Tracking Number: (2020-004)

To request a change to regulations under the authority of the California Fish and Game Commission (Commission), you are required to submit this completed form to: California Fish and Game Commission, (physical address) 1416 Ninth Street, Suite 1320, Sacramento, CA 95814, (mailing address) P.O. Box 944209, Sacramento, CA 94244-2090 or via email to FGC@fgc.ca.gov. Note: This form is not intended for listing petitions for threatened or endangered species (see Section 670.1 of Title 14).

Incomplete forms will not be accepted. A petition is incomplete if it is not submitted on this form or fails to contain necessary information in each of the required categories listed on this form (Section I). A petition will be rejected if it does not pertain to issues under the Commission's authority. A petition may be denied if any petition requesting a functionally equivalent regulation change was considered within the previous 12 months and no information or data is being submitted beyond what was previously submitted. If you need help with this form, please contact Commission staff at (916) 653-4899 or FGC@fgc.ca.gov.

**SECTION I: Required Information.**

*Please be succinct. Responses for Section I should not exceed five pages*

1. **Person or organization requesting the change (Required)**
Name of primary contact person: Kyle De Juilio
Address: [redacted]
Telephone number: [redacted].
Email address: [redacted]

2. **Rulemaking Authority (Required) -** Reference to the statutory or constitutional authority of the Commission to take the action requested: State Special Regulation (14CCR 7.50)

3. **Overview (Required) -** Summarize the proposed changes to regulations: Change from existing regulation provided below to open dates of January 1 through September 15. Only artificial flies. Restrict boat access limited to those with disability.

| | | |
|---|---|---|
| Trinity River mainstem from 250 feet downstream of Lewiston Dam to the Old Lewiston Bridge. | April 1 through September15. Only artificial flies | 2 hatchery trout or Hatchery Steelhead |

The Commission should consider the recommendation for changing the opening date from April 1 to January 1, independently of the restriction to boat access, excluding those with disability.

4. **Rationale (Required) -** Describe the problem and the reason for the proposed change: This fishery has been extended in the past related to flow management on the Trinity River, to provide for consistent or increased opportunity. Current flow management considerations merit another review of fishing opportunity in this reach. Additionally, research has shown that the hatchery impacts in this reach of river are high (Quinn and De Juilio 2012). The genetic impacts of straying salmon from the hatchery reduce the fitness of the naturally produced population. Redd superimposition is a concern in this reach of river as it exhibits the highest concentration of spawning for Chinook Salmon in the Trinity River (Gough et al. 2019). Hatchery steelhead spawn after salmon runs and cause impacts to salmon

eggs incubating in the gravels when they spawn in the same locations. Other concerns also include genetic, competition, and predation impacts to naturally produced stocks. There is reason to believe that juvenile salmon and salmon eggs are preyed upon by hatchery steelhead in freshwater environments (Naman 2008). These impacts of the hatchery steelhead program are affecting the most abundant runs of SONCC Coho Salmon, listed as threatened under the federal ESA, and Upper Klamath-Trinity River Spring-run Chinook Salmon, petitioned for listing under CESA and ESA, in California waters, and could be partially mitigated by the propose changes to State Special Regulation 14 CCR 7.50. Hatchery steelhead are released to the Trinity River to increase harvest opportunity, any fish in excess of those required for broodstock at the Trinity River Hatchery should be harvested to reduce their impacts to natural production.

A restriction to boat access, excluding those with disability, in this reach is recommended. This is due to the opinion from several local guides and anglers that those who are fishing from boats in this reach are often targeting holding spring Chinook Salmon during the summer months prior to spawning. These fish are currently petitioned for listing under the Federal ESA and CESA. The life history of these fish makes them vulnerable to fishing for an extended period of time in a limited reach below Lewiston Dam. However, we recognize that restricting boat access to anadromous waters would be a departure from current regulation and ask that you consider this suggestion independently from the change in opening date.

## SECTION II: Optional Information

5. **Date of Petition:** 12/24/2019

6. **Category of Proposed Change**
☐ Sport Fishing
☐ Commercial Fishing
☐ Hunting
☐ Other, please specify:

7. **The proposal is to:** (*To determine section number(s), see current year regulation booklet or https://govt.westlaw.com/calregs*)
☐ Amend Title 14 Section(s): 7.50
☐ Add New Title 14 Section(s):
☐ Repeal Title 14 Section(s):

8. **If the proposal is related to a previously submitted petition that was rejected, specify the tracking number of the previously submitted petition** #2019-009
Or ☐ Not applicable.

9. **Effective date**: If applicable, identify the desired effective date of the regulation.
If the proposed change requires immediate implementation, explain the nature of the emergency: January 1, 2021

10. **Supporting documentation:** Identify and attach to the petition any information supporting the proposal including data, reports and other documents:

Naman, S. 2008. Predation By Hatchery Steelhead On Natural Salmon Fry In The Upper-Trinity River, California. A Thesis Presented to the Faculty of Humboldt State University.

Quinn, S. and K. De Juilio. 2012. An Assesment of Adult Hatchery Steelhead Straying Behavior Following Release into the Trinity River from 2009-2011. Yurok Tribal Fisheries Program – Trinity Division.

Gough, S. A., N. A. Som, S. Quinn, W. C. Matilton, A. M. Hill, and W. Brock. 2019. Mainstem Trinity River Chinook Salmon Spawning Survey, 2017. USFWS, Arcata California. https://www.fws.gov/arcata/fisheries/reports/dataSeries/2017%20SpawningSurveyReport_FINAL.pdf

**11.** **Economic or Fiscal Impacts:** Identify any known impacts of the proposed regulation change on revenues to the California Department of Fish and Wildlife, individuals, businesses, jobs, other state agencies, local agencies, schools, or housing: This would likely increase contributions to the local economy of Trinity County by anglers during the months of January, February, and March annually by paying for services including: food services, lodging, guides, tackle, fuel, and others.

**12.** **Forms:** If applicable, list any forms to be created, amended or repealed:

Click here to enter text.

## SECTION 3: FGC Staff Only

Date received: 3/10/2020

FGC staff action:

☐ Accept - complete
☐ Reject - incomplete
☐ Reject - outside scope of FGC authority

Tracking Number

Date petitioner was notified of receipt of petition and pending action: ______________

Meeting date for FGC consideration: ______________________________

FGC action:

☐ Denied by FGC
☐ Denied - same as petition ______________________
Tracking Number
☐ Granted for consideration of regulation change

# An Assessment of Adult Hatchery Steelhead Straying Behavior Following Release into the Trinity River from 2009-2011

Shane Quinn & Kyle De Juilio

Yurok Tribal Fisheries Program – Trinity Division

*Abstract.* - Current spawning protocols at Trinity River Hatchery (TRH) require that spawned and unspawned adult hatchery-produced steelhead are released back to the Trinity River after weekly egg-take quotas are met. To investigate the effects of this practice, we implanted TRH steelhead with PIT and radio-telemetry tags prior to being released from the hatchery to monitor movement and behavior during the 2009-2011 spawning seasons. During the three year study, tagged TRH steelhead strayed into monitored tributaries at an average rate of 9.9%, for a total of 216 straying incidents. The majority of tributary straying (67.1%) occurred in Deadwood Creek, which is the most proximal tributary to TRH. We observed that 53.5% of tagged TRH steelhead return to the hatchery after release, which corresponds with 874 tagged TRH steelhead that never returned. Of the 874 non-returns, 212 were observed to spend an average of 17.1 days in the uppermost 2 kilometers of the main stem Trinity River near TRH. The tagged steelhead that did return to TRH spent an average of 16.8 days in the river system before returning to the hatchery. We found that the current protocols at Trinity River Hatchery increase the potential for hatchery and natural populations to interact, both in the main stem Trinity River and its tributaries.

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## Introduction:

Hatcheries were established throughout the Western United States to mitigate for declining salmon and steelhead populations (Hilborn 1992). Recent studies report that mixing hatchery and natural populations have a negative ecological impact on natural populations (McMichael et al. 1999; Kostow and Zhou 2006), and can result in decreased natural production and genetic viability (Reisenbichler and Rubin 1999; Quinn 2001; McLean et al. 2004).

In 1957, the Bureau of Reclamation began construction on the Trinity River Division (TRD) of the Central Valley Project, which transfers water from the Klamath Basin to the Sacramento Basin. The Division consists of a series of dams, lakes, power plants, tunnels, and other related facilities. At times, 90% of the Trinity River's flow was diverted to the Sacramento Basin, contributing to the decline of salmon and steelhead (*Oncorhynchus* spp.*)* populations (Stene 1994). Lewiston Dam, part of the TRD, was constructed in 1963 near Lewiston, California, and is now the uppermost limit of anadromous fish migration on the Trinity River. Trinity River Hatchery (TRH), located at the base of Lewiston Dam, was constructed to mitigate for the loss of 109 miles of anadromous fish habitat upstream of the dam (CDFG 1963).

Current protocols for TRH steelhead broodstock collection are designed to maintain run-timing characteristics of the natural population through weekly egg-take quotas. As a result, all steelhead arriving at the hatchery (regardless of natural/hatchery origin or spawning condition/ripeness) are released back to the Trinity River once the weekly egg-take quota is achieved. In 2007 and 2008, the two years prior to this project, in-river returns of TRH steelhead *Oncorhynchis mykiss* far exceeded the production goal of 22,000 for the Trinity Basin (Table 1). The increased hatchery return estimates caused concern among stakeholders and managers that hatchery practices could be negatively impacting naturally-produced steelhead stocks in the main stem Trinity River and tributaries. Furthermore, recent spawning surveys suggest TRH steelhead stray into tributaries close to the hatchery at an unknown rate (Hill 2008).

**Table 1. Run-size estimates from the CDFG Willow Creek weir for the six years prior to project implementation (2003 to 2008). Estimates are partitioned to include the hatchery and natural proportions of the overall in-river run-size estimates.**

| Year | Hatchery Estimate | Natural Estimate | % TRH Steelhead of Total Run-size Estimate |
|---|---|---|---|
| 2003 | 14,408 | 4,650 | 75.6% |
| 2004 | 19,245 | 3,947 | 83.0% |
| 2005 | 15,038 | 4,817 | 75.7% |
| 2006 | 14,049 | 5,363 | 72.4% |
| 2007 | 32,609 | 8,781 | 78.8% |
| 2008 | 46,379 | 7,506 | 86.1% |

During the steelhead spawning seasons of 2009-2011, the Yurok Tribal Fisheries Program (YTFP) conducted a monitoring effort to determine whether the current protocols at TRH increase the potential for hatchery and natural populations to interact, both in the main stem Trinity River and its tributaries. To investigate the potential for interaction, YTFP staff implanted TRH steelhead with PIT and radio-telemetry tags prior to being released from the hatchery to monitor movement and behavior.

The objectives of this project were to:

1) Verify and quantify straying of TRH-produced steelhead released back to the Trinity River after an initial return to TRH;

2) Determine spatial and temporal distribution of hatchery straying after being released back to the Trinity River;

3) Enumerate TRH steelhead returning to TRH multiple times;

4) Evaluate the stray rate of TRH steelhead prior to hatchery entrance.

# Methods:

## Study Area

The Trinity River is the largest tributary of the Klamath River Basin, the second largest river system in California, which drains approximately 31,000 $km^2$ in Northern California and Southern Oregon, with the Trinity River draining approximately 7,690 $km^2$ in California (Figure 1). It once supported large anadromous populations of fall and spring run Chinook salmon *Oncorhynchus tshawytscha* , coho salmon *O. kisutch*, and steelhead, as well as Pacific lamprey (*Lamptera tridentata*) and green sturgeon (*Acipenser medirostris*) that supported commercial and recreational fisheries, as well as cultural, subsistence, and commercial needs of native tribes throughout the region. The Klamath-Trinity River Basin is still an important producer of anadromous salmonids and the number one producer of steelhead in California (Hopelain 1998).

