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Streamflow and Juvenile Salmonid Habitat Availability at Six Rehabilitation Sites on The Trinity River, California 2008-2017

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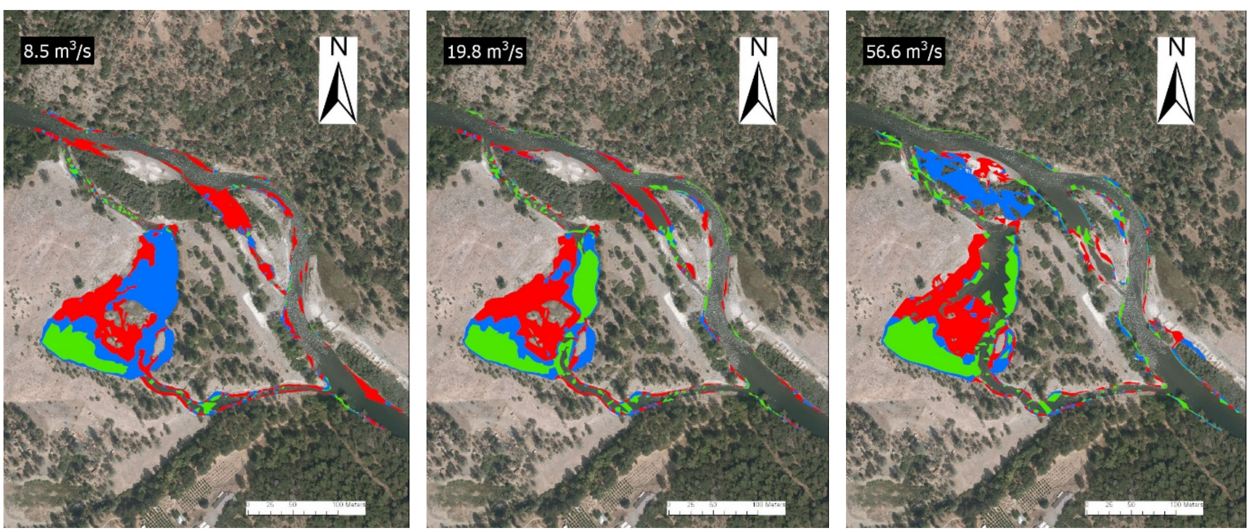

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Streamflow and Juvenile Salmonid Habitat Availability at Six Rehabilitation Sites on the Trinity River, California 2008-2017

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Abstract.— The Trinity River Restoration Program seeks to increase juvenile salmonid rearing habitat by implementing mechanical channel rehabilitation among other restoration actions. Effectiveness monitoring provides feedback to rehabilitation site designers to inform future restoration efforts and help facilitate adaptive management of the program. Recently, we documented increases in Chinook Salmon and Coho Salmon rearing habitat resulting from channel rehabilitation at summer base (12.7 m^3/s) streamflow; however, a trend analysis found 53% (10 of 19) of sites had less rearing habitat at the most recent survey than they did at the first survey after construction. Here, we assessed the effect of channel rehabilitation and subsequent trends in rearing habitat at flows ranging between 9 and 57 m^3/s at six sites by sampling just prior to construction, just after construction and during a revisit survey. Examples of constructed features included main channel meanders, split channels, side channels, alcoves, point bars and large wood jams. The area under the curve (AUC) of the streamflow to rearing habitat curves increased at five sites surveyed within a year before and after construction. Similar to the previous trend analysis, construction-related improvements were not sustained; four of six sites had lower AUC values at the most recent survey than they did at the post-construction survey. However, all sites had higher AUC values at the most recent survey than they did before construction indicating that, although diminished, construction related benefits persist at these sites. Reductions in bed relief, water surface elevation, channel sinuosity, surface area of constructed point bars and alcoves and flow entrainment at side channel entrances accounted for most of the observed habitat losses after construction; an unanticipated large increase in bed relief and water surface elevation at one site produced large increases in habitat. The Program should consider additional surveys at these sites to assess the stability of the habitat trajectories documented here.

Introduction

Trinity River salmonid populations declined within a decade of the commencement of operation of the Trinity River Division (TRD) in 1964, which on average diverted 88% (1,234 thousand acre-feet) of Trinity River water to the Central Valley (USFWS and Hoopa Valley Tribe 1999). Dam related impacts to the river and its salmonid populations include altered streamflow, sediment and large wood (LW) regimes (USFWS and Hoopa Valley Tribe 1999; USDOI 2000; Cardno-Entrix and CH2MHill 2011) as well as the elimination of 177 km of spawning and rearing areas (Moffett and Smith 1950; Locke et al. 2008). Prior to dam construction, hydraulic and placer mining from 1848 through the early 1970's (Krause 2012) changed the morphology and functioning of the channel and floodplain (Evans 1979; Frederiksen and Kamine 1980; Bailey 2008; Krause 2010). Mining activities introduced large amounts of sediment into the riparian zone and directly into the channel. Many of the resultant dredge piles of cobbles and boulders along with dam related reductions in flow variation facilitated the formation of a riparian "berm" along the channel margin that in many areas prevented water from inundating the floodplain until discharge exceeded approximately 42.5 to 56.6 m^3/s, 1,500 to 2,000 ft^3/s (USFWS and Hoopa Valley Tribe 1999). Prior to the development of this berm, the gradually sloping floodplains along alternating point bars (USFWS 1988) were inundated at much lower flows (e.g. 4 m^3/s, 150 ft^3/s). These hardened, heavily vegetated streambanks facilitated channel incision, which reduced areas of depth and velocity combinations preferred by Trinity River juvenile salmonids (Goodman et al. 2015) during much of the water year. These hydrogeomorphic impacts to spawning and rearing habitat areas and correlated declines in native fishes, including Chinook Salmon *Oncorhynchus tshawytscha*, Coho Salmon *O. kisutch*, and Rainbow Trout *O. mykiss* populations, led to restoration efforts that began in the 1980's and continue to the present.

The Trinity River Basin Fish and Wildlife Restoration Program initiated in 1985, aimed to restore anadromous salmonid production by reducing sediment input from large tributaries such as Grass Valley Creek, modernizing the Trinity River fish hatchery, establish sustainable levels of adult harvest and improve juvenile salmonid habitat (USBOR, 1992; USFWS and Hoopa Valley Tribe 1999). The juvenile habitat improvement projects included the construction of feathered edges and alcoves (USBOR, 1992) and 20 side channels (Glase, 1994). Two reports documented physical habitat changes and fish use at sites of riparian berm removal and construction of gently sloping point bars and floodplains (USFWS, 1997; Gallagher, 1999) while another report assessed the long-term performance of side channels (Boyce et al. 2018).

A more comprehensive restoration plan, initiated with the signing of the Record of Decision (ROD) (USDOI 2000), outlined the creation of the Trinity River Restoration Program (TRRP) and provided specific guidance for the regulation of discharge from Lewiston Dam, including minimum winter and summer baseflows. The TRRP incorporated many of the recommendations of the Trinity River Flow Evaluation (TRFE, USFWS and Hoopa Valley Tribe 1999), which identified the necessary restoration actions to re-initiate riverine processes, improve aquatic and riparian habitats and restore anadromous fish populations (USFWS and Hoopa Valley Tribe 1999; USDOI 2000). Restoration efforts are focused in a 64-km reach directly downstream of Lewiston Dam where habitat degradation is most pronounced (hereafter referred to as the "restoration reach"). Restoration work undertaken by the TRRP includes coarse sediment augmentation, water year (WY)-specific streamflow management and mechanical channel rehabilitation, including riparian planting. The TRRP adds coarse sediment annually to reverse the spawning gravel deficit created by dam construction and to facilitate fluvial processes. Water year-specific streamflow management, in which Lewiston Dam discharges are scaled to the amount of precipitation expected in the watershed, is intended to facilitate fluvial processes to create and maintain a dynamic and complex channel-form and to meet habitat and water temperature needs of anadromous salmonids. Mechanical channel rehabilitation includes riparian berm removal and the construction of specific features such as point-bars, floodplains, large wood structures and off channel habitats such as alcoves and side channels.

The TRRP hypothesized that a dynamic, complex channel could be re-created at a smaller scale relative to pre-TRD conditions, which in combination with other program activities would restore fish populations. Using fish production modeling, instream flow/habitat modeling and channel manipulation studies, the TRFE determined that rearing habitat availability for juvenile salmonids limits the sustainable reproductive potential of Trinity River populations. In response, the TRRP established that one of its main objectives would be to increase rearing habitat in the restoration reach, primarily through channel rehabilitation, but with the expectation that other TRRP restoration actions (e.g. streamflow management and gravel augmentation) would facilitate increases throughout the restoration reach over time (Barinaga 1996; USDOI 2000). The TRFE also identified a deficit in rearing habitat with increasing discharge at intermediate streamflows, informally referred to as the habitat “dip”. There is general agreement within the Program that elimination of this habitat reduction through channel and floodplain rehabilitation would help the Program achieve sub-objectives 2.1.1 and 2.1.3 of the Integrated Assessment Plan (IAP, TRRP and ESSA 2009), which call for increasing juvenile rearing habitat and reducing the loss of juveniles to stranding, respectively.

In addition to establishing comprehensive recommendations for the restoration of salmonid populations in the Trinity River, the TRFE also recommended that the TRRP employ an adaptive environmental assessment and management (AEAM) process, which was included in the language of the ROD. The Program is striving to realize the full manifestation of the AEAM framework, which includes monitoring the effectiveness of restoration actions and integrating the results into future restoration and management decisions. This report will partially fulfill this obligation by providing general feedback to the Program and specific information to rehabilitation site designers about the relationship between streamflow and rearing habitat availability at channel rehabilitation sites constructed by the TRRP.

Effectiveness monitoring evaluations on juvenile salmonid rearing habitat by the TRRP have primarily focused on specific channel rehabilitation sites during summer base streamflow (12.7 m^3/s, 450 ft^3/s) and have documented an immediate improvement in habitat availability due to construction (e.g. Goodman et al. 2010; Martin et al. 2013; Martin, 2016). Longer-term assessments have been conducted at systemic (Goodman et al. 2016) and site-specific (DeJuilio et al. 2014; Boyce et al. 2018) scales. The systemic estimate, using random sampling throughout the restoration reach, identified annual variation in rearing habitat levels but little overall change between 2009 and 2013 at summer base streamflow. This result was supported by Curtis et al. (2015) that found a 5% increase in active channel area coupled with a 3% decrease in channel complexity between

1980 and 2011. At winter base streamflow (8.5 m^3/s, 300 ft^3/s), DeJuilio et al. (2014) observed a large increase in rearing habitat at the Sawmill rehabilitation site after construction but found three years later that total and optimal presmolt habitat had decreased (15% and 47%, respectively), which was primarily attributed to the closing of a side channel. Boyce et al. (2018) found at summer base streamflow that 47% of TRRP rehabilitation sites provided more habitat at the time of the last survey (in some cases up to 7 years post-construction) than they did at the first survey after construction. At some sites, reductions in habitat availability were directly related to the disconnection of constructed off-channel habitat features from the mainstem channel. Habitat benefits of these and other feature types such as floodplains, feathered edges and bars manifest at other discharges. Here we provide a follow up to the summer low flow site-specific analysis and look at trends in streamflow to habitat relationships at six rehabilitation sites.

The overall goal of this report is to describe the relationship between rearing habitat and five Lewiston Dam discharges (8.5, 12.7, 19.8, 33.9 and 56.6 m^3/s, 300, 450, 700, 1,200, 2,000 ft^3/s) at TRRP rehabilitation sites over time. More specifically, the objectives of this report are to:

1) Determine the effect of construction on rehabilitation site-specific streamflow to rearing habitat relationships. We hypothesized that channel rehabilitation would increase the amount of rearing habitat at all surveyed discharges.

2) Identify trends in the relationship between streamflow and rearing habitat over time. We hypothesized that TRRP streamflow management and gravel augmentation would sustain or enhance construction related increases in habitat availability.

3) Evaluate the trend in habitat response of specific constructed features in relation to their geomorphic and hydraulic context.

Study Area

The Trinity River is the largest tributary to the Klamath River and is located in northwestern California, USA (Figure 1). The Trinity River headwaters originate in the Trinity Mountains, the Yolla Bolly Mountains and the Trinity Alps from which it flows approximately 274 km to its confluence with the Klamath River. The Trinity River watershed has a drainage area of 7,679 km^2, approximately one quarter of which is upstream of Lewiston Dam (USFWS 1989; USBOR 2009). The channel rehabilitation sites analyzed here are located in the Trinity River between Lewiston Dam and the confluence with the North Fork Trinity River.

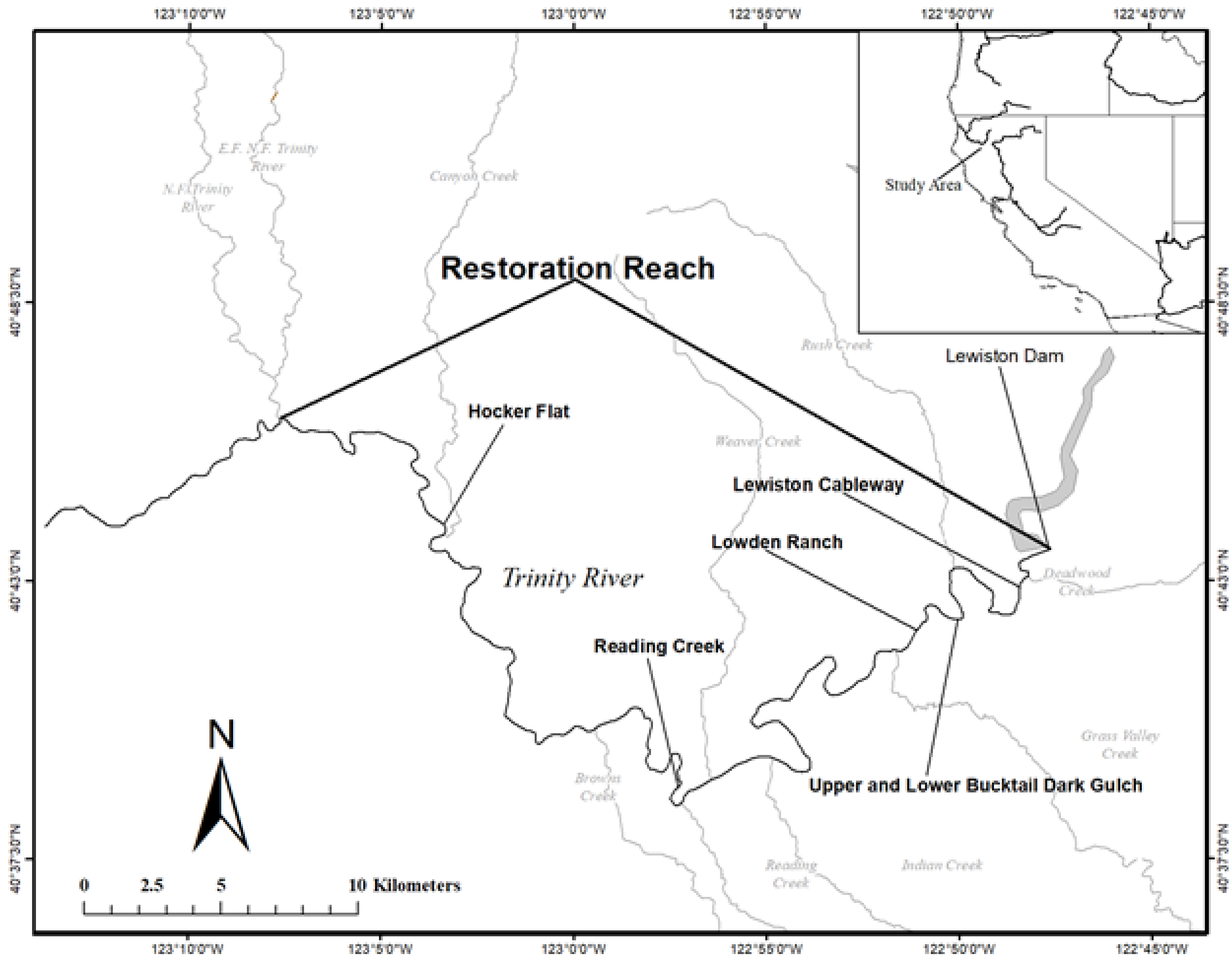


Figure 1. Channel rehabilitation sites in the Trinity River Restoration Reach from Lewiston Dam to the confluence with the North Fork Trinity River. Streamflow is from right to left. Bold labels indicate channel rehabilitation site names.

Habitat Surveys

Habitat surveys were conducted during five scheduled Lewiston dam releases (8.5, 12.7, 19.8, 33.9 and 56.6 m^3/s) at six rehabilitation sites (Table 1) from 2008-2017. Sites were typically surveyed just prior to construction, just after construction and during a revisit survey (Mean=7.6 ± 2.3 years). Lower Bucktail Dark Gulch site was constructed in 2008 and reconstructed in 2016. The revisit survey in 2015 serves as a pre-construction survey for the newly constructed site, which was re-named Bucktail. Unless explicitly referred to separately, we considered this physical location as one site when accounting for trends in habitat availability throughout the report. Hocker Flat was constructed in 2005 prior to the establishment of the sampling design implemented here and was therefore only surveyed at multiple streamflows in 2008 (post-construction) and 2017 (revisit). With the exception of Lowden Ranch (70%) and Reading Creek (64%), the other site surveys covered 100% of the length of rehabilitated channel.

Table 1. The channel rehabilitation sites analyzed to address report objectives. Sites are ordered from upstream to downstream and x indicates site and year of habitat survey. Lower Bucktail Dark Gulch and Bucktail refer to the same physical location in the restoration reach. Vertical bar indicates construction occurred between the pre- and post-construction survey.

