

Measurements of Key Life History Metrics of Coho Salmon in Pudding Creek, California¹

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Abstract

Since 2005, a life cycle monitoring project in Pudding Creek, California, has utilized a variety of methodologies including an adult trap, spawning surveys, PIT tags, electro-fishing, and a smolt trap to estimate coho salmon adult escapement, juvenile abundance, juvenile growth, winter survival, and marine survival. Adult coho salmon escapement and smolt abundance are closely related when spawner abundance is high. However, with decreasing escapement, smolt abundance appears to stabilize. Adult abundance has declined dramatically, from 1200 in 2005 to 20 in 2010. Corresponding smolt abundance initially declined from 24,000 to approximately 15,000 but maintained at that level despite continued declines in escapement. Winter survival ranged from 17 to 80 percent, and appeared to increase as the juvenile population decreased. Juvenile growth rates within the upper watershed were low during summer and significantly higher in spring and fall. PIT tag detections indicated that thirteen percent of all coho outmigrants were two year old smolts that were smaller at tagging than one year old outmigrants, but larger than one year old fish at outmigration. Over three complete coho life cycles (2006 to 2010), ocean survival appeared to strongly affect adult returns. In all years since 2006, ocean survival for Pudding Creek spawners was notably lower than reported by others in streams throughout the Pacific Northwest in previous years.

Key words: coho salmon, escapement, life history, smolt, Mendocino County

Introduction

Pudding Creek is a small coastal tributary in Mendocino County, northern California, known to support populations of coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*). As a component of a larger regional project encompassing most streams and rivers in Mendocino County, the Pudding Creek Coho Salmon Project goals include: 1) estimation of adult escapement, 2) estimation of summer juvenile abundance, 3) estimation of outmigrant production, and 4) characterization of life-history patterns. This report characterizes life history traits of coho salmon inhabiting Pudding Creek.

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Methods

Project area

The project area includes all fish-bearing stream reaches (approximately 22 km) within the Pudding Creek watershed (*fig. 1*). Most of the watershed is presently managed for timber production, and over 70 percent of the watershed is owned by the Hawthorne Timber Company, LLC and managed by CTM. Vegetation in the area is primarily comprised of coast redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menziesii*). Red alder (*Alnus rubra*), willow (*Salix* spp.), and big-leaf maple (*Acer macrophyllum*) are the primary constituents of the riparian canopy, which is nearly continuous throughout the stream network. Pudding Creek drains approximately 45 km². Streambed gradient is generally < two percent throughout the mainstem reaches.

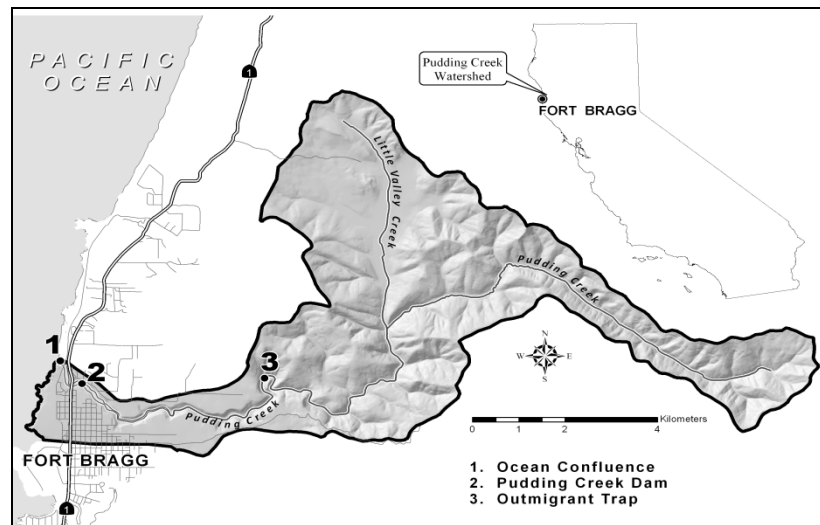


Figure 1—The Pudding Creek watershed project area.

