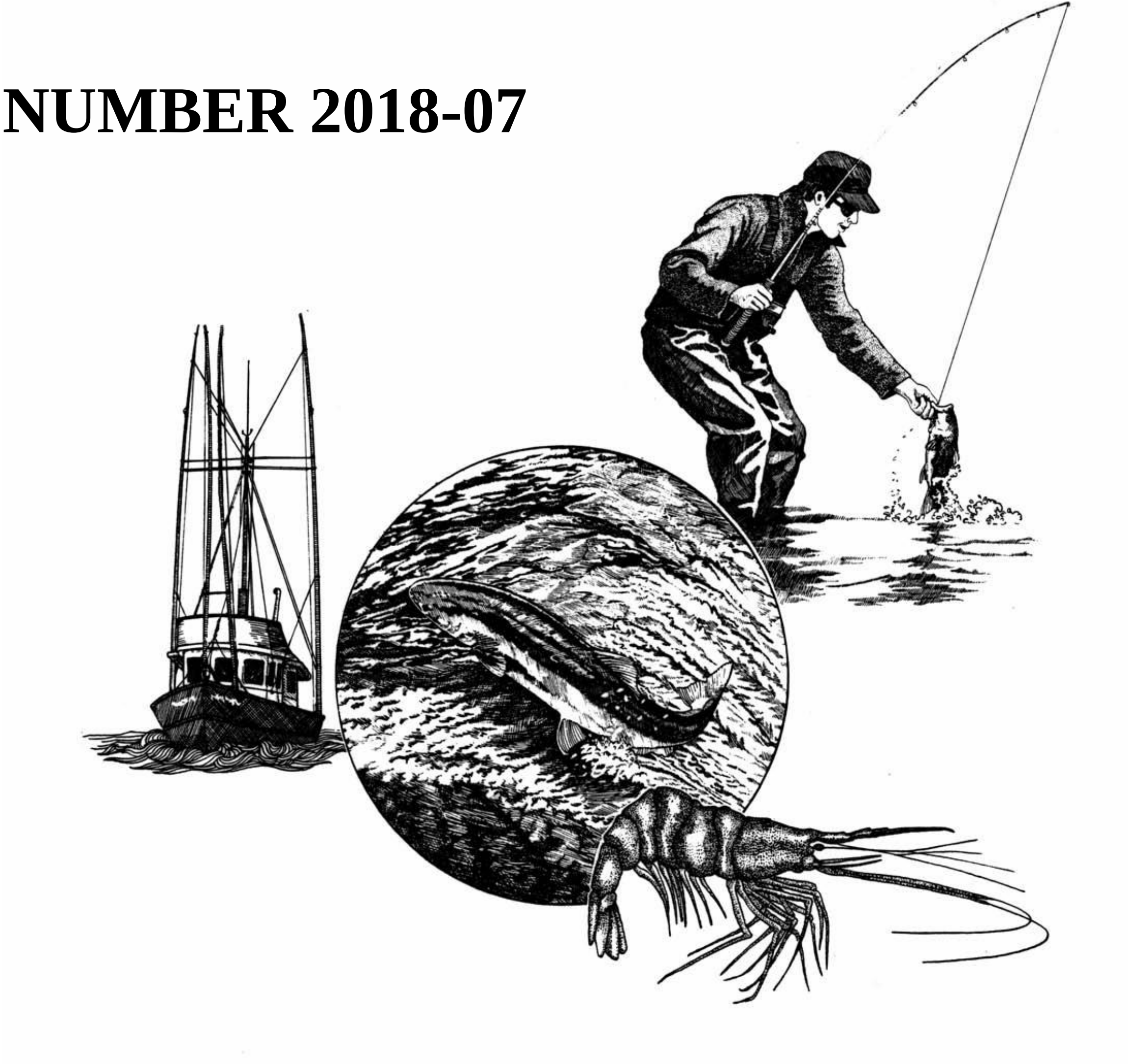
ODFW INFORMATION REPORT Series

NUMBER 2018-07



Oregon Department of Fish and Wildlife

Abundance and life history characteristics of steelhead (*Oncorhynchus mykiss*) and Coho Salmon (*Oncorhynchus kisutch*) smolts in two direct ocean tributaries on the central Oregon Coast

Abundance and life history characteristics of steelhead (*Oncorhynchus mykiss*) and Coho Salmon (*Oncorhynchus kisutch*) smolts in two direct ocean tributaries on the central Oregon coast.

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October 2018

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ABSTRACT

In 1991, the Oregon Department of Fish and Wildlife (ODFW) began an intensive research study at Tenmile Creek on the central Oregon coast to evaluate the effects of a large wood addition on juvenile salmonid populations. Nearby Cummins Creek served as a reference site. Annual monitoring of juvenile salmonid out-migrants began in 1992 at the two sites, continued through 2012 at Cummins Creek, and is ongoing at Tenmile Creek. These data offer an unusually long time-series of smolt abundance and life history characteristics for steelhead and Coho Salmon at monitoring sites located less than a kilometer from the point of ocean entry. Annual estimates of steelhead smolt abundance ranged from 740 to 3,236 smolts at Cummins Creek, and from 2,464 to 19,602 smolts at Tenmile Creek. For Coho Salmon, annual estimates ranged from 319 to 3,164 smolts at Cummins Creek, and from 1,637 to 11,553 smolts at Tenmile Creek. Steelhead smolt production at Tenmile Creek appeared to increase significantly relative to Cummins Creek following the large wood addition in 1996, but there was no evidence of a similar effect on Coho Salmon smolt production. Most steelhead smolts spent 2 years rearing in freshwater before out-migration, and we observed a higher proportion of age-1 smolts and lower proportion of age-3 smolts than several other studies in Oregon coastal streams. Coho Salmon smolt out-migrants were dominated by age-1 individuals at both sites, but there was evidence that some juvenile Coho Salmon out-migrated as age-0 smolts. Smolts of both species tended to be larger at Tenmile Creek than at Cummins Creek, and negative relationships between mean smolt size and smolt abundance suggest that rearing density may influence growth for juvenile salmonids in these streams. The median migration date of steelhead smolts was consistent over time and tracked closely between the two sites. Coho Salmon smolt out-migration timing was more variable and tended to be slightly later than for steelhead, particularly at Tenmile Creek. During peak migration, a high proportion of steelhead migrants classified as smolts based on length had body coloration consistent with smoltification. External signs of smoltification were not as prevalent among steelhead captured early in the season, particularly among smaller migrants. This long term out-migrant monitoring at the ocean entrance illustrates the variation that occurs in freshwater production and the patterns that occur in salmonid smolt life history but also shows that without spawner abundance data conclusions about freshwater production are limited.

INTRODUCTION

In 1991, the Oregon Department of Fish and Wildlife (ODFW), in cooperation with the U.S. Forest Service and other stakeholders, initiated a watershed-scale research study of the effects of a large wood addition on juvenile salmonid populations in Tenmile Creek on the central Oregon coast. Cummins Creek, a nearby stream with similar biophysical characteristics in a largely undisturbed watershed was selected as a reference site. From 1991-2003, intensive monitoring occurred in both streams to evaluate potential changes in stream habitat and fish populations before and after large wood addition to Tenmile Creek in 1996, and to compare these results with trends in Cummins Creek (Johnson et al. 2005). One of the key components of the study was monitoring the number of salmonid out-migrants annually from the study streams. Traps operated near the mouth of each stream were used to estimate salmonid smolt populations and, in conjunction with summer population estimates, determine freshwater survival rates for steelhead (*Oncorhynchus mykiss*) and Coho Salmon (*Oncorhynchus kisutch*). When the study concluded, smolt monitoring continued as part of the ODFW Salmonid Life Cycle Monitoring Project (Suring et al. 2015). Smolt monitoring ended at Cummins Creek following the 2012 trapping season. However, monitoring at Tenmile Creek is ongoing and by the end of the 2018 trapping season, 27 years of data on smolt abundance, size and migration timing had been collected for steelhead and Coho Salmon.

Additional data on steelhead smolt age and body coloration were collected at both sites, providing an unusually long and detailed record of steelhead smolt life history characteristics in the study streams. Steelhead life histories have long been of interest due to the complex array of behaviors exhibited by the anadromous form of *O. mykiss*, and the relevance of life history variation to the conservation and management of steelhead populations (Shapavalov and Taft 1954; Withler 1966; Moore et al. 2014). Variation in freshwater residence time, age at maturity, and run timing, as well as iteroparity and partial migration, all contribute to steelhead life history diversity (Busby et al. 1996). Steelhead life history characteristics in Oregon coastal streams have been examined in a variety of studies (e.g. Sumner 1948; Chapman 1958; Wagner et al. 1963; Weber and Knispel 1977; Lindsay et al. 1993), most of which have focused on size and age structure of steelhead populations based on scales collected from adult fish. In cases where life history characteristics of steelhead smolt populations have been investigated (e.g. Chapman 1958; Wagner et al. 1963, Romer et al. 2013), studies have typically covered periods of three years or less, in contrast to our monitoring period of over 20 years. The close proximity of both monitoring sites to the point of ocean entry for out-migrating smolts is another distinguishing feature of this data set. With less than a kilometer of stream habitat and no estuary downstream from the smolt traps, these sites allow direct observation of smolt life history characteristics just before ocean entry.

Thus, the goal of this report is to summarize long-term trends in abundance, age structure, migration timing and size for steelhead and Coho Salmon smolts. In addition, we present information on smoltification for steelhead, and place our results in context with other studies conducted in the region. With the additional post-treatment data now available that was not part of the analysis by Johnson et al. (2005), we also re-visit the hypothesis that large wood addition at Tenmile Creek in 1996 had a significant effect on smolt production.

METHODS

Study Area

Cummins Creek and Tenmile Creek are located on the central Oregon coast, and flow directly into the Pacific Ocean (Figure 1). The Cummins Creek watershed encompasses an area of 24.6 km^2, and has approximately 11 km of stream habitat available to anadromous salmonids. The Tenmile Creek watershed is located 5 km south of Cummins Creek and encompasses an area of 60.7 km^2. There are approximately 25 km of stream habitat available to anadromous salmonids in Tenmile Creek and its two main tributaries, South Fork Tenmile Creek and Wildcat Creek. The Yachats Basalt formation underlies the entire Cummins Creek drainage and nearly all of the Tenmile Creek drainage. The climate in the study area is Pacific Maritime, with annual precipitation of 180 to 230 cm per year. Water temperatures in the study streams typically peak at 18-20°C in late July and early August, and can drop to 4°C during the winter (ODFW, unpublished data).

