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# Age 0 Chinook and Coho Salmon Rearing Habitat Assessment of Lowden Meadows, Reading Creek, and Trinity House Gulch Rehabilitation Sites 2009-2011, Upper Trinity River

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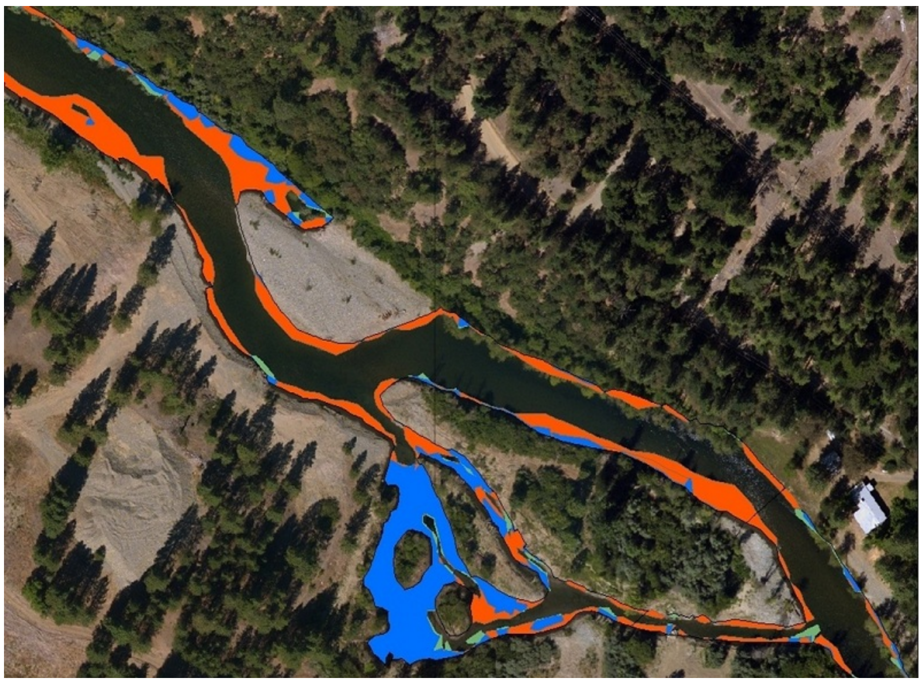

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## Table of Contents

page



## List of Tables

page

## List of Figures

page

**List of Figures, continued**

page

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*Abstract.*—The goal of the Trinity River Restoration Program is to restore and sustain natural production of anadromous fish populations downstream of Lewiston Dam. One of the primary management tools to accomplish the goal is to construct 47 channel rehabilitation sites within a 64-km reach directly downstream of Lewiston Dam. Construction of Lowden Meadows, Lower Reading Creek and Trinity House Gulch rehabilitation sites were completed in 2010 and included mainstem re-alignment, course gravel additions, side channel construction, floodplain lowering, and placement of large wood. To evaluate restoration effects, we compared Chinook Salmon and Coho Salmon rearing habitat conditions before contstruction to conditions after construction and a 340 cms (12,000 cfs) high-flow dam release. Rearing habitat abundance and quality was evaluated at five streamflows at Lowden Meadows and Lower Reading Creek sites. Trinity House Gulch was evaluated only at a summer base streamflow of 12 cms (450 cfs). Habitat abundance and quality increased in nearly all cases post-construction with the largest gains occuring at Lowden Meadows. Triniy House Gulch was the only site with reductions in habitat area, which occurred only in the highest quality habitats. When post-construction habitat densities were compared to seven previously monitored sites, Lowden Meadows ranked the third highest behind Sven Olberston and Sawmill rehabilitation sites. However, Trinity House Gulch and Reading Creek sites ranked among the lowest habitat densities with only Hocker Flat exhibiting a lower rank.

# Introduction

## TRRP Background

The strategy to restore the fishery resources of the Trinity River is to rehabilitate instream habitats through actions that integrate riverine processes and instream flow-dependent habitat needs (USFWS and HVT 1999). Implementation of this strategy is expected to lead to increased channel complexity and result in systemic increases in salmonid rearing habitat quantity and quality. Because the historical hydrologic and geomorphic effects of the dams are most pronounced between Lewiston Dam and the North Fork Trinity River, the improvements in salmonid habitat quantity and quality should also be most pronounced in this reach (hereafter referred to as the "restoration reach"). The restoration strategy is made up of four components including: (1) mechanical channel rehabilitation, (2) flow management to drive fluvial processes that create and maintain salmonid habitats and provide suitable thermal regimes, (3) coarse sediment augmentation and (4) watershed restoration. Maximum change in salmonid rearing habitat is anticipated at channel rehabilitation sites; it is also hypothesized that the restoration strategy will create synergistic effects, improving habitat throughout the restoration reach (Barinaga 1996; USDI 2000).

The design and implementation of the Trinity River Restoration Program (TRRP) is conducted under an adaptive management framework by assessing the effects of restoration actions, learning from the results and adjusting management actions to achieve programmatic goals and objectives (Holling 1978). A fundamental assessment necessary to evaluate the effectiveness of TRRP actions is to determine the changes in habitat resulting from the synergistic effects of mechanical channel rehabilitation and restoration of fluvial processes that are expected to improve and maintain riverine habitats. This assessment evaluates salmonid fry and presmolt rearing habitat response to restoration activities at specific rehabilitation sites and contributes to the TRRP adaptive management framework by providing short-term feedback to improve management actions and providing information for long-term trend analyses. Age-0 Chinook and Coho salmon rearing habitat (herein defined as rearing habitat for this report) is the primary limiting factor for salmonid populations in the Trinity River and the basis for the restoration activities (USFWS and HVT 1999).

## Project Goals and Objectives

The goal of this assessment was to evaluate the effectiveness of TRRP restoration actions to improve rearing habitat at Lowden Meadows, Lower Reading Creek, and Trinity House Gulch (THG) rehabilitation sites. We evaluated changes in Chinook salmon and Coho salmon rearing habitat that resulted from mechanical channel rehabilitation, gravel introduction, large woody debris (LWD) additions and the 2011 Trinity River Record of Decision (ROD) 340 cms (12,000 cfs) spring high-flow event (the second largest dam release since Trinity Dam was completed in 1964). Results will contribute to the adaptive management process through the evaluation of progress toward achieving TRRP goals and objectives. This is intended to provide short-term feedback to improve management actions relating to channel rehabilitation, coarse sediment augmentation, and annual flow management.

The TRRP has been implementing channel rehabilitation components of the ROD since 2005. Evaluation of project performance is critical to inform the remaining channel rehabilitation designs. The objective of this report is to quantify changes in habitat that occurred throughout the three sites listed above; before and after construction and following a high flow event. Where applicable, design goals and objectives were evaluated for their effects on habitat availability by isolating habitat polygons around the specific features of interest.

## Drainage and Channel Rehabilitation Site Description

The Trinity River is located in northwestern California within Humboldt and Trinity counties. The watershed has a drainage area of 7,679 $km^2$, approximately one quarter of which is upstream of Lewiston Dam and inaccessible to anadromous fishes (USFWS 1989; USBR 2009). The river's headwaters are in the Salmon-Trinity Mountains of northern California, from which it flows 274 km to its confluence with the Klamath River in Weitchpec, California. The restoration reach (where all rehabilitation sites and action are focused) is located within 64 km of the Trinity River between Lewiston Dam and the confluence of the North Fork Trinity River. This monitoring report focuses on the Lowden Meadows and THG rehabilitation sites located upstream and downstream of Grass Valley Creek in Lewiston, California approximately 12 river kilometers (rkm) downstream of the Lewiston Dam and the Reading Creek rehabilitation site located in Douglas City approximately 31 rkm downstream of the Lewiston Dam (Figure 1).

### *Lowden Meadows*

Lowden Meadows encompasses 1,000 m of mainstem channel. Prior to construction much of Lowden Meadows was composed of a straight, low gradient run with a mid-channel bar towards the downstream end. The channel was confined on the right bank by the valley wall but the left bank was a wide terrace composed of dredger tailings and existing wetlands (DWR 2010). The simple channel geometry limited hydraulic diversity, edge length, and the availability of rearing habitat at all flow levels. Construction of the Lowden Meadows rehabilitation site occurred during the summer of 2010.

The habitat assessment evaluated the upper 800 m of river channel (rkm 169.2-168.4; Figure 2). Pre- and post-construction mapping occurred at 5 flows between 8.7 cms (307 cfs) and 62.1 cms (2,193 cfs) during the late spring and summer months of 2009 and 2011 respectively. When preconstruction mapping was initiated during the spring of 2009, final construction designs were not available. Therefore, construction boundaries were estimated and the lower anastomosing islands were not included in the assessment. Features evaluated for changes in habitat in this report include the R-1 side channel, the R-2 off-stream rearing pond, the R-3 main channel realignment, the R-6 alcove, and the mainstem section adjacent to the R-4 low bench.

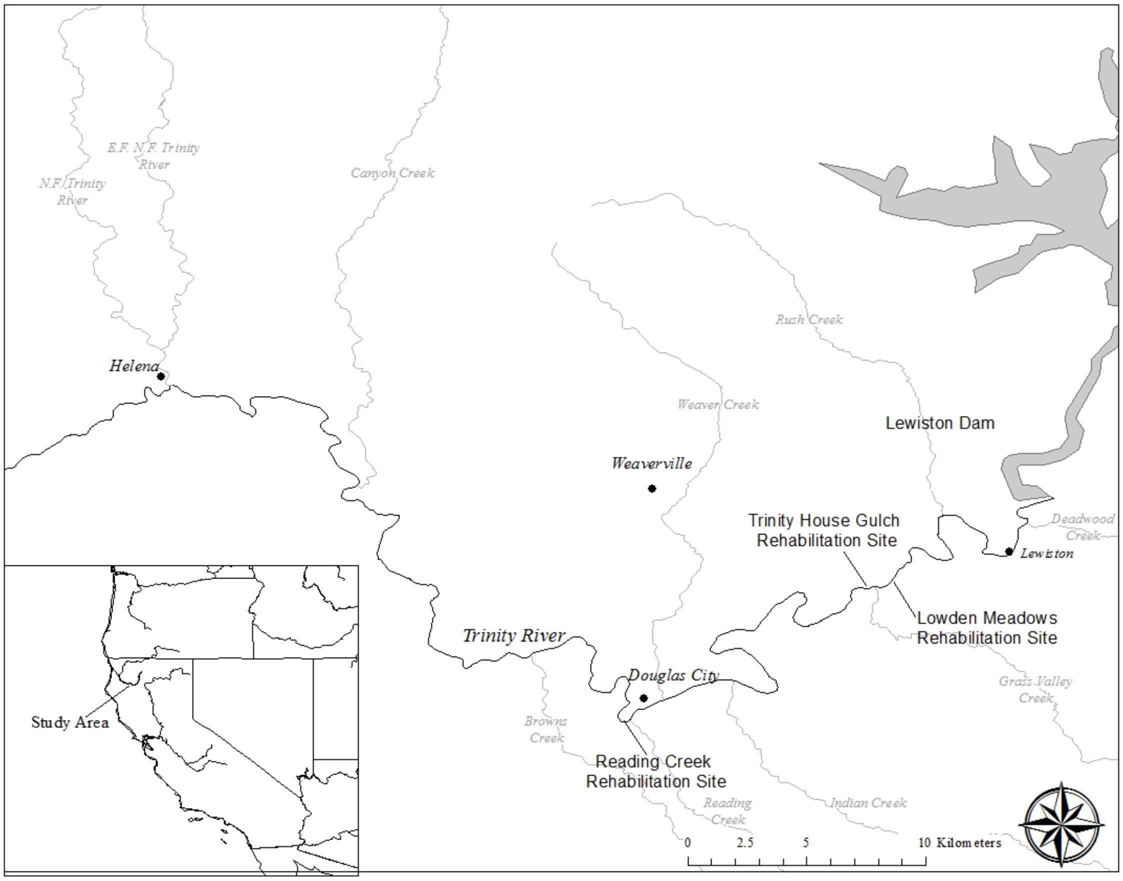



Figure 1. Location of Lowden Meadows, Trinity House Gulch and Reading Creek rehabilitation sites within the 64 km Upper Trinity River project reach. The primary restoration reach extends from Lewiston Dam near Lewiston to the confluence of the Trinity and North Fork Trinity Rivers at Helena.


Figure 2. Aerial view of Lowden Meadows rehabilitation site design elements and habitat survey extents. Yellow lines indicate pre- and post-construction winter base flow mapping extents. Dark blue lines indicate pre- and post-construction multiple flow to habitat mapping extents. The orange arrow indicates flow direction.

*Reading Creek*

The Lower Reading Creek site covers just over 600 m of mainstem channel. It is located just downstream of the Reading Creek confluence (rkm 149) and is adjacent to the Douglas City Campground. The right bank of the site is characterized by mature riparian berms along the campground section and a bedrock wall at the downstream end. The upper section of the left bank has a steep valley wall with some bedrock along the edge and a large terrace dominates the lower left bank of the site (HVT and McBain and Trush 2010). Rehabilitation actions at Reading Creek occurred in two main areas, Upper and Lower Reading Creek. During the time of pre-construction mapping it was unclear as to what, if any, type of rehabilitation work would occur within the Upper Reading Creek site. Habitat monitoring of pre- and post-construction conditions occurred within the Lower Reading Creek site only. The habitat assessment evaluated 745 m of river channel (rkm 149.5-148.8; Figure 3) at five flows ranging from 9.9 to 69.4 cms (348 – 2,451 cfs) during the late spring and summer months of 2009 and 2011. The upper 200 m that was mapped included the section of river that had no mechanical actions. Features evaluated for changes in habitat in this report include area R-4 low flow benches, the IC-4 and IC-5 transverse bars, IC-6 and IC-7 constructed point bars, and area R-5 which consisted of a forced meander, feathered edge, and a high flow scour channel (HVT and McBain and Trush 2010). The mapping did not incorporate the downstream end of the rehab site where the R-5 high flow scour channel connected to the mainstem through the alcove.

