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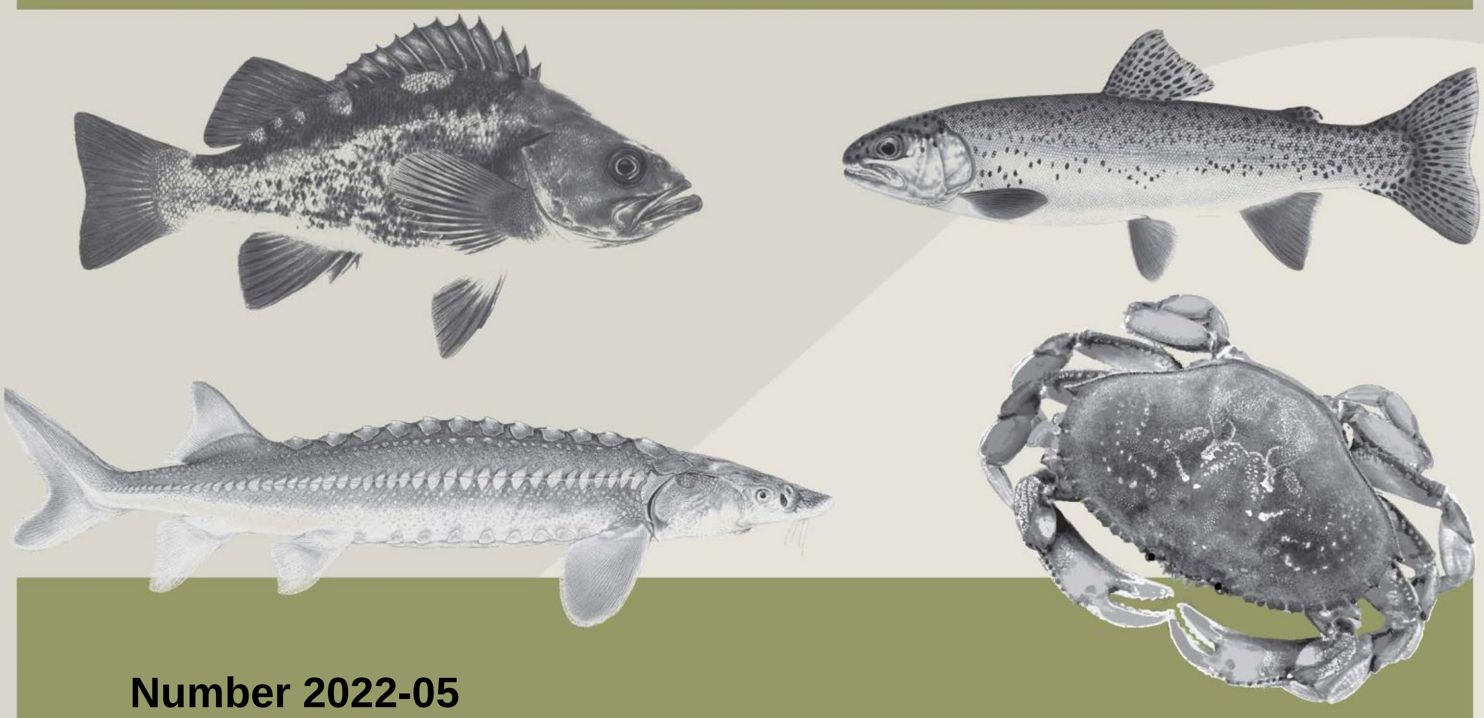

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Stream Habitat Conditions in the Lower Columbia ESU, 2007-2016

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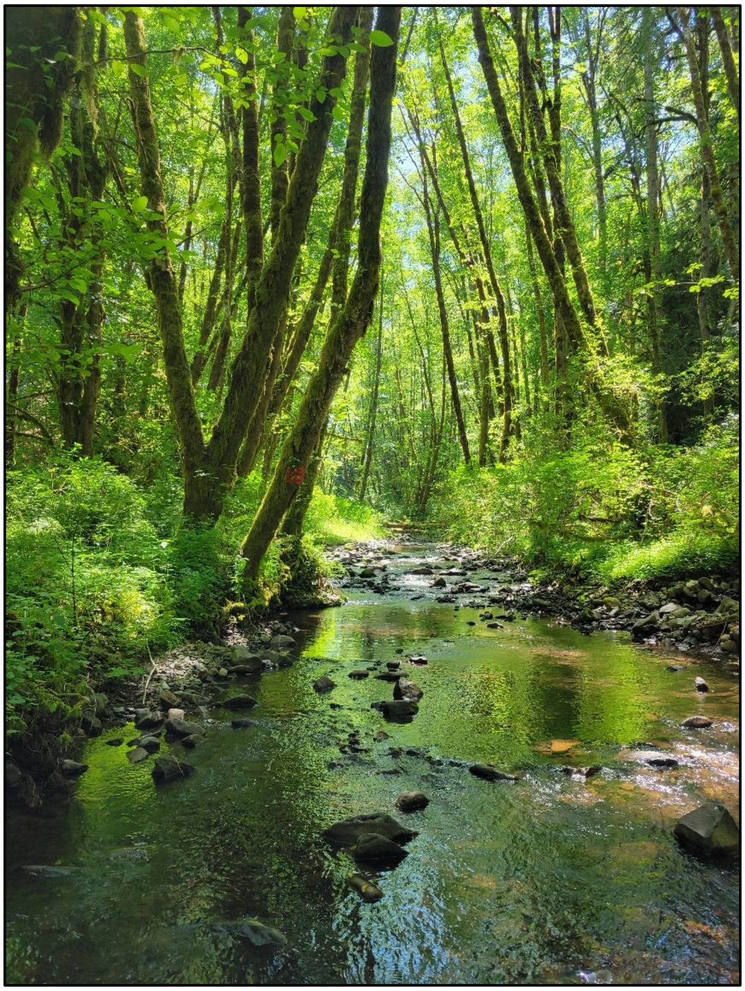

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CONTENTS

ABSTRACT

This report discusses the findings from aquatic habitat and juvenile salmonid surveys conducted between June and September during a ten-year period from 2007-2016 within the Lower Columbia Evolutionary Significant Unit (ESU). The Lower Columbia ESU is composed of three monitoring strata and eight populations. We described habitat conditions and snorkel counts of juvenile salmonids across survey years to assess progress towards desired recovery metrics for coho salmon (*Oncorhynchus kisutch*) established in the 2010 Lower Columbia Conservation and Recovery Plan. Habitat attributes were evaluated for regional trend at the stratum scale and compared to benchmark values to evaluate condition. The majority of median values for habitat attributes fell within reference thresholds defined by the 25th and 75th percentiles. The notable exception was wood volume which was low and appears to be related to surrounding land use and lithology. Trend results showed a decrease in amount of gravel in substrate across monitoring strata and an increase in the habitat capacity to support coho parr during the winter within the Cascade/Gorge stratum. We assessed the precision of individual habitat attributes by resurveying approximately ten percent of surveyed sites from 2007-2011. Results of a mixed linear model evaluating the resurveyed sites revealed habitat attributes are of sufficient precision and can be viewed as accurate across subsequent sampling years. We used the Habitat Limiting Factors Model (HLFM) to describe the available capacity and relative quality of habitat for juvenile coho salmon across the ESU, monitoring strata, land use, geology, populations, and by year. Results of the modeled habitat capacity estimates revealed a range of 835 to 1,076 parr/km across the ESU by year. These results varied when evaluated within monitoring strata or by population across sampling years but overall, the relative quality of rearing habitat could be described as low (<900 parr/km) or moderate (900-1,850 parr/km). Results of an analysis of variance (ANOVA) test suggest differences in these capacity estimates occur at the population scale or by dominant land use. The amount of high-quality rearing habitat (>1,850 parr/km) across the ESU ranged from 8.87% to 16.59% of all available coho salmon habitat by year. These estimates had the widest ranges within populations, and the tributaries in the Lower Gorge stratum had the highest percentage of available high-quality habitat across total accessible coho rearing or spawning habitat. No high-quality habitat was found in the Hood River population. Juvenile coho salmon site occupancy and abundance estimates were described by spawner year at the ESU scale. These results were derived from snorkel surveys that overlapped directly with the habitat surveys described in this report. Paired t-tests did not indicate a difference in site occupancy across spawner groups, although average abundance did decrease over the sampling period. In addition, juvenile abundance estimated from the summer snorkel counts did not exceed the summer habitat capacity at the ESU or strata scale. These results would indicate habitat quality and capacity at the population scale or within land use types are likely driving juvenile coho abundance within the Lower Columbia ESU. We compared the results of high-quality habitat and juvenile coho salmon occupancy from this report with delisting and recovery thresholds outlined in the 2010 Conservation and Recovery Plan and found these metrics have not increased to the extent desired for coho recovery.

INTRODUCTION

In 2006, monitoring programs associated with the Oregon Plan for Salmon and Watersheds (OPSW) began assessing the status and trends in fish populations (specifically coho salmon) and aquatic habitat in Oregon's Lower Columbia Evolutionary Significant Unit (ESU). The Oregon Plan was initiated in response to the petition to list coho salmon (*Oncorhynchus kisutch*) as threatened under the Endangered Species Act (ESA) in 1997. Through coordinated surveys we can evaluate freshwater habitat, fish distribution, and abundance of juvenile and adult coho salmon and steelhead trout. Stream habitat and juvenile salmonid snorkel surveys provide the broadest geographic scope of inference and tie to other program components – basin or census habitat surveys, surveys at habitat restoration sites, adult coho salmon surveys, and ODFW life cycle watersheds. While one of the primary intentions of the habitat surveys is to describe instream conditions for anadromous fish, a broad understanding of stream conditions is also achieved.

The Lower Columbia ESU consists of three monitoring strata and eight populations. The Coast stratum includes four populations: Youngs Bay, Big Creek, Clatskanie River, and Scappoose Creek. The Cascade stratum includes the Clackamas River and Sandy River populations, and the Gorge stratum includes the Lower Gorge tributaries and Hood River populations.

From 2007-2016, sites were selected within the distribution of coho salmon and steelhead spawning and rearing and were surveyed in conjunction with the Western Oregon Rearing Project. Sites were sampled between June and September each year for stream habitat and juvenile fish. Beginning in 2015, sites above the distribution of salmon and steelhead were incorporated into the sample frame to describe habitat conditions upstream of anadromous salmonid rearing and spawning habitats to provide a comprehensive perspective of habitats and fish populations throughout the drainages.

Stream habitat metrics include measures of channel morphology, instream substrate composition, and wood abundance. Fish metrics include measures of juvenile coho densities and distribution. At sites that fall outside the anadromous distribution of salmon, we electrofish to assess fish presence or absence. Using habitat metrics, we also calculate the capacity of the habitat to rear juvenile coho salmon and used that value in our evaluation of high-quality habitat (Habitat Limiting Factors Model (HLFM), Nickelson 1998). Data are summarized at the population, strata, and ESU scale.