The Pudding Creek watershed includes a dam and an associated impoundment located 0.7 km upstream of the confluence with the ocean (*fig. 1*) which historically was a water supply for the now defunct Georgia Pacific mill site. The impoundment has a surface area of nearly 0.09 km² and a volume of approximately 25 hectare-meters. The resulting reservoir inundates nearly 4.3 km of the stream network.

Due to the multiple life-history stages of coho salmon present in the Project Area, several study methods were used to characterize their abundances and life-history patterns, which follow.

Adult trapping and spawning estimates

Adult coho salmon are trapped and tagged at the Pudding Creek Dam fish ladder. Spawning surveys upstream of the pond produce estimates of spawning numbers using mark-recapture methods. The “recapture” component is the re-sight of fish tagged at the dam made by surveyors in the field.

Outmigrant trapping

Outmigrating fish are captured in a rotary screw trap (RST) with a 5 ft diameter cone. The trapping station is 6.6 km from the ocean confluence and 1.6 km from the

top of pond habitat formed by the dam (*fig. 1*). The trap is operated from February until mid June. Fish are identified, implanted with PIT tags, and size (fork length) and weight are measured. Smolt population estimates are generated using the Darroch Analysis with Rank Reduction (DARR) method (Bjorkstedt 2000). During springtime low flow periods, juvenile salmonids are also captured at the Pudding Creek Dam on an opportunistic basis.

Juvenile growth modeling

The basic model assumption is that the weight of any individual as a function of time, w_t , satisfies the stochastic differential equation

$$\frac{dw_t}{w_t} = g_t dt + \sigma dB_t,$$

where g_t is the instantaneous growth rate at time t and B_t is a standard Brownian motion. Under these assumptions, the growth over a finite time interval $[t_1, t_2]$ is

$$\ln(w_{t_2}) - \ln(w_{t_1}) = \int_{t_1}^{t_2} g_t dt + \sigma(t_2 - t_1)^{1/2} \varepsilon,$$

where ε is a standard normal deviate.

Assuming that the same g_t and σ apply to all individuals, the probability of observing N pairs of recoveries, where the k th recovery record includes the times t_{k1} and t_{k2} of the recoveries and the weights w_{k1} and w_{k2} at these times, is

$$L(\sigma, g) = \prod_{k=1}^N \frac{1}{\sqrt{2\pi\sigma^2(t_{k2} - t_{k1})}} \exp\left(-\frac{\left(\ln(w_{k2}) - \ln(w_{k1}) - \int_{t_{k1}}^{t_{k2}} g_t dt\right)^2}{2\sigma^2(t_{k2} - t_{k1})}\right).$$

For the generated results, the growth function g was taken to be piecewise constant, depending on the year and

$$\text{season: } g = \begin{cases} g_{Y, \text{winter}} & \text{from October of year Y through February of year Y + 1} \\ g_{Y, \text{spring}} & \text{from March through May of year Y} \\ g_{Y, \text{summer}} & \text{from June through September of year Y} \end{cases}$$

Counting σ , this gives a statistical model with fourteen unknown parameters, from Spring 2006 through Spring 2010⁵.

Late-summer abundance surveys

Juvenile abundance during the summer rearing period is assessed using an electro-fish sampling protocol based on a Generalized Random Tessellation Stratified (GRTS) sample draw. At 10, approximately 50 m selected reaches, juvenile abundance is estimated with depletion electro-fish sampling. PIT tags are implanted in unmarked fish.

⁵ The data extend into June of 2010; this was folded into the “Spring 2010” period.

PIT tags

All juvenile salmonids greater than 65 mm captured during summer surveys or during outmigrant trapping, are implanted with 11 mm full duplex (FDX) PIT tags.

PIT tag arrays

To detect fish at the Pudding Creek Dam that have been PIT tagged at upstream locations, multiple antennae arrays have been affixed around the dam flashboards. These arrays record a time stamp for each fish detected.