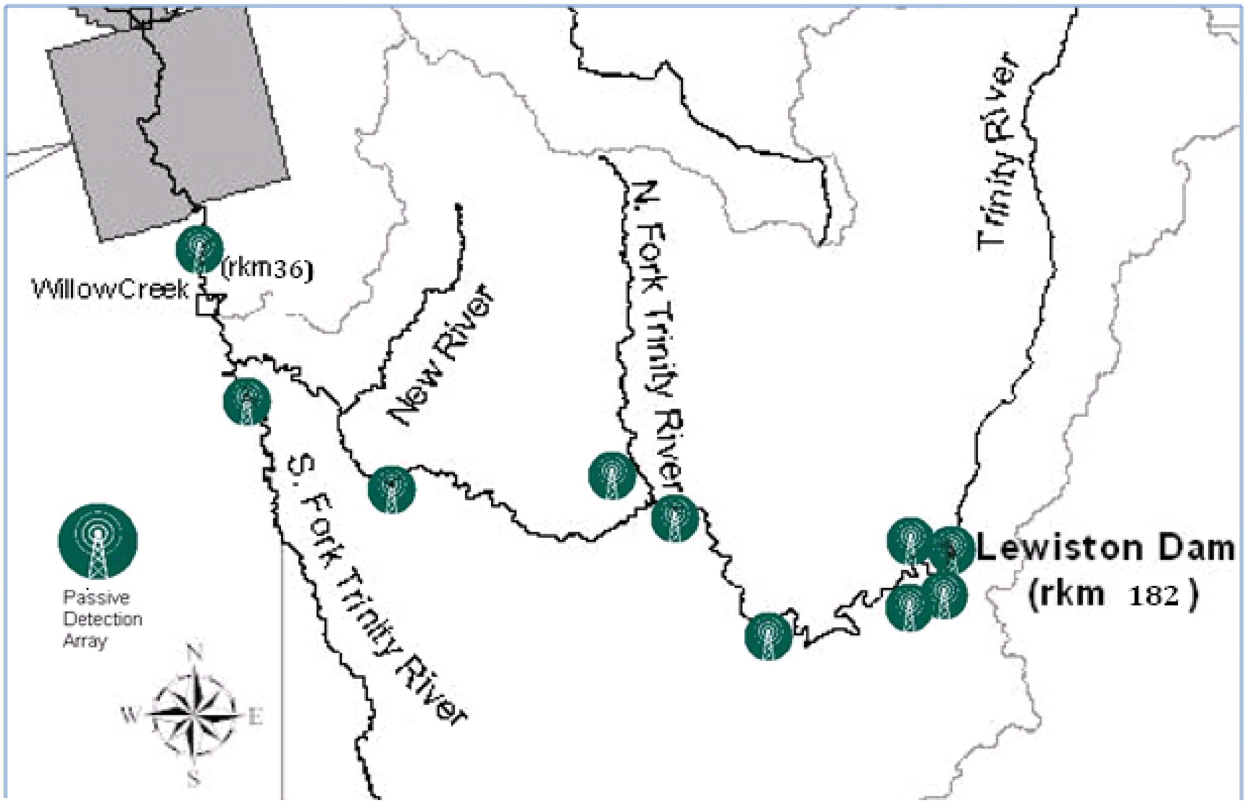

**Figure 1. Map of the study site, including radio-telemetry and PIT monitoring sites. The radio-telemetry sites were used during 2010, whereas PIT monitoring sites were used during all three years of study (2009-2011).**

The study area extended downstream from river kilometer (rkm) 182 at TRH to below Willow Creek, CA (rkm 36) where the California Department of Fish and Game (CDFG) operate an Alaskan style weir.

This study focused on the upper river and its tributaries found closest to Lewiston Dam, where flow regime is driven by releases from Lewiston Dam and there is very little tributary accretion. During the majority of this study, the water volume released from Lewiston Dam was at base flow, 300 cubic feet per second (cfs), and the end of the study coincided with spring dam releases beginning in late April and range from 2,000-11,000 cfs, depending on the water year type.

The first three streams below Lewiston Dam: Deadwood Creek (DC), Rush Creek (RC), and Grass Valley Creek (GVC), were monitored with Passive Integrated Transponder (PIT) scanning equipment. In addition, the two largest tributaries of the Trinity River, South Fork Trinity River (SFTR) and North Fork Trinity River (NFTR), were monitored using radio-telemetry equipment during 2010. The upper river tributaries (DC, RC, and GVC) were selected due to the increased potential of straying associated with their proximity to TRH, while the lower tributaries (SFTR and NFTR) were chosen because of size and overall importance to the entire Trinity River system.

**Figure 2. Photo of the upstream antenna at the Rush Creek tributary PIT monitoring site.**

## Fish Collection and Tagging

Adult TRH steelhead were tagged with a PIT tag (*Texas Instruments*®: 23mm x 3.85mm, 0.6 g) to monitor their movements after they were released back to the Trinity River. Steelhead were collected during normal CDFG hatchery spawning operations conducted weekly each year beginning the first week of January through the second week of March. Fish entering the spawning facilities are anesthetized using $CO_2$ and examined to determine species, sex, and reproductive viability, presence of clips or tags, and forklength. Hatchery personnel select fish for weekly gamete collection and all fish, regardless of whether it was spawned or not, are recycled back to the river by way of an outflow tube that terminates at the bottom of the hatchery fish ladder. To qualify for gamete collection, steelhead must be of hatchery origin, 41 cm in length or larger, and reproductively ripe. Only steelhead that met the hatchery qualifications and were not used during the weekly gamete collection were tagged. All fish were handled and tagged in accordance with industry standard protocols (Columbia Basin Fish and Wildlife Authority 1999). Forklength, sex, ripeness, and PIT tag number were recorded for each steelhead tagged. Tags were injected into the peritoneal cavity of the fish using a surgical grade 8-gauge hypodermic needle. The wound was dressed with *Duro®* quick drying gel adhesive, an effective alternative to applying sutures (Nemetz and Macmillan 1988). All tagged fish were immediately released down the outflow tube, in accordance with normal hatchery protocols.

During the 2009 TRH spawning season, a subsample of PIT-tagged steelhead (see Table 2) were randomly chosen to receive a double-mark, and were implanted with a radio-telemetry tag (*Sigma Eight*® Shark: 45mm x 17mm, 15.7 g). The double-marking technique is essential for evaluating tag retention (Bateman et al 2009). Adult fish could not be sedated using a narcotic agent due to potential human consumption; therefore, gastro-implantation was chosen over the more commonly used surgical implantation method. The gastro-implantation process reduces handling and recovery times in comparison to other surgical techniques (Keefer 2004). Radio-telemetry tags were inserted immediately prior to PIT tag injection. Tags were wrapped with bands of surgical tubing to prevent regurgitation and covered with glycerin to ease insertion into the stomach through the esophagus (Mellas and Haynes 1985).

The 2010 assessment was expanded to include an additional tagging location at the CDFG weir located in Willow Creek, CA. This weir has been operated annually since 1979 to monitor upstream migration timing and provide population estimates of anadromous salmonids for the entire Trinity River Basin. Tagging at the weir was performed during normal CDFG daily weir operations. All fish caught at the weir trap were examined by CDFG personnel to determine species, forklength, and overall health condition. All healthy salmonids were given a spaghetti tag (Floy® Tag FT-4 spaghetti tag) to determine annual run-size estimates for the Trinity River Basin, and a sub-sample of selected steelhead also received PIT and radio-telemetry tags. All tagged fish recovered in a modified fyke net trap in the river current before release above the weir in low flow.

**Table 2. Location, date, and number of adult TRH steelhead tagged.**

| Year/Location | Dates of Tagging | PIT Tags | Radio Telemetry Tags |
|---|---|---|---|
| *2009* | | | |
| TRH | 12/11/08 – 2/25/09 | 473 | 110 |
| *2010* | | | |
| WC Weir | 9/28/09 – 11/20/09 | 147 | 132 |
| TRH | 12/23/09 – 3/10/10 | 800 | 0 |
| *2011* | | | |
| TRH | 12/21/10 – 3/8/11 | 634 | 0 |
| *Total* | | *2054* | *242* |

## Data Collection

Adult TRH steelhead implanted with a PIT tag could be detected at any PIT monitoring sites in the upper Trinity River including tributaries, the main stem Trinity River, and TRH facilities (Figure 2). A PIT monitoring site is comprised of three components: a multiplexor unit (MUX), one or more in-stream antenna(e), and a power source. The antenna is a loop of insulated copper wire that emits an energy field and is connected to an *Oregon RFID*® MUX. The MUX controls the amperage and frequency of power transmitted to the antenna, and also receives and stores the PIT tag detections (tag ID code, date and time of detection). Tag detections occur when a tag is activated by coming into contact of the energy field, or "read range", of the antenna and broadcasts its unique ID code. The read range of an antenna is determined by the size and shape of the antenna, the distance between the antenna and the multiplexor, and by localized electrical interference (e.g. nearby power lines, iron ore in streambed, etc.). As a result, the read ranges between antennas varied considerably with a range of 6" to 5'. All sites were installed with two antennae, so that directional movements (i.e. upstream/downstream) could be ascertained. The power source for each site was deep-cycle 12 V batteries connected to a solar panel (50w – 85w), or AC power was used if available. Data (detection histories) would be collected weekly by connecting the MUX to a laptop PC or PDA equipped with *PTLogger* software and performing a download.

The 242 steelhead that were double-tagged in 2009 & 2010 could also be detected by fixed-site and mobile radio tracking, in addition to detection at PIT monitoring sites. Fixed sites were equipped with a 3-element YAGI antenna connected to either a *Lotek*® SRX400 receiver or *Orion*® receiver and powered by deep-cycle 12 V batteries connected to a solar panel (50w – 85w). Antennas were placed two to three meters above the ground to maximize reception at each site (Mech 1983). Radio tags were programmed to broadcast over one frequency (164 MHz) using four separate channels, which reduced the scan time of the receivers. Receivers stored detection events, but had limited memory and were downloaded weekly with WINhost (*Lotek*®) or OrionTool (*Grant Systems Engineering*®) software. Mobile radio tracking was conducted by foot, boat, or car on a semi-weekly basis using a *Lotek*® receiver attached to a collapsible directional antenna. Tag detections were recorded by date and location (rkm), and monitored to determine if it was moving or stationary, potentially indicating regurgitation or mortality.

## Analysis

### Detection Efficiencies

Detection efficiencies of PIT antenna arrays are essential to determine the correct proportion of fish that exhibit a particular trait (Horton et al. 2007). In this study, low antenna detection efficiencies would potentially result in the underestimation of straying events. The primary method used to determine antenna efficiencies at each monitoring site is called 'in situ efficiency', and is commonly used in PIT studies (Zydlewski et al. 2006). This method provides efficiency estimates using detections at each site to compare antenna efficiencies at each site. Below is the antenna efficiency (E) equation used for either antenna, in this case it is the efficiency for antenna1:

$$E_{\text{antenna1}} = (d_{\text{common}})/(d_{\text{unique antenna2}} + d_{\text{common}})$$

Where:

$d_{\text{common}}$ = the number of tags detected by both antennae

$d_{\text{unique antenna2}}$ = the number of tags detected only at antenna2

In 2010, a second method to determine efficiencies was conducted with dummy tags by simulating a detection event at each tributary site and the hatchery ladder site. The same tags implanted in TRH steelhead were inserted into a rectangular piece of wood. The float test was performed at least twice at each site tested by releasing ten dummy tags roughly 30 feet upstream of the antennae array. The percentage of successful detections was then determined for both antennae by dividing the number of detections at each antenna by the number of tags that were known to have passed by the antenna.

### Tag Retention

In 2010, a study of PIT and radio-telemetry tag retention was conducted. A total of 51 steelhead (26 male, 25 female) were processed, tagged, and released into a hatchery raceway instead of the outflow tube. In addition, 26 of the 51 (13 male, 13 female) were also implanted with radio tags. Tagged fish were held in the raceway and examined weekly to determine retention rates. Retention rate was estimated by dividing the number of tags detected each week by the total number of tags originally implanted.

### Hatchery Returns

The number of tagged TRH steelhead that returned to the hatchery was determined by the number of valid tag detections at the final hatchery antenna at the entrance of the hatchery trap. To qualify as a valid hatchery return, the tag must be initially detected by the antenna at the exit of the hatchery outflow tube that recycles fish back to the river, then later detected at the final ladder antenna without any subsequent detections at the antenna placed “down-ladder” below the hatchery trap. This would indicate movement up the hatchery ladder without descending the ladder.

Multiple returns are defined as tagged TRH steelhead that return to the hatchery more than once after tagging. To qualify as a multiple return there needed to be at least two valid hatchery returns that were separated by hatchery spawning dates.

Hatchery return rates were determined by the number of tagged TRH steelhead that returned to the hatchery divided by the total number of TRH steelhead tagged. Return timing was calculated by summing the number of days between the date that the tagged steelhead returned to TRH spawning facilities and the date it was tagged. Since the return couldn’t occur until the tagged fish returned to inside the spawning shed, the shortest time it would take to return would be roughly seven days (depending on holidays, scheduling changes, etc.) because the hatchery spawned steelhead only once per week. Differences in return rates and timing for males and females were analyzed using basic two-tailed *t*-tests.

### Straying

The number of tagged TRH steelhead that strayed was determined from PIT detections at tributary monitoring sites and also the main stem PIT monitoring site located two kilometers downstream from TRH. A “main stem stray” was any tagged fish that spent at least 14 days above the Old Lewiston Bridge monitoring site and was not detected at TRH facilities or any tributary sites. No assumptions were made of undetected tagged fish. Straying rate was determined by the number of detections at a given PIT monitoring site divided by the total number of tagged steelhead. Duration of tributary straying incidents was determined by the number of days from the first to the last detection within the tributary, while main stem straying duration was the days between tagging date and the last detection at the main stem antenna.

## 2010 Radio-telemetry from Willow Creek Weir

In 2010, an additional effort was conducted to assess migrational movements and straying of TRH steelhead prior to entrance into TRH facilities. A total of 132 TRH steelhead were tagged at the Willow Creek weir with radio-telemetry and PIT tags, and released after a brief recovery period. Seven stationary radio-telemetry sites and five passive pit arrays spread throughout 145 km of the main stem Trinity River and five different tributaries tracked migrational movements and potential straying of tagged TRH steelhead through six sections of the main stem Trinity River (Table 3). Additional movement information was gathered from manual radio tracking and information provided from anglers claiming reward tags. Migration rates (rkm/day) were also calculated from time elapsed between different site detections.