In the Lower Columbia River Conservation and Recovery Plan (2010), ODFW identified a desired status of stream habitat conditions for Lower Columbia ESU coho salmon populations. Targets for stream habitat criteria were set to assess progress toward two different recovery goals: delisting and broad sense recovery. The delisting goal is to achieve delisting from the federal endangered species list. Broad sense recovery represents a status significantly beyond delisting and is defined as populations of naturally produced coho salmon sufficiently abundance, productive and diverse that the ESU as a whole (a) will be self-sustaining and (b) will provide significant ecological, cultural, and economic benefits. In the plan, population scale delisting scenarios were created for tributary habitat based on the amount of available high-quality habitat and current abundance estimates compared to historic estimates. High quality habitat is described as habitat capable of producing ≥ 1,850 parr/km. This represents the number needed for adult spawners to replace themselves during extended periods of low marine survival (Oregon Department of Fish and Wildlife 2007). We used the Habitat Limiting Factors Model (HLFM) to calculate the amount of high-quality habitat available based on stream conditions across the Lower Columbia ESU. Because winter rearing habitat has been identified as limiting (Nickelson and Lawson 1998, Chilcote et al., 2005, and Ebersole et al. 2006), we calculated the capacity of the habitat to rear juvenile coho salmon and used that value in our evaluation of high-quality habitat.

This report discusses the findings from aquatic habitat and juvenile salmonid snorkel surveys conducted between June and September in a ten-year period from 2007-2016 in drainages within the Lower Columbia ESU. Our objectives are to (1) describe and evaluate channel morphology, instream habitat and complexity, and riparian conditions in the ESU, (2) quantify and summarize the habitat capacity for juvenile coho salmon, (3) compare stream conditions and habitat capacities to benchmark values, (4) compare juvenile coho salmon densities to modeled habitat carrying capacity, and (5) assess progress towards desired status of habitat.

For this report, we summarize the ten-year findings for the Lower Columbia ESU:

1. Describe status of the channel morphology, substrate composition, instream wood, and riparian structure in all wadeable streams in coastal drainages.
2. Evaluate trends in selected habitat variables over ten years.
3. Describe fish community at sites outside the expected anadromous distribution.
4. Extrapolate findings to all streams within the sample frame and post stratify sites based on coho distribution, geology, and land use to describe conditions within these strata.
5. Use regression models to compare original surveys and resurveys to determine precision and accuracy of individual attribute estimation.
6. Describe presence of beaver, mass wasting, habitat structures, and debris jams.
7. Estimate the potential summer and winter capacity of the habitat for coho salmon with the Habitat Limiting Factors Model (HLFM) version 7.0 (Version 5.0 in Nickelson et al. 1992).
8. Describe habitat quality for coho salmon with the HabRate model (Burke et al. 2010).
9. Compare the observed juvenile coho salmon density with the predicted summer parr capacity estimated from the HLFM.
10. Compare existing condition and trends with desired conditions for delisting and broad sense recovery as specified in the Lower Columbia River Conservation and Recovery Plan.

METHODS

Study Area and Site Selection

Oregon Plan habitat survey sites were selected within Oregon watersheds draining into the Columbia River west of and including the Hood River population. The region is divided into three monitoring strata (Gorge, Cascades, and Coast) which constitute the extent of the Lower Columbia ESU. Within these strata in Oregon, eight historical independent coho populations were surveyed; four in the Coast (Big Creek, Clatskanie River, Scappoose Creek, and Youngs Bay), two in the Cascades (Clackamas and Sandy), and two in the Gorge (Hood River and Lower Gorge Tributaries) (Figure 1).

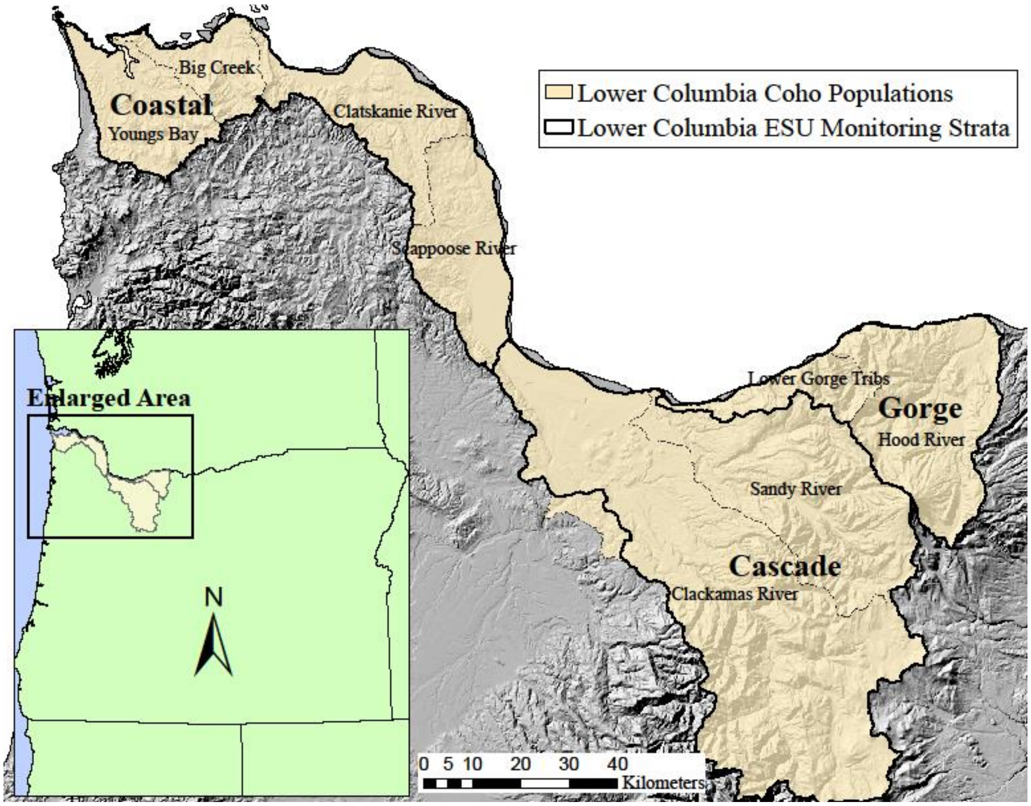

Figure 1. Lower Columbia ESU individual monitoring strata and population areas.

Survey locations, or sites, were selected based on a Generalized Random Tessellation Stratification (GRTS) design using a 1:24,000 scale digitized stream network (Stevens 2002). Sites were assigned to a rotating panel, where surveys occur annually, every three years, nine years or once only. The target number of sites to monitor is proportional to the number of stream miles in each stratum (approximately 50 sites within the Coastal and Cascade strata and approximately 10 sites within the Gorge stratum). Sites are approximately one kilometer in length and delineated based on valley and channel characteristics.

Stream Habitat Surveys

Aquatic habitat surveys were conducted in the field from mid-June through late September (Moore et al. 2007). Survey reaches were either 500 meters or one kilometer in length depending on whether they were outside or within the current coho salmon distribution, respectively (Figure 2).

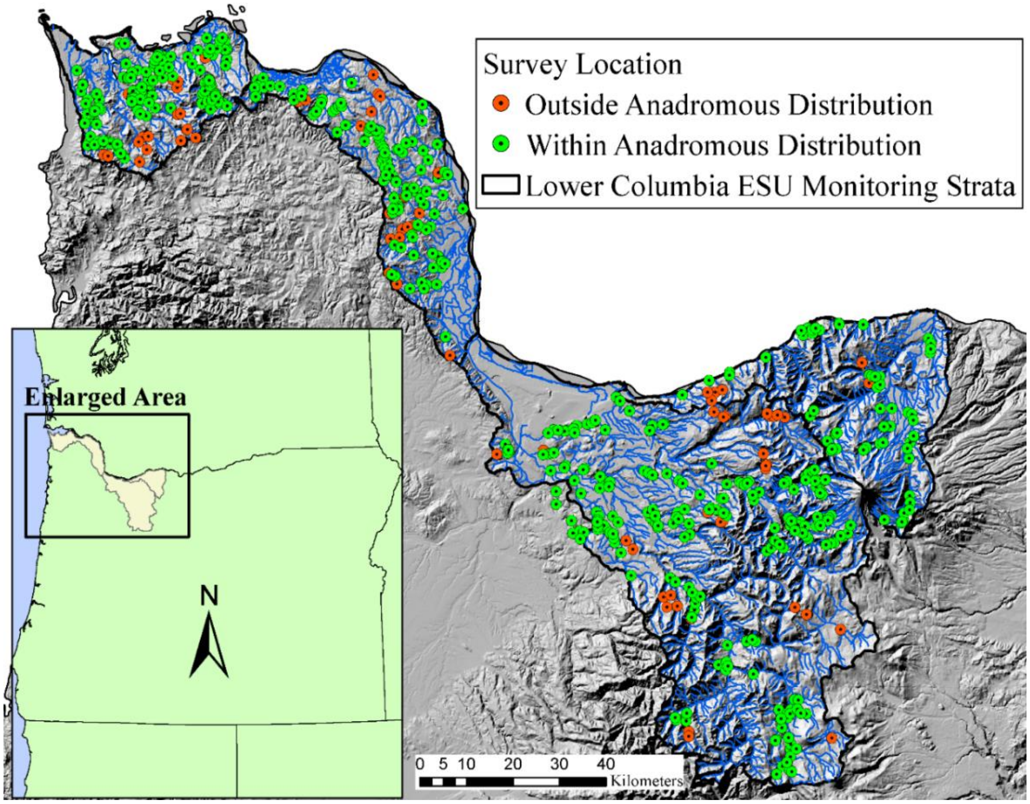

Figure 2. Survey locations from 2007-2016 within the distribution of anadromy and outside the distribution of anadromy from 2015-2016.

Surveys were summarized at the reach level to describe channel morphology and the physical structure of stream channel habitat, substrate compositions, instream wood, and the adjacent riparian vegetation.

Electrofishing Surveys

At sites upstream of the known distribution of coho salmon, fish were sampled using a backpack electrofisher. At least three pools and three fast water units totaling up to 60 meters were electrofished to determine fish species composition. Electrofishing settings were determined by using Appendix 5: Electroshocking Protocols outlined in the Aquatic Inventories Project Methods for Stream Habitat and Snorkel Surveys manual.