Results

Adult escapement

Of the two methods traditionally used to estimate adult escapement, the mark-recapture technique has proved most reliable. Thus, fish per redd estimates are shown only for 2002 and 2003; the years before mark-recapture experiments were initiated (*fig. 2*). Overall, fewer coho returned to spawn in water year 2010 than in previous project years. For comparison, escapement from eight regional streams is shown for the same time series (*fig. 3*)⁶.

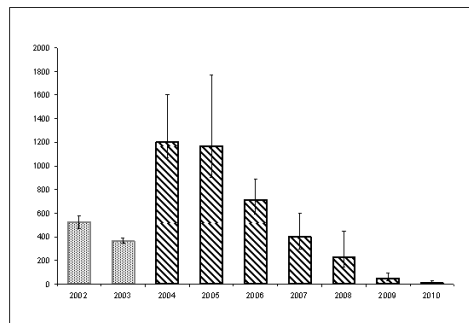


Figure 2 – Estimated coho salmon escapement based on mark-recapture (slash) and one redd per female (grey) methods with 95 percent confidence intervals (WY 2002 to 2010)

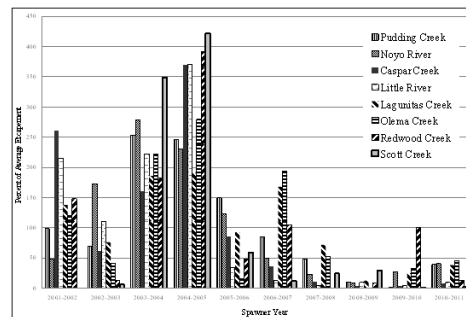


Figure 3 – CCC ESU coho salmon escapement estimates over the past 10 years. Percent of average escapement is derived from the average of escapement estimates for each watershed over the past 10 years of data (WY 2002 to 2011)

Outmigrant production

Coho smolts were more abundant in 2006 than in all other monitoring years with a population estimate of approximately 24,000 fish. From 2007 to 2010, estimates varied from approximately 13,000 fish to 16,000 (*fig. 4*). When escapement estimates are plotted with the corresponding natal lineage of smolt abundance (*fig. 5*), smolt abundance does not appear closely correlated with the abundance of the parental brood-stock.

⁶ Reichmuth, Fishery Biologist, Inventory and Monitoring Program, Point Reyes National Seashore. Unpublished.

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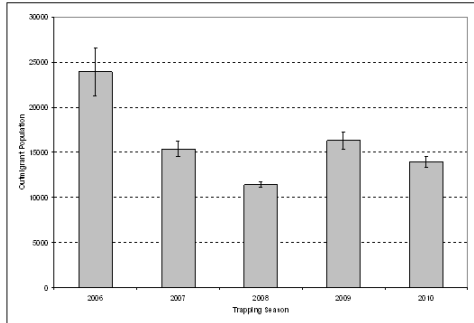


Figure 4 – Coho salmon outmigrant production point estimates for Pudding Creek, California (WY 2006 to 2010).

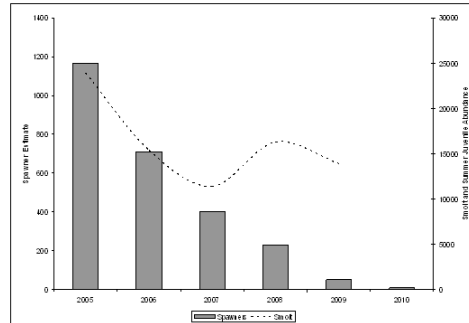


Figure 5 – Coho salmon spawner estimated and the corresponding outmigrant estimate for Pudding Creek, California (WY 2006 to 2010).

Juvenile growth

The recapture of PIT tagged juvenile salmonids produced information on seasonal instream growth. Growth seasons were defined by the period between sampling regimes, or by the period in which the sampling regimes occurred. Over five years of sampling (2006 to 2010), coho salmon growth in Pudding Creek appeared greatest in spring (February - May). Fall/winter (October - March) produced moderate growth, and summer (May - September) appeared to be a period of limited growth (*fig. 6*). In some years, growth was negative over the summer period.

