Development of New Information to Inform Fish Passage Decisions at the Yale and Merwin Hydro Projects on the Lewis River

A review of existing data to anadromous fish reintroduction, collection and transport of anadromous fish above hydropower/dam facilities

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INTRODUCTION

This review is a compliment to previous documents (PacifiCorp 2002) with specific objectives of reviewing different aspects of anadromous species reintroductions above hydropower facilities, particularly where trap and haul operations are used. At the time of this review, existing data related to recent startup of the Swift Collector were not available nor were data available from the ongoing USGS and University of Washington research project to fill in existing gaps in factors potentially limiting salmon reintroduction in the Upper Lewis Basin. As such, the specific objectives of this review were to assess the effects of smolt acclimation facilities on salmon performance, downstream collection facilities, adult upstream collection facilities, the interspecific effects of salmon reintroduction and supplementation efforts on salmonid communities, and potential effects of native and non-native taxa on reintroduction efforts.

Acclimation

Rearing and release.—Smolt acclimation facilities are commonly used to reduce stress associated with fish transport (Maule et al. 1989; Schreck et al. 1989) and for imprinting of natal waters to induce adult returns to specific acclimation streams (Dittman et al. 2010). Acclimation facilities that employ ambient surface water sources also provide more accurate indications of 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 (e.g., McLeod 2008), off-channel-raceways (e.g., Zollman et al. 2009), and semi-natural stream channels/ponds (e.g., PacifiCorp 2011).

Survival within the acclimation facilities is typically high (>98%; Appendix Table 1), 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 one to eight weeks (Cleary 2005; Clarke et al. 2011), upon which remaining smolts are often forced out of the acclimation facilities. The percent of smolts to volitionally release from acclimation facilities can vary considerably across systems. For example, in the Lostine River, OR Cleary (2005) found high (88-97% across releases) volitional release of spring Chinook smolts within 10 days of acclimation; a pattern consistent for spring Chinook in the Hood River (100%; Gerstenberger 2009). High volitional releases have also been reported for steelhead (>85%; Osborne and Rhine 1999; Gerstenberger 2009). However, Cleary et al. (2006) found considerable variability in proportion of Chinook volitional releases across years with values as low as 10.9%. Low percentage of smolts volitionally migrating have been reported elsewhere (McLean et al. 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 et al. (2012) found the amount of time spring Chinook were acclimated (2 or 4 months) had little effect on smolt survival or stray rates, but longer acclimation (4-month acclimation; November through early March) resulted in significantly slower travel times and 27% higher smolt-to-adult survival rates (SAS). However, identifying the relative effects of longer acclimation period and over-winter acclimation on these parameters was not possible.

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

Acclimation and smolt migration patterns.—The effects of acclimation on anadromous migration patterns have been inconsistent across studies. In a 10-year paired study, Clarke et al. (2010) found travel times for acclimated summer steelhead to be 10% (2.9 days) longer than for fish directly released into streams. In contrast, acclimated fall Chinook have demonstrated faster travel times than direct release hatchery smolts (3-11 days), which more closely resembled migration patterns for naturally produced smolts (Rosenberger et al. 2013). In other studies, no consistent differences have been observed in the migration timing of direct and acclimated steelhead or Chinook smolts (Fast et al. 1991; Whitesel et al. 1994; Cameron et al. 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 (e.g., SAS).

An additional concern is the effect of acclimation facilities on residualization. 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 inferences of residualization of smolts that do not volitionally release from acclimation facilities (Hausch and Melnychuk 2012), particularly given the recent results of Clarke et al. (2011) (see above) which 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 considerable variability in the influence of acclimation facilities on juvenile survival (See Appendix Table 1 for individual estimates) and SAS. Fall Chinook smolts when acclimated have illustrated higher survival rates than direct release hatchery smolts (Rosenberger et al. 2013), a pattern similar for spring Chinook (Fast et al. 1991; Cameron et al. 2013), and steelhead (Whitesel et al. 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 et al. 2001; Appleby et al. 2002; Clarke et al. 2010). Interestingly, Clarke et al (2010) found SAS for acclimated smolts to be >11% higher than observed for direct-release summer steelhead smolts; a pattern consistent in most years (6/7 years where comparable 2002 – 2010) for summer steelhead in the Umatilla River (Cameron et al. 2013). Variability in the effects of acclimation is demonstrated in Umatilla River, where SAS of fall Chinook has been lower than direct-release smolts in four of the six years monitored (Cameron et al. 2013).

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

Acclimation and adult stray rates.—Here, stray rates are specifically considered for studies where direct (e.g., experimental) comparisons were performed between acclimated and non-acclimated (direct release) groups. Again, results from most studies suggest considerably variability in the extent of stray rates. Early research with coho and Chinook found no differences in homing rates within Lake Michigan (Savitz et al. 1993). An experiment with spring Chinook in the lower Willamette using net pens as acclimation facilities, yielded a mixture of results, suggesting no clear pattern of the effect of acclimation on natal homing (Schroeder and Kenaston 2005). However, Clarke et al. (2010) found 42% lower stray rates for acclimated steelhead than observed for direct-release fish. In a recent study Dittman et al. (2010) found that despite homing to acclimation streams, a large portion (55.1%) of adult Chinook spawned at distances >25 km, which was similar to the distribution observed in wild Chinook. The broad distribution of spawners in the Yakima River is likely to be influenced by local spawning habitat within and proximate to acclimation facilities (Cram et al. 2013). The results of Cram et al. (2013) illustrate the need to consider spatial patterns in suitable habitat, when assessing stray rates and render some uncertainty in comparisons across studies.

In general, comparing stray rates across systems 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 et al. 2013), suggesting the need for *in situ* measures of stray rates across species.

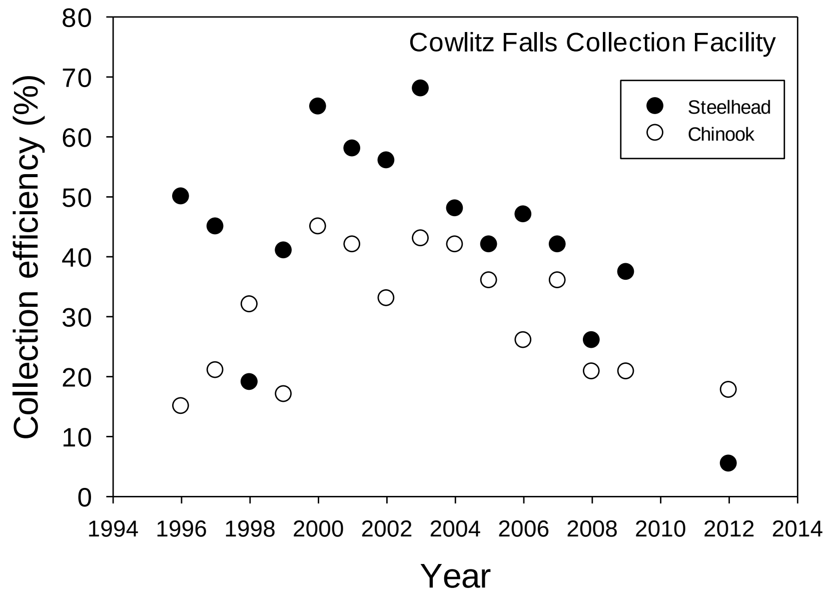
Downstream collection facilities

The focus of this review will be to summarize data from existing studies on smolt collection efficiencies and survival at collection facilities.

Juvenile collection efficiency.—A variety of collectors are used to capture downstream-migrating anadromous fish in rivers with migration barriers (Table 1). Comparisons of collection efficiencies across projects are difficult due to the inherently different dam operations and ambient conditions. Here, collection efficiencies are summarized across rivers and sites for reference.

Substantial differences in collection efficiencies were found across species, years, and collectors. For example, estimates of collection efficiency for steelhead during the period of 1996 to 2012 varied from a low of 5.4% to 68% (WDFW 2008, Unpublished report). While general trends are consistent across species, inter-annual variability may not be strongly correlated across species (r = 0.57; Figure 1).

Figure 1. Inter-annual comparison of collection efficiencies for steelhead and Chinook salmon at the Cowlitz Falls collection facility (data from Serl and Heimbigner [2013] and Serl and Morrill 2010).



At some facilities, collection efficiencies appear to be relatively consistent across species, such as the Mayfield collector on the Cowlitz river (range for CO, CH, and OM = 62 -77%), while others the collection efficiencies differ substantially across species (e.g., forebay collector at Rocky Reach Dam). There does not appear to be any consistent patterns of higher/lower collection efficiencies across species. For example, on the Cowlitz river collection efficiencies for juvenile Chinook (mean = 20.9%) are half that observed for steelhead at Cowlitz Falls (mean = 43.3%), but little difference in average collection efficiencies occurs at Mayfield (mean collection efficiency CH = 75.0% and OM =76.5%).

Given that new, state of the art collection facilities have recently been implemented (e.g., Lewis River, Baker River, Deschutes River), understanding comparable collection efficiencies is likely to require multiple years of monitoring. Early evaluations of collection efficiencies are likely to be biased due to the high inter-annual variability observed at many existing facilities and site-to-site differences. As such understanding those factors associated with or influencing collection efficiencies (e.g., variation in migration timing and the interactions with in-reservoir conditions) is needed for setting collection efficiency goals. That said, considering that the Upper Baker and Round Butte collectors are very similar to the Swift Floating Surface Collector in terms of entrance configuration it is informative to look at how effective those two projects are at capturing juvenile salmonid outmigrants. From Appendix Table 2, Upper Baker has demonstrated capture efficiencies for coho ranging from 82.6 to 99 percent (Jeanes and Verretto 2012). In the Deschutes River system, the collection efficiencies have been considerably lower for Chinook salmon (range = 46.9 – 51.2%) and steelhead (range = 16.0 – 24.2%; (range = 16.0 – 24.2%, Appendix Table 2: Hill and Quesada 2011; Hill and Quesada 2012; Hill and Quesada 2013). The estimates for the surface collector at Round Butte include both hatchery and wild fish, but no apparent difference exists between these groups. In addition, it is worth noting that the estimates of collection efficiencies at Round Butte incorporate measure of reservoir survival, a measure of downstream migrants (i.e., vs. residualized fish), and collection efficiency of fish that make it to the collector. Studies in Lake Billy Chinook indicate a large portion of the fish entering the reservoir did not make it to the surface collector (Hill and Quesada 2013).

Table 1. Average estimates and SD of collection efficiency across rivers, facilities, collectors and species (n = sample size, SS = Atlantic salmon, CO = coho, OM = steelhead, CH = Chinook). Note: estimates from individual studies are available in Appendix Table 2.

River	Facility	Collector	Species	Collection efficiency (%)	SD	n
Ariège (France)	Crampagna	Bypass/sluice	SS	66.0	-	1
	Guilhot	Bypass/sluice	SS	75.0	-	1
	Las Mijanes	Bypass/sluice	SS	32.0	-	1
	Las Rives	Bypass/sluice	SS	49.0	-	1
Baker	Lower Baker	Forebay collector-Gulper	CO	23.7	15.6	21
	Upper Baker	Forebay collector - Gulper	CO	53.9	10.7	20
		Forebay collector - Surface collector/enhanced gulper	CO	91.4	8.3	4
Columbia	Bonneville First Powerhouse	Powerhouse retrofit - PSC	OM	45.0	-	1
			CH	43.0	-	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	-	1
	John Day	Surface spill - surface bypass	CH	21.7	9.0	2
	McNary		OM	69.0	-	1
			CH	30.7	20.0	19
	Priest Rapids	Sluiceway	OM	53.4	15.9	5
			CH	1.9	-	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 - SAC	na	0.3	0.0	2
		Sluiceway	CH	3.0	-	1
		Surface spill	OM	66.9	12.1	3
			CH	17.0	9.9	2
	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	CH/OM	90.4	7.0	8
Connecticut	Bellows Falls	Bypass/sluice	SS	94.0	-	1
	Vernon Station		SS	74.0	-	1
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	CO	29.8	10.6	15
			OM	43.3	16.7	15
			CH	20.9	7.5	18
	Mayfield	Forebay collector	CO	61.5	8.0	4
			OM	76.5	4.0	2
			CH	75.0	1.4	2
Deschutes	Petlon Round Butte	Forebay collector	CH	48.5	2.8	3
			OM	19.2	4.4	3
Garonne (France)	Camon	Bypass/sluice	SS	73.0	-	1
Gave d' Aspe (France)	Bedous	Bypass/sluice	SS	55.0	-	1
	Soeix	Bypass/sluice	SS	61.0	-	1
Gave d' Ossau (France)	St. Cricq	Bypass/sluice	SS	79.0	-	1
Gave de Pau (France)	Baigts	Bypass/sluice	SS	93.0	-	1
	Castetarbe	Bypass/sluice	SS	100.0	-	1

Snake	Ice Harbor	Sluiceway	na	31.8	15.2	4
		Surface Spill - RSW	OM	42.5	6.4	2
			CH	52.0	16.8	4
	Little Goose		OM	45.3	17.7	19
			CH	38.4	16.7	36
	Lower Granite	Powerhouse retrofit - SBC	OM	22.5	6.4	2
			CH	29.0	-	1
		Surface Spill - RSW	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	Willamette Falls	Forebay collector - Inflatable rubber dam	OM	100.0	-	1
			CH	97.3	-	3
Santiam	Green Peter	Forebay collector - Floating collection horn	CH	>80%	-	3
		Forebay collector - Floating collection horn	OM	<57%	-	4

Juvenile survival through collection facilities.—While ample data exists for survival estimates through hydropower facilities (e.g., www.fpc.org), this review is constrained to estimates of survival through collection facilities where confounding issues (e.g., reservoir travel, large migration distances, etc.) are minimized. Across species, survival rates are generally high at collection facilities (mean range = 0.89 – 1; Table 2). Across types of collectors, survival estimates associated with Bonneville Dam were the lowest (<0.90), but mean survival at all other facilities was relatively high (>92%; Table 3). Survival estimates at forebay collectors (i.e., where trap and haul activities are implemented; Baker and Cowlitz) suggest mortality rates are extremely low.