Site Statistics

Habitat attributes (Table 1) were chosen from field metrics to describe the status of instream and riparian conditions and quality within the ESU and monitoring strata from 2007–2016. The total number of target sites selected, surveyed, and not surveyed were summarized by year and geographic region (strata). From 2007–2011, 10% of the total number of survey sites in each monitoring strata were re-surveyed. Surveyed habitat attributes were compared to those that were re-surveyed using a linear mixed model *(*R Development Core Team 2006). To assess the precision of habitat attributes, we used a linear mixed model to estimate the proportion of variance attributed to site, year, resurvey, and residual error. We also compared adjusted R^2 estimates. These values were considered when selecting habitat attributes for further analysis.

Table 1. Habitat attributes used in report analyses, categorized by general stream template grouping.

Habitat Category	Habitat Attribute
Channel and Valley Form	Valley width Index
	Active channel height (m)
	Active channel width (m) *
	Channel gradient (%) *
	Width: Depth Ratio
Stream Morphology	Primary channel length
	Primary channel area
	Secondary channel length
	Secondary channel area (%) *
	Pool habitat (%) *
	Slackwater pool habitat (%) *
	Residual pool depth (m) *
	Riffle depth (m)
	Units per 100 m
	Number of pools
Substrate Composition	% Fines (weighted by habitat unit area) *
	Sand and organics in riffle habitat units (%)
	% Gravel (weighted by habitat unit area) *
	Gravel in riffle habitat units (%)
	% Bedrock (weighted by habitat unit area) *
In-stream Wood	Number of wood pieces *
	Wood volume (m^3) *
	Number of large wood key pieces *

* Habitat attributes with ANOVA results.

We quantified the total number of observed occurrences of habitat restoration structures, beaver dams, debris jams, and mass wasting events (i.e., landslides). We described the distribution of surveys across land use types within populations using a United States Geological Survey (USGS) land use coverage layer in a Geographic Information System (GIS). Land use categories were as follows: agriculture, federal forest, private forest, state forest, urban, and other (mix of parks, military, and Native American holdings). Petrology was assessed using a USGS GIS geology layer (Walker et al. 2003) to identify the following petrology types: intrusive, metamorphic, sedimentary, volcanic, and glacial drift. A 1,000-meter buffer was created around individual sites to identify both dominant land use and rock type.

Habitat Status and Trends

Analysis of variance (ANOVA) tests were conducted on a selection of habitat attributes within the distribution of coho salmon to evaluate whether differences existed between monitoring strata, lithology and land use type, and individual sampling years.

To provide comparative context for evaluating percent substrate, pool habitat, secondary channels, and large wood metrics within the range of coho salmon spawning and rearing habitat we used reference values derived from a multi-agency effort to standardize setting reference conditions (Miller et al. 2016). Reference sites were selected to represent areas of least human disturbance or the most natural state. Once those sites were chosen, we extracted the 25th and 75th percentile values of a given habitat metric to compare with current data. It should be noted, reference sites described in Miller et al. 2016 only fell within our categories of sedimentary or volcanic rock so we did not compare reference thresholds with habitat data associated with intrusive, metamorphic, or glacial drift.

In addition, we used a linear mixed model to evaluate sites surveyed two or more times during the sampling period for trend detection on selected habitat metrics. All analyses were performed using R software (R Development Core Team 2006).

Habitat Capacity and Quality

To evaluate habitat capacity (estimated as parr/km) with respect to production potential of juvenile coho salmon, we used the Habitat Limiting Factors Model (Nickelson et al. 1992, Nickelson 1998, and Anlauf et al. 2007). The model was used to estimate summer and winter habitat capacities (parr/km) at each site for coho salmon by applying a density of juvenile coho salmon to each habitat unit and multiplying by the surface area of the habitat unit. The capacities are therefore an integrated variable that emphasizes stream habitat features. Summer habitat capacity is primarily a function of the amount of total pool habitat, while winter habitat capacity is influenced most by the amount of beaver-influenced and off-channel pool habitats, and complex scour pools. We used a modeled relationship to obtain winter parr estimates from summer habitat data (Anlauf et al. 2009). Stream capacity to support juvenile coho salmon during the winter was considered high if the value exceeded 1,850 parr/kilometer and low if the value was below 900 parr/kilometer. We also used ANOVA to evaluate differences in winter parr capacity across years. Only sites within the distribution of coho salmon were evaluated.

The average winter parr capacity (winter parr/km) and the lower and upper 95% confidence intervals (CI) were calculated at the ESU, stratum and population scales. The total kilometers of high-quality habitat were also estimated for the ESU, stratum and population scales. To calculate this value, the total number of sites that exceeded the high-capacity value (1850 parr/km) was multiplied by the site weight. The site weight is the total number of kilometers of coho salmon spawning and rearing habitat at the evaluated scale divided by the total number of sites surveyed. An error estimate of the kilometers of high-quality habitat was calculated based on the 95% CI of the cumulative distribution function (CDF) for winter parr, at a value of 1,850 winter parr/km on the CDF.

To evaluate habitat quality with respect to production potential of juvenile coho salmon, we used the HabRate model developed by Burke et al. 2001 and updated the model with criteria for coho salmon (Burke et al. 2010). HabRate is designed to evaluate juvenile coho salmon habitat quality based on critical habitat values defined in the literature (see Anlauf and Jones

2007 for summary). Habitat ratings of high, medium, and low are created for each habitat variable and for each stream rearing life stage for coho salmon. The model output ranks habitat quality from 1 to 3: poor, fair, and good, respectively. Results of the model were evaluated and displayed spatially at the ESU scale. Habitat requirements for discrete early life history stages (i.e., spawning, egg survival, emergence, summer rearing, and winter rearing) were summarized and used to rate the quality of reaches as poor, fair, or good, based on attributes relating to stream substrate, habitat unit type, cover, and structure (i.e., large wood, undercut banks), and gradient. A Kruskal-Wallis one-way analysis of variance was conducted on the maximum HabRate rating across years, to determine if there was statistically significant difference in HabRate values across monitoring strata. The Krustal-Wallis test is a non-parametric method analogous to the one-way ANOVA. A comparison of maximum and median HabRate values across monitoring strata was also conducted.

Empirical Juvenile Estimates, Site Occupancy, and Relationships to Parental Adult Abundance

Sample sites were surveyed by field crews using daytime snorkeling during the base flow period (mid-July to mid-October). Field crews were trained in fish identification and snorkel survey protocols described by Rodgers (2000). Surveys began at the downstream end of the sample site and proceeded upstream (Thurow 1994). All pools ≥ six square meters in surface area and ≥ 20 centimeters in maximum depth were snorkeled with a single pass to identify and count juvenile salmonids. Dive lights were used to improve visibility in shaded areas. Visibility was rated by considering factors that could impede the ability to observe fish (Rodgers 2000; Crawford 2011). Hard counts were made of coho salmon parr regardless of length. Coho salmon adult spawner abundance was obtained from spawning ground surveys following the Oregon Adult Salmonid Inventory Project protocols (Sounhein et al. 2017).

Our sampling objective for juvenile coho salmon snorkel surveys is to produce abundance estimates with 95% confidence intervals ≤30% of the estimate and to be able to detect a 15% change in occupancy with 80% certainty (Crawford and Rumsey, 2011). Analysis of our data has shown that completing 40 sites per stratum is typically sufficient to reach this objective and remain within project budgets. To evaluate habitat capacity relative to the abundance of juvenile coho salmon rearing in the summer, we compared modeled summer habitat capacity (summer parr/km) over the ten-year sampling period with empirical juvenile coho salmon estimates (juvenile coho/km) based on snorkel counts from the Western Oregon Rearing Project (WORP) (Constable and Suring 2019). For that comparison, we used summer parr/km estimated from the HLFM using pool exclusive habitat data and juvenile coho salmon/km data from the same sites in the same strata collected annually in the months of August and September, from 2007-2016. Juvenile coho salmon are identified and enumerated in pools equivalent or exceeding ≥ six square meters of surface area and ≥ 20 cm in maximum depth by snorkeling with a single pass (Constable and Suring 2013).

RESULTS

Site Statistics

From 2007 – 2016 we selected 1,520 individual survey sites for sampling (Table 2). Sampling success (completing a survey while encompassing the GRTS point) ranged from 49% to 88% across years. The primary cause for not sampling at individual locations across the sampling period was a lack of landowner permission to survey on private property.

Table 2. Percentage of sites surveyed 2007-2016 each year relative to total number of sites drawn in random pull and primary reason for sites not surveyed.

Year	Surveyed (%)	Primary Reason for Not Surveyed
2007	70.59	Access Denied / Non Responsive Landowner
2008	67.96	Access Denied / Non Responsive Landowner
2009	69.64	Access Denied / Non Responsive Landowner
2010	65.89	Lack of time
2011	55.15	Extra sites pulled
2012	62.07	Access Denied / Non Responsive Landowner
2013	88.50	Upstream of barrier to anadromy
2014	52.99	Extra sites pulled
2015	55.43	Access Denied / Non Responsive Landowner
2016	49.28	Access Denied / Non Responsive Landowner
Total Sites Pulled	Total Sites Surveyed	Total Sites Not Surveyed
1,520	927	593

In 2015 and 2016 approximately 33% of sampled sites occurred outside the known distribution of anadromy. Of the 91 sampled locations, two revealed the presence of coho salmon. Coastal Cutthroat (*Oncorhynchus clarki clarki*) were identified at 28 locations, unidentified juvenile trout at 24 locations, and brown trout (Salmo trutta) at one location. In addition, Cottidae spp. were observed at 13 locations.

Surveyed sites occurred almost exclusively within volcanic and sedimentary rock types which are the dominant petrology across the Lower Columbia ESU. Across all years, 57% of surveyed sites occurred within volcanic rock and 41% occurred within sedimentary rock (Table 3).

Table 3. Percent geology within entire ESU and individual monitoring strata based on individual sampled sites. Data depicts total number of sites surveyed and percent of dominant geology encountered within a 1000-meter buffer around the GRTS point.

Area	Intrusive %	Metamorphic %	Sedimentary %	Volcanic %	Glacial Drift %
ESU	1.27	0	41.30	56.81	0.62
Cascade/Gorge	2.07	0	38.68	58.06	1.19
Coast	0.42	0	44.10	55.48	0

On average, approximately 75% of surveyed sites occurred within federal forest and private industrial forest land ownership, while the remaining ownership largely occurred within urban and agricultural types (Table 4).

Table 4. Percent land use within individual survey years based on individual sampled sites. Data depicts number of sites surveyed and percent of dominant land use type encountered within a 1000-meter buffer around the GRTS point.

