon and migration patterns of wild coho salmon in response to the population of acclimation juvenile Chinook salmon.

*Food web and community interactions.*—During 2014, we continued to assess community interactions using a combination of stable isotope data and diet analyses. We revisited sites previously sampled during 2009 as part of a “baseline” assessment of community interactions prior to large-scale anadromous reintroductions in the upper Lewis River. Because anadromous reintroductions have been initiated at Swift Reservoir, this food web and community interaction study focused on tributaries to the reservoir, including Swift Creek, Drift Creek, Rush Creek, P8, and Cussed Hollow Creek. In addition, we also collected diet and isotope data at two sites on Clear Creek upstream of the confluence with Muddy River. At each site, we collected samples during June–July, mid–late August, and early November, after the onset of coho salmon spawning.

At each site, we sampled macroinvertebrates were sampled tissue samples and diets were collected from fish. We used a variety of sampling techniques to capture fish including backpack electrofishing, electrofishing down to a seine, snorkel herding fish into a seine, and minnow traps. We did not constrain our sampling approaches to only electrofishing methods, which were used during baseline efforts, as we were interested in the most efficient methods for capturing appropriate sample sizes across species, and the use of different sampling methods were unlikely to affect results from isotopic and diet studies.

Captured fish were anesthetized with AQUI-S, weighed, and measured; tissue and diet samples were also collected. Tissue samples were taken from the anal fin (3 mm × 3 mm) and frozen for isotopic analyses. To collect diet data, we used gastric lavage methods for all fish >60 mm. After sampling, we placed fish in flow-through recovery tanks within the sample stream; upon full recovery of equilibrium, fish were released at their point of capture. We sampled for macroinvertebrates using drift nets set in the thalweg at the bottom of each reach with set times of approximately 1 hour. We elected not to use Serber approaches, which were used in the 2009 baseline surveys, to minimize sorting of items because most fish in the food web study are drift feeders, and differences in methods are unlikely to influence interpretations of isotopic analyses.



All drift, diet, and fin clips for isotope samples were placed in water and frozen until analyzed. All diet and isotope samples were sorted by family and grouped based on functional feeding groups. Isotopic samples were prepared following the University of California, Davis Stable Isotope Facility protocol (<http://stableisotopefacility.ucdavis.edu/>). Briefly, fin samples were dried at temperatures between 50–60 degrees Celsius (°C), set aside in a dehydrator to allow for acclimation to humidity, ground using a mortar and pestle, and encapsulated in a tin capsule for analyses. All isotopic analyses were conducted by the University of California, Davis Stable Isotope Facility.

*Redd superimposition.*—Given that both bull trout and coho salmon are fall spawners, we investigated the potential for and evidence of superimposition of spawning redds (for example, Weeber and others, 2010). First, we evaluated the potential for superimposition using existing redd data for bull trout and coho salmon. We quantified the date of each redd observed for each species during recent (2012–2014) surveys in the upper Lewis River and calculated the proportion of coho salmon redds that occurred after the onset of bull trout spawning.

In 2014 and 2015, we assessed superimposition in P8 given the abundance of bull trout and the abundance of reintroduced adult coho salmon in the Swift Reservoir. Because of the potential for misidentifying bull trout redds (Dunham and others, 2001), we used existing redd location information provided by local biologists for bull trout (that is, flagged redds). Starting in mid-October of 2014 and 2015, we conducted biweekly redd surveys to identify coho salmon redds superimposed on bull trout redds. Because of high levels of suspended and delivered fine sediment in Pine Creek during the fall, accurately identifying the boundaries of existing bull trout redds can be challenging. As such, we delineated the boundaries of each redd using rocks that were painted white and identified instances of superimposition where coho salmon redds overlapped within the perimeter of bull trout redds.

## Reservoir Habitat

*Carrying capacity of reservoir habitat: zooplankton supply and demand.*—To assess the ability of the reservoirs on the Lewis River to support additional salmonids, we examined the annual progression of vertical temperature profiles, seasonal cycles of zooplankton production and distribution, and consumption demand of the existing resident planktivore community. Our approach to assess potential interactions between anadromous and resident fish and carrying capacity in each reservoir is similar to that used in our Lake Merwin predator impact studies (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report), so some methods and data presented previously overlap with the studies herein. The fish communities of each reservoir were sampled, and stable isotope analysis was used to evaluate the trophic structure of the food webs. We measured seasonal depth distribution, diets, growth, and abundance of key planktivore populations in each reservoir and used bioenergetics models to estimate their monthly consumption demand. Ultimately, planktivore consumption demand was compared to prey supply to evaluate the availability of food to support reintroduced populations of age-0 salmonids. We assumed that the carrying capacity of a reservoir had been reached if the current consumption demand exceeded 50 percent of the prey supply in any month of the growing season. To estimate how many additional subyearlings could be supported in each reservoir, we divided any surplus prey that could have been consumed without exceeding this arbitrary estimate of maximum sustainable prey exploitation by the consumption demand of individual age-0 salmonids. These estimates could be added to expected production from lotic habitats to evaluate the feasibility of reintroductions and weigh the costs against the benefits.

*Fish sampling.*—We deployed short-term gill nets for 30 minutes to 24 hours in Swift Reservoir, Yale Lake, and Lake Merwin in June–November 2013 and May–November 2014 to obtain biological samples and information on relative abundance and seasonal depth distribution of resident fish. We only set gill nets for short periods in Swift Reservoir and Yale Lake to reduce the risk of harming bull trout, which are listed as threatened under the Endangered Species Act, and all sampling was conducted through U.S. Fish and Wildlife Permit TE08551B-0. Creel sampling and trolling were also used to sample fish. Midwater trawling was conducted in June and August 2013 but was restricted to the epilimnion because of submerged standing timber in Swift Reservoir, Yale Lake, and Lake Merwin.

In the field, we identified, sexed, and counted fish by species and recorded a subset of fork lengths in millimeters and wet weights in grams. Stomachs were collected for diet analysis and scales from the preferred region were taken for age and growth analysis. In addition, fin tissue was sampled for stable isotope analysis, placed on ice in the field, and later frozen for preservation and analysis in the laboratory. Fish were handled and released or euthanized according to the University of Washington—Institutional Animal Care and Use Committee (UW—IACUC) protocol #3286–21.

*Hydroacoustics.*—Mobile hydroacoustic surveys were conducted in June, August, and November 2013 to evaluate the abundance and depth distribution of small, limnetic fish in Swift Reservoir, Yale Lake, and Lake Merwin. The hydroacoustics system used for all surveys consisted of two multiplexed split-beam 200 kilohertz transducers towed in sidelooking (12.8-degree full-beam angle) and downlooking (6.8-degree full-beam angle) orientations. The transducers were connected to a Biosonics DE-6000 scientific echosounder with the following data acquisition parameters: bottom threshold=70 m, ping rate=2–3 pulses per second, pulse width=0.3 millisecond, and target strength detection threshold=–65 decibels.

Quantitative surveys of fish abundance and distribution in August 2013 consisted of 15–18 zigzag transects across and one long transect along the center axis of Swift Reservoir, Yale Lake, and Lake Merwin (fig. F1). Qualitative surveys in June and November 2013 consisted of fewer (5–15) loose zigzag transects across, and one transect along the center axis of each body of water to examine the vertical distribution of fish. A portion of each of the surveys was repeated during daytime, at dusk, and at night to evaluate diel vertical migrations, and to more accurately estimate mean daily thermal temperatures that could be used in bioenergetics models.

The abundance of kokanee salmon and the distribution of limnetic fish were estimated from hydroacoustic survey data using standard echo-counting techniques (Beauchamp and others, 1997) with EchoView 5.4 software from Myriax Pty, Ltd. (<https://www.echoview.com/>). All targets in Yale Lake and Lake Merwin within the main target strength modes corresponding with expected fish lengths (30–275 mm in Yale Lake and 30–400 mm in Lake Merwin) were assumed to be kokanee salmon, given that the composition of angler catches was nearly 100 percent kokanee salmon in Yale Lake (with one account of a bull trout hooked) and 80 percent kokanee salmon in Lake Merwin. The other approximately 20 percent of angler catches in Lake Merwin consisted of larger, hatchery-reared rainbow trout and an occasional northern pikeminnow. Catches in midwater trawls were 92 percent age-0 kokanee salmon in Yale Lake. It is likely that some *Gasterosteus aculeatus* (threespine stickleback), pelagic fish in the superfamily Cottoidea (sculpins), and other fish species were allocated to kokanee salmon population estimates. However, this creates a conservative population estimate for the purpose of comparing zooplankton consumption demand and supply, as all planktivore species draw from the same zooplankton resources.

Targets measured by the sidelooking transducer were used to estimate fish densities within the upper 20 m of the water column over a range of 0–40 m from the survey vessel; however, side-aspect target strengths cannot be reliably converted to fish lengths. Therefore, the observed densities of side-aspect targets represented the total within a range of sizes and were used to estimate depth distributions of thermal experience (daily temperature experienced by fish), but not of size-specific densities for abundance and age-structure calculations.

Fish target strengths measured by the downlooking transducer were converted to fork lengths based on Love's (1977) equation and used to estimate size-specific target densities. Size-specific target density estimates were calculated for each 5-m depth interval. Targets were summed within specific size modes in the target strength frequency distribution that corresponded with the expected lengths of each size class of fish, and the sums were divided by the volume of water examined by the acoustic beam to calculate density. Targets outside the range of strengths associated with kokanee salmon were assumed to be background noise caused by debris and noise (if smaller), or branches of standing timber and large piscivorous fish (if larger).

**Abundance and survival.**—Abundances of age-0–2 kokanee salmon were estimated by expanding density estimates from quantitative hydroacoustic surveys by the volume of water in the corresponding depth layers. Constant recruitment and survival between years and age classes was assumed to simplify the calculations. Annual survival rate was fit to the abundance of age-0 fish and to fish age-1 to age-2, assuming there were no age-3 or older fish because the majority of kokanee salmon in Lake Merwin and Yale Lake die after the second year of life (PacifiCorp and Cowlitz PUD, 2004). We used annual survival rates to allocate the estimated abundance of age-1–2 kokanee salmon to each age class. Daily population abundances for the rest of the year were calculated using daily survival rates, derived with an exponential relationship,  $\text{survival} = e^{(-rt)}$ , where  $r$  = instantaneous mortality rate and  $t$  = time.

In Swift Reservoir, kokanee salmon were not present, and hydroacoustic surveys could not reliably estimate the abundance and survival rate of the primary planktivore, rainbow trout, because of their nearshore and surface orientation. Instead, we relied on stocking and catch data to estimate the abundance and age structure of rainbow trout. Catches from the main reservoir were entirely rainbow trout from the current year's stocking event, based on scale and length frequency analysis. We modeled consumption demand for a single cohort of 50,000 hatchery-reared rainbow trout with zero mortality from the date of stocking (June 1) to the end of November of that year. The approach of not incorporating mortality provided a maximum possible estimate of the consumption demand by rainbow trout. The total fish abundance in August, estimated by hydroacoustics, was 40,500 fish in the size class 20–200 mm and 9,800 fish in the size class 200–400 mm. The low number of rainbow trout-sized targets observed suggested that some may have been undetectable because of a nearshore or surface orientation. However, given that there were less than (<) 50,000 total fish observed by hydroacoustics in August, and the majority of these fish appeared to be <200 mm, our estimate of the consumption demand of 50,000 hatchery-reared rainbow trout was likely a reasonable approximation of the consumption demand of all planktivorous fish in Swift Reservoir.

## Bioenergetics Model Inputs

Bioenergetics models are energy balance equations that are commonly used to estimate the feeding rate (percent of maximum theoretical consumption; percent  $C_{\text{max}}$ ) and the consumption rate (amount consumed in a given time; grams of prey/day) needed to achieve the growth observed by different age classes of consumers while accounting for variability in body size, thermal experience (daily temperature experienced by the consumer), and diet of the consumer (Ney, 1993). The models operate on

a daily time step that enables simulations to track processes with high temporal resolution. These estimates depend on the energy densities of predators and prey and species-specific parameters that describe the temperature-dependent and allometric effects of body mass on consumption, metabolism, and waste (Hanson and others, 1997). We collected field data on growth, seasonal diet composition, and thermal experience to construct a set of model inputs specific to each planktivore population. We used stable isotope analysis to corroborate the diet composition data.

*Temperature profiles and thermal experience.*—Temperature profiles were recorded monthly from April to November at 1-m intervals from the surface to 30 m and at 2-m intervals from 30–60 m at two limnology stations located at one-third and two-thirds of the length of Swift Reservoir, Yale Lake, and Lake Merwin (fig. F1), and measurements were averaged between stations. Temperature profiles recorded by PacifiCorp in the late fall and winter months were used to complete the characterization of the seasonal thermal regime (PacifiCorp, 1999; PacifiCorp and Cowlitz, 2004). For each reservoir, vertical temperature profiles (fig. F2, table F3) were combined with the depth distribution of pelagic fish from hydroacoustics to calculate time- and depth-weighted thermal experience for bioenergetics simulations (Beauchamp and others, 2007).

*Stable isotope analysis.*—We characterized the food web structure of Swift Reservoir, Yale Lake, and Lake Merwin with stable isotopes to identify key trophic pathways that support or potentially limit juvenile salmonids and the other abundant resident fish that are likely to overlap in time and space with juvenile salmon (McIntyre and others, 2006). Stable isotope values of fin tissue provide an integrative signal of diet for several months to 1 year (depending on the growth rate of the consumer), providing a valuable complement to the instantaneous snapshot of diet composition provided by stomach content analysis. Tissue from representative samples of benthic invertebrates, terrestrial insects, zooplankton, planktivores, benthic feeding fish, and piscivores were immediately placed on ice in the field and then frozen within 12 hours for storage (Vander Zanden and Rasmussen, 2001). Zooplankton were identified to genus, and muscle tissue was removed from snails, *Corbicula fluminea* (Asian clams), and *Pacifastacus leniusculus* (signal crayfish). For fish samples, caudal fin tissue was clipped from three individuals within each 50-mm size class of each population. Samples were then dried at 60 °C for 48 hours, homogenized with mortar and pestle, and 0.4–0.6 mg of the resulting material was weighed in aluminum capsules for analysis. Isotope samples were analyzed by the University of Washington IsoLab using a Costech Elemental Analyzer, Conflo III, and MAT253 for continuous flow-based measurement of solid organic material. The reference material was Vienna Pee Dee Belemnite for carbon ( $\delta^{13}\text{C}$ ) and atmospheric  $\text{N}_2$  for nitrogen ( $\delta^{15}\text{N}$ ).

*Diet composition and energy density of prey.*—Seasonal diet analysis was conducted for key pelagic species to provide input data for bioenergetics modeling and to evaluate trophic interactions between resident and anadromous fish. Diet composition was evaluated for a range of sizes of the primary pelagic planktivores in each reservoir. Using a dissecting microscope, we identified stomach contents to taxonomic order for invertebrates and calculated diet proportions by wet weight (Chipps and Garvey, 2007). The energy densities of prey items were taken from literature values (table F4).

*Age and growth.*—A fish's mass at the beginning and ending dates of bioenergetics simulations was estimated based on scale analysis and observations of length and weight. Hatchery-reared rainbow trout and yearling Chinook salmon were weighed at the hatchery before stocking in Swift Reservoir (PacifiCorp and Cowlitz PUD, 2014) and again during sampling at the end of the growing season in November, providing an estimate of growth over this interval. Growth intervals for yearling Chinook salmon were used to generate feeding rates ( $p$ -values or percent  $C_{\text{max}}$  [% $C_{\text{max}}$ ]) which were then used to simulate the growth and consumption demand of subyearlings. For kokanee salmon, the length-at-age was back calculated from scale measurements using the Fraser-Lee method (Isely and Grabowski, 2007). Images and measurements of scales were recorded with Image-Pro® digital image-analysis software and a digital camera mounted on a dissecting microscope [1.6–3.2 times magnification].

Kokanee salmon lengths were converted to weight based on weight-to-fork length (FL) regressions for Yale Lake (sample size [n]=36, range=46–281 mm;  $R^2=0.996$ ,  $P < 0.001$ ):

$$\text{Weight}=0.00000198 \times \text{FL}^{3.3259} \quad (\text{F1})$$

The same procedure was used for Lake Merwin (n=179, range=91–400 mm;  $R^2$  0.964,  $P < 0.001$ ):

$$\text{Weight}=0.0000263 \times \text{FL}^{2.868} \quad (\text{F2})$$

Seasonal-size frequency distributions were examined to partition growth, and thus fitted-consumption estimates, into fast- and slow-growth seasons. The age-1 kokanee salmon captured in Lake Merwin in November 2013 had a mean fork length of 279 mm, equal to the mean back-calculated length at second annulus for the previous year's cohort. Assuming approximately equal growth conditions between years, this suggests that the majority of annual growth occurred before December 1, which is consistent with cycles of zooplankton abundance. Therefore, we allocated 90 percent of annual growth in mass to the period between April 1 and November 30. Given that the thermal regimes and zooplankton cycles followed similar patterns between reservoirs, we allocated growth in this manner for all our simulations (table F5).

**Zooplankton.**—We measured the monthly densities of crustacean zooplankton in Swift Reservoir, Yale Lake, and Lake Merwin to estimate the available food supply for resident and reintroduced anadromous salmonids. We conducted oblique tows with a Clarke-Bumpus sampler fitted with a 153-micrometer ( $\mu\text{m}$ ) mesh conical net at depths that represented the epilimnion, metalimnion, and hypolimnion during stratification and similar depths during spring and fall at both limnology stations in each body of water (fig. F1). We identified and enumerated >50 crustacean zooplankton in subsamples of each tow and measured the body length of the first 30 individuals of each genus encountered in each subsample using Image-Pro digital image-analysis software. *Daphnia* spp. were the most abundant zooplankton species found and the most significant prey item for juvenile salmonids during the growing season, so we focused our analysis on their abundance and distribution. *Daphnia* were measured from the top of the helmet to the base of the tail spine, and body length (in millimeters) was converted to wet mass (in micrograms) with the equation  $\text{wet mass} = 50 \times \text{body length}^{2.88}$  (Kuns and Sprules, 2000). Standing stock biomass was then calculated by multiplying the density of *Daphnia* by the mean wet mass and expanded based on the volume of water within each corresponding depth layer (Sorel and others, 2016). The number of *Daphnia* eggs was also enumerated in each sample to estimate zooplankton production rates with the egg-ratio method (Kuns and Sprules, 2000). We were not able to estimate production in November without data on zooplankton density in December.

**Consumption demand to prey supply ratio and carrying capacity calculation.**—The Wisconsin Bioenergetics Model (Hanson, 1997) parameterized for rainbow trout (Rand and others, 1993), kokanee salmon (Beauchamp and others, 1989), and Chinook salmon (Stewart and Ibarra, 1991) was used to estimate consumption demand. The bioenergetics model estimates the daily per-capita consumption needed to satisfy the observed growth of a mean individual from each population and age class. Simulations started at the beginning of the growing season (April 1) for kokanee salmon in Yale Lake and Lake Merwin and on the approximate stocking date (June 1) for hatchery-reared rainbow trout in Swift Reservoir (table F5). Simulations ended on November 30, which we considered as the end of the high-growth season, or at spawning. In each body of water, per-capita consumption by salmonids was expanded to the population level to reflect the abundance, size distribution, and seasonal consumption by each age class of consumer. Population-level consumption was compared to prey supply to evaluate potential food limitations.

The monthly ratio of consumption demand to prey supply was examined to estimate carrying capacity. We designated consumption demand equal to 50 percent of prey supply in the single month of greatest prey demand and supply during the growing season as a conservative estimate for carrying capacity, because the remaining 50 percent of the biomass could absorb additional sources of mortality and produce future generations of *Daphnia* (Beauchamp and others, 1995; Baldwin and others, 2000). *Daphnia* consumption demand:supply ratios were created using both (1) standing stock biomass as a lower estimate of prey supply and (2) standing stock biomass plus production within depths thermally accessible to salmonids as a higher estimate of prey supply. Using only the standing stock biomass throughout the growing season represents the lowest, most restrictive estimate of food supply because production by *Daphnia* can provide significant additional biomass. *Daphnia* standing stock biomass plus production was used to represent higher (but still conservative) estimates of carrying capacity, again assuming that carrying capacity was exceeded when the demand:supply ratio was >50 percent in any month of the growing season. To simulate the ratio of prey demand and supply assuming salmonids were thermally excluded from the epilimnion during stratification (July–September in Swift Reservoir and Yale Lake, July–October in Lake Merwin), we additionally compared consumption demand to prey supply below the epilimnion (metalimnion and hypolimnion) in those months.

For the month with the greatest demand:supply ratios, the difference between resident salmonids' consumption demand and 50 percent of prey supply was divided by the consumption demand of individual age-0 salmonids to estimate the number of additional subyearling salmonids that could have been supported in each reservoir for 1 year. We used the estimate of prey supply that included standing stock biomass and production, but it was restricted to the metalimnion and hypolimnion during stratification as our best estimate for these calculations, as it created a moderate estimate of carrying capacity by including *Daphnia* production but excluded epilimnetic prey during stratification. Consumption demand of age-0 spring Chinook salmon in Swift Reservoir was estimated with a bioenergetics simulation using the feeding rate ( $p$ -value or  $C_{\text{max}}$ ) observed for age-1 fish during the growing season (104 percent) and an estimated starting mass of 0.2 grams on April 1. Age-0 kokanee salmon were used as a surrogate for estimating the consumption demand of subyearling salmon in Yale Lake and Lake Merwin. We consider kokanee salmon as a reasonable surrogate for Chinook salmon because both species feed on *Daphnia* in the limnetic zone and exhibit diet-vertical migrations (Koehler and others, 2006; Lowery and Beauchamp, 2010).