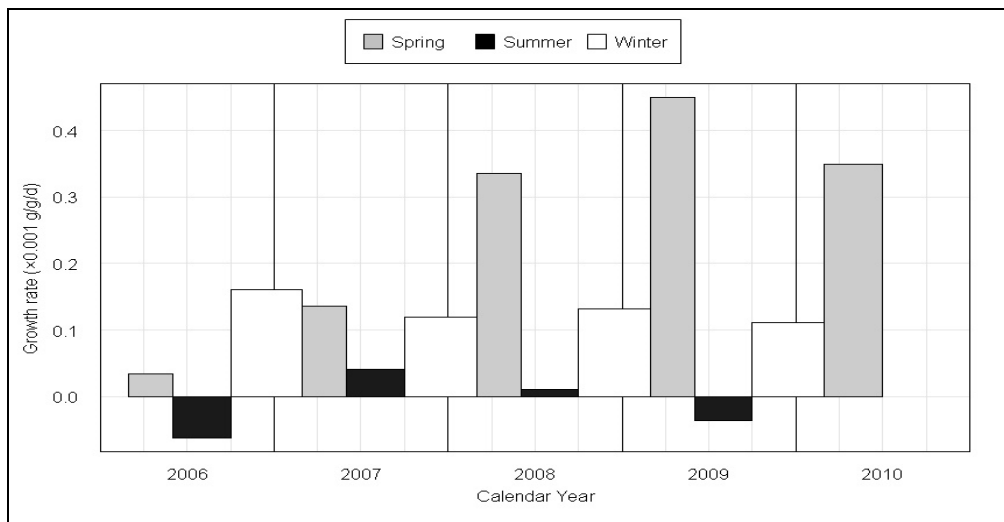


Figure 6—Growth rates of Coho salmon (*Oncorhynchus kisutch*) in Pudding Creek. Fit of individual growth data from PIT recoveries to fourteen parameter model.

Based on smolt PIT tagged at the RST and recaptured at the dam, in 2009 and 2010 significant growth occurred in the 6.1 km reach during outmigration. Respectively, mean coho smolt growth 10.6 mm ($n = 268$, $s.e. = 0.62$) and 11.8 mm ($n = 41$, $s.e. = 1.62$).

Coho salmon ocean survival

We examined six coho salmon cohorts (brood years) to estimate *spawner to spawner ratios* (2002 to 2010) – the ratio of the number of spawners to the number of their progeny that return as spawners. Two cohorts had ratios greater than 1 (more

progeny returned), and four had a ratio less than 1, suggesting poor yield from the spawning efforts after the 2003 water year (*table 1*). Outmigrant sampling combined with adult recaptures of the same cohort facilitates estimation of specific marine survival (*smolt to spawner estimates*) by two methods: Comparison of estimates between outmigrant and escapement indicates that ocean survival from 2006 to 2010 ranged from 0.08 to 0.95 percent (*table 2*). Ocean survival based on PIT tag returns from these cohorts ranged from 0.04 to 0.44 percent. PIT tag return survival estimates remained consistently lower for all cohorts (*table 2*).

Table 1—*Adult escapement estimates and spawner-to-spawner ratios for six cohort classes of coho salmon.*

Years	2002 to 2005	2003 to 2006	2004 to 2007	2005 to 2008	2006 to 2009	2007 to 2010
Spawner- to- Spawner (95% CI)	2.23 (2.05- 2.91)	1.93 (1.77- 2.21)	0.33 (0.28- 0.37)	0.2 (0.17- 0.25)	0.07 (0.05- 0.11)	0.02 (0.01- 0.05)

Table 2—*Coho salmon ocean survival (smolt to spawner estimates), calculated from population estimates and tag returns.*

Ocean Years	2006 to 2008	2007 to 2009	2008 to 2010
Comparison of Population Estimates (Percent)	0.95	0.33	0.08
PIT Tag Returns (Percent)	0.44	0.14	0.04

Coho salmon over winter survival

The proportion of juveniles PIT tagged during summer abundance surveys and recaptured at the RST indicates instream survival from late summer to spring outmigration (*table 3*). Over winter survival varied from 0.17 to 0.8. However, due to the low number of tags recaptured, confidence intervals were large, in some cases indicating unrealistic upper bounds as in 2007 and 2010.