Year	Number of Sites	Agriculture %	Federal Forest %	Private Forest %	State Forest %	Urban %	*Other %
2007	72	13.58	20.10	43.19	4.53	18.49	0.40
2008	70	9.22	30.19	49.34	2.26	8.49	0.50
2009	78	11.51	21.51	48.07	4.12	14.19	0.60
2010	85	10.78	27.33	43.69	5.44	11.86	0.90
2011	91	10.20	22.15	49.93	2.84	14.19	0.69
2012	90	12.70	18.21	49.65	4.13	15.15	0.16
2013	100	8.88	25.34	46.57	4.81	13.93	0.47
2014	62	3.75	39.66	49.42	0.81	5.87	0.50
2015	143	7.10	32.99	41.70	4.23	11.98	1.99
2016	136	5.45	31.25	46.20	5.60	9.32	2.18

* Includes, state park, tribal, and military lands.

We used a linear mixed model to examine the precision of the habitat attributes that were collected in the field by comparing sites that were resurveyed from 2007–2011 (Figure 3). The results were similar to those reported by Anlauf-Dunn and Jones (2012). Percent fine sediments and bedrock, percent secondary channel area, percent pool habitat, residual pool depth, active channel width, and wood volume and number of wood pieces all performed very well with $R^2 > 0.70$. Percent gradient ($R^2 = 0.5895$) and the number of key large wood pieces ($R^2 = 0.6079$) performed moderately well. Measurements of percent gravel ($R^2 = 0.3617$) had lower precision, with a few outliers (Figure 3). Study results from Strickland and Davies (2020) showed the use of ocular observation by trained field surveyors can sufficiently estimate individual substrate classes and can be used in place of resurveys for sites surveyed from 2012–2016.

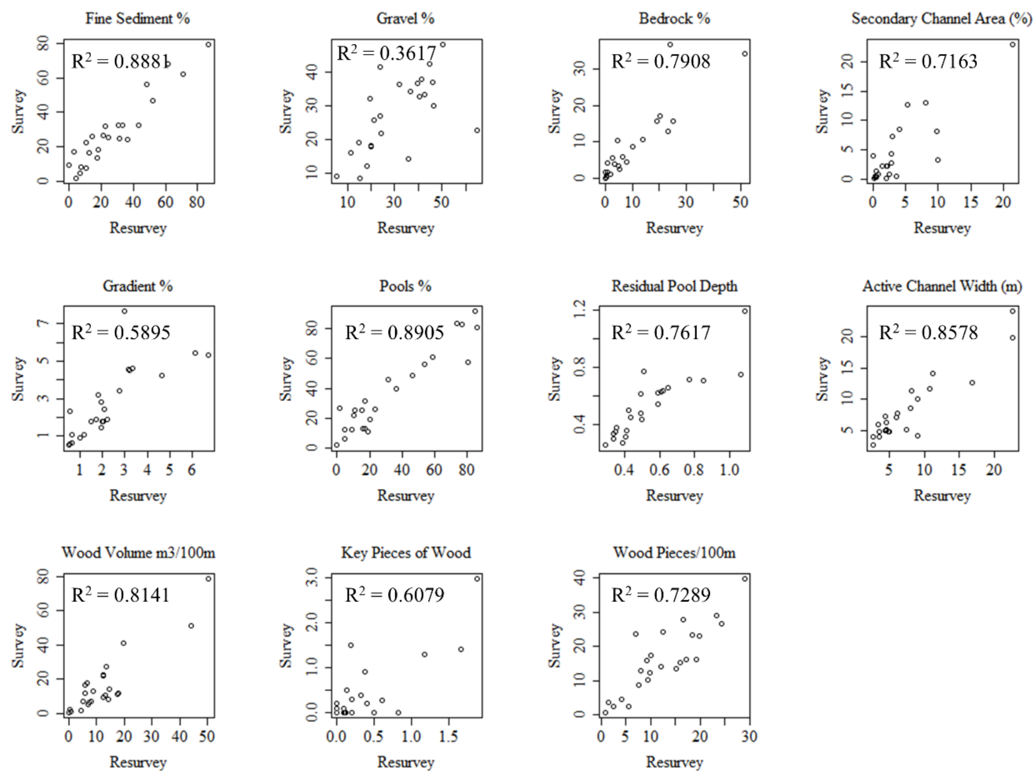

Figure 3. Results of linear mixed model comparing surveyed habitat attributes and those that were resurveyed from 2007–2011.

Beaver activity and dams were commonly observed. Beaver activity was observed across years 24% to 60% of the sites and beaver dams were observed at 9% to 22% of the sites (Table 5). Across all years, natural wood accumulations and mass wasting events were observed at a higher proportion of sites than were stream restoration structures (artificially placed wood or boulder features). In addition, culverts were observed at approximately 20% of sampled sites.

Table 5. Summary of presence of comment codes at each site within individual survey years. Percent of activity values based on the number of sites presence of observation was identified within individual survey years and the total number of sites surveyed.

Year	Beaver Dams	Beaver Activity	Debris Jams	Mass Wasting	Habitat Structures	Culverts
2007	13.89	23.61	34.72	18.06	5.56	22.22
2008	8.57	24.29	18.57	25.71	12.86	18.57
2009	17.95	39.74	16.67	10.26	1.28	23.08
2010	18.82	31.76	21.18	12.94	4.71	24.71
2011	9.89	31.87	15.38	32.97	7.69	23.08
2012	22.22	57.78	66.67	8.89	6.67	26.67
2013	22.00	60.00	70.00	40.00	10.00	21.00
2014	20.97	41.94	54.84	51.61	20.97	20.97
2015	12.59	29.37	23.08	14.69	6.29	19.58
2016	19.85	37.50	58.82	30.88	8.82	19.12

Habitat Status

Data were evaluated across monitoring strata, land use, lithology, and by year. Differences were observed among most instream habitat attributes across strata, petrology, and year (Tables 6, 7 and 8).

Table 6. Results of ANOVA assessing differences among in-stream habitat attributes across monitoring strata within the distribution of anadromy. Due to site distribution and total number across individual sample years, the Cascade and Gorge were combined as a single stratum. Dependent variable = Habitat attribute; Independent variable = Stratum. Alpha = 0.05.

Habitat Attribute	Residual DF	DF	MSE	F value	P-value
% Fine sediments*	834	1	71.86	51.15	< 0.001
% Gravel	834	1	5770	34.66	< 0.001
% Bedrock*	834	1	246.24	18.81	< 0.001
% Secondary channel area*	834	1	0.04	< 0.01	0.947
Gradient*	834	1	32.50	28.55	< 0.001
% Pool habitat	834	1	47600	66.69	< 0.001
% Slackwater pool*	834	1	197.76	12.18	< 0.001
Residual pool depth*	834	1	36.77	17.81	< 0.001
Active channel width*	834	1	36.09	69.48	< 0.001
Wood volume*	834	1	8.11	3.97	0.047
Key pieces of wood*	834	1	220.90	27.95	< 0.001
Wood pieces per 100m*	834	1	4.21	2.58	0.109

*Habitat attributes were log transformed.

Table 7. Results of ANOVA assessing differences among in-stream habitat attributes by geology within the distribution of anadromy. Dependent variable = Habitat attribute; Independent variable = geology. Alpha = 0.05.

Habitat Attribute	Residual DF	DF	MSE	F value	P-value
% Fine sediments*	832	3	13.37	9.25	< 0.001
% Gravel	832	3	938.00	5.51	0.001
% Bedrock*	832	3	133.74	10.34	< 0.001
% Secondary channel area*	832	3	16.37	1.86	0.134
Gradient*	832	3	14.23	12.61	< 0.001
% Pool habitat*	832	3	7.46	1.30	0.273
% Slackwater pool*	832	3	16.57	1.01	0.389
Residual pool depth*	832	3	2.30	1.09	0.353
Active channel width*	832	3	0.83	1.48	0.219
Wood volume*	832	3	13.72	6.84	< 0.001
Key pieces of wood*	832	3	40.95	5.09	0.002
Wood pieces per 100m*	832	3	4.81	2.96	0.032

*Habitat attributes were log transformed.

Table 8. Results of ANOVA assessing differences among in-stream habitat attributes by year within the distribution of anadromy. Dependent variable = Habitat attribute; Independent variable = individual survey year. Alpha = 0.05.

Habitat Attribute	Residual DF	DF	MSE	F value	P-value
% Fine sediments	836	9	458.60	0.74	0.672
% Gravel	836	9	553.70	3.28	< 0.001
% Bedrock*	836	9	11.77	0.88	0.543
% Secondary channel area*	836	9	13.80	1.58	0.118
Gradient*	836	9	2.89	2.50	0.008
% Pool habitat	836	9	1501.70	1.97	0.040
% Slackwater pool*	836	9	80.80	5.13	< 0.001
Residual pool depth*	836	9	2.29	1.09	0.368
Active channel width*	836	9	1.62	2.94	0.002
Wood volume*	836	9	3.69	1.82	0.062
Key pieces of wood*	836	9	17.99	2.23	0.018
Wood pieces per 100m*	836	9	6.96	4.41	< 0.001

*Habitat attributes were log transformed.

Differences were observed among all instream habitat attributes across land use types (Table 9); therefore, we rejected our null hypothesis that instream habitat attributes would not differ significantly across land ownerships.

Table 9. Results of ANOVA assessing differences among in-stream habitat attributes by land use within the distribution of anadromy. Dependent variable = Habitat attribute; Independent variable = Land use. Alpha = 0.05.

Habitat Attribute	Residual DF	DF	MSE	F value	P-value
% Fine sediments	831	4	17547	32.75	< 0.001
% Gravel	831	4	1201.50	7.14	< 0.001
% Bedrock*	831	4	326.90	27.56	< 0.001
% Secondary channel area*	831	4	27.20	3.12	0.015
Gradient*	831	4	54.23	58.91	< 0.001
% Pool habitat	831	4	38958	66.47	< 0.001
% Slackwater pool*	831	4	72.26	4.47	0.001
Residual pool depth*	831	4	13.61	6.64	< 0.001
Active channel width*	831	4	6.12	11.44	< 0.001
Wood volume*	831	4	84.70	51.34	< 0.001
Key pieces of wood*	831	4	270.40	39.21	< 0.001
Wood pieces per 100m*	831	4	44.37	31.03	< 0.001

*Habitat attributes were log transformed.

When habitat data were compared to the reference thresholds (25^{th} and 75^{th} percentiles), median values summarized across monitoring strata by and large fell between the 25^{th} and 75^{th} percentiles (Figure 4). The most noticeable exceptions across strata were active channel width and wood volume. Active channel width median values exceeded the upper 75^{th} percentile in both the Cascade/Gorge and Coast strata indicating that streams in the Lower Columbia River ESU are larger on average than those in the reference set. However, median values for wood volume were below the 25th percentile for reference conditions in both strata.