Table 2. Average estimates of survival and SD (n = sample size) through smolt collection facilities for different species, rivers, and facilities in the Pacific Northwest across species. Note: estimates from individual studies are available in Appendix Table 3.

River	Facility	Species	Survival	SD	n
Baker					
	Upper Baker	CO	1	0	4
Clackamas					
	North Fork	CO	1	-	1

		OM	0.96	0.06	5
		CH	1	-	1
		CH/CO	0.89	0.07	4
	River Mill	OM	0.99	-	1
		CH	0.99	0.01	2
Columbia					
	Bonneville	OM	0.87	0.15	30
		CH	0.89	0.11	24
Cowlitz					
	Cowlitz Falls	CO	0.99	0.02	13
		OM	0.99	0.01	13
		CH	0.98	0.03	19
	Mayfield	CO	0.95	0.001	11
		OM	0.96	0.001	9
		CH	0.95	0.04	12
Deschutes					
	Pelton Round Butte	OM	0.98	-	1
		CH	0.98	-	1
		SO	0.98	-	1
Willamette	Willamette Falls	OM	0.99	0.01	3
		CH	1	0	2

Table 3. Average estimates of smolt survival and SD at different collection facilities and rivers in the Pacific Northwest (n refers to sample size).

River	Facility	Collector type	Survival	SD	n
Baker	Upper Baker	Forebay collector - Surface collector	1	0	4
Clackamas	North Fork	Forebay collector	0.92	0.07	8
		Forebay collector - V-Screen Collector	0.99	0.01	3
	River Mill	Surface spill - Spillway weir	0.99	0.01	3
Columbia	Bonneville	Bonneville floating surface collector	0.86	0.15	21
		Sampled from barge	0.89	0.12	33
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	0.99	0.02	45
	Mayfield	Louver system	0.96	0.02	32
Deschutes	Pelton Round Butte	Guidance net/skimmer	0.98	0	2

Willamette	Willamette Falls	Mixed	0.99	0.01	5

Injury rates, measured through descaling rates (>20%) also appear to be extremely low at collection facilities (Table 4). Across all species and facilities average descaling rates are 2.7% (SD = 3.0). No apparent patterns exist in average descaling rates across species (CH = 1.4%, 2.3%, CO = 2.0%, OM = 2.7%, and SO = 0.3% [limited data]). Similar to survival, descaling rates from forebay collectors used in trap and haul operations on systems comparable to the Upper Lewis (i.e., Swift Collection Facility) were all less than 1%.

Table 4. Average estimates of descaling rates by river, facility, and species (n = sample size). See Appendix 4 for individual estimates and references.

River	Facility	Species	Descaling rate (%)	SD	n
Columbia	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	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	-	1
Deschutes	Fish Transfer	CH	0.1	0.1	2
	Fish Transfer	OM	0	0	2
	Fish Transfer	SO	0.3	-	2

In addition to high survival rates through collection facilities, reduced survival via 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% for hatchery and wild steelhead, coho, hatchery Chinook, and coastal cutthroat. Mortality rates did vary across species as delayed mortality rates for wild Chinook were as high as 3.58%. Recent tests of delayed mortality in the Cowlitz (2008-2012) found less than 0.5% across all species (Serl and Heimbigner 2013). The relatively short duration of stress relief used in the Cowlitz (24 -48 hours after which fish are forced out) may underestimate the effects of stress (i.e., additive) which may not be apparent until later in downstream migration (Budy et al. 2002; Schaller and Petrosky 2007). Although overall mortality through collection facilities and stress relief ponds is likely to be lower than through turbines (Keefer et al. 2012), further research and comparative studies are needed for site-specific mortality/benefits of management actions (e.g., 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 with just treatment groups

Effects of downstream collection facilities on other species.—In addition to salmon and steelhead smolts, collection facilities can encounter potamodromous and other anadromous species (e.g., coastal cutthroat trout), rendering concern for the effects of collection efficiencies on these non-target taxa. Numerous native and non-native species, including game and non-game species are often collected at downstream collection facilities (CTWSRO 2012; PGE 2013) through either random movements or natural, life-history movement patterns. Where evaluated, mortality estimates for non-target species appear to be generally low (<2%; Table 4). The highest mortality estimates were observed for kokanee salmon (mean = 8.6%). In general, mortality rates for non-target species at collection facilities are expected to be considerably lower than for passage through turbines and or spillway (FERC 2002).

Table 5. Mean mortality estimates and SD for non-target species at downstream fish collection facilities at different rivers, facilities, and species (n = sample size). Note specific references are located in Appendix Table 5.

River	Facility	Species	Mortality (%)	SD	n
Cowlitz	Cowlitz Falls	Coastal cutthroat	0.4	0.3	13
	Mayfield	Coastal cutthroat	0.1	-	1
Deschutes	Round Butte	Bull trout	1.7	0.3	3
		Kokanee	8.6	1.5	3
		Mt. Whitefish	0.01	0.02	3

Rainbow trout	1.4	1.2	3

Adult upstream collection facilities

The review of adult, 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 (e.g., Baker and Cowlitz Rivers) and is currently increasing across the historic range of anadromous species (Vogel 2007; Keefer et al. 2010). With this, the review includes adult injury and survival rates, fallback rates, and upstream mortality to non-target, native salmonids. Limited data currently exists for upstream capture efficiency in trap-and-haul projects, thus this aspect is not further discussed.

Adult injury and survival rates.—The collection facilities used for most trap and haul and/or long-term trapping facilities involves fish ladder systems where adults ascend fish ladders to separators, collectors, etc. (Zimmerman and Duke 1993; Henning 2010; PGE 2013). Across species, runs, and source (i.e., hatchery, wild, etc.) mortalities from adult trapping and transport activities appear to be low (M. LaRiviere, Tacoma Power, Personal Communication; Table 6). The majority of mortality events appear to occur during the trapping as opposed to hauling events (Zimmerman and Duke 1997). However, injury during hauling, measured through descaling, can be substantial (Scully and Buettner 1986). In addition, delayed mortality due to 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 (9.6%, 6.8%) in the Tucannon River, WA and steelhead at the Mayfield facility on the Cowlitz River, WA (6.7%; Appendix Table 6). Aside from these high mortality events, average mortality across species and locations was 0.4%; (SD = 0.92%). While mortality associated with trapping is generally low, the occurrence of anomalous events affecting mortality including density-independent (e.g., ambient climate conditions) and density-dependent (e.g., crowding; White River, WA in 2013) factors can result in high mortality rates.

Table 6. Estimates of mortality (mean and SD) during trap and transport activities for different species, runs, and sources in the Pacific Northwest.   Individual estimates are provided in Appendix 6.

Species	Run	Source	Mean	SD	n
Chinook	Fall	Mixed	1.4	2.5	2
Chinook	Fall	Wild	0.6	0.7	3
Chinook	Spring	Hatchery	1.4	2.5	24
Chinook	Spring	Mixed	0.7	-	1
Chinook	Spring	Wild	0.1	0.3	29
Coho	-	Hatchery/mixed	0.3	0.2	2
	-	Wild	0.2	0.3	4
Sockeye	-	-	0	-	1
Steelhead	-	Hatchery/mixed	1	1.7	3
Steelhead	-	Wild	1.7	3.3	4

Additional sources of upstream mortality for anadromous species may include stress and delayed mortality from instream conditions during freshwater migration routes. Excessive thermal exposure during migration and/or during delayed migration at tailrace areas can affect migration timing, thus indirectly affecting fish through exposure to additional stress mechanisms and reducing fitness (Keefer and Caudill 2010).   For example, excessive warming has resulted in abnormally high prespawn mortality for spring Chinook (Keefer et al. 2010; Mosser et al. 2013). Caudill et al. (2007) found excessive delay times associated with high mortality of adult Chinook and steelhead during passage at hydropower facilities. While the exact mechanisms contributing to the high mortality were not known, the results suggest the need for monitoring and evaluation of delayed migration below adult traps for consideration of management alternatives to reduce mortality if needed.

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

Fallback.—Fallback of adults migrating or transported above hydropower facilities can lead to increased stress, injury, and mortality, and considerably delay migration times (Boggs et al. 2004). Fallback is typically related to adults overshooting location of natal spawning grounds or disorientation (Naughton et al. 2006). How ambient conditions contribute to fallback rates are generally poorly understood, but likely influence rates in any given year. For example, Holbrook et al. (2009) found overall fallback rates for Atlantic salmon to range from 0.8 – 9.4%; however, fallback rates increased to over 47% during periods of excessive stream warming (>22°C). Understanding how conditions such as stream temperature and stream flow interact with management operations to reduce fallback warrants additional research.

Within the Pacific Northwest, we observed considerable variability in fallback rates across species and years (Table 7; see Appendix Table 7 for individual estimates). Overall we found the highest fallback rates for Chinook, with the highest estimates for spring Chinook (mean = 24.1%, SD = 12.9%), with considerably lower reported estimates for fallback for fall Chinook (mean = 4.9%, SD = 4.0) and spring-summer Chinook (mean = 12.4, SD = 8.0). Albeit limited in number of estimates (n =5), fallback rates for coho (mean =5.0, SD =6.7) were similar to those observed for fall Chinook but with considerably higher variability. Fallback estimates for steelhead (mean = 10.0%, SD = 7.8) were similar to those for spring and spring-summer Chinook; however, in many instances, fallback estimates includes kelts and thus may be biased high (Gleizes 2013). Estimates for sockeye salmon (mean – 5.9%, SD =4.1) were relatively low. The observed patterns indicate relatively lower fallback rates for fall spawners than observed in spring and spring/summer species/runs.

Currently few estimates of fallback are available for storage projects that utilize trap and haul methods (e.g., Round Butte). Limited annual fallback rates are available from the Cowlitz facilities (Mayfield and Cowlitz Falls), and estimates are variable (Appendix Table 7), thus rigorous comparisons between run-of-the-river projects and trap-and-haul are limited at this time.

Table 7. Average and standard deviation (SD) of fallback rates for anadromous species and runs across studies (n = the number of individual studies and/or years; See Appendix Table 7 for individual estimates).

Species	Run	Mean (%)	SD	n
Chinook	Fall	4.9	4	31
	Spring	24.1	12.9	12
	Spring-	10.3	4.7	23

	summer			
	Summer	12.4	8.0	10
Coho	-	5.0	6.7	5
Sockeye	-	5.9	4.1	9
Steelhead	-	10.0	7.8	31

Upstream mortality of non-target salmonids.—Upstream collection mortality estimates for non-target species do not appear to be common. Henning (2010) found numerous injuries to tiger muskies, but relatively low evidence of mortality. Limited data for bull trout from the Pelton adult fish trap on the Deschutes River system has found no evidence of mortality (PGE 2013), which is consistent with reports for bull trout migrating through hydropower facilities on the Columbia River (PUD 2012a; PUD 2012b). Studies specifically targeting handling effects for bull trout, however, have found mortality rates as high as 4% (Kleinschmidt 2003). Little information currently exists on upstream passage effects on coastal cutthroat trout. Although survival estimates for anadromous salmon and steelhead are relatively low (Table 5), additional data is needed to identify how upstream trap and transport may affect native salmonid survival rates.

Of particular importance for species such as bull trout, which have narrow thermal tolerances (Selong et al. 2001; McMahon et al. 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 bi-weekly average temperatures during mid-July through mid-September exceeded 16°C at depths to 9 m (M. Sorel, U. Washington, upublished data) suggest thermal regimes may be detrimental for species such as bull trout that are released in the epilimnion during these periods. Monitoring thermal regimes should be integrated into the transport protocols, with alternative release strategies should be implemented where thermal regimes are stressfull to target species. l trout transportation strategies.