**Table 3. Radio-telemetry monitoring sites for 2010 by section of main stem, plus length of each section (rkm).**

| Section | Lower Site | Upper Site | Length (in rkm) |
|---|---|---|---|
| 1 | WC Weir | Willow Creek | 5 |
| 2 | Willow Creek | Burnt Ranch | 35 |
| 3 | Burnt Ranch | North Fork | 41 |
| 4 | North Fork | Brown’s Creek | 25 |
| 5 | Brown’s Creek | Old Lewiston Bridge | 35 |
| 6 | Old Lewiston Bridge | Trinity River Hatchery | 4 |

# Results:

A total of 2,054 adult TRH steelhead were PIT-tagged over the three-year project. All fish were tagged at either TRH spawning facilities or at the Willow Creek weir (Table 4). Over 65% of tags were detected at least once (Figure 1).

**Table 4. Yearly totals of PIT-tagged adult TRH steelhead during the three-year straying assessment.**

| Year | Tagging Dates | Total Tagged | Females Tagged | Males Tagged | Detection % |
|---|---|---|---|---|---|
| 2009 | 12/4/2008 to 2/25/2009 | 473 | 231 | 242 | 64.7% |
| 2010 Weir | 9/28/2009 to 11/20/2009 | 147 | 64 | 83 | 38.1% |
| 2010 TRH | 12/23/2009 to 3/10/2010 | 800 | 385 | 415 | 75.1% |
| 2011 | 12/21/2010 to 3/8/2011 | 634 | 365 | 269 | 61.0% |

All tagged steelhead had forklength, sex, and spawning condition recorded. Average forklength remained fairly consistent throughout the three years of study (Table 5). Mean forklength for all steelhead was 62 cm (SD = 6 cm; range = 40-86 cm), with males at 63 cm (SD = 7 cm; range = 40-86 cm), and females at 62 cm (SD = 5 cm; range = 43-81 cm). Differences in average forklength between sexes was not significant (*P* > .05).

**Table 5. Forklength data (including mean, range, and standard deviation) of tagged TRH steelhead**

| Year | Mean FL | Range | Standard Deviation |
|---|---|---|---|
| 2009 | 65 cm | 42 - 86 cm | 6 cm |
| 2010 | 62 cm | 40 - 80 cm | 4 cm |
| 2011 | 61 cm | 40 - 80 cm | 7 cm |
| *Total* | *62 cm* | *40 – 86 cm* | *6 cm* |

## Detection Efficiencies

Antenna detection efficiencies using the "in situ" method ranged from 60% for the main stem site to 100% in the tributaries and at the hatchery ladder (Table 6). Due to a change in antenna configurations at the OB Main site in 2011, efficiencies could not be calculated for either antenna. No antenna was installed at GVC in 2009.

Efficiencies using the "dummy tag" method were 100% for all antennas tested. Sites tested consisted of TRH, DC, RC, and GVC. No tests were performed at the main stem site because of logistical constraints.

These antenna efficiencies were well within the typical antenna efficiencies described in the literature (Zydlewski et al. 2001; Connolly et al. 2008). Low detection efficiencies could have resulted in grossly underestimating the total amount of straying or hatchery returns, but with tributary and hatchery antennae efficiencies between 90-100% the straying and return estimates are likely to be close to the true value.

**Table 6. Antenna detection efficiencies by year for each PIT monitoring site using the "in situ" method.**

| Location /Antenna | 2009 | 2010 | 2011 |
|---|---|---|---|
| TRH / A2 | 98.0% | 100.0% | 97% |
| OB Main / A1 | 86.1% | 80.0% | N/A |
| OB Main / A2 | 63.6% | 60.0% | N/A |
| DC / A1 | 100.0% | 100.0% | 100% |
| DC / A2 | 100.0% | 100.0% | 100% |
| RC / A1 | 90.9% | 100.0% | 90% |
| RC / A2 | 87.5% | 100.0% | 100% |
| GVC / A1 | N/A | 86.7% | 88% |
| GVC / A2 | N/A | 86.7% | 100% |

## Tag Retention

Weekly retention rates for PIT tags dropped from 100% the first week to 98% the second week, and down to 84% the final week. Retention rates for females and males were 84% and 96%, respectively. Radio tag retention rates were similar: 100% the first week, then down to 88% the second week. Male and female retention rates were 92% and 85%, respectively. All radio-tagged fish were released after two weeks due to deteriorating health conditions developed in the hatchery raceways.

## Hatchery Returns

During the three-year project, 1,878 adult TRH steelhead were PIT-tagged after an initial return to TRH. An additional 29 tagged fish were not included in the hatchery return analysis because they were released on the last day of hatchery spawning operations and had no chance of returning to TRH. In total, 53.5% (*N* = 1,004) returned to TRH after being tagged. Returning fish spent an average of 16.8 days in the river before returning to TRH. Total steelhead tagged, hatchery return rate, and duration spent at large varied between the three years of study (Table 7).

**Table 7. Yearly totals of TRH tagged steelhead, returns, and time before return to TRH facilities.**

| Year | Tagged | Returns | Return Rate | Duration |
|---|---|---|---|---|
| 2009 | 473 | 211 | 44.6% | 17.1 days |
| 2010 | 792 | 490 | 61.9% | 17.1 days |
| 2011 | 613 | 303 | 49.4% | 16.2 days |
| *Total* | *1878* | *1004* | *53.5%* | *16.8 days* |

In each year male steelhead returned at a significantly higher rate ($P = < .05$) than females (Figure 3). Female return rates ranged from 41.9% to 47.9%, while male return rates ranged from 47.1% to 74.8% (Table 8). Males took longer to return to TRH, with an average at-large duration of 18.4 days compared to14.8 days for females.

**Table 8. Male and female hatchery return rates and duration at-large after release, by year.**

| Year | Female Return Rate | Male Return Rate | Female Duration | Male Duration |
|---|---|---|---|---|
| 2009 | 41.9% | 47.1% | 16.6 days | 17.5 days |
| 2010 | 47.9% | 74.8% | 14.4 days | 18.7 days |
| 2011 | 45.7% | 54.3% | 14.2 days | 18.4 days |
| *Total* | *45.7%* | *61.6%* | *14.8 days* | *18.4 days* |

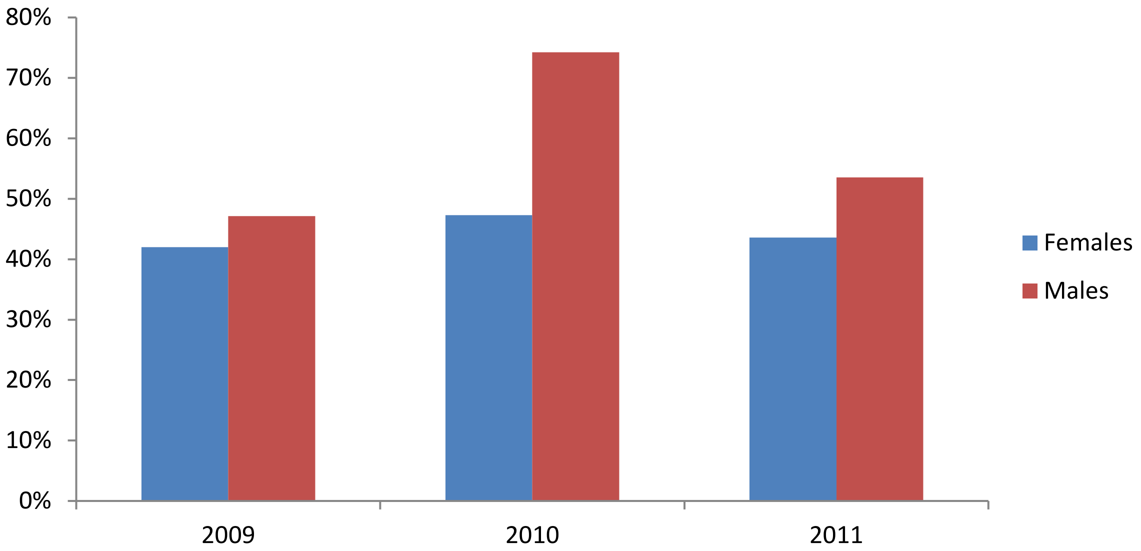

**Figure 3. A three year comparison of male and female hatchery return rates for tagged TRH steelhead.**

A total of 393 (20.9%) of all tagged steelhead returned multiple times to TRH (Table 9), and 39.1% of fish returning once made multiple returns. Males returned multiple times at a rate of 33.3%, while 9.1% of females returned multiple times.

**Table 9. Total number of tagged steelhead returning multiple times to TRH by year and sex. Number of returns is displayed in the top row.**

| Year | 1 | 2 | 3 | 4+ |
|---|---|---|---|---|
| 2009 | 211 | 61 | 7 | 1 |
| 2010 | 490 | 239 | 125 | 63 |
| 2011 | 303 | 93 | 36 | 15 |
| *Males* | *566* | *306* | *147* | *77* |
| *Females* | *438* | *87* | *21* | *2* |
| *Total* | *1004* | *393* | *168* | *79* |

## Tributary Straying

A total of 189 TRH steelhead strayed into the three monitored tributaries (Table 10), for an overall straying rate of 9.9%, with females straying at a rate of 5.4% and males at a rate of 14.7%. Steelhead straying varied annually, but males always strayed at a greater rate than females (Figure 4). In 2009, the total straying rate was 4.4%, with males straying at a rate of 5.8% and females at a rate of 3.0%. In 2010, the total straying rate was 16.3%, with males straying at a rate of 22.6% and females at a rate of 9.2%. In 2011, the total straying rate was 6.6%, with males straying at a rate of 10.7% and females at a rate of 2.7%.

**Table 10. Total number of tagged steelhead detected in monitored tributaries by sex and year.**

| Year | Tagged | Tributary Strays | Male Strays | Female Strays |
|---|---|---|---|---|
| 2009 | 473 | 21 | 14 | 7 |
| 2010 | 800 | 129 | 93 | 36 |
| 2011 | 634 | 39 | 29 | 10 |
| *Total* | *1907* | *189* | *136* | *53* |

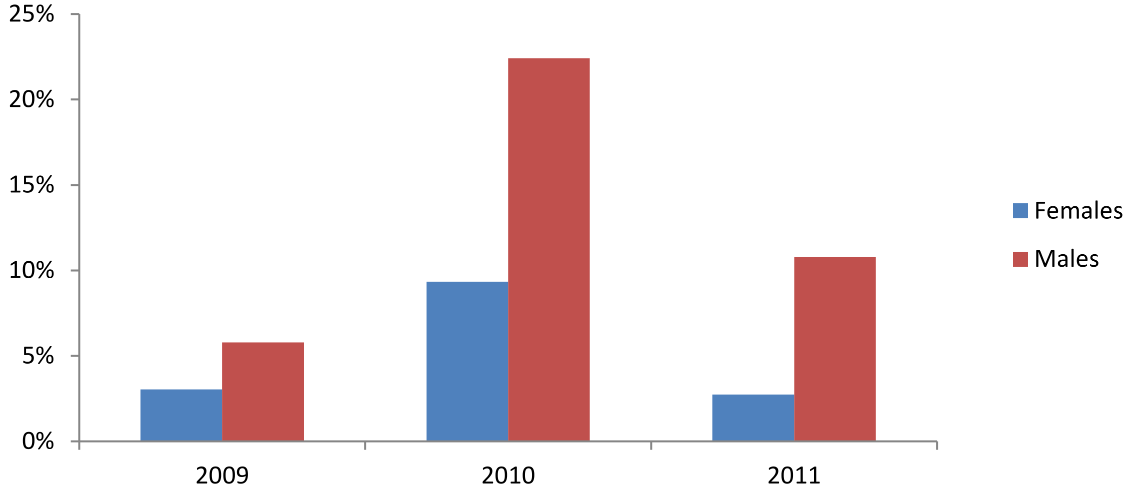

**Figure 4. Tributary straying rates of male and female tagged TRH steelhead by year.**

Straying incidents occurred each year in all of the tributaries that were monitored during this study (Table 11). Deadwood Creek had the greatest incidence of tributary straying, comprising 67.1% of all tributary straying detections. Rush Creek and Grass Valley Creek experienced similar amounts of straying during the two years that both tributaries were monitored (Table 11).

Main stem straying was defined in this study as any tagged fish that was detected at the Old Lewiston Bridge monitoring site and had spent at least 14 days in the reach directly below the hatchery and was never detected in a tributary. There was a higher occurrence of main stem straying than tributary straying in 2009 and 2011, but not in 2010 (Table 11).

**Table 11. Straying incidents detected in main stem and tributaries by year.**

| Year | Main stem Below TRH | Deadwood Creek | Rush Creek | Grass Valley Creek |
|---|---|---|---|---|
| 2009 | 88 | 13 | 10 | n/a |
| 2010 | 63 | 107 | 22 | 22 |
| 2011 | 61 | 25 | 8 | 9 |
| *Total* | *212* | *145* | *40* | *31* |

The average duration of each straying incident was similar throughout the monitored tributaries (Table 12), with the exception of Rush Creek in 2009 where one female remained upstream of the PIT antennae for 28 days. This female was witnessed building a redd above the monitoring site by the field crew.