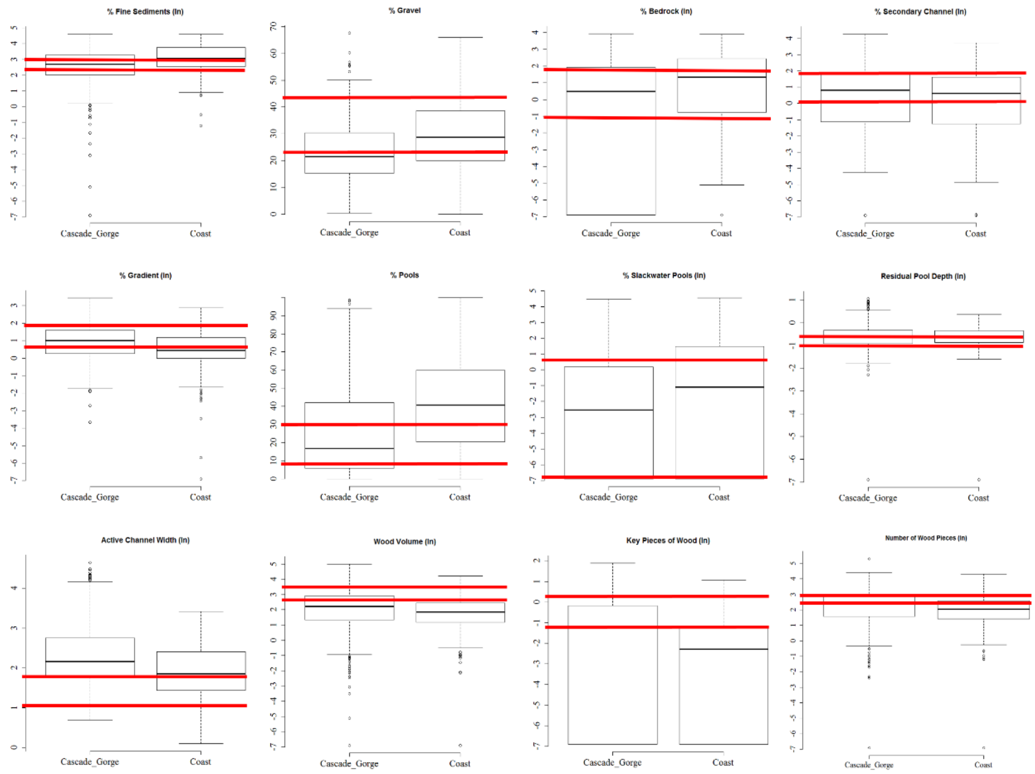

Figure 4. Boxplots of habitat attributes (y-axis) within monitoring strata (x-axis). Plots depict minimum values, lower quartile bounds, medians, upper quartile bounds, and maximum values. Horizontal red lines indicate upper and lower breakpoints for the respective habitat attributes (Miller et al. 2016).

Wood values appear to be driven by land ownership and lithology. All large wood metrics (pieces, volume, and key pieces), median values in agriculture, industrial forest, and urban ownerships were all below the 25th percentile for reference conditions (Figure 5). The only land use type to fall within reference thresholds across wood metrics was federal forests.

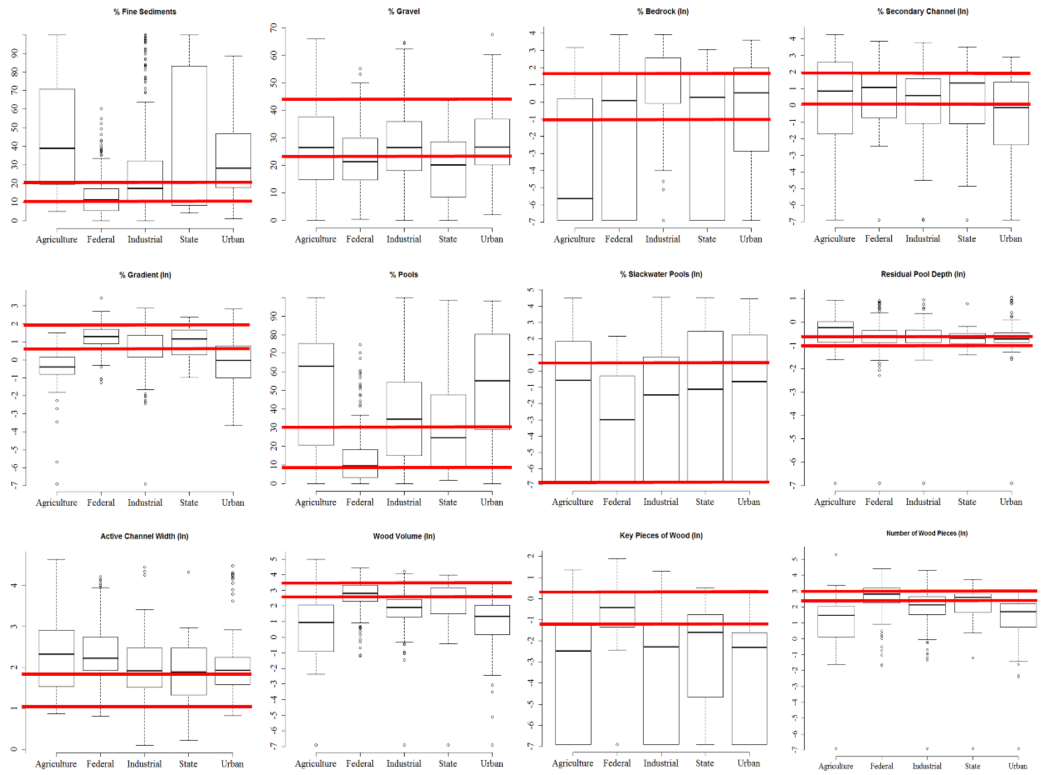

Figure 5. Boxplots of habitat attributes (y-axis) within land use types (x-axis). Plots depict minimum values, lower quartile bounds, medians, upper quartile bounds, and maximum values. Horizontal red lines indicate upper and lower breakpoints for the respective habitat attributes (Miller et al. 2016).

Median values for large wood metrics within sedimentary and volcanic rock types also fell below the 25th percentile for reference condition (Figure 6).

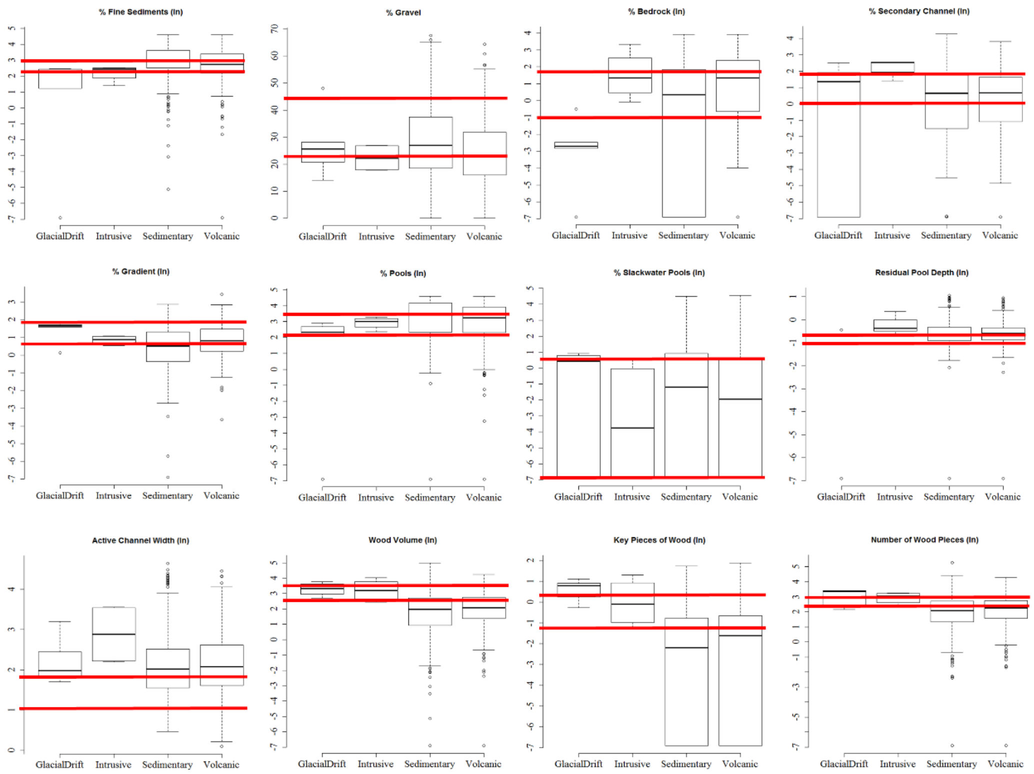

Figure 6. Boxplots of habitat attributes (y-axis) within geology (x-axis). Plots depict minimum values, lower quartile bounds, medians, upper quartile bounds, and maximum values. Horizontal red lines indicate upper and lower breakpoints for the respective habitat attributes (Miller et al. 2016).

However, ownerships (i.e., agriculture, private industrial forest, and urban) that fell below the 25th percentile for wood metrics had median values for percent gravel well within reference thresholds and median values for percent pool habitat that exceeded the 75% percentile. While state and federal ownership median values for percent gravel fell below the reference 25th percentile, median values for percent pools were within reference thresholds. The only land ownerships to exceed the 75th percentile for reference condition in fine sediments were agriculture and urban. While differences were observed in habitat metrics across years, when compared to reference thresholds, median values were relatively consistent.

Habitat Trends

Analyses of sites surveyed two or more times during the sampling period used a linear mixed model to detect trends of selected habitat metrics within monitoring strata. A decrease in percent gravel was observed in both the Coast (estimate = -0.798, p-value = 0.025) and Cascade/Gorge (estimate = -0.790, p-value = 0.004) monitoring strata, while an increasing trend for winter parr/km was observed in the Cascade/Gorge (estimate = 0.034, p-value = 0.034). No other significant trends were observed within monitoring strata for the selected habitat metrics (Table 10) over the ten-year study period.

Table 10. Results of trend analysis on selected habitat metrics. Analyses were run on sites surveyed two or more times between 2007 and 2016.