Table 3—*Over winter survival.*

Years	2007	2008	2009	2010
Over winter survival (95 percent CI)	0.71 (0.24-1.18)	0.17 (0.13–0.22)	0.61 (0.45–0.77)	0.8 (0.57-1.02)

Juvenile size at outmigration

The modal size class of coho salmon was 90 to 100 mm from 2006 to 2008. In 2009, the modal size class was smaller (80 to 90 mm) and the frequency distribution appeared to be wider. The 2010 modal size class was 100 to 105 mm, and the frequency distribution was relatively narrow (*fig. 7*). In 2006 and in 2008 a bimodal distribution was observed, with the secondary peak at approximately 140 mm. This pattern was also observed to a lesser degree in 2010. In 2007 and 2009, the bimodal distribution was not apparent. The secondary modes in the small size classes (< 60 mm) are newly emergent YOY.

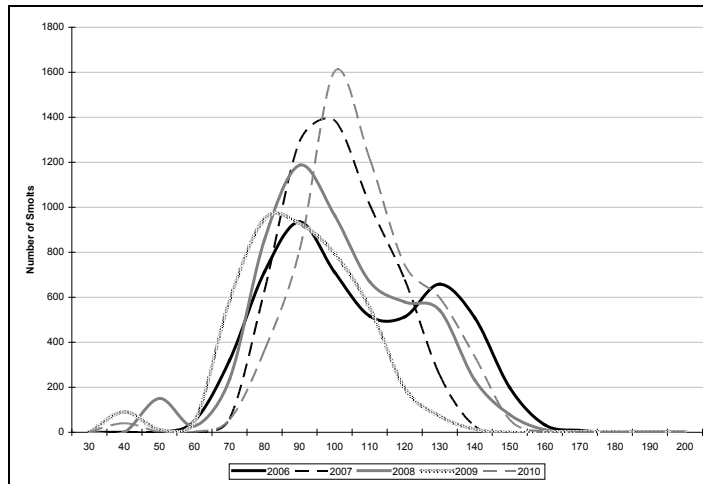


Figure 7—Smoothed histogram of coho salmon fork lengths at the outmigrant trapping station in Pudding Creek (2006 to 2010).

The mean value of annual juvenile cohort fork lengths since 2006 (*table 4*) from the RST captures indicate that the 2010 smolt were largest and the 2009 cohort were smallest.

Table 4—Mean juvenile coho fork lengths with 95 percent confidence intervals for Pudding Creek (2006 to 2010).

Year	2006	2007	2008	2009	2010
Mean Fork Length	101.9	96.5	88.1	87.7	104.2
(CI)	(0.5)	(0.4)	(0.5)	(0.5)	(0.5)

Coho juvenile two year life history

The use of PIT tags, the RST, and the PIT tag antennae array at the dam indicated evidence of a coho two year instream life history and several characteristics that appear to be associated with this behavior. Since 2009, 13 percent of all coho salmon detections at the dam array have been 2 year old juveniles. Since 2006 when downstream trapping was initiated at the RST, we have recaptured coho in their second year on multiple occasions (*fig. 8*). The recaptures at the RST also indicate that second year life history behavior is not annually consistent (*fig. 8*).

The median fork length for first year smolt (92 mm) at initial capture was greater than the group that outmigrated in their second year (76 mm). At recapture, the median value of second year smolts was greater (129 mm) than first year smolts (104 mm). A Mann-Whitney Rank Sum Test (not normally distributed) indicates a significant difference between the median values of the two groups at first capture ($P = <0.001$). A t-test of the normally distributed recaptures indicates a significant difference between the mean values of the groups ($P = <0.001$).