		Survey Year											
Site	Year of Construction	2008		2009	2010	2011	2012	2013	2014	2015	2016	2017	Report Objective
Lewiston Cableway	2008	x	|	x							x		1, 2, 3
Upper Bucktail Dark Gulch	2008	x	|	x				x					1, 2, 3
Lower Bucktail Dark Gulch	2008	x	|	x						x			1, 2, 3
Bucktail	2016									x	|	x	1
Lowden Ranch	2010			x	|	x						x	1, 2, 3
Reading Creek	2010			x	|	x						x	1, 2, 3
Hocker Flat	2005	x										x	2, 3

The sites analyzed to address the previously defined objectives are included in Table 1. Objective one included Lewiston Cableway, Upper and Lower Bucktail Dark Gulch/Bucktail, Lowden Ranch and Reading Creek. There were two components of objective two, comparison of the post-construction and revisit surveys, which included Lewiston Cableway, Upper and Lower Bucktail Dark Gulch, Lowden Ranch, Reading Creek and Hocker Flat sites. There was no revisit survey at Bucktail. The second component of objective two, comparison of the pre-construction and revisit surveys included Lewiston Cableway, Upper and Lower Bucktail Dark Gulch, Lowden Ranch and Reading Creek sites. There was no pre-construction survey at Hocker Flat. Objective three included all sites except Bucktail.

LW pieces (Median=178, range=51 to 1,306) were placed at all rehabilitation sites with the exception of Hocker Flat (Boyce and Goodman 2018); the number and type of other constructed features at the six sites also varied considerably. At Lewiston Cableway, a pre-TRRP constructed side channel on river right was re-excavated to increase the amount of streamflow diverted into it. Four point bars were placed along the length of the site, three on the left bank, one on the right bank, which were intended as sources of sediment augmentation. At Upper Bucktail Dark Gulch the left bank was cleared of all vegetation, opposite that bank, a large floodplain and low flow side channel were constructed. At Lower Bucktail Dark Gulch three gravel bars were placed, one along the top right bank, one halfway down in the middle of the channel and one along the bottom left bank at the bottom of the site. Two areas along the left bank in the middle of the site, approximately 1,000 m^2 meters each, received various amounts of large wood pieces. A low flow side channel was constructed on the right bank opposite the areas of large wood. Reconstruction of this site, now referred to as Bucktail, included a skeletal bar and mainstem channel realignment on the right bank to increase channel sinuosity. On the left bank, opposite the skeletal bar, a low flow side channel was constructed that supplies water to a large wetland and pond. Downstream, a beaver dam analog helps sustain water retention in the wetland and pond, which connect to the mainstem by another low flow side channel. Two engineered log jams (ELJ's) were placed inside the left bank of the channel realignment. A point bar and alcove were placed downstream of the ELJ's. Finally, a large gravel bar was placed at the bottom of the site on the left bank. At the top end of the Lowden Ranch site, a point bar was built adjacent to the entrance to a side channel, which supplies water to a constructed wetland. Farther downstream, the main channel was realigned to increase sinuosity and directly opposite this realignment, a point bar for gravel augmentation was constructed. Farther downstream on the left bank, the riparian berm was replaced by a large floodplain with two sloping benches and a small side channel that connected to an alcove. At Reading Creek, the Program placed four main channel meanders along the right bank and one along the left bank, which primarily function to widen the mainstem channel. A large floodplain was constructed adjacent and upslope of the right bank meanders. Downstream of the right bank meander a large floodplain and high flow scour channel were constructed at the bottom of the site. At Hocker flat, a large area of the left bank was cleared of vegetation for the construction of a floodplain.

Hereafter, we collectively refer to these features as construction or construction related. Terminology for specific constructed features (e.g. main channel meander) were taken directly from the Design_2D feature class found in the TRRP "As Built" geodatabase (TRRP unpublished data). This geodatabase is used as a repository for spatial data associated with TRRP channel rehabilitation actions including planned site designs and features that reflect what was constructed (as built) which may differ from designs in some cases.

Age-0 Chinook Salmon and Coho Salmon rearing habitat was mapped using methods described in Goodman et al. (2015), where depth, velocity, and distance to escape cover were delineated at specified thresholds (Table 2). We defined cover as wetted woody debris, vegetation or tree roots that could be used for hydraulic refugia, shade or escape from predation. Rearing habitat was divided into two developmental phases for salmon within their first year of growth (age-0) based on fork length: (1) fry or fish <50 mm, and (2) presmolt or fish 50 to 100 mm. Rearing habitat was also separated into optimal and total categories. Optimal Chinook Salmon rearing habitat for fry and presmolt life stages included areas that simultaneously meet depth (D), velocity (V), and cover (C) criteria. Total rearing habitat included optimal areas (DV, C) plus suitable areas (DV, no C and no DV, C). Validation studies have demonstrated that Coho Salmon are more strongly associated with optimal habitat areas relative to other habitat categories (Goodman et al. 2010; Alvarez et al. 2015). Therefore, Coho Salmon rearing habitat was limited to optimal areas following Martin et al. (2012). We delineated habitat categories throughout the wetted area of each study segment (including side or split channels) by ground-based GPS surveys. Each habitat measurement was geo-referenced to produce spatially explicit representations of rearing habitat areas. Water velocity values were obtained with a FlowTracker handheld Acoustic Doppler Velocimeter (SonTek). Spatial analyses were conducted with ArcGIS Pro (2.0.1).

Table 2. Salmon fry and presmolt rearing habitat criteria (FL=fork length).

Developmental phase	Variable	Criteria
Fry (<50 mm FL)	Depth	>0 to 0.6 m
	Mean column velocity	0 to 0.15 m/s
	Distance to cover	0 to 0.6 m
Presmolt (50-100 mm FL)	Depth	>0 to 1 m
	Mean column velocity	0 to 0.24 m/s
	Distance to cover	0 to 0.6 m

Analysis

We conducted habitat surveys during specific dam releases and report the raw survey data in Appendix A. We used linear interpolation (Appendix B), to adjust habitat values at the minimum and maximum streamflows that varied by more than 10% due to differences in tributary accretion between survey years (Appendix C). This normalized the discharge range of each curve and prevented artificially inflating or deflating the area under the curve to facilitate survey comparisons across years. When discussing interpolated values we reference specific figures for the streamflow to habitat curves. In addition, we describe changes in rearing habitat using the nominal dam releases as reference flows, and report actual flow levels in the Tables, Figures and Appendices.

We calculated standardized total and optimal rearing habitat for fry and presmolt life stages across multiple sites and years. Goodman et al. (2016) found that measurements of optimal rearing habitat area for presmolt and fry exhibited a Pearson's product-moment correlation (ρ) of 0.985 (CI = 0.980 to 0.989) and total rearing habitat area had a ρ of 0.983 (CI = 0.977 to 0.988). For brevity, we limited reporting to presmolt habitat area.

We calculated the area under the curve (AUC) for each streamflow to habitat curve by site and survey year to condense multiple data points into a single metric to facilitate spatiotemporal comparisons. We generated AUC values using the definite integral and the trapezoidal rule to calculate the area between a graph curve and the 'x' axis, between two given values of 'x'. Therefore, the units for this metric are simply the product of the 'x' and 'y' axes ($m^3/s*m^2/m$). We standardized habitat area (m^2) by stream length (m) to improve comparability among sites with different lengths.

To determine the effect of construction on rehabilitation site-specific streamflow to rearing habitat relationships as specified under objective one, we tested for differences in AUC from pre-construction to post-construction with a Wilcoxon-Signed Rank Test. For objective two, to identify trends in the relationship between streamflow and rearing habitat over time, we compared AUC values between the revisit survey and both the pre- and post-construction surveys by a) calculating percent change in AUC and b) plotting AUC over time. For objective three, to evaluate the trend in habitat response of specific constructed features in relation to their geomorphic and hydraulic context, we combined previously reported results (Martin et al. 2013; Martin 2014a, b) with new data reported here. The TRRP takes aerial photographs of the restoration reach every year; we compared changes in habitat availability to physical changes evident in these photographs to document the fluvial processes and specific feature types related to the trends and patterns we observed in streamflow to rearing habitat relationships at these six sites. We analyzed all data with R Studio Version 1.1.453 (R Core Team 2009-2018).

Results

Objective 1: Determine the effect of construction on rehabilitation site-specific streamflow to rearing habitat relationships.

We found moderate evidence ($p=0.03$) that channel rehabilitation increased habitat availability across surveyed discharges. Further, the median AUC of the streamflow to rearing habitat curves increased at all rehabilitation sites where survey data were available within one year before and one year after construction. AUC values for total (Median=61%, range=32% to 529%) and optimal (Median=40%, range=2.4% to 318%) habitat curves increased (Figure 2). The only decrease from pre- to post-construction occurred at Upper Bucktail Dark Gulch at a streamflow of 56.6 m^3/s, with optimal habitat decreasing 40% (Appendix B) likely due to vegetation removal during side channel construction. The maximum observed increase in AUC for the total habitat curve was at the Bucktail site (529%) re-constructed in 2016 and the maximum observed increase in AUC for the optimal habitat curve was at the Lowden Creek site (318%) constructed in 2010 (Table 3). A large proportion of the observed habitat gains at these two sites resulted from the creation of extensive off-channel features that included side channels and wetland areas. For example, across all flows, off-channel areas contain over 80% and 40% of total habitat at Bucktail and Lowden Ranch, respectively.

Despite overall increases in habitat due to construction, the streamflow to total habitat curves at Upper Bucktail Dark Gulch, Lower Bucktail Dark Gulch, Bucktail, Lowden Ranch and Reading Creek retained a “dip” or reduction in habitat availability at intermediate discharges at the post-construction survey (Figures 3 and 4).

Objective 2: Identify trends in the relationship between streamflow and rearing habitat over time.

Four of six sites had lower AUC values for the total (Median= -11%, range= -20% to 206%) and optimal (Median= -12%, range= -22% to 541%) curves at the most recent survey than they did at the post-construction survey. This indicates performance of realized construction-related benefits over time are at best mixed, and frequently have diminished (Table 3; Figure 5) at the sites available for inclusion in this analysis. For example, at Lewiston Cableway streamflows between 2009 and 2016 reduced the combined surface area of three constructed point bars by 46%, which reduced sinuosity and resulted in smaller downstream eddies and lower water surface elevations. Consequently, inundation along channel margins was also reduced and limited vegetation interactions and decreased surface flow entering the side channel by 33% during winter base-flow conditions. Alternatively, we observed marked increases in AUC for total and optimal habitat at Upper Bucktail Dark Gulch between 2009 and 2013 despite a slight reduction in habitat availability at 300 ft^3/s (Figure 3). During a spring high flow event in 2011, a large gravel bar deposit increased the water surface elevation at the site, which increased the flood frequency of the side channel and floodplain creating large habitat areas at discharges above 700 ft^3/s. Increases in optimal habitat were the result of re-vegetation during construction and natural regeneration over time. We also observed increases in AUC at Lower Bucktail Dark Gulch between 2009 and 2015 (Table 3) despite reductions in total habitat below 700 ft^3/s and optimal habitat below 450 ft^3/s (Figure 3).

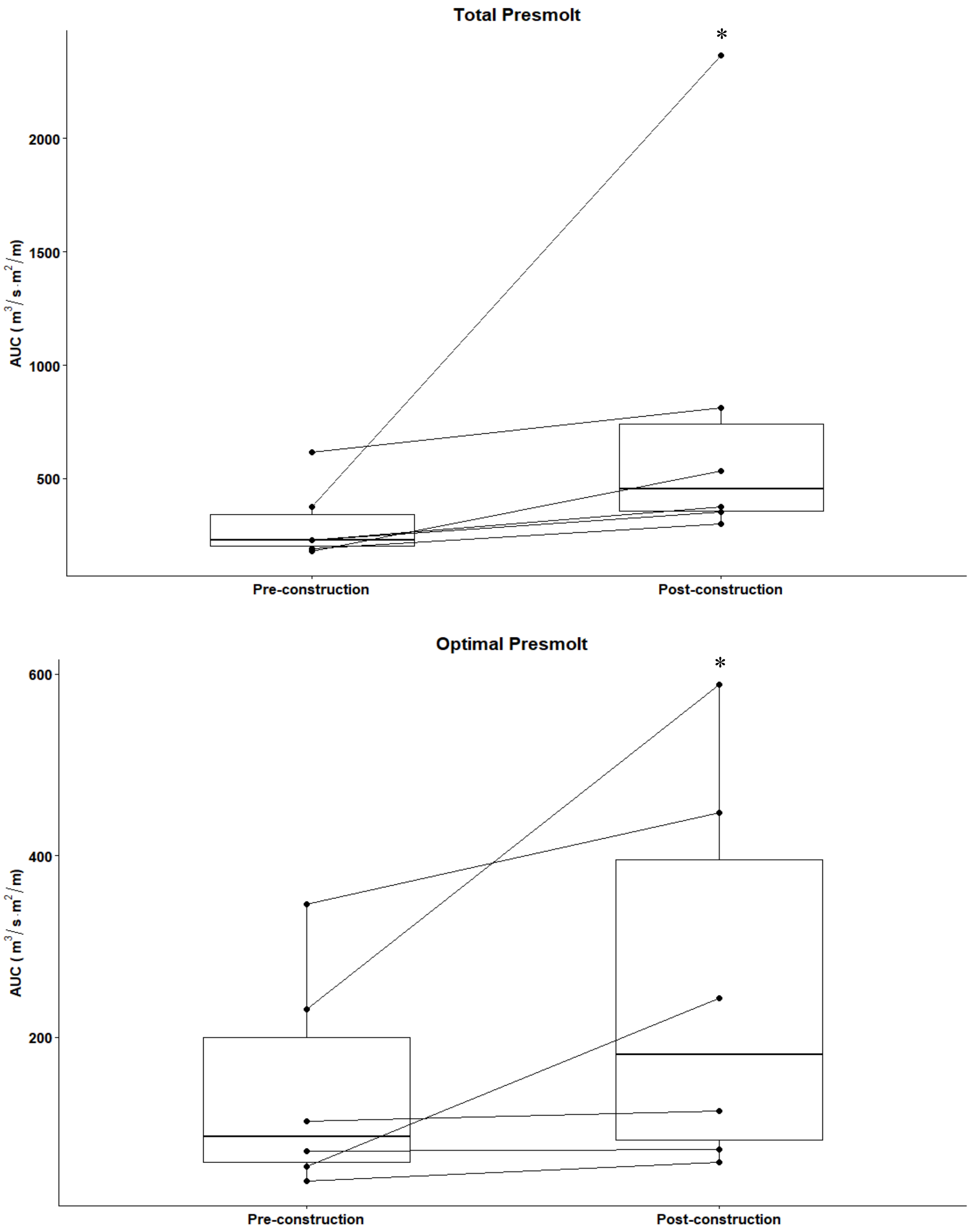


Figure 2. Variation in the AUC for total and optimal presmolt habitat curves. Lines connect individual sites from pre- to post-construction. Note the plots have different scales. Horizontal lines within the boxes indicate the median, boxes around the median indicate the interquartile range. Wilcoxon Signed Rank Test, * p=0.03.

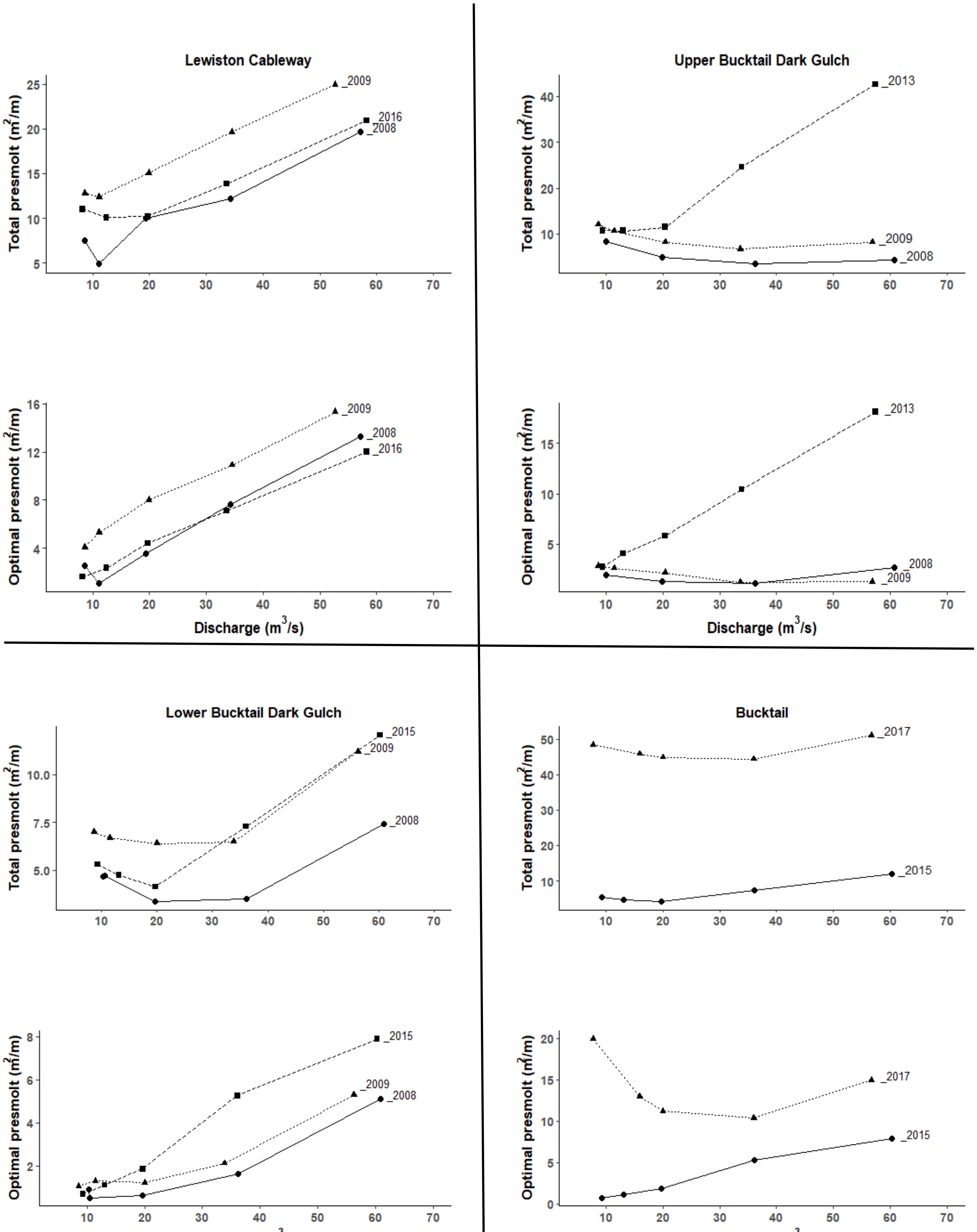


Figure 3 Total and optimal presmolt habitat density (m^2/m) at multiple streamflows at Lewiston Cableway, Upper Bucktail Dark Gulch, Lower Bucktail Dark Gulch and Bucktail. Note the y-axes have different scales and common line types for pre-construction, post-construction and revisit surveys.