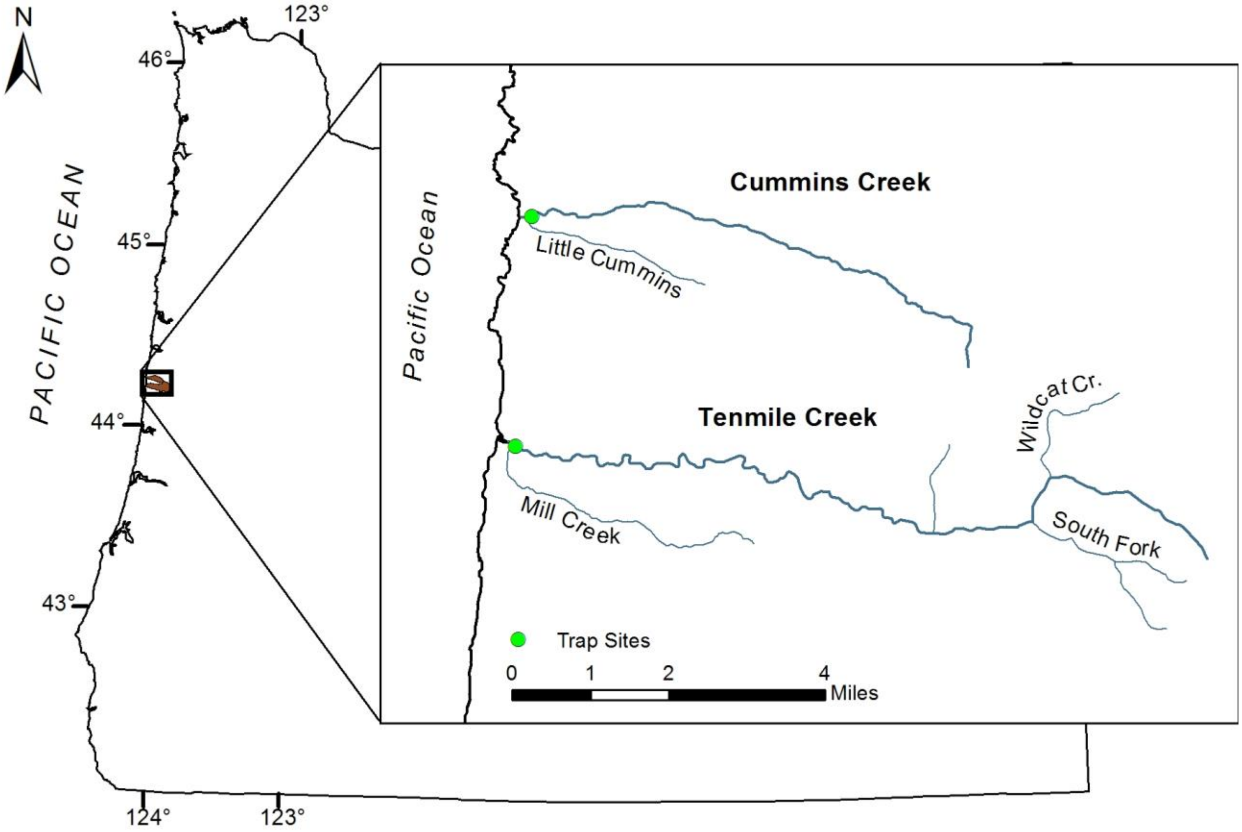


Figure 1. Map of Cummins Creek and Tenmile Creek on the central Oregon coast.

Fish species consistently occurring in the study streams include steelhead, Coho Salmon, Cutthroat Trout (*Oncorhynchus clarki*), Pacific Lamprey (*Entosphenus tridentatus*), Western Brook Lamprey (*Lampetra richardsoni*), and several species of sculpin (*Cottus* spp.). Chinook Salmon (*Oncorhynchus tshawytscha*) are also present in Tenmile Creek each year, but have been observed infrequently in Cummins Creek. Chum Salmon (*Oncorhynchus keta*) have been observed in Tenmile Creek in some years, but were not encountered in Cummins Creek during 21 years of monitoring. Eulachon (*Thaleichthys pacificus*) have been captured in both streams (Appendix 1), and Three-spined Stickleback (*Gasterosteus aculeatus*) are present in lower Tenmile Creek. Neither stream receives hatchery steelhead releases, but catches of post-spawn adult steelhead at the Tenmile Creek smolt trap indicate that 10-15% of steelhead spawners there are out-of-basin hatchery strays. Additional information about the study streams can be found in Johnson et al. (2005).

Smolt Trapping and Population Estimation

Salmonid out-migrants were sampled each spring in the two study streams using rotary screw traps. Trapping was typically initiated in the first week of March and continued through mid- to late June, when catches of Coho Salmon and steelhead smolts declined to very low levels. Traps operated continuously during this period, except when high flows precluded trapping or traps were stopped by debris between visits. Fewer than five full night trap stoppages typically occurred during the entire season. At Cummins Creek, a single screw trap with a five foot diameter cone was operated 400-500 m upstream from where the creek enters the Pacific Ocean. The exact trap location varied over time due to changes in the stream channel. The trapping location at Tenmile Creek also varied, but was always within 800-1,000 m of the mouth of the stream. Two rotary screw traps, one with a five foot diameter cone and the other with an eight foot diameter cone, were utilized at Tenmile Creek in 1993-2000 and in 2002. In all other years, trapping was conducted with a single five foot trap. Channeling flow into the rotary screw traps was critical for effective trapping in the relatively low gradient reaches near the stream mouths. At Cummins Creek, this was accomplished by building low rock walls extending out into the channel from both stream banks. At Tenmile Creek, panel walls were constructed using screened wooden frames anchored in the streambed with tripods or fence posts.

Traps were generally checked once a day to remove debris and enumerate fish caught during the previous night. More frequent checks were required during storms, particularly at night when most fish were captured. All juvenile salmonids captured were anesthetized using buffered tricaine methanesulfonate (MS-222) and enumerated by species and size class. Juvenile steelhead were separated into three size classes: 60-89 mm fork length (FL), 90-119 mm FL and ≥ 120 mm FL. We did not attempt to identify trout fry < 60 mm FL to the species level. Juvenile Coho Salmon were classified as either smolts or fry. All Age-1+ Coho Salmon migrants (based on size and body proportions) were classified as smolts regardless of their external signs of smoltification. Age-0 Coho Salmon migrants were classified as fry except in cases where their size and level of body silvering made them indistinguishable from Age-1 smolts.

Each week, FL measurements were recorded for up to 25 individuals of each size class. In addition, measured juvenile steelhead were assessed visually for external signs of smoltification and assigned to one of three categories based on the extent of body silvering

(Figure 2). Fish assigned to the "No Silvering" group had typical resident parr coloration. Fish assigned to the "Partial Silvering" group covered a wide range of silvering, but always had visible parr marks. Fish assigned to the "Silver" group showed complete body silvering and fin margin darkening typical of smolts (Wedemeyer et al. 1980). Prior to 1998, steelhead migrants were often placed into two categories instead of three based on body coloration, and so we excluded these data from our analysis. Only juvenile steelhead in the largest size class consistently showed external signs of smoltification (Johnson et al. 2005). Therefore, we defined steelhead smolts as juvenile steelhead migrants ≥ 120 mm FL, with the recognition that the actual threshold for smolting is more complex and difficult to define.

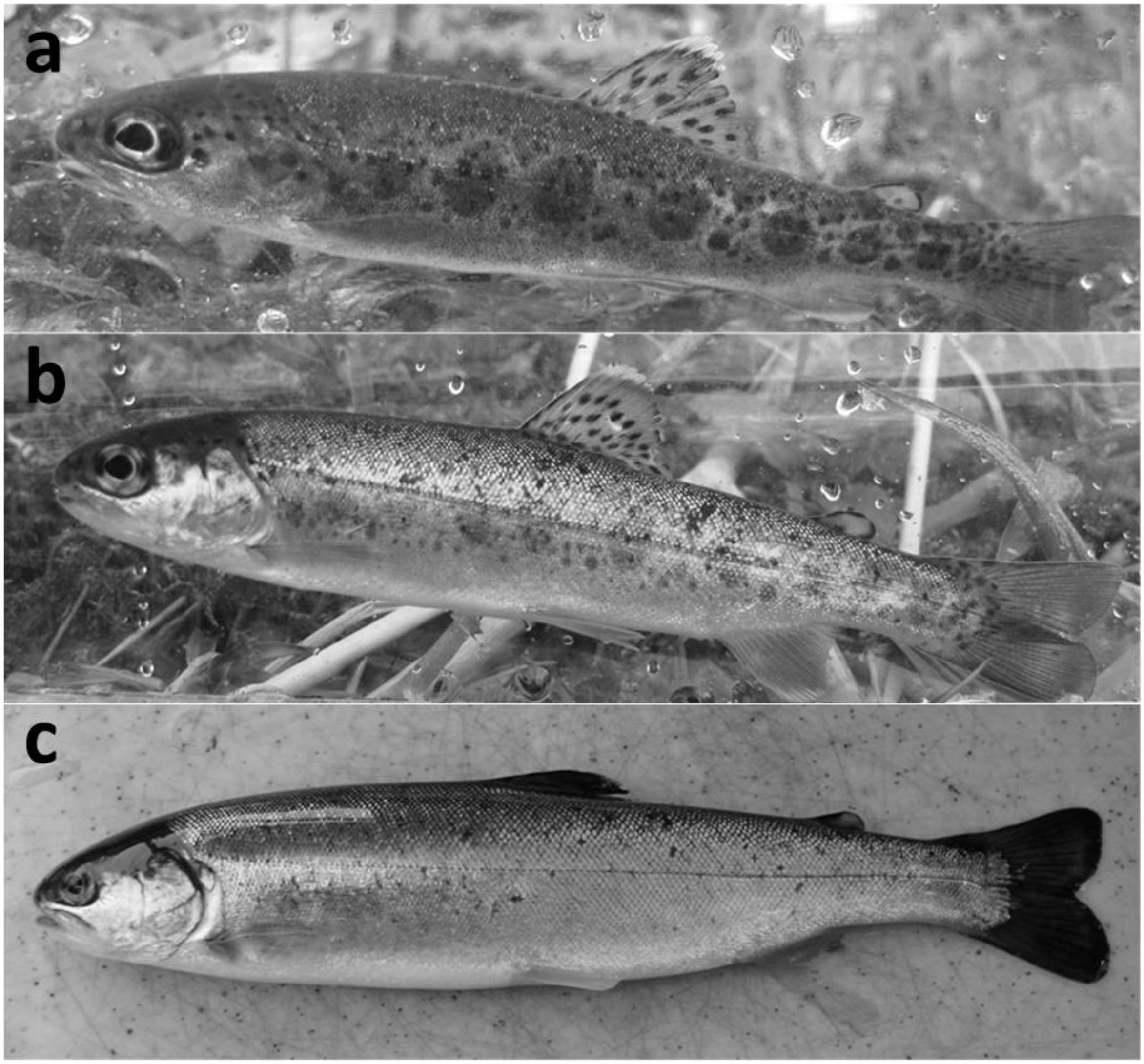


Figure 2. Examples of steelhead smolts with classified as a) No Silvering, b) Partial Silvering, and c) Silver based on external signs of smoltification.