Community-level interactions among reintroduced anadromous species and native and non-native taxa

Anadromous-resident interactions

This review will focus on the effects of anadromous reintroductions on native bull trout *Salvelinus confluentus* and coastal cutthroat trout *Oncorhynchus clarkii clarkii*, but will not cover hatchery-wild interactions of anadromous species, which has been extensively studied. Furthermore, prior to the recent reintroduction efforts wild anadromous species have been in absence to the Upper Lewis River due to the long-term barriers to migration. Certainly future considerations should be given to long-term supplementation strategies, particularly as wild anadromous populations are established (Pearsons 2002). Given the recent report describing habitat use and overlap between anadromous species and resident trout (PacifiCorp 2002), this review will focus on new information describing habitat 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, cutthroat trout) on anadromous reintroductions, and predation by non-native predators and management considerations.

Effects of anadromous reintroductions on native species

Distributional overlap.—Overlap in distribution of bull trout and juvenile Chinook, coho, steelhead, and coastal cutthroat trout is likely to be dictated by thermal requirement, local habitat quality, and life-history expression and vary across life-stage and species. The fact that both cutthroat trout and bull trout exhibit complex life-histories with movements from headwaters to reservoir environments suggests the potential for overlap within the Upper Lewis River. The importance of temperature in determining species distribution patterns and mediating interspecific interactions has been well documented. When compared, maximum growth for bull trout is considerably lower than observed for juvenile Chinook salmon, coho salmon, and steelhead (unknown for coastal cutthroat). However, the range for optimum growth is relatively similar (note; little thermal suitability information for coastal cutthroat trout currently exists; Table 8) suggesting considerable opportunities for overlap. However, understanding how thermal ranges from lab studies and those observed in different portions of species ranges (Spina 2007), may not be appropriate for *in situ* thermal preferences for the Upper Lewis River, WA.

Table 8. Estimates of water temperatures for optimum and maximum growth from existing literature for bull trout, Chinook, coho, steelhead, and coastal cutthroat trout.

Species	Optimum growth range	Maximum growth	Reference optimum	Reference maximum
Bull trout	10 - 15	13.2	(Selong et al. 2001; McMahon et al. 2007)	(Selong et al. 2001)

Chinook salmon	10-15.6	16, 18.9-20.5	(ODEQ 1995; USEPA 2001)	(WDOE 2002)
Coho salmon	10-14	15-17	(Konecki et al. 1995)	(WDOE 2002)
Steelhead	9.8 - 22	13.1,17.2	(Bear et al. 2007; Spina et al. 2007)	(Hokanson et al. 1977; Bear et al. 2007)
Coastal cutthroat trout	15	-	(Johnson et al. 1999)	-

Overlap between coastal cutthroat trout with coho salmon (e.g., Glova 1987; Trotter 1989b; Sabo and Pauley 1997; Pess et al. 2011) and steelhead/rainbow trout (e.g., Trotter 1989a; Slaney et al. 1996; Heath et al. 2010) is extensive and well established in the literature. Bull trout overlap with Chinook, steelhead, and coho can be extensive, particularly in headwater streams and reservoirs (e.g., Thurow et al. 1997; Taylor et al. 1999; Lowery 2009; Schoby and Keeley 2011; PGE 2013).

Formal assessments of overlap where supplementation programs exists in the Yakima River basin has found considerable overlap between spring Chinook salmon and steelhead distributions 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 Basin, however, supplementation release sites were specifically targeted to minimize impacts to non-target taxa (Pearsons 2008; Pearsons 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 and distribution, and thermal and habitat characteristics of the basins (i.e., are habitat conditions suitable for overlap). Ultimately, collecting before-and-after distributional data through the progression of the reintroduction process is necessary to understand potential changes in distribution and effects on native taxa.

Overlap in spawning habitat for fall spawners.—Overlap in spawning habitat can be substantial for bull trout, coho, and Chinook salmon all of which spawn during the late-summer early fall.

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, 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 2002). Based in information in the Lower Lewis River, spring Chinook typically spawn during September and October, fall Chinook spawn during mid-October through early November, and coho spawn during mid-October through early December (PacifiCorp 2002) typically spawn after bull trout.

Of greatest concern during the fall spawning period is the risk of redd superimposition. Superimposition is likely to be most pronounced as densities of Chinook and coho increase and saturate habitat. Each species is generally considered to spawn in pool-tail/riffle crest habitat (Kondolf 2000), but generally extends to areas with high intragravel flows. Intragravel flows include both upwelling (positive vertical hydraulic gradient) and downwelling (negative vertical hydraulic gradient), and use of both types of intragravel flows have 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.

Similar to 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. Overlap is likely across each of the species, but substrate use for spawning Chinook (mean =47 mm; range = 1 – 175 mm; as reviewed in Kondolf 2000) is considerably larger than observed for bull trout (mean = 29 mm; range = 3 – 58; as reviewed in Baxter and McPhail 1996) relatively similar gravel use by coho salmon (mean = 20 mm; range = 5 – 35 mm; as reviewed in Kondolf 2000; Mull 2005) with bull trout suggests a high potential for overlap in substrate use, particularly when densities are high.

The current understanding of Chinook, coho, and bull trout spawning periods in the Upper Lewis River suggests redd depth may also be an important factor in consider interspecific interactions. Bull trout redds are typically shallower (mean =16.5 cm, mean range = 11-17 cm; Weeber et al. 2010) than reported redd depths for Chinook salmon (mean = 28.4 cm, mean range = 24.2 – 43.9 cm; DeVries 1997), and coho salmon (mean range = 21.1 cm, average 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 et al. 2010). Monitoring the potential for superimposition is warranted in the Upper Lewis, particularly if Chinook and coho spawning extends to the core bull trout spawning areas (e.g., Pine Creek and tributaries).

Population-level effects.—The effects of anadromous reintroductions on native bull trout and coastal cutthroat trout populations are relatively limited, rendering consideration of other native salmonids in this review. Riley et al. (2004) found no significant effects of Chinook and coho supplementation releases on rainbow and cutthroat trout fry densities. In a review of existing studies, Naman and Sharpe (2012) found hatchery 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 occurs (Naman and Sharpe 2012; Tabor et al. 2012).

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

Early research in headwater streams in the Yakima Basin, however, suggested large increases in wild Chinook abundance did not lead to significant changes in rainbow trout growth, abundance, and biomass (McMichael and Pearsons 1998). Long term assessments, however, have found hatchery Chinook salmon supplementation has led to significant declines in rainbow trout abundance, which is likely attributable to the cumulative effects of hatchery supplementation and increases in wild Chinook abundance (i.e., replacement; Pearsons and Temple 2010). Continued monitoring in the Yakima, however has found differential results, as mean abundance of coastal cutthroat trout and mountain whitefish increased during hatchery supplementation (Temple and Pearsons 2012). While Temple and Pearsons (2012) continued to find significant decreases in rainbow trout size structure during supplementation (i.e., 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 steelhead, which typically is >5% but can approach levels as high as 17% (Hausch and Melnychuk 2012). Residualized steelhead can make relatively long upstream movements (>12 km; McMichael and Pearsons 2001). The presence of residualized steelhead can also lead to significantly reduced growth in wild rainbow trout growth (McMichael et al. 1997). The presence of steelhead residuals is likely to lead to erosion of reproductive barriers with native coastal cutthroat trout (Docker et al. 2003) and increase hybridization levels above that observed in wild populations (e.g., Ostberg et al. 2004; Heath et al. 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 (e.g., 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 et al. 2009), caution should be urged in extrapolating results where data is 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 Pearsons (2010), with long term monitoring sites (e.g., Temple and Pearsons 2012) and where the adaptive management practices are invoked is likely to provide feedback to managers to limit impacts to native taxa.

Effects of native species on anadromous reintroductions

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

Coastal cutthroat trout.—While 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, juvenile Chinook salmon represented up to 30% of winter/spring diets for juveniles/small adults (Tabor et al. 2012). While diets consisted primarily of aquatic insects during the summer, when year round predation was linked with population estimates, Tabor et al. (2012) found annual predation to be 66,000 Chinook in a given year. While seemingly high, these predation rates appear to be relatively consistent with coho predation of 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 naturally high, and no studies have evaluated predation effects on adult salmon returns or SAS. Given the relatively ubiquitous distribution of coastal cutthroat trout in the Upper Lewis, there is a potential for predation of anadromous fry/parr; however, densities of coastal cutthroat trout are relatively low (R. Al-Chokhachy, USGS, unpublished data), suggesting limited population-level effects.

Bull trout.—Across the Pacific Northwest, bull trout are considered one of the top native predators. Bull trout are considered to be highly piscivorous, particularly with increasing size (Rieman and McIntyre 1993; Wilhelm et al. 1999; Beauchamp and Van Tassell 2001). When comparing bull trout diets across studies, the proportion of fish in bull trout diets averaged 44.7% (range = 0 -100%; Table 9). When considering only large bull trout (i.e., where size is identified including adults, >500 g, and >300 mm) the average proportion of fish in diets increases to 68.2% (range = 22 – 100%). Where sympatric with kokanee salmon in reservoir/lake systems, kokanee tend to be the dominant prey (Hill et al. 2013; Guy et al. 2011; Clarke et al. 2005); this pattern is consistent (albeit limited time series) in Lake Billy Chinook where no identified Chinook juveniles were found in bull trout diets during spring or fall sampling events (Hill 2013). 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, Chinook, steelhead) within and across seasons/years. Budy et al. (2012) found bull trout diets in in the SF Walla Walla River varied considerably across years (2002-2012), with *Oncorhynchus* spp. (Chinook, steelhead, rainbow) making up anywhere between 0% and >95% 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) to be predominantly characterized as moderately low to none (Marcot et al. 2012). Although predation impacts to kokanee salmon can be relatively high in fluvial environments (Beauchamp and Van Tassell 2001), there remains considerable uncertainty of the effects on coho, Chinook, and steelhead. Bull trout predation of anadromous smolts is likely to be highest within mainstem Lewis River and in reservoir systems as distributional overlap in tributary streams appears to be currently limited (R. Al-Chokhachy, USGS, Unpublished Data). Marked increases in abundance and distribution through the reintroduction process may increase the extent of lotic 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.

Table 9. Proportion of fish (%; including sculpin) in bull trout diets across lake/rivers, life-history forms, and size classes.

Lake/river	Location	Life-history	Proportion fish in diet	Size classes	Source
Walla Walla	OR	Fluvial	96.0	Mixed	(Budy et al. 2012)
Walla Walla	OR	Fluvial	86.6	Mixed	(Budy et al. 2012)
Walla Walla	OR	Fluvial	57.0	Mixed	(Budy et al. 2012)
Walla Walla	OR	Fluvial	90.1	Mixed	(Budy et al. 2012)
Walla Walla	OR	Fluvial	0	Mixed	(Budy et al. 2012)
Walla Walla	OR	Fluvial	0	Mixed	(Budy et al. 2012)
Walla Walla	OR	Fluvial	85.7	Mixed	(Budy et al. 2012)
Walla Walla	OR	Fluvial	62.9	Mixed	(Budy et al. 2012)
NF John Day	OR	Fluvial	16.6	mixed; <475 mm	(Budy et al. 2007)
NF John Day	OR	Fluvial	13.9	mixed; <450 mm	(Budy et al. 2007)
NF Umatilla	OR	Fluvial	13.3	mixed; <400 mm	(Budy et al. 2004)
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 et al. 2013)
Lake Billy Chinook	OR	Adfluvial	83.7	501-1500 g	(Hill et al. 2013)
Lake Billy Chinook	OR	Adfluvial	100	1501-3000 g	(Hill et al. 2013)
Lake Billy Chinook	OR	Adfluvial	100	>3000 g	(Hill et al. 2013)
Meadow Fork	OR	Resident/fluvial	0	<300 mm	(Gunckel 2001)
North Powder	OR	Resident/fluvial	0	<300 mm	(Gunckel 2001)
Swan Lake	MT	Adfluvial	12.0	<301 mm	(Guy et al. 2011)
Swan Lake	MT	Adfluvial	22.0	301-500 mm	(Guy et al. 2011)

Swan Lake	MT	Adfluvial	94.0	502-700 mm	(Guy et al. 2011)
Harrison Lake	AB	Adfluvial	0	<250 mm	(Wilhelm et al. 1999)
Harrison Lake	AB	Adfluvial	1.5	>250 mm	(Wilhelm et al. 1999)
Mill Creek	WA	Resident/fluvial	12.3	<270 mm	(Underwood et al. 1995)
Tucannon	WA	Resident/fluvial	0	<225 mm	(Underwood et al. 1995)
Mill Creek	WA	Resident/fluvial	50.4	100-250 mm	(Martin et al. 1992)
Pend Oreille	ID	Adfluvial	100	>400 mm	(Clarke et al. 2005)
Wolf Fork	WA	Resident/fluvial	23.5	100-250 mm	(Martin et al. 1992)
Wolf Fork	WA	Resident/fluvial	9.0	100-250	(Martin et al. 1992)

Impacts of native and non-native salmonid predators to reintroduction efforts

Considerable populations of native and non-native predators exist within the Upper Lewis Basin as a result of fisheries management objectives and native species distributions. Within the Upper Lewis Basin the main native predator is the northern pikeminnow *Ptychocheilus oregonensis*. In addition to northern pikeminnow, non-native predators including tiger muskellunge (northern pike *Esox lucius* x muskellunge *E. masquinongy* cross), bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, and brown bullheads *Ictalurus nebulosus.* Given the extensive review of non-native species effects on anadromous species (PacifiCorp 2002), this study only included new literature related to existing native and non-native predators within the Upper Lewis Basin. Of particular concern in the Upper Lewis Basin is the uncertainty in predation rates of tiger musky, the relative strength of predation of largemouth bass, and the need for potential management actions to control native and non-native predators.