## Assessing the Effects of Anadromous Reintroductions on Bull Trout—Simulation Analyses

We assessed the potential effects of anadromous reintroductions on bull trout in the upper Lewis River using an individual-based modeling framework (for example, Al-Chokhachy and others, 2015). We integrated field data from ongoing research and monitoring conducted by the Washington Department of Fish & Wildlife and PacifiCorp and the results of this study with existing data for bull populations in the Pacific Northwest to parameterize the model. We used the modeling framework to evaluate



three main objectives to assess the effects of anadromous salmon reintroduction including: (1) reductions in the carrying capacity for juvenile bull trout because of overlap in resources; (2) potential effects of coho salmon redd superimposition on existing bull trout redds; and (3) reductions in subadult and adult bull trout carrying capacity, growth, and survival in reservoir environments as a result of residualized salmon. Our goal with this modeling effort was to evaluate the relative importance of each of these factors on the extant bull trout population. We focused our efforts on the bull trout population in Swift Reservoir given the current state of anadromous reintroductions in the upper Lewis River Basin.

## Model Inputs

**Growth.**—We used individual-specific information from PIT-tagged subadult and adult bull trout (age-3 and above) for estimates of annual growth. We only included growth estimates where the interval between marking and recapture was >300 days to avoid the potential effects of handling on growth (for example, McCormick and others, 1998) and (or) erroneous extrapolations of annual growth estimates from short-interval recaptures. We accounted for differences in the interval between marking and recapture across individuals by scaling growth to 365 days. We assumed age-3 bull trout were approximately 350 mm based on feedback from the Lewis River Bull Trout Working Group. We then used the individual growth data (fig. F3) to estimate size for subsequent ages using an exponential decay model of decreasing growth with age. Given that few estimates of age-2 adfluvial bull trout are available, we used this model to also estimate age-2 growth within the reservoir environment. We used the size-at-age information in Al-Chokhachy and others (2015) for age-1 fish (table F6) and considered bull trout emigration to the reservoir to occur primarily at age-2 (Fraley and Shepard, 1989; Downs and others, 2006; Johnston and others, 2007).

**Survival.**—We used a combination of local and literature-based estimates of survival at different ages of bull trout. For egg-to-fry survival and age-1 survival, we relied on estimates from the literature (Bowerman and Budy, 2012; Bowerman and others, 2014) as no empirical data in the Lewis River was available for these age classes. Next, we used estimates of reservoir survival for age-6 and older from Swift Reservoir PIT-tag analyses (Stillwater Sciences, 2016). No estimates of juvenile through early adult (age-2–5) survival are currently available for adfluvial bull trout populations. As such, we linearly interpolated estimates for age-2–5 between known estimates (age-1 and age-6, table F6).

**Sexual maturity, frequency of spawning, and fecundity.**—We relied on literature estimates of sexual maturity and the professional opinions of local biologists. Sexual maturity in adfluvial bull trout populations has been found to occur between age-4 and age-6 (Fraley and Shepard, 1989; Hagen and Taylor, 2001; Downs and others, 2006; Johnston and others, 2007). For this study, we assumed 25 percent of age-4 fish, 50 percent of age-5 fish, and 100 percent of fish older than age-5 to be mature.

The spawning frequency of bull trout populations is largely considered to be annual unless populations are at extremely high densities (Johnston and Post, 2009). As such, we modeled bull trout spawning annually for bull trout in the Swift Reservoir population. Finally, we used an empirical, literature-based estimate of adfluvial bull trout length-fecundity from Johnston and others (2007) where  $\text{fecundity} = 0.00172 \times \text{Fork Length}^{2.31}$ .

**Baseline population model.**—For each model run, we simulated bull trout population dynamics for 50 total years. To avoid bias associated with transient dynamics, we did not begin recording results until year 31 of each simulation ( $n=20$  years per simulation). We used the IBM framework to identify and track individual outcomes of growth, survival, sex, and sexual maturity. For each individual, we randomly selected growth, survival, and sexual maturity values for each year based on the model inputs (for example, table F6). Given the high variability in egg survival (Bowerman and others, 2014), we modeled egg-to-fry survival using a beta distribution ( $\alpha=21.33$ ;  $\beta=2.99$ ) based on field estimates of survival at this life stage. For all other age classes, we selected survival estimates from normal distributions based on the empirical and literature-derived estimates of the mean and variance of the normal distributions for each estimate. For maturity, we determined sexual maturity of individuals within an age class using proportional sampling methods.

We assumed density-dependent mechanisms would control survival and consequently, population size. We assumed density-dependent effects would occur at the emergence-to-juvenile stage consistent with previous studies (that is, fry to age-1; Van Kirk and Hill, 2007; Johnston and Post, 2009). We adjusted the carrying capacity of the population to where the mean annual adult population was approximately 275 adults based on existing redd count and abundance estimates and feedback from the Lewis River Bull Trout Working Group.

**Model perturbations.**—We assessed each of our objectives by perturbing the model based on likely interactions between anadromous salmon and bull trout (see the “Stream habitat” and “Reservoir habitat” sections in this chapter). First, we assessed the effects of changes in carrying capacity of early life-history stages as a result of substantial increases in the biomass represented in juvenile salmon. We reduced the carrying capacity by 20 percent given the overlap observed in juvenile-rearing habitat and diets in tributary habitat (see the “Distributional overlap” sections in this chapter).

To address the second objective (to assess distributional overlap between coho salmon and bull trout at different life stages and environments), we evaluated the effects of coho salmon redd superimposition by assuming 20 percent of the annual bull

trout redds would be superimposed by adult coho salmon. Although this proportion is higher than observed in field studies, we used this estimate to quantify the population-level effects relative to other perturbations.

Our third perturbation focused on changes in the reservoir environment resulting from substantial increases in the biomass of juvenile salmon. Juvenile Chinook and coho salmon are spending considerable portions of the year in the reservoir environment (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report). In addition, collection information suggests a large portion of juvenile salmon are residualizing in Swift Reservoir either volitionally (for example, Perales and others, 2015) or because it is difficult to find the juvenile collection facility (for example, Beeman and others, 2016). Large increases in salmon densities may increase potential competition in the reservoir environment, thus increasing density-dependent mechanisms such as reduced growth and survival. Indeed, Johnston and Post (2009) found large changes in bull trout abundance led to substantial compensatory changes in population demographics and vital rates. For this study, we evaluated such effects by independently and simultaneously reducing growth and survival of all reservoir age classes by 20 percent.

## Results and Discussion

### Stream Habitat

*Distributional overlap of bull trout and coho salmon.*—During 2015, we snorkeled a total of 10.57 km of stream during two survey periods. The extent of sampling in 2015 was greater than during 2013 (3.25 km) and 2014 (2.86 km), largely because of spatial expansion of surveys, but also because multiple surveys were used in 2015. Surveys from 2013 and 2014 indicated relatively few coho salmon in the Pine Creek drainage (fig. F4). Although we observed considerably more juvenile coho salmon in 2014 ( $n=40$ ) than in 2013 ( $n=2$ ), the density of coho salmon appeared to be relatively low. However, in 2015, we found higher numbers of juvenile coho salmon in Pine Creek than observed in previous years (figs. F5, F6, F7). The largest densities of coho salmon were found in P3, in reaches of Pine Creek adjacent to P3, and in Rush Creek. Relatively few coho salmon were observed in P8 and the upper reaches of Pine Creek (figs. F5, F6). The apparent differences between the 2013 and 2014 data and the 2015 data in Pine Creek and tributaries are likely because of the timing of surveys, as the 2015 surveys were conducted earlier in the summer months, and sampling was done in different reaches (that is, clumped distribution of salmonids; Al-Chokhachy and others, 2009). The lower numbers of juvenile coho salmon during the later surveys in 2015 in Pine Creek and P8 suggest that juvenile coho salmon may emigrate downstream in the Pine Creek system during the summer, likely because of cold stream temperatures (Ebersole and others, 2006b) and the lack of slow-water habitat with cover (Bisson and others, 1988; Giannico and Healey, 1999). These conclusions are supported by the finding of the highest densities of juvenile coho salmon in and around P3, a tributary with habitat linked with high densities of juvenile coho salmon, and observations of juvenile coho salmon in side channel habitats.

The relative abundance of juvenile coho salmon varied substantially between tributaries. Despite the higher densities in 2015, juvenile coho salmon represent a low proportion of the total number of fish observed in the majority of reaches in 2013 (fig. F8A), 2014 (fig. F8B), and 2015 (fig. F9). This pattern is considerably different than results from P3 and Rush Creek (fig. F10), where juvenile coho salmon represent a large portion of the total number of fish observed. Together, these results suggest that overlap between juvenile coho salmon and bull trout does occur in key bull trout spawning and rearing tributaries, a pattern not surprising given recent results from Lowery and Beauchamp (2015). However, our results also suggest the degree of overlap varies considerably between streams.

*Distributional overlap of acclimation spring Chinook and juvenile coho salmon.*—The temporal overlap between acclimation spring Chinook and juvenile coho salmon and other species during 2014 and 2015 appears to be relatively short (fig. F11). The median days between release and emigration past the antenna in Clear Creek is 6 days (range=3–362 days). Approximately 60 percent of the 6,150 fish observed at the antenna emigrated by 7 days. However, more than 35 percent of the fish remained in Clear Creek for more than 50 days. These juvenile Chinook salmon that resided for more than 50 days in Clear Creek all occurred during 2014. It is unknown if fish that resided longer in Clear Creek were released directly into the river or were placed into the acclimation ponds adjacent to Clear Creek. The short time that hatchery-reared spring Chinook salmon remained within the tributaries suggests that the potential impacts on native fish within tributaries is likely to be minimal; however, the impacts may be more severe within the reservoir environment (see “Assessing the Effects of Anadromous Reintroductions on Bull Trout” section in this chapter).

*Food web and community interactions.*—Anadromous species can bring substantial nutrient resources to freshwater ecosystems (Gresh and others, 2000; Scheuerell and others, 2005). The influx of nutrients and forage can alter food webs (Bilby and others, 1998; Scheuerell and others, 2007) and, in some cases, enhance the growth and condition of freshwater fish (Wipfli and others, 2004; Guyette and others, 2013; Swain and others, 2014). In the upper Lewis River Basin, our results suggest small,

subtle shifts in the community food webs as a result of the reintroduction and presence of wild juvenile coho salmon. Contrasting stable isotope data from pre-reintroduction (2009) and post-reintroduction in P8 suggests only small shifts in the forage resources utilized by juvenile bull trout (figs. F12A, F12B) but no shifts in trophic position (DeNiro and Epstein, 1978). This pattern is consistent with results for small (<150 mm) and larger (>150 mm) coastal cutthroat trout. Diet signatures from 2014 indicate coho salmon juveniles overlapped with coastal cutthroat trout in both trophic position and carbon sources, a pattern consistent with previous studies (Bilby and others, 1996). Our results from 2014 also suggest that juvenile bull trout and coho salmon feed at similar trophic levels and utilize generally similar prey resources. All three species appear to utilize a variety of food resources including larvae of Diptera (true flies) and Trichoptera (caddisflies), Lepidoptera spp., and adult Plecoptera (stoneflies). We found similar patterns for Rush Creek with coho salmon, coastal cutthroat trout, and bull trout demonstrating generally consistent trophic position and using similar forage resources (fig. F13). Our results are consistent with a recent study by Lowery and Beauchamp (2015) in the Skagit River, Washington, where juvenile bull trout in tributary habitats demonstrated high overlap in forage niche with coho salmon and juvenile steelhead.

Diet data for the different tributaries indicate seasonal differences in diet resources and diet overlap among the different species. During the late spring–summer, there was much diet overlap between juvenile coho salmon, bull trout, sculpin, and coastal cutthroat trout (fig. F14) with a high proportion of diets comprised of Ephemeroptera (mayflies), caddisflies, and true flies. In addition, diet data from all species except for sculpins suggest the importance of terrestrial inputs. Fall diet data suggest considerable shifts with diets of coastal cutthroat trout <150 millimeters shifting to a greater proportion of caddisflies (fig. F15). Data from juvenile coho salmon and coastal cutthroat trout (>150 millimeters) indicate continued use of terrestrial prey items. Together, these data suggest considerable overlap in diets from late spring through the summer, a period with typically low streamflow, but this overlap appears to attenuate during the fall.

We found surprisingly little evidence of predation on young-of-year anadromous salmon in our spring–summer isotope data. This is somewhat surprising given the extent of predation on young-of-year that can occur in tributaries with anadromous fish spawning (Tabor and others, 2012). The lack of evidence of predation on young-of-year coho salmon is likely because of the relatively low densities of juvenile coho salmon within bull trout distribution areas compared to tributaries with high densities of coho salmon redds (for example, Clear Creek; fig. F16).

*Redd superimposition.*—Between 2012 and 2014, adult coho salmon demonstrated a broad distribution of spawning activity and substantial evidence of spawning in Pine Creek and P8 (fig. F16). Based on existing redd data, we found that coho salmon spawning initiated after the majority of bull trout spawning occurred each year (60 percent of total bull trout spawning activity; fig. F17). Furthermore, we found that 80 percent of the coho salmon spawning occurred after the end of documented bull trout spawning. The observed timing is consistent or earlier than reported for many populations of coho salmon in the Pacific Northwest (Weitkamp and others, 1995), suggesting a high potential for temporal overlap and superimposition.

During 2014 and 2015, we conducted multiple redd surveys per week beginning in early October and continuing through mid–late November. Based on existing bull trout redd information and coho salmon spawning surveys, we confirmed evidence of coho salmon redd superimposition on existing bull trout redds in 2014 ( $n=2$ ) but no evidence of coho salmon spawning in 2015. The lack of coho salmon spawning in 2015, however, is likely driven by the fact that fewer adult coho salmon (3,754) were transported to Swift Reservoir in 2015 than in previous years (for example, in 2014, when 9,179 fish were transported) and relative to recovery planning and yearly management targets of 7,500 fish (Lesko, 2018). Furthermore, 2015 represented anomalous in-tributary conditions with extremely low stream flows, which likely altered coho salmon spawn timing and site selection. Although bull trout and coho salmon historically overlapped across much of their distributions in the Pacific Northwest (Cavender, 1978) and redd superimposition was likely to be minimal to minimize the negative effects (Connell, 1980), the lack of natal homing for transported hatchery-reared coho salmon adults and variable stray rates (Keefer and Caudill, 2012) suggests the need for further monitoring.

## Reservoir Habitat

*Relative abundance of fish.*—The primary pelagic planktivores captured by anglers and our sampling in Swift Reservoir were hatchery-reared rainbow trout and Chinook salmon smolts. Each spring, Swift Reservoir is stocked with approximately 50,000 hatchery-reared rainbow trout of catchable size (200–250 mm; PacifiCorp and Cowlitz, 2014). Stocking has historically been in April but was delayed until early June in 2013–2016 to avoid interactions with outmigrating anadromous salmonid smolts. Several thousand hatchery-reared yearling Chinook salmon smolts were released in tributaries of the Swift Reservoir in 2013 and 2014 as part of the reintroduction (PacifiCorp and Cowlitz, 2014). Fish typically migrate out in late spring and early summer, but some of these fish were captured in the reservoir in the fall (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report). Three-spine stickleback were another planktivore observed in 2013 and 2014. A relatively small population of adfluvial bull trout residing in Swift Reservoir consume invertebrates when they are juveniles but become highly piscivorous as adults (Lowery and Beauchamp, 2015).



Kokanee salmon were the primary pelagic planktivore captured in Yale Lake in 2013 and 2014 (table F7). The population of kokanee salmon in Yale Lake is self-sustaining and spawns in October at age-3 (after their third growing season) in Cougar Creek, a tributary of the upper portion of the reservoir (fig. F1; PacifiCorp and Cowlitz, 2004). Other planktivores in Yale Lake include three-spine stickleback and juvenile sculpin. There is also a small population of adfluvial bull trout.

Kokanee salmon were the primary pelagic planktivore in Lake Merwin in 2013 and 2014 (table F7). Annually, approximately 45,000 kokanee salmon are stocked as fingerlings in fall, and another 48,000 are stocked as yearlings in spring (PacifiCorp and Cowlitz PUD, 2014). Natural production of kokanee salmon is considered minimal from Lake Merwin tributaries, although most fish mature at age-3 and attempt to spawn in September–October. The primary source of natural recruitment of kokanee salmon into Lake Merwin is considered to be entrainment from Yale Lake (PacifiCorp and Cowlitz, 2004). Northern pikeminnow are abundant in Lake Merwin and can be planktivorous as juveniles and piscivorous as adults (Petersen and Kitchell, 2001); however, they generally occupy nearshore habitats during spring and warmer shallower water in the limnetic zone during the summer, thus reducing the likelihood of predation on or competition with salmon (Brown and Moyle, 1981). The consumption demand of the northern pikeminnow population is examined in detail in this report (see “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report) and is, therefore, not covered here.

*Thermal experience and depth distribution of pelagic planktivores.*—Thermal regimes and stratification have a large effect on metabolic rates driving consumption demand, vertical distribution of fish, and rates of zooplankton production. Epilimnetic temperatures in Swift Reservoir and Yale Lake fluctuated between 13–14 °C in May, and 22–23 °C in August. The hypolimnion remained at approximately 5 °C throughout the year (fig. F2). Epilimnetic temperatures were slightly warmer in Lake Merwin at 14–16 °C in May and peaked at 22–24 °C in July and August. Unlike Swift Reservoir and Yale Lake, the hypolimnion in Lake Merwin warmed from 5–6 °C in April to 15–18 °C in October.

Vertical distributions of fish are influenced by a number of factors including prey density and distribution, temperature, and predation risk (Clark and Levy, 1988; Scheuerell and Schindler, 2003; Hardiman and others, 2004). Stratification strongly influenced the vertical distributions of salmonids during summer (Quinn and others, 2012). Epilimnetic temperatures exceeded the thermal preferences of salmonids during peak summer stratification in all three bodies of water, but the metalimnion remained usable year-round (fig. F2). In general, fish occupied the upper 40 m of the water column in Swift Reservoir during daylight in spring–fall (fig. F18). During dusk and night, most fish were in the upper 0–15 m of the water column in spring and fall and from 10–30 m during summer. A similar seasonal pattern was observed for kokanee salmon in Yale Lake and Lake Merwin; however, fish in Lake Merwin were more shallowly distributed in spring and fall, and deeply distributed in summer than in Yale Lake (figs. F19, F20). We expect that Chinook salmon would exhibit similar patterns of seasonal depth distribution and diel vertical migrations as do kokanee salmon (for example, Clark and Levy, 1988; Lowery and Beauchamp, 2010). In Yale Lake at night, fish were distributed at 5–40 m during spring and fall but were more concentrated at 15–30 m during the summer. In Lake Merwin, nighttime fish distribution was bimodal in spring and fall with a larger mode at 0–10 m and a smaller mode at 20–40 m. As expected (Quinn and others, 2012), fish were distributed in a single deeper mode at 20–50 m in the summer in Lake Merwin. The deeper fish distributions observed in August relative to June in all three bodies of water suggest decreased access to epilimnetic prey resources during the peak of summer stratification.

*Stable isotope analysis.*—Diet and stable isotope analyses revealed that salmonids in these reservoirs depend on zooplankton and specifically *Daphnia* during the growing season, as expected (Spencer and others, 1991; Tabor and others, 1996), but insects provided a significant supplementary source of energy when *Daphnia* were less abundant. Fluctuations in water level, often resulting from drawdown, can alter the species composition of littoral and benthic macroinvertebrate communities, productivity, and timing of prey production (for example, Furey and others, 2006). Stable isotope analysis clarified the trophic levels and relative dependence on pelagic and benthic energy pathways of the species and size classes of organisms within the food webs and corroborated our identification of the key pelagic planktivore populations. Organisms representing benthic-littoral energy pathways, such as snails and small *Catostomus macrocheilus* (largescale suckers), were enriched in  $\delta^{13}\text{C}$  ( $\delta^{13}\text{C}$ ; delta c 13, ratio of carbon isotopes  $^{12}\text{C}$  and  $^{13}\text{C}$ ), and organisms representing pelagic energy pathways, such as filter-feeding *Daphnia* were depleted of  $\delta^{13}\text{C}$  in all three bodies of water (figs. F21, F22, F23). Stable isotope signatures varied within and among species, size classes, trophic levels, and reservoirs according to position in and structure of each food web.

Three-spine sticklebacks and Chinook and coho salmon were the most dependent on pelagically derived nutrients in Swift Reservoir, whereas rainbow trout exhibited more benthic influence (fig. F21). Larger sculpin also appeared to rely on pelagic nutrients but could have been feeding on consumers of limnetically derived detritus. Kokanee salmon were the primary pelagic planktivores in Yale Lake and Lake Merwin (fig. F22; fig. 7 in “Piscine Predator Impact Studies 2013–2014, Lake Merwin, Washington,” chap. E of this report.). As expected, kokanee salmon showed the greatest dependence on pelagic prey of all fish in Yale Lake as evidenced by their  $\delta^{15}\text{N} > 3\text{‰}$  ( $\delta^{15}\text{N}$ , delta 15, ratio of nitrogen isotopes  $^{15}\text{N}$  and  $^{14}\text{N}$ ) above zooplankton and  $\delta^{13}\text{C}$  values similar to *Daphnia* and other zooplankton (Stockwell and others, 1999). However,  $\delta^{13}\text{C}$  values for *Daphnia* and kokanee salmon were surprisingly dissimilar in Lake Merwin, a pattern warranting further investigation. Small northern pikeminnow also relied on pelagic prey to a large degree in Lake Merwin (see “Piscine Predator Impact Studies 2013–2014, Lake

Merwin, Washington,” chap. E of this report). Secondary consumers (that is, invertivores) were enriched in  $\delta^{15}\text{N}$  relative to primary consumers, and piscivores were further enriched relative to invertivores.

