Migration, growth, and survival of juvenile Coho Salmon (*Oncorhynchus kisutch*) in Coast Redwood Forested Watersheds

Final Report

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Progress Statement: This project is a work in progress with the current focus on analysis within a modeling framework. The outcome of this collaborative effort is to obtain coho salmon over-winter survival estimates as they relate to habitat correlates in redwood dominated forested streams. The overall project objective is to inform managers on the relationship between measured habitat features and survival of coho salmon in three separate watersheds having contrasting land management regimes.

Introduction

Systemic population declines of coho salmon throughout all freshwater habitats in California (Brown et al. 1994) have led to both federal and state listings under the federal (ESA) and California (CESA) Endangered Species Acts (Federal Register 1997, CDFG 2002). Both listings have triggered the development of recovery plans which include delisting goals (CDFG 2004, NOAA 2014) for the Southern Oregon Northern California Coho (SONCC) ESU. Millions of dollars have already been spent in the effort to recover coho salmon populations in California. With the exception of migration barrier removals, the evaluation of fisheries habitat restoration projects remains a challenge. Conservation strategies that restore and improve habitat quality, quantity, and connectivity are essential to maximize the persistence of salmonid populations (Greene et al. 2010). However, Roni et al. (2010) wrote that despite many large well-funded restoration efforts much debate remains over the effectiveness of various restoration techniques.

The complex life histories exhibited by coho salmon indicate overall production is likely a function of large-scale habitat diversity, quantity, and distribution. Recent studies highlight juvenile salmonid survival, growth, and fidelity can vary largely among stream reaches (Zydlewski et al. 2006, Roni et al. 2012). This study was designed to measure key life history components and habitat features that influence the production of juvenile coho salmon in three coastal watersheds of northern California. These productivity metrics (i.e. growth, survival, emigration) will be used to test the effectiveness of concurrent large-scale stream habitat restoration projects, such as those occurring in the Mill Creek watershed, relative to basins with contrasting management regimes. Results from this study will provide land managers and restoration groups measured biological responses to restoration treatments and riparian forest conditions. Findings from this study will also inform future restoration planning and limiting factors insight for threatened and endangered coho salmon throughout the coastal redwood region.

Part of a larger project: Although the research and funding supported by the League is restricted to Mill Creek, two other study locations using the same methods and hypothesis were also implemented during the same timeline. The three watersheds that comprise the collaborative study area are similar in size, flow directly into or are in close proximity to the Pacific Ocean, and are composed of coast redwood dominated forests. The goal of this larger collaborative study is to evaluate freshwater habitat, growth, and survival of coho salmon in streams throughout their range in coastal Northern California. The varying land use histories reflect gradients in latitude on the landscape, anthropogenic impacts, and current and planned watershed and stream habitat restoration. Project partners include California Department of Fish and Wildlife, Save The Redwoods League, and Humboldt State University. The three watersheds include:

- *Mill Creek*: Historic industrial timberland under new management for historic forest and stream habitat conditions and current large scale in-stream, and upslope restoration.
- *Prairie Creek*: National and State Park, upper basin old growth forest, lower basin
- *Freshwater Creek*: Historic and current industrial timber forest management.

Research questions

This research was designed to assess vital coho salmon life history attributes (i.e. survival, growth, emigration) in relation to an unprecedented large-scale habitat restoration project occurring in Mill Creek, California. Further planning indicated a need to expand the study to other basins to increase our inference across a broad spectrum of watershed management regimes. *A priori* model development will be used to refine specific hypothesis as they relate to individual variables- *see analysis section*. Specific research objectives are as follows:

1. Compare emigration timing and possible early emigration of juvenile coho salmon.
2. Compare growth of juvenile coho salmon between fall tagging and spring outmigration.
3. Estimate and compare survival of juvenile coho salmon between fall tagging and spring outmigration.
4. Investigate relationships between emigration, survival, and growth as they relate to habitat quality and stream restoration in redwood dominated streams.
5. Make recommendations for life stage specific habitat restoration.

Methods

Study Areas

Mill Creek—The Mill Creek watershed drains 60 km^2 including the two main tributaries, the East Fork Mill Creek and the West Branch Mill Creek that join to form the mainstem Mill Creek (California Department of Parks and Recreation 2011) (Figure 1, Figure 2). Mean annual rainfall ranges from 60-150 inches and mean monthly temperatures range from 41 to 67 F°. Lower reaches of Mill Creek are broad, flat valley bottoms with large amounts of stable sediment in terraces located above the active channel (Madej et al. 1986). The Mill Creek property supports both anadromous and resident salmonid populations, including coho salmon (*Oncorhynchus kisutch*), fall Chinook salmon (*O. tshawytscha*), chum salmon (*O. keta*), steelhead (*O. mykiss irideus*), and coastal cutthroat trout (*O. clarki clarki).* Coho salmon are currently the only federally listed fish species found on the property. Mill Creek was managed for industrial timber production from the early 1850's and most of the upper basin has been logged at least once since 1920 (Stillwater Sciences 2002). With the help of Save The Redwoods League and other partners, the State of California purchased the Mill Creek property from Stimson Lumber Company in June 2002, and transferred the property into a California State Park. The Mill Creek property was acquired by the State of California, where maintenance and enhancement of habitat for state-listed and federally listed species was a primary intent of the purchase and is a component of the vision statement (State Parks 2010). To achieve these goals, the California Department of Parks and Recreation has developed a Watershed Management Plan (WMP) that is sufficiently detailed to initiate an implementation schedule for watershed-related natural resources restoration and protection (California Department of Parks and Recreation 2011). As part of the WMP large scale in-stream aquatic habitat enhancement, and flood plain reconnection and restoration activities have been implemented in the East Fork Mill Creek (California Department of Parks and Recreation 2011). Since 2006, numerous complex wood jams have been created in the East Fork (Fiori et al. 2009).