**Table 12. Average duration of straying incidents by monitoring site and year.**

| Year | Main Stem Below TRH | Deadwood Creek | Rush Creek | Grass Valley Creek |
|---|---|---|---|---|
| 2009 | 15.8 | 5.8 | 10.2 | n/a |
| 2010 | 16.4 | 5.9 | 4.9 | 4.9 |
| 2011 | 19.4 | 4.1 | 4.8 | 3 |
| *Avg.* | *17.1* | *5.5* | *6.5* | *4.2* |

## 2010 Radio-telemetry at Willow Creek Weir

Of the 132 radio-tagged fish, a total of 99 (75%) were detected at least once upstream of the weir, four (3%) were found dead on the weir from tagging mortalities, six (4.5%) were detected by manual tracking downstream of the weir but never above the weir, and 23 (17.5%) were never detected by either tag type at the 12 monitoring locations, or by manual tracking.

Three tagged TRH steelhead (2.3%) were detected straying into tributaries prior to entry into TRH, including one female detected straying into NFTR that was never detected again, and two males that strayed into RC and DC for less than two days, then continued upstream to TRH.

Forty-five (35%) of 128 tagged steelhead successfully completed the upstream migration from Willow Creek weir to TRH. Therefore, 83 (65%) didn't fully migrate upstream (i.e. returned to ocean, shed both tags, caught in the sport fishery, strayed, or were mortalities). Reaches 1 and 6 had significantly higher tag disappearances than other reaches combining for 66.2% of all the missing tags (Figure 5, Table 13).

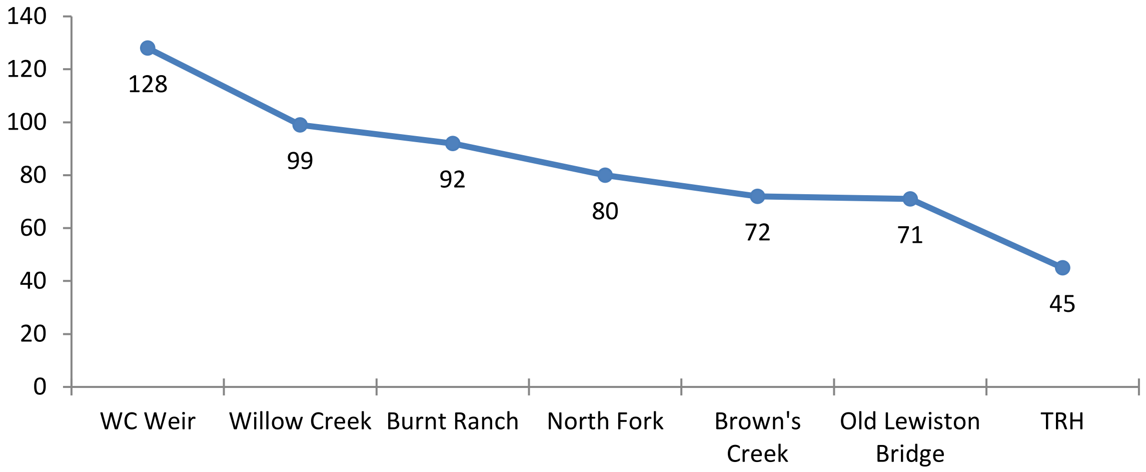

**Figure 5. Number of tagged TRH steelhead detected at each of the main stem monitoring reaches.**

**Table 13. Total number and percentage of radio- tag loss (or final known location) of tagged steelhead migrating upstream.**

| | Reach 1 | Reach 2 | Reach 3 | Reach 4 | Reach 5 | Reach 6 |
|---|---|---|---|---|---|---|
| Tags Disappeared Within Reach | 29 | 7 | 12 | 8 | 1 | 26 |
| % of Total Disappeared Tags | 34.9% | 8.4% | 14.5% | 9.6% | 1.2% | 31.3% |

The tag recovery rate at TRH of 35% of tagged steelhead from the Willow Creek weir is within the 17% to 42% spaghetti tag recovery rate reported by CDFG from 2006 to 2010, although it is on the higher end (Table 14).

**Table 14. CDFG spaghetti tag recovery at TRH from 2006-2010. "*" indicates tags recovered by the YTFP Steelhead Straying project in 2010.**

| Year | 2006 | 2007 | 2008 | 2009 | 2010 | 2010* |
|---|---|---|---|---|---|---|
| Total Tagged | 1975 | 3404 | 4216 | 775 | 1437 | 128* |
| Recovered at TRH | 828 | 949 | 892 | 128 | 332 | 45* |
| % Recovered | 42% | 28% | 21% | 17% | 23% | 35%* |

Upriver migration rates of steelhead were highly variable between reaches (Table 15), averaging 1.41 km/day from the weir to TRH (102.7 total days). The maximum migration rate was 4.8 km/day between Brown's Creek and the Old Lewiston Bridge main stem monitoring sites. The minimum migration rate was 0.88 km/day in the uppermost reach between Old Lewiston Bridge and TRH.

**Table 15. Average cumulative number of days it took for tagged steelhead to pass through each reach on their upward migration to TRH and the average migration rate through each of the main stem Trinity River radio-telemetry reaches.**

| Reach | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Average Day | 7.2 | 22.2 | 64.2 | 72.5 | 89.1 | 102.7 |
| Average Migration Rate (km/day) | 2.4 | 4.6 | 4.1 | 2.9 | 4.8 | .88 |

## Discussion:

We found that the current protocols at Trinity River Hatchery increase the potential for hatchery and natural populations to interact, both in the main stem Trinity River and its tributaries. Our results show that TRH steelhead stray into tributaries after being released back into the Trinity River at a rate of 9.9%, and when main stem strays are included, the straying rate increases to over 21%, and can be directly attributed to the current hatchery practice of releasing TRH-produced steelhead back to the Trinity River because if they were not released to back to the river, there would be no additional opportunity for these fish to stray. In other river systems it has been observed that the straying of hatchery fish pose threats to wild salmon and steelhead populations (Quinn 1993). The majority of detected straying incidents occurred within two kilometers of the TRH ladder, though tributary straying was detected in all monitored tributaries. This practice conflicts with the <u>Steelhead Restoration and Management Plan for California</u> (McEwan 1996) that states, "Existing hatchery and rearing programs will be operated to minimize impacts to natural stocks to the maximum extent possible". There was no documentation found that listed any specific reason why TRH steelhead are released back into the Trinity River.

Radio-telemetry data provided by tagging at the Willow Creek weir suggests there is a low rate (2.3%) of tributary straying by TRH steelhead prior to returning to the hatchery. Compared to the 9.9% straying rate of TRH steelhead released from TRH back to the river, it is clear that the current TRH protocol of releasing adult TRH steelhead back into the Trinity River greatly increases the hatchery impact on the natural salmon and steelhead populations within the Trinity River, especially in the upper river and tributaries. The most significant impact from the current TRH protocol is the addition of more hatchery fish to the natural spawning population, but at a minimum, the current protocol increases the number of hatchery steelhead in the river system and it has been observed that increased numbers of hatchery fish pose conservation risks to wild salmonids (Waples 1991; Currens et al. 1997). These concerns include potential negative competitive interactions (Flagg et al. 2000; Kostow and Zhou 2006; Kostow 2009), disease transfer (Currens et al. 1997; Amos and Thomas 2002), and interbreeding with wild salmonids (Waples 1991; Kostow et al. 2003; Hayes et al. 2004; Araki et al. 2007).

According to the straying data, male TRH steelhead have a greater impact on the natural salmon and steelhead populations within the Trinity River because of the increased straying rate versus female TRH steelhead (14.7% to 5.4%). Also, hatchery return data showed that 33.3% of male TRH steelhead returned to the hatchery multiple times, which provides an opportunity for male TRH steelhead to be used multiple times throughout the season's spawning procedures.

The Willow Creek weir migration data provided hatchery return rates similar to tag recovery data provided by the CDFG spaghetti tagging effort. The 35% hatchery return rate of the radio-telemetry tags fell within the range of spaghetti tag recoveries from the past five year (17% to 42%), and the radio-telemetry data provided insight into where most of these tags are lost. Tag loss can be defined as tags that fail to continue upstream migration, whether this is due to predation, sport fishing, straying, or actual tag loss. Our data showed that there were two areas where the majority of tags were lost: either during the first five kilometers above the Willow Creek weir or during the last five kilometers below Trinity River Hatchery. The 31.3% tag loss observed in the upper reach below the Lewiston Dam is most likely main stem straying of hatchery produced steelhead, which has been the reach documented as having the greatest occurrence of straying for all salmonid species in the Trinity River (Chamberlain et al. 2012). The 22% loss of radio-telemetry tags below the weir represent an even greater insight into the spaghetti tag estimates provided by CDFG, and the possibility that CDFG is not adequately estimating the number of spaghetti tagged fish that fail to continue their upstream migration after being caught at the weir. The spaghetti tags are used to estimate the total in-river escapement for the Trinity River basin, including the proportions of natural and hatchery produced salmon and steelhead that spawn in natural areas. If the CDFG spaghetti tag data is comparable to our radio telemetry data, and 22% of the spaghetti-tagged fish at the Willow Creek weir turn downstream and never migrate past the weir, then the in-river and natural area spawner estimates of hatchery produced steelhead provided by CDFG may be grossly over-estimated.

We recommend that the managers of TRH change the current hatchery protocol that requires all TRH steelhead to be released back to the Trinity River. The current protocols are negatively influencing the natural salmon and steelhead populations within the Trinity River and its tributaries by providing additional opportunity for interaction. These practices may also be having a deleterious genetic effect on the TRH steelhead population from allowing male TRH steelhead to contribute on multiple spawning occasions: so, male TRH steelhead should be removed from the system once they return to the hatchery, or at least all re-run male steelhead should not be spawned. Also, we recommend that further evaluation is needed on the CDFG weir spaghetti tagging effort, and the possibility of the spaghetti tag data drastically over-estimating the in-river return estimates due to run-back steelhead that return downstream after being caught at the weir.

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U.S. Fish & Wildlife Service

*Arcata Fisheries Data Series Report DS 2019-62*

# Mainstem Trinity River Chinook Salmon Spawning Survey, 2017

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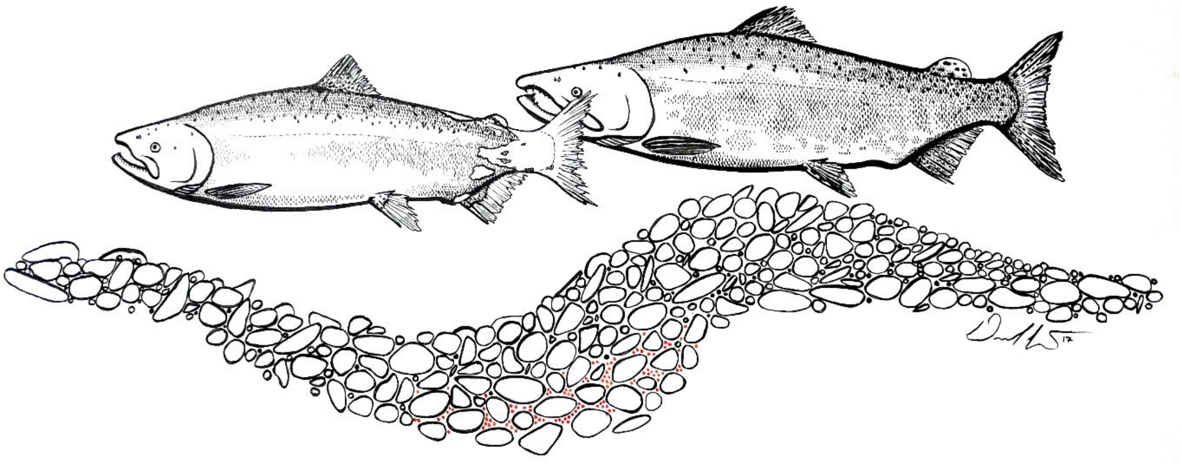

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# Mainstem Trinity River Chinook Salmon Spawning Survey, 2017

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*Abstract.*— Salmon redds and carcasses were surveyed on the mainstem Trinity River, California from Lewiston Dam to the confluence with the Klamath River, during the 2017 spawning season to map spawning abundance and distribution, evaluate pre-spawn mortality, and characterize redds by species and spawner origin. The total redd count in 2017 was 1,982. We applied generalized additive models to the spatiotemporal distribution of unmarked and hatchery-marked spawned female salmon carcasses to apportion redd counts by natural- and hatchery-origin Chinook Salmon *Oncorhynchus tshawytscha* and Coho Salmon *O. kisutch*. This methodology only allows for the partitioning of redds constructed by hatchery- and natural-produced females and does not account for the origin of the male spawners. We estimated that 1,600 (95% c.i.: 1,435–1,762) redds were constructed by natural-origin Chinook Salmon, 348 (95% c.i.: 186–513) by hatchery-origin Chinook Salmon, and the remaining 34 were attributed to Coho Salmon. Natural-origin Chinook Salmon spawned throughout the mainstem river while the distribution of redds constructed by hatchery-origin Chinook Salmon was highly skewed toward Lewiston Dam and the Trinity River Hatchery (about 59% were within 10 km of the dam). Pre-spawn mortality of female Chinook Salmon was 1.8% for carcasses observed in all reaches and 2.0% within an intensively managed ‘restoration reach’, which is a focal area for habitat restoration improvements being implemented by the Trinity River Restoration Program (TRRP). Long-term trend analyses from 2002 to 2017 showed no significant change in the abundance of natural-origin Chinook Salmon redds constructed in the mainstem Trinity River, while the number of hatchery-origin Chinook Salmon redds decreased. The proportion of total annual natural-origin Chinook Salmon redds decreased in the reaches nearest to Lewiston Dam and increased in reaches farther downstream from 2002 to 2017, while the annual component of hatchery-origin Chinook Salmon redds remained almost completely within the two reaches nearest to Lewiston Dam.