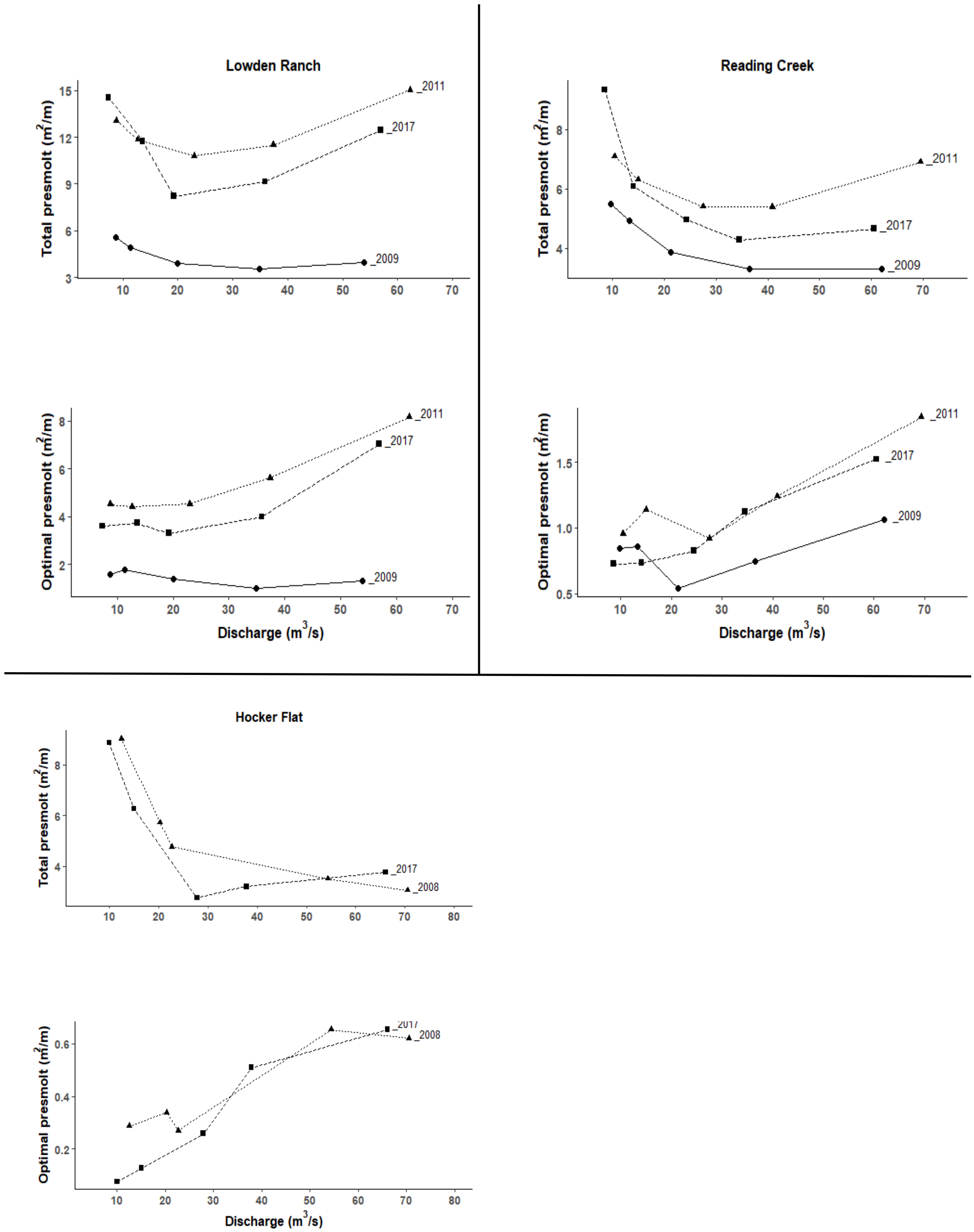
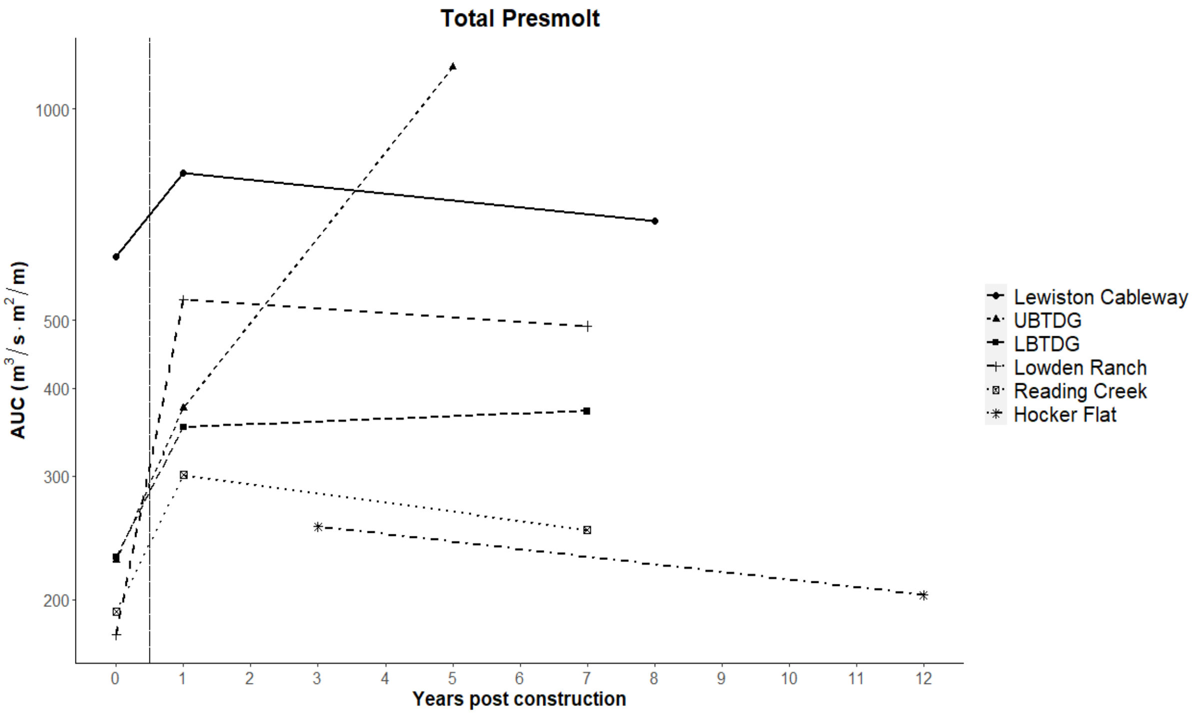


Figure 4. Total and optimal presmolt habitat density (m^2/m) at multiple streamflows at Lowden Ranch, Reading Creek and Hocker Flat. Note the y-axes have different scales and common line types for pre-construction, post-construction and revisit surveys.

Table 3. AUC values and percent change before (PreC) and after (PostC) construction.

Site	Survey Year	AUC Total	AUC Optimal	Change Total from PreC	Change Optimal from PreC	Change Total from PostC	Change Optimal from PostC
Lewiston Cableway	2008	615.48	347.07	- -	- -	- -	- -
	2009	811.49	447.02	32%	29%	- -	- -
	2016	692.38	348.68	12%	0.46%	-15%	-22%
Upper Bucktail Dark Gulch	2008	227.37	74.71	- -	- -	- -	- -
	2009	374.73	76.53	65%	2.44%	- -	- -
	2013	1,148.01	490.47	405%	556%	206%	541%
Lower Bucktail Dark Gulch	2008	230.00	107.57	- -	- -	- -	- -
	2009	351.82	118.78	53%	10%	- -	- -
	2015	371.01	229.97	61%	114%	5%	94%
Bucktail	2015	376.24	230.72	- -	- -	- -	- -
	2017	2,364.91	588.06	529%	155%	- -	- -
Lowden Ranch	2009	178.31	58.09	- -	- -	- -	- -
	2011	534.38	242.90	200%	318%	- -	- -
	2017	490.57	214.40	175%	269%	-8%	-12%
Reading Creek	2009	192.24	41.60	- -	- -	- -	- -
	2011	301.18	62.88	57%	51%	- -	- -
	2017	251.34	55.34	31%	33%	-17%	-12%
Hocker Flat	2008	254.16	27.99	- -	- -	- -	- -
	2017	203.13	22.94	- -	- -	-20%	-18%



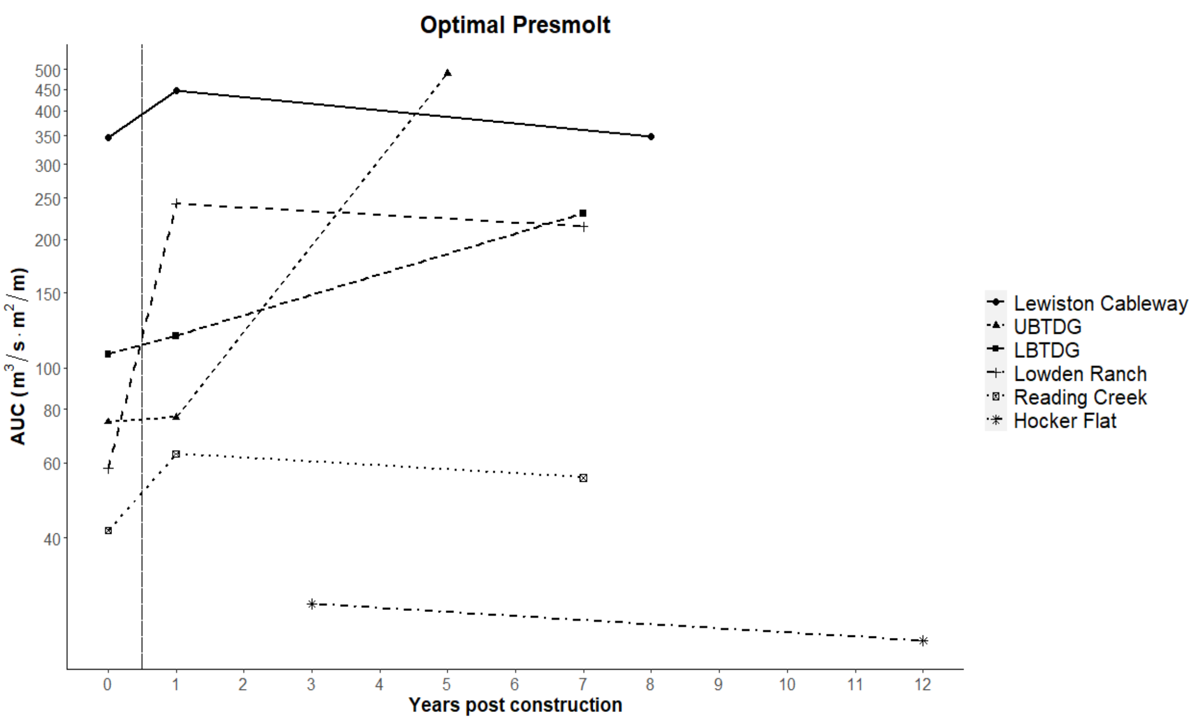


Figure 5. The AUC for total and optimal presmolt habitat before (year 0) and after construction (n=six rehabilitation sites). Vertical line separates pre-construction from post-construction habitat. Note the scales are different and UBTDG and LBTDG refer to Upper Bucktail Dark Gulch and Lower Bucktail Dark Gulch, respectively. There was no pre-construction survey at Hocker Flat.

All five sites had higher AUC values for the total (Median= 61%, range= 12% to 405%) and optimal (Median= 114%, range= 0.46% to 556%) curves at the most recent survey than they did before construction indicating that, although diminished, construction-related benefits persisted at these sites (Table 3; Figure 6). For example, we observed an 8% and 12% reduction in total and optimal AUC values, respectively from post-construction to revisit surveys conducted at Lowden Ranch; however, the revisit AUC values were still 175% and 269% above pre-construction values, respectively.

We documented reduction of total habitat at intermediate flows (Figures 3 and 4) at the most recent survey at five of six sites (Lewiston Cableway, Lower Bucktail Dark Gulch, Lowden Ranch, Reading Creek and Hocker Flat). The attenuation of the dip at 450 ft^3/s for total habitat noted at Lewiston Cableway after construction was not sustained while the improvement in optimal habitat was sustained. The reduction in total habitat noted at Upper Bucktail Dark Gulch was eliminated. There was no reduction of optimal habitat at Lower Bucktail Dark Gulch or Hocker Flat at the most recent survey.

Objective 3: Document the specific construction features and geomorphic/hydraulic conditions associated with observed habitat responses over time.

Fluvial processes affected rearing habitat availability at all six channel rehabilitation sites. Sediment aggradation and/or scour caused changes to bar morphology, channel sinuosity and bed relief, which changed the distribution and extent of areas meeting our habitat criteria and at some sites, affected the performance of off-channel features. Additionally, the loss or recruitment of escape cover affected optimal habitat levels at all six sites.

Five peak streamflows (≥ 170 m^3/s, 6,000 ft^3/s) passed through Lewiston Cableway after the post-construction survey in 2009; by 2016, the combined surface area of three constructed point bars (IC-8, IC-9 and IC-10) had been reduced by 46% (Figure 7). Coarse sediment mobilization reduced sinuosity and resulted in smaller downstream eddies and lower water surface elevations. Consequently, inundation along channel margins was also reduced and limited vegetation interactions and decreased surface flow entering the side channel by 33% during winter base-flow conditions.

Alternatively, we documented dramatic increases in total and optimal habitat at Upper Bucktail Dark Gulch, which experienced three peak streamflows (≥ 6,000 ft^3/s) including a 348 m^3/s (12,290 ft^3/s) event in 2011. A large gravel bar (180 m in length) deposited along the right bank of the mainstem that was over 2 m in depth at some locations, which reduced conveyance in the mainstem and raised the water surface elevation at the upstream end of the site, causing floodplain and side channel inundation at much lower mainstem discharges. The floodplain was designed to flood at 127 m^3/s (4,500 ft^3/s). Since 2013, however, the floodplain begins to wet at flows around 700 ft^3/s (Figure 8). Re-vegetation efforts during construction along with natural regeneration over time facilitated increases in optimal habitat.

Sediment aggradation at the entrance to the low flow side channel (R4) at Lower Bucktail Dark Gulch in 2011 reduced streamflow entering the channel at or below approximately 1,200 ft3/s (Figure 9), which was responsible for most of the habitat loss observed at this site in 2015. At higher streamflows, habitat availability was just above post-construction

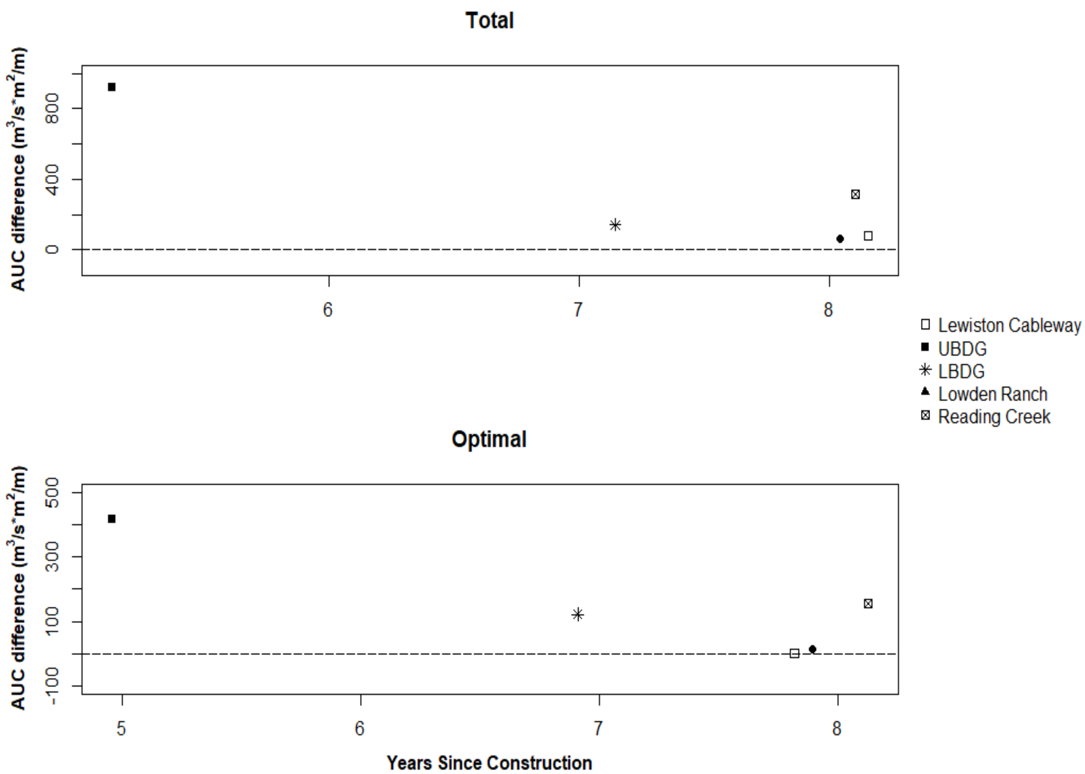


Figure 6. The difference in the AUC ($m^3/s * m^2/m$) of the streamflow to total and optimal presmolt habitat curves between the pre-construction survey and the most recent survey (n=five rehabilitation sites). Note that UBDG and LBDG refer to Upper Bucktail Dark Gulch and Lower Bucktail Dark Gulch, respectively.