Prairie Creek— Prairie creek is a fourth-order tributary whose confluence with Redwood Creek

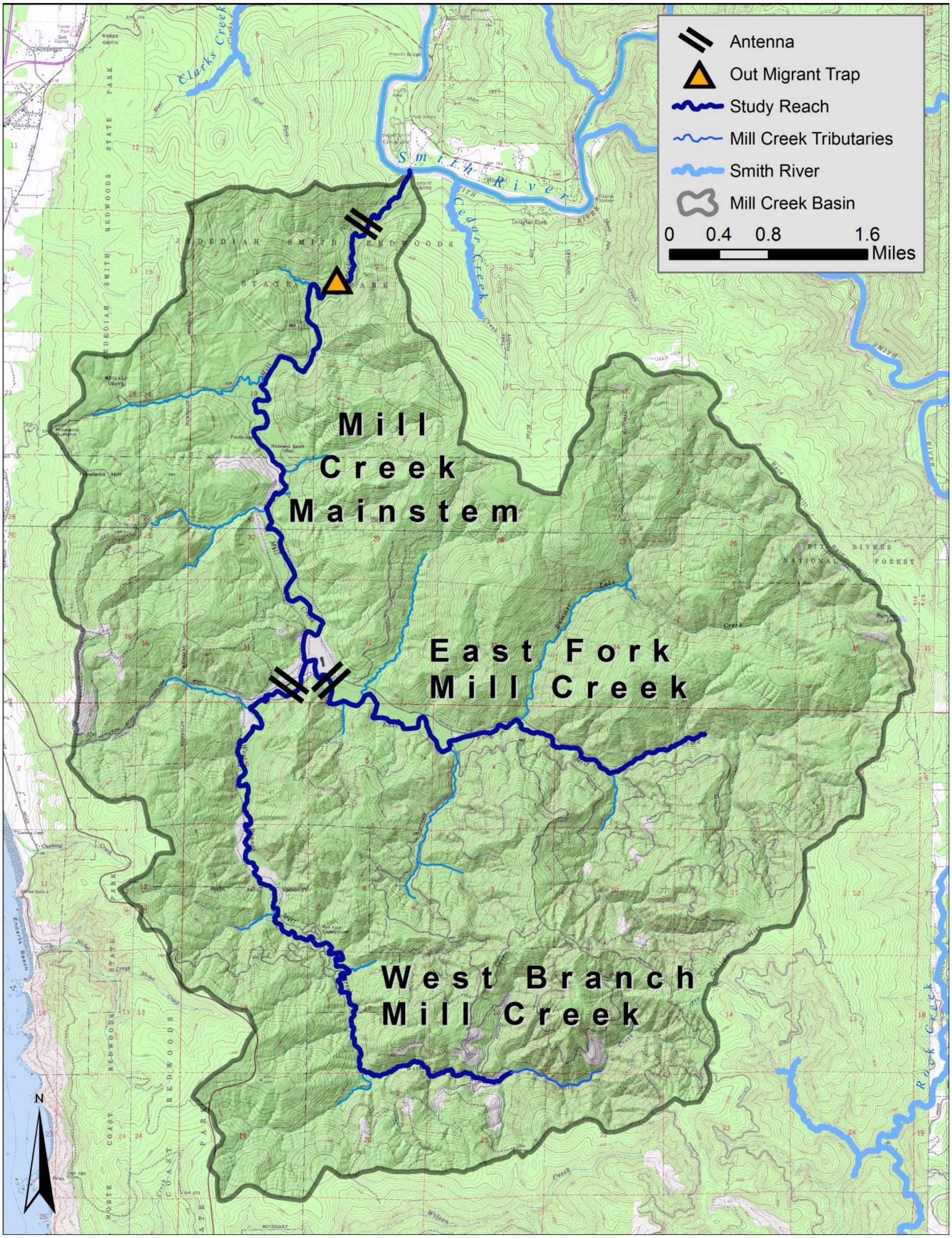

Figure 1. Mill Creek watershed, tributary to the Smith River, Del Norte County, CA. Locations of PIT tag antenna arrays and the migrant trapping station are shown near the mouth. The three stream reaches are labeled in text on the map and separated by antenna arrays.

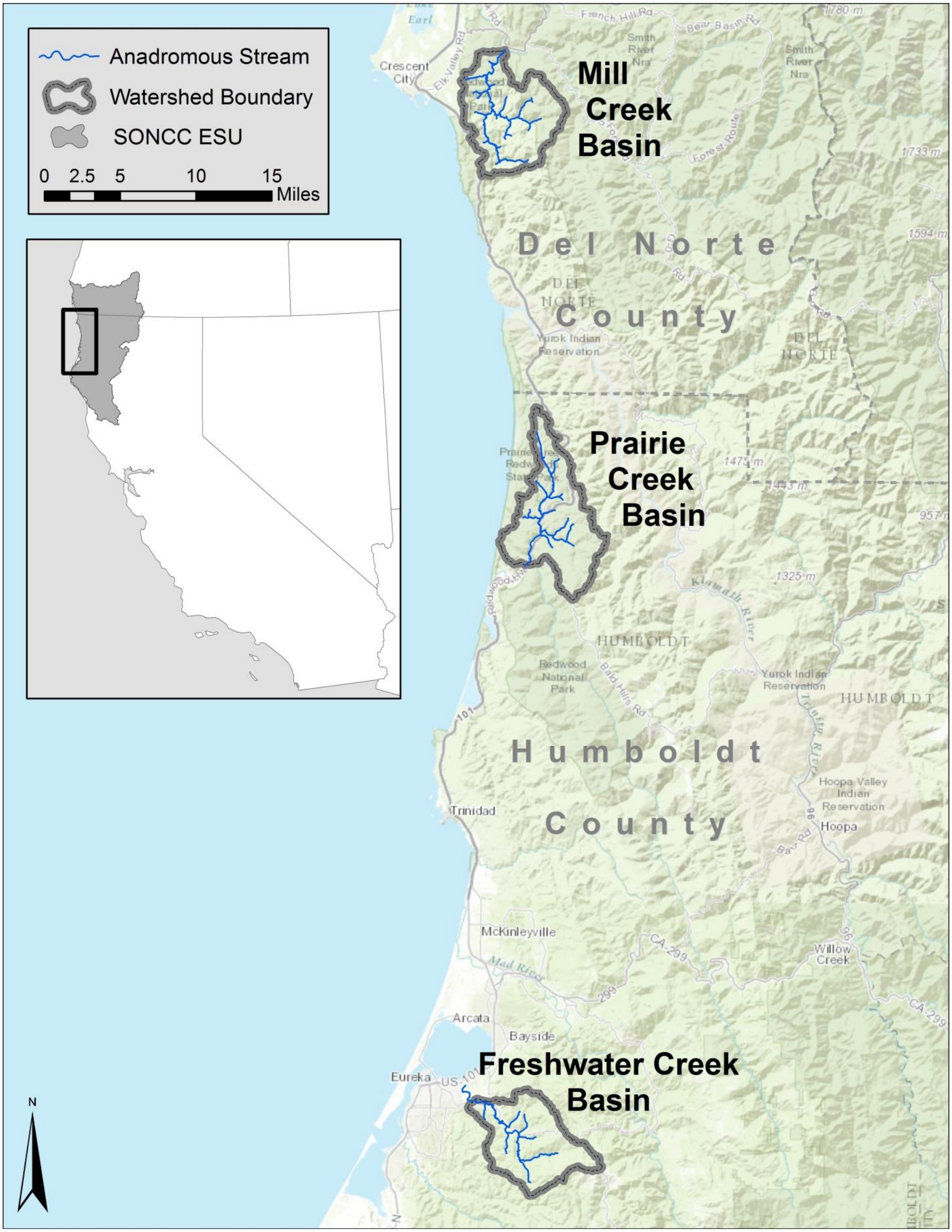

Figure 2. Map of the greater study area, including Mill, Prairie and Freshwater Creeks, tributaries to Smith River, Redwood Creek and Humboldt Bay, respectively (California, U.S.A.). The Coho Salmon Southern Oregon Northern California Coast (SONCC) Evolutionary Significant Unit (ESU) boundary is displayed on the inset.