## Introduction

The Trinity River, California, once supported large populations of naturally produced anadromous salmonids, including spring- and fall-run Chinook Salmon *Oncorhynchus tshawytscha* (USFWS and HVT 1999). Prior to the construction of Trinity and Lewiston dams, the spawning of spring- and fall-run Chinook Salmon was separated temporally and spatially due to the timing of adult upstream migration of each race and the hydrology of the river. In 1940s, Moffett and Smith (1950) noted that “almost without exception, Trinity River salmon migrating above the South Fork spawn in the 72 miles of river between the North Fork and Ramshorn Creek.”

Following construction of Lewiston Dam [river kilometer (rkm 182.2)], spring- and fall-run Chinook Salmon spawning in the mainstem Trinity River exhibited considerable spatial and temporal overlap due to lack of access to historic spawning areas for the spring-run. High redd densities became frequent within the upper-most portions of the river below the dam, where presumably hatchery-origin salmon and their progeny comingled and spawned with naturally produced fish. Trinity River Hatchery (TRH), located at the base of Lewiston Dam, is operated to mitigate for the loss of Chinook Salmon, Coho Salmon *O. kisutch*, and steelhead *O. mykiss* production upstream of the dam. Rogers (1972) documented that in 1970 more than 50% of Chinook Salmon spawned in the two miles (3.2 km) below Lewiston Dam and 80% spawned above Douglas City (around rkm 150.1). Redd surveys in the 1980s and 1990s between North Fork Trinity River (rkm 118.2) and Cedar Flat (rkm 79.1) documented variable spawning use in these reaches, with redd counts ranging from a low of 187 in 1998 to a high of 928 redds in 1997 (USFWS 1986, 1987; Quihillalt 1999). Chamberlain et al. (2012) noted that the mean distance from Lewiston Dam of natural-origin Chinook Salmon redds upstream of Cedar Flat increased from 2002 to 2011. Rupert et al. (2017a) noted that when the mainstem Trinity River was divided into reach-scale sections, natural-origin Chinook Salmon spawning activity decreased near Lewiston Dam and increased in sections of the river farther downstream.

In an effort to restore the fishery resources of the Trinity River, the Secretary of the Interior signed the Trinity River Mainstem Fishery Restoration Record of Decision (ROD) in 2000 (USDOI 2000) and the Trinity River Restoration Program (TRRP) was established. The goal of the TRRP is to:

> "…restore and sustain natural production of anadromous fish populations downstream of Lewiston Dam to pre-dam levels, to facilitate dependent tribal, commercial, and sport fisheries' full participation in the benefits of restoration via enhanced harvest opportunities" (TRRP and ESSA 2009).

To achieve this goal, the TRRP implements a suite of actions (flow management, mechanical channel rehabilitation, coarse sediment augmentation, and watershed restoration) to restore riverine habitats and restore habitat-creating alluvial processes (USFWS and HVT 1999; USDOI 2000). Collectively, these actions are intended to increase and maintain salmonid habitats in the 64-km section of the Trinity River from Lewiston Dam downstream to the North Fork Trinity River (restoration reach), which was severely degraded due the operation of the Trinity River Division (TRD) of the Central Valley Project. Downstream of the North Fork confluence, the Trinity River valley narrows and accretions of flow and sediment from tributaries attenuate many of the morphological impacts that have occurred in the restoration reach (USFWS and HVT 1999).

The Integrated Assessment Plan (IAP; TRRP and ESSA 2009) sets forth a list of objectives to evaluate the effectiveness of TRRP restoration actions. Salmon spawning surveys are preformed to provide data to address Objective 3, specifically sub-objectives 3.1 and 3.3:

> **Objective 3**: Restore and maintain natural production of anadromous fish populations.
>
> > **Sub-objective 3.1**: Increase spawning, incubation, and emergence success of anadromous spawners.
> >
> > **Sub-objective 3.3**: Minimize impacts of predation and genetic interactions between and among hatchery and natural anadromous fish.

The IAP proposes assessing spawning at three spatial scales: system, reach, and site scales. Each of these spatial scales evaluates the effects of restoration efforts on Chinook Salmon spawning at different resolutions. System-scale analysis evaluates the response to all restoration activities combined over time. Reach-scale analysis evaluates the response to management actions within sections of the river that have unique hydrology and sediment supplies. Finally, site-scale analysis provides insight on changes in spawning distribution/abundance within restoration sites and the localized effects of mechanical channel rehabilitation. The IAP also states that "increased spawner success will likely occur within 3–4 brood cycles following completion of channel rehabilitation and subsequent fluvial and geomorphic evolution."

This report details the results from salmon spawning survey data collected in 2017 on the mainstem Trinity River. Surveying salmon carcasses provides pre-spawn mortality data and carcass estimates and reflect the species and origin composition of spawned salmon. Surveying salmon redds provides the location and spawn timing of individual redds. When analyzed together, each year's data produces a spatially and temporally explicit set of observed redd locations with each redd having an associated probability of construction by female natural-origin Chinook Salmon, hatchery-origin Chinook Salmon, natural-origin Coho Salmon, and hatchery-origin Coho Salmon. We define 'hatchery-origin' as fish produced and released from Trinity River Hatchery (TRH), and 'natural-origin' as fish that emerge from a redd, regardless of parental origin. These data sets facilitate an array of analyses over a range of spatial and temporal scales, which we use to investigate spawning distribution and abundance. Where applicable, we use the performance measures set forth by the IAP to evaluate changes in spawning as responses to the restoration actions of the TRRP.

## Methods

### Survey Area and Timing

The Trinity River from Lewiston Dam to its confluence with the Klamath River was delineated into 14 survey reaches ranging in length from 3.3 to 21.3 km (Figure 1, Table 1). Reach breaks were based on river access locations and channel distances that could be surveyed in a day. Two whitewater sections were not surveyed: the 9.7-km Pigeon Point run (Reach 8) and the 15.6-km section that includes the Burnt Ranch Gorge (Reach 11). In 2016, the boundary separating Reaches 5 and 6 was moved from Roundhouse (rkm 135.7) to Evan's Bar (rkm 137.4) because of a change in private landowner permission to use their river access.

Reaches 1–7 were surveyed weekly and Reaches 9–14 (excluding Reach 11) were surveyed every other week, as conditions permitted, for salmon carcasses and redds as described in Rupert et al. (2017a). Surveys in 2017 began August 30 and concluded December 20. This period was intended to encompass the majority of Chinook Salmon spawning activity.

### Redd Identification

Chinook and Coho salmon spawning periods temporally overlap and natural- and hatchery-origin salmon spawn in the same areas in the mainstem Trinity River. Given that redds are not visually distinguishable by these species and origin types, the estimated proportion and spatial distribution of fresh female carcasses of hatchery- and natural-origin Chinook and Coho salmon were used to infer the probability of redd construction by species and origin. Since only female carcasses are used in the hatchery–natural analysis, the estimates of redds constructed by natural-origin females do not account for hatchery-produced males spawning with naturally produced females. Therefore natural-origin spawning estimates should be considered maximum values given that estimates were not adjusted downward to account for hatchery–natural mating pairs. Generalized Additive Models (GAM) were used with the spatiotemporal distribution of carcasses to estimate the longitudinal gradient in proportional distribution of spawned females by species (Chinook or Coho salmon) and origin (hatchery or natural) along the river channel and over time (Rupert et al. 2017a). Cumulative redd counts were arranged by survey day within reach boundaries and season total estimates of redds by species and origin were calculated by summing predicted probabilities of construction for each species–origin category (Rupert et al. 2017a).

### Carcasses Estimation

Carcass abundance estimates for Reaches 1 and 2 were generated via a hierarchical latent variables model as described in Rupert et al. (2017a). This model assumes a latent (unobservable) ecological process interacts with a detection process to produce the observed counts of carcasses (Kery and Schaub 2012). For this survey, the latent process is the true

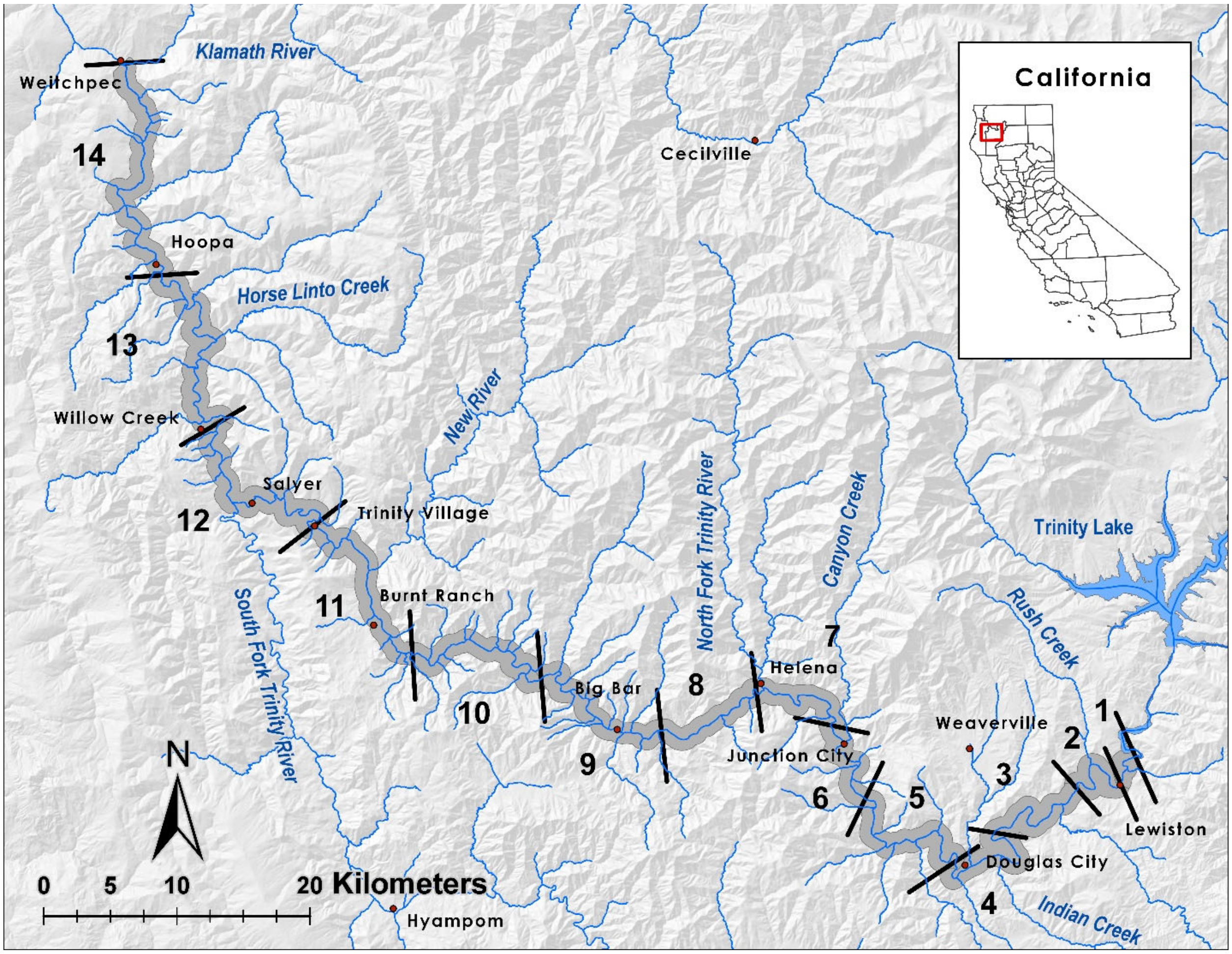

Figure 1. Survey Reaches 1–14 (Lewiston Dam to Weitchpec) on the mainstem Trinity River, California. Dangerous whitewater conditions precluded surveys in Reaches 8 and 11.

abundance of carcasses. As not all carcasses are observed (imperfect detection), a separate observation process links the unobserved latent process to the observed data. In essence, annual carcass estimates were generated by first estimating weekly detection probabilities. Next, weekly counts of fresh carcasses (those arriving since the prior survey) were assumed to arise from a binomial process, which allows the estimation of weekly abundances. Finally, weekly estimates were summed to create an annual abundance estimate as a derived parameter.

## Pre-Spawn Mortality

Fresh carcasses were described as spawned (≤1/3 eggs retained), partially spawned (1/3–2/3 eggs retained), or unspawned (≥2/3 eggs retained). These spawning condition data were used to assess levels of pre-spawn mortality. Female carcasses designated as 'spawned' and 'partially spawned' were considered successful spawners. Unspawned carcasses were considered pre-spawn mortalities. Measurement of pre-spawn mortality is limited to occurrence within the time and space of the surveys. Therefore, pre-spawn mortality in the lower Klamath River of Trinity River-bound fish and pre-spawn mortality of spring-run Chinook Salmon prior to the first survey are not reflected in our data and analyses.