Tiger muskellunge.—Data related to tiger musky predation on salmonids, continues to be rare in the literature (see PacifiCorp 2002), rendering the need to consider diet data for closely related northern pike *E. lucius*. Recent diet studies have indicated considerably higher northern pike predation of salmonids than observed in Schmetterling (2001). In Alaska, Sepulveda et al. (2013) found the extent of predation to vary based on suitable habitat. In streams with suitable thermal and physical habitat (i.e., high overlap in distribution) salmonids were the dominant prey item across sample sites and spring and summer months (48-70% diet mass). In an adjacent stream, with habitat only suitable in the lower reaches, the proportion of salmonids in diets was relatively high in the lower reaches (31%) but zero in reaches with unsuitable habitat. Interestingly, Sepulveda et al. (2013) found no correlation in the proportion of Chinook or coho salmon in diets with size of pike (range = 25 – 100 cm), suggesting relatively high predation potential across size classes.

Other studies have also found considerable pike predation on salmonids (Muhlfeld et al. 2008; Spens and Ball 2008). In Montana, Muhlfeld et al. (2008), in particular, found northern pike to consume a mixture of soft-rayed and bony-rayed fishes. Pike diets varied across seasons with predation on bull trout and cutthroat trout to be relatively high during winter and spring with proportion of diet >50% during the spring months. Summer predation was minimal, likely due to thermal segregation of the species. 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 cutthroat over bull trout at smaller size classes, suggesting an interaction in predation across size classes. These recent results suggest salmonids are extremely vulnerable to pike (Haught and von Hippel 2011), indicating tiger musky predation on salmonids is likely to be considerable. Total predation estimates, however, will require extensive diet data which can vary across individuals (PacifiCorp 2002), and population estimates across size classes, given the potential for musky to be long-lived (>8 years; Schmuck and Petersen 2006).

Other non-natives.—Data continues 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 et al. 2004), which is consistent with other studies in the Pacific Northwest (Washburn 1999; 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 (Washburn 1999). In Lake Washington, Tabor et al. (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% of small (100-199 mm) largemouth bass diets (shipping canal). Given the relative abundance of smaller-sized largemouth bass, population-level predation may be an additional limitation to reintroduction efforts where present (e.g., Karchesky and Bennett 1999). Such results highlight the need for *in situ* studies of largemouth bass predation, and potential for competition-effects between juvenile bass and juvenile salmonids (Gray 2005).

Management consideration.—Given the relative abundance of northern pikeminnow and presence of additional non-native predators in the Upper Lewis, there continues to be concerns over 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 et al. 1996; Porter 2012). The effects of predator controls, however, are complex (Harvey and Kareiva 2005; Carey et al. 2012). After 22 years and over 2 million northern pikeminnow removed in the Columbia River Northern Sport Reward Fishery Program, for example, there appears to be no apparent trends in annual harvest and catch-per-unit-effort appears to be increasing (Porter 2012), rendering questions regarding the population-level impacts. Within certain reservoirs (e.g., John Day Reservoir), however, population indices of northern pikeminnow are decreasing; attributing this decline to management actions, however, has been challenging as non-native populations of walleye *Sander vitreus* have increased during this period.

Management actions in the Columbia have met target goals of reducing predation impacts, but there is uncertainty as to how these actions have affected overall salmon survival (Beamsderfer et al. 1996).   The challenges associated with management actions also stem from potential indirect effects of managing one population on sympatric predator populations (Harvey and Kareiva 2005) or compensatory mechanisms within the source population (Beamsderfer et al. 1996).   Prior to implementing management actions to control native non-native predator populations, considerable data related to species distribution, abundance, and community interactions (e.g., food web) are suggested as a means to avoid unintended consequences and improve the efficiency of management actions (if needed). Ultimately, with ample data, scenario modeling should be completed (e.g., Harvey and Kareiva 2005) and an adaptive management framework should be established with iterative analyses of monitoring and evaluation data.

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Appendix

Appendix Table 1. Estimates of smolt survival in acclimation facilities across rivers, acclimation facility, year, species and run, age class, and acclimation facility type and reference.

River	Location	Year	Species	Type	Age	Facility type	Survival (%)	Reference
Catherine Creek	Catherine Creek	2002	Chinook	Spr.	-	Aluminum raceways, lined with vinyl	99.7	(McLean et al. 2003)
Clearwater River	Big Canyon	2008	Chinook	Fall	1+	Aluminum circular tanks	98.5	(McLeod 2009)
Clearwater River	Big Canyon	2008	Chinook	Fall	0+	Aluminum circular tanks	99.5	(McLeod 2009)
Clearwater River	Big Canyon	2007	Chinook	Fall	1+	Aluminum circular tanks	96.9	(McLeod 2008)
Clearwater River	Big Canyon	2007	Chinook	Fall	0+	Aluminum circular tanks	98.7	(McLeod 2008)
Clearwater River	Big Canyon	2007	Chinook	Fall	1+	Aluminum circular tanks	97.8	(McLeod 2007)
Clearwater River	Big Canyon	2007	Chinook	Fall	0+	Aluminum circular tanks	98.5	(McLeod 2007)
Grand Ronde River	Upper Grand Ronde	2002	Chinook	Spr.	-	Aluminum raceways, lined with vinyl	99.7	(McLean et al. 2003)
Hood River	Blackberry	2008	Steelhead	Sum.	-	Polypropylene-lined tanks	99.7	(Gerstenberger 2009)
Lostine River	Lostine River	2007	Chinook	Spr.	-	PVC-lined raceways	99.9	(Zollman et al. 2009)
MF Hood River	Parkdale	2008	Steelhead	Win.	-	Painted concrete	99.9	(Gerstenberger 2009)

Snake River	Capt. John Rapids	2008	Chinook	Fall	1+	In-ground, lined pond	99.8	(McLeod 2009)
Snake River	Capt. John Rapids	2008	Chinook	Fall	0+	In-ground, lined pond	99.8	(McLeod 2009)
Snake River	Capt. John Rapids	2007	Chinook	Fall	1+	In-ground, lined pond	99.9	(McLeod 2008)
Snake River	Capt. John Rapids	2007	Chinook	Fall	0+	In-ground, lined pond	99.7	(McLeod 2008)
Snake River	Capt. John Rapids	2007	Chinook	Fall	1+	In-ground, lined pond	99.1	(McLeod 2007)
Snake River	Capt. John Rapids	2007	Chinook	Fall	0+	In-ground, lined pond	99.9	(McLeod 2007)
Snake River	Pittsburg Landing	2008	Chinook	Fall	1+	Aluminum circular tanks	97.9	(McLeod 2009)
Snake River	Pittsburg Landing	2008	Chinook	Fall	0+	Aluminum circular tanks	99.7	(McLeod 2009)
Snake River	Pittsburg Landing	2007	Chinook	Fall	1+	Aluminum circular tanks	97.7	(McLeod 2008)
Snake River	Pittsburg Landing	2007	Chinook	Fall	0+	Aluminum circular tanks	98.4	(McLeod 2008)
Snake River	Pittsburg Landing	2007	Chinook	Fall	1+	Aluminum circular tanks	99.6	(McLeod 2007)
Snake River	Pittsburg Landing	2007	Chinook	Fall	0+	Aluminum circular tanks	99.7	(McLeod 2007)
Umatilla River	Bonifer	1993	Steelhead	Sum.	-	na	99.5	(Rowan 1994)
Umatilla River	Bonifer	1993	Steelhead	Sum.	-	na	99.8	(Rowan 1994)
Umatilla River	Minthorn	1993	Steelhead	Sum.	-	na	98.6	(Rowan 1994)

Appendix Table 2. Estimates of collection efficiency by river, facility, collection method, year, species (Spp.; CO = coho, CH = Chinook, SO = sockeye, OM = steelhead, SS = Atlantic salmon).**See USACOE (2007) for references cited within.

River	Facility	Method	Year	Spp.	Collection efficiency (%)	Source
Ariège (France)	Crampagna	Bypass/sluice	na	SS	66	Johnson et al. 2006
Ariège (France)	Guilhot	Bypass/sluice	na	SS	75	Johnson et al. 2006
Ariège (France)	Las Mijanes	Bypass/sluice	na	SS	32	Johnson et al. 2006
Ariège (France)	Las Rives	Bypass/sluice	na	SS	49	Johnson et al. 2006
Baker	Lower Baker	Forebay collector-Gulper	1992	CO	11.3	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	1993	CO	7.8	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	1994	CO	17.6	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	1995	CO	7.2	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	1996	CO	9.2	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	1997	CO	23.1	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	1998	CO	56.8	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	1999	CO	27.2	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2000	CO	45.2	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2001	CO	22.9	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2002	CO	21.9	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2003	CO	8.2	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2004	CO	17.3	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2005	CO	31.6	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2006	CO	25.4	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2007	CO	33.5	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2008	CO	7.8	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2009	CO	38.5	(PSE 2012)

Baker	Lower Baker	Forebay collector-Gulper	2010	CO	8.3	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2011	CO	18.2	(PSE 2012)
Baker	Lower Baker	Forebay collector-Gulper	2012	CO	57.7	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1988	CO	40.9	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1989	CO	41.8	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1990	CO	62.7	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1991	CO	48.5	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1992	CO	59.3	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1993	CO	27.2	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1994	CO	73.2	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1995	CO	58.8	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1996	CO	42.5	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1997	CO	48.4	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1998	CO	64	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	1999	CO	62	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2000	CO	56.8	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2001	CO	54.9	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2002	CO	55.3	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2003	CO	45.1	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2004	CO	55.6	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2005	CO	54.1	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2006	CO	61.5	(PSE 2012)
Baker	Upper Baker	Forebay collector - Gulper	2007	CO	65.5	Jeanes and Verretto 2012
Baker	Upper Baker	Forebay collector - Surface collector/enhanced gulper	2008	CO	92.7	Jeanes and Verretto 2012
Baker	Upper Baker	Forebay collector - Surface collector/enhanced gulper	2009	CO	99	Jeanes and Verretto 2012
Baker	Upper Baker	Forebay collector - Surface collector/enhanced gulper	2010	CO	--	Jeanes and Verretto 2012

Baker	Upper Baker	Forebay collector - Surface collector/enhanced gulper	2011	CO	82.6	Jeanes and Verretto 2012
Columbia	Bonneville PH1	Powerhouse retrofit - PSC	2000	All	83	Ploskey et al. 2000 cited in USACOE 2007
Columbia	Bonneville PH1	Powerhouse retrofit - PSC	2000	All	84	Ploskey et al. 2000 cited in USACOE 2007
Columbia	Bonneville PH1	Sluiceway	2002	All	33	(Ploskey et al. 2003)
Columbia	Bonneville PH1	Sluiceway	2002	All	29	(Ploskey et al. 2003)
Columbia	Bonneville PH1	Sluiceway	2004	All	33	(Ploskey et al. 2005)
Columbia	Bonneville PH1	Sluiceway	2004	All	38	(Ploskey et al. 2005)
Columbia	Bonneville PH1	Sluiceway	2005	All	37	(Ploskey et al. 2006)
Columbia	Bonneville PH1	Sluiceway	2005	All	71	(Ploskey et al. 2006)
Columbia	Bonneville PH1	Sluiceway	2000	CH	68	Evans et al. 2006 cited in USACOE 2007
Columbia	Bonneville PH1	Sluiceway	2000	CH	29	(Reagen et al. 2006)
Columbia	Bonneville PH1	Powerhouse retrofit - PSC	2000	CH	43	Evans et al. 2001 cited in USACOE 2007
Columbia	Bonneville PH1	Sluiceway	2001	CH	70	Evans et al. 2006 cited in USACOE 2007
Columbia	Bonneville PH1	Sluiceway	2001	CH	77	(Reagan et al. 2006)
Columbia	Bonneville PH1	Sluiceway	2002	CH	48	Evans et al. 2006 cited in USACOE 2007
Columbia	Bonneville PH1	Sluiceway	2002	CH	35	(Reagan et al. 2006)
Columbia	Bonneville PH1	Sluiceway	2004	CH	47	Evans et al. 2006 cited in USACOE 2007
Columbia	Bonneville PH1	Sluiceway	2004	CH	53	(Reagan et al. 2006)
Columbia	Bonneville PH1	Sluiceway B2CC	2008	CH	16.7	(FPC 2008)
Columbia	Bonneville PH1	Sluiceway	2000	OM	44	(Reagan et al. 2006)
Columbia	Bonneville PH1	Powerhouse retrofit - PSC	2000	OM	45	Evans et al. 2001 cited in USACOE 2007
Columbia	Bonneville PH1	Sluiceway	2002	OM	65	(Reagan et al. 2006)
Columbia	Bonneville PH1	Sluiceway	2004	OM	55	(Reagan et al. 2006)