Trap efficiency was estimated by marking up to 25 fish of each species and size class daily and releasing these fish at least 200 m upstream from the trap. Occasionally, up to 50 steelhead smolts were marked each day when periods of high flow and low trap efficiency coincided with the peak in smolt out-migration. Fish were marked with either a small clip on the caudal fin or with an injection of dye at the base of the ventral fin. Smolt population estimates were made using the Bayesian Time Stratified Petersen Analysis System (BTSPAS) Package (Bonner and Schwarz 2014) in R 3.3.1 (R Core Team 2016). Data were grouped by week using a diagonal recapture matrix, and catch during periods when the traps could not be operated was inferred using the P-spline model in BTSPAS (Bonner and Schwarz 2011). Weekly abundance estimates from the BTSPAS analysis were used to characterize out-migration timing. Pearson correlation coefficients and associated *P* values for comparisons among abundance estimates and other variables measured at the study sites were determined in R 3.3.1.

Estimating Age Composition

Each spring from 1992-2002, 2005-2006, and 2008-2012, scale samples were collected from juvenile steelhead caught in the traps to determine the age composition of steelhead smolt populations at the two sites. For Coho Salmon, scale samples were collected from smolts in 1992-2002 at Tenmile Creek, and from 1992-1999 at Cummins Creek. In general, scale samples were taken from up to10 fish per 10-mm size class each month, but in 2008 and 2009 scale samples were collected from 5 fish per 10-mm size class each week. In 2012, scale samples were taken from every third steelhead smolt captured at Cummins Creek (Ohms et al. 2013). Ages were determined by mounting the scales on glass slides and counting the number of annuli while viewing the scales with a microfiche reader. Age determinations were made by experienced personnel, and scales were often aged by more than one person to ensure consistency. For each year, the age composition of each 10-mm size class was applied to the length frequency of smolts to determine the age composition of the smolt population.

Evaluating Effects of Tenmile Creek Wood Addition

Randomized intervention analysis (Carpenter et al. 1989) was used to test whether smolt abundance increased in Tenmile Creek following the addition of large wood in 1996. Cummins Creek was used as the reference system in the paired time series before and after the large wood addition. Pre-manipulation differences between the two sites were based on smolt abundance in 1992-1996. Smolts captured in 1996 out-migrated shortly after the unplanned wood addition in February and before the planned wood addition in October (Johnson et al. 2005), and thus experienced pre-manipulation stream characteristics during nearly all of their freshwater rearing period. Steelhead smolt out-migrants in 1997 and 1998 included fish that had reared in Tenmile Creek before and after the large wood addition, and so post-manipulation differences between the two sites were calculated using steelhead smolt estimates from 1999-2012. For Coho Salmon, smolt out-migrants in 1997 were excluded from the analysis as a transition year, and the 2000 smolt class was also removed because we were not able to make a population estimate for Cummins Creek that year. The test statistic for the intervention analysis was the absolute value of the difference between mean pre- and post-manipulation differences between the treatment and reference sites. The *P* value for the test was determined using a Monte Carlo analysis with 5,000 randomizations in which differences between the two sites were randomly assigned to periods before and after the large wood addition (Carpenter et al. 1989). Randomizations were conducted using the Single-Case Randomization Tests (SCRT) package (Bulté and Onghena 2008) in R 3.3.1 (R Core Team 2016). The Durbin-Watson statistic was used to test for temporal autocorrelation in the time-series data, which can result in underestimation of *P* values in the analysis (Carpenter et al. 1989).

RESULTS AND DISCUSSION

Smolt Abundance

Considerable annual variation in steelhead smolt abundance was observed in the two study streams, with estimates ranging from 740 to 3,236 smolts at Cummins Creek and from 2,464 to 19,602 smolts at Tenmile Creek (Table 1). Trap efficiency for steelhead smolts was consistently higher at Cummins Creek than at Tenmile Creek due to its smaller size and less complex channel. The precision of population estimates were similar at the two sites, however, and 95% confidence intervals typically encompassed values 10-30% above and below the point estimate (Table 1). Smolt production per kilometer in Tenmile Creek was usually at least twice that in Cummins Creek (Figure 3) based on the length of stream habitat available at each site. Differences in smolt production between the two sites were smaller when the comparison was based on total stream surface area, but smolt production was still generally higher in Tenmile Creek. Habitat surveys were not available for all years, but based on average stream surface area from summer habitat surveys in 1991-2000, smolt production averaged 0.045 smolts/m^2 in Tenmile Creek and 0.028 smolts/m^2 in Cummins Creek during the period from 1992-2012. Steelhead smolt production in both streams was significantly higher than at other ODFW coastal monitoring sites (Suring et al. 2015) based on stream length or surface area.

The number of juvenile steelhead migrants 90-119 mm FL, termed pre-smolts here because they are expected to eventually out-migrate as smolts after further growth, was typically much lower than the number of steelhead smolts. Nevertheless, pre-smolt numbers were substantial at both sites, averaging 744 fish per year at Cummins Creek and 2,459 fish per year at Tenmile Creek in years with sufficient recaptures to make a population estimate (Appendix 1). Some of the pre-smolts exhibited body silvering associated with the smoltification process, but silvering was always very limited in this size group and most pre-smolts showed typical parr coloration. Although our current understanding is that most of these fish will spend at least one more year in freshwater before migrating out as smolts, consistent recapture rates at the trap indicate that many of these pre-smolts are migrating downstream in a determined way. These migrants would have no way of knowing their close proximity to the ocean, and may reverse course when they reach saltwater. Some pre-smolts at the larger end of the size range, particularly those captured early in the season, may out-migrate later in the same spring after additional growth and smoltification. Thus, there is likely significant movement of pre-smolts past the trapping site in both directions during the spring, and some fish counted as pre-smolts may be counted as smolts later in the season. Double counting is unlikely to have a significant influence on the smolt population estimate, but does illustrate the difficulty of making precise distinctions about salmonid life history stages, even when the fish are being captured very close to the ocean.

Table 1. Estimated number (± 95% confidence interval) of steelhead and Coho Salmon smolts at Tenmile Creek from 1992-2018 and at Cummins Creek from 1992-2012.

	Tenmile Creek		Cummins Creek	
Year	Steelhead	Coho Salmon	Steelhead	Coho Salmon
1992	5,575 ± 1,831	5,260 ± 472	740 ± 182	1,022 ± 110
1993	7,752 ± 1,139	5,234 ± 318	1,342 ± 302	728 ± 76
1994	4,721 ± 778	9,315 ± 484	1,514 ± 496	1,278 ± 151
1995	2,464 ± 1,770	1,637 ± 325	1,547 ± 1,054	1,057 ± 112
1996	5,490 ± 1,815	2,330 ± 243	2,397 ± 617	475 ± 120
1997	7,294 ± 1,756	2,995 ± 278	2,810 ± 706	717 ± 137
1998	11,126 ± 1,764	5,426 ± 417	2,031 ± 868	2,167 ± 302
1999	7,517 ± 1,513	1,767 ± 171	2,253 ± 621	623 ± 143
2000	14,404 ± 2,033	1,996 ± 221	3,236 ± 335	7 ± n/a
2001	18,473 ± 2,746	4,916 ± 488	2,901 ± 280	319 ± 49
2002	6,146 ± 1,107	6,218 ± 778	1,362 ± 257	1,078 ± 157
2003	8,306 ± 1,666	6,179 ± 494	1,460 ± 365	1,414 ± 247
2004	11,142 ± 2,140	6,673 ± 461	2,483 ± 543	2,213 ± 137
2005	12,982 ± 4,092	10,381 ± 759	1,898 ± 341	2,666 ± 171
2006	6,855 ± 1,115	6,790 ± 414	1,878 ± 174	2,468 ± 398
2007	11,729 ± 2,630	7,770 ± 770	1,230 ± 272	2,327 ± 206
2008	13,986 ± 4,680	7,670 ± 713	1,432 ± 186	3,164 ± 292
2009	13,083 ± 2,732	8,604 ± 668	1,749 ± 186	3,033 ± 186
2010	10,428 ± 4,157	8,407 ± 855	1,450 ± 180	2,709 ± 178
2011	12,468 ± 2,454	11,553 ± 1,025	1,590 ± 206	1,857 ± 231
2012	3,970 ± 1,105	7,327 ± 586	2,009 ± 402	1,862 ± 441
2013	13,374 ± 2,180	8,288 ± 931		
2014	9,280 ± 1,586	10,447 ± 747		
2015	9,850 ± 1,619	7,339 ± 621		
2016	8,666 ± 2,462	8,440 ± 1,105		
2017	6,369 ± 2,487	10,193 ± 3,455		
2018	19,602 ± 5,370	11,191 ± 745		

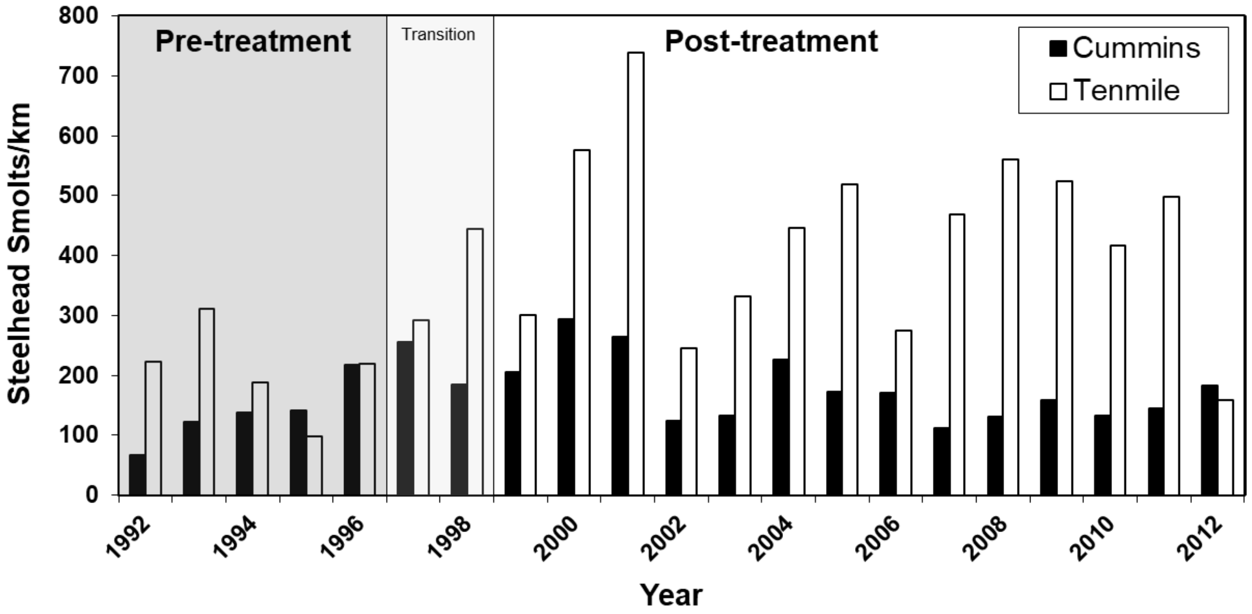


Figure 3. Estimated number of steelhead smolt migrants per kilometer of stream habitat at Cummins Creek and Tenmile Creek, 1992-2012.