occurs near Orick, California. Draining a watershed of 34.4 km^2, the stream flows for 20 kilometers and is located almost entirely within the boundaries of Redwood National and State Parks (Cannata et al. 2006). The climate of the study area is considered mild and is characterized by dry, foggy summers and rainy winters. Mean annual precipitation is 177 cm, most of which falls between November and March (77%). Upper Prairie Creek flows through old-growth Coast redwood forest with aquatic habitat consisting of roughly 50% pools, with the remainder being relatively shallow runs and riffles. Lower Prairie Creek flows though patches of coast redwood, meadows and pastures and its aquatic habitat is characterized by frequent deep pools. Prairie Creek supports several species of salmonids including: Chinook salmon, coho salmon, steelhead, and coastal cutthroat trout.

Freshwater Creek– The Freshwater Creek basin is located in Humboldt County between Eureka to the south and Arcata to the north. Freshwater Creek, which drains into Humboldt Bay via the Eureka Slough, is a fourth order stream with a drainage area of approximately 92 km^2 (Mull and Wilzbach 2007). Levees confine the channel in the lower 6 km and the surrounding land is primarily used for cattle grazing. The mainstem from river kilometer 6 to river kilometer 9.7 is mainly held in small parcel residential properties. The remaining watershed encompassing 13 km, contains the majority of anadromous fish habitat, and is privately owned and managed for commercial timber production. Annual rainfall is approximately 150 cm in the headwaters and 100 cm near the mouth, with nearly 90% accumulating between October and April. The fishery resources of the basin include three species of salmonids including: Chinook salmon, coho salmon, and steelhead trout. Occasionally, chum salmon are observed.

Fall Captures and PIT Tagging

Fish tagging was conducted within each basin by its respective field crew each fall before the first freshets when rearing fish were still associated with their summer rearing habitats. A stratified sample of pools throughout each basin was identified and sampled for juvenile coho salmon using seine nets. Before captured fish were sorted into taggable fish (≥ 65mm) and non-taggable fish (< 65mm), a random subsample of five individuals was taken from each pool seined to estimate the fall size distribution, thereby identifying a population percentage on which inference can be made. Non-taggable fish were counted, allowed to recover from handling, and released. To minimize effects of added weight on taggable coho salmon, PIT tags (Oregon RFID, Portland, Oregon; half-duplex; 0.1 g, 12.0 mm long × 2.12 mm diameter) were used for fish ≥ 65 cm fork length as recommended in Peterson et al. (1994). Individual fish were measured for length and weight, and tagged by insertion of a PIT tag through a small incision in the body cavity following the tagging methodology of Rebenack et al. (2015). Tags were inserted by hand through a 1-2 mm ventral incision slightly posterior to the pectoral fins. Tagged individuals were allowed to recover from the procedure before their release back into the pool from which they were captured.

PIT Tag Antenna Stations

A series of PIT (passive integrated transponder) tag antenna arrays were constructed in the three study basins including three arrays in the Mill Creek (Figure 1), two arrays in Prairie Creek, and three arrays in Freshwater Creek during the fall of 2013 and operated continuously during the winters of 2013-2016. Each antenna location was established at the terminal end of a reach having tagged juvenile coho salmon. Antennas are used to identify movement patterns and reach-based survival as it relates to stream habitat correlates (e.g. low-velocity habitat) and redwood forest conditions (e.g. late seral, recovering) (Figure 1). Each antenna array was paired, with each array spanning the entire stream width to maximize detection probabilities and movement direction of migrating PIT tagged coho salmon (Bennett et al. 2011, Roni et al. 2012).

Outmigrant Trapping

Outmigrant traps were located near the mouths of all study basins (*see* Mill Creek [Figure 1] as an example). The Mill Creek and Prairie Creek studies used rotary screw outmigrant traps (5' diameter cone) while Freshwater Creek used a modified pipe trap connected to permanent weir structure. As part of individual life-cycle monitoring stations, traps operated 24 hours a day, from March through June to capture downstream migrating coho salmon smolt's for developing smolt population estimates based on trapping efficiencies. All captured coho salmon with PIT tags derived from the previous fall tag group were weighed and measured so we could estimate winter growth rates of individual fish. Capture histories of these fall tagged cohorts at both the traps and antenna arrays were used to generate a capture matrix for estimating detection probabilities, movements, and survival.

Habitat Inventory

Coho salmon habitat attributes were censused throughout each study reach (Figure 1) using methods adapted from Bouwes et al. (2011). The protocol is structured around a general understanding of the link between habitat attributes and how they directly relate to the specific life history requirements of salmonid fishes. We focused on the abundance of two key features that likely influence reach-level winter rearing fidelity and survival: Large wood debris (LWD), and low velocity/ off channel habitats. These habitat attributes characterize each study reach and provide predictor variables in explaining vital rates of survival, fidelity, and winter growth across multiple habitat scales.

Large Woody Debris– Following the CHaMP protocol (2013), we counted and classified LWD pieces that existed inside the bankfull channel (i.e., within bankfull width and beneath bankfull height). Dimensions of the bankfull channel were visually assessed in the field using indicators including scour lines, vegetation limits, changes in bank slope, changes between bed and bank materials, and presence of flood-deposited silt (USFS 1995). Bankfull indicators are present year-round, which allowed LWD surveys to occur during summer months when instream pieces are most visible and accessible. LWD data was collected once over the course of the three-year study and took place during summer 2014 between the first and second years of biological data collection. All pieces of wood ≥ 1.0 m long × 0.1 m diameter within bankfull were classified into one of four length classes and one of four diameter classes to estimate wood volume per stream kilometer. Due to high variability in size and low frequency of extra-large LWD pieces, all pieces greater than 15 m long or 60 cm in diameter were individually measured for accuracy (nearest 0.1 m). All LWD located within the bankfull prism was tallied regardless of its surrounding habitat type. For LWD existing partially within the bankfull prism, only the portion within the prism was measured and tallied. Pieces protruding from the stream bank or benthos were counted only if the exposed volume satisfied measurement criteria.