Bull trout are often considered the top predator in natural lakes and reservoirs (Beauchamp and Van Tassell, 2001; Clarke and others, 2005; Guy and others, 2011). Our stable isotope results are consistent with that conclusion as we found bull trout at the top of the food web in both Yale Lake and Swift Reservoir (figs. F21, F22). In Yale Lake, bull trout  $\delta^{13}\text{C}$  values suggest coastal cutthroat trout, rainbow trout, and sculpin are likely prey resources. In Swift Reservoir, we evaluated bull trout forage resources using isotope samples collected prior to and after anadromous fish reintroductions (2013–2014). Our results indicate a considerable shift in prey resources with more benthically derived  $\delta^{13}\text{C}$  (fig. F21) for smaller (100–400 mm) and larger (>400 mm) bull trout since salmon reintroduction began. The  $\delta^{13}\text{C}$  values suggest bull trout are not utilizing coho or Chinook salmon as a food resource, a pattern which may be because of the large volume of water and low encounter rates with juvenile salmon. Concomitantly, recent results by Lowery and Beauchamp (2015) suggest the majority of fish consumed by even very large bull trout (for example, 700 mm) are <150 mm. Given that acclimation Chinook salmon have been released at mean lengths of 134 mm (in 2015) and 148 mm (in 2014), our results suggest that even minimal growth would likely exceed the predation window by most bull trout. Juvenile coho salmon emigration, however, has been extremely variable across years (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report) and juvenile coho salmon emigrants collected at the Eagle Cliff screw trap during the spring (March–May) have been considerably smaller (2015 mean=102 mm; standard deviation=39). Together these data suggest that a substantial portion of juvenile coho salmon are likely available as prey resources for larger bull trout.

**Diet analysis.**—The results of stable isotope analyses were largely corroborated by stomach contents analyses. Stomach contents of age-0–2 kokanee salmon, age-1 hatchery-reared rainbow trout, and age-1 Chinook salmon (the primary pelagic planktivores based on relative abundance and stable isotope analysis) all exhibited similar seasonal trends in the proportions of zooplankton and insects consumed (table F8). *Cladocera* (cladocerans), including mostly *Daphnia*, represented 54–68 percent of diets in spring, with immature aquatic insects (10–36 percent) contributing most of the remainder. Cladocerans increased to 76–100 percent of diets during summer when they were more available and 86–89 percent in fall. Overall, *Daphnia* was the most common prey consumed, which emphasized the focus on *Daphnia* abundance and distribution as a determining factor in carrying capacity. In Swift Reservoir and Lake Merwin, Copepoda (copepods) represented <2 percent of stomach contents across species and seasons but were somewhat more prevalent in diets of kokanee salmon in Yale Lake (6–16 percent). *Holopedium gibberum*, a Cladoceran encased in a gelatinous shell, were common in zooplankton samples from Yale Lake (mean=3.5 per liter (L), standard error[SE]=2.1/L in the epilimnion), and Swift Reservoir and Lake Merwin to a lesser degree but were rare in diets. Terrestrial insects represented a small proportion of diets (mean=5.0 percent, SE=1.5 percent) compared to aquatic insects (mean=11.5 percent, SE=3.5 percent), and both were most common in spring followed by fall. Rainbow trout diets suggested a higher reliance on zooplankton (59–100 percent during spring and fall), a pattern contrary to previous studies (Clarke and others, 2005) and our isotope results. However, only four samples of rainbow trout diets were analyzed to represent the summer season and some sampling occurred during the peak of a *Daphnia* bloom, so the results of stomach contents analysis likely underrepresent the true proportion of benthic invertebrates in their summer diet composition. Although rainbow trout had nearly doubled in weight since release, the isotopic signature of their hatchery feed (enriched in  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ) may have influenced their values, further contributing to their seemingly benthic signature.

**Zooplankton.**—A strong late spring peak in *Daphnia* occurred in all reservoirs between May and July, with a smaller secondary peak in September–October (fig. F24). In general, moderate to high densities of *Daphnia* (2.5–26 individuals per L) persisted in the epilimnion and metalimnion throughout the growing season in all three reservoirs. Densities in the epilimnion were generally twice that of the metalimnion, and hypolimnetic densities were always below 1 *Daphnia*/L with the exception of May–August in Lake Merwin.

*Daphnia* standing stock biomass followed similar patterns as density in all three reservoirs but was somewhat less variable than density across months as *Daphnia* production was highly variable and did not follow the same progression as density. The dampening of the fluctuation in *Daphnia* biomass relative to density resulted from the inverse relationship between mean individual mass and density because of increased production of smaller individuals when density increased (fig. F24). Production varied widely among months from a fraction to an order of magnitude greater than standing stock biomass (figs. F25, F26, F27). Many months of high production translated into increases in biomass the following month (and vice versa) as expected; however, significant production did not always translate into increased biomass. This could have been a result of a few different potential sources of error in our estimates of production. Monthly sampling events were too far apart to capture all the dynamics of egg ratios, which are notoriously variable across short intervals. Further, we did not account for entrainment out of reservoirs, and our egg-production model did not incorporate information on *Daphnia* age structure (Lynch, 1982; Brett and others, 1992). Despite these potential sources of bias, we consider our production estimates to be reliable for estimating salmon carrying capacity.

**Kokanee salmon abundance.**—Kokanee salmon were approximately one-half as abundant in Lake Merwin as in Yale Lake, but annual survival rates were similar. We estimated that the annual survival rate for kokanee salmon in Yale Lake was

35 percent and that in August there were 396,262 age-0; 139,847 age-1; and 49,354 age-2 kokanee salmon. We estimated that the annual survival rate for kokanee salmon in Lake Merwin was 32 percent and that in August there were 189,937 age-0; 60,105 age-1; and 19,020 age-2 kokanee salmon. The observed survival rates are considerably higher than estimated from a study using similar sampling methods in Lake Billy Chinook (25 percent; Beauchamp and Van Tassell, 2001); the difference may be attributed to differences in angling pressure.

*Resident planktivore consumption demand to prey supply ratios and carrying capacity.*—Exceeding the carrying capacity of the reservoir for pelagic planktivores would have pronounced negative effects on juvenile growth, survival, and production of salmon smolts (Hyatt and Stockner, 1985; Edmundson and Mazumder, 2001). Even in a month of high prey availability, fish can only consume a limited amount of prey as dictated by stomach volume and digestion rate. In months of low prey availability, consumption by juvenile salmon is limited by the rate at which they can capture prey (as a function of their size-dependent foraging abilities and prey densities), and antipredation behaviors that limit their ability to forage at certain times of day or at certain depths (Stockwell and Johnson, 1999; Koski and Johnson, 2002). Significant prey shortages during the growing season would hinder their ability to acquire enough energy to effectively fight disease and survive. Furthermore, food limitation and size-dependent predation risk promotes risk-taking behavior, which increases predation mortality (Biro and others, 2005).

Our simulations indicated that the Swift Reservoir, Yale Lake, and Lake Merwin all offered a moderate surplus of *Daphnia* to support consumption demand by reintroduced anadromous salmonids, but a significant portion of prey was also consumed by resident pelagic planktivores. Resident pelagic planktivores fed at moderate to high levels relative to their potential maximum in all three reservoirs (59–123 %C<sub>max</sub>; table F5), but their consumption demand fluctuated based on ambient water temperatures and mean fish size (figs. F25, F26, F27). Kokanee salmon in Lake Merwin had the highest feeding rate (92–123 %C<sub>max</sub>) across age classes from April through November, while the feeding rate was intermediate for hatchery-reared rainbow trout in Swift Reservoir (78 %C<sub>max</sub>) and kokanee salmon in Yale Lake (59–86 %C<sub>max</sub>; table F5). Consumption demand on *Daphnia* by the planktivore populations in all three reservoirs started at moderate levels in April–June (20–34 metric tons [MT]/month), peaked in August–October (33–55 MT/month), then declined with decreasing water temperatures (figs. F25, F26, F27).

Swift Reservoir had ample prey resources available from May to August, as well as October–November, suggesting that fish would have access to plenty of food during the critical stages of reservoir entry in spring, and again in late summer–fall when fish store energy before winter. The ratio of consumption demand by rainbow trout to prey supply in Swift Reservoir started low in June and increased through September (fig. F25A). Consumption demand to *Daphnia* supply ratios were <10 percent of standing stock biomass in June (prior to stratification and with all depth layers summed) but increased in July–September once stratification was established. Consumption demand was 21 percent of the most conservative estimate of prey supply. Biomass within the metalimnion and hypolimnion (epilimnion thermally inaccessible) in July and increased to 56 percent in August and 96 percent in September (figs. 25B, C). However, consumption demand was <30 percent of biomass in all months examined if the whole water column was considered. The demand:supply ratio if production was also included was <30 percent in the metalimnion and hypolimnion and <15 percent in the whole water column in all months examined (fig. 25D). Biomass was 5–10 times greater than consumption demand in October–November. These ratios suggest that a moderate amount of surplus prey would be available to support additional demand if production is considered in addition to biomass. There was a surplus of approximately 9 MT of *Daphnia* biomass and production in the metalimnion and hypolimnion in September, the month of highest demand:supply ratios, which could have been consumed without exceeding the 50 percent carrying capacity cutoff according to our simulations. Dividing this biomass by the estimated consumption demand of a subyearling spring Chinook salmon in Swift Reservoir yielded an estimate of roughly 150,000 juvenile salmon that could have been supported during their first year by the surplus prey in the month of greatest prey demand:supply ratio.

Simulated consumption demand of kokanee salmon in Yale Lake (fig. F26A) exceeded *Daphnia* standing stock biomass plus production in April and May, as *Daphnia* did not begin to bloom until June (figs. F26B, C). Consumption demand in June was 61 percent of biomass but only 16 percent of biomass plus production. During peak thermal stratification from July through September, consumption demand was 39–122 percent of biomass in the metalimnion and hypolimnion or 22–37 percent of biomass plus production. Across the entire water column from July through September, consumption demand was 22–65 percent of biomass or 7–15 percent of biomass plus production (fig. F26D). Simulated consumption was 66–70 percent of the biomass in October–November and 17 percent of biomass plus production in October (production data not available for November). These ratios suggest that a moderate amount of surplus prey would be available during the summer growing season to support additional demand in Yale Lake if production is considered in addition to standing stock biomass. The surplus biomass and production of *Daphnia* in the metalimnion and hypolimnion in September, the month of highest demand:supply ratio during the summer growing season, without exceeding 50 percent of prey supply, was roughly 14 MT. Dividing this by the consumption demand of an individual age-0 kokanee salmon (as a surrogate for a subyearling salmon) yielded an estimate of an additional 330,000 fish that could have been supported in the reservoir through their first year.

In April, before the major bloom of *Daphnia* was established, our simulated consumption demand for kokanee salmon in Lake Merwin (fig. F27A) was 143 percent of standing stock biomass of *Daphnia* but only 8 percent of biomass plus production (fig. F27B, C). The consumption demand to prey supply ratio dropped significantly when the spring *Daphnia* bloom was



established in May and was <15 percent of biomass in May–June (fig. F27D). Consumption demand increased, and prey supply began to decrease in July–August, with demand:supply ratios increasing to 33–36 percent of biomass in the metalimnion and hypolimnion, and 20–28 percent in the whole water column. Consumption demand began to outstrip prey supply in September–October when it was 94–125 percent of biomass and 37–65 percent of biomass plus production in the metalimnion and hypolimnion. The demand:supply ratio in September–October, when *Daphnia* in the entire water column was included, was 41–57 percent biomass and 18–22 percent biomass plus production. Simulated prey demand was approximately twice the biomass in November. Overall, Lake Merwin also offers a moderate surplus of prey resources from April through September. Dividing surplus biomass and production in the metalimnion and hypolimnion in September, the month of highest demand:supply ratios during the summer growing season, by the consumption demand of an individual age-0 kokanee salmon yielded an estimate of 130,000 additional subyearling fish that could have been supported in the reservoir for their first year.

Overall, our results indicate that the seasonal supply and depth-distribution of *Daphnia* are important factors regulating the carrying capacity of Swift Reservoir, Yale Lake, and Lake Merwin for resident and juvenile anadromous Salmonids, which will share zooplankton resources. Our findings are particularly relevant given the effects of size on juvenile salmon survival (Ebersole and others, 2006a; Pess and others, 2011). Furthermore, Zabel and Achord (2004) found that the length of juvenile Chinook salmon in the Salmon River Basin had a strong effect on survival to outmigration within populations but not across multiple populations. The results from Zabel and Achord (2004) also suggest the potential for size-dependent survival advantages at subsequent life stages. Size has also been found important for juvenile Chinook salmon in California's Central Valley, where larger and faster growing individuals at marine entry exhibited greater survival during years when overall survival to adulthood was lower for their cohort (Woodson and others, 2013). Together, these results illustrate the importance of considering the capacity of the reservoir and lake environments, which likely will influence the overall success of anadromous reintroductions.

## Assessing the Effects of Anadromous Reintroductions on Bull Trout

We employed the use of a population model, not to necessarily emulate the “truth” but to consider potential effects of reintroduced salmon populations on extant bull trout populations and also identify potential data gaps in our current knowledge (Conroy and Moore, 2001). The “baseline” population model with demographic stochasticity alone resulted in a simulated population of more than 250 adult bull trout (fig. F28). Within any simulation run, our models demonstrated considerable interannual variability, a result that is consistent with long-term monitoring of bull trout populations (Kovach and others, 2017).

Results from our perturbations (fig. F29) indicate that reductions in the carrying capacity of bull trout tributary streams (fig. F30) and reservoir and lake survival (fig. F31) would likely have the largest effects on the existing bull trout population. We considered reductions in carrying capacity to be relevant given the considerable overlap in distribution and forage patterns observed in our field studies and the effects of reduced carrying capacity on bull trout recruitment (Ratliff and others, 2015). In general, there is a paucity of information describing salmon–bull trout interactions, particularly at the early life stages. Lowery and Beauchamp (2015) found considerable overlap in both distribution and forage. Under such natural conditions, competitive interactions are likely minimized as a result of niche segregation. However, the bull trout population in the upper Lewis River Basin remains relatively small with limited distribution. While adult anadromous salmon can contribute substantial nutrient inputs to headwater environments (Naiman and others, 2002; Kohler and others, 2012), juvenile salmon can also represent substantial vectors for exporting nutrients (Kohler and others, 2013). Indeed, the net benefit to freshwater ecosystems can be highly variable (Janetski and others, 2009). Our results suggest any considerable reductions in carrying capacity within this distribution may lead to declines in the abundance of bull trout populations.

In general, adfluvial bull trout populations demonstrate considerable resiliency, likely because of the stability of lentic habitat (Kovach and others, 2017). While bull trout populations sympatric with kokanee salmon can be particularly robust with large, adfluvial spawners (Johnston and others, 2007; Ratliff and others, 2015), there remains a paucity of information regarding anadromous salmon and steelhead reintroductions. Our results indicate the greatest risk to bull trout in the upper Lewis River Basin would occur through reductions in bull trout survival in the reservoir environment (fig. F31) and the population-level consequences of such changes. For example, in addition to reductions in abundance, our results also indicate reductions in survival may lead to considerably higher interannual variations in abundance (coefficient of variation [CV]=0.22) relative to baseline conditions (CV=0.17). A concern for bull trout in the studied environments is the seemingly large number of residualized salmon (see “Assessment of Juvenile Fish Production and Outmigration Success on the Lewis River, Washington,” chap. D of this report) that, with even moderate growth, may escape predation by most bull trout (Lowery and Beauchamp, 2015). Increased density dependence can have significant effects on bull trout survival and recruitment (Johnston and Post, 2009; Ratliff and others, 2015). However, our early food web results suggest that bull trout and coho and Chinook salmon in Swift Reservoir are utilizing different forage resources. It remains unclear how the forage base and food web will change throughout the reintroduction, but if competition for forage increases, particularly if residualized salmon exceed bull trout gape limitations of bull trout (Lowery and Beauchamp, 2015) and yearly smolts exceed capacity, there may be negative consequences for bull trout.

Our simulations indicate even moderate levels of redd superimposition are unlikely to have large effects on bull trout. These results are likely driven by compensatory mechanisms associated with density dependence (for example, Paul and others, 2000). It is unclear, however, how superimposition may exacerbate variability in population abundance when coupled with substantial environmental stochastic events.

## Conclusions

Historically, bull trout and coho and Chinook salmon likely occurred sympatrically in the upper Lewis River Basin with varying degrees of overlap across different life stages. Since the 1930s, however, there have been large changes in the upper Lewis River Basin resulting from habitat alterations (for example, building of hydropower facilities, the eruption of Mount Saint Helens), which have altered the physical and hydrologic template. As such, there continues to be uncertainty in how anadromous reintroductions will influence native salmonids such as bull trout. Further, there remains very limited information about bull trout interactions with juvenile salmon in reservoirs and lakes across the Pacific Northwest to provide guidance. In the upper Lewis River, the low proportion of juvenile salmon at downstream collectors and bull trout forage patterns (see the “Assessing the Effects of Anadromous Reintroductions on Bull Trout” section in this chapter) suggest a large portion of juvenile salmon may not be available as prey to all but the largest bull trout. Because it is unclear how increases in biomass in the reservoir and lake environments will alter the existing food webs and, concomitantly, affect bull trout at different life stages, continued monitoring is needed.

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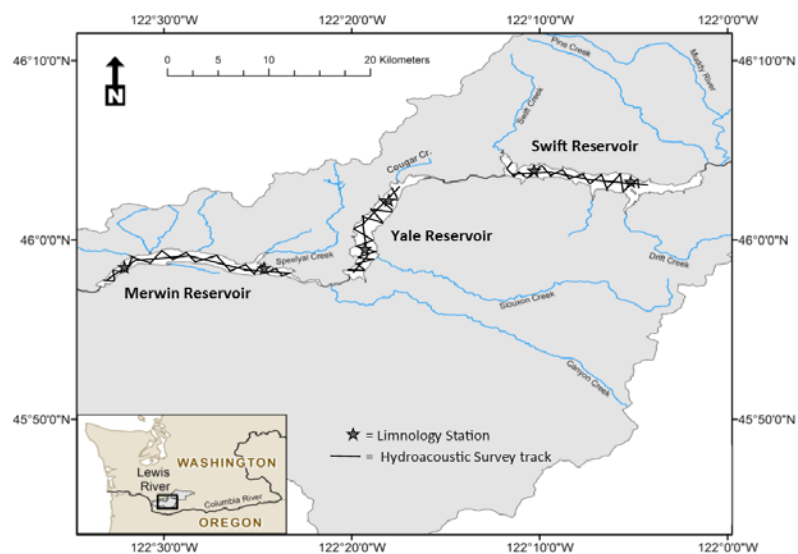


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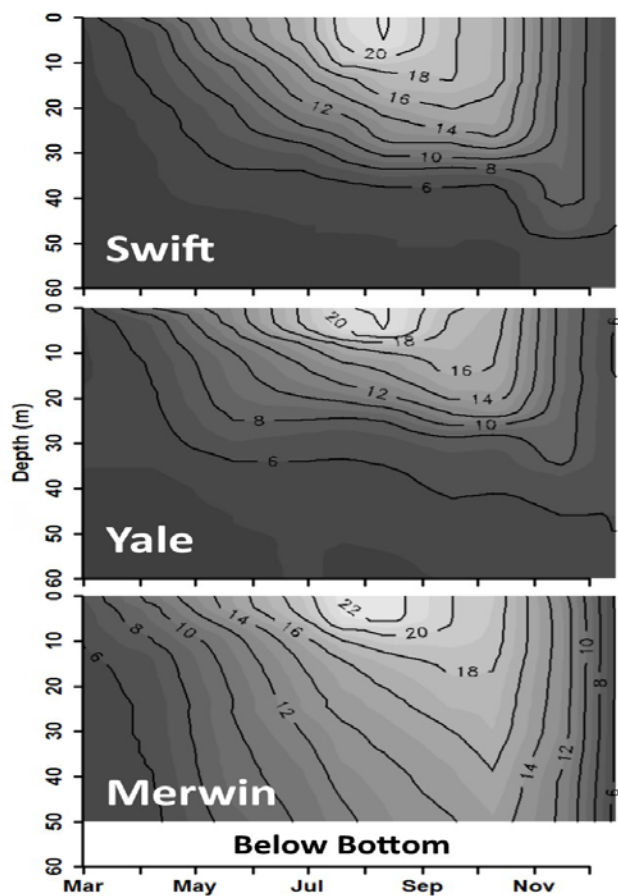
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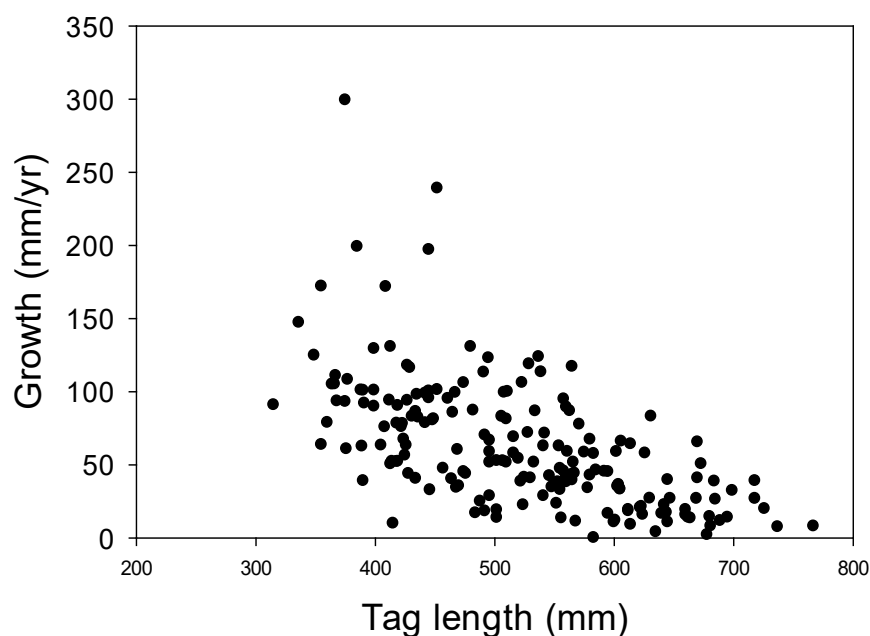
## Figures