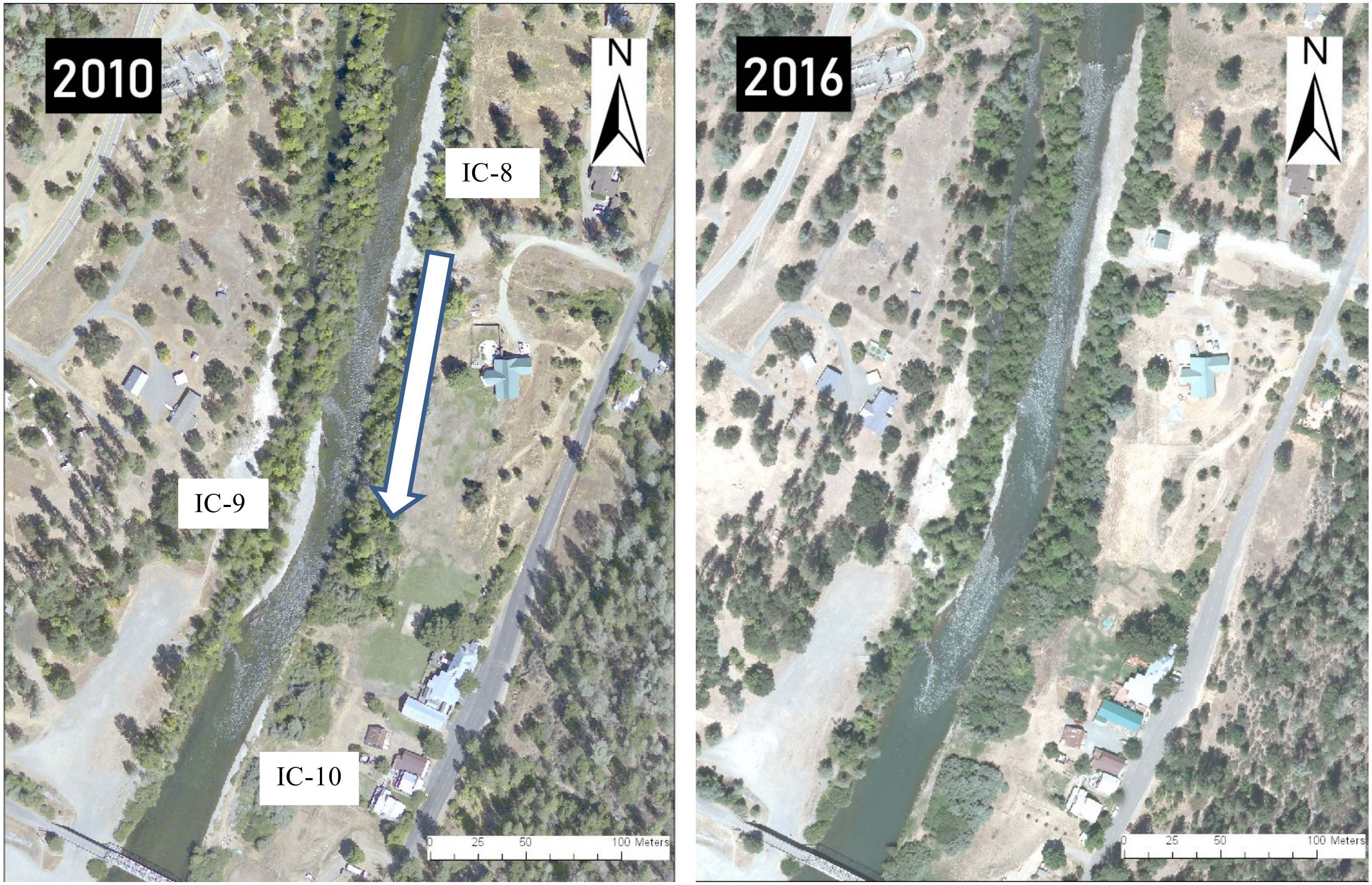


Figure 7. Partial aerial views of Lewiston Cableway rehabilitation site showing a reduction in surface area of three constructed point bars (numbered in left panel) between 2010 at 13.5 (475 ft^3/s) and 2016 at 12.5 (440 ft^3/s) m^3/s, respectively. The white arrow indicates direction of flow.

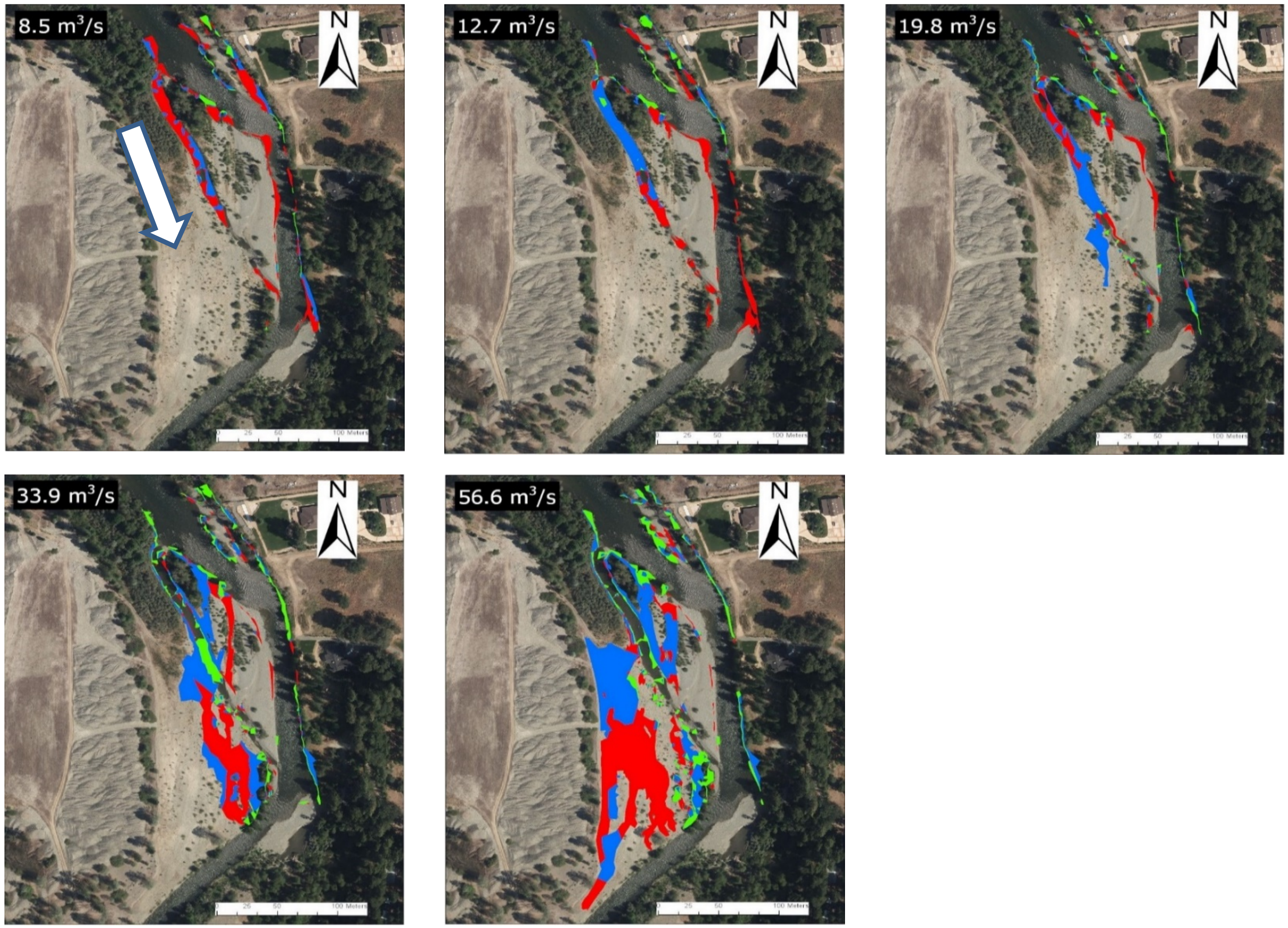


Figure 8. Partial aerial views of Upper Bucktail Dark Gulch rehabilitation site in 2013 showing the floodplain becoming inundated as flow increased from 8.5 m^3/s to 56.6 m^3/s. Blue areas indicate optimal presmolt habitat, red and green areas indicate suitable presmolt habitat. The white arrow indicates direction of flow.

levels (Figure 3). Optimal habitat increased beyond levels observed at post-construction above 450 ft^3/s as streamflow began inundating the vegetation in the side channel. Despite the losses at lower flows, the downstream end of the side channel still provided habitat benefits by functioning as an alcove (Figure 9), although its surface area decreased 43% at 450 ft^3/s until the site was reconstructed in 2016 (Figure 10).

The relationship between streamflow and total habitat changed similarly from the post-construction survey (2011) to the revisit survey (2017) at Lowden Ranch and Reading Creek (Figure 4). At both sites, sediment re-distribution in the mainstem changed the bed relief and thus water surface elevation, which may be responsible for the observed increases in winter base flow habitat levels (Figures 11 and 12). However, as flows exceeded 450 ft^3/s, habitat availability decreased relative to the post-construction survey at both sites. At Lowden Ranch large decreases in optimal habitat at higher discharges occurred due to the restriction of flow entering the high flow channel connected to the lower alcove on the left bank. Loss of areas of inundation in the island at the top of the site and along both mainstem banks just below the main channel realignment (R3) also reduced optimal habitat. At Reading Creek steady decreases in suitable habitat resulted from course sediment mobilization around the five constructed main channel meanders (labeled redundantly as R4 and R5), which reduced inundation of the constructed floodplain and high flow scour channel (R4) at the bottom of the site.

Unlike the congruent pattern between total and optimal habitat to discharge relationship observed at other sites, we documented an inverse relationship between total and optimal habitat with increasing discharge at Hocker Flat (Figure 4). However, the amount of both habitat types decreased at most discharges between the post-construction and revisit surveys. At the time of the post-construction survey in 2008 sediment had deposited at the upstream end of the site and toward the bottom of the site forming an alcove and mid-channel bar, respectively. The surface area of the alcove measured at 450 ft^3/s, decreased from 657 to 584 m^2 between 2008 and 2012 and completely disappeared by 2017, eliminating areas of suitable habitat (Figure 13).

Discussion

The TRRP restoration strategy rests on a foundational hypothesis that channel rehabilitation in conjunction with streamflow management, gravel augmentation and watershed restoration will facilitate geo-fluvial processes that will lead to increases in rearing habitat through the creation of a more complex and dynamic channel form (USFWS and Hoopa Valley Tribe 1999; TRRP and ESSA 2009). Trend analyses of rearing habitat availability at winter base streamflow (300 ft^3/s) at Sawmill rehabilitation site (DeJuilio et al. 2014) and summer base streamflow (450 ft^3/s) at systemic (Goodman et al. 2016) and rehabilitation site-specific (Boyce et al. 2018) scales over various intervals (up to nine years) found equivocal evidence in support of this hypothesis. Possible explanations for this are (1) increases in rearing habitat over time may not occur at all discharges such as winter and summer base streamflow, (2) the interaction of TRRP restoration actions require more time for habitat increases to manifest, (3) the duration, magnitude, frequency or timing of streamflow events (under the current management regime) are not sufficient to catalyze the desired fluvial processes necessary to create more habitat, (4) changes to the TRRP restoration philosophy

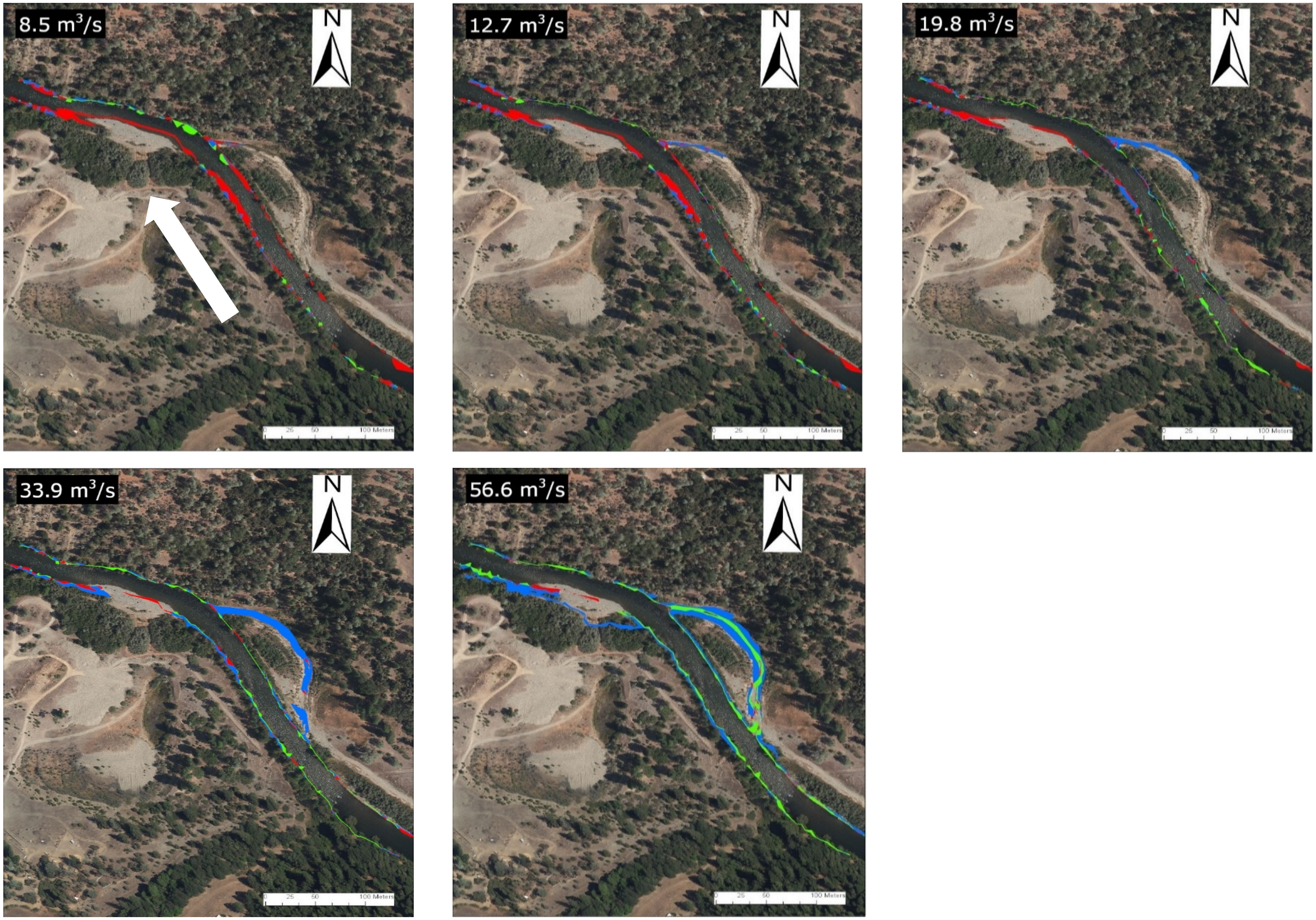


Figure 9. Partial aerial views of Lower Bucktail Dark Gulch rehabilitation site showing the side channel become inundated as flow increased from 8.5 to 56.6 m^3/s. Blue areas indicate optimal presmolt habitat, red and green areas indicate suitable presmolt habitat. The white arrow indicates direction of flow.

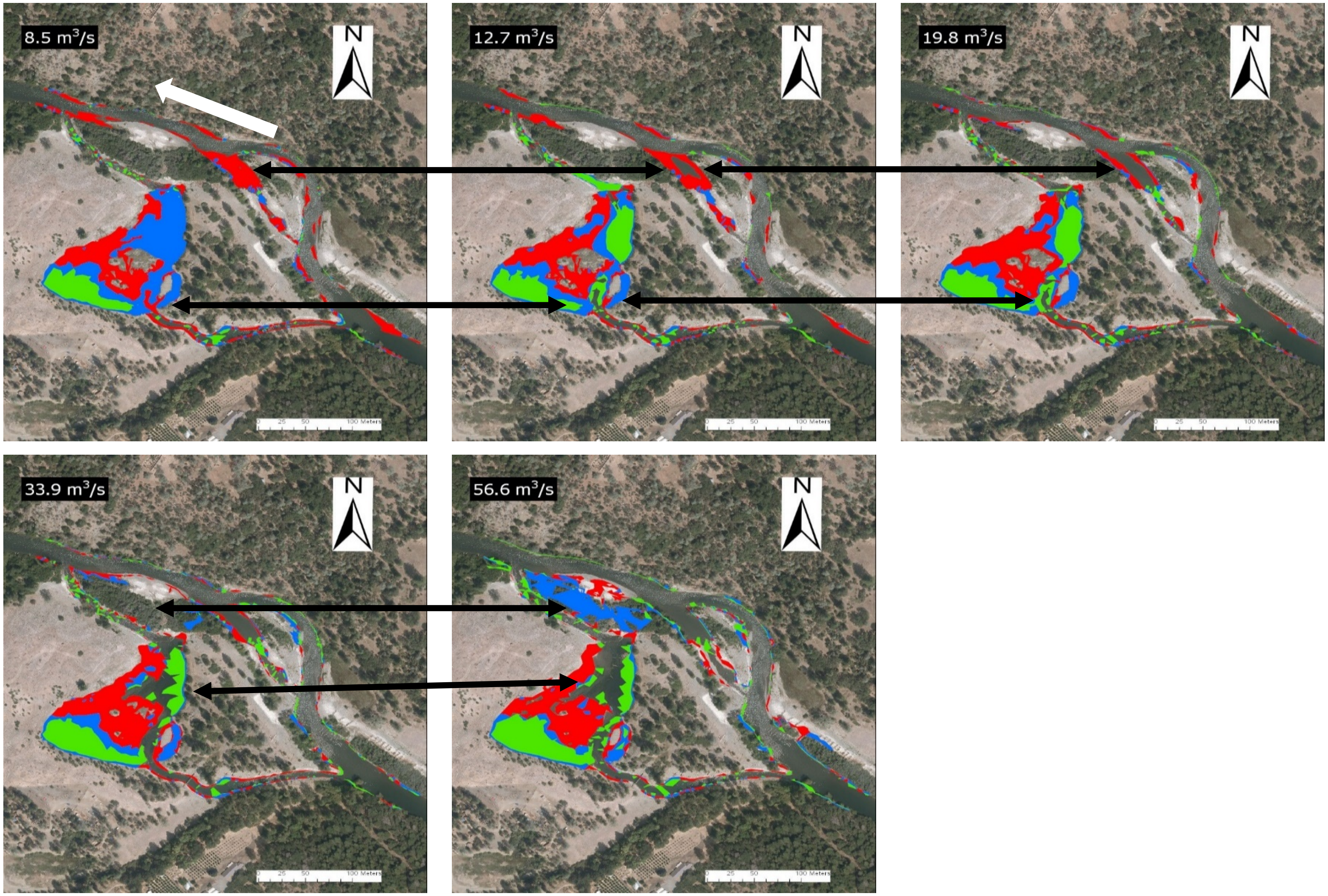


Figure 10. Aerial view of Bucktail rehabilitation site after construction. Black arrows indicate areas where depth and velocity changed as flow increased from 8.5 to 56.6 m^3/s, which generated the "dip" in the streamflow to habitat curve. Blue areas indicate optimal presmolt habitat, red and green areas indicate suitable presmolt habitat. The white arrow indicates direction of flow.