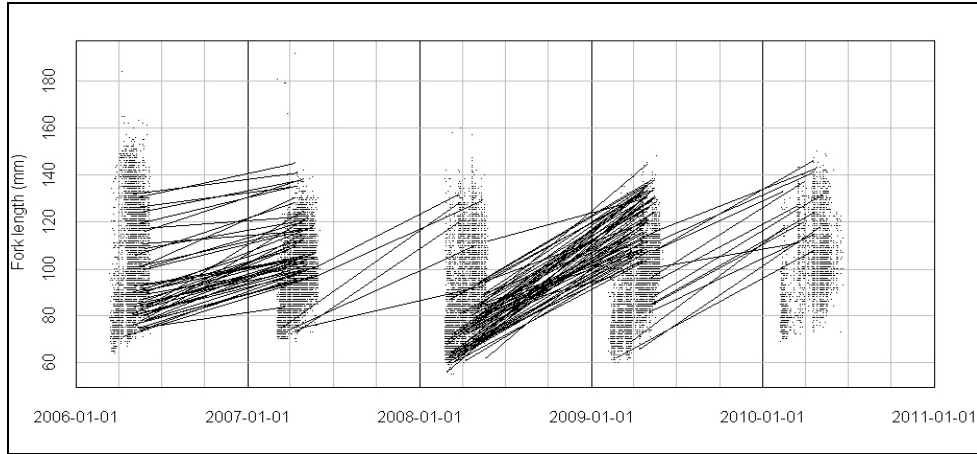


Figure 8—Length of individual Coho salmon at the Pudding Creek RST vs. time. The length of each fish measured in each spring survey is shown as a dot. Line segments join successive recoveries of the same individual PIT tag in spring surveys. All recaptures occurred at RST.

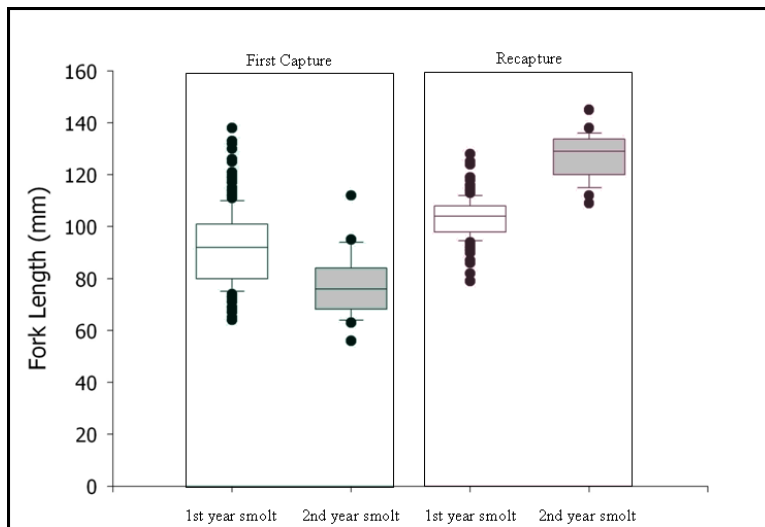


Figure 9—Fork lengths for first year smolts compared to second year smolts at first capture and recapture at the RST.

Discussion

Spawning abundance

The current analysis of escapement and outmigration for coho salmon suggest the Pudding Creek population is following the trend found in other streams throughout California (*fig. 3*), which further suggests the causes for the immediate decline may be at the regional scale.

Juvenile abundance

At the RST, coho salmon outmigrant numbers have remained consistent since 2007 after a significant decrease from 2006 (*table 1*). A comparison of coho salmon spawners to their outmigrant offspring the following spring suggested the outmigrant population was dependent on the number of spawners from 2006 to 2008, a pattern not reflected in 2009 and 2010 (*fig. 5*).

The outmigrant trap is approximately 6 km from the ocean confluence, with spawning, rearing, and overwintering habitat located between it and the ocean. Thus, the trap may not actually estimate the true outmigrant population. PIT tag recaptures in returning adult coho salmon suggest that the outmigrant population may be considerably higher than our stated estimates (*table 2*). However, this is contingent on whether chronic mortality of PIT tagged fish is significant. To test for chronic mortality, in 2010, 50 percent of the tagged fish were tagged with a right maxillary clip rather than a PIT tag. The tag rate of these two groups in adults returning during water year 2012 will indicate whether chronic mortality is an issue.