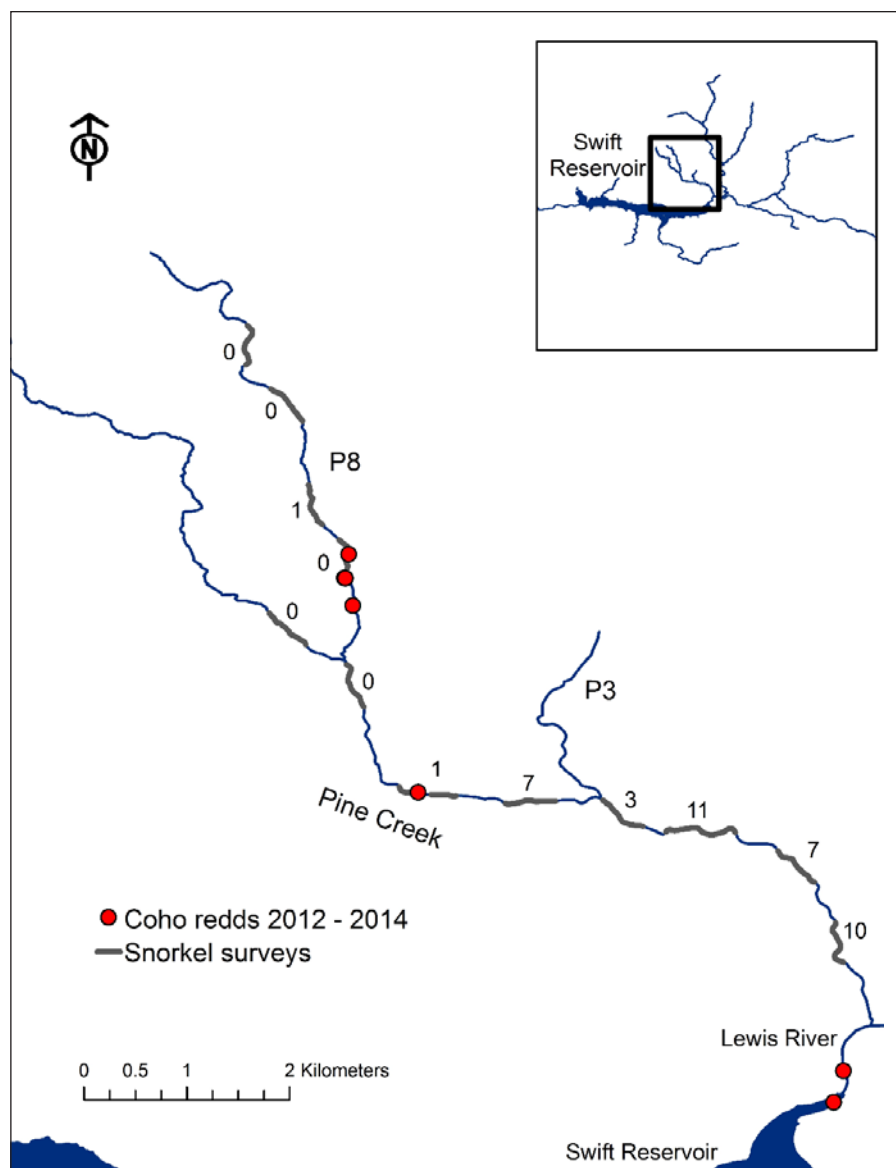
**Figure F1.** Map of North Fork of the Lewis River reservoirs in Washington with respect to the hydrologic basin (gray shaded area). Stars show the temperature and zooplankton sampling locations; solid lines indicate the hydroacoustic survey tracks. (Cr., creek)



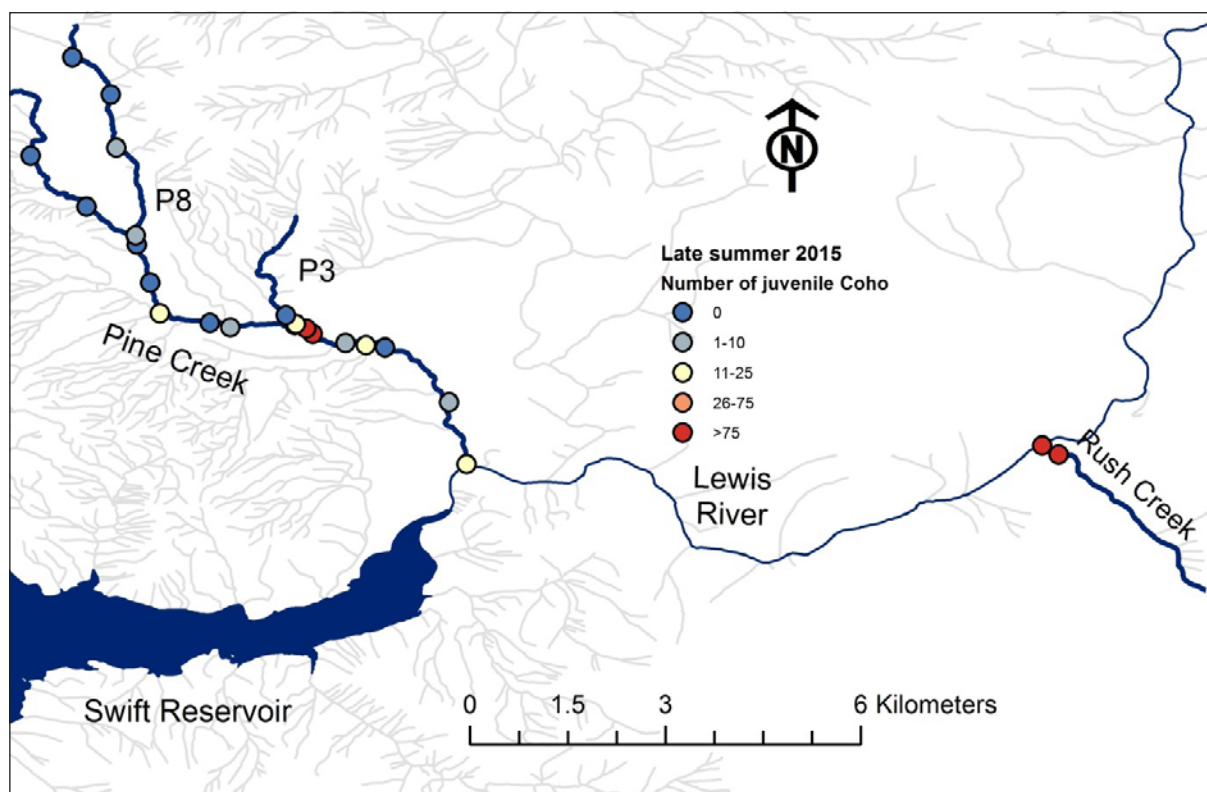
**Figure F2.** Isoclines of mean water temperature (degrees Celsius) with respect to depth (in meters [m]) in Swift Reservoir, Yale Lake, and Lake Merwin, Washington, during March–December 2013.



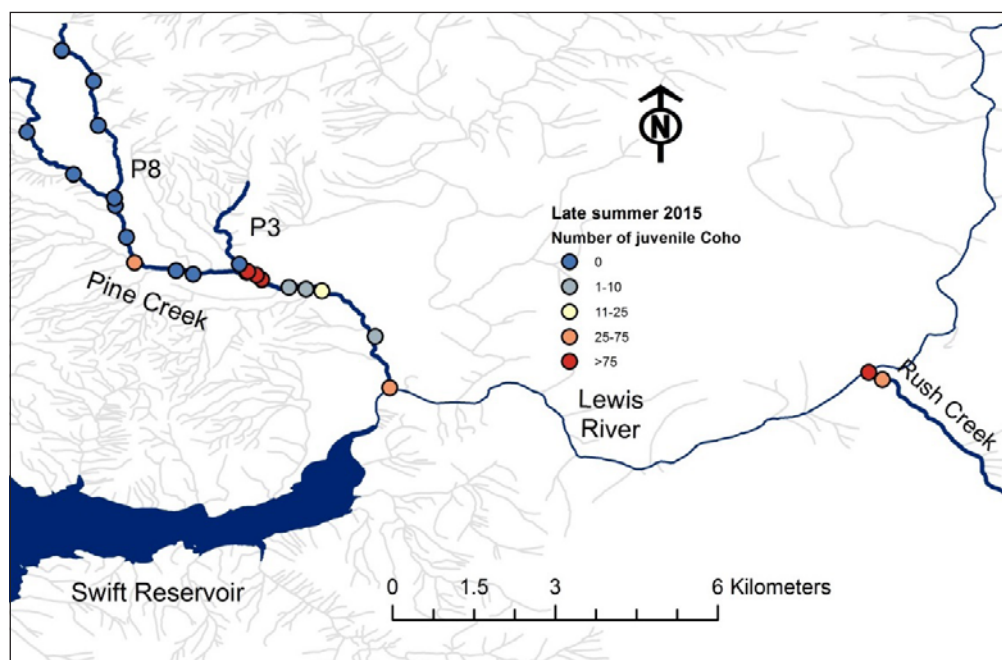
**Figure F3.** Annual individual bull trout growth data for fish individually marked by Washington Department of Fish and Wildlife and PacifiCorp biologists from 1993–2016 in Swift Reservoir, Washington, in relation to length at tagging (in millimeters). Growth rate is in millimeters per year (mm/yr).



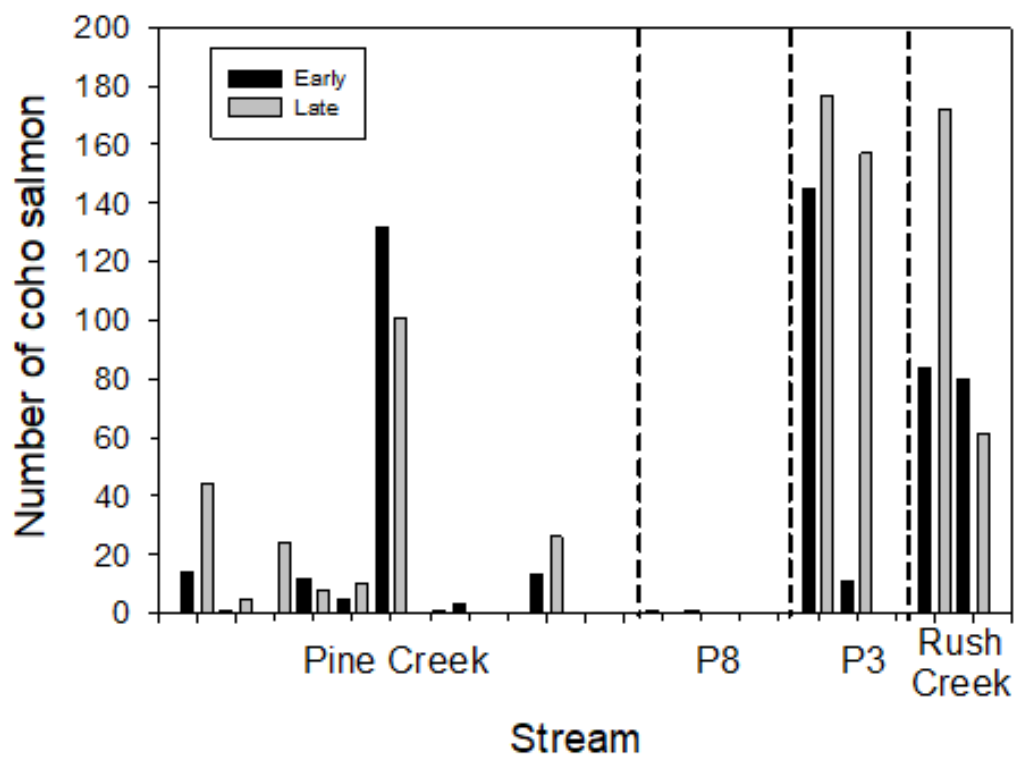
**Figure F4.** The location of coho salmon redds (red circles; 2012–2014) in Pine Creek and a tributary to Pine Creek (P8), Washington; snorkel surveys used to identify overlap in the distribution of bull trout and coho salmon during 2013 and 2014 (gray); and the number of juvenile coho salmon (number by reach) detected in surveys. The black box in the inset map shows the location of Pine Creek and tributaries within Swift Reservoir.



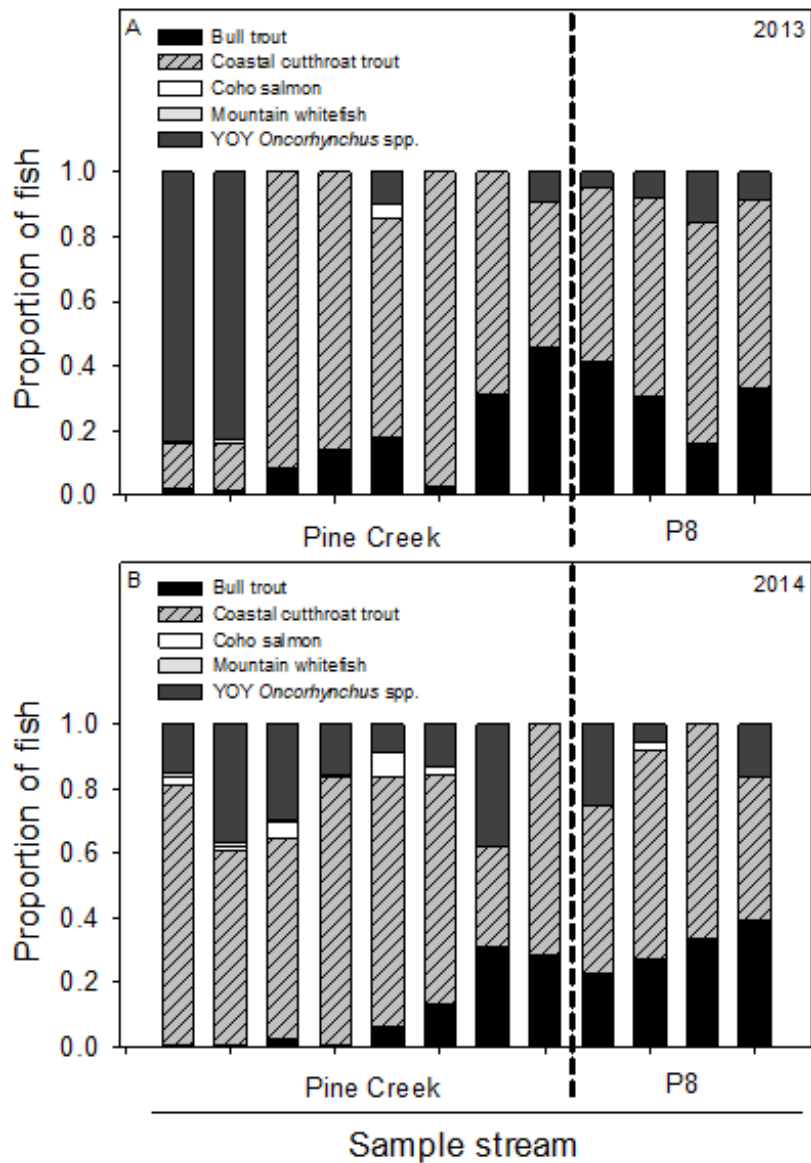
**Figure F5.** The number of juvenile coho salmon observed during daytime snorkel surveys during early summer (June 2015) in Pine Creek, P8, P3, and Rush Creek, Washington.



**Figure F6.** The number of juvenile coho salmon observed during daytime snorkel surveys during mid-late summer (July–September 2015) in Pine Creek, P8, P3, and Rush Creek, Washington.

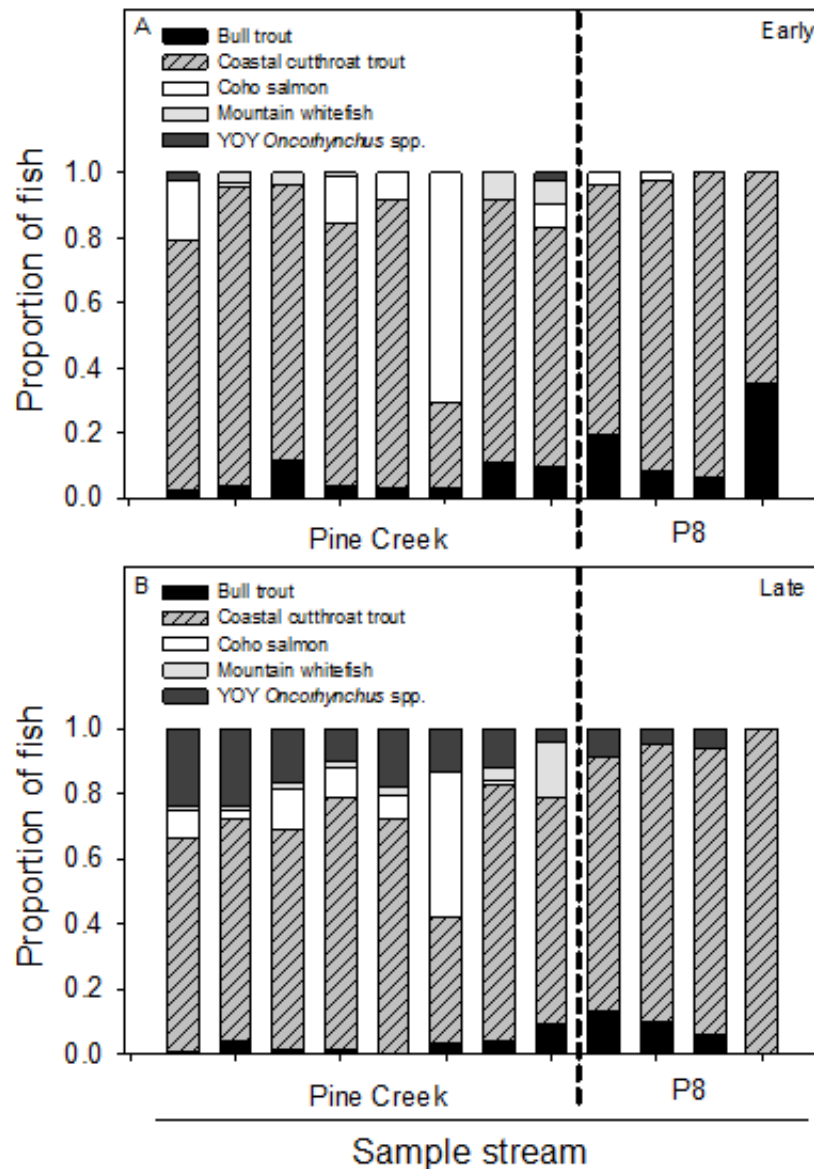


**Figure F7.** The number of juvenile coho salmon observed during snorkel surveys in early (June 2015) and mid-late summer (July–September 2015) in Pine Creek, P8, P3, and Rush Creek, Washington. Study areas are separated by dashed lines.

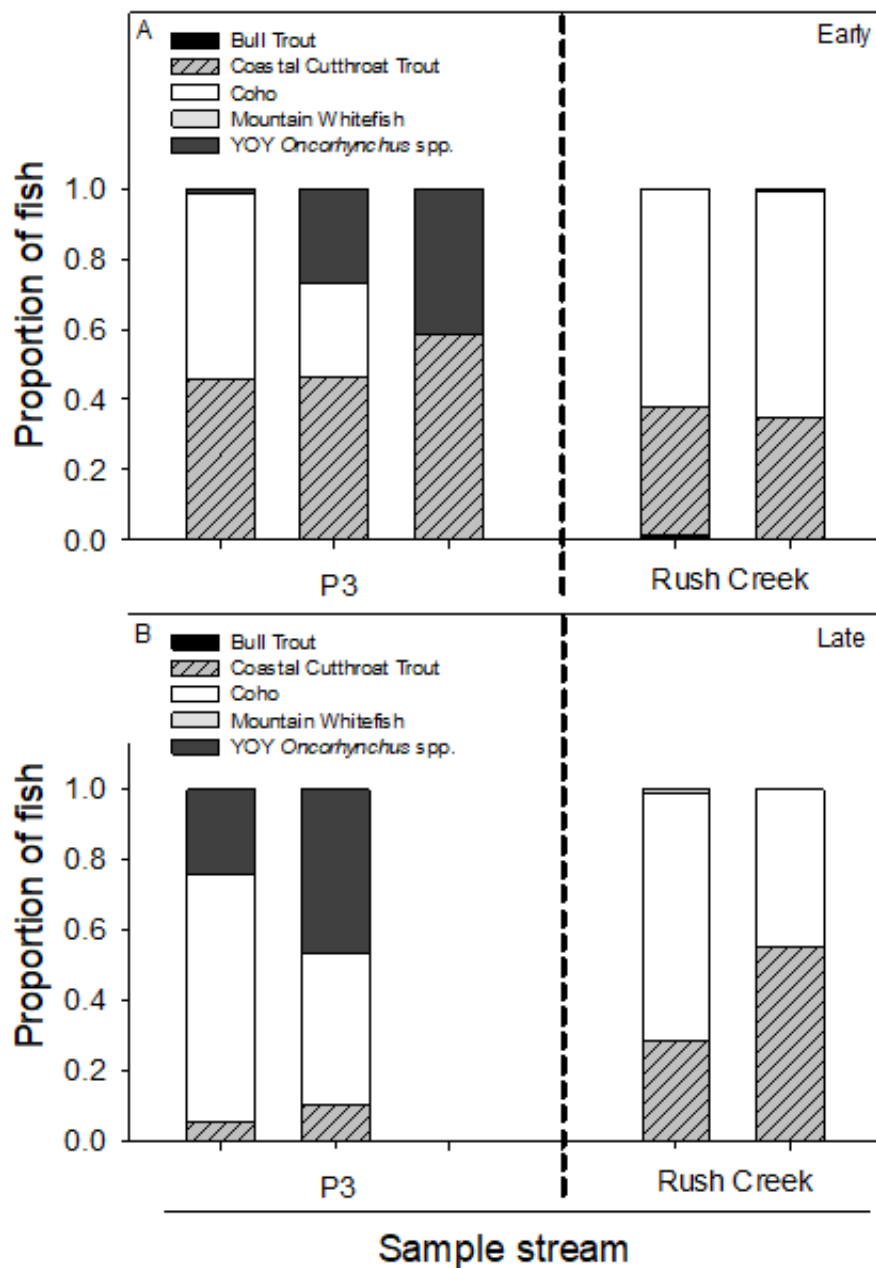


**Figure F8.** The proportion of bull trout, coastal cutthroat trout, young-of-year (YOY) coho salmon, mountain whitefish, and YOY *Oncorhynchus* spp. (rainbow trout/steelhead and coastal cutthroat trout) observed during snorkel surveys in different reaches (denoted by column) in Pine Creek and P8 during 2013 and 2014. Reaches are ordered in a downstream to upstream manner; left-to-right, and 2013 and 2014. Reaches are not the same-see methods; study areas are separated by dashed lines.