Table 1. Reach boundaries [and river kilometer (rkm)] for the mainstem Trinity River, California, salmon spawning surveys. Agencies involved in data collection include California Department of Fish and Wildlife (CDFW), Shasta–Trinity National Forest (USFS), U.S. Fish and Wildlife Service (USFWS), Yurok Tribal Fisheries Program (YTFP), and Hoopa Valley Tribal Fisheries Department (HVT).

| | Boundaries | | |
|---|---|---|---|
| Reach | Upstream | Downstream (rkm) | Surveying agency |
| 1 | Lewiston Dam (rkm 182.2) [a] | Old Lewiston Bridge (178.7) | USFS, YTFP, CDFW |
| 2 | Old Lewiston Bridge | Bucktail River Access (171.6) | CDFW, YTFP |
| 3 | Bucktail River Access | Steel Bridge River Access (160.7) | CDFW, YTFP |
| 4 | Steel Bridge River Access | Douglas City Campground (150.1) | CDFW, YTFP |
| 5 | Douglas City Campground | Evan's Bar (137.4) [b] | CDFW, YTFP |
| 6 | Evan's Bar [b] | Junction City Campground (127.1) | USFWS, HVT |
| 7 | Junction City Campground | Pigeon Point Campground [c] (117.4) | USFWS, HVT |
| 8 | Pigeon Point Campground [c] | Big Flat River Access (107.6) | NOT SURVEYED |
| 9 | Big Flat River Access | Del Loma River Access (93.8) | USFWS, HVT |
| 10 | Del Loma River Access | Cedar Flat River Access (79.1) | USFWS, HVT |
| 11 | Cedar Flat River Access | Hawkins Bar (63.4) | NOT SURVEYED |
| 12 | Hawkins Bar | Camp Kimtu in Willow Creek (42.6) | USFWS, HVT |
| 13 | Camp Kimtu in Willow Creek | Roland’s Bar in Hoopa Valley (21.3) | USFWS, HVT |
| 14 | Roland’s Bar in Hoopa Valley | Weitchpec (Trinity mouth; 0.0) | USFWS, HVT |

[a] The spillway and pool directly downstream of Lewiston Dam were not surveyed and presumed to have no redds.

[b] In 2015 and earlier the river access separating Reaches 5 and 6 was at Roundhouse (rkm 135.7).

[c] Pigeon Point Campground access is 0.8 km downstream of the North Fork Trinity River confluence (rkm 118.2). The primary area where Trinity River Restoration Program actively manages to improve channel morphology and salmon habitat is in Reaches 1–7.

## Redd–Carcass Relationship

Spawning density was hypothesized to affect the crews' ability to observe redds and carcasses with equal efficiency, especially in the high spawning density areas of Reaches 1 and 2 (Bradford and Hankin 2012). This hypothesis would be supported if the number of redds surveyed in an area was not proportional to the number of spawned female carcasses found in that same area. To determine if this occurred, the estimates of spawned female Chinook Salmon carcasses were compared with corresponding counts of Chinook Salmon redds from Reaches 1 and 2. These values were log-transformed and analyzed using linear regression. These two variables would be considered proportional if the slope of their linear relationship was not significantly different than '1'. A slope that is significantly different than '1' would indicate that these variables are not proportional and some density-dependent observer error could be inferred.

## Trends in Redd Abundance and Distribution

Data from 2017 were combined with the preceding fifteen years (2002–2016) of mainstem Trinity River redd data from Chamberlain et al. (2012) and Rupert et al. (2017a, 2017b) for long-term analyses of redd abundance and distribution. Past years' data availability was sometimes limited since not all variables analyzed were previously collected (i.e., spatially explicit redd data are not available for Reaches 12–14 prior to 2007). Redd abundance and distribution were analyzed at three spatial scales: the system (~50–100 km sections), reach (~10–20 km sections), and site (~1–2 km sections) scales. The 2017 data were examined and, when applicable, included with previous years' data for multi-year trend analyses.

For spatial analyses, the river was partitioned into individual segments based on morphology and referred to as 'riffle units' (Rupert et al. 2017b). A riffle unit is defined as a section of river that corresponds to a singular pool–riffle–pool sequence that typically ranges between 0.1 and 0.5 km in length. These units were delineated by this sequence for redd abundance analyses because Chinook Salmon typically build redds in patches proximate to riffle crests. Therefore, riffle units generally contain an undivided group of redds. Riffle unit designations were based on the 'morphological units' delineated by Gaeuman et al. (2016). Where Gaeuman et al. (2016) used hydraulic controls (i.e., riffles) to delineate morphological units, the deepest locations (i.e., pools) between these hydraulic controls were used to split riffle units. As a result, the morphological units from Gaeuman et al. (2016) were shifted slightly upstream. Aerial photography was used to construct riffle units downstream of the restoration reach (excluding Reaches 8 and 11) because the morphological units developed by Gaeuman et al. (2016) were limited to the restoration reach. In total, the mainstem Trinity River was divided into 482 riffle units.

The riffle unit method described in this report refers to the method used for partitioning the river in Rupert et al. (2017b). In Rupert et al. (2017a), the smallest spatial units were based on contiguous 400-m (and occasionally 200-m) sections of the Science Advisory Board dataframe (SAB units; Buffington et al. 2014). This change in methodology is an improvement over that used in Rupert et al. 2017a because redd groupings are no longer split and the three spatial scale sections better reflect local spawning habitat and TRRP channel rehabilitation sites or suites of sites. The upstream and downstream site-, reach-, and system-scale section boundaries changed slightly as a result to reflect the newer riffle unit divisions. The complete 2002–2017 data set was analyzed using the newer riffle unit-based divisions at each spatial scale.

Contiguous groups of riffle units were combined to create the sections used for the site-scale analysis (Table 2). These site designations were generally based on the TRRP site designations of the Science Advisory Board dataframe (Buffington et al. 2014). However, the total count of site-scale units was reduced from 57 to 44 by merging the smallest site-scale sections of the SAB dataframe into the most appropriate adjacent site-scale sections. This spatial scale was used to evaluate changes in natural- and hatchery-origin Chinook Salmon redd abundance at a scale similar to TRRP restoration sites or suites of sites. Changes in spawning abundance within these sites was analyzed using linear regression of the annual proportion (number of redds in the site / sum of redds in the restoration reach) of redds.

Ten reach-scale sections were also used to evaluate long-term trends in natural- and hatchery-origin Chinook Salmon redd abundance (Figure 2, Table 3). These reaches consisted of groups of sites and were intended to evaluate redd abundance at a spatial scale that was an intermediate between the system and site scales. Our reach-scale designations closely resemble those defined by HVT et al. (2011), who partitioned the restoration reach into five ‘rehabilitation reaches’ that were delineated by differences in hydrology and sediment supply characteristics. Boundaries of the other five river sections downstream of the restoration reach were set similarly. Changes in spawning abundance within these reaches were analyzed using linear regression analyses of both the annual number and proportion (number of redds in reach / sum of redds in all reaches) of natural- and hatchery-origin Chinook Salmon redds.

Changes in redd abundance and distribution at the system scale were evaluated over the entire mainstem and also separately for the restoration reach (Reaches 1–7) and remaining surveyed river downstream of the restoration reach (Reaches 9–10 and 12–14). Linear models were used to detect trends in redd abundance. Mean distance from Lewiston Dam of natural- and hatchery-origin Chinook Salmon redds built upstream of Cedar Flat were evaluated using linear regression models.

Table 2. The reach- and site-scale sections used for redd abundance and distribution analysis within the restoration reach. Sites are listed with the approximate location of their upstream boundary, shown as distance from the Klamath River confluence (rkm).

| Reach | Site (rkm) | TRRP Rehabilitation | Length (km) |
|---|---|---|---|
| Lewiston | Hatchery (182.20) | 2006 | 0.69 |
| | Sven Olbertson (181.51) | 2008 | 1.28 |
| | Old Bridge (180.22) | 2008 | 1.75 |
| | Sawmill (178.47) | 2009 | 1.60 |
| | Upper Rush Creek (176.87) | | 1.46 |
| Limekiln | Lower Rush Creek (175.41) | | 1.33 |
| | Dark Gulch (174.08) | 2008 | 2.81 |
| | Lowden Ranch (171.27) | 2010 | 1.73 |
| | Trinity House Gulch (169.54) | 2010 | 0.72 |
| | Tom Lang Gulch (168.82) | | 1.48 |
| | Poker Bar (167.34) | | 2.30 |
| | China Gulch (165.05) | | 1.47 |
| | Limekiln Gulch (163.57) | 2015 | 2.38 |
| | Steel Bridge (161.20) | | 1.67 |
| | McIntyre Gulch (159.53) | | 1.53 |
| | Vitzthum Gulch (158.00) | 2007 | 2.02 |
| | Upper Indian Creek (155.98) | 2007 | 0.56 |
| Douglas City | Lower Indian Creek (155.42) | 2007 | 1.52 |
| | Upper Douglas City (153.90) | 2007, 2015 | 0.83 |
| | Douglas City (153.07) | 2013 | 1.30 |
| | Reading Creek (151.77) | 2010 | 1.77 |
| | Upper Steiner Flat (150.00) | | 1.26 |
| | Lower Steiner Flat (148.74) | 2012 | 1.90 |
| | Lorenz Gulch (146.83) | 2013 | 1.49 |
| | The Canyon (upstream) (145.34) | | 2.17 |
| Junction City | The Canyon (downstream) (143.18) | | 2.23 |
| | Dutch Creek (140.95) | | 2.56 |
| | Evan's Bar (138.38) | | 1.28 |
| | Soldier Creek (137.11) | | 0.89 |
| | Chapman Ranch (136.22) | | 1.10 |
| | Deep Gulch (135.13) | | 1.11 |
| | Sheridan Creek (134.02) | | 1.15 |
| | Oregon Gulch (132.87) | | 0.76 |
| | Sky Ranch (132.12) | | 1.20 |
| | Upper Junction City (130.91) | 2012 | 0.89 |
| | Lower Junction City (130.01) | 2014 | 0.67 |
| North Fork | Hocker Flat (129.34) | 2005 | 1.88 |
| | Upper Conner Creek (127.46) | | 1.12 |
| | Conner Creek (126.34) | 2006 | 1.71 |
| | Wheel Gulch (124.63) | 2011 | 1.05 |
| | Valdor Gulch (123.58) | 2006 | 1.84 |
| | Elkhorn (121.74) | 2006 | 1.50 |
| | Pear Tree Gulch (120.24) | 2006 | 1.33 |
| | Bagdad (118.92) [a] | | 1.52 |

[a] the downstream boundary of the Bagdad site was at rkm 117.4

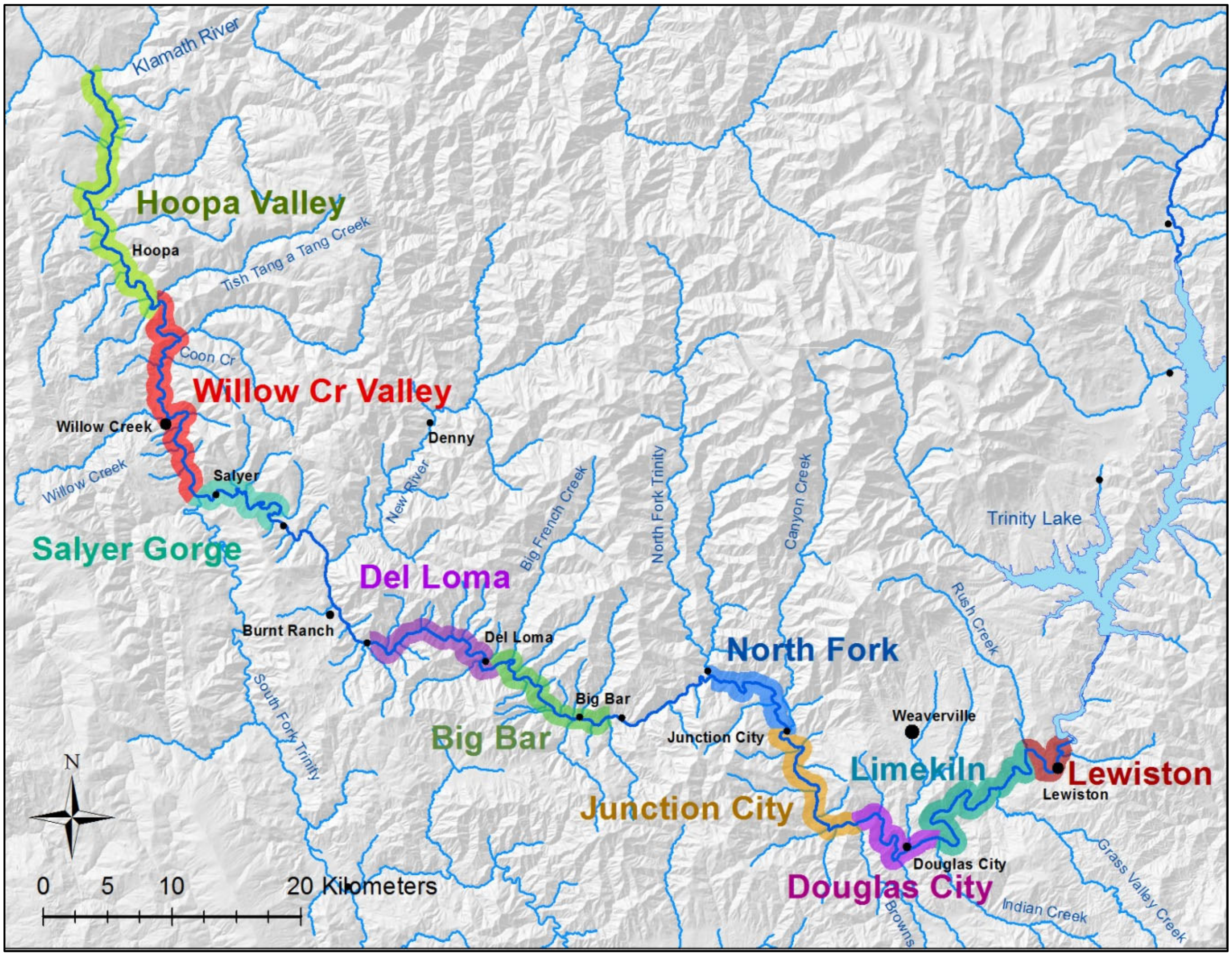

Figure 2. The ten sections of the mainstem Trinity River used for reach-scale analyses of Chinook Salmon redd distribution.