Steelhead smolt abundance in both streams tended to be higher in the post-treatment period than before the wood addition in 1996. However, the percentage increase in smolt abundance at Tenmile Creek (108%) was much larger than at Cummins Creek (28%), and the average annual difference between sites increased from 3,692 smolts in the pre-treatment period to 8,897 smolts in the post-treatment period. The randomized intervention analysis indicated that this change was much larger than expected by chance and that steelhead smolt production in Tenmile Creek increased significantly relative to Cummins Creek following the large wood addition ($P < 0.01$). There was some evidence of temporal autocorrelation in the time series, but it was not significant (Durbin-Watson statistic = 1.50, $P = 0.14$). These results corroborate those of Johnson et al. (2005), whose comparison differed in that it was based on smolt production by brood year instead of smolt out-migration year, covered a shorter post-treatment period and was made for Tenmile Creek separately from Cummins Creek. Johnson et al. (2005) found that steelhead smolt abundance increased post-treatment in both streams, complicating interpretation of the observed increase in Tenmile Creek. With the additional post-treatment data now available and an analysis that incorporates information from both study sites, we found strong evidence for increased steelhead smolt production at Tenmile Creek following the large wood addition.

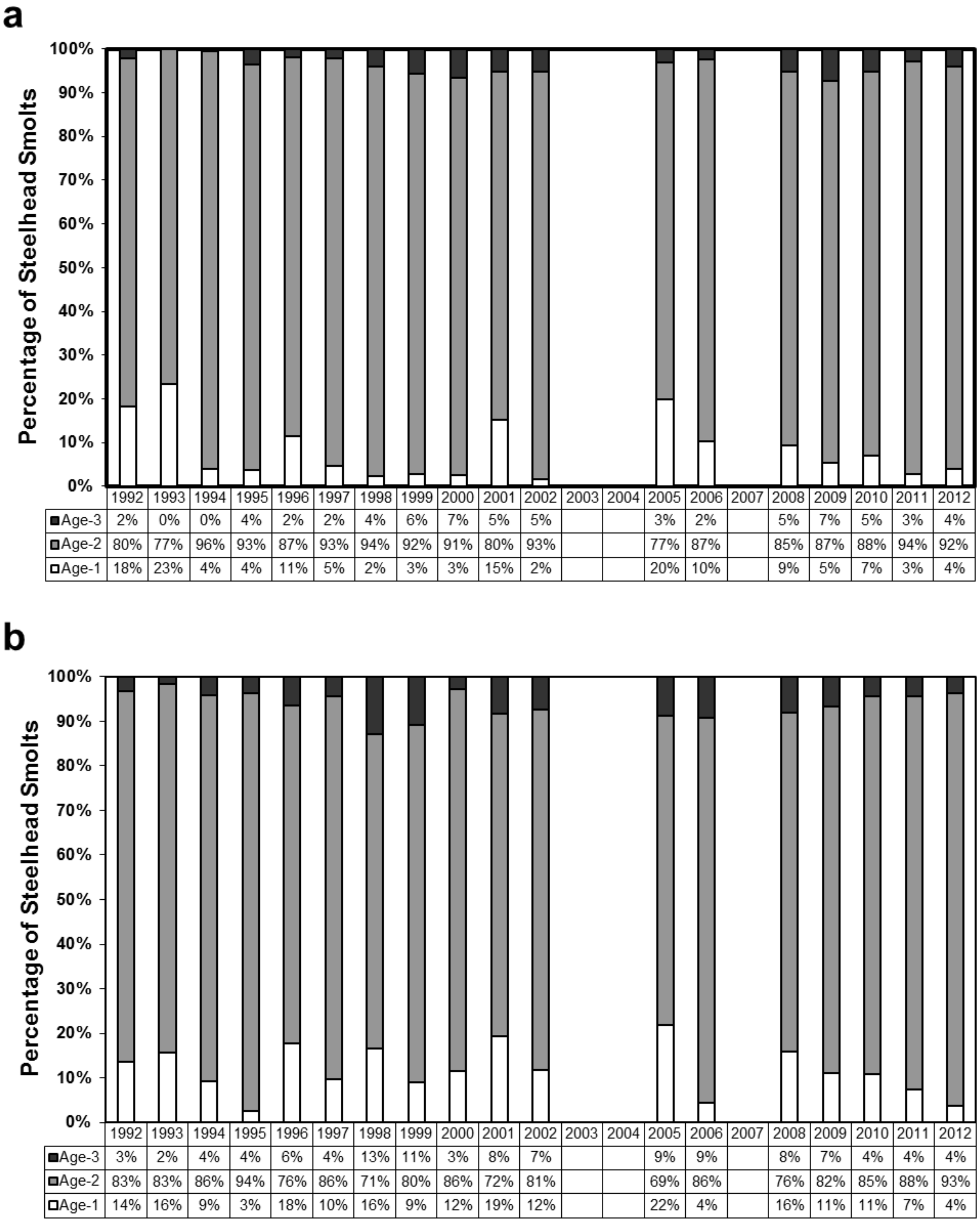
Coho Salmon smolt estimates ranged from 319 to 3,164 smolts at Cummins Creek, and from 1,637 to 11,553 smolts at Tenmile Creek (Table 1). In 2000, only seven Coho Salmon smolts were captured during the entire season at Cummins Creek and all seven were also recaptured, indicating that this may have been the entire smolt population. Given the small sample size, we excluded this year from all analyses. Coho Salmon smolt production per kilometer in Tenmile Creek was consistently higher than Cummins Creek, averaging 245 smolts/km from 1992-2012, while Cummins Creek averaged 151 smolts/km during the same period. The difference was smaller when the comparison was based on summer stream surface area, with Tenmile Creek averaging 0.029 smolts/m² and Cummins Creek averaging 0.024 smolts/m². Coho Salmon smolt populations at both sites were generally higher following the 1996 wood addition, and the randomized intervention analysis did not indicate a significant increase in Coho smolt production in Tenmile Creek following the restoration ($P = 0.27$). There was also no evidence of temporal autocorrelation in the Coho Salmon time series data (Durbin-Watson statistic = 2.24, $P = 0.96$). These results support the original conclusion by Johnson et al. (2005) that the wood addition did not have a significant effect on Coho Salmon smolt production in Tenmile Creek.

The abundance of Coho Salmon smolts was significantly correlated between the two sites over time ($r^2 = 0.45$, $P = 0.001$), with both showing a general increasing trend from 1992-2012. Steelhead smolt abundance, in contrast, was not significantly correlated between the two sites ($r^2 = 0.13$, $P > 0.10$). This was surprising because environmental factors potentially affecting steelhead smolt production, like temperature and stream flow, would be correlated between sites. We do not have data on adult spawner abundance for either site, but Johnson et al. (2005) noted differences in the density of age-0+ steelhead between sites that likely reflected seeding levels by adult fish. Differences in adult returns could explain the lack of temporal correspondence in smolt production, but the complicated relationship between seeding levels, juvenile growth and age at smolting in a population with multiple age classes may also contribute.

Age Composition

Age determinations based on scale samples were made for a total of 2,702 steelhead smolts at Cummins Creek and 3,321 steelhead smolts at Tenmile Creek. Annual sample sizes varied from 87-282 smolts at Cummins Creek, and from 83-301 smolts at Tenmile Creek. The age composition of steelhead smolt populations at Cummins and Tenmile creeks was generally quite similar, with age-2 smolts predominating across all years and age-1 and age-3 smolts consistently present in smaller numbers. Within this overall pattern, there was substantial variation in age composition through time. Estimates of the contribution of age-2 smolts to the population varied from 77-94% at Cummins Creek and from 69-94% at Tenmile Creek (Figure 4). On average, age-1 smolts accounted for 8% of the smolt population at Cummins Creek and 12% of the smolt population at Tenmile Creek. The percentage of age-1 smolts at Cummins Creek was more variable than at Tenmile Creek, ranging from a low of 2% to a high of 23% (Figure 4a). Age-3 smolts were the least numerous age class in most years, accounting for an average of 4% of smolts at Cummins Creek and 6% of smolts at Tenmile Creek across all years.

On average, 88% of the steelhead smolts in Cummins Creek and 82% of the steelhead smolts in Tenmile Creek had spent two years in freshwater prior to migration, results very similar to those from steelhead life history studies conducted in nearby Oregon coastal river basins (Chapman 1958; Wagner et al. 1963; Lindsay et al. 1993; Suring et al. 2015). However, several of these studies found that 3-year old smolts made up a larger proportion of migrants and that 1-year old smolts made up a smaller proportion of migrants than we observed at Tenmile Creek and Cummins Creek. This difference was evident for smolt age composition analyses based on adult steelhead scales (Chapman 1958; Lindsay et al. 1993) and steelhead smolt scales (Chapman 1958; Wagner et al. 1963).



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
■Age-3	2%	0%	0%	4%	2%	2%	4%	6%	7%	5%	5%			3%	2%		5%	7%	5%	3%	4%
▨Age-2	80%	77%	96%	93%	87%	93%	94%	92%	91%	80%	93%			77%	87%		85%	87%	88%	94%	92%
□Age-1	18%	23%	4%	4%	11%	5%	2%	3%	3%	15%	2%			20%	10%		9%	5%	7%	3%	4%

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
■Age-3	3%	2%	4%	4%	6%	4%	13%	11%	3%	8%	7%			9%	9%		8%	7%	4%	4%	4%
▨Age-2	83%	83%	86%	94%	76%	86%	71%	80%	86%	72%	81%			69%	86%		76%	82%	85%	88%	93%
□Age-1	14%	16%	9%	3%	18%	10%	16%	9%	12%	19%	12%			22%	4%		16%	11%	11%	7%	4%

Figure 4. Age composition of steelhead smolt population at (a) Cummins Creek and (b) Tenmile Creek, 1992-2012.