Over winter survival

Based on the spring recaptures at the RST of fish originally PIT tagged in summer, over winter survival in Pudding Creek appears to increase as juvenile abundance decreases (*table 4, fig. 4*). We believe this is the result of reduced density dependent competition among rearing juveniles for habitat and feed.

Marine survival

Coho salmon spawner-to-spawner and outmigrant-to-spawner ratios were low for the WY 2008, WY 2009 and WY 2010 runs (*tables 1 and 2*). A poor spawner-to-spawner estimate indicates low production at any point in the coho salmon life cycle; however, poor smolt to spawner estimates clearly point to low survival at sea (*table 3*). Our smolt to spawner estimates are much lower than observed in California coastal streams (e.g., greater than six percent in Waddell Creek [Shapovalov and Taft 1954]) and in many streams further north (greater than 10 percent in Puget Sound [Mathews and Buckely 1976]), However, our results are consistent recent rates of less than one percent in Oregon streams (Lewis 2004).

Size

By mean fork length, smolts in Pudding Creek were largest in 2010 (*table 5*) and smallest in 2009. The summer of 2009 was extremely dry, which may account for the diminished size. Although 2006 and 2010 smolts were comparatively large, they were small compared to those in Waddell Creek, CA (Shapovalov and Taft 1954). In 2009 and 2010, mean fork length increased by approximately 11 mm as fish migrated the final 6.1 km between the RST and the dam (near the ocean confluence). These additional 11 mm would make the Pudding Creek mean FLs as measured at the RST more comparable to those reported in the 1930s Waddell Creek study. However, the Waddell Creek weir was located 2.2 km from the ocean confluence. Waddell smolts probably also grew between trapping site and the ocean. We compared the length of Pudding Creek coho smolt captured between 2006 and 2008 to those captured in a similar monitoring project on Prairie Creek, Humboldt County, CA⁷. The main land-

⁷ W. Duffy, California Cooperative Fisheries Research Unit, 2011, unpublished data.

use difference between these two otherwise similar watersheds is that Prairie Creek has not undergone significant timber harvesting. Pudding Creek, on the other hand, has been managed for timber harvest for over a century. Coho outmigrants from Pudding Creek (97.5 mm) are somewhat larger than those from Prairie Creek (96.8 mm; $p = 0.011$ for the two-sided heteroscedastic t-test). This information suggests that the characteristics of coho size at outmigration are variable by watershed. Coho forklengths were comparable to the size range reported by Bradford et al. (1997) throughout Oregon and Washington.

Growth

Coho salmon in Pudding Creek grow well in spring, and moderately in fall-winter. Summer appears to be a period of low growth, which is likely due to diminished carrying capacity stemming from the annual summer drought. These findings support the notion that stream enhancement projects intended to augment pool habitat (e.g., through the introduction of large wood into the channel) may be effective to increase juvenile salmon survival and growth over summer.

Based on smolt captures at the dam that were tagged at the RST, on average coho smolt grew approximately 11 mm while traveling the last 6.1 km of stream, which is nearly 10 percent of their total growth within the last 100 days of stream residency. This suggests the importance of lower channel habitat for juvenile growth.

Coho juvenile 2 year life history

A second year life history likely supports three important life history functions. First, it allows undersized fish with little potential for marine survival a second year to increase size. Second, it is one pathway for genetic mixing between the cohort classes. Finally, a two year life history can help ensure adequate recruitment when poor spawning occurs by contributing juveniles from one year to the next.

The mechanism for second year life history in juveniles appears to be, in part, the slower downstream movement exhibited by smaller smolts. We can determine the length of time smolt spend between the RST and the dam and compare this period to fork length measurements taken at the RST (*fig. 10*). The analysis of these data indicate that larger fish move rapidly through the stream network, while smaller fish take considerably more time in downstream migration. Considering that streamflow generally does not allow downstream migration in Pudding Creek past early June, which is approximately a 100 day window for migration, smaller fish will more likely be prevented from migrating to the ocean.