Metric	Strata	Estimate	MSE	F value	P-value
Winter Parr/km	Coast	0.008	0.058	0.248	0.632
	Cascade/Gorge	0.034	1.417	7.699	0.034
% Secondary Channel	Coast	-0.001	0.001	0.003	0.961
	Cascade/Gorge	-0.027	0.952	3.247	0.074
% Pool Habitat	Coast	-0.006	0.031	0.155	0.703
	Cascade/Gorge	0.074	1.490	4.361	0.074
% Slackwater Pool Habitat	Coast	0.046	1.712	2.562	0.140
	Cascade/Gorge	0.041	1.546	3.957	0.079
Residual Pool Depth	Coast	-0.002	0.001	0.248	0.635
	Cascade/Gorge	-0.009	0.052	3.474	0.101
Wood Pieces/100m	Coast	0.042	0.291	2.607	0.144
	Cascade/Gorge	0.017	0.149	1.045	0.334
Wood Volume	Coast	0.011	0.024	0.179	0.684
	Cascade/Gorge	-0.030	0.426	2.842	0.134
Key Pieces of Wood	Coast	0.003	0.002	0.064	0.806
	Cascade/Gorge	-0.012	0.079	1.600	0.240
% Gravel	Coast	-0.798	418.15	6.671	0.025
	Cascade/Gorge	-0.790	683.06	13.782	0.004

Habitat Capacity and Quality

Modeled estimates of winter parr capacity within the distribution of coho salmon spawning and rearing were stratified by year, monitoring strata, land use, lithology, and by population to assess variation (Table 11). Differences were only observed between land use and populations.

Table 11. Results of ANOVA assessing results among winter parr/km by stratum, land use, geology, year, and population within the distribution of available coho salmon spawning and rearing habitat. Summer data were modeled using the Habitat Limiting Factors Model (HLFM) to reflect winter habitat capacity. Alpha = 0.05.

Independent Variable	Dependent Variable	Residual DF	DF	MSE	F value	P-value
Stratum	Winter Parr/km*	793	1	1.66	1.89	0.169
Land Use	Winter Parr/km*	790	4	8.09	9.62	< 0.001
Geology	Winter Parr/km*	791	3	0.59	0.67	0.573
Year	Winter Parr/km*	785	9	0.81	0.92	0.507
Population	Winter Parr/km*	496	7	4.81	5.58	< 0.001

*Habitat attributes were log transformed.

Among land use types, the median value for winter parr/km on agricultural lands fell within the bounds of moderate habitat quality (900 – 1,850 parr/km) likely because of larger stream size and percent pool habitat, while all other land use types had median values that signified low quality habitat (< 900 parr/km). Sites that fell within federal ownership types also had upper quartile bounds below the low-quality habitat threshold likely due to limited pool habitat relative to other ownership types. Among the independent populations, only Youngs Bay had a median parr capacity within moderate habitat quality. The Hood River and Lower Gorge populations both had upper quartile bounds below the low-quality habitat threshold (Figure 7).

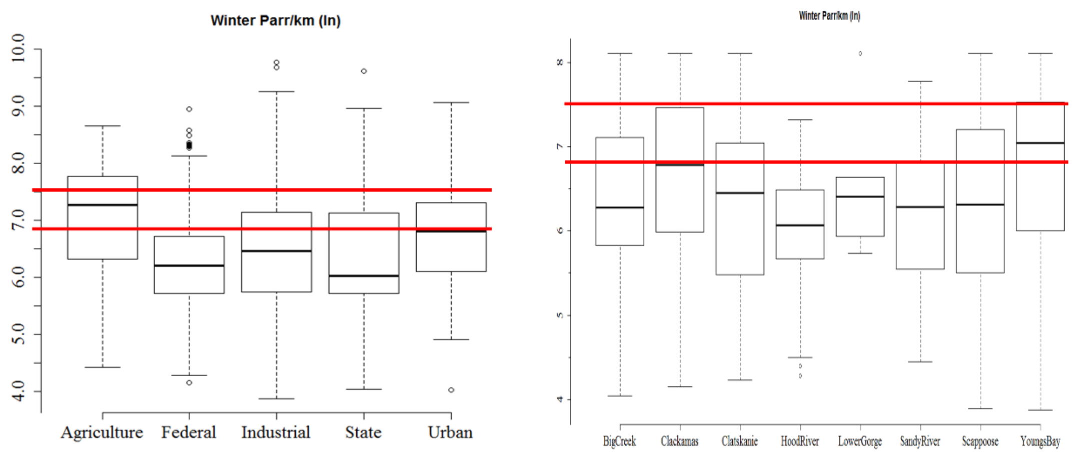

Figure 7. Boxplots of winter parr/km (y-axis) within a) land use types and b) populations (x-axis). Plots depict minimum values, lower quartile bounds, medians, upper quartile bounds, and maximum values. The horizontal red lines indicate thresholds for high quality habitat (>1850 parr/km) and low-quality habitat (<900 parr/km).

Summary statistics derived at the ESU level for individual sampling years at a site revealed mean values of winter parr capacity that ranged from a low of 835 parr/km in 2012 to a high of 1,076 parr/km in 2011 (Table 12).

Table 12. Summary statistics across individually sampled survey years for winter parr/km in the Lower Columbia coho ESU within the distribution of available coho salmon spawning and rearing habitat.

Year	N	Mean	StdDev	Lower95%	Upper95%
2007	71	865.74	839.29	713.19	1018.29
2008	66	1034.94	905.48	977.84	1192.04
2009	71	1007.98	910.69	840.62	1175.34
2010	78	978.80	911.92	851.08	1106.52
2011	85	1076.04	886.17	928.59	1223.50
2012	90	835.32	782.17	703.13	967.50
2013	96	921.96	793.79	799.51	1044.42
2014	62	928.57	856.48	755.83	1101.30
2015	90	925.48	928.60	781.65	1069.30
2016	86	964.85	800.75	832.82	1096.88

When these mean values were evaluated within the Coast monitoring stratum a low of 866 parr/km was observed in 2012 and a high of 1,159 parr/km 2008 (Table 13).

Table 13. Summary statistics across individually sampled survey years for winter parr/km in the Coast monitoring stratum of the Lower Columbia coho ESU within the distribution of available coho salmon spawning and rearing habitat.

Year	N	Mean	StdDev	Lower95%	Upper95%
2007	35	955.01	864.67	738.51	1171.51
2008	32	1158.94	898.77	882.09	1435.79
2009	43	1143.25	960.41	897.32	1389.18
2010	38	1038.99	849.57	839.01	1238.96
2011	43	998.17	801.13	818.13	1178.21
2012	48	866.18	737.52	675.56	1056.79
2013	50	976.44	827.63	781.84	1171.04
2014	28	997.08	1024.65	697.09	1297.08
2015	37	936.56	987.29	675.55	1198.58
2016	45	973.99	810.78	774.23	1173.75

Within the Cascade/Gorge stratum a low of 779 parr/km was observed in 2007, while a high of 1,156 parr/km was observed in 2011 (Table 14).

Table 14. Summary statistics across individually sampled survey years for winter parr/km in the Cascade and Gorge monitoring strata of the Lower Columbia coho ESU within the distribution of available coho salmon spawning and rearing habitat. Due to site distribution and total number across individual sample years, the Cascade and Gorge were combined as a single stratum.

Year	N	Mean	StdDev	Lower95%	Upper95%
2007	36	778.96	804.41	563.99	993.93
2008	34	918.24	896.21	759.80	1076.67
2009	28	800.24	784.38	606.71	993.77
2010	40	921.62	963.97	760.59	1082.66
2011	42	1155.77	958.99	921.09	1390.45
2012	42	800.05	828.86	619.02	981.08
2013	46	862.75	750.82	719.33	1006.16
2014	34	872.14	682.63	676.75	1067.54
2015	53	917.74	885.25	755.91	1079.58
2016	41	954.81	789.48	785.62	1124.00

We were also able to calculate winter parr/km at the population scale and found the Hood River population had the lowest mean estimate with 485 parr/km, while the Youngs Bay population had the highest mean estimate with 1,260 parr/km (Table 15).

Table 15. Summary statistics for winter parr/km across individual populations in the Lower Columbia coho ESU within the distribution of available coho salmon spawning and rearing habitat.

Population	N	Mean	StdDev	Lower95%	Upper95%
Big Creek	65	869.71	730.76	736.41	1003.01
Clackamas River	128	1228.96	1030.65	1108.88	1349.14
Clatskanie River	65	839.06	821.52	718.39	959.74
Hood River	56	484.79	297.15	420.37	549.20
Lower Gorge Tribs	5	1078.92	1138.68	166.30	1991.55
Sandy River	60	693.56	565.94	593.20	793.91
Scappoose Creek	48	857.94	813.27	687.51	1028.38
Youngs Bay	77	1260.19	916.42	1102.69	1417.70

Across sampling years at the ESU scale and within the distribution of total available habitat for coho salmon spawning and/or rearing, the percent of habitat considered high quality (>1,850 parr/km) was lowest (8.87%, ±4.98%) in 2012 and highest (16.59%, ±6.57%) in 2011 (Table 16).

Table 16. HLFM results across the Lower Columbia ESU by year within the distribution of available coho salmon spawning and rearing habitat. High quality (HQ) is considered >1850 winter parr per km.

Year	Number of Sites	Surveyed km	Coho Habitat (km)	HQ Habitat Sites	HQ Habitat (km)	Percent HQ	Percent Error	Error (km)
2007	71	71.12	1,397.87	7	137.58	9.84	5.96	83.30
2008	66	67.81	1,397.87	9	185.54	13.27	5.77	80.69
2009	71	72.82	1,397.87	10	191.96	13.73	6.95	97.08
2010	78	79.94	1,397.87	13	227.33	16.26	6.54	91.42
2011	85	84.41	1,397.87	14	231.85	16.59	6.57	91.79
2012	90	90.19	1,397.87	8	123.99	8.87	4.98	69.67
2013	96	97.37	1,397.87	11	157.91	11.30	5.07	70.92
2014	62	62.34	1,397.87	9	201.81	14.44	7.14	99.83
2015	90	89.88	1,397.87	14	217.74	15.58	5.98	83.53
2016	86	84.39	1,397.87	13	215.34	15.41	6.32	88.40

Within the Coast stratum the percent of high-quality habitat ranged from 8.18% (±7.20%) to 24.84% (±8.37) (Table 17), and the Cascade/Gorge ranged from 6.88% (±8.26%) to 20.08% (±8.16%) (Table 18).

Table 17. HLFM results across the Coast stratum in the Lower Columbia ESU by year within the distribution of available coho salmon spawning and rearing habitat. High quality (HQ) is considered >1850 winter parr per km.

Year	Number of Sites	Surveyed km	Coho Habitat (km)	HQ Habitat Sites	HQ Habitat (km)	Percent HQ	Percent Error	Error (km)
2007	35	35.46	539.77	4	60.88	11.28	9.08	49.00
2008	42	32.83	539.77	4	65.76	12.19	10.27	55.43
2009	43	43.73	539.77	8	98.74	18.29	10.13	54.66
2010	38	39.16	539.77	7	96.48	17.88	10.32	55.70
2011	43	42.34	539.77	5	63.74	11.81	8.52	46.01
2012	48	48.90	539.77	4	44.15	8.18	7.06	38.13
2013	50	51.93	539.77	6	62.36	11.55	7.20	38.88
2014	28	28.59	539.77	6	113.27	20.99	11.93	64.41
2015	37	38.19	539.77	7	98.92	18.33	9.98	53.89
2016	45	44.28	539.77	11	134.09	24.84	8.37	47.70

Table 18. HLFM results across the Cascade and Gorge strata in the Lower Columbia ESU by year within the distribution of available coho salmon spawning and rearing habitat. High quality (HQ) is considered >1850 winter parr per km. Due to site distribution and total number across individual sample years, the Cascade and Gorge were combined as a single stratum.