*Trinity House Gulch*

The THG rehabilitation site extends along 400 m of mainstem channel. THG is located just downstream of the Grass Valley Creek confluence (rkm 167.6). Prior to construction the right bank of the site was described as a high terrace with dredger tailings that terminated at the downstream end at the THG confluence. The left bank of the site has a levee built to protect a private landowner's property along the upper half and had heavily vegetated banks on the downstream half. Rehabilitation actions at THG included the IC-1 and IC-3 gravel bar additions, construction of the R-1 forced meander, floodplain lowering at R-1 and construction of the R-2 low flow side channel (HVT and McBain and Trush 2010). The location of the THG rehabilitation site coincided with GRTS site 39 in Panel 3 of the systemic habitat assessment (Alvarez et al. 2013). Pre and post-construction/post 2011 spring release base flow mapping of THG was accomplished by adding 50 m to the bottom end of GRTS 39 in 2010 and 2011. The habitat assessment covered the entire area of rehabilitation (rkm 167.9-167.5; Figure 4) at a summer base flow discharge of 14.3 cms (505 cfs) pre-construction and 13.6 cms (480 cfs) post-construction.

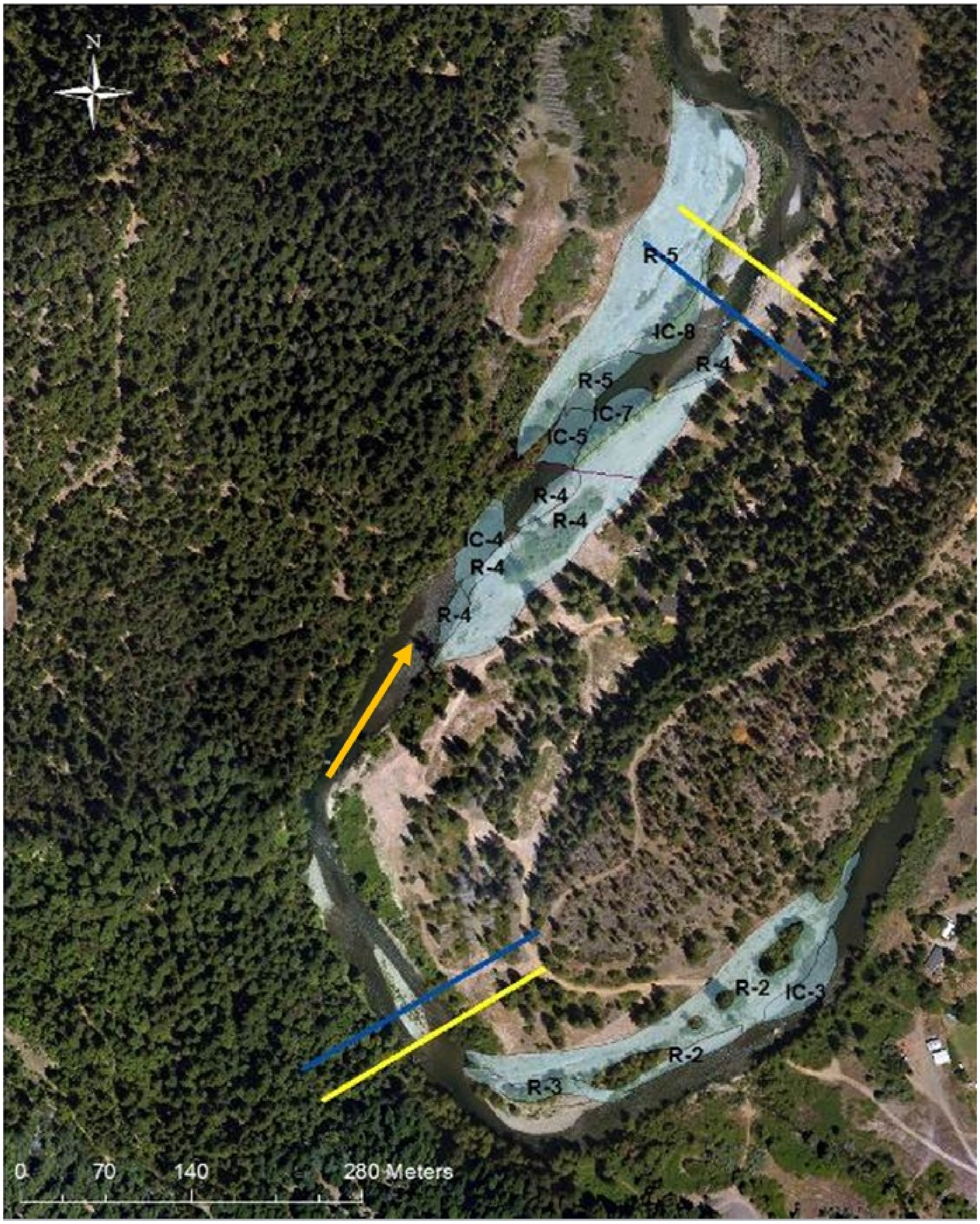



Figure 3. Aerial view of Reading Creek rehabilitation site design elements and habitat survey extents. Yellow lines indicate pre- and post-construction winter base flow mapping extents. Dark blue lines indicate pre- and post-construction multiple flow to habitat mapping extents. The orange arrow indicates flow direction.


Figure 4. Aerial view of Trinity House Gulch rehabilitation site design elements and habitat survey extents. Yellow lines indicate pre- and post-construction summer base flow mapping extents. The orange arrow indicates flow direction.

## Field and Analytical Methods

Rearing habitat was characterized and quantified by developing planar maps of the study area following methods described by Goodman et al. (2010). Rearing habitat definitions are summarized in Table 1. We refined the description of our habitat assessment to age 0 salmonid winter rearing habitat (Martin et al. 2012), rather than simply rearing habitat as used in past reporting. This refined habitat definition relates more directly to the life stage of interest to the TRRP (USFWS and HVT 1999) and the foundation of habitat suitability data used to derive mapping criteria (Hampton 1997). Age 0 presmolt rearing habitat criteria were also updated in Martin et al. (2012). The size range was adjusted from 50-200 mm FL to 50-100 mm FL.

Table 1. Guilds and their associated habitat criteria for fish habitat mapping as part of the 2008 Trinity River site assessment (Goodman et al. 2010).

| Habitat Guild | Variable | Criteria |
|---|---|---|
| Chinook salmon and Coho salmon fry (<50 mm) | Depth | >0 to 0.61 m |
| | Mean column velocity | 0 to 0.15 m/sec |
| | Distance to Cover | 0 to 0.61 m |
| | Cover type | No cover, vegetation or wood |
| Chinook salmon and Coho salmon presmolt (50 ≥ *X* < 100 mm) | Depth | >0 to 1 m |
| | Mean column velocity | 0 to 0.24 m/sec |
| | Distance to Cover | 0 to 0.61 m |
| | Cover type | No cover, vegetation or wood |

The fish habitat survey identified areas that met guild definitions within each survey area at a specific streamflow. In the field, two kinds of habitat areas were mapped independently of each other. They included depth/velocity areas and cover habitat. A depth/velocity area must meet both depth and velocity criteria to be included. Cover areas must have cover in-water that can be used by fry or presmolt. The survey data were developed as a series of spatially referenced geographic information system (GIS) layers. Within GIS, surveyed polygons (depth/velocity and/or cover) were overlaid and used to represent areas of fry and presmolt rearing. Once the GIS polygons were created that include four qualities of habitat (DV, C; DV, No C; No DV, C; and No DV, No C; Table 2), areas of the polygons for each type of habitat were summed. Because the study areas were completely mapped and not just sampled, there are no sampling errors associated with the habitat areas to report.

Table 2. Mapped habitat categories with resulting four associated habitat qualities. Chinook salmon total habitat was defined as areas that meet any combination of depth/velocity and cover criteria. Optimal Chinook salmon habitat or Coho salmon habitat were defined as areas that simultaneously meet depth/velocity and cover criteria.

| | Depth/Velocity (DV) | Outside Depth/Velocity (No DV) |
|---|---|---|
| **Cover (C)** | DV,C – *Optimal habitat | No DV, C – *Suitable habitat |
| **Outside Cover (No C)** | DV, No C – *Suitable habitat | No DV, No C – Unsuitable habitat (not reported) |

*Total habitat reported includes optimal habitat + all suitable habitats present.

Within this report we assess “optimal” and total Chinook salmon habitat. For this report, we define optimal habitat as being areas that meet both the depth/velocity and cover criteria. Total Chinook salmon habitat (total habitat) includes areas that meet any combination of depth/velocity or cover criteria (including optimal habitat areas). It is calculated by summing optimal habitat and the 2 suitable habitats together. Coho salmon rearing habitat is limited to areas that meet both depth/velocity and cover criterion and all other areas are considered unsuitable habitat for this analysis. Habitat suitability criteria studies, rearing habitat validation studies (Goodman et al. 2010) and published literature pertaining to Coho salmon (McMahon and Hartman 1989), all support a high preference for cover during this phase of their development. A separate layer indicating the river bank or water’s edge was also created. Habitat densities were calculated to facilitate across-site comparisons. For this report, habitat density ($m^2/m$) is defined as the amount of measured rearing habitat ($m^2$) per length of the 142 cms (5,000 cfs) channel centerline (m). Site specific streamflows evaluated in the habitat density analysis ranged from 8.6 to 20.3 cms (302-718 cfs). Hocker Flat was evaluated in summer 2008; Sven Olberston, Lewiston Cableway, Hoadley Gulch, Dark Gulch, Lower Indian Creek were evaluated in summer and fall 2009; Sawmill was evaluated in the spring of 2010; and Lowden Meadows, Reading Creek and THG were mapped in 2011. Percent optimal habitat is derived as a percentage of the total habitat available. It is calculated by dividing optimal habitat by the total habitat and multiplying by 100.

At the Lowden Meadows and Reading Creek sites where flow-habitat mapping occurred, discharges during the time of surveys can differ between pre and post-construction mapping enough to prevent direct comparison of habitat areas. To compare the amount of change before and after construction where discharges were not directly comparable, a polynomial equation was fit to one of the flow-habitat discharge relationships (best fit). This equation was then used to calculate habitat estimates at the same discharges for pre and post-construction/post high flow. To isolate habitat polygons around the R-4 benches at Reading Creek for analysis, the construction area polygons were buffered 10 m in GIS. Subsequently, the habitat areas selected were summed to describe available habitat over the range of mapped flows in and around the low benches. For some comparisons, analysis and figures presented within this report are limited to presmolt results in order to simplify reporting. In these cases, fry habitat was evaluated and exhibited similar results as displayed in the presmolt data. Fry habitat areas were always presented in the tables.

## Results

### Lowden Meadows

Pre-construction rearing habitat surveys were conducted at the Lowden Meadows site during the late winter and spring of 2009. A winter base flow map 816 m long was produced at a discharge of 8.7 cms (307 cfs). The base flow post-construction assessment was conducted in the fall of 2011 at a discharge of 8.8cms (311cfs). At winter base flow, total fry and presmolt rearing habitat across the whole site increased by 140% and 121% respectively post-construction (Figure 5). Optimal

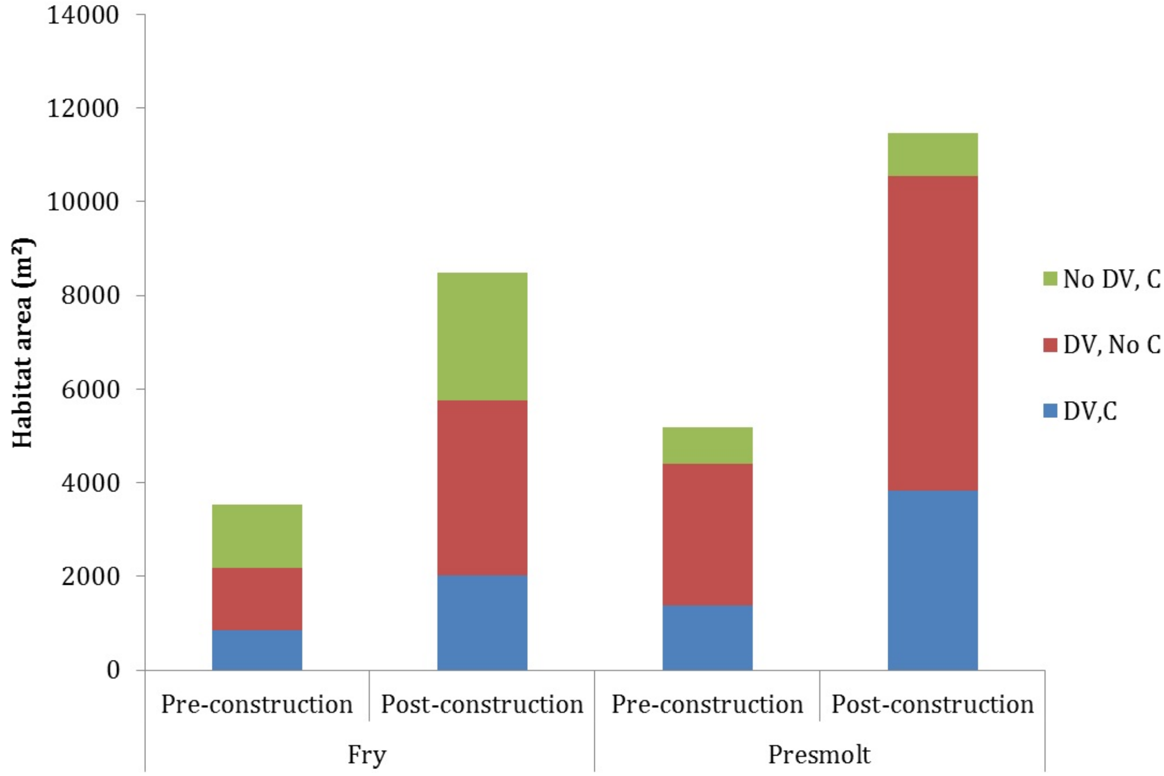


Figure 5. Chinook and Coho salmon rearing habitat quantities at the entire Lowden Meadows rehabilitation site (rkm 168.4-169.2). Pre-construction estimates were conducted at 8.7 cms (307 cfs) in 2009 and post-construction at 8.8 cms (311 cfs) in 2011. Habitat categories correspond to combinations of depth/velocity and in-water escape cover criteria.

habitat increased 140% for fry and 177% for presmolt at base flow. Calculated habitat areas ($m^2$), allowed for pre and post-construction comparisons for the main channel, side channel, ponded area, alcove and the combined total (Table 3).