LWD volume per reach (V_{reach}) was calculated as

$$V_{reach(i)} = N_{reach(i)} M_i$$

where N_{reach} is the total number of pieces per reach in each size class (i) and M_i is the corresponding geometric mean LWD volume for that size class, where the constant represents the geometric mean volume pieces within each size class bin. Geometric mean volumes were calculated by Rentmeester (2014) where volumes were estimated from measurements of more than 75,000 pieces of LWD collected by the U.S. Forest Service in Oregon and Washington. Reach-specific volume estimates and LWD counts were expressed in terms of density as pieces/km and m^3/km, respectively, to account for varying stream lengths within the study area.

Low-velocity Winter Rearing Area— We estimated the percentage of low-velocity rearing habitat available for juvenile coho salmon within each reach during periods of typical winter flows between November 2014 and March 2015. Streams were divided into individual habitat units separated by distinct hydraulic breaks to assess each unit by area (m^2) and type. To ensure channel unit data was representative of winter habitat during *typical* winter flows and standardized across streams, all surveys were completed between the 25th and 50th percentile (2nd quartile) median flow statistics for November through April according to United States Geological Survey (USGS) streamflow records (USGS 2014). The 2nd quartile flows were chosen as the survey range to capture the most common flow range during winter months and ensure a relatively stable stage height for eight-hour survey days.

Winter habitat data was collected once throughout each stream to compare the three years of biological data forcing the underlying assumption that the relationship between low-velocity habitat area and stream discharge was proportional over the course of the study. For example, if a stream reach flowing at 100 cubic meters per second (cms) is characterized by 25% low velocity rearing area, the reach would remain at 25% regardless of time.

A two-tiered classification system developed by Hawkins et al. (1993) and modified by the Colombia Habitat Monitoring Program (CHaMP 2013) was used for classifying stream habitat. Crews worked upstream from the start of each reach, classifying units as either fast-water (FW) or slow-water (SW) and further categorizing slow water unit types based on visual assessment. Fast-water unit types were not further distinguished in the survey due to the known preference of coho salmon for slow water (Bisson et al. 1988). Slow-water units were classified as main channel pools (e.g. scour pools, plunge pools, dam pools) or off-channel units (backwaters, alcoves). Off-channel unit distinctions were used as a measure of floodplain connectivity. Estimates for low velocity rearing area (m^2) were generated using the basin visual estimation technique (BVET) developed by Dolloff et al. (1993). Lengths and widths were estimated for all fast-water and slow-water units, while every fifth unit of each type was estimated *and measured*. Measured values were used to calculate calibration coefficients for visual estimates made by individual crew members. Calibrations were also used to correct for slow and fast units separately.

Analysis

See survival modeling section on page 12.

Results

Fall Tagging Effort

To follow individual cohorts through the winter we PIT tagged young-of-the-year coho salmon over three years across three basins (Table 1). We attempted to spread PIT tags out evenly while accounting for individual reach lengths to ensure entire reaches were represented with tagged fish. We tagged fish across all reaches over the three years except lower Mill Creek in 2015. High flows during that fall prevented us from getting a tag group out in lower Mill Creek compromising our fall closure period. However, similar numbers coho salmon were tagged in each reach and basin across years (Table 1). The number of tags used for this study was determined by estimating potential overwinter survival coupled with reasonable estimates of detection probability at antennas and the spring outmigrant traps. This exercise was critical to ensure enough fall tagged fish were intercepted in the spring to obtain reasonable estimates of survival, growth, and emigration timing.

Table 1. Number of young-of-the-year coho salmon that received PIT tags during the falls of 2013 to 2015 across three northern California basins.

	# Pit Tagged Coho Salmon by Reach and Year			
Basin	**Reach**	**2013**	**2014**	**2015**
MILL CREEK	East Fork Mill	472	467	415
	West Branch Mill	493	550	406
	Mainstem Mill	477	368	0
	Totals:	**1442**	**1385**	**821**
PRAIRIE CREEK	Upper Prairie Creek	447	441	564
	Lower Prairie Creek	192	277	325
	Totals:	**639**	**718**	**889**
FRESHWATER CREEK	Freshwater Tributaries	421	237	266
	Upper Freshwater	566	483	428
	Lower Freshwater	322	252	315
	Totals:	**1309**	**972**	**1009**
Total Tags by Year:		**3390**	**3075**	**2719**

Wood Inventory

We estimated the total number and volume of large wood debris (LWD) throughout the seven study reaches across the three basins. Total counts of LWD were similar (range: 5205 to 5428 pieces) for all three basins despite having different reach lengths (Table 2). Mill Creek had the lowest average LWD occurrence per kilometer representing less than half of the average wood occurrence in Freshwater Creek. However, Mill Creek contained the largest average LWD volume by kilometer indicating the basin likely has much larger pieces of LWD on average (Table 2). Prairie Creek contained the most LWD exceeding 60 centimeters in diameter (19.9/ KM) followed by Mill Creek (18.0/ KM) and Freshwater Creek (15.0/ KM). Mill Creek contained the most consistent large pieces throughout all three reaches; both the lower Prairie Creek and lower Freshwater Creek reaches had very few large logs per kilometer compared to their upper reaches (Table 2).

Table 2. Summary statistics of large wood debris inventories across 56.3 kilometers in three basins, Humboldt and Del Norte counties, California.