Columbia	Bonneville PH2	Sluiceway - B2CC	2004	All	31	(Ploskey et al. 2005)
Columbia	Bonneville PH2	Sluiceway - B2CC	2004	All	40	(Ploskey et al. 2005)
Columbia	Bonneville PH2	Sluiceway - B2CC	2005	All	32	(Ploskey et al. 2006)
Columbia	Bonneville PH2	Sluiceway - B2CC	2005	All	44	(Ploskey et al. 2006)
Columbia	Bonneville PH2	Sluiceway - B2CC	2004	CH	37	Evans et al. 2005 cited in USACOE 2007
Columbia	Bonneville PH2	Sluiceway - B2CC	2004	CH	37	Evans et al. 2005 cited in USACOE 2007
Columbia	Bonneville PH2	Sluiceway - B2CC	2005	CH	40	Evans et al. 2005 cited in USACOE 2007
Columbia	Bonneville PH2	Sluiceway - B2CC	2005	CH	29	Evans et al. 2005 cited in USACOE 2007
Columbia	Bonneville PH2	Sluiceway - B2CC	2004	OM	74	(Reagan et al. 2006)
Columbia	Bonneville PH2	Sluiceway - B2CC	2005	OM	66	(Reagan et al. 2006)
Columbia	John Day	Surface spill - surface bypass	2001	CH	28	(FPC 2001)
Columbia	John Day	Surface spill - surface bypass	2008	CH	15.3	(FPC 2008)
Columbia	Priest Rapids	Sluiceway	1992	All	2.7	McFadden et al. 1993 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	1992	All	3.8	Ransom 1997 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	1994	All	2.9	Ransom 1997 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	1995	All	8.3	Ransom 1997 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	1995	All	5.7	Ransom 1997 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	1996	All	3.2	Ransom 1997 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	1996	All	2.8	Ransom 1997 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	2001	CH	1.9	Robichaud et al. 2003 cited in USACOE 2007
Columbia	Priest Rapids	Sluiceway	2006	OM	39	(Timko et al. 2011)
Columbia	Priest Rapids	Sluiceway	2007	OM	34	(Timko et al. 2011)
Columbia	Priest Rapids	Sluiceway	2008	OM	59	(Timko et al. 2011)
Columbia	Priest Rapids	Sluiceway	2009	OM	66	(Timko et al. 2011)

Columbia	Priest Rapids	Sluiceway	2010	OM	69	(Timko et al. 2011)
Columbia	Rocky Reach	Surface spill - Combined spillway	1998	All	27.7	Iverson and Birmingham 1998 cited in USCOE 2007
Columbia	Rocky Reach	Surface spill - Combined spillway	1998	All	33.1	Iverson and Birmingham 1998 cited in USCOE 2007
Columbia	Rocky Reach	Forebay collector	2002	CH	5	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2002	CH	2	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2002	CH	23	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2002	CH	17	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2004	CH	27	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Surface spill - Combined spillway	2004	CH	38.6	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Surface spill - Combined spillway	2004	CH	37.6	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2005	CH	32	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Surface spill - Combined spillway	2005	CH	36.2	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Surface spill - Combined spillway	1999	OM	28.5	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2002	OM	27	(Steig et al. 2003)
Columbia	Rocky Reach	Forebay collector	2002	OM	30	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2002	OM	29	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2004	OM	67	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Surface spill - Combined spillway	2004	OM	16.7	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2005	OM	68	Steig et al. 2007 cited in USACOE 2007

Columbia	Rocky Reach	Surface spill - Combined spillway	2005	OM	20.1	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Surface spill - Combined spillway	2005	OM	21.9	Steig et al. 2007 cited in USACOE 2007
Columbia	Rocky Reach	Forebay collector	2006	OM	66	Steig et al. 2007 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	1999	All	13	Ploskey et al. 2001 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	1999	All	12	Ploskey et al. 2001 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2000	All	6	Moursund et al. 2001 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2000	All	7	Moursund et al. 2001 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2001	All	18	Moursund et al. 2002 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2001	All	5	Moursund et al. 2002 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2002	All	25	Johnson et al. 2003 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2002	All	11	Johnson et al. 2003 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2004	All	7	Johnson et al. 2005 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2004	All	4	Johnson et al. 2005 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2002	CH	10	Hausman et al. 2004, Counihan et al. 2006 cited ini USACOE 2007
Columbia	The Dalles	Sluiceway	2003	CH	12	Hansel et al. 2004 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2003	CH	17	Hansel et al. 2004 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2004	CH	7	Hansel et al. 2005 and Counihan et al. 2006 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2004	CH	1	Cash et al. 2005 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2004	CH	7	Hansel et al. 2005, Counihan et al. 2006

						cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2004	CH	8	Cash et al. 2005 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2005	CH	4	Beeman et al. 2006a cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2005	CH	11	Beeman et al. 2006a cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2002	OM	14	Hausman et al. 2004 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2004	OM	5	Cash et al. 2005 cited in USACOE 2007
Columbia	The Dalles	Sluiceway	2002	TW	8	Hausman et al. 2004, Counihan et al. 2006 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1989	All	8.6	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1990	All	5.7	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1991	All	4.2	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1994	All	5.8	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1995	All	10	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1995	All	9.9	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1996	All	3	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1996	All	3.7	Ransom 1997 cited in USACOE 2007
Columbia	Wanapum	Powerhouse retrofit - SAC	1996	All	0.3	Kumagai et al. 1997 cited in USACOE 2007
Columbia	Wanapum	Powerhouse retrofit - SAC	1997	All	0.3	Kumagai et al. 1997 cited in USACOE 2007
Columbia	Wanapum	Sluiceway	1996	CH	3	Robichaud et al. 2003 cited in USACOE 2007
Columbia	Wanapum	Surface spill	2002	CH	10	Robichaud et al. 2003 cited in USACOE 2007
Columbia	Wanapum	Surface spill	2004	CH	24	USACOE 2007
Columbia	Wanapum	Surface spill	2008	OM	53.5	(Timko et al. 2010)
Columbia	Wanapum	Surface spill	2009	OM	70.2	(Timko et al. 2010)
Columbia	Wanapum	Surface spill	2010	OM	77	(Timko et al. 2011)

Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	1990	CH &OM	84.3	(Skalski et al. 1996)
Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	1990	CH &OM	76.5	(Skalski et al. 1996)
Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	1991	CH &OM	95	(Skalski et al. 1996)
Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	1991	CH &OM	97	(Skalski et al. 1996)
Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	1992	CH &OM	89	(Skalski et al. 1996)
Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	1992	CH &OM	93.4	(Skalski et al. 1996)
Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	Overall	CH &OM	92	(Skalski et al. 1996)
Columbia	Wells	Powerhouse retrofit - Surface bypass units with retrofit baffle bays	Overall	CH &OM	96.2	(Skalski et al. 1996)
Connecticut	Bellows Falls	Bypass/sluice	na	SS	94	(Johnson and Dauble 2006)
Connecticut	Vernon Station	Bypass/sluice	na	SS	74	Hanson 1999 in Johnson et al. 2006
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1997	CH	17	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1998	CH	18	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1999	CH	24	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2000	CH	24	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2001	CH	23	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2002	CH	22	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2003	CH	13	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	CH	14	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	CH	14	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	CH	12	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	CH	12	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	CH	30.5	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	CH	31	(Serl and Morrill, 2010)

Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	CH	20.1	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	CH	20	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2008	CH	26.1	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2009	CH	39.6	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2012	CH	16.6	(Serl and Heimbigner 2013)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1996	CO	15	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1997	CO	21	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1998	CO	32	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1999	CO	17	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2000	CO	45	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2001	CO	42	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2002	CO	33	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2003	CO	43	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	CO	42	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	CO	36	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	CO	26	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	CO	36	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2008	CO	20.8	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2009	CO	20.8	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2012	CO	17.7	(Serl and Heimbigner 2013)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1996	OM	50	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1997	OM	45	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1998	OM	19	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1999	OM	41	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2000	OM	65	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2001	OM	58	(Serl and Morrill, 2010)

Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2002	OM	56	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2003	OM	68	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	OM	48	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	OM	42	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	OM	47	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	OM	42	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2008	OM	26	(Serl and Morrill, 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2009	OM	37.4	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2012	OM	5.4	(Serl and Heimbigner 2013)
Cowlitz	Mayfield	Forebay collector	1964	CH	76	(USACOE 2007)
Cowlitz	Mayfield	Forebay collector	1965	CH	74	(USACOE 2007)
Cowlitz	Mayfield	Forebay collector	1964	CO	50	(USACOE 2007)
Cowlitz	Mayfield	Forebay collector	1965	CO	62	(USACOE 2007)
Cowlitz	Mayfield	Forebay collector	2001	CO	67	(USACOE 2007)
Cowlitz	Mayfield	Forebay collector	2012	CO	67	Serl and Heimbigner 2013
Cowlitz	Mayfield	Forebay collector	1964	OM	73.6	(USACOE 2007)
Cowlitz	Mayfield	Forebay collector	1965	OM	79.3	(USACOE 2007)
Deschutes	Round Butte	Forebay collector - double – V screen	2010	CH	46.9	(Hill and Quesada 2011)
Deschutes	Round Butte	Forebay collector - double – V screen	2011	CH	51.7	(Hill and Quesada 2012)
Deschutes	Round Butte	Forebay collector - double – V screen	2012	CH	46.9	(Hill and Quesada 2013)
Deschutes	Round Butte	Forebay collector - double – V screen	2010	OM	17.4	(Hill and Quesada 2011)
Deschutes	Round Butte	Forebay collector - double – V screen	2011	OM	24.2	(Hill and Quesada 2012)
Deschutes	Round Butte	Forebay collector - double – V screen	2012	OM	16	Hill and Quesada 2013)
Garonne (France)	Camon	Bypass/sluice	na	SS	73	(Johnson and Dauble 2006)
Gave d' Aspe (France)	Bedous	Bypass/sluice	na	SS	55	Johnson et al. 2006
Gave d' Aspe (France)	Soeix	Bypass/sluice	na	SS	61	Johnson et al. 2006

Gave d' Ossau (France)	St. Cricq	Bypass/sluice	na	SS	79	Johnson et al. 2006
Gave de Pau (France)	Baigts	Bypass/sluice	na	SS	93	Johnson et al. 2006
Gave de Pau (France)	Castetarbe	Bypass/sluice	na	SS	100	Johnson et al. 2006
Santiam	Green Peter	Forebay collector - Floating collection horn	na	CH	>80%	(AECOM 2010)
Santiam	Green Peter	Forebay collector - Floating collection horn	4 yrs late 1960s	OM	<57%	(AECOM 2010)
Snake	Ice Harbor	Sluiceway	1982	All	13	Johnson et al. 1982 cited in USACOE 2007
Snake	Ice Harbor	Sluiceway	1983	All	30	Johnson et al. 1982 cited in USACOE 2007
Snake	Ice Harbor	Sluiceway	1986	All	50	Sullivan et al. 1986 cited in USACOE 2007
Snake	Ice Harbor	Sluiceway	1987	All	34	Ransom and Ouellette 1988 cited in USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2005	All	28	USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2005	All	38	USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2005	CH	60	USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2005	CH	29	Axel et al. 2006 cited in USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2006	CH	68	USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2006	CH	51	USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2005	OM	47	Axel et al. 2006 cited in USACOE 2007
Snake	Ice Harbor	Surface Spill - RSW	2006	OM	38	USACOE 2007
Snake	Lower Granite	Powerhouse retrofit - SBC	2000	All	43	Anglea et al. 2001 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2002	All	65	USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2005	All	31	Dawson et al. 2006 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2005	All	25	Dawson et al. 2006 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	1998	CH	49	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	1998	CH	49	(FPC 2001)

Snake	Lower Granite	Surface Spill - RSW	1999	CH	26	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	1999	CH	26	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	2000	CH	38	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	2000	CH	38	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	2000	CH	38	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	2000	CH	55	(FPC 2001)
Snake	Lower Granite	Powerhouse retrofit - SBC	2000	CH	29	Plumb et al. 2002 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2001	CH	79	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	2001	CH	75	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2001	CH	82	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2001	CH	60	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	2002	CH	22	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2002	CH	22	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2002	CH	60	(FPC 2002)
Snake	Lower Granite	Surface Spill - RSW	2002	CH	56	Plumb et al. 2003 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2003	CH	32	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2003	CH	42	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2003	CH	49	(FPC 2004)
Snake	Lower Granite	Surface Spill - RSW	2003	CH	58	Plumb et al. 2004 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2004	CH	55	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2004	CH	61	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2005	CH	72	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2005	CH	76	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2005	CH	35	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2005	CH	69	USACOE 2007