The Lowden Meadows rehabilitation site was mapped at a range of flows over an area that included the main channel forced meander (IC-2 and R-3), the side channel/pond complex (R-1 and R-2) on river left and the gravel augmentation area. The area where multiple flow mapping occurred will be referred to as Lowden Meadows (A). Lowden Meadows (A) exhibited increases in optimal and total habitat at all flows post-construction (Table 4, Figure 6). The highest increases occurred at the highest comparable flow of 53.9 cms (1,903 cfs). At this discharge optimal habitat increased 641% and 452% for fry and presmolt respectively. For the same flow, fry and presmolt total habitat increased 231% and 252%. The shape of the streamflow to habitat curve changed somewhat for total habitat. A dip in habitat was still present at lower flows however the slope of the curve at higher flows increased post-construction. The shape of the flow-optimal habitat curve changed dramatically. Pre-construction, optimal habitat peaked at 12.7 cms (448 cfs). Post-construction, optimal habitat increased as the discharge rose above 12.7 cms (448 cfs). There was no (DV, no C) suitable fry habitat pre-construction at 53.9 cms.

This illustrated the confined, riparian dominated nature of the channel edges at Lowden Meadows prior to rehabilitation. Post-construction fry suitable habitat (DV, no C) values were estimated at 935 m².

Table 3. Habitat conditions at winter base flows before and after construction at Lowden Meadows rehabilitation site. Side channel, ponded area, and alcove were not present before construction. Habitat categories correspond to areas (m²) meeting the depth/velocity dual criteria of rearing habitat for Chinook salmon and Coho salmon fry (<50 mm FL) and presmolt (50>*X*<100 mm FL).

| | | | | | Habitat category (m²) | | | |
|---|---|---|---|---|---|---|---|---|
| **Evaluation type** | **Location** | **Length (m)** | **Life stage** | **Dis-charge (cms)** | **DV,C** | **DV, No C** | **No DV, C** | **Total habitat** |
| Lowden pre-construction | Main channel | 816 | Fry | 8.7 | 840 | 1,349 | 1,344 | 3,533 |
| | | | Presmolt | 8.7 | 1,386 | 3,009 | 793 | 5,188 |
| | Side channel | 0 | Fry | - - | - - | - - | - - | - - |
| | | | Presmolt | - - | - - | - - | - - | - - |
| | Ponded area | 0 | Fry | - - | - - | - - | - - | - - |
| | | | Presmolt | - - | - - | - - | - - | - - |
| | Alcove | 0 | Fry | - - | - - | - - | - - | - - |
| | | | Presmolt | - - | - - | - - | - - | - - |
| | Entire site | 816 | Fry | 8.7 | 840 | 1,349 | 1,344 | 3,533 |
| | | | Presmolt | 8.7 | 1,386 | 3,009 | 793 | 5,188 |
| Lowden post-construction | Main channel | 816 | Fry | 8.8 | 834 | 3,026 | 1,202 | 5,063 |
| | | | Presmolt | 8.8 | 1,465 | 5,524 | 571 | 7,560 |
| | Side channel | 221 | Fry | 1.3 | 183 | 325 | 148 | 656 |
| | | | Presmolt | 1.3 | 257 | 565 | 75 | 897 |
| | Pond | 70 | Fry | NA | 806 | 108 | 1,159 | 2,073 |
| | | | Presmolt | NA | 1,880 | 254 | 85 | 2,219 |
| | Alcove | 75 | Fry | NA | 190 | 293 | 217 | 700 |
| | | | Presmolt | NA | 238 | 369 | 169 | 777 |
| | Entire site | 816 | Fry | 8.8 | 2,014 | 3,752 | 2,726 | 8,491 |
| | | | Presmolt | 8.8 | 3,840 | 6,713 | 900 | 11,452 |

Table 4. Habitat conditions at multiple discharges before and after construction at Lowden Meadows (A) rehabilitation site. Habitat categories correspond to areas ($m^2$) meeting the depth/velocity dual criteria of rearing habitat for Chinook salmon and Coho salmon fry (<50 mm FL) and presmolt (50>*X*<100 mm FL).

| Evaluation type | Life stage | Dis-charge (cms) | Habitat category ($m^2$) | | | |
|---|---|---|---|---|---|---|
| | | | DV, C | DV, No C | No DV, C | Total habitat |
| Lowden (A) pre-construction | Fry | 8.7 | 759 | 1,009 | 1,328 | 3,096 |
| | | 11.4 | 941 | 548 | 1,695 | 3,185 |
| | | 20.0 | 588 | 136 | 2,192 | 2,916 |
| | | 34.0 | 261 | 11 | 2,528 | 2,800 |
| | | 53.9 | 640 | 0 | 2,563 | 3,203 |
| | Presmolt | 8.7 | 1,296 | 2,450 | 786 | 4,533 |
| | | 11.4 | 1,448 | 1,392 | 1,188 | 4,029 |
| | | 20.0 | 1,139 | 381 | 1,641 | 3,161 |
| | | 34.0 | 820 | 95 | 1,970 | 2,885 |
| | | 53.9 | 1,081 | 7 | 2,123 | 3,210 |
| Lowden (A) post-construction | Fry | 8.8 | 1,906 | 3,470 | 2,570 | 7,946 |
| | | 12.7 | 1,709 | 2,216 | 3,411 | 7,336 |
| | | 23.0 | 2,721 | 1,523 | 2,994 | 7,238 |
| | | 37.4 | 3,754 | 951 | 3,802 | 8,506 |
| | | 62.1 | 5,238 | 927 | 5,516 | 11,681 |
| | Presmolt | 8.8 | 3,686 | 6,193 | 790 | 10,669 |
| | | 12.7 | 3,592 | 4,541 | 1,528 | 9,661 |
| | | 23.0 | 3,698 | 3,084 | 2,017 | 8,799 |
| | | 37.4 | 4,574 | 1,821 | 2,981 | 9,376 |
| | | 62.1 | 6,659 | 1,517 | 4,095 | 12,272 |

Mainstem habitat areas were isolated from off channel habitat to evaluate the effect of the two treatment types (forced meander, gravel augmentation). Total available fry habitat in the mainstem at winter base flow increased by 47% post-construction and presmolt total available habitat increased 49% post-construction in the mainstem. There was a 1% decrease in optimal habitat for fry and an increase of 6% for presmolt. The increases in mainstem total habitat resulted from two changes. The first adjustment occurred where the IC-2 forced meander was constructed. An alcove was included on the downstream end of the bar. This alcove contributed to the habitat increases as well as the eddy formed on river left downstream of the meander (Figure 7). To quantify changes in habitat initiated by the meander construction an entire wavelength of river was analyzed, assuming the constructed forced meander was ½ of a wavelength. At winter base flow, total presmolt habitat within this section of river increased 1036 $m^2$ or 77% post-construction. Rearing habitat increased within this section at all measured flows (Figure 8).

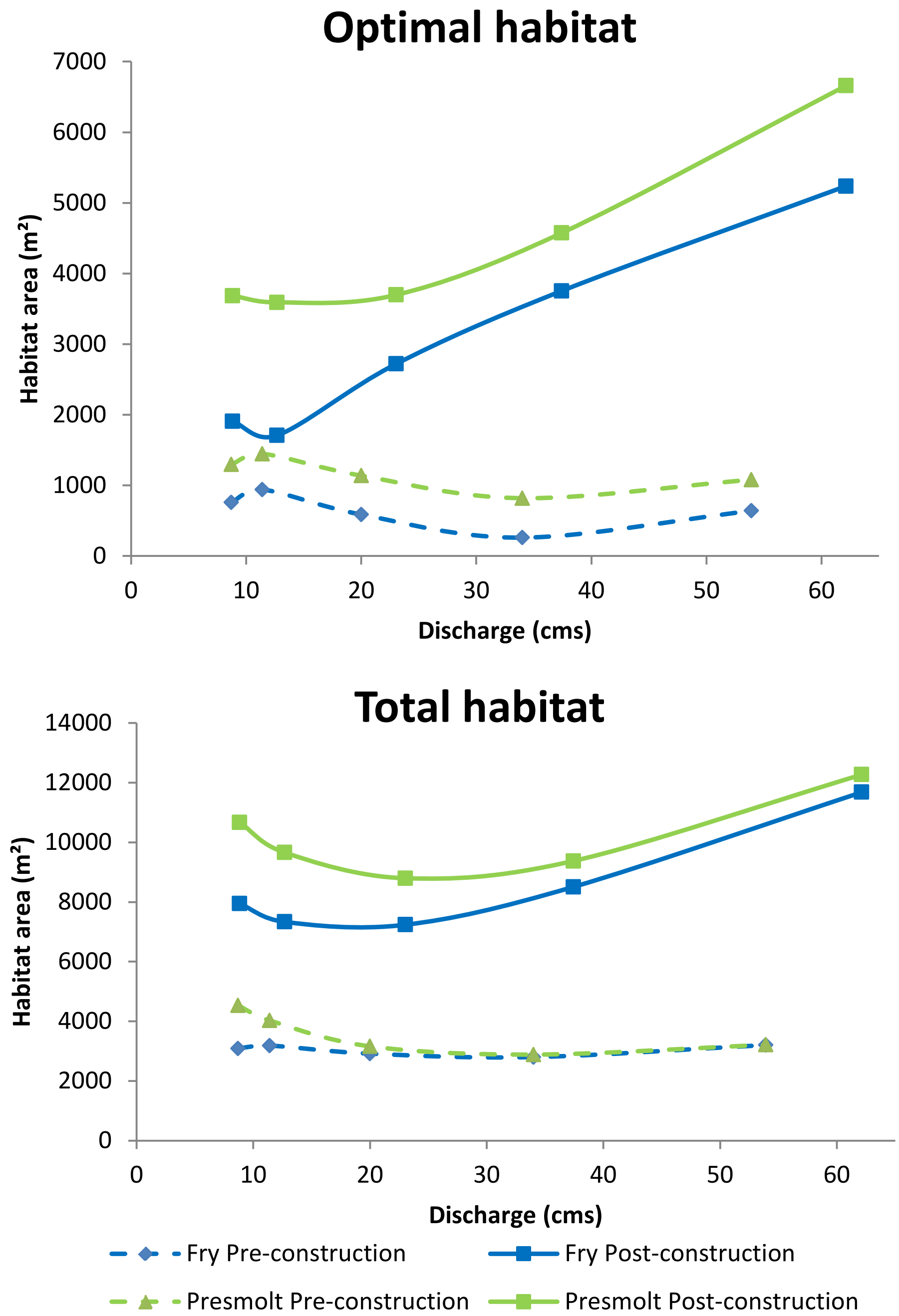



Figure 6. Estimates of Chinook and Coho salmon rearing habitat by streamflow at Lowden Meadows (A) rehabilitation site. Optimal Chinook and Coho salmon habitat was defined as areas within depth/velocity and in-water escape cover (DV,C) criteria. Total Chinook salmon rearing habitat (total habitat) was defined as areas that met any combination of depth/velocity or in-water escape cover criteria. The fry life stage is defined as fish <50 mm FL and presmolt as 50>*X*<100 mm FL.