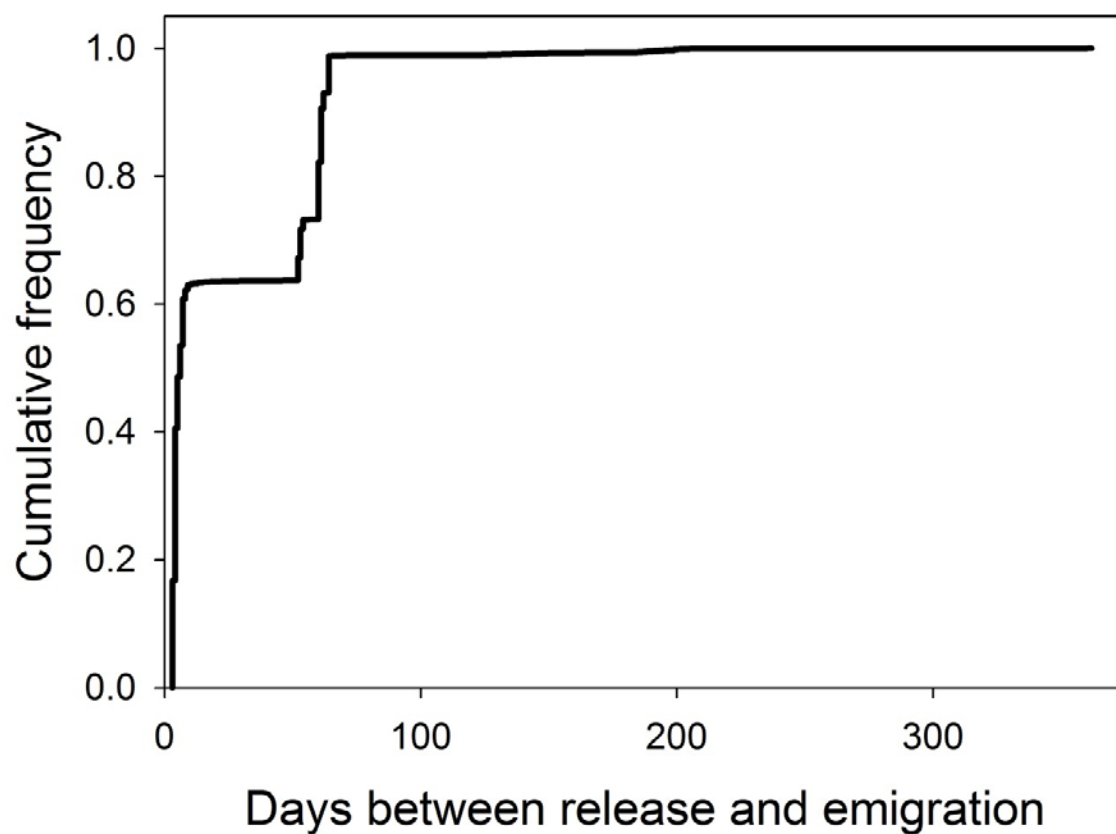




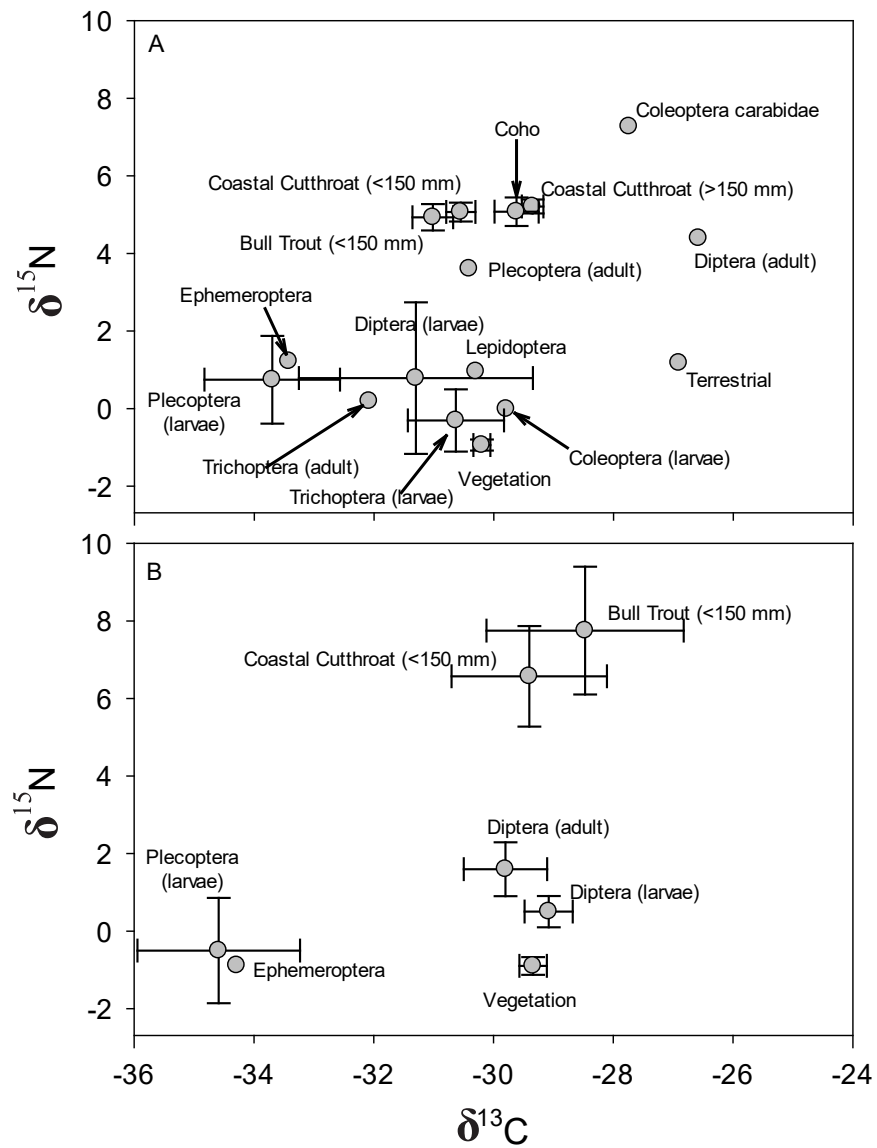
**Figure F9.** The proportion of bull trout (black), coastal cutthroat trout (gray hatched), young-of-year (YOY) coho salmon (white), mountain whitefish (light gray), and *Oncorhynchus* spp. (rainbow trout/steelhead and coastal cutthroat trout; dark gray) observed during snorkel surveys in different reaches (denoted by column) in Pine Creek and P8 during *A*, early 2015 (June–July) and *B*, late 2015 (August). Reaches are ordered in a downstream to upstream manner (left-to-right); study areas are separated by dashed lines.



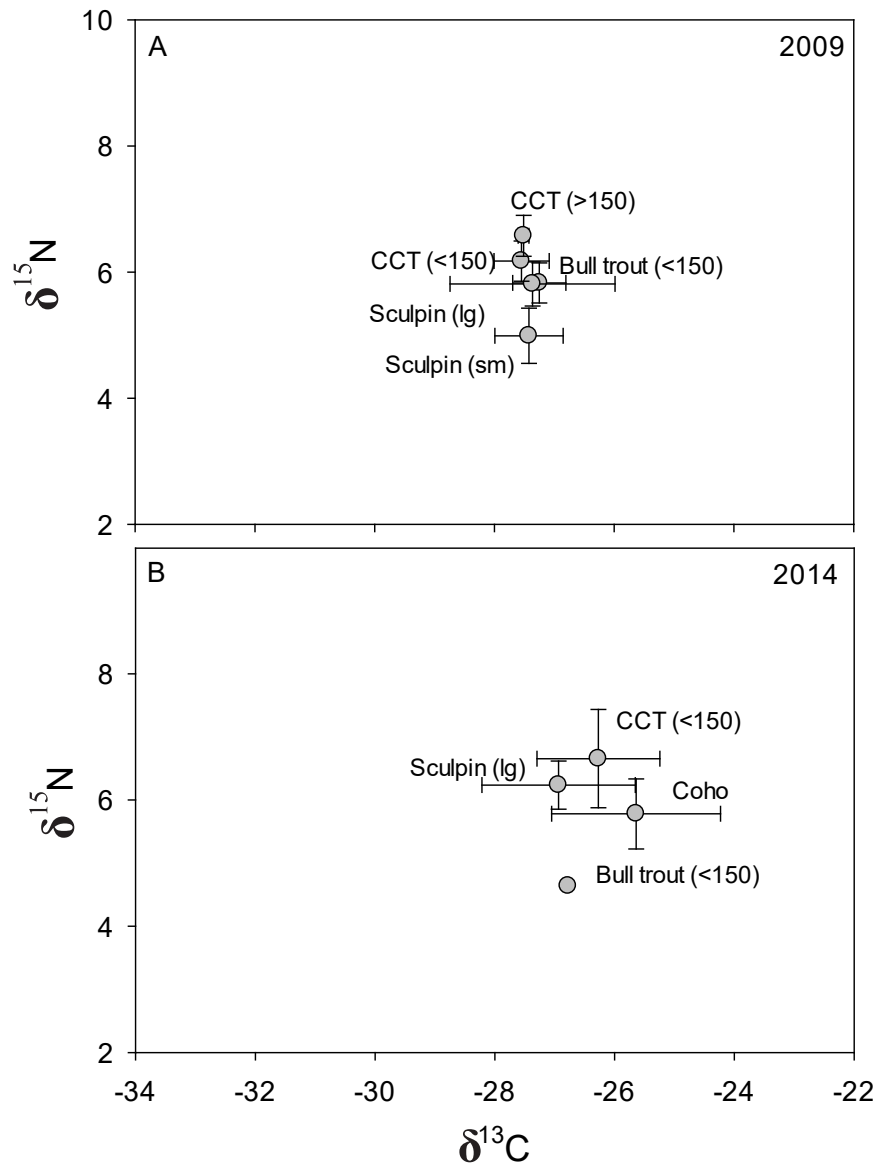
**Figure F10.** The proportion of bull trout (black), coastal cutthroat trout (gray hatched), young-of-year (YOY) coho salmon (white), mountain whitefish (light gray), and YOY *Oncorhynchus* spp. (rainbow trout/steelhead and coastal cutthroat trout; dark gray) observed during snorkel surveys in different reaches (denoted by column) in P3 (small tributary to Pine Creek) and Rush Creek during A, early 2015 (June–July) and B, late 2015 (August). Reaches are ordered in a downstream to upstream manner (left-to-right); the downstream reach on P3 was sampled during late July and the most upstream reach was not resampled as very few fish were observed. Study areas are separated by dashed lines.



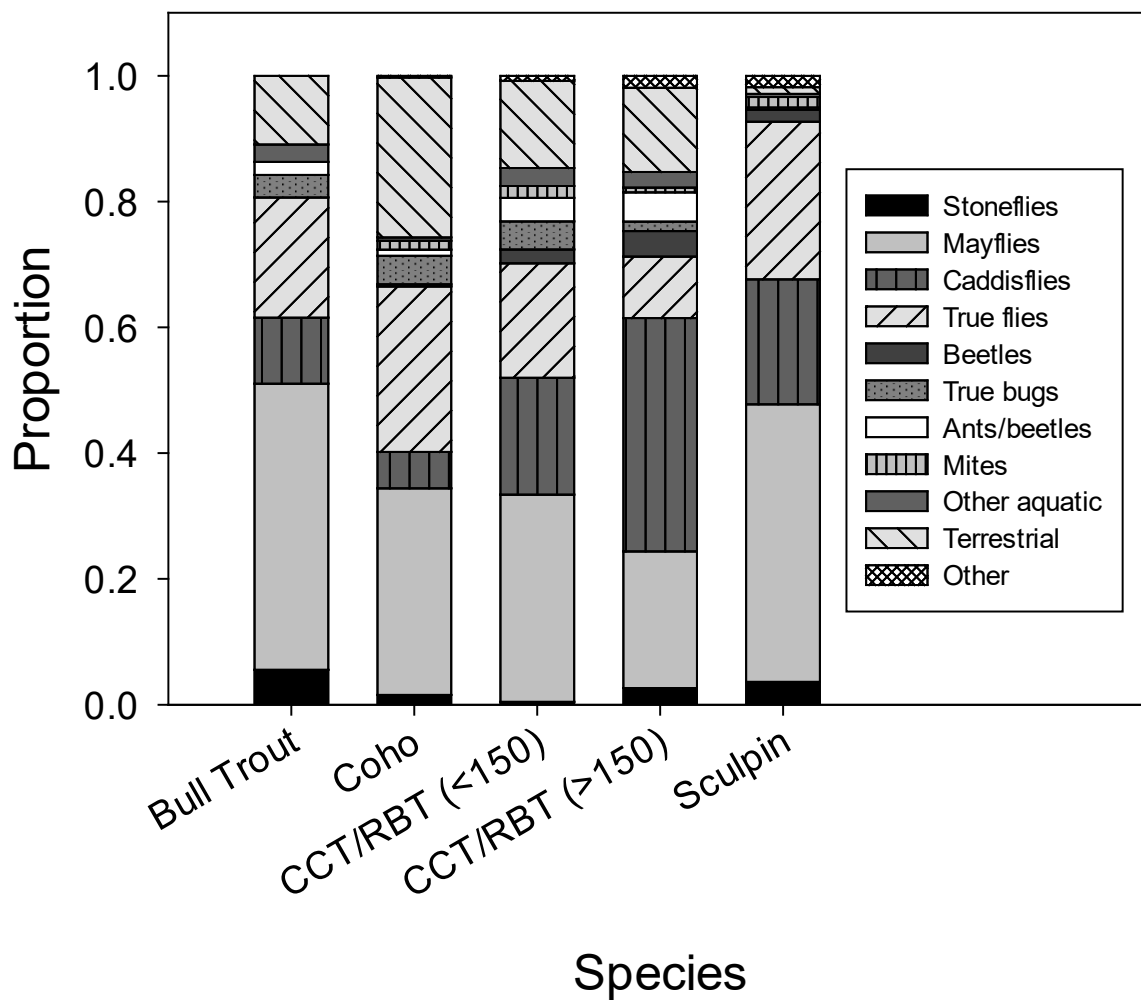
**Figure F11.** The cumulative frequency of the days between release and emigration past the Clear Creek, Washington, passive integrated transponder-tag antenna for acclimation spring Chinook salmon released during the spring of 2014 and 2015.



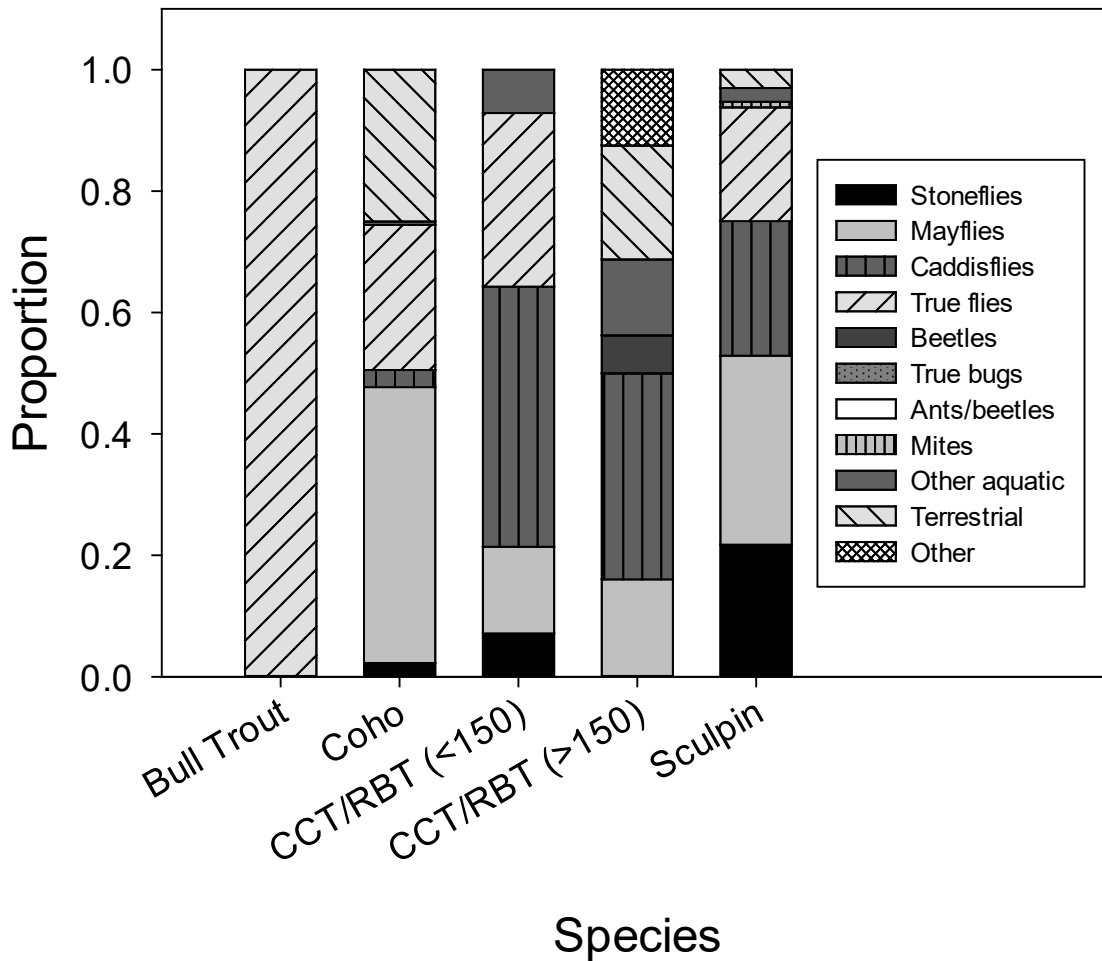
**Figure F12.** Stable isotope results with 95-percent confidence intervals during late spring–summer in *A*, 2009 (prior to anadromous reintroductions) and *B*, 2014 (after the onset of anadromous reintroductions) for different size classes (measured in millimeters; mm) of fish from P8, a main tributary to Pine Creek and the major bull trout spawning tributary in the Swift Reservoir portion of the upper Lewis River, Washington.