Snake	Lower Granite	Surface Spill - RSW	2005	CH	37	USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2006	CH	24	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2006	CH	32	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2006	CH	16	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2006	CH	16	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2006	CH	58	USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2006	CH	30	USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2007	CH	25	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2007	CH	32	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2007	CH	13	(FPC 2007)
Snake	Lower Granite	Surface Spill - RSW	2007	CH	9	(FPC 2007)
Snake	Lower Granite	Surface Spill - RSW	2008	CH	37	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2008	CH	38	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2008	CH	14	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2008	CH	16	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2009	CH	32	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2009	CH	45	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2009	CH	17	(FPC 2009)
Snake	Lower Granite	Surface Spill - RSW	2009	CH	15	(FPC 2009)
Snake	Lower Granite	Surface Spill - RSW	2010	CH	17	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2010	CH	26	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2010	CH	15	(FPC 2010)
Snake	Lower Granite	Surface Spill - RSW	2010	CH	11	(FPC 2010)
Snake	Lower Granite	Surface Spill - RSW	2011	CH	34	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2011	CH	42	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2011	CH	19	(FPC 2011)

Snake	Lower Granite	Surface Spill - RSW	2011	CH	17	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	1998	OM	59	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	1998	OM	59	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	1999	OM	36	(FPC 2003)
Snake	Lower Granite	Surface Spill - RSW	1999	OM	37	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	1999	OM	31	(FPC 2001)
Snake	Lower Granite	Surface Spill - RSW	2000	OM	59	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2000	OM	63	(FPC 2002)
Snake	Lower Granite	Surface Spill - RSW	2000	OM	53	(FPC 2002)
Snake	Lower Granite	Powerhouse retrofit - SBC	2000	OM	27	Plumb et al. 2002 cited in USACOE 2007
Snake	Lower Granite	Powerhouse retrofit - SBC	2000	OM	18	Plumb et al. 2002 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2001	OM	89	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2001	OM	91	(FPC 2002)
Snake	Lower Granite	Surface Spill - RSW	2001	OM	87	(FPC 2002)
Snake	Lower Granite	Surface Spill - RSW	2002	OM	24	(FPC 2006)
Snake	Lower Granite	Surface Spill - RSW	2002	OM	23	(FPC 2002)
Snake	Lower Granite	Surface Spill - RSW	2002	OM	27	(FPC 2002)
Snake	Lower Granite	Surface Spill - RSW	2002	OM	61	Plumb et al. 2003 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2002	OM	62	Plumb et al. 2003 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2003	OM	32	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2003	OM	67	Plumb et al. 2004 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2003	OM	69	Plumb et al. 2004 cited in USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2004	OM	73	(FPC 2008)
Snake	Lower Granite	Surface Spill - RSW	2005	OM	68	(FPC 2008)

Snake	Lower Granite	Surface Spill - RSW	2005	OM	49	USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2005	OM	41	USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2006	OM	35	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2006	OM	37	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2006	OM	27	USACOE 2007
Snake	Lower Granite	Surface Spill - RSW	2007	OM	22	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2007	OM	24	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2008	OM	28	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2008	OM	35	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2009	OM	44	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2009	OM	46	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2010	OM	19	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2010	OM	22	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2011	OM	38	(FPC 2011)
Snake	Lower Granite	Surface Spill - RSW	2011	OM	41	(FPC 2011)
Willamette	Willamette Falls	Forebay collector - Inflatable rubber dam	To 2011	CH	97.3	(AECOM 2010)
Willamette	Willamette Falls	Forebay collector - Inflatable rubber dam	To 2011	OM	100	(AECOM 2010)

Appendix Table 3. Estimates of survival through collectors by river, facility, collection method, year, species, origin (H = hatchery, W = wild, Mixed = mixed origin) and reference.

River	Dam	Collection method	Year	Spp.	Origin	Survival	Reference
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.44	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.49	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.58	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.69	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2002	OM	H	0.74	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.79	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2002	OM	H	0.81	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2002	OM	H	0.83	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2002	OM	H	0.85	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.86	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2002	OM	H	0.87	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.89	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.89	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.91	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.93	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.94	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2002	OM	H	0.95	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.95	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.95	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.96	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.96	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.96	(Clemens et al. 2009)

Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	0.96	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.98	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	0.98	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	OM	H	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	OM	H	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.66	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	CH	Mixed	0.72	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.73	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.73	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.77	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	CH	Mixed	0.78	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	CH	Mixed	0.87	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	CH	Mixed	0.87	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	CH	Mixed	0.87	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.88	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.90	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	CH	Mixed	0.91	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.92	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.92	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	CH	Mixed	0.96	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	0.98	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	CH	Mixed	0.99	(Clemens et al. 2009)

Columbia	Bonneville	Sampled from barge	2003	CH	Mixed	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Bonneville floating surface collector	2003	CH	Mixed	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	CH	Mixed	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2003	CH	Mixed	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	1.00	(Clemens et al. 2009)
Columbia	Bonneville	Sampled from barge	2004	CH	H	1.00	(Clemens et al. 2009)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1997	CO	H	0.93	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1998	CO	H	0.98	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1999	CO	H	0.98	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2008	CO	H	0.98	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2002	CO	H	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	CO	H	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	CO	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2000	CO	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2001	CO	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2003	CO	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	CO	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	CO	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2009	CO	H	1.00	(Serl and Morrill

							2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2012	CO	H	99.8	(Serl and Heimbigner 2013)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1997	OM	Mixed	0.95	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2008	OM	Mixed	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1998	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1999	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2012	OM	W	99.5	(Serl and Heimbigner 2013)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2000	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2002	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2009	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2001	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2003	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	OM	Mixed	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1997	CH	H	0.88	(Serl and Morrill

							2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1998	CH	H	0.95	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2001	CH	H	0.97	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	CH	W	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	CH	W	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2005	CH	H	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2003	CH	H	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	1999	CH	H	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2000	CH	H	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2008	CH	W	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	CH	H	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	CH	W	0.99	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2002	CH	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2006	CH	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2007	CH	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2008	CH	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2004	CH	W	1.00	(Serl and Morrill

							2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2009	CH	H	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2009	CH	W	1.00	(Serl and Morrill 2010)
Cowlitz	Cowlitz Falls	Forebay collector - retrofit baffle	2012	CH	W	99.7	(Serl and Heimbigner 2013)
Cowlitz	Mayfield	Louver system	2000	CO	Mixed	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	2001	CO	Mixed	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	1995	CO	H	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	1996	CO	H	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	1997	CO	H	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	1998	CO	H	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	1999	CO	H	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	2002	CO	Mixed	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	2003	CO	Mixed	0.95	(FERC 2004)
Cowlitz	Mayfield	Louver system	2008	CO	W	0.96	(FPC 2011)
Cowlitz	Mayfield	Louver system	2009	CO	W	0.98	(Henning 2010)
Cowlitz	Mayfield	Louver system	2000	OM	Mixed	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	2001	OM	Mixed	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	2002	OM	Mixed	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	2003	OM	Mixed	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	2009	OM	Mixed	0.99	(Henning 2010)
Cowlitz	Mayfield	Louver system	1995	OM	H	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	1996	OM	H	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	1997	OM	H	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	1998	OM	H	0.96	(FERC 2004)
Cowlitz	Mayfield	Louver system	1999	OM	H	0.96	(FERC 2004)

Cowlitz	Mayfield	Louver system	2000	CH	Mixed	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	2001	CH	Mixed	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	2002	CH	Mixed	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	2003	CH	Mixed	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	1995	CH	H	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	1996	CH	H	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	1997	CH	H	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	1998	CH	H	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	1999	CH	H	0.97	(FERC 2004)
Cowlitz	Mayfield	Louver system	2012	CH	W	0.96	(Gleizes 2013)
Cowlitz	Mayfield	Louver system	2009	CH	W	0.95	(Henning 2010)
Columbia	N/a	Collected at Lower Granite Dam	2010	CH	Mixed	0.98	(McMichael et al. 2011)
Clackamas	North Fork	Forebay collector - V-Screen Collector	2012	CO	Mixed	1.00	(Ackerman 2012)
Clackamas	North Fork	Forebay collector	2001	OM	Mixed	0.86	Heisey et al. 2002
Clackamas	North Fork	Forebay collector	2001	OM	Mixed	0.97	Heisey et al. 2002
Clackamas	North Fork	Forebay collector - V-Screen Collector	2012	OM	Mixed	0.98	(Ackerman 2012)
Clackamas	North Fork	Forebay collector	2001	OM	Mixed	0.98	(Heisey et al. 2002)
Clackamas	North Fork	Forebay collector	2001	OM	Mixed	0.99	(Heisey et al. 2002)
Clackamas	North Fork	Forebay collector - V-Screen Collector	2012	CH	Mixed	1.00	(Ackerman 2012)
Clackamas	North Fork	Forebay collector	2001	CH/CO	Mixed	0.80	(Heisey et al. 2002)
Clackamas	North Fork	Forebay collector	2001	CH/CO	Mixed	0.87	(Heisey et al. 2002)
Clackamas	North Fork	Forebay collector	2001	CH/CO	Mixed	0.95	(Heisey et al. 2002)
Clackamas	North Fork	Forebay collector	2001	CH/CO	Mixed	0.95	(Heisey et al. 2002)
Deschutes	Pelton Round Butte	Guidance net/skimmer	2010	OM	H	0.98	(PGE 2011)
Deschutes	Pelton Round Butte	Guidance net/skimmer	2010	CH	H	0.98	(CTWSRO 2012)
Deschutes	Pelton Round Butte	Guidance net/skimmer	2010	SO	H	0.98	(CTWSRO 2012)
Deschutes	Pelton Round Butte	Guidance net/skimmer	2011	SO	H	0.97	(PGE 2012)

Deschutes	Pelton Round Butte	Guidance net/skimmer	2011	CH	H	0.99	(PGE 2012
Deschutes	Pelton Round Butte	Guidance net/skimmer	2011	OM	H	0.99	(PGE 2012)
Deschutes	Pelton Round Butte	Guidance net/skimmer	2012	SO	H	0.97	(PGE 2012)
Deschutes	Pelton Round Butte	Guidance net/skimmer	2012	CH	H	0.98	(PGE 2012
Deschutes	Pelton Round Butte	Guidance net/skimmer	2012	OM	H	0.99	(PGE 2012)
Clackamas	River Mill	Surface spill - Spillway weir	2004	OM	Mixed	0.99	(Karchesky et al. 2008)
Clackamas	River Mill	Surface spill - Spillway weir	2004	CH	Mixed	0.98	(Karchesky et al. 2008)
Clackamas	River Mill	Surface spill - Spillway weir	2004	CH	Mixed	0.99	(Karchesky et al. 2008)
Baker	Upper Baker	Forebay collector - Surface collector	2011	CO	Mixed	1.00	(Jeanes and Verretto 2012)
Baker	Upper Baker	Forebay collector - Surface collector	2010	CO	Mixed	1.00	(Jeanes and Verretto 2012)
Baker	Upper Baker	Forebay collector - Surface collector	2009	CO	Mixed	1.00	(Jeanes and Verretto 2012)
Baker	Upper Baker	Forebay collector - Surface collector	2008	CO	Mixed	1.00	(Jeanes and Verretto 2012)
Willamette	Willamette Falls	From hatchery	2008	OM	H	0.98	(Karchesky 2008)
Willamette	Willamette Falls	From hatchery	2008	OM	H	0.99	(Karchesky et al. 2008)
Willamette	Willamette Falls	From hatchery	2008	OM	H	1.00	(Karchesky et al. 2008)
Willamette	Willamette Falls	From hatchery	2008	CH	H	1.00	(Karchesky et al. 2008)
Willamette	Willamette Falls	From hatchery	2008	CH	H	1.00	(Karchesky et al. 2008)

Appendix Table 4. Descaling estimates (%) at different rivers, facilities, collector, year, species, and reference.

River	Facility	Collector	Year	Spp.	Age	Descaling rates	Source
Columbia River	John Day	Juvenile bypass	1998	CH	1+	6.1	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1999	CH	1+	6.2	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2000	CH	1+	2.4	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2001	CH	1+	1.7	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2002	CH	1+	3.1	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2003	CH	1+	4.6	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1998	CH	0+	2.2	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1999	CH	0+	0.9	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2000	CH	0+	0.6	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2001	CH	0+	0.9	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2002	CH	0+	1	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2003	CH	0+	0.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2000	CH	1+	3.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2001	CH	1+	1.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2002	CH	1+	2.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2003	CH	1+	2.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2000	CH	0+	0.5	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2001	CH	0+	0.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2002	CH	0+	0.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2003	CH	0+	0.9	(Martinson et al. 2004)
Columbia	Bonneville Dam PH1	Juvenile	1989	CH	0+	4.2	(Martinson et al.