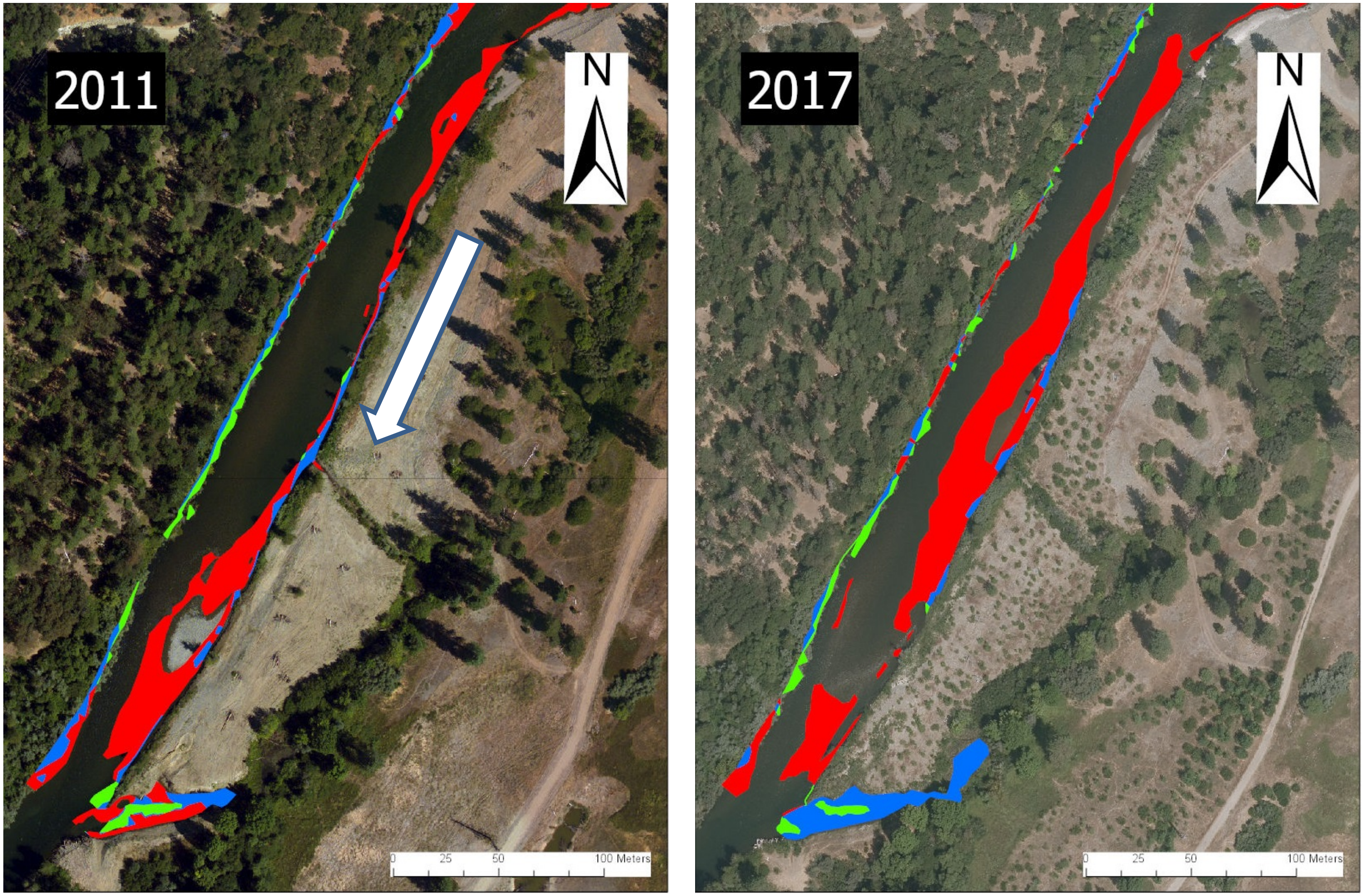


Figure 11. Partial aerial views of the downstream end of Lowden Ranch rehabilitation site showing sediment mobilization and an increase in habitat area between the post construction (2011) and revisit (2017) surveys. Habitat areas were mapped at 8.8 (311 ft^3/s) and 7.4 (261 ft^3/s) m^3/s, respectively. Blue areas indicate optimal presmolt habitat, red and green areas indicate suitable presmolt habitat. The white arrow indicates direction of flow.

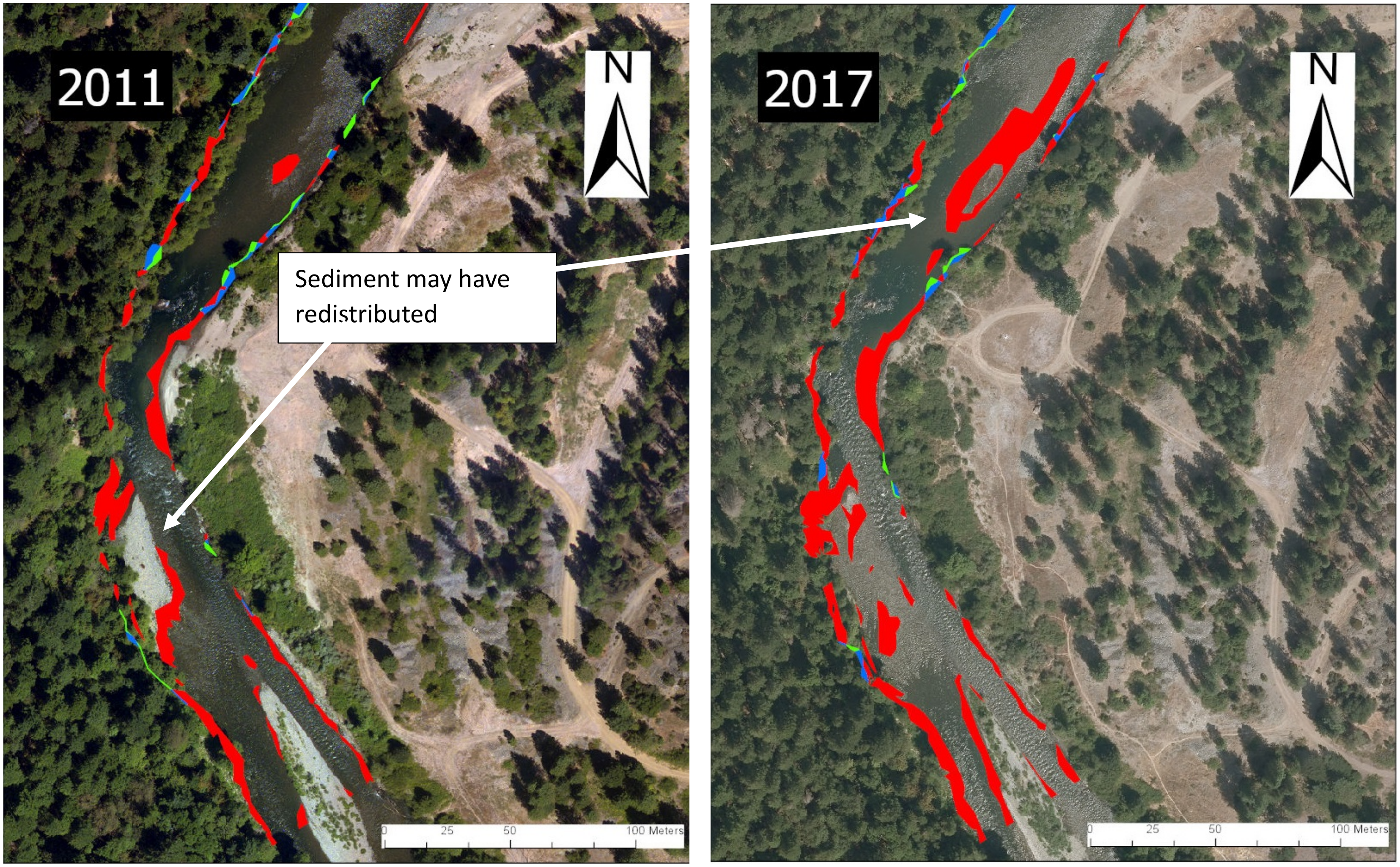


Figure 12. Partial aerial views of the upstream end of Reading Creek rehabilitation site showing sediment mobilization and an increase in habitat area between the post construction (2011) and revisit (2017) surveys. Habitat areas were mapped at 10.5 (371 ft^3/s) and 8.6 (304 ft^3/s) m^3/s, respectively. Blue areas indicate optimal presmolt habitat, red and green areas indicate suitable presmolt habitat. The white arrow indicates direction of flow.

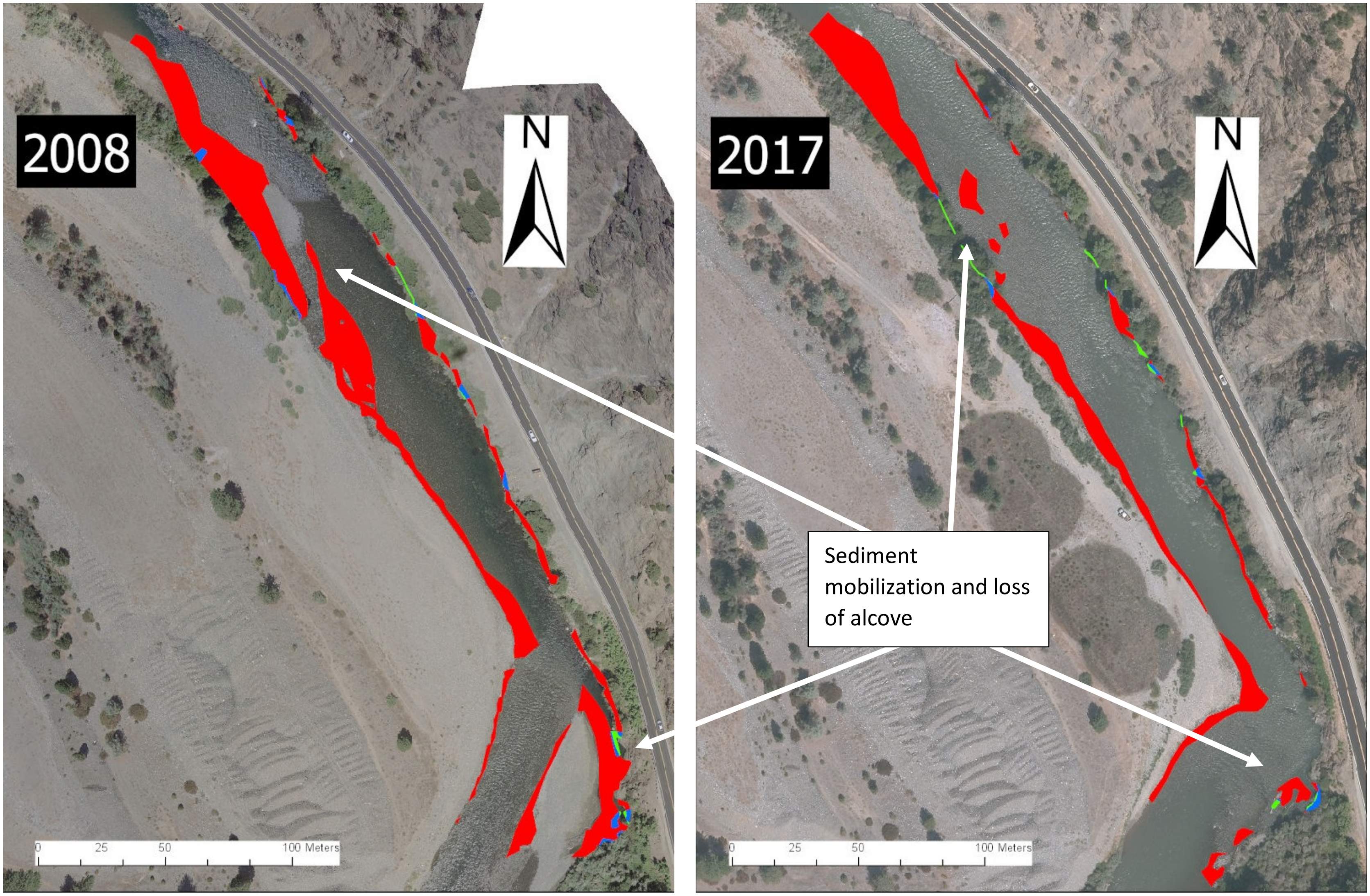


Figure 13. Aerial views of Hocker Flat rehabilitation site showing sediment mobilization and loss of an alcove and medial bar between the post construction (2008) and revisit (2017) surveys. Habitat areas were mapped at 20.3 (717 ft^3/s) and 15.1 m^3/s (533 ft^3/s), respectively. Blue areas indicate optimal presmolt habitat, red and green areas indicate suitable presmolt habitat. The white arrow indicates direction of flow.

and associated methodologies might confound interpretation of effectiveness monitoring results and (5) the hypothesis needs revision given that only about 25% of the restoration reach is alluvial (Buffington et al. 2014).

In support of the TRRP's adaptive management mandate and as a follow up to a previous trend analysis of habitat availability at summer base streamflow (Boyce et al. 2018), we documented construction-related increases and subsequent trends in streamflow to rearing habitat relationships at six channel rehabilitation sites. Similar to DeJuilio et al. 2014 and Boyce et al. 2018, we found that rearing habitat availability improved as a direct result of channel rehabilitation (Figure 2) but some of these increases were not sustained over time (Figure 5). We found evidence of habitat benefits from channel rehabilitation efforts at all sites and nearly all streamflows with one exception (one streamflow at a single site). However, after construction benefits were not typically sustained with reductions in habitat area between 8 and 20% at four of the 6 sites (Table 3). Despite these reductions, all sites had higher AUC values at the revisit survey than at the pre-construction survey (Figure 6). This general consistency in habitat trends across sites, discharges and time indicates that loss of habitat benefits is not strictly a low flow phenomenon related to off-channel feature performance. Given current approaches to site design, construction-related habitat improvements might represent the maxima achievable from channel rehabilitation suggesting that the Program should consider site designs that will dampen the effect of a loss of habitat availability. For example, Lowden Ranch and Reading Creek had similar trends in AUC (~12% reduction) at the revisit survey but the effect differed because the initial increases from construction were so much higher at Lowden Ranch. Perhaps the TRRP should reconsider the goal of consistent increases in habitat over time. It may be more realistic to expect habitat availability to vary temporally and longitudinally (Goodman et al. 2016).

Although not explicitly stated, a sub-objective of TRRP habitat restoration efforts has been to eliminate the dip in habitat at intermediate streamflows between approximately 4 and 127 m^3/s (150-4,500 ft^3/s) documented in the TRFE. Here, we targeted a narrower range of streamflows and documented that, despite increases in habitat, the dip persists at most sites after construction as well as at the most recent revisit surveys. At Bucktail, the dip manifested as flow increased and areas in the mainstem and the side channel and pond became too deep and/or too fast but disappeared at higher flows as the riparian zone was inundated (Figures 3 and 10). We observed a modest construction-related attenuation of the dip in total habitat at 450 ft^3/s at Lewiston Cableway, which was not sustained through the revisit survey (Figure 3). Upper Bucktail Dark Gulch was the only site where the dip in total habitat was eliminated at the revisit survey due to deposition of a large amount of sediment, demonstrating that in this location, fluvial processes increased habitat benefits over time. The design for this site did not predict this outcome and we did not document this at the other sites in this study. Prior to dam construction and the resultant development of a narrow trapezoidal channel, alluvial reaches of the Trinity River were characterized by the presence of alternating point bars with gently sloping floodplains (USFWS 1988) that provided critical habitat in the form of shallow and low velocity areas (Hampton 1988). The TRFE hypothesized that this bar morphology provided the necessary physical conformation to produce a positive linear relationship between streamflow and habitat. The results presented here indicate that perhaps the Program should re-prioritize construction efforts aimed at regenerating those specific pre-TRD conditions where possible relative to the design and implementation of more complex channel features (e.g. Bucktail). Simply increasing the length of channel without a riparian berm and with a re-connected floodplain might produce this streamflow to habitat relationship in some geomorphological contexts present in specific segments of the restoration reach.

This report did not systematically evaluate the relationship between water year-specific releases and the amount of rearing habitat available at rehabilitation sites over time. In addition, the scope of this habitat synthesis report precluded a rigorous geophysical assessment of all six sites. However, we did infer the cumulative effect of streamflows from expert observations in the field, changes in habitat availability and geomorphic changes evident in aerial photographs, which may be helpful in future site designs. For example, sediment mobilization at Lewiston Cableway resulted in a reduction in sinuosity and loss of habitat availability at three constructed point bars (Figure 7). The point bars were intended to initiate a meander sequence that did not occur; however, their loss was not unexpected because these bars were conceived as sources of gravel for augmentation.