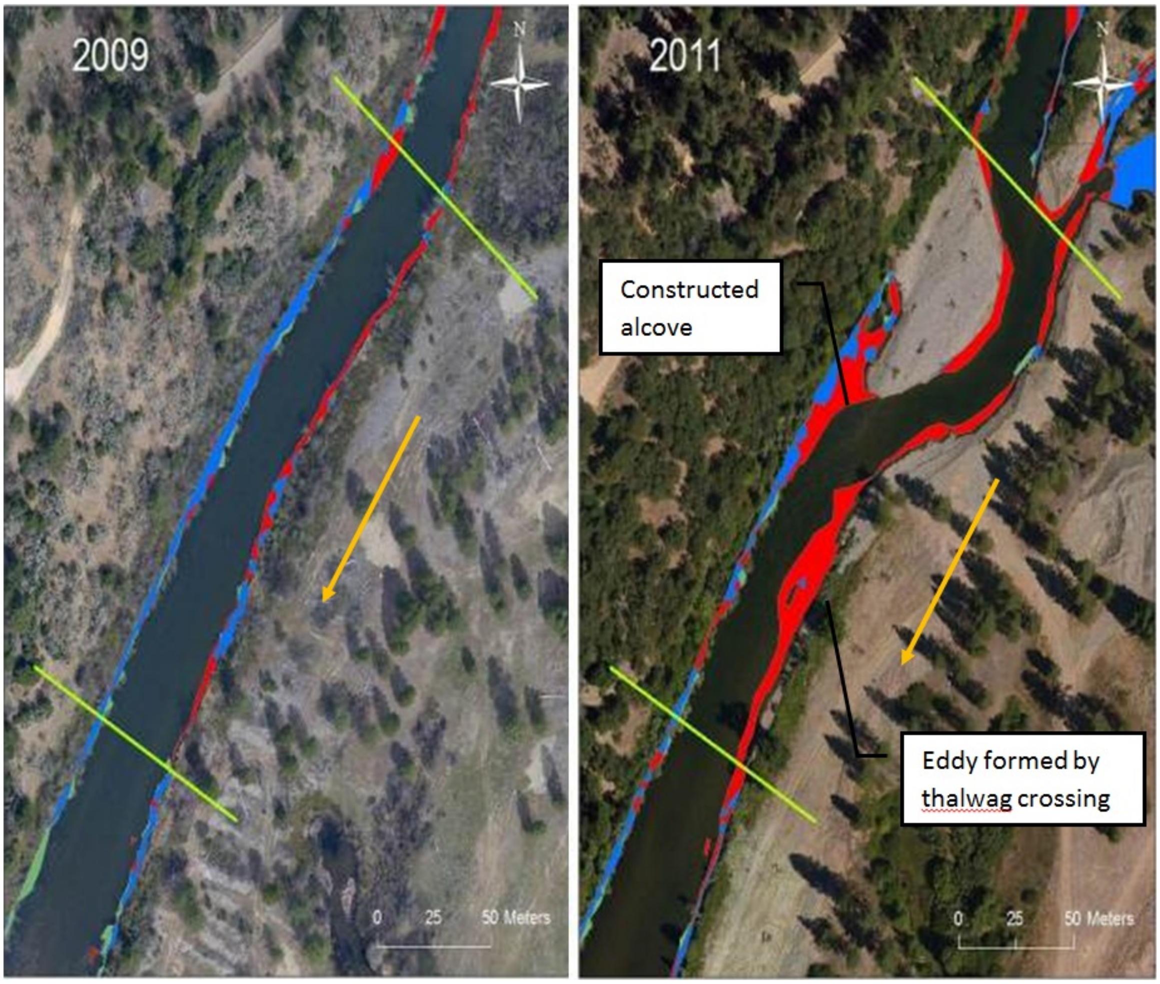


Figure 7. Aerial views of the IC-2/R-3forced meander location at Lowden Meadow rehabilitation site (rkm 168.9) before construction (left photo) and after construction (right photo). Blue areas indicate optimal presmolt habitat and red and green areas indicate suitable presmolt habitat. Yellow lines indicate the extent of the habitat area comparison. The orange arrow indicates flow direction. Mainstem discharge pre-construction was 8.7 cms (307 cfs) and 8.8 cms (311 cfs) post-construction.

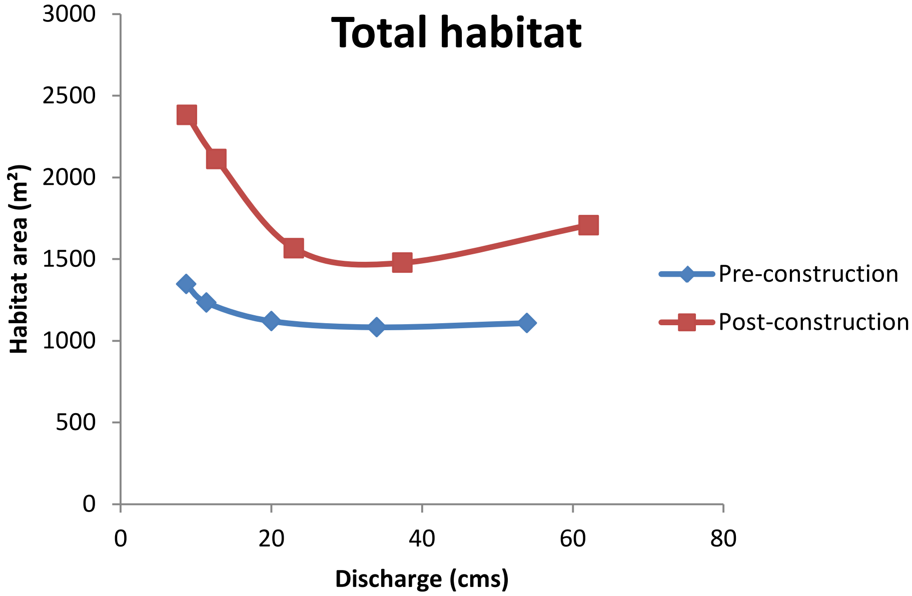



Figure 8. Total presmolt habitat before and after construction around the IC-2/ R-3 constructed forced meander within the area bounded by the yellow lines in Figure 6.

The second mainstem section that exhibited positive increases in habitat occurred downstream of the gravel injection site adjacent to the R-4 low bench. The mid-channel bar area (area above low flow wetted edge) increased from 236 $m^2$ to 558 $m^2$, a 136% increase (Figure 9). It also, migrated towards the left bank (looking downstream), which caused an increase in slow water below the bar. As a result, winter base flow total habitat increased 1,048 $m^2$ or 69%, upstream and downstream of the bar where slow water was created. The post-construction flow-habitat curve exhibited a dip around the 34 cms (1,200 cfs) point. This occurred when the water overtopped the bar. Habitat began to increase again at higher flows as the water spread out across the left bank (Figure 10).

Constructed off channel habitats including the R-1 side channel, R-2 ponded area and R-6 alcove/high flow channel were evaluated to compare habitat creation. All three features did not exist prior to construction at the discharges surveyed. Therefore results are focused on post-construction conditions. Also, optimal habitat results for all three features exhibited a similar response as total habitat (similar curve with lower values) and as such, reporting focuses on total habitat. The ponded area had the highest habitat values of the three features at all flows except 23.0 cms (812 cfs) where the alcove/high flow channel had slightly more habitat (Figure 11). It was at this flow monitoring bench that the alcove became a connected and flowing side channel, which explains the large increase in habitat. Percent optimal habitat was calculated for all three features at all flows. The ponded area and alcove/high flow channel had the highest values observed of any features evaluated to date. Percent optimal habitat within the ponded area ranged from 85% at winter base flow to 63% at the highest flows. Percent optimal habitat for the side channel ranged from 33% (at 12.7 cms) to 67% at the highest flow and the alcove/high flow channel had values ranging from 29% (at 12.7 cms) to 79% (at 37.4 cms).

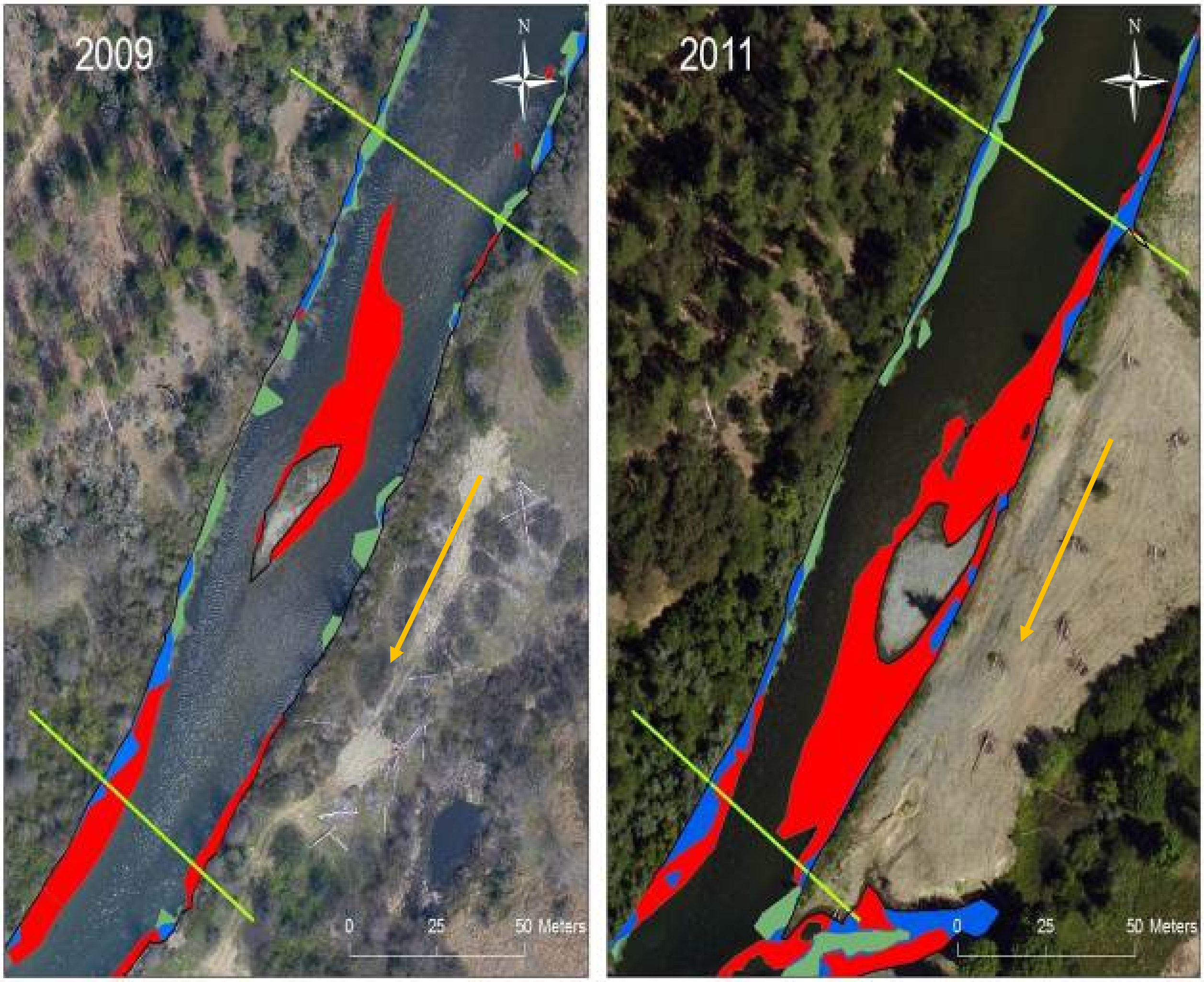



Figure 9. Aerial views of mid-channel bar location downstream of 2011 gravel injection at Lowden Meadows rehabilitation site (rkm 168.55) before construction (left photo) and after construction (right photo). Black lines indicate wetted edge, blue areas indicate optimal presmolt habitat and red and green areas indicate suitable presmolt habitat. Yellow lines indicate the extent of the habitat area comparison. The orange arrow indicates flow direction. Mainstem discharge pre-construction was 8.7 cms (307 cfs) and 8.8 cms (311 cfs) post-construction.

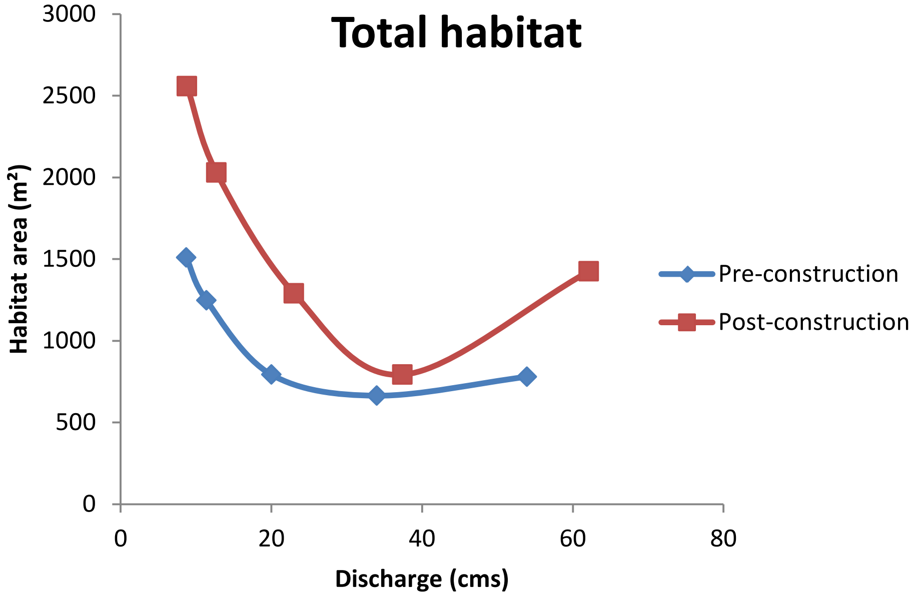



Figure 10.  Total presmolt habitat before and after construction around the mid-channel bar formed near the R-4 low bench within the area highlighted in Figure 8.

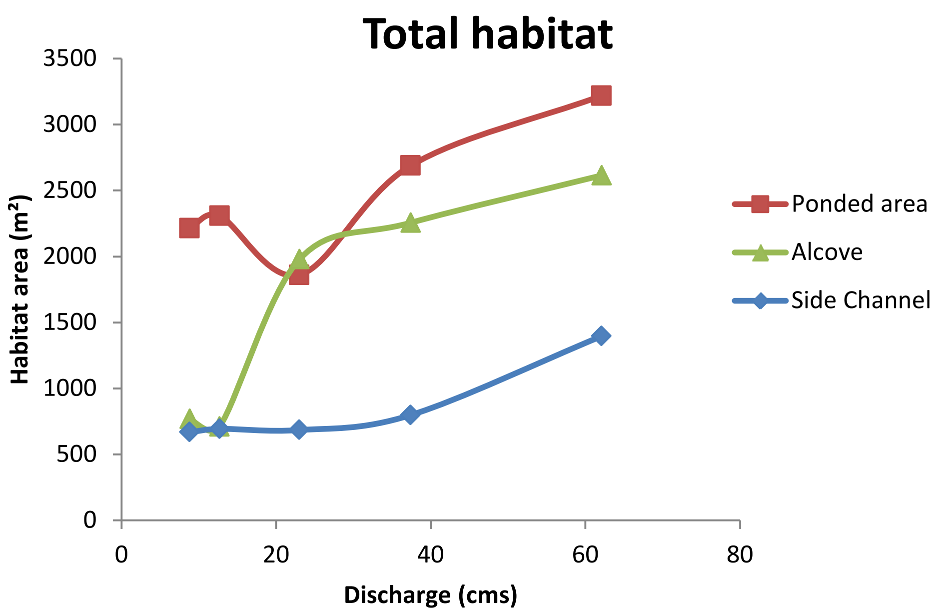



Figure 11.  Total presmolt habitat measured at five flows post-construction within the R-1 side channel, R-2 ponded area and R-6 alcove/high flow channel at Lowden Meadows rehabilitation site.