Year	Number of Sites	Surveyed km	Coho Habitat (km)	HQ Habitat Sites	HQ Habitat (km)	Percent HQ	Percent Error	Error (km)
2007	36	35.66	858.10	3	72.19	8.41	7.76	66.60
2008	34	34.97	858.10	4	98.14	11.44	5.67	48.64
2009	28	29.09	858.10	2	58.99	6.88	8.26	70.91
2010	40	29.88	858.10	6	172.31	20.08	8.16	69.99
2011	42	42.07	858.10	8	163.19	19.02	9.24	79.32
2012	42	41.29	858.10	4	83.13	9.69	6.99	59.99
2013	46	45.44	858.10	5	94.42	11.00	7.13	61.15
2014	34	33.75	858.10	3	76.28	8.89	8.55	73.33
2015	53	51.68	858.10	8	132.82	15.48	7.37	63.28
2016	41	40.11	858.10	6	128.37	14.96	9.05	77.65

When summarized to the population scale, the Clackamas River had the most available high-quality habitat with 93 kilometers (±21.91 km), while the Lower Gorge Tributaries had the highest percentage with a little over 27% (±32.02%). The Hood River population had the second highest amount of available spawning or rearing habitat available but was found to have no high-quality habitat (Table 19).

Table 19. HLFM results across populations in the Lower Columbia ESU within the distribution of available coho salmon spawning and rearing habitat. High quality (HQ) is considered >1850 winter parr per km.

Population	Number of Sites	Surveyed km	Coho Habitat (km)	HQ Habitat Sites	HQ Habitat (km)	Percent HQ	Percent Error	Error (km)
Big Creek	65	66.25	77.87	6	7.05	9.06	5.41	4.22
Clackamas River	128	127.19	394.25	30	92.99	23.59	5.56	21.91
Clatskanie River	65	66.72	151.05	6	13.58	8.99	4.74	7.06
Hood River	56	54.85	233.79	0	0	0	0	0
Lower Gorge Tribs	5	3.68	17.60	1	4.79	27.19	32.02	5.63
Sandy River	60	59.28	212.46	3	10.75	5.06	4.86	10.32
Scappoose Creek	48	47.55	167.83	7	24.71	14.72	8.03	13.48
Youngs Bay	77	79.67	143.01	20	35.90	25.10	8.02	11.47

Results of the Kruskal-Wallis chi-squared test assessing differences among HabRate ratings found significant differences in at least one dependent variable across all independent variables (Table 20). A multiple comparison test detected differences in summer and winter rearing habitat between monitoring strata, where the average rating was greater in the Coast stratum for both life history types. The multiple comparison test also detected differences in spawning and emergence, and summer rearing habitat between survey years. Differences were detected in spawning and emergence, and winter rearing habitat between land use types. These differences were observed between agriculture and federal forests, and federal forests and urban areas. Federal forests had the highest average spawning and emergence rating, while also having the lowest average rating for winter rearing habitat. In addition, differences were detected in spawning and emergence habitat between agriculture and private forests, where the average rating was greater on private forests. The multiple comparison test did not detect any differences in life history stages across petrology types or populations.

Table 20. Results of Kruskal-Wallis rank sum test assessing differences among HabRate life history ratings across monitoring strata, land use, geology, year and population within the distribution of anadromy. Dependent variable = Life history stage, independent variables = stratum, land use, geology, year, and population.

Life History Stage	DF	Chi-Square Test	P-value
	Monitoring Strata		
Spawning and Emergence	1	2.48	0.115
Overwinter Habitat	1	16.05	< 0.001
Summer Habitat	1	12.94	< 0.001
	Land Use		
Spawning and Emergence	4	26.49	< 0.001
Overwinter Habitat	4	43.11	< 0.001
Summer Habitat	4	9.37	0.053
	Geology		
Spawning and Emergence	3	2.66	0.447
Overwinter Habitat	3	1.17	0.761
Summer Habitat	3	3.77	0.287
	Year		
Spawning and Emergence	9	25.16	0.003
Overwinter Habitat	9	24.53	0.004
Summer Habitat	9	37.93	< 0.001
	Population		
Spawning and Emergence	7	13.57	0.059
Overwinter Habitat	7	13.32	0.065
Summer Habitat	7	19.02	0.008

Empirical Juvenile Estimates, Site Occupancy, and Relationships to Parental Adult Abundance

Abundance estimates of juvenile coho salmon were lower in 2016 relative to the average from the 2013-2015 brood group (Figure 8, p-value <0.01). The 2016 Lower Columbia ESU abundance estimate was the lowest recorded in the ten years of monitoring in the ESU and was under 20% of the average of the annual estimates since monitoring started in the ESU. Abundance estimates among the three full brood groups were similar, but this similarity is at least partially due to the large confidence intervals in the first brood group (which averaged 53% of the estimates). Paired t-tests indicated average abundance from 2007-2011 (149,952) was higher than the average abundance from 2012-2016 (78,785), p-value <0.01. An average of 37 parr were produced per female spawner in the Lower Columbia ESU and ranged from seven, when female spawner abundance was highest, to 71, when female spawner abundance was lowest. Counts of coho salmon from snorkel surveys and resurveys were significantly correlated (R^2 = 0.97), indicating surveys were precise and repeatable (Constable and Suring 2020).

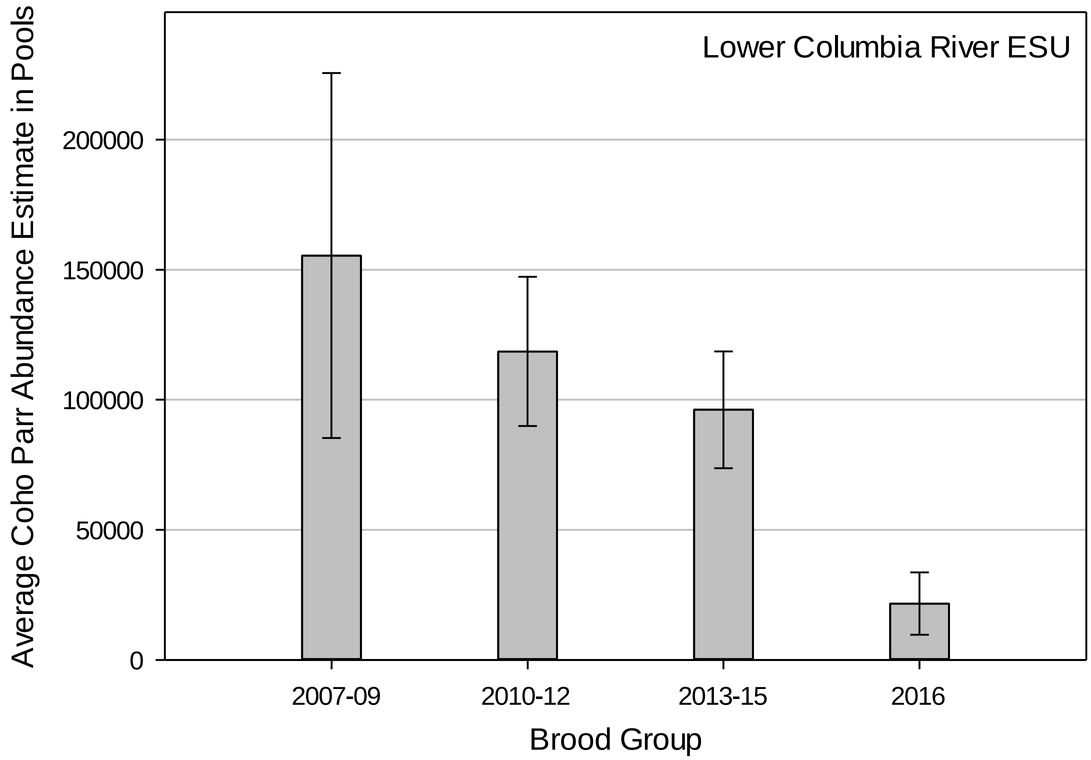

Figure 8. Three-year (brood group) trends of coho salmon parr abundance estimates in the Lower Columbia River ESU, based on snorkel surveys in 1st through 3rd order streams from 2007-2016. 2016 is presented as a single year. Gray bars show the abundance estimate and black lines show the 95% CI.

As with the abundance estimate, the 2016 estimate of site occupancy was the lowest recorded since monitoring began in the ESU. The 2016 site occupancy estimate was just over 50% of average from 2007-2016 and lower than that of the 2013-2015 brood group (Figure 9, p-value <0.01). The site occupancy estimate for the 2010-2012 brood group was similar to the 2013-2015 brood group, but lower than that of the 2007-2009 brood group (p-value= 0.02). Paired t-tests did not indicate differences in site occupancy from 2007-2011 to 2012-2016.

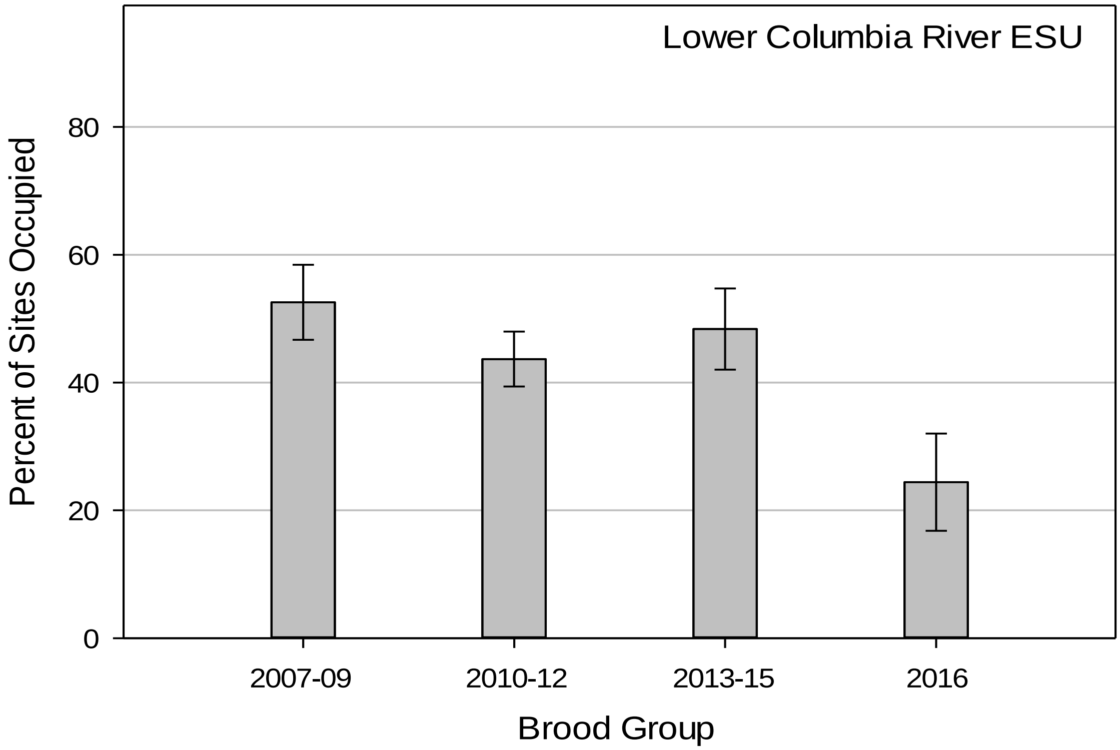

Figure 9. Three-year (brood group) trends in coho salmon parr site occupancy in the Lower Columbia River ESU based on snorkel surveys in 1st through 3rd order streams from 2007-2016. 2016 is presented as a single year. Gray bars show the abundance estimate and black lines show the 95% CI.