**Figure F13.** Stable isotope results with 95-percent confidence intervals during late spring–summer in *A*, 2009 (prior to anadromous reintroductions) and *B*, 2014 (after the onset of anadromous reintroductions) for different size classes (large [lg]  $\geq 80$  mm; small [sm],  $< 80$  mm) of fish from Rush Creek, one of the major bull trout spawning tributaries in the Swift Reservoir portion of the upper Lewis River, Washington. (mm, millimeter; CCT, coastal cutthroat trout;  $\geq$ , greater than or equal to;  $<$ , less than)

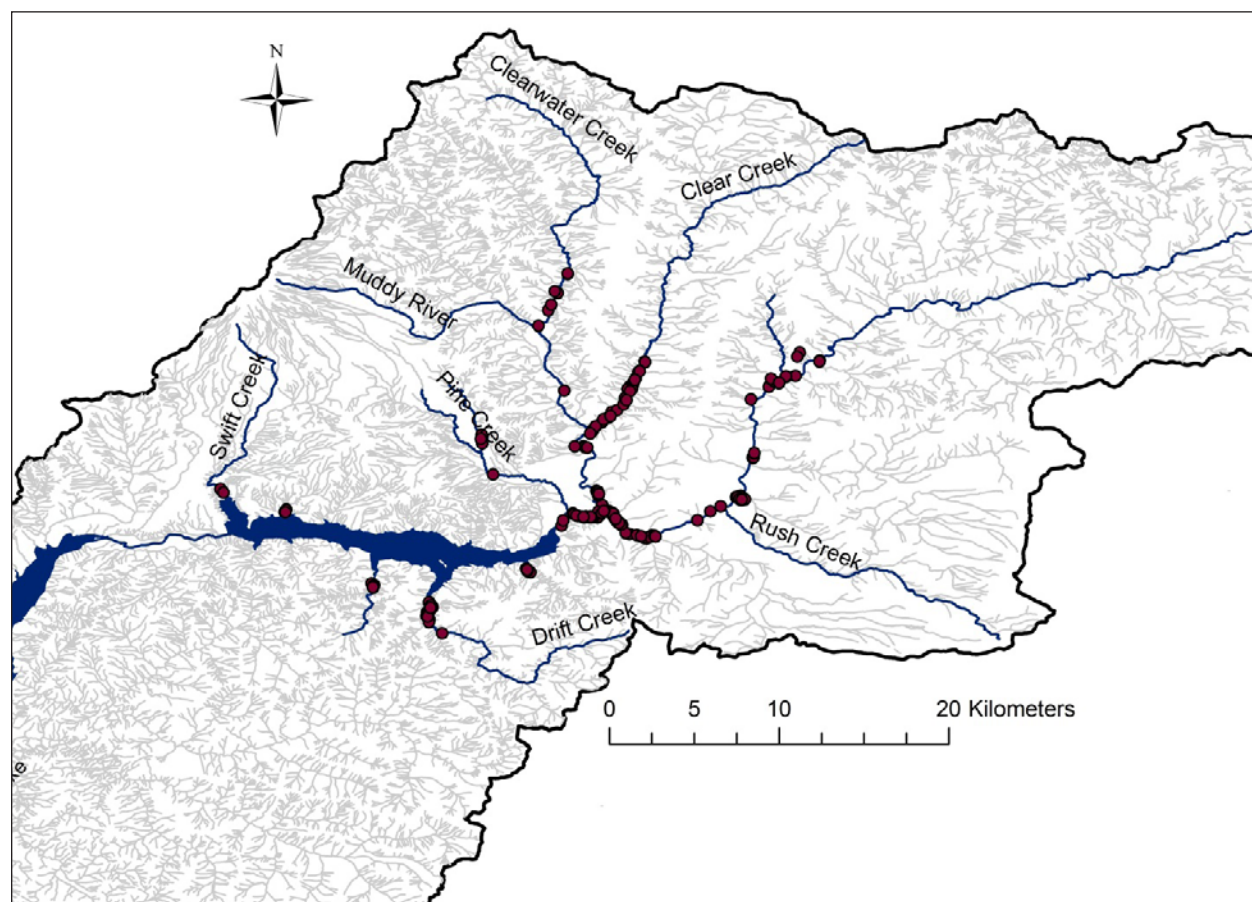


**Figure F14.** The proportion of bull trout, juvenile coho salmon, coastal cutthroat trout (CCT)/rainbow trout (RBT) by size class as measured in millimeters [mm] and sculpin diets as Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddisflies), Diptera (true flies), Coleoptera (beetles), Hemiptera (true bugs), Hymenoptera (ants and bees), Trombidiformes (mites), other aquatic insects, terrestrial insects, and other prey items (fish, fish eggs, worms, snails) during the late spring–summer (June–August).

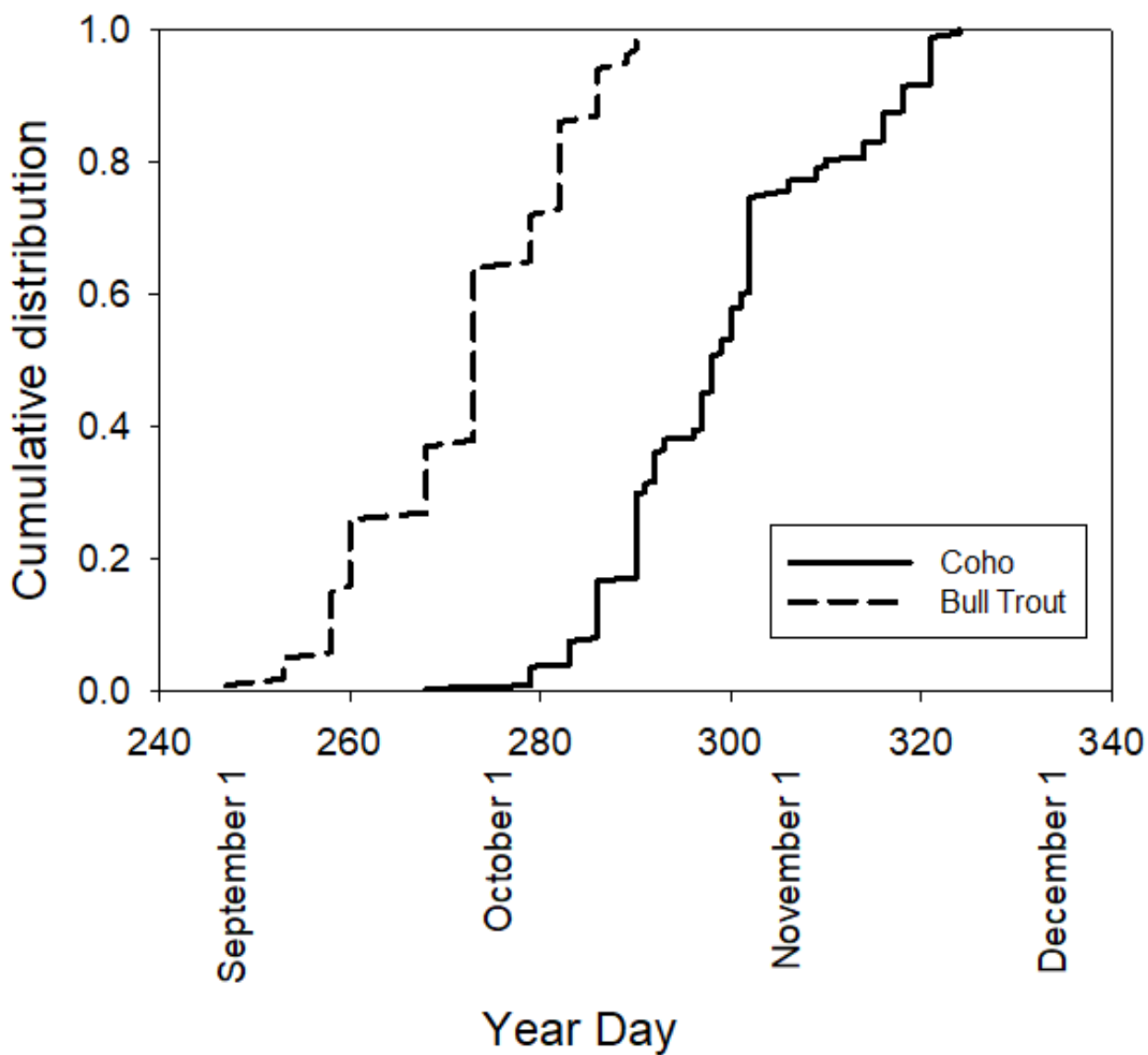


**Figure F15.** The proportion of bull trout, juvenile coho salmon, coastal cutthroat trout (CCT)/rainbow trout (RBT) to by size class as measured in millimeters [mm], and sculpin diets as Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddisflies), Diptera (true flies), Coleoptera (beetles), Hemiptera (true bugs), Hymenoptera (ants and bees), Trombidiformes (mites), other aquatic insects, terrestrial insects, and other prey items (fish, fish eggs, worms, snails) during the late fall (November). Only one bull trout diet was collected during the fall sampling.

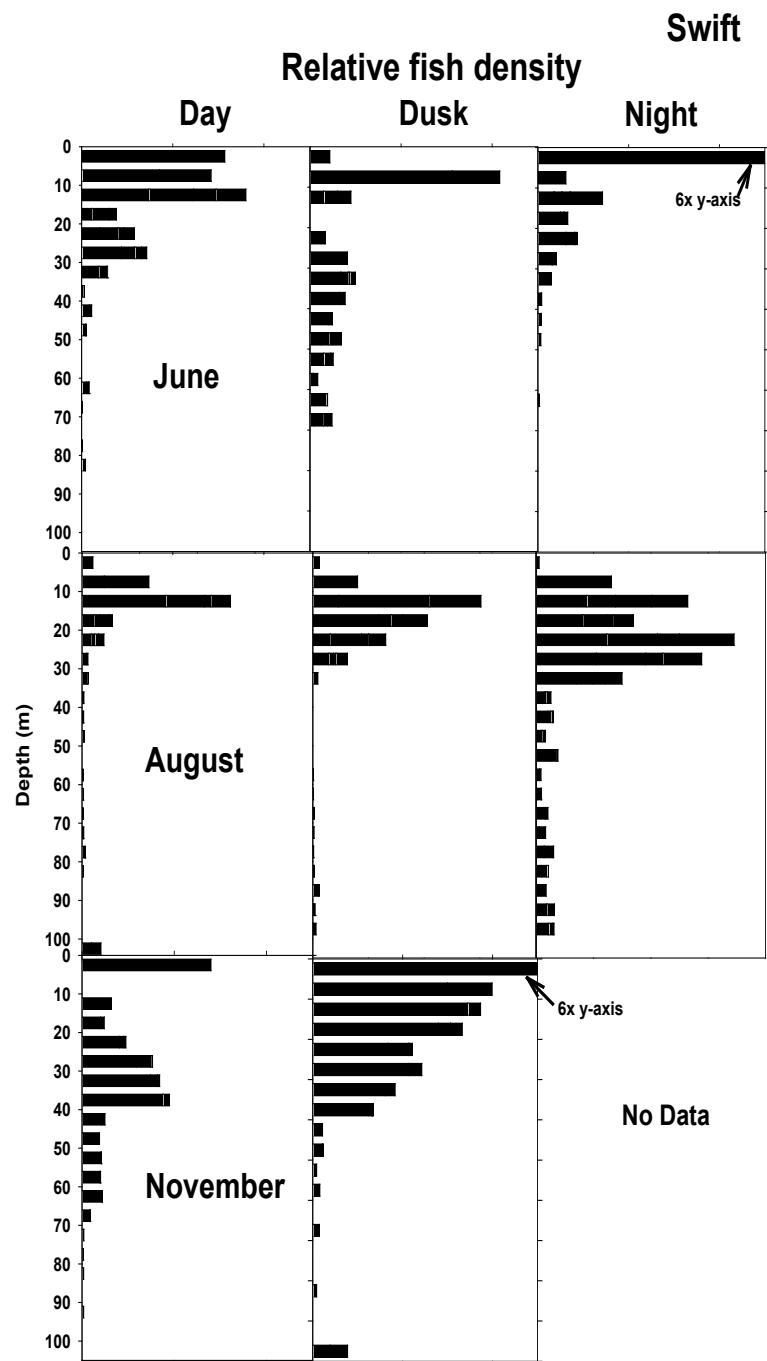




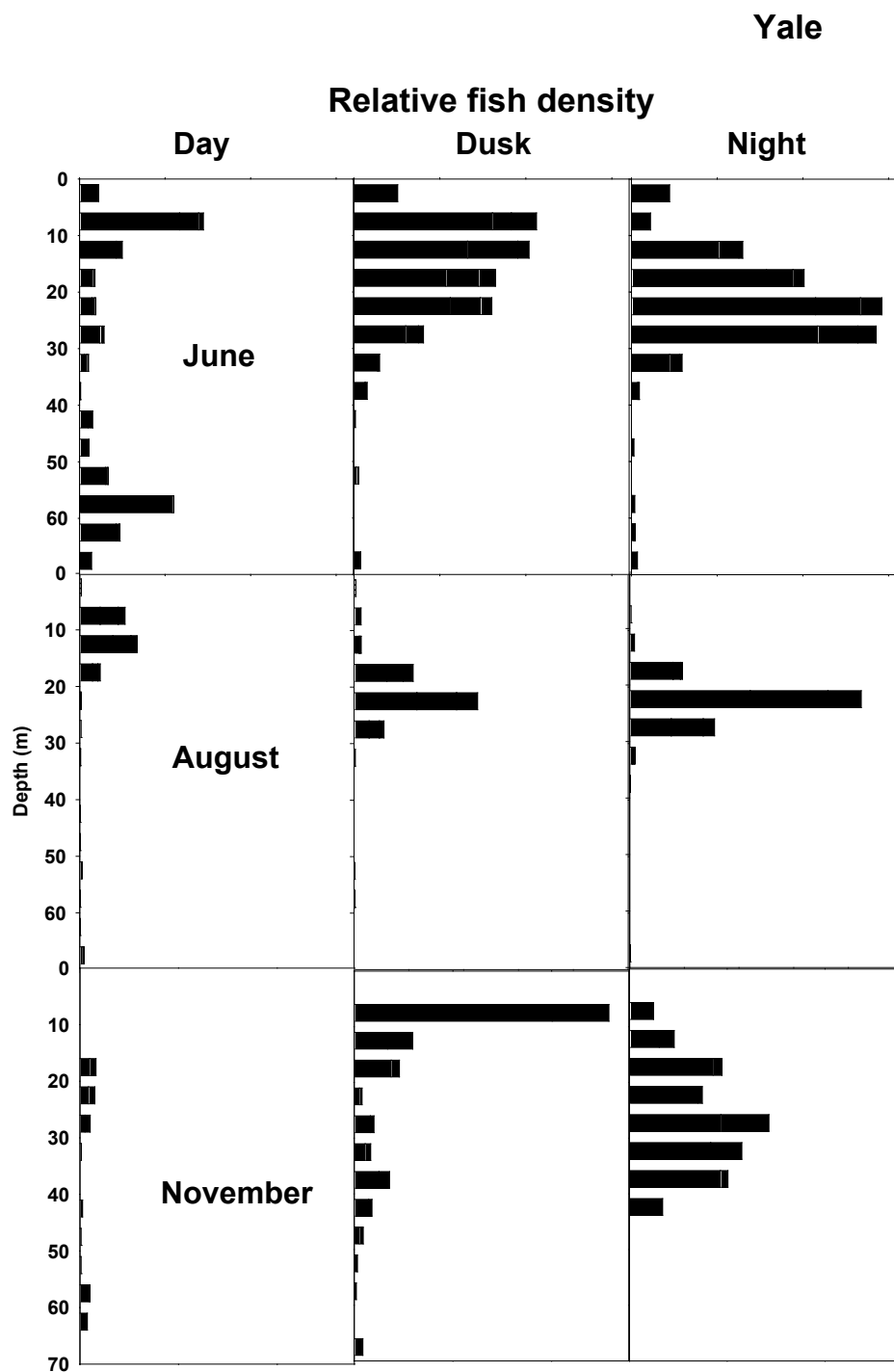
**Figure F16.** The distribution of coho salmon redds in the upper Lewis River, Washington, from surveys conducted in 2012 to 2014.



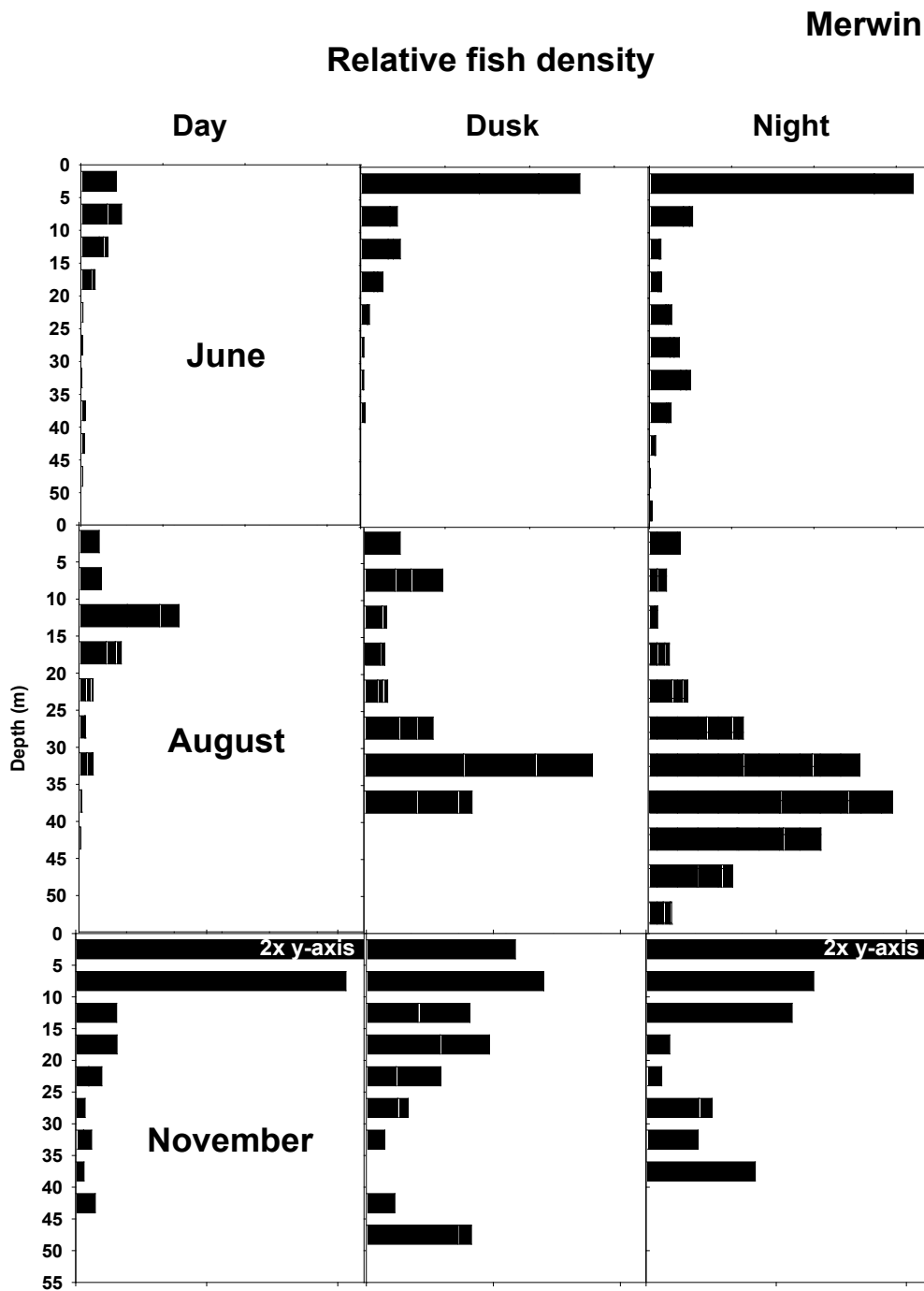
**Figure F17.** The cumulative frequency distributions of the timing (shown as year day) of coho salmon (solid) and bull trout (dashed) redds in the upper Lewis River, Washington.



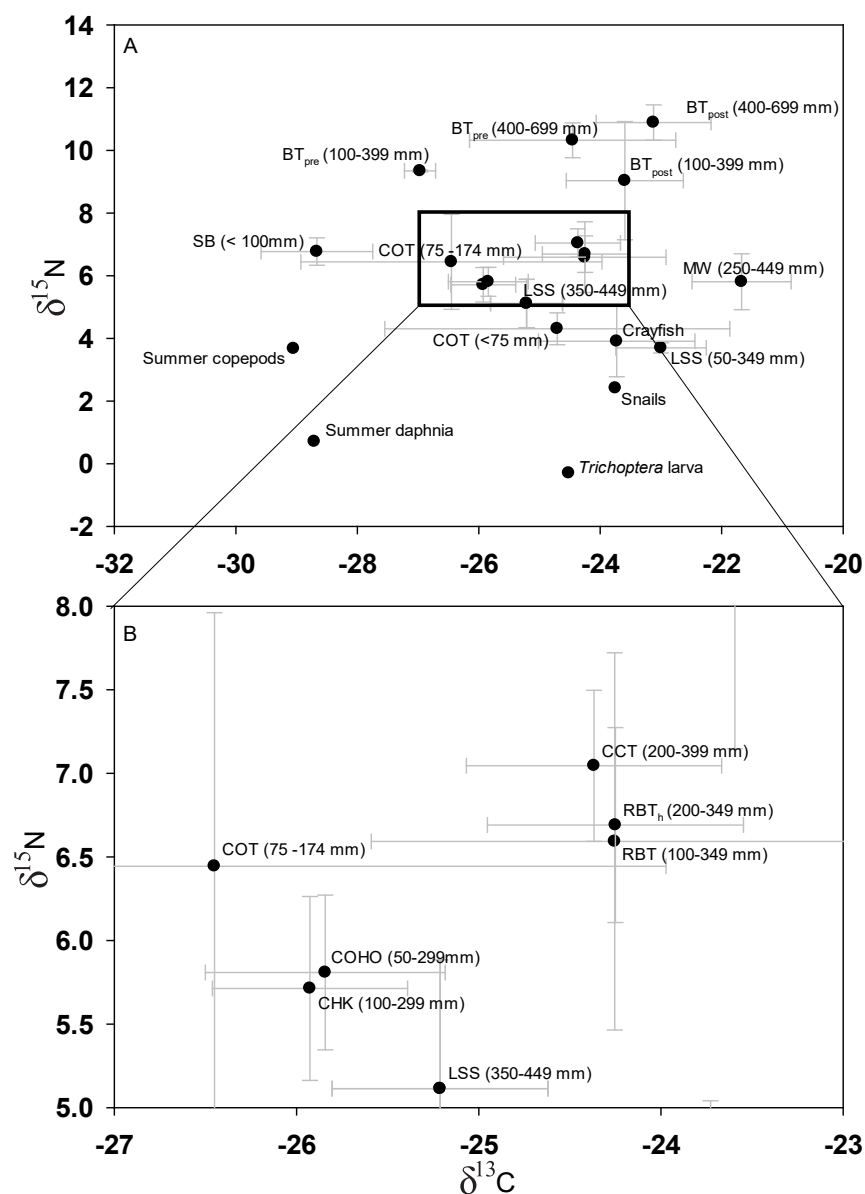
**Figure F18.** Day, dusk, and night sequence of hydroacoustic target depth distributions (measured in meters [m]) in June, August, and November 2013 in Swift Reservoir, Washington.