### Lower Reading Creek

Pre-construction rearing habitat surveys were conducted at the Lower Reading Creek rehabilitation site during the late winter and spring of 2009. The base flow post-construction assessment was conducted in the fall of 2011 at a discharge of 10.5 cms (371 cfs). At winter base flow, total fry and presmolt rearing habitat across the whole site increased by 25% and 27% respectively post-construction (Table 5, Figure 12). Optimal habitat increased 10% at base flow for both fry and presmolt.

Table 5. Habitat conditions at winter base flows before and after construction at Reading Creek rehabilitation site. Habitat categories correspond to areas (m²) meeting the depth/velocity dual criteria of rearing habitat for Chinook salmon and Coho salmon fry (<50 mm FL) and presmolt (50>*X*<100 mm FL).

| Evaluation type | Length (m) | Life stage | Dis-charge (cms) | Habitat category (m²) | | | |
|---|---|---|---|---|---|---|---|
| | | | | DV, C | DV, No C | No DV, C | Total habitat |
| Lower Reading pre-construction | 806 | Fry | 9.9 | 535 | 2,599 | 506 | 3,640 |
| | 806 | Presmolt | 9.9 | 733 | 3,893 | 309 | 4,934 |
| Lower Reading post-construction | 806 | Fry | 10.5 | 588 | 3,305 | 674 | 4,567 |
| | 806 | Presmolt | 10.5 | 806 | 4,992 | 456 | 6,253 |

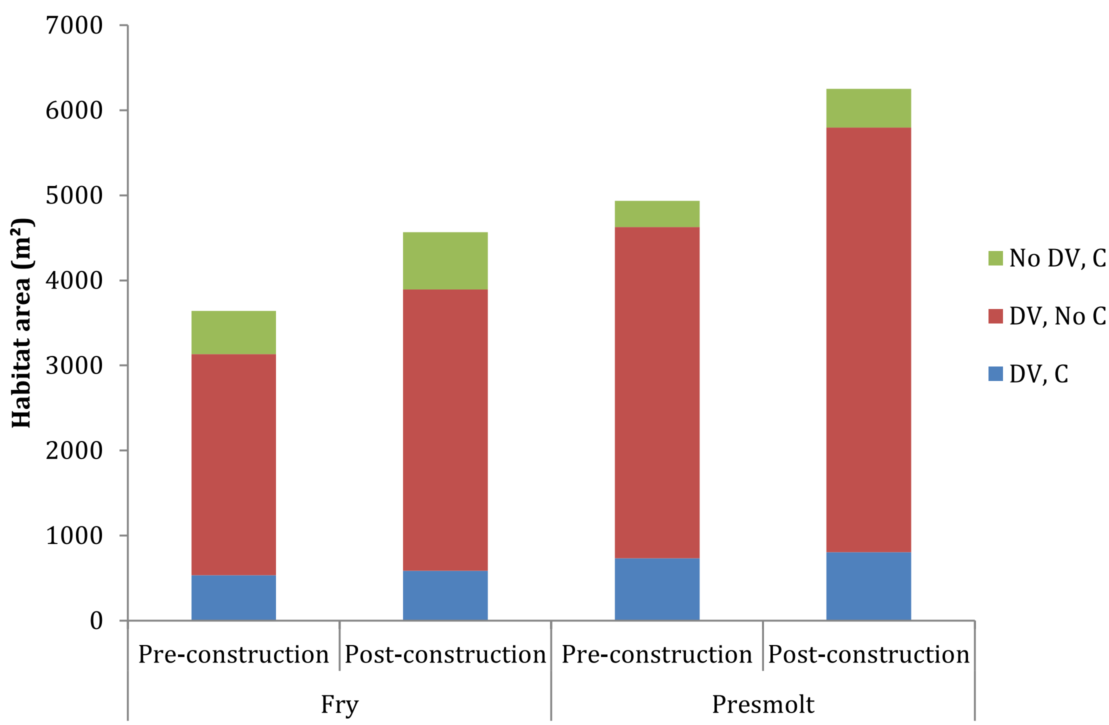



Figure 12. Chinook and Coho salmon rearing habitat quantities at the Reading Creek rehabilitation site (rkm 148.7-149.5).

Table 6. Habitat conditions at multiple discharges before and after construction at Reading Creek (A) rehabilitation site. Habitat categories correspond to areas (m²) meeting the depth/velocity dual criteria of rearing habitat for Chinook salmon and Coho salmon fry (<50 mm FL) and presmolt (50>*X*<100 mm FL).

| Evaluation Type | Length (m) | Life stage | Dis-charge (cms) | Habitat category (m²) | | | |
|---|---|---|---|---|---|---|---|
| | | | | DV, C | DV, No C | No DV, C | Total habitat |
| Reading Creek (A) pre-construction | 720 | Fry | 10 | 495 | 2,302 | 450 | 3,247 |
| | | | 13 | 474 | 2,035 | 647 | 3,157 |
| | | | 21 | 272 | 1,251 | 820 | 2,343 |
| | | | 37 | 405 | 522 | 1,330 | 2,257 |
| | | | 62 | 656 | 337 | 1,468 | 2,462 |
| | | Presmolt | 10 | 683 | 3,475 | 263 | 4,420 |
| | | | 13 | 690 | 2,845 | 431 | 3,967 |
| | | | 21 | 436 | 2,019 | 655 | 3,110 |
| | | | 37 | 603 | 930 | 1,132 | 2,665 |
| | | | 62 | 859 | 545 | 1,265 | 2,670 |
| Reading Creek (A) post-construction | 720 | Fry | 11 | 567 | 3,004 | 535 | 4,107 |
| | | | 15 | 668 | 2,173 | 785 | 3,626 |
| | | | 28 | 510 | 1,684 | 1,062 | 3,256 |
| | | | 41 | 698 | 1,603 | 1,467 | 3,769 |
| | | | 69 | 1,140 | 1,659 | 1,894 | 4,693 |
| | | Presmolt | 11 | 771 | 4,615 | 331 | 5,717 |
| | | | 15 | 918 | 3,635 | 536 | 5,088 |
| | | | 28 | 741 | 2,782 | 832 | 4,354 |
| | | | 41 | 1,000 | 2,183 | 1,165 | 4,349 |
| | | | 69 | 1,484 | 2,531 | 1,550 | 5,565 |

A portion of the rehabilitation site was mapped at multiple flows ranging from 9.9 to 69.4 cms (348 – 2,451 cfs). The area extends over 745 m of the mainstem river and the intent was to evaluate the effects on rearing habitat through construction of the R-4 floodplain, R-5 main channel meander, IC-4 and IC-5 transverse bars and IC-7 and IC-8 point bars. This multi-flow section is referred to as Lower Reading Creek (A). Results of the flow-habitat mapping are presented in Table 6. A goal of the Lower Reading Creek project design was to "increase and sustain availability, quantity and quality of anadromous fish habitat between 8.5 and 56.6 cms (300 - 2,000 cfs) for all life stages" (HVT and McBain and Trush 2010). Figure 13 demonstrates increases in optimal and total habitat across all flows. The smallest increases in habitat occurred at the lowest flows (described above) and the largest increases were observed at the highest flows. At a discharge of 62.0 cms (2,190 cfs) optimal habitat increased post-construction by 56% and 58% for fry and presmolt and total habitat increased by 81% and 97% respectively. The shape of the curve shifted slightly to the right for optimal habitat and the slope of the curve at higher flows was slightly steeper post-construction. There was a slight change to the shape

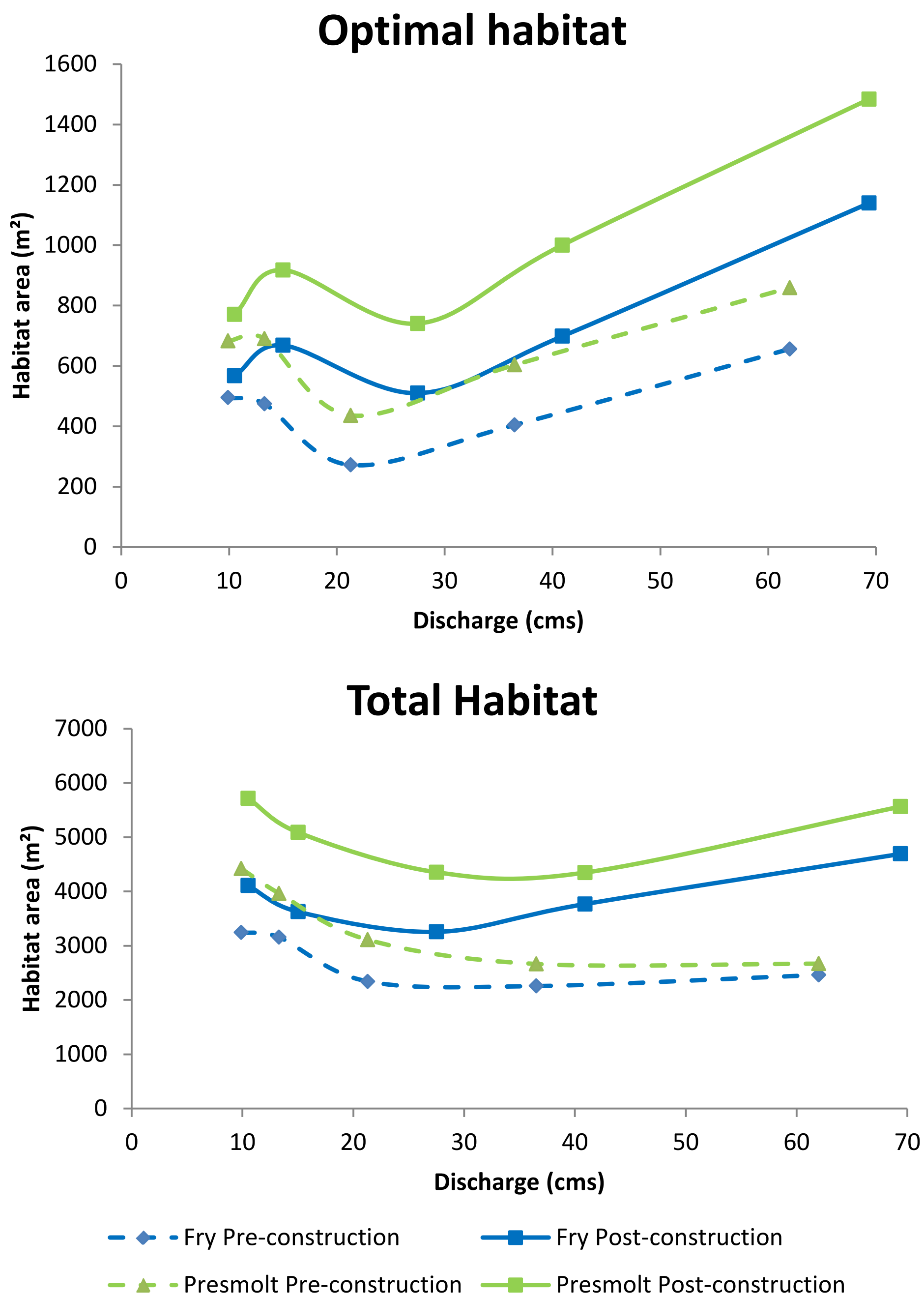



Figure 13. Estimates of Chinook and Coho salmon rearing habitat by streamflow at Reading Creek (A) rehabilitation site. Optimal Chinook and Coho salmon habitat was defined as areas within depth/velocity and in-water escape cover (DV,C) criteria. Total Chinook salmon rearing habitat (total habitat) was defined as areas that met any combination of depth/velocity or in-water escape cover criteria. The fry life stage is defined as fish <50 mm FL and presmolt as 50>*X*<100 mm FL.

of the total habitat curve where habitat was increasing post construction at the highest mapped flows instead of remaining stable (flat-lined).

The R-5 forced meander was constructed in conjunction with IC-5 and IC-7 to increase channel sinuosity, decrease radius of curvature, increase channel complexity and improve the likelihood of future channel migration towards the left bank (HVT and McBain and Trush 2010). Habitat areas pre- and post-construction were summed from the top of the IC-5 transverse bar to the bottom of the flow-habitat mapping area to evaluate the effects these features had (in conjunction with the 2011 spring high flow event) on rearing habitat. Winter base flow total habitat increased by 119% for fry and 107% for presmolt throughout this section (Figure 14). Modest increases of 16% and 19% were observed for optimal fry and presmolt winter base flow habitat, respectively. Much greater increases were detected at the highest comparable discharge (62.0 cms, 2,190 cfs). Optimal habitat increases of 1,401% for fry and 1,618% for presmolt as well as a 369% gain in fry total habitat and 441% increase for presmolt total habitat were observed at a discharge of 62.0 cms (2,190 cfs).