River		bypass					2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1990	CH	0+	7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1991	CH	0+	9.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1992	CH	0+	4.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1993	CH	0+	3.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1994	CH	0+	2.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1995	CH	0+	6.7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1996	CH	0+	5.1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1997	CH	0+	4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1998	CH	0+	4.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1999	CH	0+	3.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2000	CH	0+	9.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2001	CH	0+	1.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2002	CH	0+	7.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2003	CH	0+	7.7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1989	CH	1+	2.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1990	CH	1+	2.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1991	CH	1+	2.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1992	CH	1+	2.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1993	CH	1+	1.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1994	CH	1+	0.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1995	CH	1+	1.1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1996	CH	1+	0.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1997	CH	1+	1.4	(Martinson et al. 2004)

Columbia River	Bonneville Dam PH1	Juvenile bypass	1998	CH	1+	1.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1999	CH	1+	1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2000	CH	1+	3.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2001	CH	1+	0.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2002	CH	1+	3.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2003	CH	1+	2.6	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1998	CO	-	5.6	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1999	CO	-	3.7	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2000	CO	-	1.4	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2001	CO	-	1.6	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2002	CO	-	3.1	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2003	CO	-	2.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2000	CO	-	1.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2001	CO	-	0.7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2002	CO	-	1.1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2003	CO	-	1.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1989	CO	-	3.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1990	CO	-	5.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1991	CO	-	4.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1992	CO	-	6.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1993	CO	-	2.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1994	CO	-	1.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1995	CO	-	2.2	(Martinson et al. 2004)
Columbia	Bonneville Dam PH1	Juvenile	1996	CO	-	2.5	(Martinson et al.

River		bypass					2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1997	CO	-	2.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1998	CO	-	2.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1999	CO	-	1.1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2000	CO	-	4.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2001	CO	-	0.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2002	CO	-	2.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2003	CO	-	2.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1989	OM	-	4.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1990	OM	-	6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1991	OM	-	7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1992	OM	-	6.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1993	OM	-	2.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1994	OM	-	2.7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1995	OM	-	2.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1996	OM	-	2.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1997	OM	-	1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1998	OM	-	2.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1999	OM	-	1.1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2000	OM	-	7.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2001	OM	-	0	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2002	OM	-	7.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2003	OM	-	4.4	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1990	OM	-	14.9	(Martinson et al. 2004)

Columbia River	Bonneville Dam PH1	Juvenile bypass	1991	OM	-	8.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1992	OM	-	12.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1993	OM	-	8.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1994	OM	-	7.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1995	OM	-	10.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1996	OM	-	7.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1997	OM	-	6.8	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1998	OM	-	6.3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	1999	OM	-	3	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2000	OM	-	12.6	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2001	OM	-	12	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2002	OM	-	12.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH1	Juvenile bypass	2003	OM	-	7.5	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1998	OM	-	1.6	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1999	OM	-	1.9	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2000	OM	-	1.8	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2001	OM	-	1.4	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2002	OM	-	2.8	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2003	OM	-	3.3	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1998	OM	-	7.2	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	1999	OM	-	6.1	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2000	OM	-	5.6	(Martinson et al. 2004)
Columbia River	John Day	Juvenile bypass	2001	OM	-	4.7	(Martinson et al. 2004)
Columbia	John Day	Juvenile	2002	OM	-	7.2	(Martinson et al.

River		bypass					2004)
Columbia River	John Day	Juvenile bypass	2003	OM	-	8.7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2000	OM	-	1.1	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2001	OM	-	2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2002	OM	-	3.2	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2003	OM	-	2.9	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2000	OM	-	5	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2001	OM	-	4.7	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2002	OM	-	6.5	(Martinson et al. 2004)
Columbia River	Bonneville Dam PH2	Juvenile bypass	2003	OM	-	7.5	(Martinson et al. 2004)
Cowlitz River	Mayfield		2009	CH	-	4.1	(Henning 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2004	CH	-	0.18	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2005	CH	-	0.18	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2006	CH	-	0.07	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2007	CH	-	0.29	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2008	CH	-	0.53	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2009	CH	-	0.7	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		1997	CH	-	2.43	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		1998	CH	-	0.05	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		1999	CH	-	0.08	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2000	CH	-	0.07	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2001	CH	-	0.39	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2002	CH	-	0.17	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility		2003	CH	-	0.86	(Serl and Morrill 2010)

Cowlitz River	Cowlitz Falls Fish Facility	2004	CH	-	2.87	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2005	CH	-	0.43	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2006	CH	-	0.18	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2007	CH	-	0.1	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2008	CH	-	0.33	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2009	CH	-	1.06	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2012	CH	-	0.7	(Serl and Heimbigner 2013)
Cowlitz River	Cowlitz Falls Fish Facility	1997	CO	-	0.61	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1998	CO	-	0.02	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1999	CO	-	0.13	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2000	CO	-	0.02	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2001	CO	-	0.16	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2002	CO	-	0.11	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2003	CO	-	0.14	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2004	CO	-	3.66	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2005	CO	-	0.06	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2006	CO	-	0.03	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2007	CO	-	0.05	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2008	CO	-	0.09	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2009	CO	-	0.19	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2012	CO	-	0.5	(Serl and Heimbigner 2013)
Cowlitz River	Cowlitz Falls Fish Facility	1997	OM	-	0.91	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1998	OM	-	0.62	(Serl and Morrill

						2010)
Cowlitz River	Cowlitz Falls Fish Facility	1999	OM	-	0.14	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2000	OM	-	0.01	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2001	OM	-	0.04	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2002	OM	-	0.03	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2003	OM	-	0.13	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2004	OM	-	1.37	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2005	OM	-	0.13	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2006	OM	-	0.09	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2007	OM	-	0.17	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2008	OM	-	0.19	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2009	OM	-	0.27	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1997	OM	-	2.34	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1998	OM	-	0.62	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1999	OM	-	0.1	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2000	OM	-	0	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2001	OM	-	0.03	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2002	OM	-	0.02	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2003	OM	-	0.31	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2004	OM	-	0.97	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2005	OM	-	0.07	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2006	OM	-	0.09	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2007	OM	-	0.23	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2008	OM	-	0.21	(Serl and Morrill 2010)

Cowlitz River	Cowlitz Falls Fish Facility	2009	OM	-	0.16	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2012	Om	-	0.7	(Serl and Heimbigner 2013)
Deschutes River	Round Butte	2011	CH	-	0	(PGE 2013)
Deschutes River	Round Butte	2012	CH	-	0.1	(PGE 2013)
Deschutes River	Round Butte	2011	OM	-	0	(PGE 2013)
Deschutes River	Round Butte	2012	OM	-	0.02	(PGE 2013)
Deschutes River	Round Butte	2011	SO	-	0.3	(PGE 2013)
Deschutes River	Round Butte	2012	SO	-	-	(PGE 2013)

Appendix Table 5. Mortality estimates (%) for non-target species at downstream fish collection facilities at different rivers, facilities, and species.

River	Facility	Year	Species	Mortality (%)	Reference
Cowlitz River	Cowlitz Falls Fish Facility	1997	Cutthroat	1.5	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1998	Cutthroat	0.54	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	1999	Cutthroat	0.38	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2000	Cutthroat	0.28	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2001	Cutthroat	0.28	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2002	Cutthroat	0.1	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2003	Cutthroat	0.08	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2004	Cutthroat	0.14	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2005	Cutthroat	0.39	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2006	Cutthroat	0.14	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2007	Cutthroat	0.14	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2008	Cutthroat	0	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2009	Cutthroat	0.71	(Serl and Morrill 2010)
Cowlitz River	Cowlitz Falls Fish Facility	2012	Cutthroat	0	(Serl and Heimbigner 2013)
Cowlitz River	Mayfield Dam	2009	Cutthroat	0.09	(Henning 2010)
Cowlitz River	Mayfield Dam	2012	Cutthroat		(Gleizes 2013)
Deschutes River	Round Butte	2010	Bull trout	1.4	(CTWSRO 2011)
Deschutes River	Round Butte	2010	Kokanee	6.9	(PGE 2011)
Deschutes River	Round Butte	2010	Rainbow trout	2.1	(PGE 2011)
Deschutes River	Round Butte	2010	Mt. Whitefish	0	(PGE 2011)
Deschutes River	Round Butte	2011	Bull trout	1.98	(CTWSRO 2012)
Deschutes River	Round Butte	2011	Kokanee	9.1	(PGE 2012)
Deschutes River	Round Butte	2011	Rainbow trout	2	(PGE 2012)
Deschutes River	Round Butte	2011	Mt. Whitefish	0.04	(PGE 2012)
Deschutes River	Round Butte	2012	Bull trout	1.7	(PGE 2013)

Deschutes River	Round Butte	2012	Kokanee	9.7	(PGE 2013)
Deschutes River	Round Butte	2012	Rainbow trout	0	(PGE 2013)
Deschutes River	Round Butte	2012	Mt. Whitefish	0	(PGE 2013)

Appendix Table 6. Estimates of adult mortality (% mort.) during trap and transport for different species, runs, source, river, and facility and associated reference.

River	Facility	Year	Spp.	Run	Source	% mort.	Reference
Cowlitz	Mayfield	2009	CH	Fall	Mixed	1.6	(Henning 2010)
Deschutes	Pelton Trap	2012	CH	Spring	Wild	0	(PGE 2013)
SF Mackenzie	Cougar	2010	CH	Spring	Mixed	0	(Zymonas and Hogansen 2013)
SF Mackenzie	Cougar	2011	CH	Spring	Mixed	0.8	(Zymonas and Hogansen 2013)
Tucannon	FHT	1986	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1987	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1988	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1989	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1990	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1991	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1992	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1993	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1994	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1995	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1996	CH	Spring	Wild	1.3	(Gallinat and Ross 2012)
Tucannon	FHT	1997	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1998	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1999	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2000	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2001	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2002	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2003	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2004	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2005	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2006	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2007	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2008	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2009	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2010	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	2011	CH	Spring	Wild	0	(Gallinat and Ross 2012)
Tucannon	FHT	1988	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1989	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1990	CH	Spring	Hatchery	0.5	(Gallinat and Ross 2012)

Tucannon	FHT	1991	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1992	CH	Spring	Hatchery	1	(Gallinat and Ross 2012)
Tucannon	FHT	1993	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1994	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1995	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1996	CH	Spring	Hatchery	6.8	(Gallinat and Ross 2012)
Tucannon	FHT	1997	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1998	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	1999	CH	Spring	Hatchery	0.7	(Gallinat and Ross 2012)
Tucannon	FHT	2000	CH	Spring	Hatchery	9.6	(Gallinat and Ross 2012)
Tucannon	FHT	2001	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	2002	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	2003	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	2004	CH	Spring	Hatchery	0	(Gallinat and Ross 2012)
Tucannon	FHT	2005	CH	Spring	Hatchery	2.6	(Gallinat and Ross 2012)
Tucannon	FHT	2006	CH	Spring	Hatchery	3.8	(Gallinat and Ross 2012)
Tucannon	FHT	2007	CH	Spring	Hatchery	5.4	(Gallinat and Ross 2012)
Tucannon	FHT	2008	CH	Spring	Hatchery	0.3	(Gallinat and Ross 2012)
Tucannon	FHT	2009	CH	Spring	Hatchery	0.8	(Gallinat and Ross 2012)
Tucannon	FHT	2010	CH	Spring	Hatchery	1.1	(Gallinat and Ross 2012)
Tucannon	FHT	2011	CH	Spring	Hatchery	1.6	(Gallinat and Ross 2012)
Umatilla	Threemile	1996	CH	Spring	Wild	0.4	(Zimmerman and Duke 1996)
Umatilla	Threemile	1993	CH	Spring	Wild	0.7	(Zimmerman and Duke 1993)
Umatilla	Threemile	1995	CH	Spring	Wild	0.8	(Zimmerman and Duke 1995)
Umatilla	Threemile	1997	CH	Fall	Mixed	0	Zimmerman and Duke 1997
Umatilla	Threemile	1997	CH	Spring	Mixed	0.7	Zimmerman and Duke 1997
Umatilla	Threemile	1996	CH	Fall	Wild	0	Zimmerman and Duke 1996
Umatilla	Threemile	1993	CH	Fall	Wild	0	Zimmerman and Duke 1993
Umatilla	Threemile	1995	CH	Fall	Wild	0	Zimmerman and Duke 1995
Cowlitz	Mayfield	2009	CO	-	Hatchery	0.3	Henning 2010
Cowlitz	Mayfield	2009	CO	-	Wild	0.6	Henning 2010
Umatilla	Threemile	1997	CO	-	Mixed	0	Zimmerman and Duke 1997
Umatilla	Threemile	1996	CO	-	Wild	0	Zimmerman and Duke 1996
Umatilla	Threemile	1993	CO	-	Wild	0	Zimmerman and Duke 1993
Umatilla	Threemile	1995	CO	-	Wild	0	Zimmerman and Duke 1995
Deschutes	Pelton Trap	2012	SO	-	Wild	0	PGE 2013
Cowlitz	Mayfield	2009	ST	-	Wild	6.7	Henning 2010
Cowlitz	Mayfield	2009	ST	-	Hatchery	3	Henning 2010
Deschutes	Pelton	2012	ST	-	Wild	0	PGE 2013

	Trap						
Umatilla	Threemile	1993	ST	-	Wild	0.1	Zimmerman and Duke 1993
Umatilla	Threemile	1997	ST	-	Mixed	0	Zimmerman and Duke 1997
Umatilla	Threemile	1996	ST	-	Mixed	0	Zimmerman and Duke 1996
Umatilla	Threemile	1995	ST	-	Wild	0	Zimmerman and Duke 1995

Appendix Table 7. Fallback rates over dam facilities for adult anadromous species by river, dam, year, species, run, and reference. Note: CH = Chinook salmon, CO = coho salmon, SO = sockeye salmon, and ST = steelhead.