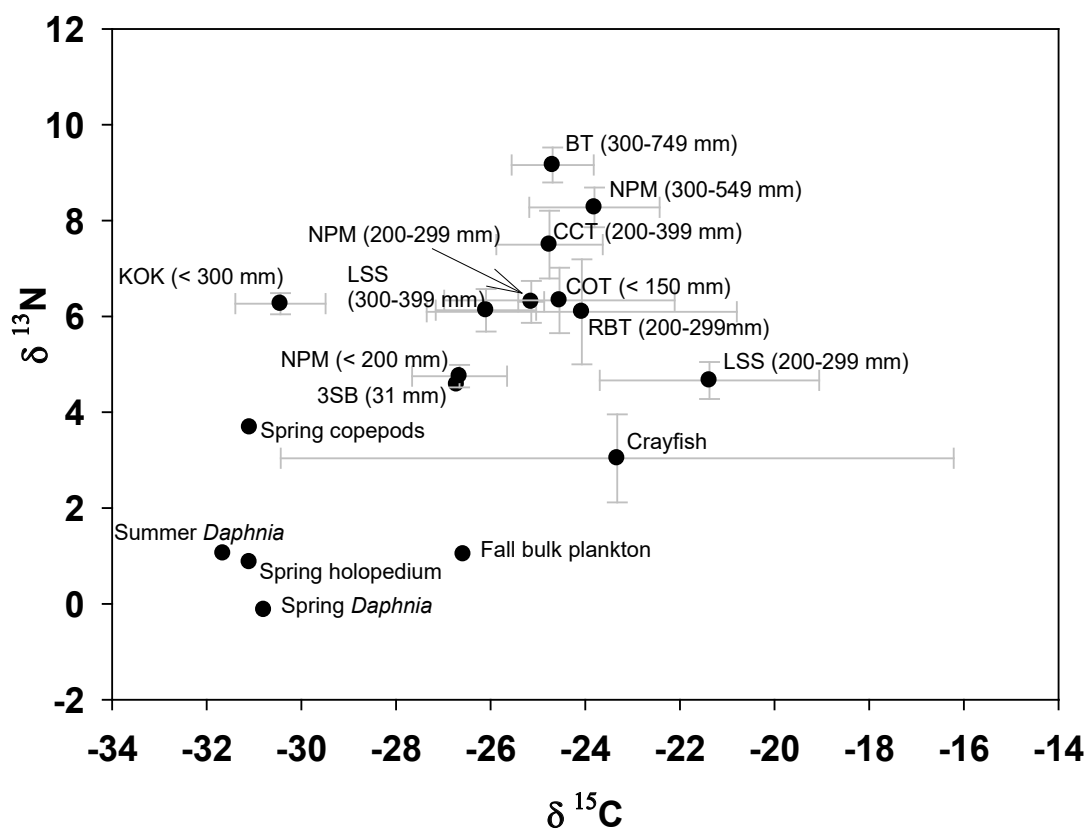
**Figure F19.** Day, dusk, and night sequence of hydroacoustic target depth distributions (measured in meters; m) in June, August, and November 2013 in Yale Lake, Washington.



**Figure F20.** Day, dusk, and night sequence of hydroacoustic target depth distributions (measured in meters [m]) in June, August, and November 2013 in Lake Merwin, Washington.

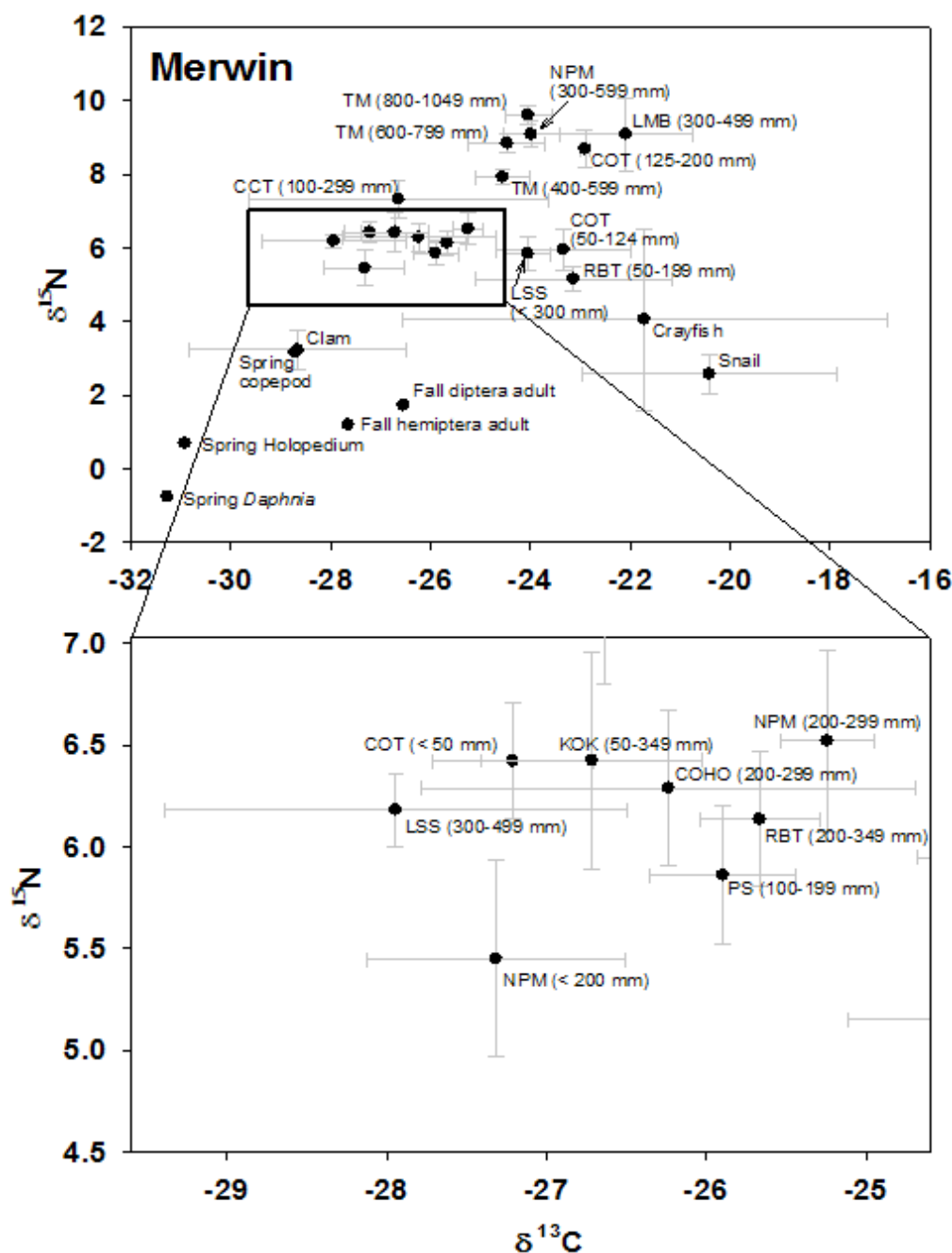


**Figure F21.** Mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values (plus or minus two standard error) for organisms sampled (lengths measured in millimeters; mm) in Swift Reservoir, Washington; *B*, is an enlarged inset of *A*, for ease of interpretation. (BT<sub>pre</sub>, bull trout sampled in 2010 before significant reintroduction of anadromous salmonids; BT<sub>post</sub>, bull trout sampled in 2013–2014 after the reintroduction had begun; CCT, coastal cutthroat trout; CHK, spring Chinook salmon; COHO, coho salmon; COT, sculpin; LSS, large-scale sucker; MW, mountain whitefish; RBT, rainbow trout; RBT<sub>h</sub>, hatchery-reared rainbow trout; SB, three-spine stickleback)

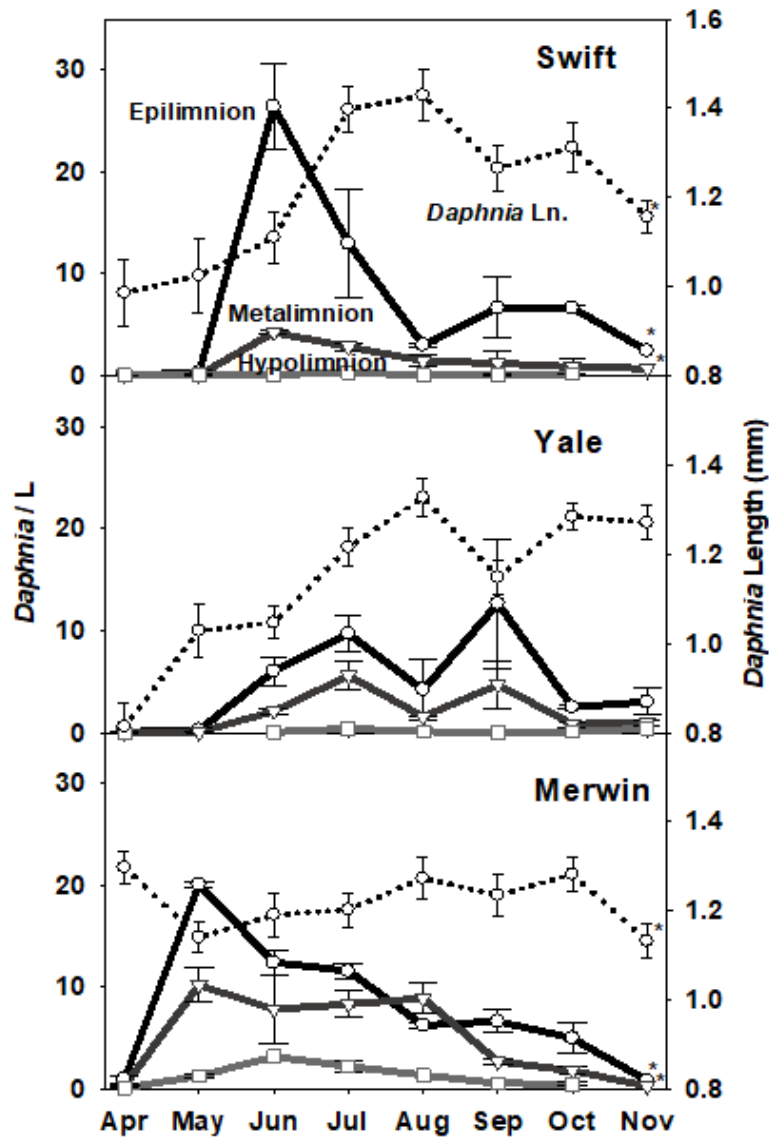


**Figure F22.** Mean  $\delta^{15}\text{N}$  versus  $\delta^{13}\text{C}$  (plus or minus two standard error) for organisms sampled (lengths measured in millimeters; mm) in Yale Lake, Washington. (BT, bull trout; CCT, coastal cutthroat trout; COT, sculpin; KOK, kokanee; LSS, large-scale sucker; NPM, northern pikeminnow; RBT, rainbow trout; SB, three-spine stickleback; sampling occurred during 2013–2014)

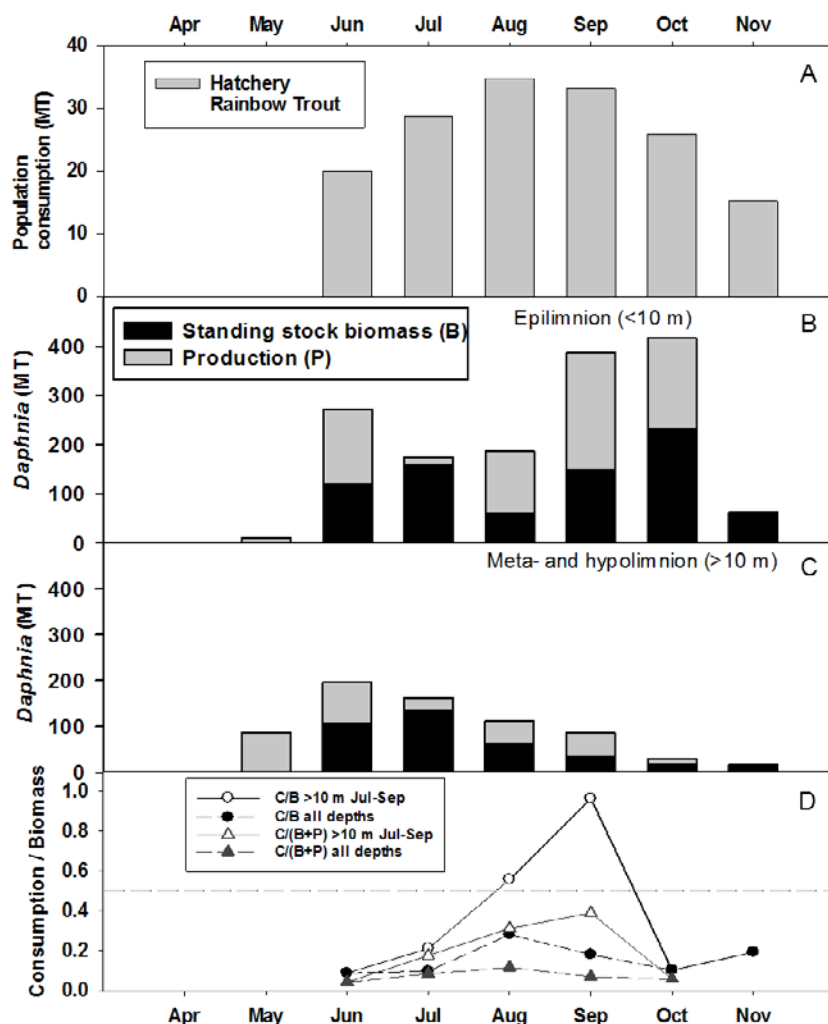




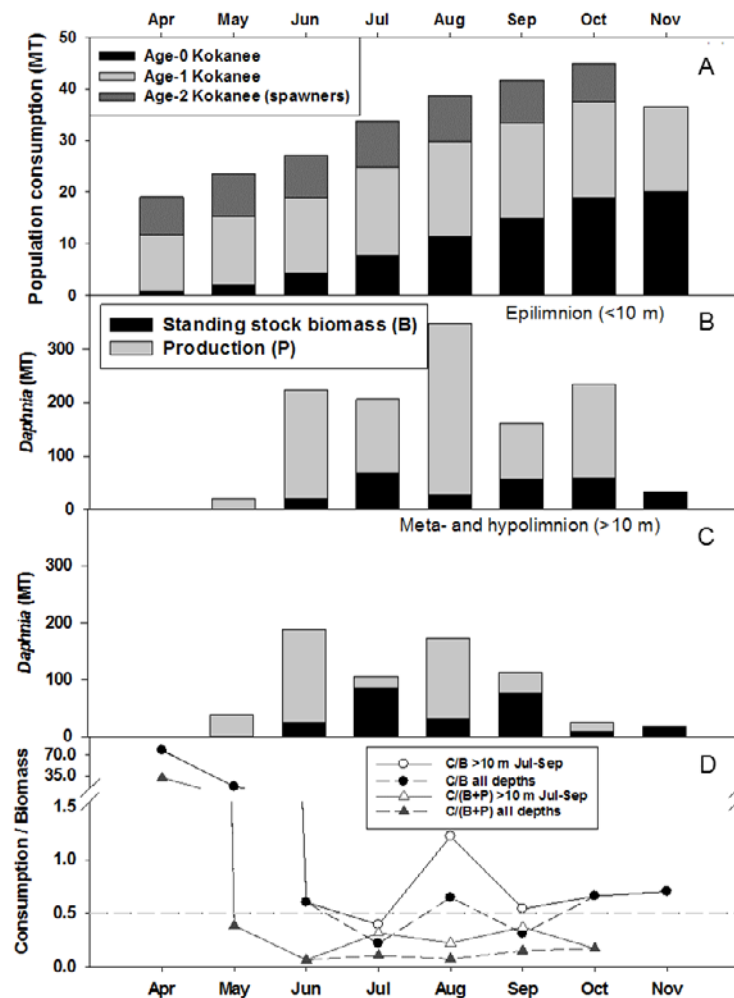
**Figure F23.** Mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  (plus or minus two standard error) for organisms sampled (lengths measured in millimeters; mm) in Lake Merwin. (CCT, coastal cutthroat trout; COHO, coho salmon; COT, sculpins; crayfish, signal crayfish; KOK, kokanee; LMB, largemouth bass; LSS, largescale sucker; NPM, northern pikeminnow; RBT, rainbow trout; PS, pumpkinseed sunfish; snail, juga snail; TM, tiger muskellunge; sampling occurred during 2013–2014)



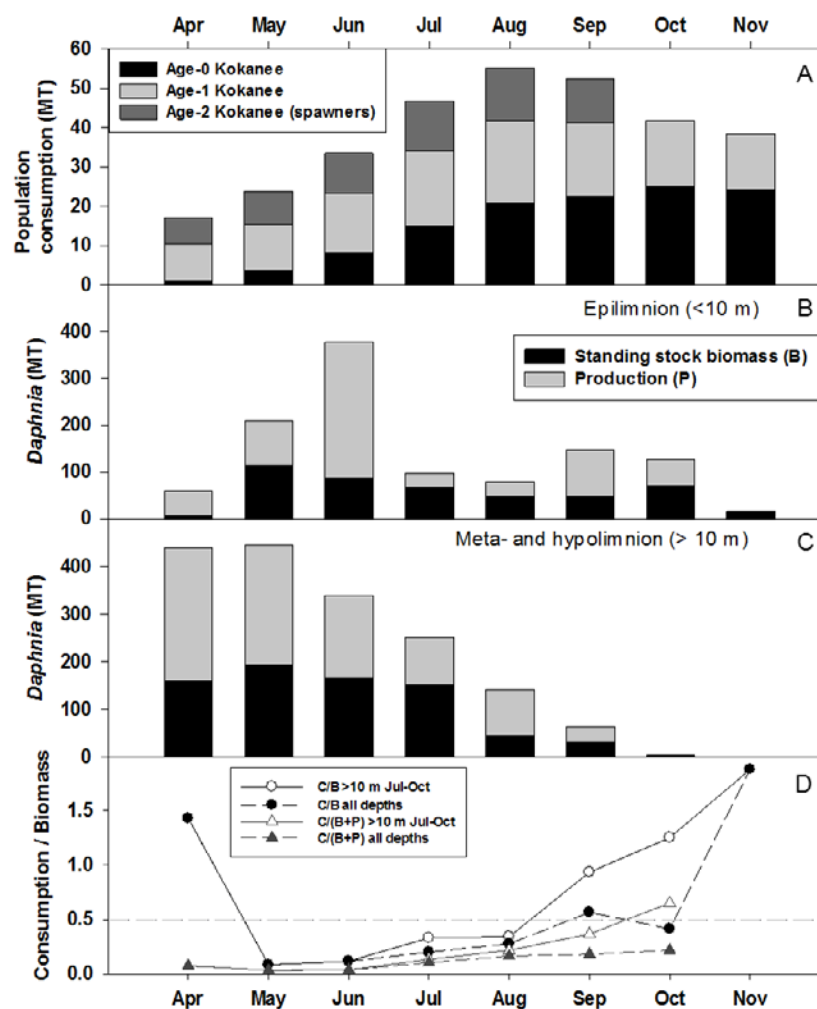
**Figure F24.** The mean monthly density of *Daphnia* (plus or minus  $\pm$  one standard error [SE]) in three depth strata from two stations located approximately one-third and two-thirds along the length (measured in meters [m]) of Swift Reservoir, Yale Lake, and Lake Merwin between April and November 2014. The mean length (measured in millimeters [mm]) of *Daphnia* ( $\pm 1$  SE) measured each month is also included. \*Data from the lower sampling site in Swift Reservoir and Lake Merwin collected in November 2013 are included to show a complete growing season, as samples could not be collected in these reservoirs in November 2014.