The primary goal of the R-4 500 cfs benches was to increase bankfull channel width and encourage sediment deposition within the mainstem channel flows (HVT and McBain and Trush 2010). A secondary goal of the R-4 500 cfs benches was to provide temporary habitat at intermediate flows (HVT and McBain and Trush 2010). Habitat availability in and 10 m around (buffered to capture any localized effects) the R-4 low benches is displayed in Figure 15. Polynomial equations were used to calculate change at 28.3 cms (1,000 cfs) for total habitat. Fry total habitat increased 286 $m^2$ or 106% and presmolt total habitat increased 385 $m^2$ or 132%. Pre-construction total habitat dipped with increasing flows. Post-construction conditions exhibited increases in total habitat as flows overtopped the benches, as hypothesized in the design document. Optimal habitat around the R-4 benches displayed some increases in habitat and the shape of the streamflow to habitat curve changed dramatically. Polynomial equations did not fit the optimal habitat curves very well, therefore changes are described qualitatively. Pre-construction optimal habitat decreased sharply between the low and intermediate discharge, then increased slowly. Post-construction optimal habitat availability remained relatively stable across flows.

It was hypothesized that the IC-7 and IC-8 point bars would increase rearing habitat at low flows (HVT and McBain and Trush 2010). It was our objective to test this. However, the 357 cms (12,600 cfs) high flow event transported most of the gravel placed in these locations downstream. Figure 16 illustrates the IC-7 and IC-8 point bar design drawings along with the R-4 river meander across from R-8. Also included in the figure is the pre and post-construction low flow water's edge measured during the habitat assessment. The post-construction edge of water is very close to the pre-construction conditions within the IC-7 and IC-8 areas. For this reason, there was no evaluation of habitat change due to bar construction.

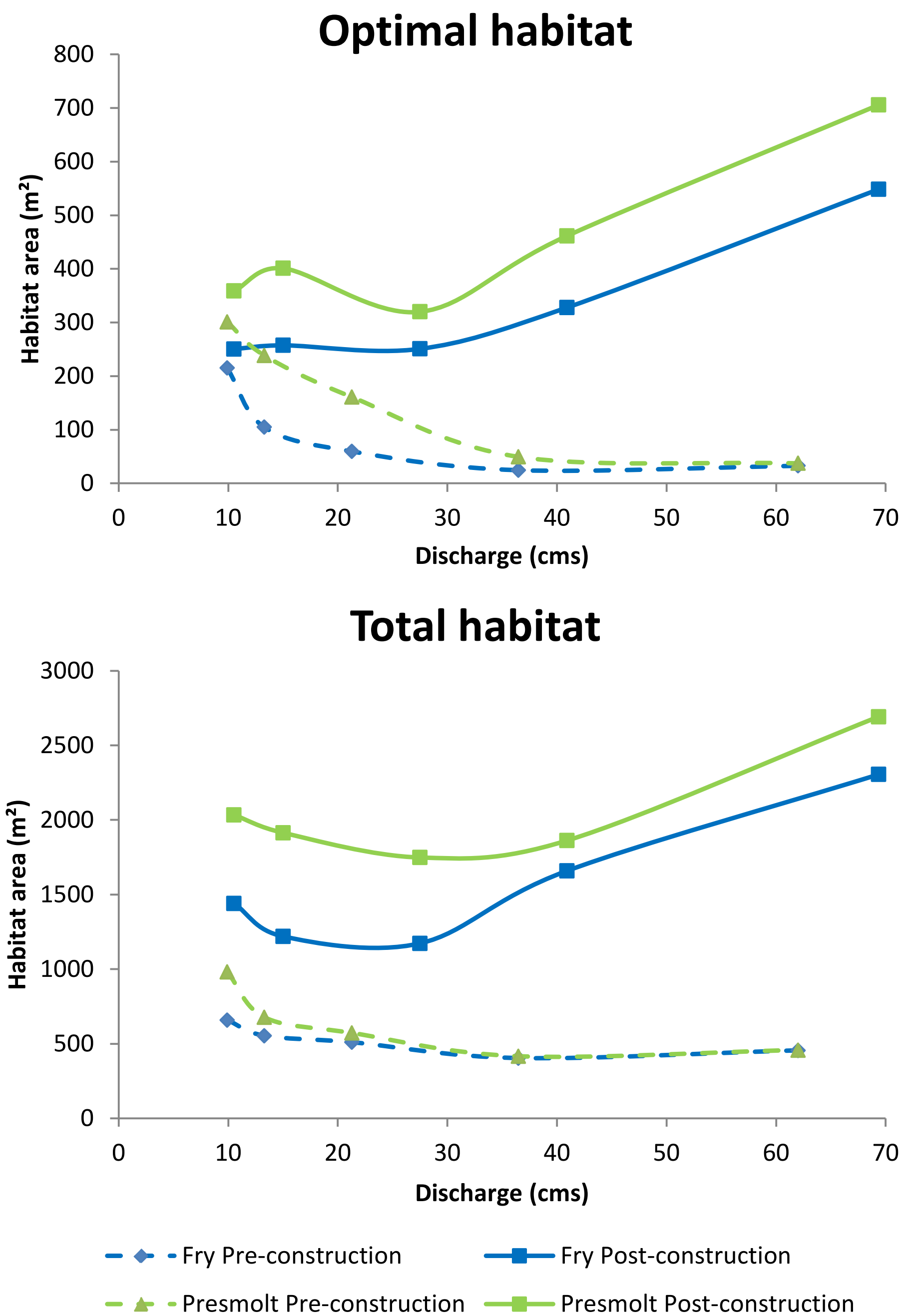



Figure 14. Estimates of Chinook and Coho salmon rearing habitat by streamflow within the IC-5, R-5, IC-7 and IC-8 complex of features at Reading Creek (A) rehabilitation site. Optimal Chinook and Coho salmon habitat was defined as areas within depth/velocity and in-water escape cover (DV, C) criteria. Total Chinook salmon rearing habitat (total habitat) was defined as areas that met any combination of depth/velocity or in-water escape cover criteria. The fry life stage is defined as fish <50 mm FL and presmolt as 50>$X$<100 mm FL.

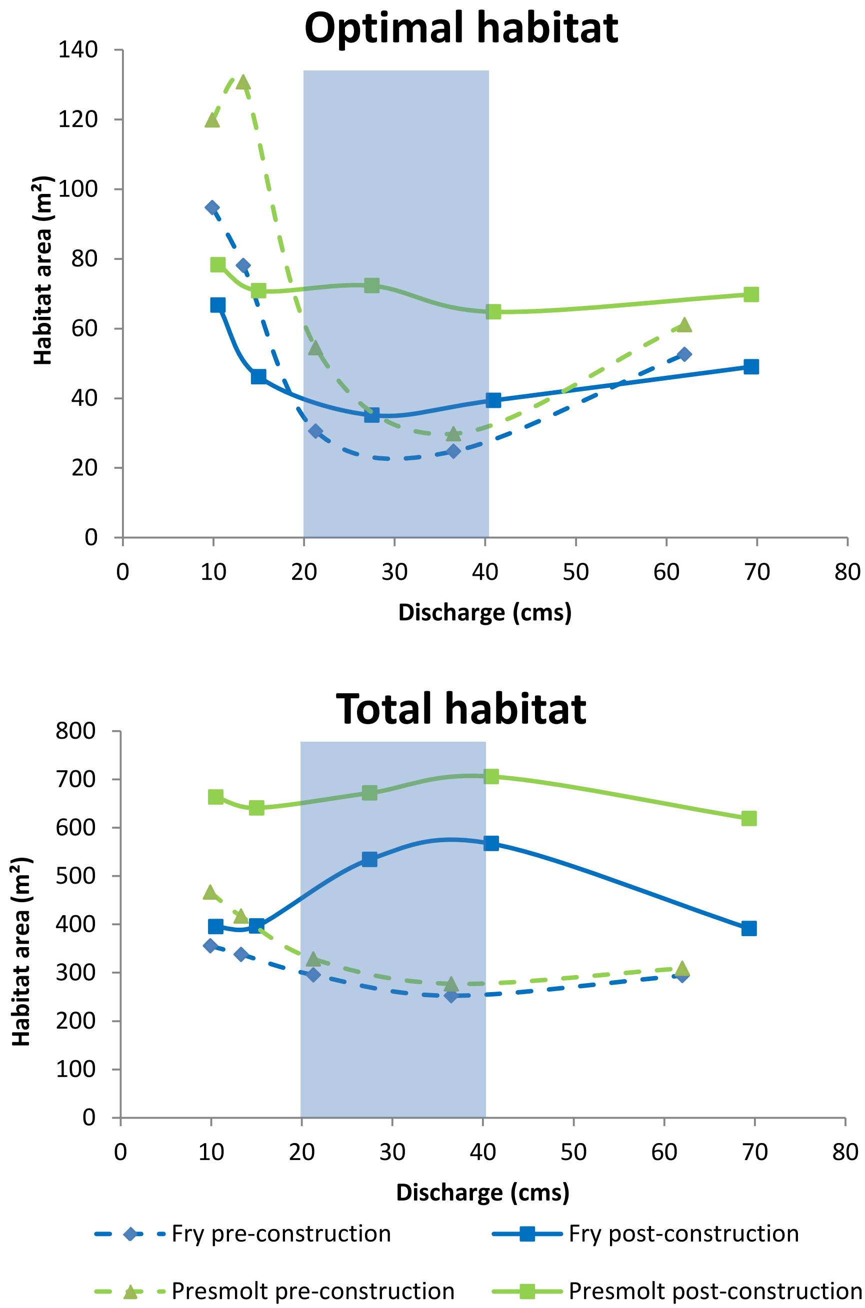



Figure 15. Estimates of Chinook and Coho salmon rearing habitat by streamflow within 10 m around the Reading Creek rehabilitation site R-4 benches. The blue shaded areas represent the intermediate range of discharges the features were designed to interact with to increase habitat. Optimal Chinook and Coho salmon habitat was defined as areas within depth/velocity and in-water escape cover (DV,C) criteria. Total Chinook salmon rearing habitat (total habitat) was defined as areas that met any combination of depth/velocity or in-water escape cover criteria. The fry life stage is defined as fish <50 mm FL and presmolt as 50>*X*<100 mm FL.

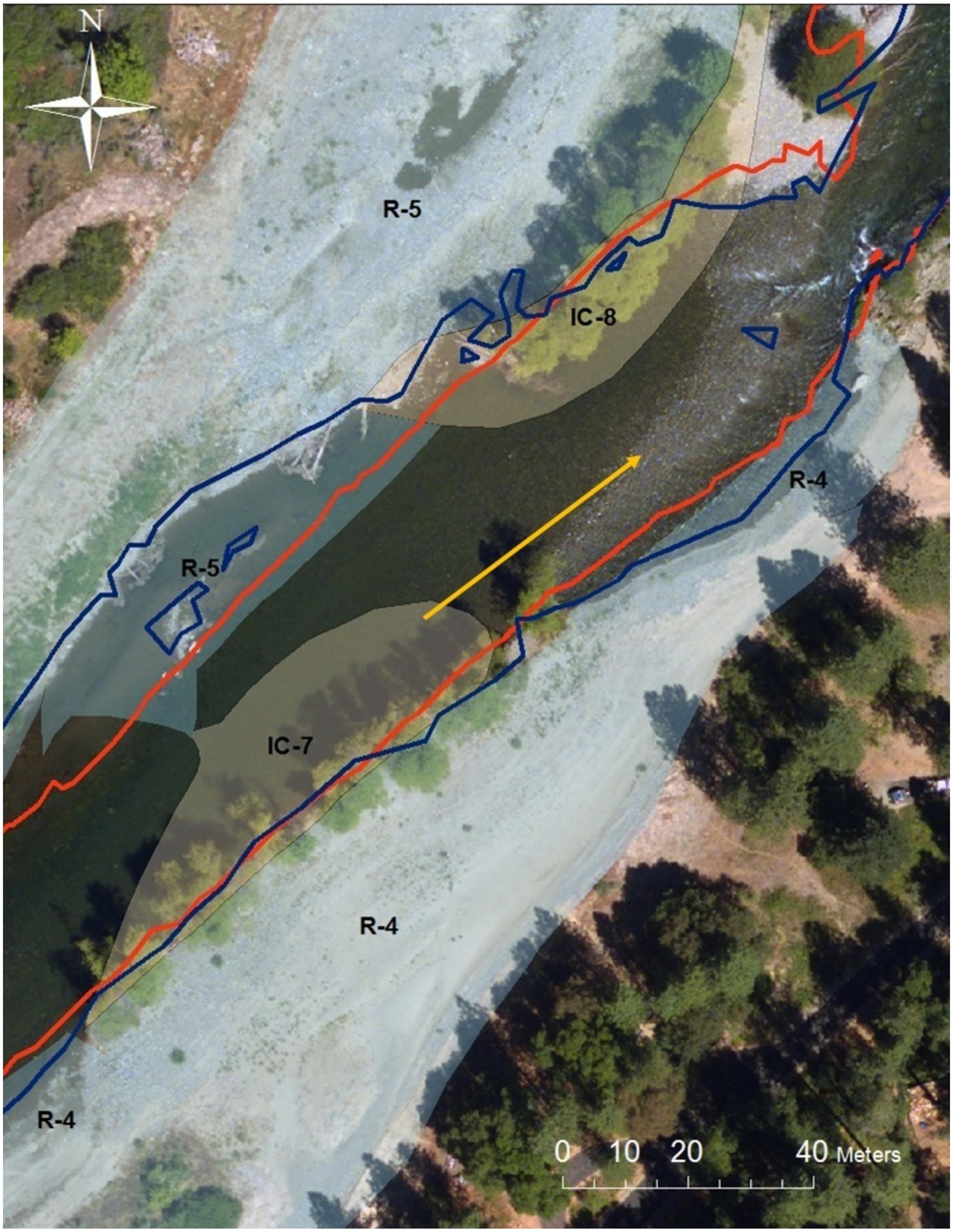



Figure 16. An aerial photo, taken in 2011, of a lower portion of the Reading Creek rehabilitation site (rkm 148.8). IC-7 and IC-8 were designed point bars constructed in 2010. R-4 and R-5 were designed river meanders and floodplain excavation areas also constructed in 2010. The red lines represent pre-construction wetted edge surveyed in 2009 at 9.9 cms (350 cfs). The blue lines represent post-construction/ post-high-flow wetted edge surveyed in 2011 at 10.5 (371 cfs). The orange arrow indicates flow direction.