Table 3. River sections [with river kilometer (rkm)] used for the reach-scale analysis of redd abundance.

| | Boundaries | | |
|---|---|---|---|
| Section | Upstream (rkm) | Downstream (rkm) | Length (km) |
| Lewiston Rehab | Lewiston Dam (182.20) | Rush Creek (175.41) | 6.79 |
| Limekiln Rehab | Rush Creek | Indian Creek (155.42) | 19.99 |
| Douglas City Rehab | Indian Creek | Browns Creek (143.18) | 12.25 |
| Junction City Rehab | Browns Creek | Canyon Creek (129.34) | 13.84 |
| North Fork Rehab | Canyon Creek | North Fork Trinity River (117.40) | 11.94 |
| Big Bar | Big Flat access riffle unit (107.82) | Del Loma access riffle unit (94.03) | 13.79 |
| Del Loma | Del Loma access riffle unit | Cedar Flat access riffle unit (79.31) | 14.72 |
| Salyer Gorge | Hawkins Bar river access (63.76) | South Fork Trinity River (50.33) | 13.41 |
| Willow Creek Valley | South Fork Trinity River | Tish Tang a Tang Creek (26.95) | 23.40 |
| Hoopa Valley | Tish Tang a Tang Creek | Weitchpec (Trinity River mouth; 0.0) | 26.95 |

# Results

## Survey Success and Conditions

Crews were able to complete 86% of the originally scheduled surveys in 2017, including missed surveys that were rescheduled for the following week (Appendix A). The first scheduled surveys on Reaches 4–7 were cancelled due to wildfires causing smoky air conditions and road and river access closures. Other missed surveys, which were mostly for Reach 6 and downstream from mid-November to early December, were usually cancelled due to rain events causing increased turbidity and poor visibility. Additionally, surveys on Reaches 1–4 and 13 were completed the week of December 17, which was one week more than initially scheduled.

Trinity River discharge at Lewiston, California, was about 13.1 $m^3/s$ during the first half of the survey season before dropping to about 9.0 $m^3/s$ in mid-October, at which it remained for the remainder of season (Appendix B). At Hoopa, California, mean daily flows on the mainstem Trinity River ranged between 18.2 and 31.4 $m^3/s$ from the start of the survey season to early November before rain events caused flows to increase in mid-November. Mean daily flow peaked at 277.5 $m^3/s$ on November 21 before coming back down to about 36.0 $m^3/s$ by mid-December.

Crews reported water visibility between 1.5 and 3.0 m during most of the surveys in 2017 (Appendix A). Visibility was occasionally higher (>3.0), particularly in the lower reaches. Visibility was lower (0.9–1.5 m) during some early season surveys and less than 0.9 m once in Reach 9 in early September after a project in Sheridan Creek temporarily increased turbidity.

## Salmon Carcasses

During the 2017 surveys, 527 fresh (conditions 1 and 2 as described in Rupert at al. 2017a) Chinook Salmon carcasses were examined (Table 4). Of these fresh carcasses, 333 (63.4%) were females, 39 (7.4%) were adipose fin-clipped (‘ad-clip’), and 32 (6.1%) had been marked with a spaghetti tag at the Willow Creek or Junction City weir operated by the California Department of Fish and Wildlife. Chinook Salmon released from the TRH are batch-marked with coded-wire tags (CWT) and externally marked using an ad-clip at a constant fractional mark rate of about 25%. From the 39 ad-clipped fresh Chinook Salmon carcasses observed, 31 head samples were collected (Table 5). Data from CWT recoveries yielded an average annual production multiplier (i.e., tagging rate) of 0.240 in 2017.

Of the 333 fresh female Chinook Salmon carcasses recovered, 25 (7.5%) were ad-clipped, and of these, 20 heads were collected. CWTs were recovered and read from all 20 (100%) of these heads. Of the spawned female hatchery-origin Chinook Salmon carcasses (spring and fall broods combined) with associated CWT data, 90% (18 of 20) were recovered within 10 km of Lewiston Dam (Figure 3).

Relatively few (six) Coho Salmon carcasses were recovered during the 2017 surveys (Table 6). Of these, three were fresh and of these, none (0%) were right maxillary-clipped, which would indicate hatchery origin. Only one of the Coho Salmon carcasses was a fresh spawned female. The limited number of spawned female Coho Salmon carcasses recovered inhibited the ability to differentiate Coho Salmon redds by origin in 2017.

Table 4. Summary of fresh (conditions 1 and 2) Chinook Salmon carcass data by survey reach, 2017 Trinity River surveys.

| Reach | Total | Males | Females | Female proportion | Ad-clipped | Weir-tagged |
|---|---|---|---|---|---|---|
| 1 | 120[a] | 33 | 85 | 72.0% | 17 | 9 |
| 2 | 119 | 43 | 76 | 63.9% | 13 | 9 |
| 3 | 76 | 38 | 38 | 50.0% | 3 | 4 |
| 4 | 38 | 18 | 20 | 52.6% | 1 | 1 |
| 5 | 53 | 24 | 29 | 54.7% | 4 | 3 |
| 6 | 62 | 18 | 44 | 71.0% | 1 | 1 |
| 7 | 20 | 6 | 14 | 70.0% | 0 | 0 |
| 9 | 25 | 9 | 16 | 64.0% | 0 | 3 |
| 10 | 13 | 3 | 10 | 76.9% | 0 | 2 |
| 12 | 0 | 0 | 0 | - | 0 | 0 |
| 13 | 1 | 0 | 1 | 100.0% | 0 | 0 |
| 14 | 0 | 0 | 0 | - | 0 | 0 |
| Total | 527[a] | 192 | 333 | 63.4% | 39[b] | 32 |

[a] includes two carcasses of unknown sex

[b] head samples were collected from 31 of the 39 fresh ad-clipped Chinook Salmon carcasses

Table 5. Coded-wire tag (CWT) information retrieved from fresh adipose fin-clipped Chinook Salmon carcasses, 2017 Trinity River surveys.

| Carcasses | CWT | Brood Year | Run type | Release type | Production multiplier | Production multiplier |
|---|---|---|---|---|---|---|
| 1 | 060605 | 2013 | Spring | Advanced fingerling | 4.24 | 0.236 |
| 1 | 060606 | 2013 | Spring | Advanced fingerling | 4.15 | 0.241 |
| 1 | 060609 | 2013 | Fall | Fingerling | 4.12 | 0.243 |
| 2 | 060612 | 2013 | Spring | Yearling | 4.22 | 0.237 |
| 1 | 060615 | 2014 | Fall | Fingerling | 4.13 | 0.242 |
| 2 | 060689 | 2014 | Spring | Advanced fingerling | 4.27 | 0.234 |
| 1 | 060691 | 2014 | Spring | Advanced fingerling | 4.14 | 0.242 |
| 6 | 060692 | 2014 | Fall | Advanced fingerling | 4.09 | 0.244 |
| 5 | 060693 | 2014 | Fall | Advanced fingerling | 4.08 | 0.245 |
| 1 | 060694 | 2014 | Fall | Fingerling | 4.28 | 0.233 |
| 1 | 060696 | 2014 | Spring | Yearling | 4.27 | 0.234 |
| 2 | 060697 | 2014 | Fall | Yearling | 4.18 | 0.239 |
| 1 | 060775 | 2015 | Fall | Fingerling | 4.27 | 0.234 |
| 4 | 060780 | 2015 | Fall | Yearling | 4.25 | 0.236 |
| 1 | 068849 | 2013 | Spring | Fingerling | 4.18 | 0.239 |
| 1 | | -- Missing CWT/head -- | | | NA | NA |
| | | | | | Mean = 4.17 | Mean = 0.240 |

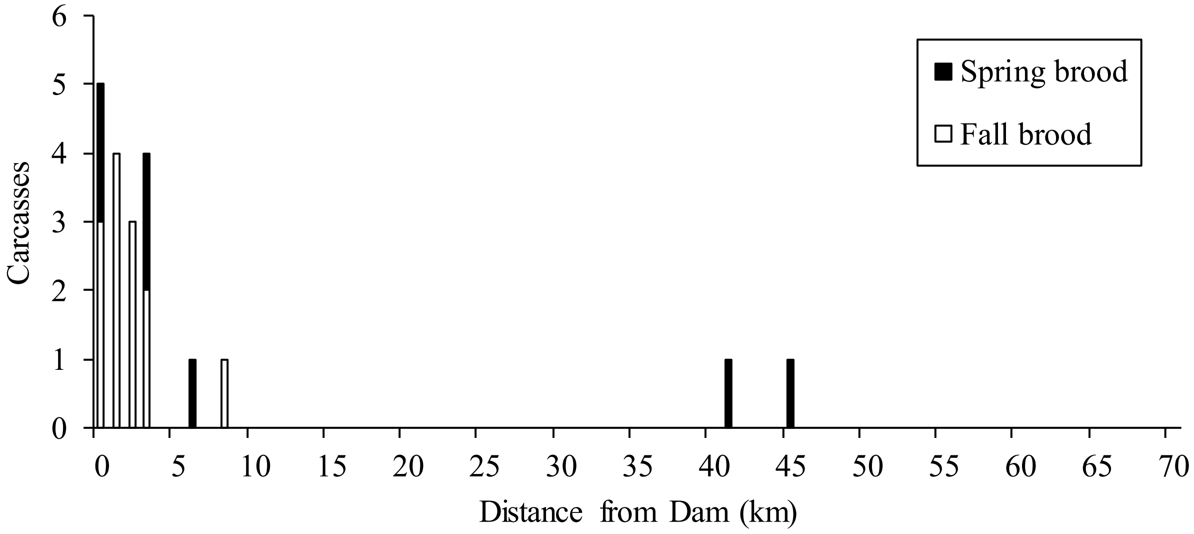

Figure 3. Distribution of coded-wire-tagged (CWT) spawned female Chinook Salmon carcasses by brood type (spring and fall) located in the mainstem Trinity River downstream of Lewiston Dam in 2017.

Table 6. Summary of fresh (conditions 1 and 2) Coho Salmon carcass data by survey reach, 2017 Trinity River surveys.

| Reach | Total | Males | Females | Female proportion | Maxillary-clipped | Weir-tagged |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0.0% | 0 | 0 |
| 2 | 0 | 0 | 0 | - | 0 | 0 |
| 3 | 2 | 1 | 1 | 50.0% | 0 | 0 |
| 4 | 0 | 0 | 0 | - | 0 | 0 |
| 5 | 0 | 0 | 0 | - | 0 | 0 |
| 6 | 0 | 0 | 0 | - | 0 | 0 |
| 7 | 0 | 0 | 0 | - | 0 | 0 |
| 9 | 0 | 0 | 0 | - | 0 | 0 |
| 10 | 0 | 0 | 0 | - | 0 | 0 |
| 12 | 0 | 0 | 0 | - | 0 | 0 |
| 13 | 0 | 0 | 0 | - | 0 | 0 |
| 14 | 0 | 0 | 0 | - | 0 | 0 |
| Total | 3 | 2 | 1 | 33.3% | 0 | 0 |

### Carcass Estimates

The hierarchical latent variables model estimated 366 (95% CI: 277–499) Chinook Salmon carcasses in Reach 1 and 498 (95% CI: 356–735) in Reach 2 in 2017. Estimates of spawned female Chinook Salmon carcasses were 250 (95% CI: 186–353) in Reach 1 and 316 (95% CI: 218–475) in Reach 2.

### Pre-spawn Mortality

Six fresh unspawned female Chinook Salmon carcasses were found in 2017, all without a hatchery mark, which yielded a pre-spawn mortality rate among female Chinook Salmon throughout the mainstem Trinity River of 1.8% (Table 7). Weekly pre-spawn mortality rates ranged from 0.0% to 8.0% (the first six survey weeks were combined, as were the final three, due to small sample sizes; Figure 4). Annual pre-spawn mortality of female Chinook Salmon in the Trinity River restoration reach was 2.0% in 2017.

The lone (one) fresh female Coho Salmon carcass encountered in 2017 was of natural-origin and had spawned (Table 8). Note that pre-spawn mortality rates were based on data collected through late December, while Coho Salmon are still spawning.