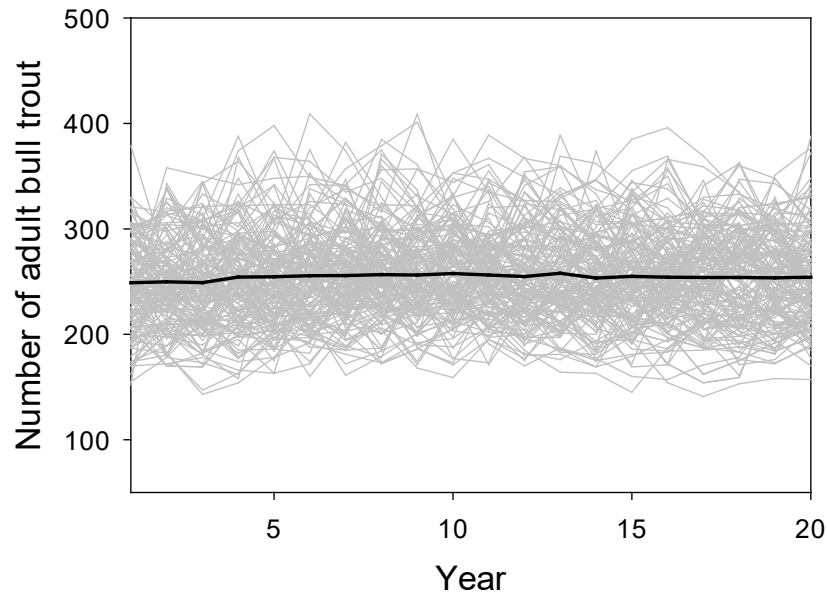
**Figure F25.** Estimates for Swift Reservoir, Washington, of *A*, monthly consumption (in metric tons; MT) demand of *Daphnia* by a cohort of hatchery-reared rainbow trout; *B*, *Daphnia* supply from April through November, stratified by depth in the epilimnion (the warm upper layer in which temperatures were relatively constant across depths [approximately 5–10 m deep from April through September and 10–18 m deep in October and November]); *C*, *Daphnia* supply stratified by depth in the metalimnion (the middle layer in which temperatures decreased significantly with depth [approximately 15–35 m deep in April–September]) and hypolimnion (the deepest layer in which temperatures were more stable and cooler than the metalimnion); and *D*, the ratio of consumption demand to prey supply for a range of prey supply scenarios. Dotted line represents 50 percent consumption over biomass ratio at which carrying capacity is reached. (m, meter)



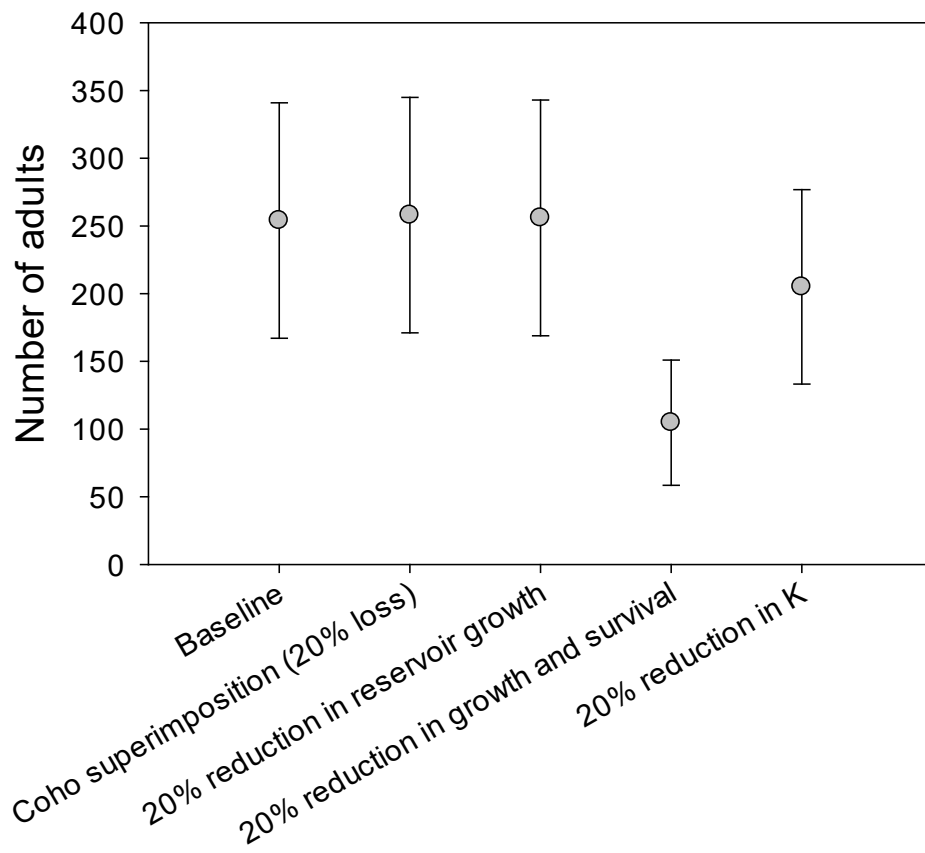
**Figure F26.** Estimates for Yale Lake, Washington of the *A*, monthly consumption (in metric tons [MT]) demand of *Daphnia* by three age-classes of kokanee salmon; *B*, *Daphnia* supply from April through November, stratified by depth in the epilimnion (the warm upper layer in which temperatures were relatively constant across depths [approximately 5–10 m deep from April through September and 10–18 m deep in October and November]); *C*, *Daphnia* supply in the metalimnion (the middle layer in which temperatures decreased significantly with depth [approximately 15–35 m deep in April–September]) and hypolimnion (the deepest layer in which temperatures were more stable and cooler than the metalimnion); and *D*, the ratio of consumption demand to prey supply for a range of prey supply scenarios. Dotted line represents 50 percent consumption over biomass ratio at which carrying capacity is reached. (m, meter)



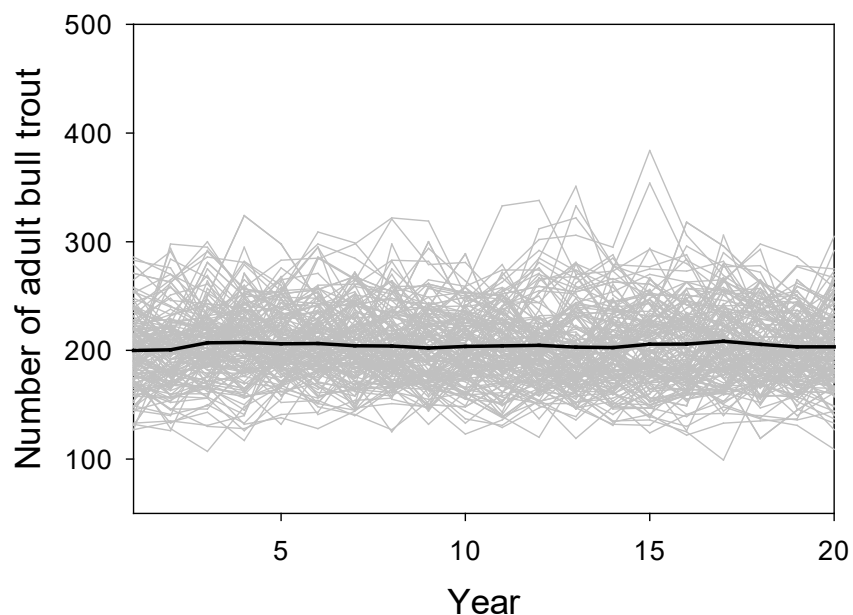
**Figure F27.** Estimates for Lake Merwin, Washington of *A*, monthly consumption (in metric tons [MT]) demand of *Daphnia* by three age-classes of kokanee salmon; *B*, *Daphnia* supply from April through November, stratified by depth in the epilimnion (the warm upper layer in which temperatures were relatively constant across depths [approximately 5–10 m deep from April through September and 10–18 m deep in October and November]); *C*, *Daphnia* supply stratified by depth in the metalimnion (the middle layer in which temperatures decreased significantly with depth [approximately 15–35 m deep in April–September]) and hypolimnion (the deepest layer in which temperatures were more stable and cooler than the metalimnion); and *D*, the ratio of consumption demand to prey supply for a range of prey supply scenarios. Dotted line represents 50 percent consumption over biomass ratio, at which carrying capacity is reached.



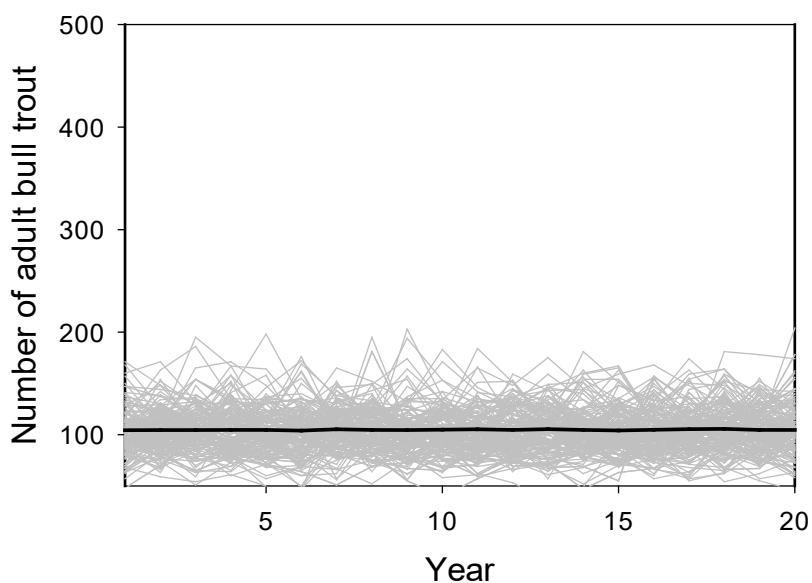
**Figure F28.** Simulation results indicating the number of adult bull trout in each simulation (gray) and the mean (black) for the 20 years of model runs under the baseline bull trout population model with no effects of salmon reintroductions.



**Figure F29.** The mean (95-percent confidence interval) number of adult bull trout across all simulation years ( $n=6,000$ ) under the baseline population model (no perturbations, current population), where a 20 percent loss of egg survival occurs through coho salmon redd superimposition, a 20 percent reduction in reservoir growth, a 20 percent reduction in reservoir growth and survival, and a 20 percent reduction in bull trout tributary carrying capacity (K). (% , percent)



**Figure F30.** Simulation results indicating the number of adult bull trout in each simulation (gray) and the mean (black) for the 20 years of model runs where carrying capacity of tributary juvenile bull trout rearing is reduced by 20 percent of the baseline levels as a result of increased distribution and abundance of juvenile salmon.



**Figure F31.** Simulation results indicating the number of adult bull trout in each simulation (gray) and the mean (black) for the 20 years of model runs where bull trout growth and survival in the reservoir are reduced by 20 percent through reductions in reservoir carrying capacity as a result of increased abundance of juvenile and residualized salmon.



Tables

**Table F1.** Estimates of water temperatures for optimum and maximum growth from existing literature for bull trout, Chinook salmon, coho salmon, steelhead, and coastal cutthroat trout.

[ODEQ, Oregon Department of Environmental Quality; EPA, U.S. Environmental Protection Agency; NA, not available]

Species	Optimum growth range (degrees Celsius)	Maximum growth (degrees Celsius)	Reference optimum	Reference maximum
Bull trout	10–15	13.2	Selong and others, 2001; McMahon and others, 2007	Selong and others, 2001
Chinook salmon	10–15.6	16, 18.9–20.5	ODEQ, 1995; EPA, 2001	Washington State Department of Ecology, 2002
Coho salmon	10–14	15–17	Konecki and others, 1995	Washington State Department of Ecology, 2002
Steelhead	9.8–22	13.1, 17.2	Bear and others, 2007; Spina, 2007	Hokanson and others, 1977; Bear and others, 2007
Coastal cutthroat trout	15	NA	Johnson and others, 1999	-

**Table F2.** Percent of fish, including sculpin, in bull trout diets by lake or river, life-history forms, and size classes.

[OR, Oregon; &lt;, less than; mm, millimeter; WA, Washington; &gt;, greater than; AB, Alberta, Canada; NA, not applicable; MT, Montana; g, gram; ID, Idaho]

Lake/river	Location	Life-history	Percent fish in diet	Size classes	Source
Walla Walla River	OR	Fluvial	96.0	Mixed	Budy and others, 2012
Walla Walla River	OR	Fluvial	86.6	Mixed	Budy and others, 2012
Walla Walla River	OR	Fluvial	57.0	Mixed	Budy and others, 2012
Walla Walla River	OR	Fluvial	90.1	Mixed	Budy and others, 2012
Walla Walla River	OR	Fluvial	0	Mixed	Budy and others, 2012
Walla Walla River	OR	Fluvial	0	Mixed	Budy and others, 2012
Walla Walla River	OR	Fluvial	85.7	Mixed	Budy and others, 2012
Walla Walla River	OR	Fluvial	62.9	Mixed	Budy and others, 2012
North Fork John Day River	OR	Fluvial	16.6	mixed; <475 mm	Budy and others, 2007
North Fork John Day River	OR	Fluvial	13.9	mixed; <450 mm	Budy and others, 2007
North Fork Umatilla River	OR	Fluvial	13.3	mixed; <400 mm	Budy and others, 2004
Skagit River	WA	Fluvial	0 <sup>1</sup>	30–95 mm	Lowery and Beauchamp, 2015
Skagit River	WA	Fluvial	72.8 <sup>1</sup>	96–300 mm	Lowery and Beauchamp, 2015
Skagit River	WA	Fluvial	89.9 <sup>1</sup>	301–450 mm	Lowery and Beauchamp, 2015
Skagit River	WA	Fluvial	86.7 <sup>1</sup>	>450 mm	Lowery and Beauchamp, 2015
Miette Lake	AB	Adfluvial	0	NA	Donald and Alger, 1993
Southesk Lake	AB	Adfluvial	27.0	NA	Donald and Alger, 1993
Flathead Lake	MT	Adfluvial	77.9	NA	Fraley and Shepard, 1989
Flathead Lake	MT	Adfluvial	100	NA	Leathe and Graham, 1982
Skagit River	WA	Fluvial	58.8	Adult	Lowery, 2009
Skagit River	WA	Fluvial	61.5	Adult	Lowery, 2009
Lake Billy Chinook	OR	Adfluvial	28.6	<300 mm	Beauchamp and Van Tassel, 2001
Lake Billy Chinook	OR	Adfluvial	44.3	300–450 mm	Beauchamp and Van Tassel, 2001
Lake Billy Chinook	OR	Adfluvial	85.9	>450 mm	Beauchamp and Van Tassel, 2001
Lake Billy Chinook	OR	Adfluvial	37.7	200–500 g	Hill and others, 2014
Lake Billy Chinook	OR	Adfluvial	83.7	501–1500 g	Hill and others, 2014
Lake Billy Chinook	OR	Adfluvial	100	1501–3000 g	Hill and others, 2014
Lake Billy Chinook	OR	Adfluvial	100	>3000 g	Hill and others, 2014
Meadow Fork Creek	OR	Resident/fluvial	0	<300 mm	Gunckel, 2001
North Powder River	OR	Resident/fluvial	0	<300 mm	Gunckel, 2001
Swan Lake	MT	Adfluvial	12.0	<301 mm	Guy and others, 2011
Swan Lake	MT	Adfluvial	22.0	301–500 mm	Guy and others, 2011
Swan Lake	MT	Adfluvial	94.0	502–700 mm	Guy and others, 2011
Harrison Lake	AB	Adfluvial	0	<250 mm	Wilhelm and others, 1999
Harrison Lake	AB	Adfluvial	1.5	>250 mm	Wilhelm and others, 1999
Mill Creek	WA	Resident/fluvial	12.3	<270 mm	Underwood and others, 1995
Tucannon River	WA	Resident/fluvial	0	<225 mm	Underwood and others, 1995
Mill Creek	WA	Resident/fluvial	50.4	100–250 mm	Martin and others, 1992
Lake Pend Oreille	ID	Adfluvial	100	>400 mm	Clarke and others, 2005
Wolf Fork	WA	Resident/fluvial	23.5	100–250 mm	Martin and others, 1992
Wolf Fork Creek	WA	Resident/fluvial	9.0	100–250 mm	Martin and others, 1992

<sup>1</sup>Estimates are a weighted mean across sample sizes and include both tributary and mainstem habitat (where applicable). Estimates include fish, fish eggs, and carcasses and are the mean across seasons.

**Table F3.** Thermal experience of pelagic planktivore consumption demands across different dates and simulation days within a bioenergetics modeling framework in Swift Reservoir, Yale Lake, and Lake Merwin, Washington. (°C, degree Celsius)

Date	Simulation day	Thermal experience (°C)		
		Swift Reservoir	Yale Lake	Lake Merwin
1-April	1	6.6	5.6	7.8
18-May	49	10.8	8.2	11.9
30-June	89	14.3	9.5	13.5
19-July	109	14.7	11.7	15
15-August	135	15.1	12.5	16.2
17-September	167	14.6	14	17
13-October	193	9.1	11.5	17.3
15-November	225	8.2	8	12.7
15-December	255	5.9	5.9	5.8
1-January	270	5.2	5.4	5.9
1-March	330	4.5	4.9	6.1
31-March	365	6.6	5.6	7.8

**Table F4.** Energy density (joules/gram) of prey items consumed by pelagic planktivores. An indigestible fraction of 17 percent was assessed on all invertebrate prey consumed (Beauchamp and others, 2007).

Day	<i>Daphnia</i>	Copepoda (Copepod)	Terrestrial insects	Aquatic insects
1	1,950 <sup>1</sup>	2,260	5,000	3,400
365	1,950	2,260	5,000	3,400

<sup>1</sup>Energy density for *Daphnia* taken from Luecke and Brandt (1993) and Stockwell and others (1999).

**Table F5.** Starting and ending dates and consumer weights used in bioenergetics simulations and outputs of feeding rate (%C<sub>max</sub>) and consumption in biomass.

[mm, millimeter; wt., weight; g, gram; RBT<sub>h</sub>, hatchery-reared rainbow trout]

Species	Age	%C <sub>max</sub>	Start date	End date	Fork length (mm)	Initial wt. (g)	Final wt. (g)	Growth (g)	Consumption (g)	<i>Daphnia</i> consumption (g)
Swift Reservoir										
RBT <sub>h</sub>	1	78	1-June	20-November	258	200.0	362.0	162	3,499	3,149
Chinook salmon	0	104	1-April	30-November	25	0.2	30.5	30.3	331	299
Yale Lake										
Kokanee salmon	0	86	1-April	30-November	25	0.1	40.6	41	288	234
	1	74	1-April	30-November	163	45.0	143.5	98	1,227	952
	2	59	1-April	30-October	236	154.0	219	64	1,498	1,124
Lake Merwin										
Kokanee salmon	0	123	1-April	30-November	25	0.3	81.1	81	867	729
	1	92	1-April	30-November	190	90.0	253.0	163	2,794	2,194
	2	100	1-April	30-September	279	271	498	227	4,186	3,121

**Table F6.** Model inputs of survival, growth, and percent maturity by age for bull trout in the Swift Reservoir, Washington.

[NA, not available]

Age	Survival (standard deviation)	Growth (standard deviation, millimeter)	Percent (%) mature
egg–fry <sup>1</sup>	0.44 (34) <sup>1</sup>	NA	0
fry–age-1	0.21 (0.12) <sup>1</sup>	85 (20)	0
2	0.21 (0.12) <sup>2,4</sup>	152 (74)	0
3	0.37 (0.13) <sup>2,4</sup>	112 (54)	0
4	0.54 (0.19) <sup>2,4</sup>	80 (43)	25
5	0.70 (0.25) <sup>2,4</sup>	59 (30)	50
6	0.84 (0.30) <sup>3,4</sup>	36 (19)	100
7	0.84 (0.30) <sup>3,4</sup>	26 (19)	100
8	0.84 (0.30) <sup>3,4</sup>	25 (17)	100
9	0.84 (0.30) <sup>3,4</sup>	21 (12)	100
10	0.84 (0.30) <sup>3,4</sup>	17 (10)	100
11	0.84 (0.30) <sup>3,4</sup>	16 (9)	100
12	0.84 (0.30) <sup>3,4</sup>	15 (8)	100
13	0.84 (0.30) <sup>3,4</sup>	14 (8)	100
14	0.84 (0.30) <sup>3,4</sup>	13 (7)	100
15	0.84 (0.30) <sup>3,4</sup>	13 (7)	100
16	0.84 (0.30) <sup>3,4</sup>	12 (7)	100

<sup>1</sup>Bowerman and Budy, 2012; Bowerman and others, 2014.<sup>2</sup>No data for subadult adfluvial exist. Estimates are estimated by linear increase from age-1 estimates to age-6 estimates.<sup>3</sup>Stillwater Sciences, 2016.<sup>4</sup>Standard deviation estimated as proportional to adults (Al-Chokhachy and Budy, 2008).**Table F7.** Relative abundance of fish species observed in sampling conducted in this study and predominant summer crustacean zooplankton found in Swift Reservoir, Yale Lake, and Lake Merwin, Washington.

[NA, species absent]

	Swift Reservoir	Yale Lake	Lake Merwin
Northern pikeminnow	NA	Moderate	High
Largescale sucker	High	High	High
Kokanee salmon	NA	High	High
Rainbow trout	High	Rare	Moderate
Coastal cutthroat trout	Rare	Rare	Rare
Bull trout	Rare	Rare	NA
Tiger muskellunge	NA	NA	Moderate
Sculpins	Moderate	Moderate	Moderate
Three-spine stickleback	Moderate	Rare	Rare
Mountain whitefish	Rare	NA	NA
Largemouth bass	NA	NA	Rare
Juvenile coho salmon	Rare	NA	Rare
Juvenile Chinook salmon	Moderate	NA	NA
Predominant summer zooplankton	<i>Daphnia</i>	<i>Daphnia</i>	<i>Daphnia</i>

**Table F8.** Seasonal diet proportions (n=total number of diets) for invertebrate-feeding salmonids including spring Chinook salmon, hatchery-reared rainbow trout, and kokanee salmon captured in Swift Reservoir, Yale Lake, and Lake Merwin, June–November 2013 and May–November 2014, and also including Cladocerans, Copepoda, terrestrial insects, aquatic insects, and fish.

Size class	Season	n	<i>Cladocerans</i>	<i>Copepoda</i>	Terrestrial insects	Aquatic insects	Fish
Swift Reservoir—Spring Chinook Salmon							
100–299	Spring	4	0.546	0	0.100	0.104	0.250
100–299	Summer	7	1.000	0	0	0	0
100–299	Fall	11	0.855	0	0.009	0.136	0
Swift Reservoir—Hatchery-Reared Rainbow Trout							
200–399	Spring	10	0.593	0	0.046	0.360	0
200–299	Summer	4	0.999	0.001	0	0	0
200–399	Fall	13	0.893	0.002	0.049	0.056	0
Yale Lake—Kokanee Salmon							
0–299	Spring	14	0.684	0.084	0.043	0.189	0
0–299	Summer	14	0.755	0.162	0	0.083	0
100–199	Fall	17	0.879	0.062	0.059	0	0
Lake Merwin—Kokanee Salmon							
0–399	Spring	17	0.536	0.018	0.202	0.243	0
200–399	Summer	11	0.908	0.001	0.018	0.073	0
100–399	Fall	13	0.857	0	0.043	0.100	0