Likewise, habitat gains at Upper Bucktail Dark Gulch and flow-specific habitat losses at Lower Bucktail Dark Gulch resulted from sediment aggradation during the same flow event in 2011. A seven-year study of a sub-section of Lowden Ranch using detailed topographic surveys, bedload flux and changes in mean flow depths attributed an increase (2011-2016)and then a decrease (2016-2017) in bed relief and habitat availability to flow and gravel management (Gaeuman and Boyce 2018; Gaeuman et al. 2019). Goodman et al. 2016 found that larger magnitude dam releases did not result in greater improvements in habitat, however, site-specific changes were observed at nearly every site. It is clear that flow management can affect habitat availability at specific locations. The observations and conclusions in this and previous habitat reports (DeJuilio et al. 2014; Boyce et al. 2018 among others) are based on a survey protocol limited to the range of streamflows reported here; the TRRP and the habitat effectiveness monitoring group have transitioned to developing hydrodynamic models as a primary means of assessing habitat availability. This methodology will facilitate habitat assessment at a wider range of streamflows in the near future (Wright et al. 2017).

The evolution of TRRP restoration philosophy and associated methodological changes might confound interpretation of the relationship between time since construction and the sustainability of habitat benefits after construction (Figure 5). Buffington et al. 2014 analyzed all Phase I (2005-2010) restoration activities conducted by the TRRP and documented changes to the rehabilitation site design process during three discrete sub-phases (2005-2006; 2007; 2008-2010). In the first sub-phase, sites such as Hocker Flat (2005) were relatively simple involving vegetation removal and floodplain recontouring; in the second and third, large wood placement increased (Boyce and Goodman 2018) and considerably more in-channel work was implemented. With the exception of Hocker Flat, all sites in the post-construction to revisit comparison (Objective 2) were constructed in the third sub-phase. Despite this apparent consistency through the year of construction and the collaborative nature of the TRRP site design process (all designers contribute expertise throughout), variation among these sites in the number and type of constructed features and the geomorphic context of the site make it difficult to conclusively identify a general mechanism of habitat degradation. Indeed, in some cases the same fluvial process (e.g.

sediment aggradation) was responsible for loss and gain of rearing habitat at different sites (e.g. Upper and Lower Bucktail Dark Gulch).

The stream evolution model (SEM), an extension of previous channel evolution models (Schumm et al. 1984; Simon and Hupp 1986) considers stream evolution as cyclical (Cluer and Thorne 2014) and postulates that single-threaded channels are not the "norm" and instead, multi-threaded channels represent the pre-modified state for many systems. Infrastructure, navigational safety concerns, the riparian berm, mine tailings, as well as the limited alluvial nature of the restoration reach itself likely eliminate the possibility of progressing through the entire cycle. However, channel rehabilitation could potentially help establish a truncated version of the cycle and follow a "short-circuit" identified in the model particularly between Stage 2 (channelized), Stage 3 (degradation) and Stage 1 (sinuous single thread). In areas where there is space for latitudinal migration and an absence of infrastructure, it may be possible to restore the channel to Stage 7 (laterally active). These considerations should precipitate a necessary discussion within the Program about finding the optimal contribution among various restoration and site design philosophies like process-based restoration (e.g. stage O, see Powers et al. 2018 and references therein), morphodynamic modeling (Gaeuman 2014) and in-channel construction. Establishing the appropriate balance between constructing static channel features with relatively stable morphologies and life expectancies and facilitating fluvial processes by developing management objective-specific hydrographs eliminating the riparian berm, re-connecting the floodplain and augmenting gravel remains an important challenge for the Program. In areas with significant loss of construction-related habitat, the Program should also consider implementing measures to maintain and/or reconfigure particular restoration features as a means of sustaining that balance and successfully applying the AEAM process.

The relationship between river discharge and juvenile salmonid habitat availability as defined by the criteria in this analysis has been a useful metric by which to assess restoration progress; however, establishing the appropriate target level for restoring rearing habitat has been a source of ongoing discussions within the Program (TRRP and ESSA 2009). The TRFE developed a model, SALMOD or Salmonid Potential Production Model, which provided much of the foundation for the ROD (TRRP and ESSA 2009). This model evaluated the effect of varying environmental conditions on juvenile production and concluded that a 4-fold increase in rearing habitat would lead to a 2-fold increase in smolt production (USFWS and Hoopa Valley Tribe 1999). More recently, Beechie et al. (2014) developed estimates of potential rearing habitat increases under three restoration scenarios currently implemented by the TRRP using Trinity River-specific habitat measurements and concluded that under the most optimistic (and intensive) channel rehabilitation scenarios, an increase in rearing habitat of approximately 100% is possible, which is supported by the results presented here (Table 3; Appendix B). Defining a realistic but also beneficial rearing habitat target undergirds the Program's continuing efforts to develop fish production estimates to inform a decision support system or DSS (St. Clair and Burns 2013; Buffington et al. 2014). More recently, the Stream Salmonid Simulator (S3) model expanded on recent advances in modeling juvenile salmon migration and population dynamics and linked it to empirical data related to rearing habitat use and outmigrant estimates from the Trinity River (Perry et al. 2018). One input to the S3 model, habitat capacity, expressed as the number of juveniles a given area can support, has the potential to become the metric of choice given the critical role of S3 in the overall DSS. However, the Program continues to face the challenge of defining a target for increasing rearing habitat regardless of which specific metric is under consideration; the current objective is simply to increase rearing habitat (expressed as area under the streamflow to habitat curve) over time (Fish Work Group unpublished guidelines).

Rearing habitat is critical to successfully restoring natural salmonid production in the Trinity River. It may now be appropriate, however, to reconsider its relative influence among additional factors (e.g. adult escapement/run size, adult spawning habitat/success, freshwater vs. marine survival and temperature) affecting the Program's ability to achieve that goal. Habitat capacity estimates generated from the outputs of hydrodynamic models in conjunction with S3 will facilitate tests of the general hypothesis that rearing habitat limits fish production. For example, one could model the effect of increased rearing habitat capacity at a range of discharges on realized fish production (e.g. fry/spawner). A natural test of the habitat limitation hypothesis would be several successive years of adult returns approaching pre-TRD levels and relating that to outmigration abundances and corresponding brood year returns. Between 2002 and 2017, escapement of natural origin spring-run Chinook Salmon above the Junction City weir exceeded the current TRRP goal of 6,000 fish only four times whereas escapement of fall-run Chinook Salmon above the Willow Creek weir never exceeded the TRRP goal of 62,000 fish (Gough et al, in prep.). Gough et al. 2019 reported no significant change in the abundance of natural-origin Chinook Salmon redds constructed in the mainstem Trinity River over the same period. These observations indicate that, at least recently, the restoration reach has not been seeded with enough juveniles to facilitate assessments of carrying capacity and look for evidence consistent with the rearing habitat limitation hypothesis. It is important to note that interpreting such hypothetical data would be difficult given the numerous environmental variables responsible for a given year's escapement, including the relative influence of freshwater and marine environments on growth and survival.

An important factor linked to the abundance of Pacific salmon is size-dependent mortality related to growth and predation during the period of early marine residence (Beamish and Mahnken 2001; Beamish et al. 2004; Graham et al. 2019). However, there is a growing body of evidence that the interaction between streamflow management, growth and survival during freshwater outmigration is critically important (Buchanan et al. 2013; Michel et al. 2015, Chitaro et al. 2019) particularly in degraded systems with altered hydrological regimes (Michel 2019). Using coded wire tag recoveries, Hankin and Logan (2010), documented increased survival rates of larger (e.g. 40-50 g vs 4-5 g) juvenile hatchery salmon released from Klamath and Trinity fish hatcheries and a differential effect of increased streamflows on survival between the two rivers. In the Klamath River, increased flows were associated with increased survival whereas in the Trinity River no such association was found. Interestingly, Schwarz et al. 2009 found some evidence of a negative effect of the higher flow regime that resulted from ROD implementation on mean fork length of juveniles at the Willow Creek downstream migrant trap between 1993 and 2006. The implication of that evidence is that lower temperatures associated with that flow regime (Gaeuman et al. 2016), typical of hypolimnal-release dams, are constraining growth during the rearing and outmigration period. Support for this hypothesis comes from model estimates of Trinity River-specific growth rates of juvenile Chinook (Perry et al. 2015) and Coho (Manhard et al. 2018) salmon. Typically, streamflow recommendations to regulate instream temperatures are made when exceedance of some upper threshold is expected

(USEPA 2003); however, it is far less common for streamflow managers to target periods when the temperature drops below a lower threshold (Buccola 2017). Water temperatures in the lower Klamath and Trinity rivers frequently exceed EPA criteria, however, temperatures in the upper Trinity exceed those criteria far less frequently (David and Goodman 2017). This presents the Program with an opportunity to develop alternative approaches to streamflow management that would facilitate greater control over water temperature and link the hydrograph to real time hydrology.

Conclusions

This analysis and previous rearing habitat trend analyses (DeJuilio et al. 2014; Goodman et al. 2016; Boyce et al. 2018), have reported similar results across a range of discharges and multiple spatial and temporal scales. It is clear that channel rehabilitation produced large increases in rearing habitat but some of those increases were not sustained over time; however, with the exception of Lower Bucktail Dark Gulch at 450 ft^3/s (Boyce et al. 2018), all other rehabilitation sites analyzed to date have sustained rearing habitat above pre-construction conditions. Habitat monitoring at the systemic level (Goodman et al. 2016), documented annual variation in rearing habitat but no significant increases between 2009 and 2013. One question that remains is whether the relative consistent pattern of post-construction habitat reductions represent a continual downward trend or the beginning of a plateau. The Program should consider another revisit survey of these sites to address this question. These trend analyses cover a relatively long period for river restoration programs, however, in the context of the SEM or even the life cycle of a few generations of salmon cohorts, it is brief. The Program has constructed 33 of 47 proposed channel rehabilitation projects, which means there will be future construction-related increases in habitat and more time for all TRRP restoration actions to catalyze geomorphological changes to the channel.

Despite the limited alluvial nature of the restoration reach, we have documented evidence of the influence of fluvial processes on rehabilitation site evolution. For example, constructed gravel bars at Lewiston Cableway, intended as sources of gravel for the restoration reach reduced in size between 2008 and 2016. At Lowden Ranch, sediment mobilization and changes in bed relief and bank inundation were associated with slight reductions in habitat; however, constructed off-channel features at the top (side channel/wetland) and bottom (anastomosing channel) of the site are still functioning well. Sediment aggradation at the entrance to the constructed side channel at Lower Bucktail Dark Gulch caused habitat availability to approach pre-construction levels at summer low flow. Re-construction of this site produced large gains in habitat at Bucktail (Table 3; Appendix A), which exceeded design team predictions (HVTFD et al. 2015); however, 80% of that habitat is dependent on the continued functioning of the side channel that supplies water to the pond/wetland (Figure 10). Hocker Flat is a site that should be considered for maintenance or a complete re-design; the lack of cover habitat is a particular facet that could be targeted by such actions.

The results presented here and in previous analyses utilized a survey or map-based assessment (habitat mapping) that requires physically measuring variables within a limited range (300-2,000 ft^3/s) of streamflows, which do not include the complete range of hydraulic conditions experienced by juvenile salmonids in the restoration reach. Hydrodynamic models will provide an enhanced perspective on the performance of particular sites at a much larger range of streamflows and have the potential to provide insight into spatial and temporal changes to rearing habitat at the systemic scale. This technology aligns the methods of effectiveness monitoring and rehabilitation site design, which will facilitate direct comparisons between design predictions and as-built conditions. To realize the full potential of this alignment for improving the efficiency of the adaptive management process, design reports should include specific, quantitative habitat predictions reflective of the Program consensus for the appropriate habitat metric.

The TRRP implements channel rehabilitation, gravel augmentation and instream flow management, including the development of hydrographs to help meet specific physical and biological objectives. The pilot river corridor management plan (Gaeuman et al. 2016) provides a framework to integrate those actions and account for spatial variation in channel form, mediating the effects of those actions. The adaptive management process will benefit from that framework but it also requires the flexibility to develop additional restoration strategies (e.g. synchronizing Lewiston Dam releases with natural hydrology during the rearing period), which would create a more robust suite of management actions to meet the challenge of restoring natural salmonid production in the Trinity River.

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Appendices

Appendix A. Raw rearing habitat values and survey discharges (Q).

Table A-1. Lewiston Cableway (Cableway) rehabilitation site. Habitat categories correspond to areas (m^2) meeting the depth (D), velocity (V) and cover (C) criteria for Chinook and Coho Salmon fry (<50 mm) and presmolt (50 to 100 mm).

Site	Length (m)	Year of Construction	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Total (sq.m/m)	Optimal (sq.m/m)
Cableway	494	2008	2008	Fry	8.6	1,010	1,351	392	2,753	5.58	2.04
					11.1	454	795	581	1,829	3.71	0.92
					19.3	1,549	2,156	500	4,205	8.52	3.14
					34.3	2,881	413	2,150	5,444	11.02	5.83
					57.2	5,602	279	3,902	9,783	19.81	11.35
				Presmolt	8.6	1,261	2,342	141	3,744	7.58	2.55
					11.1	547	1,399	488	2,434	4.93	1.11
					19.3	1,753	2,923	296	4,972	10.07	3.55
					34.3	3,767	1,007	1,264	6,038	12.23	7.63
					57.2	6,560	457	2,944	9,961	20.18	13.29
			2009	Fry	8.6	1,731	2,193	843	4,767	9.66	3.51
					11.1	2,288	1,408	1,157	4,853	9.83	4.63
					19.9	3,369	1,046	2,040	6,455	13.07	6.82
					34.5	4,181	834	3,835	8,850	17.92	8.47
					52.7	6,084	258	5,754	12,096	24.50	12.32
				Presmolt	8.6	2,029	3,732	545	6,306	12.77	4.11
					11.1	2,619	2,681	826	6,126	12.41	5.30
					19.9	3,964	2,036	1,446	7,446	15.08	8.03
					34.5	5,382	1,677	2,634	9,693	19.63	10.90
					52.7	7,555	480	4,282	12,317	24.95	15.30
			2016	Fry	8.2	722	3,029	398	4,149	8.40	1.46
					12.4	1,072	2,460	522	4,054	8.21	2.17
					19.7	2,018	1,601	864	4,483	9.08	4.09
					33.6	3,056	966	2,239	6,261	12.68	6.19
					58.2	5,585	78	4,396	10,059	20.37	11.31
				Presmolt	8.2	808	4,319	313	5,440	11.02	1.64
					12.4	1,165	3,386	429	4,980	10.09	2.36
					19.7	2,187	2,142	695	5,024	10.18	4.43
					33.6	3,512	1,549	1,784	6,845	13.86	7.11
					58.2	6,455	348	3,526	10,329	20.92	13.07

Table A-2. Upper Bucktail Dark Gulch (UBTDG) rehabilitation site. Habitat categories correspond to areas (m^2) meeting the depth (D), velocity (V) and cover (C) criteria for fry (<50 mm) and presmolt (50 to 100 mm).

Site	Length (m)	Year of Construction	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Total (sq.m/m)	Optimal (sq.m/m)
UBTDG	335	2008	2008	Fry	x						
					9.9	418	1,135	432	1,985	5.93	1.25
					19.9	256	394	516	1,166	3.48	0.77
					36.3	241	102	530	873	2.61	0.72
					60.7	547	44	763	1,354	4.05	1.63
				Presmolt	x						
					9.9	644	1,942	207	2,793	8.34	1.92
					19.9	426	835	346	1,607	4.80	1.27
					36.3	365	387	405	1,157	3.46	1.09
					60.7	716	108	595	1,419	4.24	2.14
			2009	Fry	8.6	634	1,659	514	2,807	8.38	1.89
					11.4	534	1,353	629	2,516	7.51	1.60
					20.4	381	806	952	2,139	6.39	1.14
					33.6	262	693	899	1,854	5.54	0.78
					56.9	261	1,073	835	2,169	6.48	0.78
				Presmolt	8.6	933	2,888	215	4,036	12.05	2.79
					11.4	871	2,395	292	3,558	10.63	2.60
					20.4	717	1,402	616	2,735	8.16	2.14
					33.6	407	1,093	755	2,255	6.73	1.21
					56.9	427	1,644	669	2,740	8.18	1.28
			2013	Fry	9.4	695	1,640	488	2,823	8.43	2.07
					13.0	897	1,290	807	2,994	8.94	2.68
					20.4	1,364	793	1,104	3,261	9.74	4.07
					33.9	3,118	2,701	1,814	7,633	22.80	9.31
					57.4	5,576	5,299	2,415	13,290	39.69	16.65
				Presmolt	9.4	898	2,393	285	3,576	10.68	2.68
					13.0	1,361	1,859	343	3,563	10.64	4.06
					20.4	1,947	1,373	521	3,841	11.47	5.81
					33.9	3,490	3,282	1,443	8,215	24.53	10.42
					57.4	6,066	6,274	1,925	14,265	42.60	18.12

Table A-3. Lower Buck Tail Dark Gulch (LBTDG) rehabilitation site. Habitat categories correspond to areas (m^2) meeting the depth (D), velocity (V) and cover (C) criteria for fry (<50 mm) and presmolt (50 to 100 mm).