These contrasts in age composition may reflect real ecological differences, as Cummins Creek and Tenmile Creek generally have very different habitat characteristics compared to streams in nearby river basins due to variation in geology, vegetation and anthropogenic impacts. Differences in age composition may also be due to methodological and classification factors. Size-dependent marine survival of steelhead smolts has been documented (Ward and Slaney 1988; Ward et al. 1989), and could explain differences between freshwater age compositions drawn from smolt populations and returning adult spawners. Small 1-year old smolts may have lower marine survival and make a proportionally lower contribution to the adult spawner population, while the opposite may be true of 3-year old smolts. The relatively high percentage of 1-year old smolts in our study may also reflect the difficulty of classifying steelhead migrants. Some of the smaller steelhead smolts captured, many of them age-1 fish, did not show external signs of smoltification and may not have out-migrated as smolts until the following year. These fish made up a small proportion of total migrants, but would have biased the estimated number of age-1 migrants upward to some extent. Scale reading errors could also lead to systematic underestimation of smolt ages. However, we do not think that this was a factor in our study due to the experience level of the scale readers, the fact that scales were often read by more than one person, and the consistency of our results through time. Finally, the age composition was determined based on the length frequency of smolts captured at the trap and so differences in capture probability for different sized smolts could result in the overrepresentation of smaller, younger fish. Size selectivity may be a significant source of bias, as we observed higher trap efficiency for steelhead pre-smolts compared to smolts in most years, with trap efficiency for pre-smolts double that of smolts in some years.

For the analysis of age structure of Coho Salmon smolt populations, a total of 798 scale samples from Cummins Creek and 1,280 scale samples from Tenmile Creek were used. Annual sample sizes varied from 57-152 smolts at Cummins Creek, and from 62-205 smolts at Tenmile Creek. Coho smolt populations were dominated by age-1 fish, particularly at Cummins Creek. On average, age-1 smolts made up 99% of the smolt population at Cummins Creek, while age-0 and age-2 smolts each accounted for 0.5% of out-migrating smolts. At Tenmile Creek, age-1 smolts made up 97% of the population on average, but there was more variability in the contribution of other age classes through time. Age-2 smolts made up 1.5% of the Tenmile Creek smolt population on average, with a range of 0-4.2% from 1992-2002. Age-0 fish accounted for 1.6% of smolts at Tenmile Creek on average, but were estimated to have contributed as much as 8% of the smolt population in a single year. Age-0 smolts at both sites were generally only captured near the end of the smolt trapping season in late May through June, and may make a larger contribution to the smolt population than our results indicate if they continue to out-migrate during the summer. Many of these age-0 juvenile Coho Salmon vary in their external signs of smoltification, and may or may not be designated as smolts depending on the observer. As with smaller size classes of steelhead, determining the migratory status of these fish would require more intensive study. They also appear to compose a very small portion of the overall smolt population in most years. Research in Washington has indicated that age-0 Coho Salmon migrants from streams that flow directly into marine waters can contribute to adult returns (Bennett et al. 2015), although fish in that study out-migrated in the fall.

Smolt Size

An average of 229 steelhead smolts at Cummins Creek and 271 steelhead smolts at Tenmile Creek were measured for fork length each year to determine the length frequency of the smolt population. Mean steelhead smolt fork length at Cummins Creek ranged from 141-157 mm over 21 years of monitoring. Steelhead smolts at Tenmile Creek were larger, on average, than those at Cummins Creek in most years (Figure 5), and mean smolt fork lengths at Tenmile Creek ranged from 148-165 mm. Mean smolt fork length was negatively correlated with estimated smolt abundance at Cummins Creek ($r^2 = 0.28$, $P < 0.05$), but there was no relationship between smolt fork length and abundance at Tenmile Creek ($r^2 = 0.02$, $P = 0.47$). Genetic samples collected from 154 steelhead smolts at Cummins Creek in 2012 indicated that the sex ratio of smolts was slightly biased toward females, and that there was no significant difference in fork length between male and female smolts (Ohms et al. 2013).

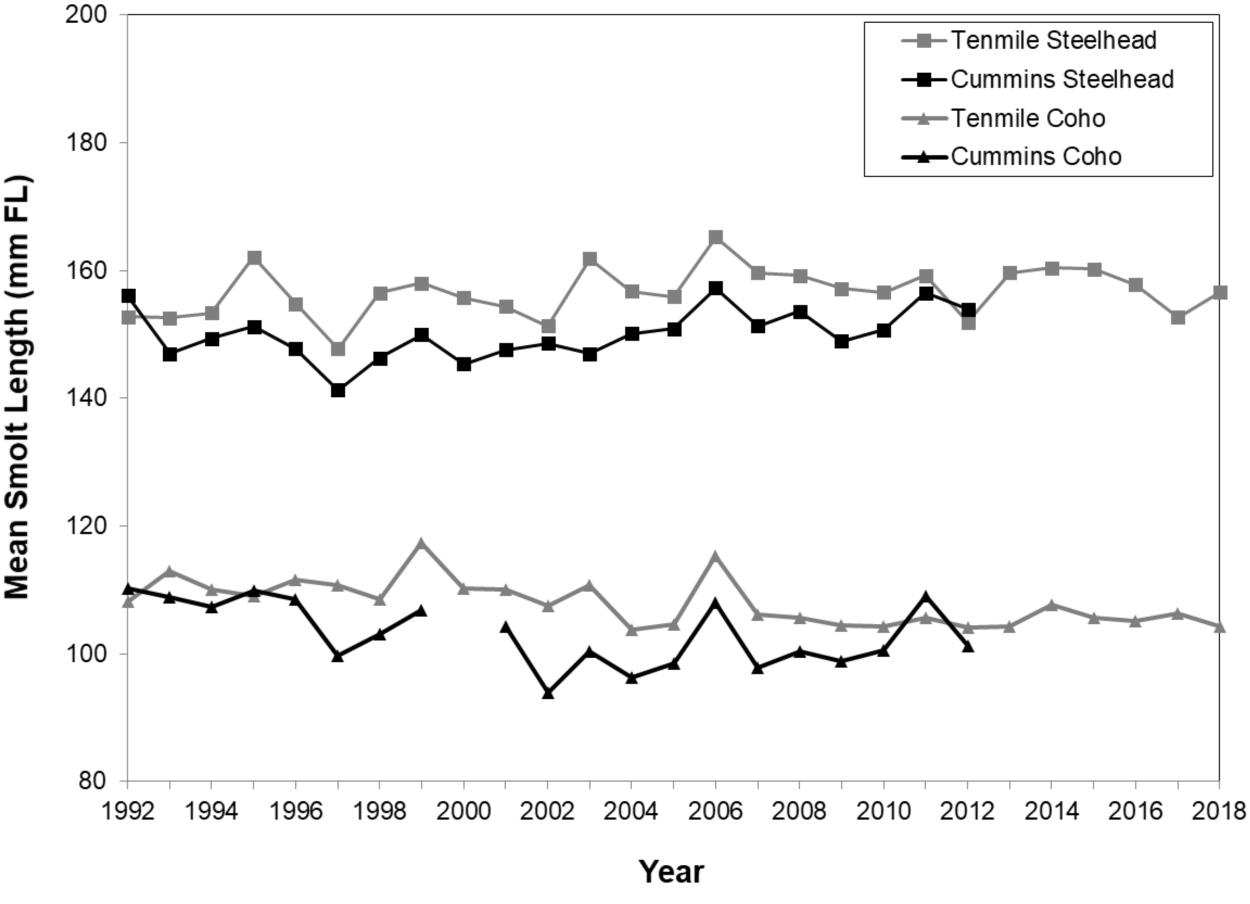


Figure 5. Mean fork length (mm) of steelhead and Coho Salmon smolts at Tenmile Creek from 1992-2018 and at Cummins Creek from 1992-2012.

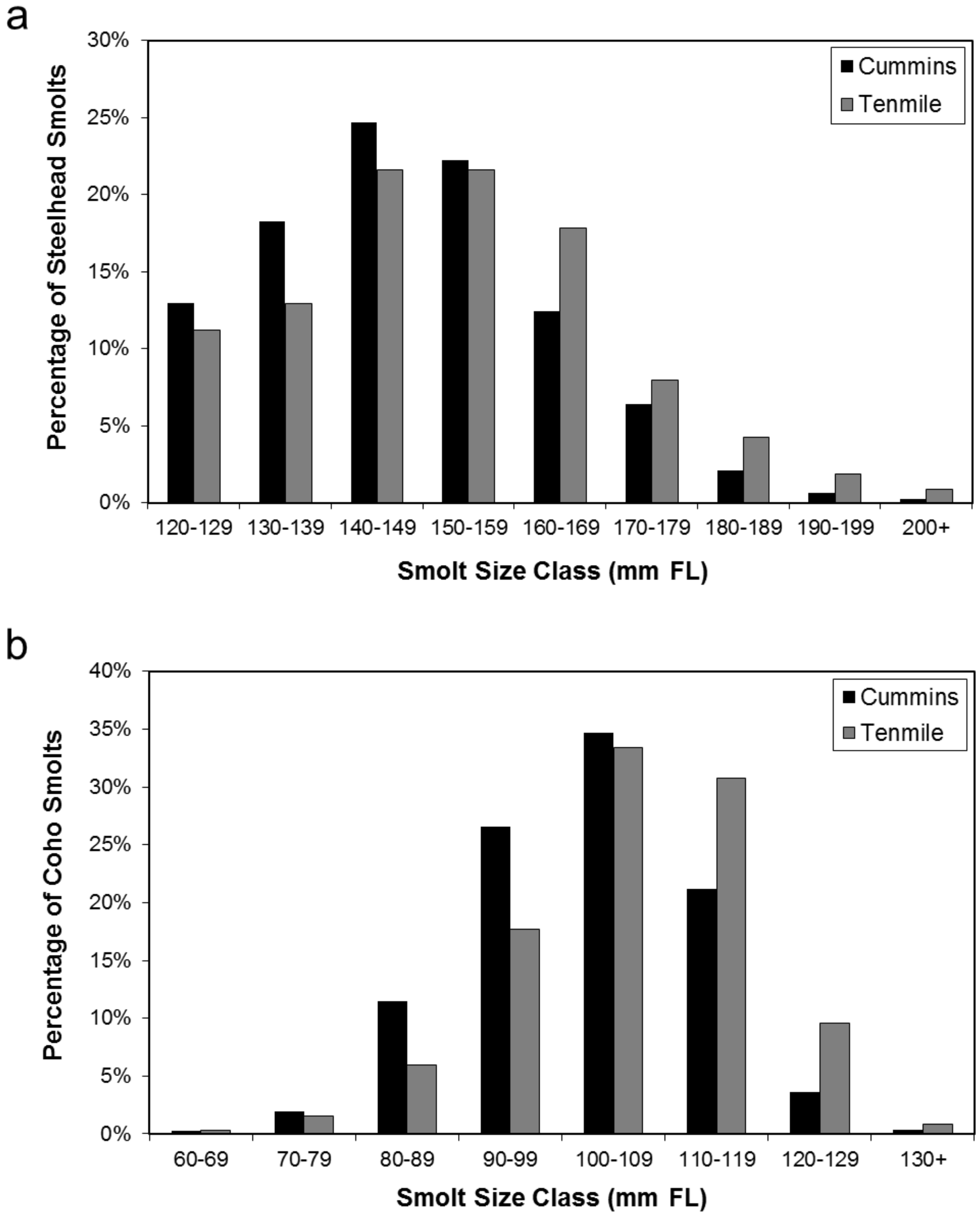


Figure 6. Length frequency distribution of (a) steelhead smolts and (b) Coho Salmon smolts captured at Cummins Creek and Tenmile Creek from 1992-2012.