River	Dam	Year	Spp.	Run	% Fallback	Reference
North Santiam	Bennett Dams	2003	CH	Spring	1.18	(Schroeder et al. 2007)
Umatilla	Threemile	1994-1995	CH	Spring	43.8	(Zimmerman and Duke 1995)
Umatilla	Threemile	1994-1995	CH	Fall	0.0	(Zimmerman and Duke 1995)
Columbia	Bonneville	1996	CH	Spring-summer	13.8	(Boggs et al. 2004)
Columbia	Bonneville	1997	CH	Spring-summer	14.6	(Boggs et al. 2004)
Columbia	Bonneville	1998	CH	Spring-summer	11.2	(Boggs et al. 2004)
Columbia	Bonneville	2000	CH	Spring-summer	13	(Boggs et al. 2004)
Columbia	Bonneville	2001	CH	Spring-summer	4.1	(Boggs et al. 2004)
Columbia	Bonneville	1996	CH	Spring-summer	16.4	(Bjornn et al. 2000)
Columbia	Bonneville	1997	CH	Spring-summer	19.9	(Bjornn et al. 2000)
Columbia	Bonneville	1998	CH	Spring-summer	15.9	(Bjornn et al. 2000)
Columbia	Bonneville	1996	CH	Fall	-	(Boggs et al. 2004)
Columbia	Bonneville	1997	CH	Fall	-	(Boggs et al. 2004)
Columbia	Bonneville	1998	CH	Fall	3.5	(Boggs et al. 2004)
Columbia	Bonneville	2000	CH	Fall	3.9	(Boggs et al. 2004)
Columbia	Bonneville	2001	CH	Fall	4.8	(Boggs et al. 2004)
Columbia	The Dalles	1996	CH	Spring-summer	13.3	(Boggs et al. 2004)
Columbia	The Dalles	1997	CH	Spring-summer	14.4	(Boggs et al. 2004)
Columbia	The Dalles	1998	CH	Spring-summer	11.5	(Boggs et al. 2004)
Columbia	The Dalles	2000	CH	Spring-summer	9.6	(Boggs et al. 2004)
Columbia	The Dalles	2001	CH	Spring-summer	5.5	(Boggs et al. 2004)
Columbia	The Dalles	1996	CH	Fall	-	(Boggs et al. 2004)
Columbia	The Dalles	1997	CH	Fall	-	(Boggs et al. 2004)
Columbia	The Dalles	1998	CH	Fall	10.2	(Boggs et al. 2004)

Columbia	The Dalles	2000	CH	Fall	8.5	(Boggs et al. 2004)
Columbia	The Dalles	2001	CH	Fall	6.9	(Boggs et al. 2004)
Columbia	John Day	1996	CH	Spring-summer	11.9	(Boggs et al. 2004)
Columbia	John Day	1997	CH	Spring-summer	9.9	(Boggs et al. 2004)
Columbia	John Day	1998	CH	Spring-summer	10.6	(Boggs et al. 2004)
Columbia	John Day	2000	CH	Spring-summer	6.0	(Boggs et al. 2004)
Columbia	John Day	2001	CH	Spring-summer	3.0	(Boggs et al. 2004)
Columbia	John Day	1996	CH	Fall	-	(Boggs et al. 2004)
Columbia	John Day	1997	CH	Fall	-	(Boggs et al. 2004)
Columbia	John Day	1998	CH	Fall	3.7	(Boggs et al. 2004)
Columbia	John Day	2000	CH	Fall	2.6	(Boggs et al. 2004)
Columbia	John Day	2001	CH	Fall	2.6	(Boggs et al. 2004)
Columbia	McNary	1996	CH	Spring-summer	9.3	(Boggs et al. 2004)
Columbia	McNary	1997	CH	Spring-summer	8.0	(Boggs et al. 2004)
Columbia	McNary	1998	CH	Spring-summer	9.2	(Boggs et al. 2004)
Columbia	McNary	2000	CH	Spring-summer	4.3	(Boggs et al. 2004)
Columbia	McNary	2001	CH	Spring-summer	1.4	(Boggs et al. 2004)
Columbia	McNary	1998	CH	Fall	2.1	(Boggs et al. 2004)
Columbia	McNary	2000	CH	Fall	2.0	(Boggs et al. 2004)
Columbia	McNary	2001	CH	Fall	3.5	(Boggs et al. 2004)
Cowlitz	Mayfield	2009	CH	Fall	12.0	(Henning 2010)
Cowlitz	Mayfield	2012	CH	Fall	1.5	(Gleizes 2013)
Cowlitz	Cowlitz Falls	2012	CH	Spring	0.7	(Serl and Heimbigner 2013)
North Santiam	Bennett Dams	2005	CH	na	2.9	(Schroeder et al. 2006)
Columbia	McNary	1996	CH	Spring	22.6	(Keefer et al. 2004)
Columbia	McNary	1997	CH	Spring	27.5	(Keefer et al. 2004)
Columbia	McNary	1998	CH	Spring	19.6	(Keefer et al. 2004)
Columbia	McNary	2000	CH	Spring	20.9	(Keefer et al. 2004)
Columbia	McNary	2001	CH	Spring	7.6	(Keefer et al. 2004)
Columbia	Lower Granite	1996	CH	Spring	35.5	(Keefer et al. 2004)

Columbia	Lower Granite	1997	CH	Spring	36.4	(Keefer et al. 2004)
Columbia	Lower Granite	1998	CH	Spring	28.3	(Keefer et al. 2004)
Columbia	Lower Granite	2000	CH	Spring	35.4	(Keefer et al. 2004)
Columbia	Lower Granite	2001	CH	Spring	10.4	(Keefer et al. 2004)
Columbia	McNary	1996	CH	Summer	10.7	(Keefer et al. 2004)
Columbia	McNary	1997	CH	Summer	13.8	(Keefer et al. 2004)
Columbia	McNary	1998	CH	Summer	10.6	(Keefer et al. 2004)
Columbia	McNary	2000	CH	Summer	8.5	(Keefer et al. 2004)
Columbia	McNary	2001	CH	Summer	0.6	(Keefer et al. 2004)
Columbia	Lower Granite	1996	CH	Summer	22.2	(Keefer et al. 2004)
Columbia	Lower Granite	1997	CH	Summer	12.5	(Keefer et al. 2004)
Columbia	Lower Granite	1998	CH	Summer	25.7	(Keefer et al. 2004)
Columbia	Lower Granite	2000	CH	Summer	17.4	(Keefer et al. 2004)
Columbia	Lower Granite	2001	CH	Summer	2	(Keefer et al. 2004)
Columbia	Bonneville	1998	CH	Fall	4.2	(Bjornn et al. 2000)
Columbia	McNary	1996	CH	Fall	-	(Keefer et al. 2004)
Columbia	McNary	1997	CH	Fall	-	(Keefer et al. 2004)
Columbia	McNary	1998	CH	Fall	1.7	(Keefer et al. 2004)
Columbia	McNary	2000	CH	Fall	3.8	(Keefer et al. 2004)
Columbia	McNary	2001	CH	Fall	3.7	(Keefer et al. 2004)
Columbia	Lower Granite	1996	CH	Fall	-	(Keefer et al. 2004)
Columbia	Lower Granite	1997	CH	Fall	-	(Keefer et al. 2004)
Columbia	Lower Granite	1998	CH	Fall	0	(Keefer et al. 2004)
Columbia	Lower Granite	2000	CH	Fall	5.9	(Keefer et al. 2004)
Columbia	Lower Granite	2001	CH	Fall	16.7	(Keefer et al. 2004)
Umatilla	Threemile	1994-1995	CO	na	0.0	(Zimmerman and Duke 1995)
Columbia	Wells	2004	CO	-	3.3	(Murdoch et al. 2005)
Columbia	Wanapum	2004	CO	-	16.7	(Murdoch et al. 2005)
Cowlitz	Mayfield	2009	CO	-	3.3	(Henning 2010)

Cowlitz	Mayfield	2009	CO	-	1.5	(Henning 2010)
Cowlitz	Mayfield	2012	CO	-	0.5	(Gleizes 2013)
Columbia	Bonneville	1997	SO	na	11.4	(Naughton et al. 2006)
Columbia	The Dalles	1997	SO	na	4.9	(Naughton et al. 2006)
Columbia	John Day	1997	SO	na	3.6	(Naughton et al. 2006)
Columbia	McNary	1997	SO	na	2	(Naughton et al. 2006)
Columbia	Priest Rapids	1997	SO	na	4.2	(Naughton et al. 2006)
Columbia	Wanapum	1997	SO	na	4	(Naughton et al. 2006)
Columbia	Rock Island	1997	SO	na	1.9	(Naughton et al. 2006)
Columbia	Rocky Reach	1997	SO	na	7.1	(Naughton et al. 2006)
Columbia	Bonneville	1998	SO	-	13.7	(Bjornn et al. 2000)
Umatilla	Threemile	1994-1995	ST	-	1.3	(Zimmerman and Duke 1995)
Columbia	Bonneville	1996	ST	-	4.9	(Boggs et al. 2004)
Columbia	Bonneville	1997	ST	-	9.1	(Boggs et al. 2004)
Columbia	Bonneville	2000	ST	-	6.9	(Boggs et al. 2004)
Columbia	Bonneville	2001	ST	-	4.3	(Boggs et al. 2004)
Columbia	The Dalles	1996	ST	-	6	(Boggs et al. 2004)
Columbia	The Dalles	1997	ST	-	6.6	(Boggs et al. 2004)
Columbia	The Dalles	2000	ST	-	6.3	(Boggs et al. 2004)
Columbia	The Dalles	2001	ST	-	6.1	(Boggs et al. 2004)
Columbia	John Day	1996	ST	-	10.1	(Boggs et al. 2004)
Columbia	John Day	1997	ST	-	7.9	(Boggs et al. 2004)
Columbia	John Day	2000	ST	-	4.3	(Boggs et al. 2004)
Columbia	John Day	2001	ST	-	5.3	(Boggs et al. 2004)
Columbia	McNary	1996	ST	-	7.4	(Boggs et al. 2004)
Columbia	McNary	1997	ST	-	10.7	(Boggs et al. 2004)
Columbia	McNary	2000	ST	-	9.8	(Boggs et al. 2004)
Columbia	McNary	2001	ST	-	7.1	(Boggs et al. 2004)
Columbia	Bonneville	1996	ST	-	5.2	(Bjornn et al. 2000)
Columbia	Bonneville	1997	ST	-	9.9	(Bjornn et al. 2000)
Cowlitz	Mayfield	2009	ST	-	30.8	(Henning 2010)
Cowlitz	Mayfield	2009	ST	-	38.7	(Henning 2010)
Cowlitz	Mayfield	2012	ST	-	67.4	(Gleizes 2013)
Cowlitz	Cowlitz Falls	2012	ST	-	2.0	(Serl and Heimbigner 2013)
Columbia	McNary	1996	ST	Spring	9.3	(Keefer et al. 2004)
Columbia	McNary	1997	ST	Spring	7.8	(Keefer et al. 2004)
Columbia	McNary	1998	ST	Spring	-	(Keefer et al. 2004)

Columbia	McNary	2000	ST	Spring	8.8	(Keefer et al. 2004)
Columbia	McNary	2001	ST	Spring	4.8	(Keefer et al. 2004)
Columbia	Lower Granite	1996	ST	Spring	12.1	(Keefer et al. 2004)
Columbia	Lower Granite	1997	ST	Spring	14.7	(Keefer et al. 2004)
Columbia	Lower Granite	1998	ST	Spring	-	(Keefer et al. 2004)
Columbia	Lower Granite	2000	ST	Spring	16.9	(Keefer et al. 2004)
Columbia	Lower Granite	2001	ST	Spring	16.2	(Keefer et al. 2004)