### Trinity House Gulch

Construction designs at THG included gravel bar additions (IC-1 and IC-3), a main channel meander (R-1) and low flow side channel construction (R-2). Pre-construction habitat mapping occurred at THG during the summer of 2010 at a mainstem discharge of 14.3 cms (505 cfs). The post-construction assessment was conducted in the summer of 2011 at a discharge of 13.6 cms (480 cfs). Total habitat for fry and presmolt increased by 45% and 49% respectively post-construction (Table 7, Figure 17). Post-construction optimal habitat decreased by 32% and 23% for fry and presmolt respectively. The high flow event that occurred post-construction in May of 2011 closed off the side channel entrance to low flows and relocated much of the gravel that was placed (Figure 18). Sixty-one percent of the increase in total habitat at the site resulted from the alcove still being present at the downstream end of the side channel, post-construction/post-high flows. As displayed in Figure 18, much of the constructed gravel bars were mobilized and the R-1 area on river right (forced meander) was filled in with alluvial material. Therefore changes in habitat were not analyzed around these features.

Table 7. Habitat conditions at winter base flows before and after construction at Trinity House Gulch rehabilitation site. The alcove was not present before construction. Habitat categories correspond to areas (m²) meeting the depth/velocity dual criteria of rearing habitat for Chinook salmon and Coho salmon fry (<50 mm FL) and presmolt (50>*X*<100 mm FL).

| Evaluation Type | Location | Length (m) | Life stage | Dis-charge (cms) | Habitat category (m²) DV, C | DV, No C | No DV, C | Total habitat |
|---|---|---|---|---|---|---|---|---|
| Trinity House Gulch pre-construction | Mainstem | 463 | Fry | 14 | 459 | 847 | 440 | 1,747 |
| | | | Presmolt | 14 | 566 | 1,320 | 334 | 2,220 |
| | Alcove | 0 | Fry | - - | - - | - - | - - | - - |
| | | | Presmolt | - - | - - | - - | - - | - - |
| | Entire Site | 463 | Fry | 14 | 459 | 847 | 440 | 1,747 |
| | | | Presmolt | 14 | 566 | 1,320 | 334 | 2,220 |
| Trinity House Gulch post-construction | Mainstem | 463 | Fry | 14 | 197 | 1,518 | 267 | 1,982 |
| | | | Presmolt | 14 | 277 | 2,184 | 187 | 2,649 |
| | Alcove | 89 | Fry | 0 | 115 | 397 | 47 | 559 |
| | | | Presmolt | 0 | 160 | 500 | 2 | 662 |
| | Entire Site | 463 | Fry | 14 | 312 | 1,915 | 314 | 2,541 |
| | | | Presmolt | 14 | 437 | 2,684 | 189 | 3,310 |

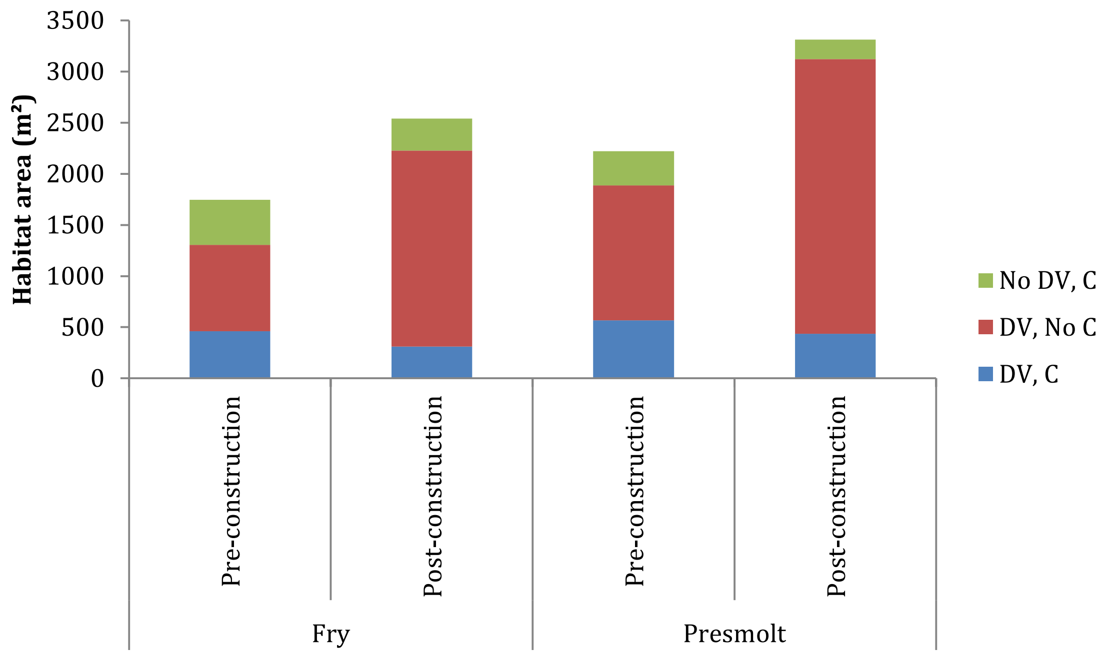



Figure 17. Chinook and Coho salmon rearing habitat quantities at the Trinity House Gulch rehabilitation site (rkm 167.5-167.9). Pre-construction estimates were conducted at 9.9 cms (350 cfs) in 2009 and post-construction at 10.5 cms (371 cfs) in 2011. Habitat categories correspond to combinations of depth/velocity and in-water escape cover criteria. The fry life stage is defined as fish <50 mm FL and presmolt as 50>*X*<100 mm FL.

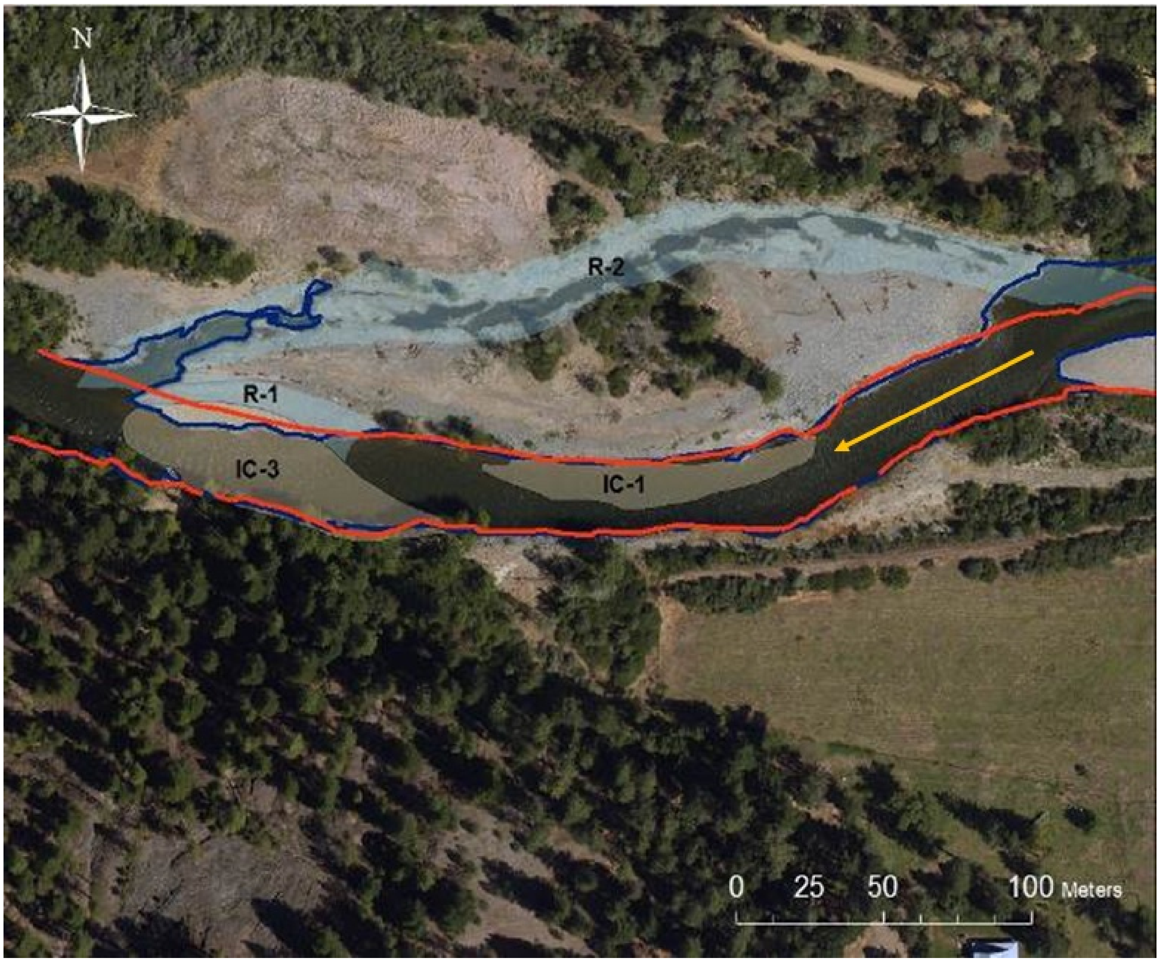
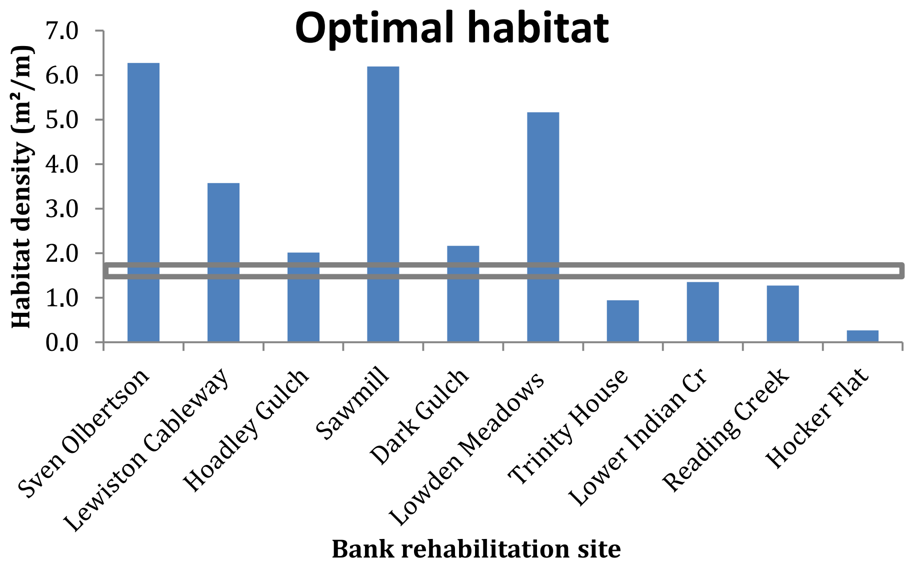



Figure 18. Aerial photo taken in 2011 of the Trinity House Gulch rehabilitation site (rkm 167.5-167.9). IC-1 and IC-3 were designed point bars constructed in 2010. R-1 was a designed river meander and R-2 was a designed low flow side channel also constructed in 2010. The red lines represent pre-construction wetted edge surveyed in 2010 at 14.3 cms (505 cfs). The blue lines represent post-construction wetted edge surveyed in 2011 at 13.6 (480 cfs). The orange arrow indicates flow direction.

**Across sites**

Total and optimal presmolt habitat density was calculated for all three sites and compared to previously monitored rehabilitation sites (Figure 19). Post-construction, Lowden Meadows had the third highest optimal habitat density observed at 5.2 $m^2/m$, following the Sven Olberston and Sawmill rehabilitation sites. Lowden Meadows also had the third highest total habitat density amongst monitored sites. THG and Reading Creek had the second and third lowest presmolt optimal habitat densities, respectively. Both Reading Creek and THG had total presmolt habitat densities of 7.1 $m^2/m$ following rehabilitation. Only the Hocker Flat rehabilitation site exhibited lower optimal and total habitat densities since the onset of these evaluations.



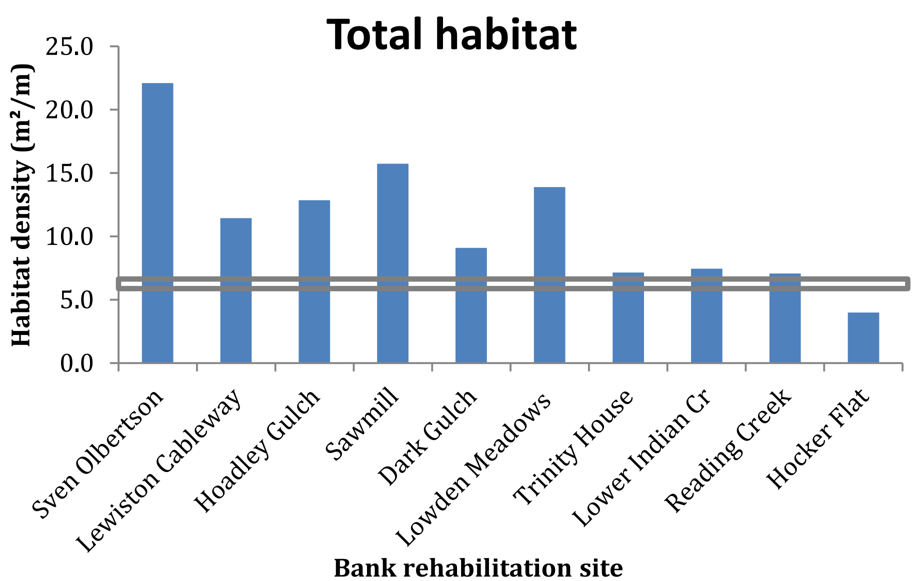




Figure 19. Post-construction habitat density by bank rehabilitation site. Site-specific streamflows evaluated in this analysis ranged from 8.6 to 20.3 cms (302-718 cfs). Gray lines indicate mean values surveyed over the past 3 years (2009, 2010, 2011) within the primary restoration reach at 12.7 cms (450 cfs).