The length frequency distribution of steelhead smolts was similar between the two sites, with the 140-149 mm and 150-159 mm size classes accounting for the largest percentage of smolts. Smolts less than 140 mm tended to make up a larger percentage of the population at Cummins Creek, while Tenmile Creek had a higher percentage of smolts in all of the size classes greater than 160 mm (Figure 6a). Mean smolt fork lengths typically differed by 20-30 mm among the three age groups at both sites (Table 2). However, there was broad overlap in size ranges among age groups, and variation among age-2 smolts often spanned nearly the entire size range observed among all smolts during a given year.

Mean steelhead smolt fork lengths at Tenmile Creek were similar to those observed in the nearby Alsea River basin (Chapman 1958; Wagner et al. 1963) and at other ODFW monitoring sites on the central Oregon coast (Suring et al. 2015), while smolts at Cummins Creek tended to be smaller. Steelhead smolts in both streams were significantly smaller than those observed at ODFW Salmonid Life Cycle Monitoring sites on the northern Oregon coast (Suring et al. 2015). Compared with steelhead smolts in the Alsea basin (Wagner et al. 1963), out-migrants in Cummins and Tenmile creeks tended to be smaller at age 1 and 2, but larger at age 3. Given the importance of age at migration on smolt size and the higher proportion of 1-year-old smolts we observed compared to other studies, mean smolt size would be expected to be relatively low in our study streams. Mean smolt size and size at age appeared to be particularly low in Cummins Creek, which may be an indicator of reduced growth in this relatively small stream. Mean smolt fork length at Cummins Creek was negatively correlated with the population estimate over time, so density dependence may also play a role in limiting steelhead growth rates at this site. Due to the relatively high trapping efficiency at Cummins Creek, it is unlikely that the smaller observed size of steelhead smolts there is due to sampling bias.

Table 2. Sample size, mean fork length (mm), and size range by age class for steelhead smolts and Coho Salmon smolts sampled at Tenmile Creek and Cummins Creek.

	Tenmile Creek			Cummins Creek		
	N	Mean FL	Range	N	Mean FL	Range
Steelhead						
Age-1	455	131	(120-179)	218	131	(120-163)
Age-2	2,498	156	(120-234)	2,314	150	(120-212)
Age-3	368	187	(140-270)	170	176	(140-241)
Coho						
Age-0	31	85	(66-106)	4	90	(82-94)
Age-1	1,218	107	(64-173)	786	105	(72-140)
Age-2	35	127	(112-153)	8	132	(112-152)

For Coho Salmon, an average of 256 smolts at Cummins Creek and 371 smolts at Tenmile Creek were measured for fork length each year. Mean smolt fork length at Cummins Creek ranged from 94-110 mm. This excludes the year 2000 when only seven smolts were captured and mean smolt fork length was 113 mm. Coho Salmon smolts at Tenmile Creek tended to be larger than those at Cummins Creek (Figure 5), and mean smolt fork length at Tenmile Creek ranged from 104-117 mm. The generally larger size of Coho Salmon smolts at Tenmile Creek was also evident in the length frequency distributions (Figure 6b). Mean smolt fork lengths typically differed by 15-20 mm among the three age groups within the Coho Salmon smolt population at both Cummins Creek and Tenmile Creek (Table 2). However, as was the case for steelhead smolts, there was broad overlap in size ranges among age groups, and variation among the dominant age class (age-1 smolts) often spanned the entire size range observed among smolts. Mean Coho Salmon smolt fork length had a significant negative relationship with smolt abundance at Tenmile Creek ($r^2 = 0.42$, $P < 0.001$) and a marginally significant negative relationship with smolt abundance at Cummins Creek ($r^2 = 0.19$, $P = 0.05$), suggesting that rearing density may influence growth potential at both sites.

Migration Timing

The overall pattern of steelhead smolt out-migration was very consistent through time at both sites. A small proportion of the smolts migrated out in March and early April, followed by a steep increase in smolt out-migrants in late April and early May, and nearly all migrants had left the streams by the end of May (Figure 7a). The median migration date, when 50% of smolts were estimated to have migrated past the trap, typically fell within a two-week period in late April and early May and tracked very closely between the two sites (Figure 7a). Compared with steelhead smolts, out-migration timing for Coho Salmon smolts was more variable (Figure 7b) and tended to be slightly later, especially at Tenmile Creek (Figure 8). We did not see evidence of a temporal trend in out-migration timing for either species at Tenmile Creek or Cummins Creek.

Photoperiod is thought to be the most important environmental cue for the parr-smolt transformation in anadromous salmonids (Hoar 1976; Wedemeyer et al. 1980), which likely explains the consistency in migration timing we observed across years with dramatically different weather and flow conditions. Water temperature can also be an important modifying factor (Wagner 1974; Wedemeyer 1980; Quinn 2005; Zydlewski et al. 2005), but we do not have adequate water temperature data from these sites to investigate this relationship. The congruence in steelhead migration timing between the two sites suggests that an external cue common to both influenced migration timing. As noted above, the position of our smolt traps near the mouths of these direct ocean tributaries means that date of capture at the trap is nearly identical to the timing of ocean entry for out-migrating smolts. Based on catch estimates at the traps, it was typical for 60-80% of the steelhead smolts migrating out of the study streams to enter saltwater during a four-week period between mid-April and mid-May. Median steelhead smolt migration dates at Cummins and Tenmile creeks were generally at least one week later than those observed at other ODFW coastal monitoring sites where traps are located 30-80 km from the ocean (Suring et al. 2015). Based on downstream migration rates of steelhead smolts in Oregon coastal rivers (Johnson et al. 2010), the timing of ocean entry for smolts would be very similar among all of these sites.

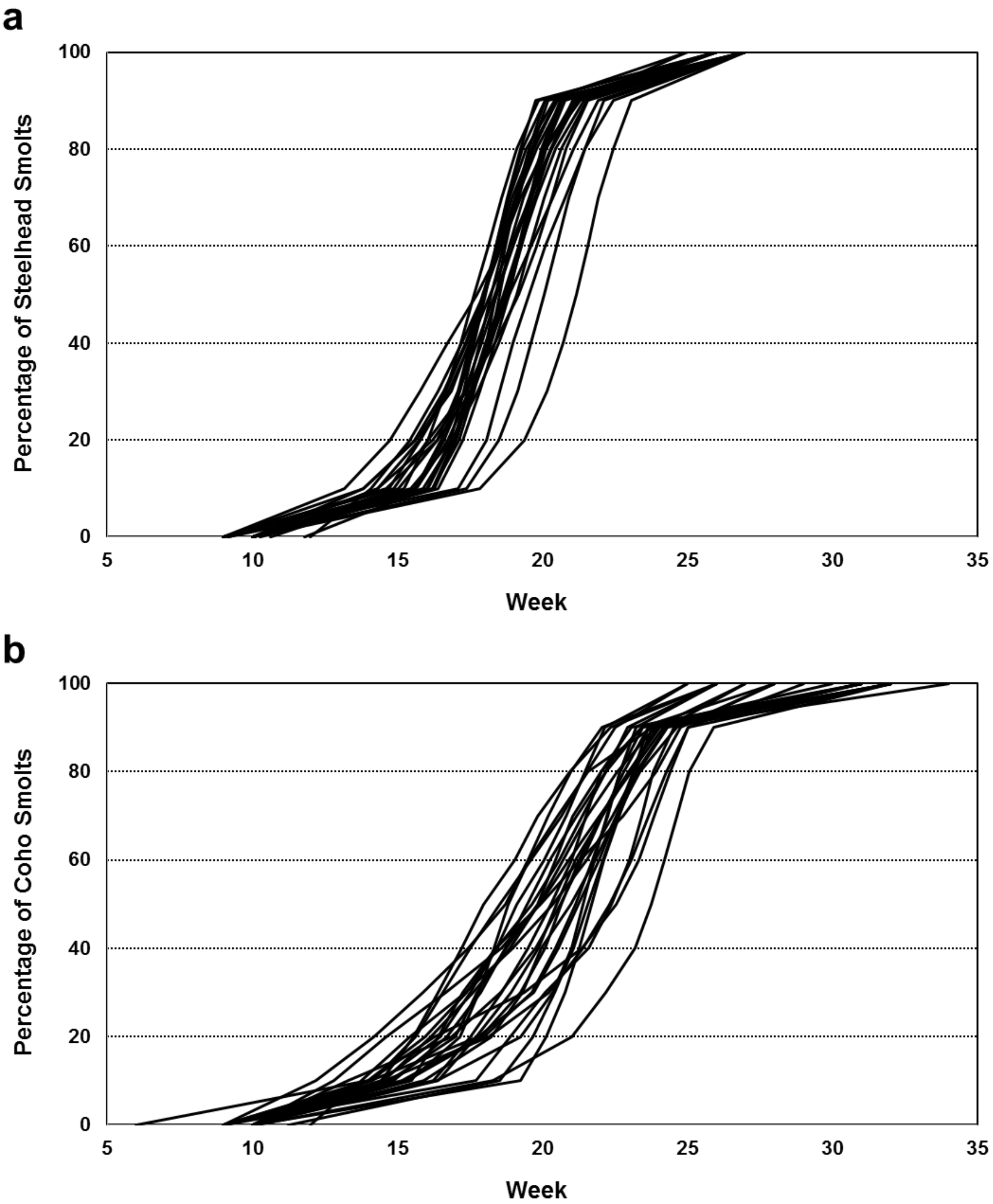


Figure 7. Cumulative percentage of total out-migrants by Julian week for (a) steelhead smolts and (b) Coho Salmon smolts at Tenmile Creek, 1992-2018.