In Pudding Creek coho salmon that stayed a second year were significantly smaller than the rest of their cohort upon initial capture (*fig. 9*). We found the mean fork length at first capture of these fish to occur at approximately 75 mm, which is also the size class that takes longest to outmigrate (*fig. 10*). However, when they outmigrated the following year they were significantly larger than that year's cohort. This is consistent with the findings of Bell and Duffy on Prairie Creek, CA (2007).

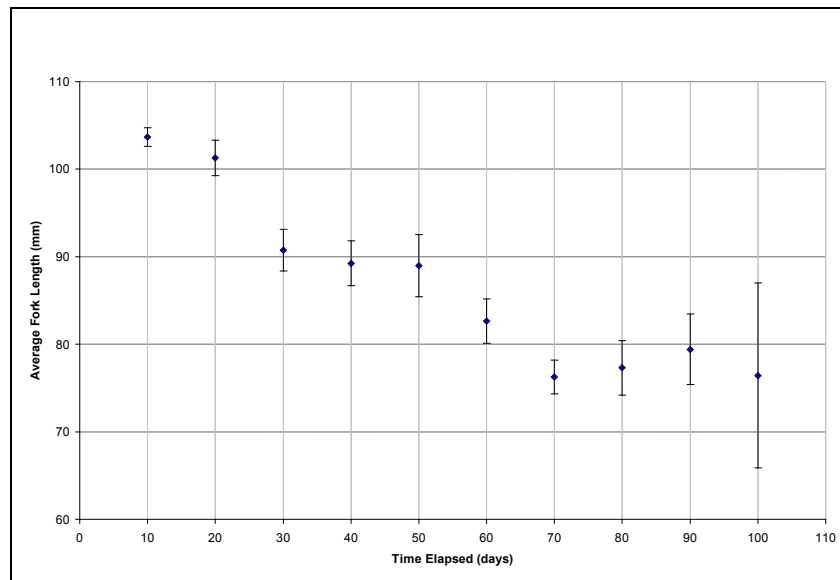


Figure 10—Time elapsed between original capture at RST and subsequent detection at dam vs. initial measured fork length. Error bars are 95 percent confidence intervals.

The dam and impoundment raise many issues regarding the affects on salmonids, and presently we do not understand the degree to which it benefits or hinders them. On one hand, the impoundment may benefit coho because it acts as over-wintering refugia for juveniles during high winter flows, and as summer rearing habitat. However, dam and impoundment may be detrimental due to low dissolved oxygen levels in the pond during summer from decaying non-native vegetation, fish passage issues, predation, and the division of the coastal lagoon. Decisions regarding the future of the dam structure will soon be necessary due to changing regional socio-economic conditions. More resources should be allotted to research on the dam as it relates to salmonids before these decisions are made.

References

- Bell, E.; Duffy, W.G. 2007. **Previously undocumented two-year freshwater residency of juvenile Coho salmon in Prairie Creek, California.** Transactions of the American Fisheries Society 16: 966-970.
- Bradford, M.J.; Taylor, G.C.; Allan, A.J. 1997. **Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level.** Transactions of the American Fisheries Society 126: 49-64.
- Bjorkstedt, E.P. 2005. **DARR 2.0: Updated software for estimating abundance from stratified mark-recapture data.** U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Nation Marine Fisheries Service, Southwest Fisheries Science Center. NOAA-TM-NMFS-SWFSC-368.
- Matthews, S.B.; Buckley, R. 1976. **Marine mortality of Puget Sound coho salmon (*Oncorhynchus kisutch*).** Journal of the Fisheries Research Board of Canada 33: 1677-1684.
- Shapovalov, L.; Taft, A.C. 1954. **The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special**

reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin 98. California Department of Fish and Game. 375 p.

Lewis, M. 2004. **Hatchery coho marine survival.** Oregon Department of Fish and Wildlife, Salem, Oregon.
<http://nrimp.dfw.state.or.us/OregonPlan/default.aspx?p=134&XMLname=33.xml> .