Basin	Reach	Reach Length (km)	LWD Count (pieces)	LWD Count (pieces/km)	Volume (m^3)	Volume (m^3/km)	"XL" LWD (piece/km)
MILL CREEK	East Fork Mill	6.5	1511	231.1	496.4	75.9	17.6
	West Branch Mill	9.2	2661	289.5	1049.9	114.2	21.8
	Mainstem Mill	9.3	1033	111.3	862.5	92.9	14.7
	Totals:	**25.0**	**5205**	**208.1**	**2408.8**	**96.3**	**18.0**
PRAIRIE CREEK	Upper Prairie Creek	13.7	3906	284.4	1144.4	83.3	25.8
	Lower Prairie Creek	4.7	1430	301.6	255.1	53.8	8.2
	Totals:	**18.5**	**5336**	**288.4**	**1399.4**	**75.6**	**19.9**
FRESHWATER CREEK	Upper Freshwater	5.0	1625	323.6	683.8	136.2	27.9
	Lower Freshwater	7.8	3803	486.3	461.0	58.9	6.8
	Totals:	**12.8**	**5428**	**424.1**	**1144.8**	**89.4**	**15.0**

Low Velocity Habitat

We estimated the surface areas of all low-velocity and off-channel features during winter base-flow conditions throughout the seven study reaches across the three basins. The availability of reach-level low-velocity habitats ranged from 846 to 2185 meters squared per kilometer though overall basin totals were similar ranging from 1312 to 1494 meters squared per kilometer (Table 3). Mill Creek had the lowest fraction of low-velocity habitat relative to fast-velocity habitat equaling 12.1%. Prairie Creek and Freshwater Creek had much higher fractions of low-velocity habitats ranging from 18.7% to 19.0%, respectively. The amount of available off-channel aquatic habitats during winter base flow conditions differed in total area and the number of individual features between each basin. On average, Mill Creek contained over twice as much off-channel habitat area per kilometer than Freshwater Creek (Table 3). Both Mill Creek and Prairie Creek had similar densities of off-channel features per kilometer with freshwater creek having far fewer features (Table 3). These data, coupled with LWD will inform reach-based survival models on measured winter habitat heterogeneity. Hypothesis driven candidate models will explore the relationships of hydrology and LWD to winter habitat quality and floodplain connectivity.

Table 3. Summary statistics of low-velocity and off-channel habitats measured during winter base-flow conditions across 55.4 kilometers in three basins, Humboldt and Del Norte counties, California.

Basin	Reach	Reach Length (km)	Low Velocity Habitat (m^2/km)	Percent Low Velocity Habitat	Off Channel Habitat Area (m^2/km)	Off Channel Habitat (units/km)
MILL CREEK	East Fork Mill	6.5	979.3	9.3%	376.5	11.2
	West Branch Mill	9.2	924.9	11.2%	434.2	19.0
	Mainstem Mill	8.4	2185.2	14.1%	569.5	5.2
	Totals:	**24.1**	**1379.7**	**12.1%**	**459.4**	**12.1**
PRAIRIE CREEK	Upper Prairie Creek	13.7	1369.0	19.5%	318.5	11.1
	Lower Prairie Creek	4.7	1859.3	17.2%	473.3	10.1
	Totals:	**18.5**	**1494.9**	**18.7%**	**358.2**	**10.9**
FRESHWATER CREEK	Upper Freshwater	5.0	846.3	15.9%	146.8	10.2
	Lower Freshwater	7.8	1611.3	20.4%	238.0	5.2
	Totals:	**12.8**	**1312.1**	**19.0%**	**202.4**	**7.2**

Overwinter Growth Rates

Daily overwinter growth rates were summarized using fall tagged coho salmon that were captured subsequently as smolt's in outmigrant traps during the spring (Figure 3). Growth rate patterns appear to vary consistently by size class, basin, and year. For example, 2015 growth rates were consistently larger than the previous two years regardless of basin or fish size category (Figure 3). Additionally, fish from the smallest size category, grew consistently faster than larger size classes independent of basin and year, indicating non-linier growth patterns (Figure 3). These data will be important to consider relative survival models since growth data may provide additional explanatory value to reach-specific survival estimates.

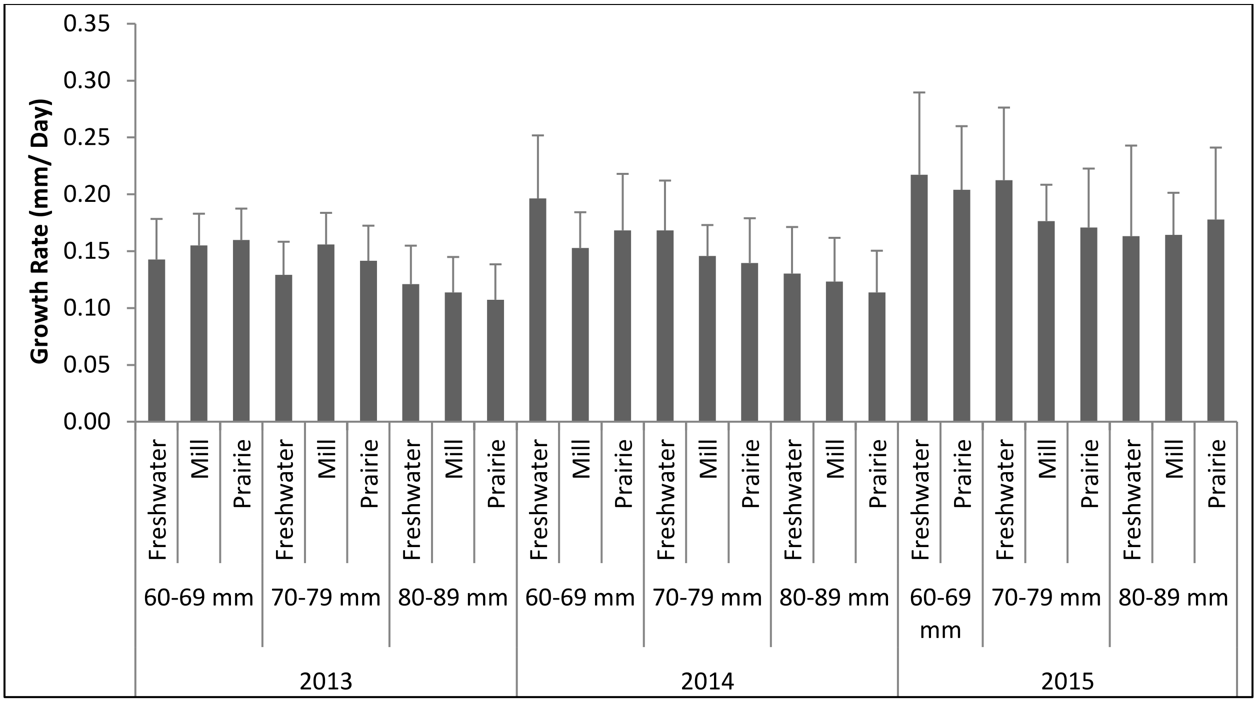

Figure 3. Mean winter growth rates of juvenile coho salmon across three basins from the winters of 2013, 2014, and 2015. Error bars represent one standard deviation from the mean growth rate. Growth is summarized by three separate size bins of coho salmon at first capture due to differences in size-specific growth rates. Smaller individuals grew at a faster rate on average than larger individuals independent of basin or year.