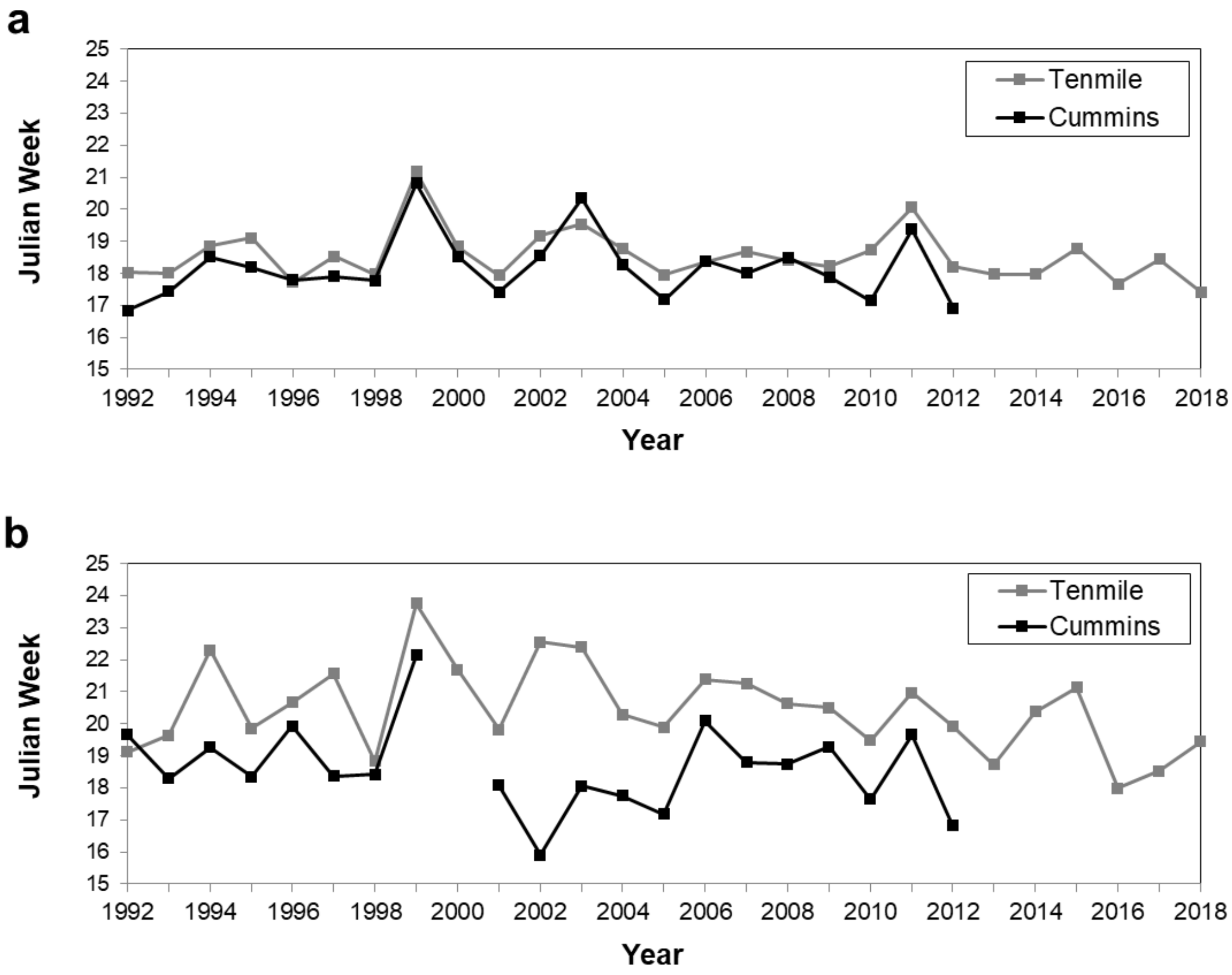


Figure 8. Median migration timing in Julian weeks for (a) steelhead smolts and (b) Coho Salmon smolts from 1992-2012 at Cummins Creek and from 1992-2018 at Tenmile Creek.

External Signs of Smoltification

From 1998 through 2012, body coloration was evaluated and assigned to one of three smoltification categories for 3,532 steelhead smolts at Cummins Creek and 3,885 steelhead smolts at Tenmile Creek. Despite the somewhat subjective classification criteria and the fact that classifications were made by many different observers over time, we found strong trends in external signs of smoltification related to fish size and out-migration timing. Patterns in smoltification were nearly identical between the two sites, and so only results for Tenmile Creek are presented here. In March, most fish showed partial silvering and only the largest steelhead smolts were fully silvered (Figure 8). Many of the nominal steelhead smolts captured in March showed no external signs of smoltification, and the percentage of fish showing no silvering increased with decreasing smolt size. By April, a much higher percentage of steelhead smolts were fully silvered, including nearly all steelhead in the largest size categories. A majority of smolts in the smallest size categories showed either full or partial silvering in April, but there

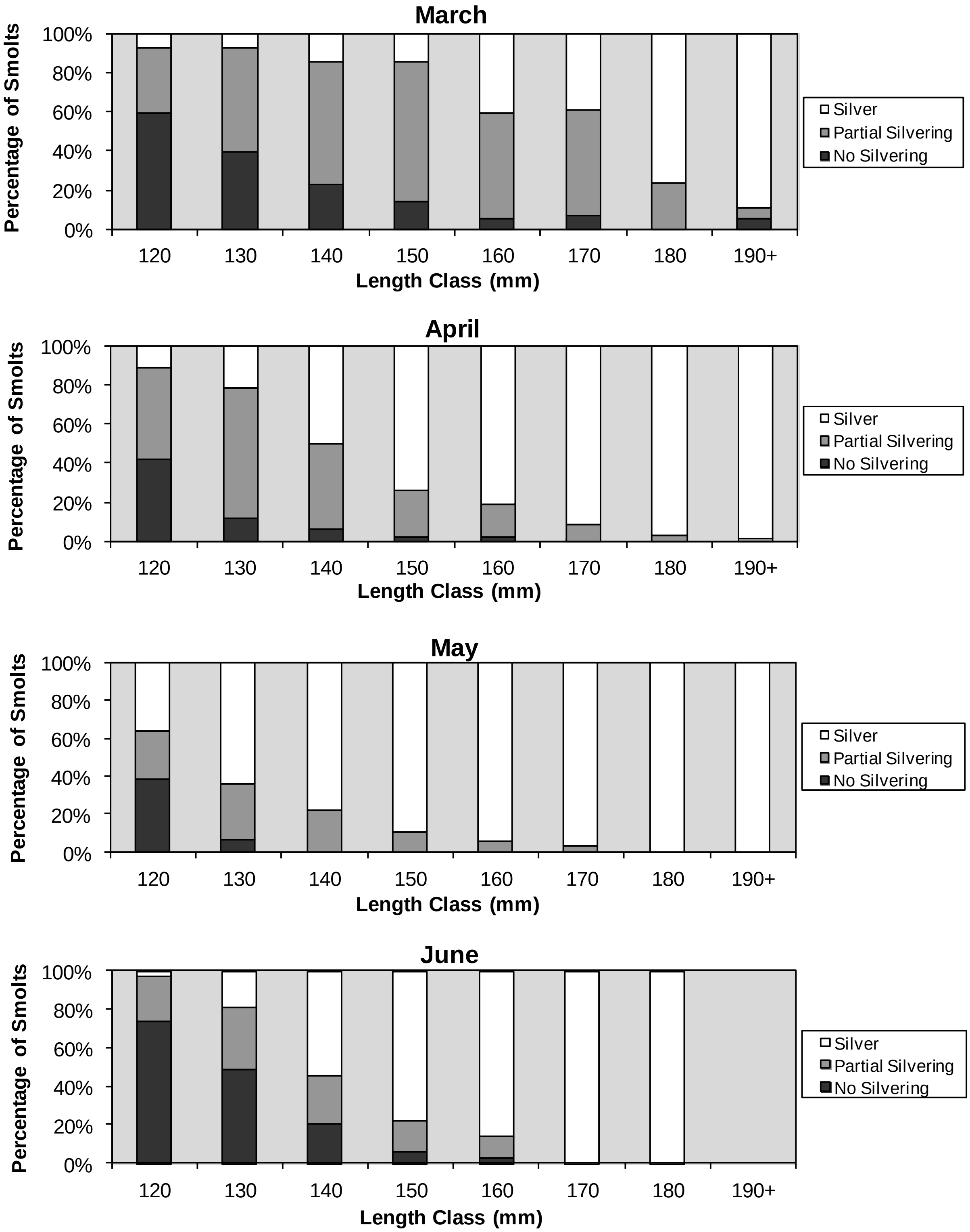


Figure 8. Percentage of steelhead smolts in 10-mm size classes assigned to three levels of smoltification at Tenmile Creek during each month of the smolt trapping season, 1998-2012.

were still some steelhead migrants that showed no external signs of smoltification. In May, nearly all of the smolts >140 mm FL were fully silvered, and even smolts in the smallest size groups generally showed full or partial silvering. This pattern reversed in June, when the total number of smolt migrants declined to a low level and many of the migrants <140 mm FL showed no silvering. Some migrants >140 mm FL also showed no external signs of smoltification, but most of the larger steelhead smolts captured in June were fully silvered.

When steelhead smolts from all size classes were combined and the data organized by trapping week (Figure 9), a very strong pattern emerged that was consistent across years. From early March to mid-April (weeks 10-16), the percentage of fully silvered steelhead smolts increased from less than 10% to over 70% while the percentage of migrants showing no silvering steadily dropped. The percentage of fish showing partial silvering initially increased and then fell during this period. From mid-April to late May (weeks 17-22), over 80% of the smolts were fully silvered and the percentage of partially silvered fish was fairly consistent. At the end of May, the number of fully silvered smolts started to drop and quickly declined to zero in June (weeks 23-26). The percentage of fish showing partial or no silvering quickly increased during this time and accounted for all the fish captured in late June.