Site	Length (m)	Year of Construction	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Total (sq.m/m)	Optimal (sq.m/m)
LBTDG	403	2008	2008	Fry	10.3	324	860	152	1,336	3.32	0.80
					10.5	131	1,131	192	1,455	3.61	0.33
					19.6	187	490	282	958	2.38	0.46
					36.2	519	171	500	1,190	2.95	1.29
					60.9	1,911	173	827	2,911	7.22	4.74
				Presmolt	10.3	371	1,403	105	1,879	4.66	0.92
					10.5	206	1,577	117	1,900	4.71	0.51
					19.6	252	893	217	1,361	3.38	0.63
					36.2	655	399	364	1,418	3.52	1.63
					60.9	2,066	248	672	2,986	7.41	5.13
			2009	Fry	8.6	379	1,817	172	2,367	5.87	0.94
					11.5	431	1,509	273	2,214	5.49	1.07
					20.0	340	1,064	459	1,864	4.63	0.84
					33.8	624	469	872	1,966	4.88	1.55
					56.3	1,875	885	1,328	4,089	10.15	4.65
				Presmolt	8.6	431	2,269	120	2,820	7.00	1.07
					11.5	527	1,989	177	2,694	6.68	1.31
					20.0	497	1,784	302	2,583	6.41	1.23
					33.8	854	1,072	694	2,620	6.50	2.12
					56.3	2,132	1,306	1,072	4,510	11.19	5.29
			2015	Fry	9.3	235	1,268	421	1,925	4.78	0.58
					13.1	421	940	232	1,592	3.95	1.04
					19.7	706	502	344	1,553	3.85	1.75
					36.1	1,816	154	787	2,757	6.84	4.51
					60.3	2,545	101	2,101	4,747	11.78	6.32
				Presmolt	9.3	277	1,485	379	2,141	5.31	0.69
					13.1	448	1,266	204	1,919	4.76	1.11
					19.7	749	618	301	1,669	4.14	1.86
					36.1	2,121	335	482	2,938	7.29	5.26
					60.3	3,180	211	1,466	4,857	12.05	7.89

Table A-4. Bucktail rehabilitation site. Habitat categories correspond to areas (m^2) meeting the depth (D), velocity (V) and cover (C) criteria for fry (<50 mm) and presmolt (50 to 100 mm).

Site	Length (m)	Year of Construction	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Total (sq.m/m)	Optimal (sq.m/m)
Bucktail	403	2016	2015	Fry	9.3	235	1,268	421	1,925	4.78	0.58
					13.1	421	940	232	1,592	3.95	1.04
					19.7	706	502	344	1,553	3.85	1.75
					36.1	1,816	154	787	2,757	6.84	4.51
					60.3	2,545	101	2,101	4,747	11.78	6.32
				Presmolt	9.3	277	1,485	379	2,141	5.31	0.69
					13.1	448	1,266	204	1,919	4.76	1.11
					19.7	749	618	301	1,669	4.14	1.86
					36.1	2,121	335	482	2,938	7.29	5.26
					60.3	3,180	211	1,466	4,857	12.05	7.89
			2017	Fry	7.7	3,225	6,711	7,654	17,591	43.65	8.00
					15.9	2,666	5,176	7,781	15,623	38.77	6.62
					20.0	2,192	5,927	7,916	16,036	39.79	5.44
					36.0	1,980	5,307	7,802	15,088	37.44	4.91
					56.7	4,810	4,245	7,731	16,786	41.65	11.94
				Presmolt	7.7	8,025	8,608	2,854	19,488	48.36	19.91
					15.9	5,226	8,027	5,221	18,474	45.84	12.97
					20.0	4,518	7,977	5,590	18,085	44.88	11.21
					36.0	4,170	8,104	5,612	17,886	44.38	10.35
					56.7	6,027	8,061	6,514	20,601	51.12	14.96

Table A-5. Lowden Ranch rehabilitation site. Habitat categories correspond to areas (m^2) meeting the depth (D), velocity (V) and cover (C) criteria for fry (<50 mm) and presmolt (50 to 100 mm).

Site	Length (m)	Year of Construction	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Total (sq.m/m)	Optimal (sq.m/m)
Lowden Ranch	816	2010	2009	Fry	8.7	759	1,009	1,328	3,096	3.79	0.93
					11.4	941	548	1,695	3,184	3.90	1.15
					20.0	588	136	2,192	2,916	3.57	0.72
					34.9	261	11	2,528	2,800	3.43	0.32
					53.9	640	0	2,563	3,203	3.93	0.78
				Presmolt	8.7	1,296	2,450	786	4,532	5.55	1.59
					11.4	1,448	1,392	1,188	4,028	4.94	1.77
					20.0	1,139	381	1,641	3,161	3.87	1.40
					34.9	820	95	1,970	2,885	3.54	1.00
					53.9	1,081	7	2,123	3,211	3.94	1.32
			2011	Fry	8.8	1,906	3,470	2,570	7,946	9.74	2.34
					12.7	1,709	2,216	3,411	7,336	8.99	2.09
					23.0	2,721	1,523	2,994	7,238	8.87	3.33
					37.4	3,754	951	3,802	8,507	10.43	4.60
					62.3	5,238	927	5,516	11,681	14.32	6.42
				Presmolt	8.8	3,686	6,193	790	10,669	13.07	4.52
					12.7	3,592	4,541	1,528	9,661	11.84	4.40
					23.0	3,698	3,084	2,017	8,799	10.78	4.53
					37.4	4,574	1,821	2,981	9,376	11.49	5.61
					62.3	6,659	1,517	4,096	12,272	15.04	8.16
			2017	Fry	7.4	2,206	4,654	1,868	8,728	10.70	2.70
					13.6	2,052	2,611	2,537	7,200	8.82	2.52
					19.3	1,720	622	3,604	5,946	7.29	2.11
					35.9	2,295	395	4,218	6,908	8.47	2.81
					56.9	4,802	231	4,808	9,841	12.06	5.88
				Presmolt	7.4	2,944	7,788	1,131	11,863	14.54	3.61
					13.6	3,045	4,999	1,545	9,589	11.75	3.73
					19.3	2,704	1,379	2,620	6,703	8.21	3.31
					35.9	3,259	943	3,254	7,456	9.14	3.99
					56.9	5,739	542	3,871	10,152	12.44	7.03

Table A-6. Reading Creek rehabilitation site. Habitat categories correspond to areas (m^2) meeting the depth (D), velocity (V) and cover (C) criteria for fry (<50 mm) and presmolt (50 to 100 mm).

Site	Length (m)	Year of Construction	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Total (sq.m/m)	Optimal (sq.m/m)
Reading Creek	806	2010	2009	Fry	9.8	495	2,302	450	3,247	4.03	0.61
					13.3	474	2,035	647	3,156	3.92	0.59
					21.3	272	1,251	820	2,343	2.91	0.34
					36.5	405	522	1,330	2,257	2.80	0.50
					62.0	656	337	1,468	2,461	3.05	0.81
				Presmolt	9.8	683	3,475	263	4,421	5.49	0.85
					13.3	690	2,845	431	3,966	4.92	0.86
					21.3	436	2,019	655	3,110	3.86	0.54
					36.5	603	930	1,132	2,665	3.31	0.75
					62.0	859	545	1,265	2,669	3.31	1.07
			2011	Fry	10.5	567	3,004	535	4,106	5.09	0.70
					15.0	668	2,173	785	3,626	4.50	0.83
					27.5	510	1,684	1,062	3,256	4.04	0.63
					40.9	698	1,603	1,467	3,768	4.67	0.87
					69.4	1,140	1,659	1,894	4,693	5.82	1.41
				Presmolt	10.5	771	4,615	331	5,717	7.09	0.96
					15.0	918	3,635	536	5,089	6.31	1.14
					27.5	741	2,782	832	4,355	5.40	0.92
					40.9	1,000	2,183	1,165	4,348	5.39	1.24
					69.4	1,484	2,531	1,550	5,565	6.90	1.84
			2017	Fry	8.6	479	4,331	301	5,111	6.34	0.59
					14.1	440	2,126	484	3,050	3.78	0.55
					24.4	539	1,682	789	3,010	3.73	0.67
					34.5	726	1,016	1,087	2,829	3.51	0.90
					60.5	1,062	877	1,552	3,491	4.33	1.32
				Presmolt	8.6	587	6,740	193	7,520	9.33	0.73
					14.1	592	3,977	332	4,901	6.08	0.73
					24.4	666	2,673	662	4,001	4.96	0.83
					34.5	904	1,640	909	3,453	4.28	1.12
					60.5	1,226	1,141	1,387	3,754	4.66	1.52

Table A-7. Hocker Flat rehabilitation site. Habitat categories correspond to areas (m^2) meeting the depth (D), velocity (V) and cover (C) criteria for fry (<50 mm) and presmolt (50 to 100 mm).

Site	Length (m)	Year of Construction	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Total (sq.m/m)	Optimal (sq.m/m)
Hocker Flat	396	2005	2008	Fry	12.5	79	2,212	67	2,357	5.95	0.20
					20.3	66	1,023	343	1,433	3.62	0.17
					22.7	78	1,023	203	1,304	3.29	0.20
					54.4	164	423	299	886	2.24	0.42
					70.5	224	364	429	1,016	2.57	0.56
				Presmolt	12.5	114	3,431	32	3,576	9.03	0.29
					20.3	134	1,857	276	2,267	5.72	0.34
					22.7	106	1,606	175	1,887	4.77	0.27
					54.4	259	926	204	1,389	3.51	0.65
					70.5	246	557	406	1,209	3.05	0.62
			2017	Fry	10.1	26	2,456	12	2,493	6.30	0.06
					15.1	38	1,653	69	1,760	4.44	0.10
					27.9	87	551	228	866	2.19	0.22
					37.9	158	550	430	1,137	2.87	0.40
					66.0	165	421	694	1,279	3.23	0.42
				Presmolt	10.1	30	3,476	8	3,513	8.87	0.08
					15.1	50	2,377	56	2,483	6.27	0.13
					27.9	102	773	213	1,089	2.75	0.26
					37.9	202	676	385	1,264	3.19	0.51
					66.0	259	632	600	1,491	3.76	0.65

Appendix B. Rationale for using linear interpolation for spatiotemporal comparisons of AUC values and tables of interpolated discharge and rearing habitat measurements at each rehabilitation site.

Figures B-1 and B-2 below show two hypothetical surveys with a discharge difference >10% at the low (8 vs. 9 m^3/s) end of the range. The AUC value for the second survey would be higher than the first survey based only on the range of discharges. These survey discharge-range discrepancies occur at the tails of the flow-to-habitat curves, which are sections of these curves with relatively linear flow-to-habitat patterns. To avoid AUC differences resulting solely from changes in the range of flows observed between surveys, a simple linear interpolation method was employed to normalize the discharge range using the following equation:

$$y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$$

Where, in our example from Figure B-2 we can calculate a habitat value at a discharge of 9 m^3/s with:

x_1=8 m^3/s, x_2=9 m^3/s, x_3=12.7 m^3/s
y_1=7 m^2 and y_3=5.5 m^2.

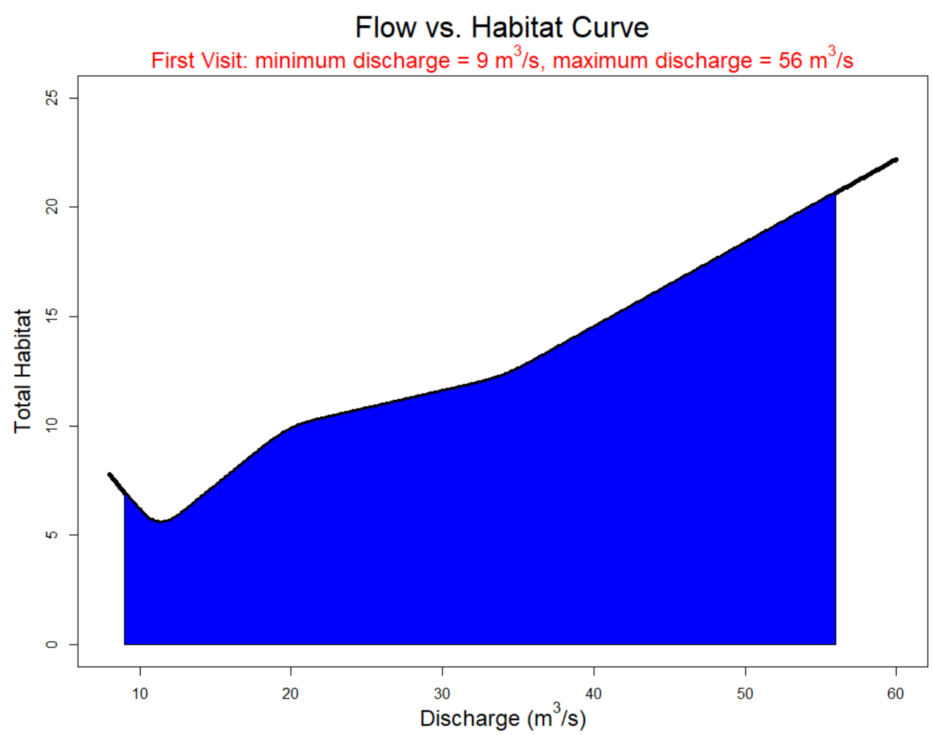

Figure B-1. An example curve with AUC (blue area) calculated after first survey with a minimum and maximum discharge of 9 and 56 m^3/s, respectively.

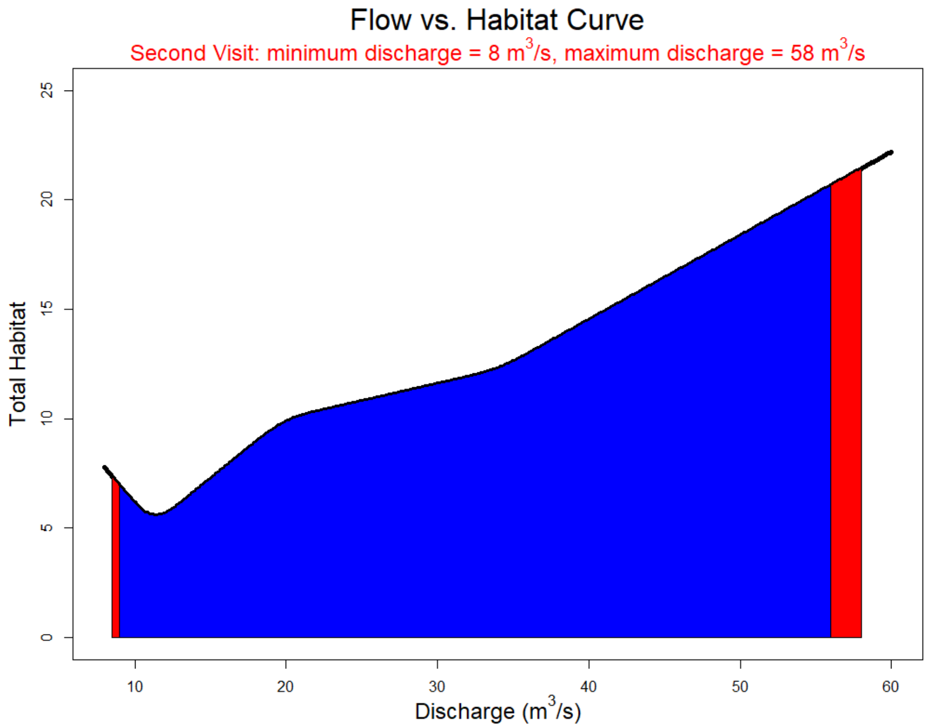

Figure B-2. The curves from the first survey (blue) and a subsequent survey (red) completed at the same site with a minimum and maximum discharge of 8 and 58 m^3/s, respectively.

Table B-1. Interpolated discharge, rearing habitat and percent change values (highlighted) at Lewiston Cableway (Cableway) rehabilitation site. Habitat categories correspond to areas (m^2) meeting depth (D), velocity (V) and cover (C) criteria of rearing habitat for Chinook and Coho Salmon fry (<50 mm) and presmolt (50-100 mm).

				Habitat Category							
Site	**Survey Year**	**Lifestage**	**Q**	**DV,C**	**DV, No C**	**No DV, C**	**Total**	**Change Total from 2008**	**Change Optimal from 2008**	**Change Total from 2009**	**Change Optimal from 2009**
Cableway	2008	Fry	8.6	1,010	1,351	392	2,753	- -	- -	- -	- -
			11.1	454	795	581	1,830	- -	- -	- -	- -
			19.3	1,549	2,156	500	4,205	- -	- -	- -	- -
			34.3	2,881	413	2,150	5,444	- -	- -	- -	- -
			57.2	5,602	279	3,902	9,783	- -	- -	- -	- -
		Presmolt	8.6	1,261	2,342	141	3,744	- -	- -	- -	- -
			11.1	547	1,399	488	2,434	- -	- -	- -	- -
			19.3	1,753	2,923	296	4,972	- -	- -	- -	- -
			34.3	3,767	1,007	1,264	6,038	- -	- -	- -	- -
			57.2	6,560	457	2,944	9,961	- -	- -	- -	- -
	2009	Fry	8.6	1,731	2,193	843	4,767	73%	71%	- -	- -
			11.1	2,288	1,408	1,157	4,853	165%	404%	- -	- -
			19.9	3,369	1,046	2,040	6,455	54%	117%	- -	- -
			34.5	4,181	834	3,835	8,850	63%	45%	- -	- -
			52.7	6,084	258	5,754	12,096	24%	9%	- -	- -
		Presmolt	8.6	2,029	3,732	545	6,306	68%	61%	- -	- -
			11.1	2,619	2,681	826	6,126	152%	379%	- -	- -
			19.9	3,964	2,036	1,446	7,446	50%	126%	- -	- -
			34.5	5,382	1,677	2,634	9,693	61%	43%	- -	- -
			52.7	7,555	480	4,282	12,317	24%	15%	- -	- -
	2016	Fry	8.2	722	3,029	398	4,149	51%	-29%	-13%	-58%
			12.4	1,072	2,460	522	4,054	122%	136%	-16%	-53%
			19.7	2,018	1,601	864	4,483	7%	30%	-31%	-40%
			33.6	3,056	966	2,239	6,261	15%	6%	-29%	-27%
			57.2	5,482	114	4,308	9,904	1%	-2%	-18%	-10%
		Presmolt	8.2	808	4,319	313	5,440	45%	-36%	-14%	-60%
			12.4	1,165	3,386	429	4,980	105%	113%	-19%	-56%
			19.7	2,187	2,142	695	5,024	1%	25%	-33%	-45%
			33.6	3,512	1,549	1,784	6,845	13%	-7%	-29%	-35%
			57.2	6,335	397	3,455	10,187	2%	-3%	-17%	-16%

Table B-2. Interpolated discharge, rearing habitat and percent change values (highlighted) at Upper Bucktail Dark Gulch (UBTDG) rehabilitation site. Habitat categories correspond to areas (m^2) meeting depth (D), velocity (V) and cover (C) criteria of rearing habitat for Chinook and Coho Salmon fry (<50 mm) and presmolt (50-100 mm). Note that AUC was calculated using four discharge levels because there was no survey at 8.5 m^3/s in 2008.