Migration Timing

Multiple PIT tag antennas were operated year-round on Mill, Prairie and Freshwater Creeks near or downstream of each creek mouth to monitor emigration timing within and among basins. Antenna detections show emigration occurred moderately throughout each winter with two peak migration periods in fall and spring (Figure 4). Fall emigration occurred concurrently with short periods of elevated discharge from the first fall freshets in all basins each year. Alternatively, peak spring emigration occurred relatively independent from discharge. Prairie and Freshwater Creek temporal emigration patterns typically showed a few small clusters of fall emigrants followed by a much larger group moving out in the spring, however, Mill Creek migration timing was less clear. During the first two study years, the number of detected emigrants was muted during fall and spring periods. In 2015, two additional antenna arrays were installed on two small tributaries near the Smith River estuary significantly improving our ability to detect early emigrants from Mill Creek (*see Figure 9 in* Parish and Garwood 2016). The marked increase in emigrants per day detected from Mill Creek (Figure 4) during 2015-16 season suggests that coho salmon early emigration rates throughout coastal Northern California are variable across basins and could be relatively high in Mill Creek. Accounting for early emigration in over-winter survival models is essential to obtaining unbiased survival estimates given fish that leave a subbasin early would otherwise be assumed to have suffered increased mortality after accounting for detection rates.

Although multiple PIT tag antenna arrays were utilized near the outlet of each basin to estimate survival and emigration rates, additional arrays were operated year-round in upper Mill (2), Prairie (1) and Freshwater (5) Creeks. While observation data from these sites is not specifically useful for our CJS survival model, summarized intra-basin detections are valuable for answering questions

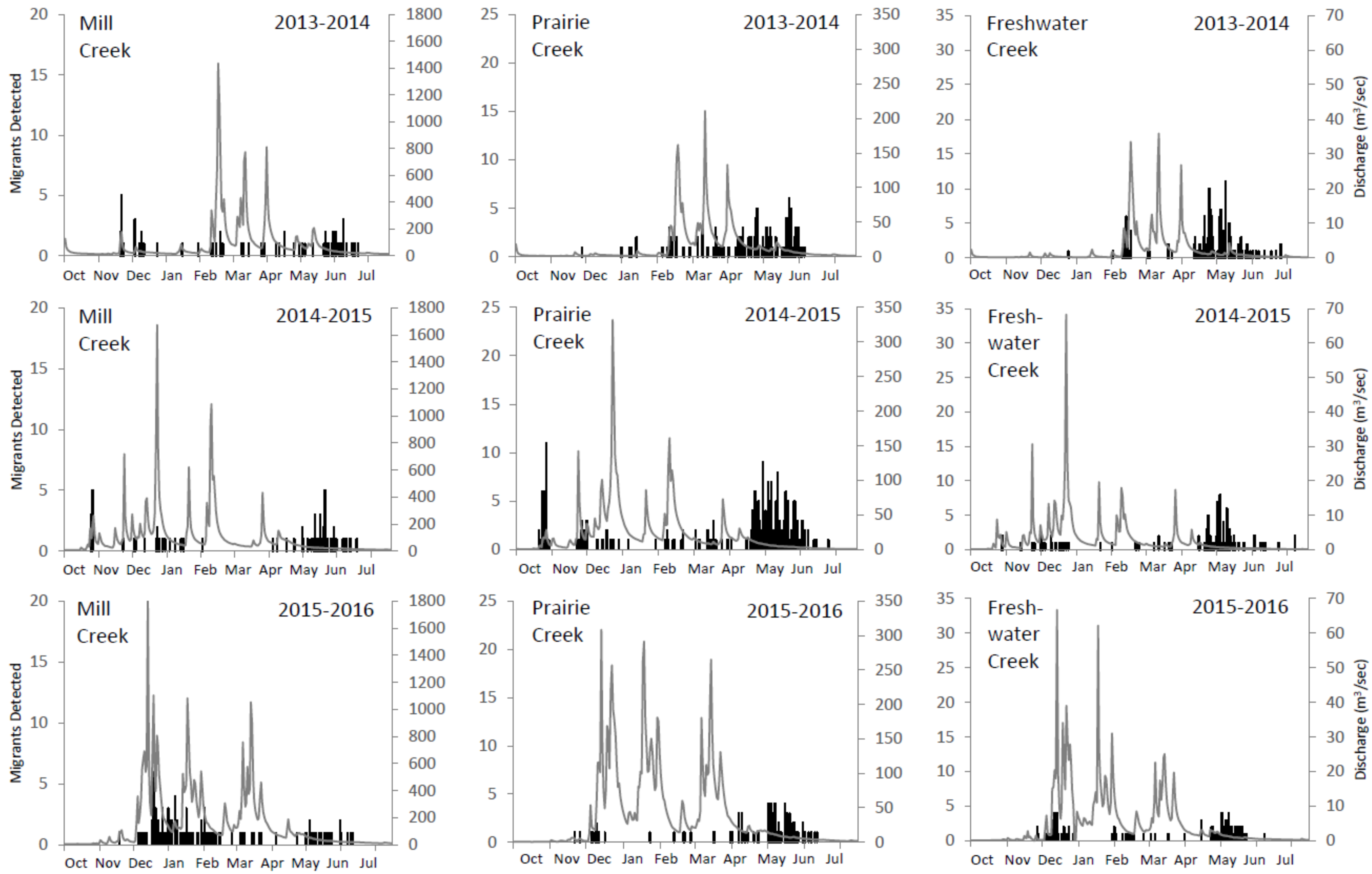

Figure 4. Observed temporal patterns of juvenile Coho Salmon emigration past antenna arrays shown as emigrants per day indicated by black bars (primary *y*-axis) in Mill, Prairie and Freshwater Creeks. The gray line displays daily average discharge from the nearest flow gage (USGS) to each basin (secondary *y*-axis).

related to coho salmon movement and spatial distributions. Table 4 summarizes intra-basin movements by counts of individuals from specific reaches that were observed at *any* antenna in the basin. Counts are categorized as early detections, n_e (i.e. detected before typical spring trapping begins on March 15th) or spring detections, n_s (i.e. detected after trapping begins). The percent early detections, $n_e/(n_e+n_s)$, can be interpreted as a relative measure of whether more movement was detected before spring versus during spring. For example, a value > 50% indicates more individuals were detected on antennas outside of their tagging reach before spring than during spring.

Similar to Figure 3 which suggests individual coho salmon from Mill Creek had a higher tendency to emigrate earlier than those in Freshwater and Prairie Creeks, a similar pattern exists in Table 4. The Mill Creek basin overall showed higher percent early detections than Prairie and Freshwater Creeks during all three years. While early movements appear to vary by basin, they show an even stronger relationship with location within each watershed. For example, the mainstem Mill Creek tag group expressed a higher tendency to emigrate from the reach early that did the East Fork and West Branch tag groups. Although raw counts of movements fail to account for variance in detection and survival probabilities across basins and years, these results further emphasize the need to execute a multi-basin modeling strategy to increase our confidence of what we observed.