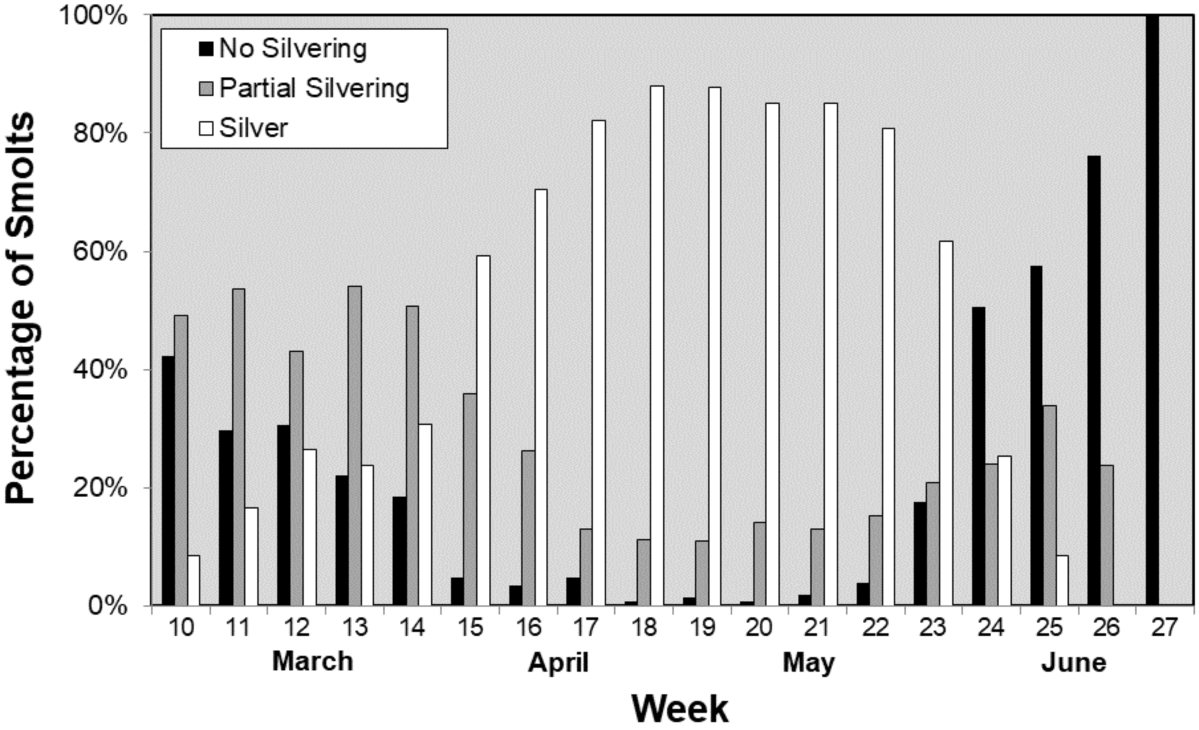


Figure 9. Percentage of steelhead smolts assigned to three levels of smoltification by Julian week at Tenmile Creek, 1998-2012.

Body silvering and fin darkening are part of a suite of physiological and behavioral changes associated with the parr-smolt transformation in steelhead and other anadromous salmonids (Wedemeyer et al. 1980). We found that a high percentage of steelhead migrants ≥ 120 mm FL showed at least some body silvering, and that most fish we classified as smolts showed nearly complete body silvering during the peak period of out-migration. Early and late in the season, however, many migrants did not show external signs of smoltification, particularly in the smaller size classes. These fish account for a relatively small portion of the overall smolt population estimate, but their status is important for understanding steelhead smolt abundance, age composition and behavior in the study streams. As noted above in the section on steelhead smolt abundance, it is unclear how smaller steelhead migrants behave once they migrate past the trap and encounter saltwater, particularly those fish that show no external signs of smoltification. Many of these fish are captured early in the season, and it is likely that at least some of them continue rearing in the lower sections of the study streams and then out-migrate as partially or fully silvered smolts later in the same season. Others, particularly those caught late in the season, may spend another year in freshwater before undergoing the parr-smolt transformation. At this time, we do not have any direct evidence suggesting how large a proportion this may be. If a large percentage of the steelhead migrants showing limited or no signs of smoltification do remain in freshwater for another season, or if they swim back upstream of the trap to rear prior to out-migration later in the same season, the estimates we make at the traps would tend to overestimate the actual number of smolts. On the other hand, there are also some steelhead less than 120 mm fork length that display partial silvering (ODFW, unpublished data). If these fish are out-migrating as smolts at the time of capture or after additional rearing downstream from the trap site, it would tend to offset the bias from counting juvenile steelhead that are not smolting.

Overall, observations on body coloration supported our size criteria for identifying steelhead smolts, but they also illustrated the complexity of classifying steelhead migrants as smolts. The size threshold for smoltification in these streams does appear to be around 120 mm FL, but there is clearly significant variation among individuals in this size range. Further research is needed to understand the fate of downstream migrating pre-smolts and juvenile steelhead ≥ 120 mm FL that show limited or no external signs of smoltification.

CONCLUSIONS

Monitoring at Tenmile Creek and Cummins Creek has provided valuable information about long-term trends in smolt abundance, and the influence of large wood on salmonid populations. Results presented by Johnson et al. (2005), and confirmed here, illustrate that increasing wood abundance in the stream channel can significantly increase steelhead smolt production. Reduced instream structure and complexity has been identified as a primary limiting factor affecting Oregon coast steelhead abundance (ODFW 2014), and more research is warranted to understand how large wood additions and other stream restoration techniques influence steelhead smolt production. The effect of increased large wood on Coho Salmon smolt production in Tenmile Creek was not as clear, due in part to high variability in Coho Salmon smolt abundance in the years immediately before and after the wood placement. Adult spawner escapement was generally quite low during this period, which likely had a strong effect on Coho Salmon smolt production independent of habitat conditions in the study streams (Johnson et al.

2005). Spawner escapement has generally been much higher in recent years, and Coho Salmon smolt abundance increased and became less variable at Tenmile Creek and Cummins Creek over time. Average Coho Salmon smolt size also appeared to decline in both streams as smolt abundance increased. These patterns suggest that the sites have approached their carrying capacity, but we lack basin-specific spawner abundance data needed to evaluate this definitively.

Temporal trends in steelhead smolt abundance were not as congruous between Tenmile Creek and Cummins Creek, and smolt production in Tenmile Creek varied considerably before and after wood addition. Given the consistency in age structure of the steelhead smolt population through time, it is clear that smolt production from particular brood years can vary widely in these streams. Steelhead smolt abundance and the ability to estimate out-migrant numbers has been identified as a critical uncertainty for steelhead management (ODFW 2014), and long-term monitoring at Tenmile Creek illustrates how much steelhead smolt production can vary from year to year. As was the case for Coho Salmon, we lack adequate spawner escapement data to determine how much of this variation can be attributed to adult seeding levels. Evaluating relationships between steelhead spawner abundance and smolt production can be challenging due to the fact that juvenile steelhead may initially rear in small streams and then move downstream into large mainstem river habitats as they grow. Tenmile Creek and Cummins Creek present a situation where smolt traps have been located at the lower end of freshwater habitat, allowing for more complete estimates of smolt abundance than can typically be achieved at monitoring sites in tributaries of larger river systems (Johnson et al. 2005). With this advantage and its long baseline of data, Tenmile Creek would be an excellent location for further investigation into the relationship between steelhead spawner abundance and smolt production. Monitoring of adult steelhead at Tenmile Creek could also provide a more robust evaluation of the prevalence of hatchery spawners in the basin and how they might affect steelhead smolt production.

ACKNOWLEDGEMENTS

Steve Johnson managed data collection at Tenmile Creek and Cummins Creek for many years, and the high quality of the smolt trapping data are a direct result of his unique skills and dedication. Jeff Rodgers, Mario Solazzi and Tom Nickelson were also instrumental in the completion of the original Tenmile Creek study. Jack Sleeper of the U.S. Forest Service and Paul Engelmeyer of the Audubon Society of Portland have made an invaluable contribution to research and monitoring work at these sites. Funding for this work was provided by the Sport Fish Restoration Program administered by the U.S. Fish and Wildlife Service, as well as the Siuslaw National Forest, U.S. Forest Service. We thank the many ODFW employees that have contributed to data collection at the smolt traps, with William Ratliff deserving special recognition for his many seasons of work. We also thank Steve Johnson, Derek Wiley, Matt Weeber, and John Spangler for valuable comments that significantly improved the quality of the manuscript.

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APPENDIX

Appendix 1. Estimated number (± 95% confidence interval) or trap catch (in parenthesis) of 90-119 mm fork length steelhead and Coho Salmon fry out-migrants, and trap catch of adult Eulachon at Tenmile Creek from 1992-2018 and at Cummins Creek from 1992-2012.

	Tenmile Creek			Cummins Creek		
	Steelhead	Coho Salmon		Steelhead	Coho Salmon	
Year	90-119 mm FL	Fry	Eula.	90-119 mm FL		Eula.
1992	3,627 ± 843	1,695 ± 1,139	24	631 ± 361	1,043 ± 909	33
1993	2,006 ± 463	10,427 ± 5,676	6	385 ± 106	(5)	1
1994	1,893 ± 455	2,316 ± 2,038	1	(14)	(3)	3
1995	(21)	3,739 ± 1,691	1	386 ± 292	(8)	0
1996	2,853 ± 896	(17)	1	723 ± 174	0	1
1997	2,919 ± 907	(122)	0	472 ± 182	(5)	0
1998	2,681 ± 786	(98)	0	1,630 ± 613	(3)	0
1999	1,645 ± 680	(21)	0	(42)	0	0
2000	5,629 ± 860	(109)	0	2,159 ± 337	(2)	0
2001	6,567 ± 1,005	10,422 ± 4,884	26	1,411 ± 225	(11)	1
2002	1,994 ± 729	64,255 ± 19,745	0	645 ± 288	(255)	0
2003	2,125 ± 776	118,848 ± 50,872	3	427 ± 139	21,642 ± 15,960	1
2004	1,305 ± 368	20,893 ± 15,225	0	570 ± 196	(52)	0
2005	2,530 ± 951	(213)	10	692 ± 129	18,519 ± 7,472	0
2006	1,123 ± 359	(160)	0	302 ± 104	(9)	0
2007	3,728 ± 862	36,155 ± 9,720	1	810 ± 176	40,004 ± 31,621	0
2008	1,964 ± 451	(221)	2	520 ± 86	(36)	1
2009	3,457 ± 670	(277)	0	866 ± 137	(33)	0
2010	1,928 ± 1,317	48,527 ± 13,289	0	569 ± 151	6,511 ± 3,252	0
2011	1,764 ± 457	14,023 ± 10,139	0	522 ± 272	0	0
2012	758 ± 308	(59)	0	423 ± 216	(19)	1
2013	3,832 ± 592	(198)	63			
2014	869 ± 331	(338)	3			
2015	1,897 ± 815	(340)	26			
2016	1,130 ± 351	(464)	1			
2017	1,246 ± 700	(519)	0			
2018	3,870 ± 727	4,421 ± 4,377	2			