DISCUSSION

We sampled 61% of sites in the sample frame during the study period. The lowest sampling success occurred from 2014-2016 primarily because non-wadeable (≥ 4th order) sample sites were included with the intent of utilizing a protocol appropriate for larger streams. We propose future studies include large stream habitat along with focused stratified sampling at the population scale and within land use types. ANOVA results suggest these strategies would address the observed in-stream habitat differences (Tables 9 and 11).

The increasing trend of winter parr/km in the Cascade/Gorge stratum was perplexing initially because median wood values, which play a major role in the HLFM, were all below the lower thresholds for reference conditions. These results reflected those of a previous Lower Columbia habitat assessment that primarily used data from census type surveys (Anlauf et al. 2005). In addition, all selected wood metrics showed a declining trend across the study period, although none that were significant. Other primary HLFM influencers such as scour pool and beaver pond area did not show any significant trend response (P-value > 0.05), but they did show a general increase across the sampling period (slope estimate of 0.074 and 0.041 respectively). If we assume the larger stream size within the Cascade/Gorge stratum (Cascade/Gorge average active channel width was 14.5 meters and the Coast was 8.1 meters), along with a general increase of pool area across time, this may underlie the increasing trend in parr capacity.

Beaver activity and beaver dams were observed in all strata across all years. Within years, the proportion of observed beaver activity was significantly greater than constructed dams. This is likely attributed to most beaver dams across Western Oregon being small, ephemeral, and generally unable to withstand peak winter flow events (Leidholt-Bruner et al. 1992). These results were expected and have been observed during previous studies (Anlauf-Dunn and Jones 2012, Strickland et al. 2018, Crowley and Strickland 2022). While beaver dams and ponds are identified and measured as individual habitat types, features such as beaver trails, chewed sticks, and scat are collected largely as ancillary notes and comments. These features and others such as restoration activity, mass wasting, and debris jams were viewed as a general description of presence or absence within individual sites. It should be noted these data are not a required field entry. When fluctuations of activities across years are observed, the higher number of recorded activities is likely biased towards newer or larger concentrations as these are more readily observed by field crews.

Habitat capacity and quality were stratified by monitoring area, populations, land use, and lithology. We did not see a significant difference in habitat capacity estimates between monitoring strata or across geology types, but differences were observed between populations and land use types (P-value < 0.05). Crowley and Strickland (2022) explored these during winter habitat conditions across the Scappoose Bay and Clatskanie River populations in 2013. While there was not a significant difference in coho rearing habitat capacity between the two populations, a difference in adult spawning and juvenile emergence habitat quality was detected. The Clatskanie River had a greater percentage of gravel substrate, while the Scappoose had an overall greater percentage of fine sediment substrate types. We also observed a significant difference in spawning and emergence habitat between land use types (Agriculture-Federal Forest, Agriculture-Private Forest, and Federal Forest-Urban). This result is interesting as we observed a significant decreasing trend of percent gravel across both the Coast and Cascade/Gorge strata. This further strengthens the need for stratified sampling within populations and land use types.

Within the current dataset, the differences observed in HabRate spawning and juvenile emergence across land use types may warrant further investigation utilizing methods described in Anlauf-Dunn et al. (2014). The same is true for the decreasing trend in percent gravel across monitoring strata. These methods may allow for investigation of both spawning habitat quality and proximity to juvenile rearing habitat as well as exploring correlations between juvenile habitat condition and presence or abundance of adult spawners.

Across sampling years juvenile abundance estimated from the summer snorkel counts did not exceed the summer habitat capacity at the ESU or strata scale. These findings were expected and similar to those reported in Anlauf-Dunn and Jones (2012) for coastal Oregon streams. In general, empirical juvenile estimates, summer parr capacity and winter parr capacity were higher across sampling years in the Coast stratum than in the Cascade/Gorge stratum. This is interesting because the Cascade/Gorge stratum has 858 km of available spawning and rearing habitat for coho compared to 540 km in the Coast stratum.

The rate of parr produced per female spawner in the Lower Columbia ESU (LC) was 40% lower, on average, than the rate in the Oregon Coast ESU (OC) (Constable and Suring 2021). The parr per spawner rate in the LC appeared to be less influenced by female spawner abundance, but data suggest any compensatory effect of adult abundance on the rate of parr production was weaker and less consistent in the LC than what has been observed in the OC. Differences between the ESU's are perhaps due to spawner densities (female spawners/km) that are lower in the LC than those in the OC.

The Cascade/Gorge contains more high quality (HQ) winter rearing habitat (108 km) when compared to the Coast (81 km). Approximately 86% of the available HQ habitat in the Cascade/Gorge resides in the Clackamas River population. Anlauf et al. (2005) previously hypothesized over-winter habitat was the primary limiting factor to juvenile coho abundance across the Lower Columbia ESU. Although a significant gap in time exists between the 2005 and 2007-2016 datasets (and sampling approaches differed significantly), our results largely reflect those that were reported in the 2005 assessment.

The Lower Columbia River Conservation and Recovery Plan for Oregon Populations of Salmon and Steelhead (2010) identified goals for HQ habitat intended to help populations of coho salmon persist during periods of poor marine survival (Lawson 1993, Nickelson and Lawson 1998, and ODFW 2007). These goals align to the hypothesis proposed by Nickelson and Lawson (1998) that a threshold proportion of habitat must remain of sufficient quality for a population to maintain acceptable probabilities of persistence. Our results indicate an increase in the miles of high-quality habitat across the ESU and within six out of the eight populations when compared to miles reported in the 2005 Lower Columbia River Coho Habitat Assessment (Anlauf et al. 2005) (Table 21).

Table 21. Comparison of total miles of high-quality habitat (HQ) within populations necessary for delisting and recovery outlined in the Lower Columbia River Conservation and Recovery Plan (2010), with total miles of HQ within populations surveyed 2007-2016, and those described in the Lower Columbia River Coho Salmon Habitat Assessment (LCCHA) (Anlauf et al. 2005.)

Population	HQ (miles) Necessary		2007-2016	LCCHA (2005)
	Delisting Scenario	Max Feasible Scenario	HQ Habitat (miles)	HQ Habitat (miles)
Big Creek	0	10	4.38	11.40
Clackamas River	0	61	57.78	27.09
Clatskanie River	19	19	8.44	0
Hood River	53	10	0	0
Lower Gorge Tribs	10	10	2.97	0
Sandy River	37	37	6.68	4.54
Scappoose Creek	10	24	15.35	0
Youngs Bay	0	20	22.30	1.43
All Populations	129	191	117.92	44.49

2007-2016 total (within populations) miles available to juvenile coho = 868.59
LCCHA – 2005 total miles (within populations) available to juvenile coho = 1,019.05

Unfortunately, the increase in habitat quality does not correlate with the three-year brood group trends of coho salmon parr abundance (Figure 8). In addition, we did not observe an increase coho salmon parr site occupancy across the three-year brood groups (Figure 9). Results from estimates of empirical counts, habitat capacity, and high-quality habitat suggest individual populations and/or land use types are likely driving the relative abundance of juvenile coho along with the capacity and quality of coho rearing habitat across strata.
The Conservation and Recovery Plan (2010) also set thresholds for juvenile coho that identify delisting criteria and broad sense recovery based on the percent of habitat occupied. We determined average percent occupancy of juvenile coho across sites from 2007-2016 using empirical snorkel counts and compared those with the thresholds outlined in the 2010 plan. These were used to assess the occupied habitat evaluation (Table 22). Two populations met delisting criteria (Big Creek and Youngs Bay), but no populations met the broad sense recovery criteria. Interestingly, the Big Creek and Youngs Bay populations also met delisting criteria for HQ habitat. It should be noted that only five surveys were conducted in the Lower Gorge Tributaries between 2007 and 2016. All five sites were occupied, but since we did not conduct at least six surveys, the population automatically failed the occupied habitat evaluation based on criteria established in the plan. All other populations met the evaluation criteria with six or more years of data.

Table 22. Comparison of coho salmon parr site occupancy in the Lower Columbia River ESU based on snorkel surveys in first through third order streams from 2007-2016 with delisting and recovery thresholds outlined in the Lower Columbia Conservation and Recovery Plan (2010).

	Occupancy Threshold		2007-2016	Occupied Habitat Evaluation	
Population	Delisting (% occupancy)	Broad Sense (% occupancy)	Juvenile Coho (avg. % occupancy)	Delisting (Pass/Fail)	Broad Sense (Pass/Fail)
Big Creek	0	95	66	Pass	Fail
Clackamas River	85	85	39	Fail	Fail
Clatskanie River	90	90	82	Fail	Fail
Hood River	80	90	14	Fail	Fail
Lower Gorge Tribs	50	95	100	Fail	Fail
Sandy River	75	85	27	Fail	Fail
Scappoose Creek	90	90	48	Fail	Fail
Youngs Bay	0	95	41	Pass	Fail

Although juvenile occupancy has not increased to the extent desired for coho recovery, ongoing management actions (i.e., stream restoration and regulatory efforts) may have contributed to more, high quality freshwater rearing habitat for coho salmon within the Lower Columbia River ESU, potentially improving their future persistence. Ecological processes (e.g., wood recruitment) may lag these restoration actions by years to decades before outcomes manifest as changes to instream habitat. Results of this report should be used with future monitoring efforts to evaluate stream habitat changes through time and when comparing current HQ habitat with desired status goals identified in the Conservation Plan.

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