Survival Model Development

The numerous objectives of our project could be summed up in two overarching goals: (1) Assess overwinter survival of juvenile coho salmon and its variability across coastal California streams which vary in a range of land use/ownership types. (2) Attain a quantitative evaluation of instream fish habitat (i.e. LWD and low-velocity rearing availability) to compare with basin and reach specific overwinter survival. These parameters will help managers understand how restoration practices should applied relative to specific stream conditions with the goal of maximizing juvenile coho salmon survival. Based on coho salmon survival and emigration work completed regionally by Ricker and Anderson (2011) and Rebenack (2015), we set out to achieve our goals within the watershed boundaries of Mill, Prairie and Freshwater creeks. The modeling approach that was originally presented in the League grant(s) subsequently could not fulfill the overall objectives of the project. Because of the complexities of the parameter estimation, we changed our approach to a different statistical theory (Bayesian) and software (WinBUGS/JAGS) which has taken extra time to learn apply.

Cormack-Jolly Seber (CJS) capture-recapture models (Lebreton and Pradel 2002) are being used to estimate annual probabilities of capture, over-winter survival, and emigration of PIT tagged juvenile coho salmon. When evaluating the effects of stream-based habitat variables on a response variable (overwinter survival) it is crucial to account for other environmental of behavioral effects on survival variability. Survival estimation of overwintering coho salmon is problematic if mortality and emigration from the study area cannot be estimated separately. In cases where spring downstream migrant traps are relied upon to detect juveniles for survival estimation, results are biased if individuals emigrate before spring. Thus, early emigrants must be accounted for to accurately understand the relationship between the survival of stream-dwelling coho salmon and their winter habitat.

The general arrangement for utilizing CJS models to estimate overwinter survival of Coho Salmon used by Rebenack et al. (2015) is being followed which includes a tagging effort each fall before the first seasonal freshets. Throughout each year multiple PIT tag antennas were operated on Mill, Prairie and Freshwater Creeks downstream of the tagging locations to detect individuals leaving

Table 4. Basin- and reach-specific counts of juvenile Coho Salmon detected leaving their tagging reach before March 15th (n_e) or during spring (n_s). Values for early detection greater than 50% indicate more individuals were detected leaving their tagging reach early that during spring. Note: percentages represent raw detection histories and do not account for survival or detection probabilities.

Year / BASIN / Reach	Fall Tagged Coho	Early Detections (n_e)	Spring Detections (n_s)	Percent Early Detection $n_e/(n_e+n_s)$
2013-14				
MILL CREEK	**1431**	**102**	**69**	**59.6%**
East Fork Mill	472	24	33	42.1%
West Branch Mill	491	37	27	57.8%
Mainstem Mill	468	41	9	82.0%
PRAIRIE CREEK	**637**	**95**	**215**	**30.6%**
Upper Prairie Creek	447	80	193	29.3%
Lower Prairie Creek	190	15	22	40.5%
FRESHWATER CREEK	**705**	**182**	**232**	**44.0%**
Freshwater Tributaries	191	47	87	35.1%
Upper Freshwater	293	82	78	51.3%
Lower Freshwater	221	53	67	44.2%
2014-15				
MILL CREEK	**1385**	**73**	**83**	**46.8%**
East Fork Mill	467	31	34	47.7%
West Branch Mill	550	30	41	42.3%
Mainstem Mill	368	12	8	60.0%
PRAIRIE CREEK	**718**	**126**	**149**	**45.8%**
Upper Prairie Creek	441	78	107	42.2%
Lower Prairie Creek	277	48	42	53.3%
FRESHWATER CREEK	**500**	**98**	**181**	**35.1%**
Freshwater Tributaries	105	13	41	24.1%
Upper Freshwater	170	35	66	34.7%
Lower Freshwater	225	50	74	40.3%
2015-16				
MILL CREEK	**821**	**112**	**81**	**58.0%**
East Fork Mill	415	69	32	68.3%
West Branch Mill	406	43	49	46.7%
Mainstem Mill	0	N/A	N/A	N/A
PRAIRIE CREEK	**504**	**38**	**94**	**28.8%**
Upper Prairie Creek	241	9	66	12.0%
Lower Prairie Creek	263	29	28	50.9%
FRESHWATER CREEK	**329**	**61**	**61**	**50.0%**
Freshwater Tributaries	61	10	12	45.5%
Upper Freshwater	107	17	25	40.5%
Lower Freshwater	161	34	24	58.6%

the basins. Additionally, downstream migrant traps were used during the spring as another detection point to compliment PIT tag antenna data.

A CJS Bayesian mixed effects model adapted from Kéry and Schaub (2012) is being implemented using JAGS (Plummer 2016) modeling software to estimate the effects reach-specific stream habitat has on the overwinter survival of Coho Salmon tagged within the reaches in the fall. Nested random group effects for basin and reach will be specified in the model to account for variation in overwinter survival due to basin and reach. Fish fork length and instantaneous growth rates will also be included as continuous individual covariates in the model. Modeling in the Bayesian framework facilitates the implementation of random effects through use of BUGS (Bayesian inference Using Gibbs Sampling) language (Kéry and Schaub 2012). For more information on using Bayesian versus frequentist modeling techniques, see Ellison (2004) and Kéry and Schaub (2012).

Outreach and Contributions to Other Studies

Information gathered from this study has been disseminated on multiple occasions to a wide group of stakeholders over the past three years including two Mill Creek Advisory Committee Meetings, two Smith River Advisory Council Meetings, one Del Norte County Resource Conservation District Meeting, and numerous California Department of Fish and Wildlife meetings concerning the development of coho salmon life-cycle monitoring stations. For example, State Parks staff are tracking LWD in Mill Creek as it relates to previous wood loading projects in East Fork Mill Creek. They intend to use the LWD data and protocol from this effort to secure future funding for a full LWD census of all anadromous waters to inform future strategic wood loading projects. Other concurrent studies used the League funded coho salmon tag data generated by the Mill Creek coho salmon survival program. Products from these studies include:

Parish, M. and J. Garwood. 2015. Distribution of juvenile salmonids and seasonally available aquatic habitats within the lower Smith River basin and estuary, Del Norte County, California. Final Report to the California Department of Fish and Wildlife, Fisheries Grants Restoration Program, Contract: P1310518. Smith River Alliance, Crescent City, CA. 62p.