## Discussion

Post-construction rearing habitat monitoring at Lowden Meadows demonstrated the highest initial increases of total habitat observed at any rehabilitation site to date. The R-2 ponded area provided 2-3 times more rearing habitat than the low flow side channel at all measured flows. The ponded area is connected to the side channel at all flows at both the upstream and downstream locations of this feature. Snorkel observations conducted in April during the Trinity River juvenile salmonid density study documented large numbers of Chinook and Coho salmon juveniles utilizing the constructed side channel, ponded area and alcove features, including 350 Coho fry along the south east side of the ponded area (Figure 2) (Kyle DeJuilio, personal communication, April 19, 2012). It is important to monitor the function of the side channel over the long term, understanding that the function of the ponded area is dependent upon the side channel staying open to the mainstem. One should note that the ponded area will not likely provide spawning habitat, however the side channel may be utilized for spawning in the future (it was not utilized in 2011). In addition, the alcove/high flow channel is providing similar amounts of habitat as the side channel at low flows and over twice the habitat at higher flows (8.5 -56.6 cms, 300 - 2,000 cfs). Future evaluations of the long term functionality of these features will continue well into the future. The goal of the R-4 low bench was to encourage gravel to deposit near it and increase the bar surface area. One year post construction and following a significant flow, this feature is performing as desired. The bar area has more than doubled in size and rearing habitat increased following construction.

Initial increases in habitat at Reading Creek were relatively low at base flow and improved as flows increased. Post 2011 high flow, the R-5 forced meander and IC- 7 constructed point bar are not functioning as intended. The IC-7 point bar mobilized and did not direct flows into the R-5 meander as designed. Without the directed flow, the long term function of the R-5 feature may be in question and could jeopardize the habitat gains realized at this location. One hypothesis for the long term evolution of the R-5 forced meander is that alluvial material moves into the area from upstream and replaces the IC-7 bar, which could help maintain the R-5 feature. Another hypothesis is that sediment may build up and fill in the R-5 area over time without an opposite bar to force water through the feature.

Total base flow habitat increased by almost 50% at the THG rehabilitation site, while optimal habitat decreased. Much of the increase was due to the alcove which represents the downstream end of the side channel. One year post-construction, the side channel does not flow at lower flow levels but will still provide habitat benefits at higher discharges. In hindsight, this was a very difficult location to build a persistent low flow side channel due to the large amount of alluvial material placed upstream at the Grass Valley Creek high flow injection point and Lowden Meadows rehabilitation site. The overall decrease in optimal habitat resulted from deposition of gravel in and along the upstream section of the site on river left (Figure 20). This area just downstream of Grass Valley Creek exhibited shallow depths with slow velocities and dense aquatic vegetation prior to the 2011 high flows. It should be noted the infilling of this feature likely did not occur due to rehabilitation actions at THG and was caused from downstream movement of alluvial material.

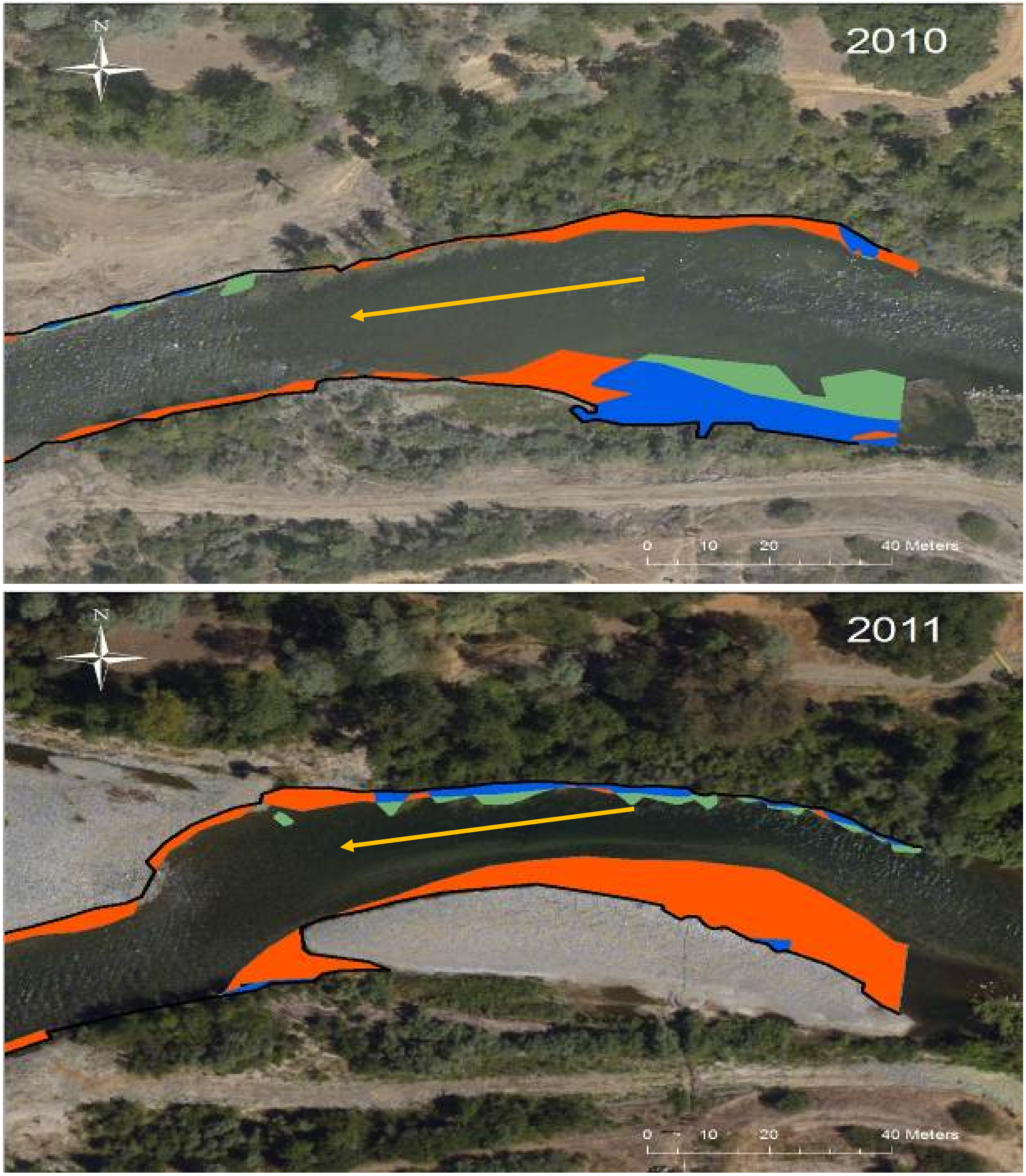



Figure 20. Aerial views of the new alluvial bar location at the top of the Trinity House Gulch rehabilitation site, just below Grass Valley Creek (rkm 167.9) before construction (upper photo) and post-construction/post-2011-high-flow-event (lower photo). Black lines indicate wetted edge, blue areas indicate optimal presmolt habitat and red and green areas indicate suitable presmolt habitat. The orange arrow indicates flow direction. Mainstem discharge pre-construction was 14.3 cms (505 cfs) and 13.6 cms (480 cfs) post-construction.

A common feature implemented at all three sites was a ‘forced meander’. All constructed point bars were similar in length (90-100 m). However, there was a significant difference between the one constructed at Lowden Meadows and the other ones built at THG and Reading Creek. The IC-2 forced meander bar at Lowden was intended to act similar to a floodplain and not be easily mobilized. Also a wood jam was constructed at the top of the Lowden Meadows IC-2 bar to deflect water and help minimize scour of the bar. The Lowden Meadows IC-2 bar was designed to be 3 m in height above the mainstem channel elevation (DWR 2010), meaning the top of it would become inundated at 8,500 cfs (DWR 2010). This required approximately 9,000 $yds^3$ of course sediment additions for the single feature. By contrast, the two THG constructed point bars and transverse bar (IC-1, IC-2, IC-3) required 3,000 $yds^3$ of gravel (HVT and McBain and Trush 2010) and the Reading Creek IC-7 and IC-8 constructed point bars required 3,100 $yds^3$ of course sediment additions (HVT and McBain and Trush 2010) (Figure 21). There are several factors that determined the differences between the forced meander designs; (1) FEMA requirement to not raise water surface elevations by more than one foot; (2) the different site conditions across the three sites that enable different sized bars in some locations while they were precluded in other locations; and (3) the decision to use 5 inch minus coarse sediment to build the bars at THG and Reading Creek with the purpose of placing material easily transported by ROD flows. The 2011 high flow event mobilized most of the constructed point bars at THG and Reading Creek, whereas the IC-2 point bar at Lowden received some scour, but remains intact and functioning as intended (Figure 22).

Overall, there were large variations in habitat response to management actions at the three sites monitored in 2011. There were features with similar objectives at all three sites, including forced meanders, side channels and gravel additions. However there were obvious differences in how these features performed or reacted to the 2011 high flow event. The features built at Lowden Meadows were working and have contributed to the large gains in habitat. In contrast, many of the features at Reading Creek and THG such as forced meanders and side channels did not persist following the 2011 high flow event and resulted in lower habitat gains. The TRRP anticipates an interaction between site construction and other management actions to create a dynamic system. Therefore, persistence of a feature is not the only measure of its success. However, evolution of features to a more complex channel with increased habitat can be a measure of success. Although evolution of the Reading Creek and THG sites was observed it was not coupled with the expected increases in channel complexity or habitat area in the short term. The discrepancy in performance between these sites may be useful for planning future channel construction site designs and the anticipated response from management actions.

Figure 21. Post-construction (pre-high-flow) photos of the IC-2 constructed point bar at Lowden Meadows rehabilitation site (upper photo) and the IC-7 constructed point bar (pre-high flow) at Reading Creek rehabilitation site (lower photo). Discharges at the Lowden Meadows site were 14.3 cms (506 cfs) and were 31.1 cms (1,100 cfs) at the Reading Creek site during the time the photos were taken.

Figure 22. Post-2011 high flow photo of the IC-2 constructed point bar at Lowden Meadows.

## Recommendations

The construction of multiple features at Lowden Meadows contributed to high habitat gains. As with all constructed features, long term monitoring should occur to document changes and evolution of the R-1, R-2, IC-2/R-3 and R-6 features and the influence of these changes on the quality and quantity of available fish habitat. The R-2, IC-2/R-3 and R-6 features are unlike any other constructed feature to date on the Trinity River; therefore monitoring their condition could help illustrate the potential for future implementation.

Many constructed point bars were mobilized during the 2011 high flow event. It is recommended to reconsider the objectives of these elements. Many factors contribute to point bar function at high flows including bar shape, confinement, floodplain elevation, etc. Also, the use of additional alluvial material or larger size substrate in combination with constructed log jams (at the head of the feature) may provide persistence over longer time periods.

Following the 2011 high flow, two of the three constructed side channels no longer flow at base flow. Nevertheless, they will provide valuable habitat at higher flows; however, consistent availability for fry and presmolt rearing at winter base flow is the most desirable state. Factors including expected upstream sediment sources should be considered. Also the use of hard points such as large wood or boulders may help maintain functioning side channel entrances (Montgomery, D.R., and T.B. Abbe. 2002; Montgomery, D.R., and T.B. Abbe. 2006).

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# Appendix

## Conversion Factors

TRRP documents generally report metric units. Exceptions are noted in the text of a particular report. Below is a concise list in conversion factors for common units of measure used in the TRRP.

| Quantity | English Unit | Metric Unit | Multiplication Factor, English to Metric | Multiplication Factor, Metric to English |
|---|---|---|---|---|
| Length | inches (in) | millimeters (mm) | 25.4 | 0.0393 |
| | inches (in) | centimeters (cm) | 2.54 | 0.3937 |
| | feet (ft) | meters (m) | 0.3048 | 3.2808 |
| | US survey feet | meters(m) | 12/39.37 | 39.37/12 |
| | miles (mi) | kilometers (km) | 1.6093 | 0.62139 |
| Area | square feet ($ft^2$) | square meters ($m^2$) | 0.092903 | 10.764 |
| | square miles ($mi^2$) | square kilometers ($km^2$) | 2.59 | 0.3861 |
| | square yards ($yd^2$) | square meters ($m^2$) | 0.836127 | 1.19599 |
| | acres (acre) | hectare (ha) | 0.4047 | 2.471 |
| Volume | cubic feet ($ft^3$) | cubic meters ($m^3$) | 0.028317 | 35.315 |
| | cubic yards ($yd^3$) | cubic meters ($m^3$) | 0.76455 | 1.308 |
| | acre-feet (ac-ft) | cubic meters ($m^3$) | 12.33.5 | 0.0008107 |
| | acre-feet (ac-ft) | cubic decameters ($dam^3$) | 1.2335 | 0.8107 |
| | thousand acre-feet (TAF) | cubic decameters ($dam^3$) | 1233.5 | 0.0008107 |
| Flow | cubic feet per second (cfs) | cubic meters per second (cms) | 0.028317 | 35.315 |
| Velocity | feet per second (ft/s) | meters per second (m/s) | 0.3048 | 3.2808 |
| Mass | pounds (lb) | kilograms (kg) | 0.4536 | 2.2046 |
| Temperature | degrees Fahrenheit (°F) | degrees Celsius (°C) | (°F - 32) /1.8 | (1.8 x °C) + 32 |