				Habitat Category							
Site	**Survey Year**	**Lifestage**	**Q**	**DV,C**	**DV, No C**	**No DV, C**	**Total**	**Change Total from 2008**	**Change Optimal from 2008**	**Change Total from 2009**	**Change Optimal from 2009**
UBTDG	2008	Fry	x	x	x	x	x	- -	- -	- -	- -
			9.9	418	1,135	432	1,985	- -	- -	- -	- -
			19.9	256	394	516	1,166	- -	- -	- -	- -
			36.3	241	102	530	873	- -	- -	- -	- -
			60.7	547	44	763	1,354	- -	- -	- -	- -
		Presmolt	x	x	x	x	x	- -	- -	- -	- -
			9.9	644	1,942	207	2,793	- -	- -	- -	- -
			19.9	426	835	346	1,607	- -	- -	- -	- -
			36.3	365	387	405	1,157	- -	- -	- -	- -
			60.7	716	108	595	1,419	- -	- -	- -	- -
	2009	Fry	8.6	634	1,659	514	2,807	x	x	- -	- -
			9.9	588	1,517	567	2,672	35%	41%	- -	- -
			20.4	381	806	952	2,139	83%	49%	- -	- -
			33.6	262	693	899	1,854	112%	9%	- -	- -
			56.9	261	1,073	835	2,169	60%	-52%	- -	- -
		Presmolt	8.6	933	2,888	215	4,036	x	x	- -	- -
			9.9	904	2,659	251	3,814	37%	40%	- -	- -
			20.4	717	1,402	616	2,735	70%	68%	- -	- -
			33.6	407	1,093	755	2,255	95%	12%	- -	- -
			56.9	427	1,644	669	2,740	93%	-40%	- -	- -
	2013	Fry	9.4	695	1,640	488	2,823	x	x	1%	10%
			9.9	723	1,591	532	2,846	43%	73%	7%	23%
			20.4	1,364	793	1,104	3,261	180%	433%	52%	258%
			33.9	3,118	2,701	1,814	7,633	774%	1,194%	312%	1,090%
			57.4	5,576	5,299	2,415	13,290	882%	919%	513%	2,036%
		Presmolt	9.4	898	2,393	285	3,576	x	x	-11%	-4%
			9.9	962	2,319	293	3,574	28%	49%	-6%	6%
			20.4	1,947	1,373	521	3,841	139%	357%	40%	172%
			33.9	3,490	3,282	1,443	8,215	610%	856%	264%	757%
			57.4	6,066	6,274	1,925	14,265	905%	747%	421%	1,321%

Table B-3. Interpolated discharge, rearing habitat and percent change values (highlighted) at Lower Buck Tail Dark Gulch (LBTDG) rehabilitation site. Habitat categories correspond to areas (m^2) meeting depth (D), velocity (V) and cover (C) criteria of rearing habitat for Chinook and Coho Salmon fry (<50 mm) and presmolt (50-100 mm).

				Habitat Category							
Site	Survey Year	Lifestage	Q	DV,C	DV, No C	No DV, C	Total	Change Total from 2008	Change Optimal from 2008	Change Total from 2009	Change Optimal from 2009
LBTDG	2008	Fry	10.3	324	860	152	1,336	- -	- -	- -	- -
			10.5	131	1,131	192	1,455	- -	- -	- -	- -
			19.6	187	490	282	958	- -	- -	- -	- -
			36.2	519	171	500	1,190	- -	- -	- -	- -
			60.9	1,911	173	827	2,911	- -	- -	- -	- -
		Presmolt	10.3	371	1,403	105	1,879	- -	- -	- -	- -
			10.5	206	1,577	117	1,900	- -	- -	- -	- -
			19.6	252	893	217	1,361	- -	- -	- -	- -
			36.2	655	399	364	1,418	- -	- -	- -	- -
			60.9	2,066	248	672	2,986	- -	- -	- -	- -
	2009	Fry	10.3	410	1,636	231	2,277	70%	27%	- -	- -
			11.5	431	1,509	273	2,214	52%	229%	- -	- -
			20.0	340	1,064	459	1,864	95%	82%	- -	- -
			33.8	624	469	872	1,966	65%	20%	- -	- -
			56.3	1,875	885	1,328	4,089	40%	-2%	- -	- -
		Presmolt	10.3	487	2,105	153	2,745	46%	31%	- -	- -
			11.5	527	1,989	177	2,694	42%	156%	- -	- -
			20.0	497	1,784	302	2,583	90%	97%	- -	- -
			33.8	854	1,072	694	2,620	85%	30%	- -	- -
			56.3	2,132	1,306	1,072	4,510	51%	3%	- -	- -
	2015	Fry	10.3	284	1,182	371	1,837	38%	-12%	-19%	-31%
			13.1	421	940	232	1,592	9%	221%	-28%	-2%
			19.7	706	502	344	1,553	62%	278%	-17%	108%
			36.1	1,816	154	787	2,757	132%	250%	40%	191%
			60.3	2,545	101	2,101	4,747	63%	33%	16%	36%
		Presmolt	10.3	322	1,427	333	2,082	11%	-13%	-24%	-34%
			13.1	448	1,266	204	1,919	1%	117%	-29%	-15%
			19.7	749	618	301	1,669	23%	197%	-35%	51%
			36.1	2,121	335	482	2,938	107%	224%	12%	148%
			60.3	3,180	211	1,466	4,857	63%	54%	8%	49%

Table B-4. Interpolated discharge, rearing habitat and percent change values (highlighted) at Bucktail rehabilitation site after a pre-construction (2015) and post-construction (2017) survey. Habitat categories correspond to areas (m^2) meeting depth (D), velocity (V) and cover (C) criteria of rearing habitat for Chinook and Coho Salmon fry (<50 mm) and presmolt (50-100 mm).

				Habitat Category					
Site	**Survey Year**	**Lifestage**	**Q**	**DV,C**	**DV, No C**	**No DV, C**	**Total**	**Change Total from 2015**	**Change Optimal from 2015**
Bucktail	2015	Fry	9.3	235	1,268	421	1,925	- -	- -
			13.1	421	940	232	1,592	- -	- -
			19.7	706	502	344	1,553	- -	- -
			36.1	1,816	154	787	2,757	- -	- -
			60.3	2,545	101	2,101	4,747	- -	- -
		Presmolt	9.3	277	1,485	379	2,141	- -	- -
			13.1	448	1,266	204	1,919	- -	- -
			19.7	749	618	301	1,669	- -	- -
			36.1	2,121	335	482	2,938	- -	- -
			60.3	3,180	211	1,466	4,857	- -	- -
	2017	Fry	9.3	3,116	6,411	7,679	17,206	794%	1,226%
			15.9	2,666	5,176	7,781	15,623	881%	533%
			20.0	2,192	5,927	7,916	16,036	933%	210%
			36.0	1,980	5,307	7,802	15,088	447%	9%
			56.7	4,810	4,245	7,731	16,786	254%	89%
		Presmolt	9.3	7,479	8,495	3,316	19,290	801%	2,600%
			15.9	5,226	8,027	5,221	18,474	863%	1,067%
			20.0	4,518	7,977	5,590	18,085	984%	503%
			36.0	4,170	8,104	5,612	17,886	509%	97%
			56.7	6,027	8,061	6,514	20,601	324%	90%

Table B-5. Interpolated discharge, rearing habitat and percent change values (highlighted) at Lowden Ranch rehabilitation site. Habitat categories correspond to areas (m^2) meeting depth (D), velocity (V) and cover (C) criteria of rearing habitat for Chinook and Coho Salmon fry (<50 mm) and presmolt (50-100 mm).

				Habitat Category							
Site	**Survey Year**	**Lifestage**	**Q**	**DV,C**	**DV, No C**	**No DV, C**	**Total**	**Change Total from 2009**	**Change Optimal from 2009**	**Change Total from 2011**	**Change Optimal from 2011**
Lowden Ranch	2009	Fry	8.7	759	1,009	1,328	3,096	- -	- -	- -	- -
			11.4	941	548	1,695	3,184	- -	- -	- -	- -
			20.0	588	136	2,192	2,916	- -	- -	- -	- -
			34.9	261	11	2,528	2,800	- -	- -	- -	- -
			53.9	640	0	2,563	3,203	- -	- -	- -	- -
		Presmolt	8.7	1,296	2,450	786	4,532	- -	- -	- -	- -
			11.4	1,448	1,392	1,188	4,028	- -	- -	- -	- -
			20.0	1,139	381	1,641	3,161	- -	- -	- -	- -
			34.9	820	95	1,970	2,885	- -	- -	- -	- -
			53.9	1,081	7	2,123	3,211	- -	- -	- -	- -
	2011	Fry	8.8	1,906	3,470	2,570	7,946	157%	151%	- -	- -
			12.7	1,709	2,216	3,411	7,336	130%	82%	- -	- -
			23.0	2,721	1,523	2,994	7,238	148%	363%	- -	- -
			37.4	3,754	951	3,802	8,507	204%	1338%	- -	- -
			53.9	4,737	935	4,938	10,610	231%	640%	- -	- -
		Presmolt	8.8	3,686	6,193	790	10,669	135%	184%	- -	- -
			12.7	3,592	4,541	1,528	9,661	140%	148%	- -	- -
			23.0	3,698	3,084	2,017	8,799	178%	225%	- -	- -
			37.4	4,574	1,821	2,981	9,376	225%	458%	- -	- -
			53.9	5,956	1,620	3,720	11,296	252%	451%	- -	- -
	2017	Fry	8.7	2,174	4,226	2,008	8,408	172%	186%	6%	14%
			13.6	2,052	2,611	2,537	7,200	126%	118%	-2%	20%
			19.3	1,720	622	3,604	5,946	104%	193%	-18%	-37%
			35.9	2,295	395	4,218	6,908	147%	779%	-19%	-39%
			56.9	4,802	231	4,808	9,841	207%	650%	-7%	1%
		Presmolt	8.7	2,965	7,203	1,218	11,386	151%	129%	7%	-20%
			13.6	3,045	4,999	1,545	9,589	138%	110%	-1%	-15%
			19.3	2,704	1,379	2,620	6,703	112%	137%	-24%	-27%
			35.9	3,259	943	3,254	7,456	158%	297%	-20%	-29%
			56.9	5,739	542	3,871	10,152	216%	431%	-10%	-4%

Table B-6. Interpolated discharge, rearing habitat and percent change values (highlighted) at Reading Creek rehabilitation site. Habitat categories correspond to areas (m^2) meeting depth (D), velocity (V) and cover (C) criteria of rearing habitat for Chinook and Coho Salmon fry (<50 mm) and presmolt (50-100 mm).

Site	Survey Year	Lifestage	Q	Habitat Category DV,C	DV, No C	No DV, C	Total	Change Total from 2009	Change Optimal from 2009	Change Total from 2011	Change Optimal from 2011
Reading Creek	2009	Fry	9.8	495	2,302	450	3,247	- -	- -	- -	- -
			13.3	474	2,035	647	3,156	- -	- -	- -	- -
			21.3	272	1,251	820	2,343	- -	- -	- -	- -
			36.5	405	522	1,330	2,257	- -	- -	- -	- -
			62.0	656	337	1,468	2,461	- -	- -	- -	- -
		Presmolt	9.8	683	3,475	263	4,421	- -	- -	- -	- -
			13.3	690	2,845	431	3,966	- -	- -	- -	- -
			21.3	436	2,019	655	3,110	- -	- -	- -	- -
			36.5	603	930	1,132	2,665	- -	- -	- -	- -
			62.0	859	545	1,265	2,669	- -	- -	- -	- -
	2011	Fry	10.5	567	3,004	535	4,106	26%	15%	- -	- -
			15.0	668	2,173	785	3,626	15%	41%	- -	- -
			27.5	510	1,684	1,062	3,256	39%	88%	- -	- -
			40.9	698	1,603	1,467	3,768	67%	72%	- -	- -
			62.0	1,025	1,644	1,783	4,452	81%	56%	- -	- -
		Presmolt	10.5	771	4,615	331	5,717	29%	13%	- -	- -
			15.0	918	3,635	536	5,089	28%	33%	- -	- -
			27.5	741	2,782	832	4,355	40%	70%	- -	- -
			40.9	1,000	2,183	1,165	4,348	63%	66%	- -	- -
			62.0	1,358	2,441	1,450	5,249	97%	58%	- -	- -
	2017	Fry	9.8	471	3,850	341	4,662	44%	-5%	14%	-17%
			14.1	440	2,126	484	3,050	-3%	-7%	-16%	-34%
			24.4	539	1,682	789	3,010	28%	98%	-8%	6%
			34.5	726	1,016	1,087	2,829	25%	79%	-25%	4%
			60.5	1,062	877	1,552	3,491	42%	62%	-22%	4%
		Presmolt	9.8	588	6,137	223	6,948	57%	-14%	22%	-24%
			14.1	592	3,977	332	4,901	24%	-14%	-4%	-36%
			24.4	666	2,673	662	4,001	29%	53%	-8%	-10%
			34.5	904	1,640	909	3,453	30%	50%	-21%	-10%
			60.5	1,226	1,141	1,387	3,754	41%	43%	-28%	-10%

Table B-7. Interpolated discharge, rearing habitat and percent change values (highlighted) at Hocker Flat rehabilitation site after a post-construction (2008) and revisit (2017) survey. Habitat categories correspond to areas (m^2) meeting depth (D), velocity (V) and cover (C) criteria of rearing habitat for Chinook and Coho Salmon fry (<50 mm) and presmolt (50-100 mm).

Site	Survey Year	Lifestage	Q	Habitat Category: DV,C	DV, No C	No DV, C	Total	Change Total from 2008	Change Optimal from 2008
Hocker Flat	2008	Fry	12.5	79	2,212	67	2,357	- -	- -
			20.3	66	1,023	343	1,433	- -	- -
			22.7	78	1,023	203	1,304	- -	- -
			54.4	164	423	299	886	- -	- -
			70.5	224	364	429	1,016	- -	- -
		Presmolt	12.5	114	3,431	32	3,576	- -	- -
			20.3	134	1,857	276	2,267	- -	- -
			22.7	106	1,606	175	1,887	- -	- -
			54.4	259	926	204	1,389	- -	- -
			70.5	246	557	406	1,209	- -	- -
	2017	Fry	12.5	32	2,071	39	2,142	-9%	-59%
			15.1	38	1,653	69	1,760	23%	-42%
			27.9	87	551	228	866	-34%	12%
			37.9	158	550	430	1,137	28%	-4%
			66.0	165	421	694	1,279	26%	-26%
		Presmolt	12.5	40	2,948	31	3,019	-16%	-65%
			15.1	50	2,377	56	2,483	10%	-63%
			27.9	102	773	213	1,089	-42%	-4%
			37.9	202	676	385	1,264	-9%	-22%
			66.0	259	632	600	1,491	23%	5%

Appendix C. Percentage difference in discharge due to tributary accretion.

Table C-1. Percentage difference in discharge before construction (A), after construction (B) and during a revisit survey (C). The x indicates the site was not surveyed.

Site	Survey	Discharge (cms)	Change from A	Change from B
Lewiston Cableway	A	8.6	- -	- -
		11.1	- -	- -
		19.3	- -	- -
		34.3	- -	- -
		57.2	- -	- -
	B	8.6	0	- -
		11.1	0	- -
		19.9	3	- -
		34.5	1	- -
		52.7	-8	- -
	C	8.2	-5	-5
		12.4	12	12
		19.7	2	-1
		33.6	-2	-3
		58.2	2	10
Upper Bucktail Dark Gulch	A	x	- -	- -
		9.9	- -	- -
		19.9	- -	- -
		36.3	- -	- -
		60.7	- -	- -
	B	8.6	x	- -
		11.4	15	- -
		20.4	3	- -
		33.6	-7	- -
		56.9	-6	- -
	C	9.4	x	x
		13.0	32	14
		20.4	3	0
		33.9	-7	1
		57.4	-5	1
Lower Bucktail Dark Gulch	A	10.3	- -	- -
		10.5	- -	- -
		19.6	- -	- -
		36.2	- -	- -
		60.9	- -	- -
	B	8.6	-17	- -
		11.5	10	- -
		20	2	- -
		33.8	-7	- -
		56.3	-8	- -
	C	9.3	-10	8
		13.1	25	14
		19.7	1	-2
		36.1	0	7
		60.3	-1	7

Table C-2. Percentage difference in discharge due to tributary accretion before construction (A), after construction (B) and during a revisit survey (C).

Site	Survey	Discharge (cms)	Change from A	Change from B
Bucktail	A	9.3	- -	- -
		13.1	- -	- -
		19.7	- -	- -
		36.1	- -	- -
		60.3	- -	- -
	B	7.7	-17	- -
		15.9	21	- -
		20	2	- -
		36	0	- -
		56.7	-6	- -
Lowden Ranch	A	8.7	- -	- -
		11.4	- -	- -
		20	- -	- -
		34.9	- -	- -
		53.9	- -	- -
	B	8.8	1	- -
		12.7	11	- -
		23	15	- -
		37.4	7	- -
		62.3	16	- -
	C	7.4	-15	-16
		13.6	19	7
		19.3	-4	-16
		35.9	3	-4
		56.9	6	-9
Reading Creek	A	9.8	- -	- -
		13.3	- -	- -
		21.3	- -	- -
		36.5	- -	- -
		62	- -	- -
	B	10.5	7	- -
		15	13	- -
		27.5	29	- -
		40.9	12	- -
		69.4	12	- -
	C	8.6	-18	-18
		14.1	6	-6
		24.4	15	-11
		34.5	-5	-16
		60.5	-2	-13

Table C-3. Percentage difference in discharge due to tributary accretion before construction (A), after construction (B) and during a revisit survey (C).

Site	Survey	Discharge (cms)	Change from A	Change from B
Hocker Flat	B	12.5	- -	- -
		20.3	- -	- -
		22.7	- -	- -
		54.4	- -	- -
		70.5	- -	- -
	C	10.1	- -	-20
		15.1	- -	-26
		27.9	- -	23
		37.9	- -	-30
		66.0	- -	-6