Walkley, J., J. Deibner-Hanson, and J. Garwood. 2015. *2015 Mill Creek LCM station-juvenile coho salmon outmigrant trapping project, Smith River, California*. Annual Progress Report to the California Department of Fish and Wildlife Fisheries Restoration Grants Program, Grantee agreement: P1410547. Smith River Alliance, Crescent City, CA. 14p.

Parish, M. and J. Garwood. 2016. *Winter distributions, movements, and habitat use by juvenile salmonids throughout the lower Smith River basin and estuary, Del Norte County, California*. Final Report to the California Department of Fish and Wildlife, Fisheries Grants Restoration Program, Contract: P1410545. Smith River Alliance, Crescent City, CA. 51p.

Walkley, J. and J. Deibner-Hanson, 2017. *2016 Mill Creek LCM station-juvenile coho salmon outmigrant trapping project, Smith River, California*. Annual Progress Report to the California Department of Fish and Wildlife Fisheries Restoration Grants Program, Grantee agreement: P1410547. Smith River Alliance, Crescent City, CA. 14p.

Literature Cited

Bennett, T. and R. Wissmar. 2011. Fall and spring emigration timing of juvenile coho salmon from East Twin River, Washington. Northwest Science 85: 562-570.

Bisson, P. A., K. Sullivan, and J. L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society, 117:262-273.

Bouwes, N. et al. 2011. Scientific protocol for salmonid habitat surveys within the Columbia Habitat Monitoring Program. Prepared by the Integrated Status and Effectiveness Monitoring Program and published by Terraqua, Inc., Wauconda, WA. 118 pages.

Brown et al. 1994. Historical decline and current status of coho salmon in California. North American Journal of Fisheries Management 14: 237-261.

California Department of Parks and Recreation. 2010. Del Norte Coast Redwoods State Park Preliminary General Plan Amendment/Final Environmental Impact Report: Mill Creek Addition.

California Department of Parks and Recreation. 2011. Local watershed plan: Mill Creek property and watershed. Del Norte Coast Redwoods State Park. 95p.

Cannata, S., R. Henly, J. Erler, J. Falls, D. McGuire, and J. Sunahara. 2006. Redwood Creek watershed assessment report. Coastal Watershed Planning and Assessment Program and North Coast Watershed Assessment Program, California Resources Agency and California Environmental Protection Agency, Sacramento, California.

CDFG. 2002. Status review of California coho salmon north of San Francisco. Report to California Fish and Game Commission.

CDFG 2004. Recovery strategy for California coho salmon. 594p.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. (April 2) Basinwide estimation of habitat and fish populations in streams. USDA Forest Service General Technical Report, SE-83.

Ellison, A. M. 2004. Bayesian inference in ecology. Ecology Letters 7:509-520.

Fiori, R. A., J. Beneger, S. S. Beesley, T. B. Dunklin, C. Moore, D. Gale, and S. Nova. 2009 (April 2). Preliminary Evaluation of Experimental Wood Loading Performance Following a Five Year Flood Event. American Fisheries Society Cal/Neva Conference. Santa Rosa, CA.

Green, C. J, Hall, K. Guilbault, and T. Quinn. 2010. Improved viability of populations with diverse life-history portfolios. Biology Letters 6(3): 382-386.

Hawkins, C. P., J. L. Kershner, P. A. Bisson, M. D. Bryant, L. M. Decker, S. V. Gregory, D. A. McCullough, C. K. Overton, G. H. Reeves, R. J. Steedman and M. K. Young. 1993. A hierarchial approach to classifying stream habitat features. Fisheries 18:3-12.

Kéry, M., and M. Schaub. 2012. Bayesian population analysis using WinBUGS: A hierarchical perspective. Academic Press, Waltham, Massachusetts.

Madej, M.A., O'Sullivan, C. and N. Varnum. 1986. An Evaluation of Land Use, Hydrology, and Sediment Yield in the Mill Creek Watershed. Northern California, Redwood National Park Research and Development Technical Report Number 17, 66 p.

Mull, K.E., and Wilzbach, M.A. 2007. Selection of spawning sites by coho salmon in a northern California stream. North American Journal of Fisheries Management 27: 1343-1354.

Lebreton, J. D., R. Pradel. 2002. Multistate recapture models: modeling incomplete individual histories. Journal of Applied Statistics, 29(1–4): 353–369.

Parish, M. and J. Garwood. 2016. Winter distributions, movements, and habitat use by juvenile salmonids throughout the lower Smith River basin and estuary, Del Norte County, California. Final Report to the California Department of Fish and Wildlife, Fisheries Grants Restoration Program, Contract: P1410545. Smith River Alliance, Crescent City, CA. 51p.

Plummer, M. 2016. JAGS version 4.2.0 manual. Available: http://mcmc-jags.sourceforge.net/. (February 2017).

Rebenack, J. J., and S. Ricker, C. Anderson, M. Wallace, D. Ward. 2015. Early emigration of juvenile Coho Salmon: implications for population monitoring. Transactions of the American Fisheries Society, 144:163-172.

Rentmeester, S. 2014. Large wood volume calculation v1.0. Monitoring Resources. Available: https://www.monitoringresources.org/Document/Method/Details/872. (April 19, 2014).

Ricker, S., and C. Anderson. 2011. Freshwater Creek salmonid life cycle monitoring station, annual report, January, 2011. California Department of Fish and Wildlife: Anadromous Fisheries Resource Assessment and Monitoring Program, Arcata, California.

Roni, P., G. Pess, T. Beechie and S. Morley. 2010. Estimating changes in coho salmon and steelhead abundance from watershed restoration: how much restoration is needed to measurably increase smolt production? North American Journal of Fisheries Management. 30(6): 1469-1484.

Roni, P. T. Bennett, R. Holland et al. 2012. Factors affecting migration timing, growth, and survival of juvenile coho salmon in two coastal Washington watersheds. Transactions of the American Fisheries Society 141: 890-906.

Stillwater Sciences, 2002. Mill Creek Property, Interim Management Recommendations. Prepared for Save the Redwoods League, San Francisco, California and the California Coastal Conservancy. Oakland, California.

USFS (United States Forest Service). 1995. A guide to field identification of bankfull state in the western United States. (31-minute video) USDA Forest Service, Stream Systems Technology Center, Fort Collins, CO.

Zydlewski, G. B., G. Horton, T. Dubreuil, B. Letcher, S. Casey, and J. Zydlewski. 2006. Remote monitoring of fish in small streams: a unified approach using PIT tags. Fisheries 31(10):492–502.