Table 7. Pre-spawn mortality rates of Chinook Salmon in the Trinity River below Lewiston Dam (Reaches 1–14) and in the restoration reach (Reaches 1–7), 2009–2017 surveys. Pre-spawn mortalities by week and reach for unmarked and ad-clipped Chinook Salmon are presented in Appendix C.

| Year | Reaches 1-14 (Lewiston Dam to Klamath River) | Reaches 1-7 (Lewiston Dam to North Fork) |
|---|---|---|
| 2009 | 7.9% | 6.8% |
| 2010 | 10.2% | 9.5% |
| 2011 | 4.6% | 4.6% |
| 2012 | 2.4% | 2.4% |
| 2013 | 5.1% | 6.1% |
| 2014 | 11.5% | 9.1% |
| 2015 | 0.8% | 0.0% |
| 2016 | 0.7% | 0.8% |
| 2017 | 1.8% | 2.0% |

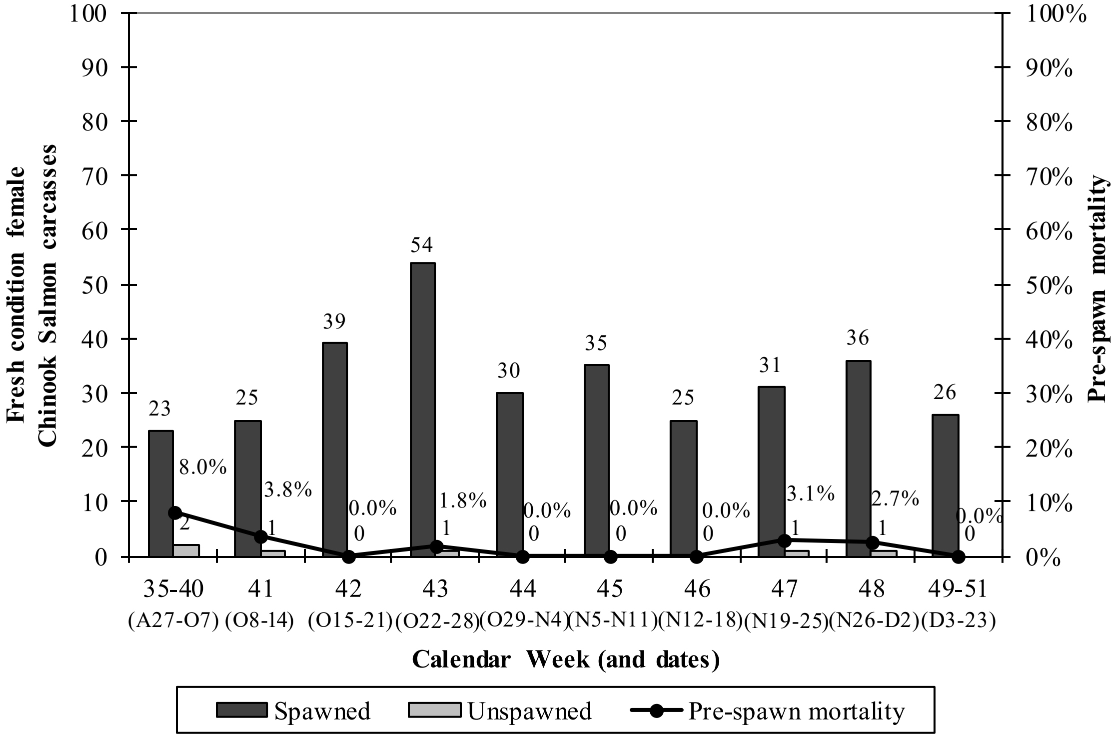

Figure 4. Weekly pre-spawn mortality from fresh (conditions 1 and 2) female Chinook Salmon carcasses, Trinity River surveys 2017. Calendar weeks 36–40 and 48–51 were combined because sample sizes were low in at least one of those weeks.

Table 8. Pre-spawn mortality rates of natural- and hatchery-origin Coho Salmon, Trinity River surveys, 2009–2017. Note that these pre-spawn mortality rates were based on data only collected through late December. Spawning success often varies, typically improving over time, and our surveys did not extend over the entire Coho Salmon spawning period.

| Year | Natural-origin | Hatchery-origin | Combined |
|---|---|---|---|
| 2009 | 7.1% | 20.3% | 16.1% |
| 2010 | 21.9% | 16.2% | 17.0% |
| 2011 | 6.1% | 15.1% | 11.6% |
| 2012 | 3.6% | 11.8% | 10.4% |
| 2013 | 10.7% | 6.1% | 6.6% |
| 2014 | 35.1% | 28.5% | 29.8% |
| 2015 | 33.3% [a] | 50.0% [a] | 40.0% [a] |
| 2016 | 0.0% [b] | 0.0% [b] | 0.0% [b] |
| 2017 | 0.0% [c] | - | 0.0% [c] |

[a] the sample size for Coho Salmon was only five carcasses in 2015

[b] the sample size for Coho Salmon was only two carcasses in 2016

[c] the sample size for Coho Salmon was only one carcass in 2017

## Salmon Redds

During the 2017 surveys, 1,982 salmon redds were identified (Table 9). A majority of the redds (1,600; 80.7%) were estimated to have been constructed by natural-origin female Chinook Salmon, while hatchery-origin female Chinook Salmon accounted for 348 (17.6%) of the total redd count (Table 10). Coho Salmon redds accounted for 34 (1.7%) of the surveyed redds. The low numbers of spawned female Coho Salmon carcasses collected in 2017 precluded the differentiation of hatchery- and natural-origin Coho Salmon redds. Note that Coho Salmon spawning continued beyond our survey season, and our estimates of Coho Salmon redds are included only to differentiate them from Chinook Salmon redds.

Natural-origin Chinook Salmon redds were constructed throughout most of the mainstem Trinity River in 2017, though the lowest numbers were in the downstream-most reaches (Figure 5). Hatchery-origin Chinook and Coho (both origin types) salmon redds were consistently skewed toward Lewiston Dam. Little to no spawning by hatchery-origin Chinook Salmon or Coho Salmon was detected downstream of Reach 7.

Table 9. Redd counts (before species differentiation) by week and reach, Trinity River surveys 2017. NS = No Survey for scheduled surveys that were missed. Dashes (-) represent days when surveys were not scheduled.

| Week | Reach | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| start | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 10 | 12 | 13 | 14 | Total |
| Aug. 27 | 0 | - | - | - | - | - | - | - | - | - | - | - | - |
| Sep. 3 | 1 | 0 | 0 | NS | NS | NS | NS | - | - | - | - | - | 1 |
| Sep. 10 | 6 | 3 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | - | - | - | 14 |
| Sep. 17 | 13 | 13 | 3 | 10 | 15 | 2 | 1 | - | - | - | - | - | 57 |
| Sep. 24 | 8 | 13 | 16 | 34 | 32 | 18 | NS | 3 | 3 | - | - | - | 127 |
| Oct. 1 | 22 | 52 | 21 | 29 | 24 | 44 | NS | - | - | 0 | 0 | 0 | 192 |
| Oct. 8 | 6 | 14 | 26 | 21 | 41 | 53 | 60 | 122 | 3 | - | - | - | 346 |
| Oct. 15 | 16 | 15 | 21 | 17 | 25 | 37 | 17 | - | - | 16 | 2 | NS | 166 |
| Oct. 22 | 8 | 5 | 4 | 17 | 31 | 21 | 54 | 78 | NS | - | - | - | 218 |
| Oct. 29 | 8 | 6 | 13 | 5 | 43 | 15 | 26 | - | - | 16 | 32 | 17 | 181 |
| Nov. 5 | 16 | 8 | 19 | 10 | 15 | 3 | 22 | 111 | 96 | - | - | - | 300 |
| Nov. 12 | 21 | 25 | 14 | 7 | 8 | 3 | 7 | - | - | NS | NS | NS | 85 |
| Nov. 19 | 51 | 18 | 16 | NS | NS | 1 | NS | NS[a] | NS[a] | - | - | - | 86 |
| Nov. 26 | 21 | 19 | 17 | 10 | 10 | 4 | 2 | 44 | 27 | NS[a] | NS | NS | 154 |
| Dec. 3 | 8 | 8 | 3 | 0 | 5 | 2 | 0 | NS[a] | NS[a] | 6 | - | - | 32 |
| Dec. 10 | 5 | 4 | 0 | 0 | 0 | NS | NS | 1 | 6 | NS[a] | 3 | 2 | 21 |
| Dec. 17 | 0 | 0 | 1 | 0 | - | - | - | - | - | 1 | 0 | - | 2 |
| Total | 210 | 203 | 175 | 161 | 251 | 204 | 189 | 359 | 135 | 39 | 37 | 19 | 1,982 |

[a] missed survey rescheduled for the following week

Table 10. Estimated numbers and bootstrap-generated 95% confidence intervals of salmon redds by species and origin observed in the mainstem Trinity River, 2017. Natural- and hatchery-origin estimates are for the maternal first generation only.

| Species | Origin | Redd estimate | 95% confidence limits | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Chinook Salmon | All | 1,948 [b] | - | - |
| | Natural | 1,600 | 1,435 | 1,762 |
| | Hatchery | 348 | 186 | 348 |
| Coho Salmon [a] | All | 34 [b] | - | - |
| | Natural | NA [c] | - | - |
| | Hatchery | NA [c] | - | - |

[a] The survey season only partially covers the Coho Salmon spawning period

[b] Confidence intervals are generated with both Chinook and Coho salmon data. Not enough female Coho Salmon carcasses were found in 2017 to calculate a confidence interval.

[c] Not enough Coho Salmon carcasses were observed in 2017 to calculate separate estimates for natural- and hatchery-origin Coho Salmon redds.

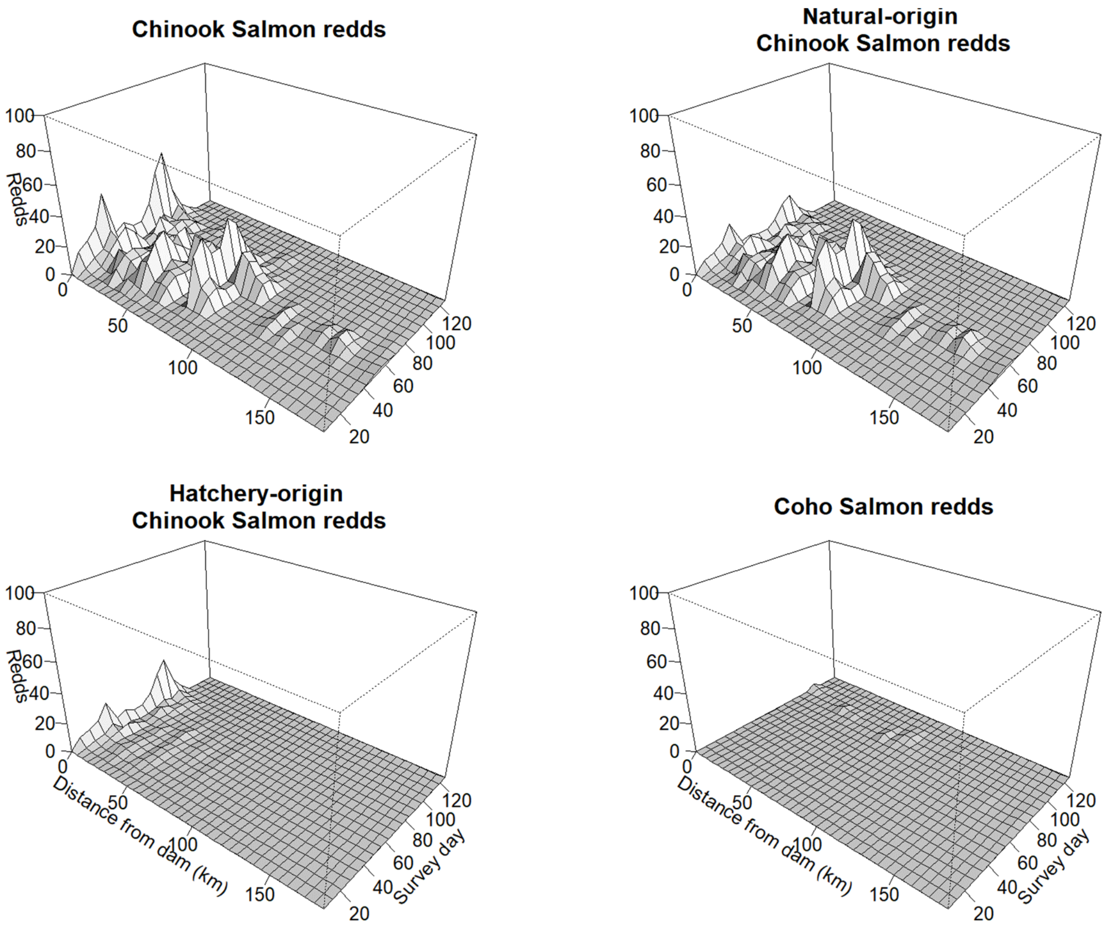

Figure 5. Spatiotemporal distribution of mainstem Trinity River salmon redds from Lewiston Dam to Weitchpec, 2017. Surveys were not conducted in Reaches 8 (rkm 107.6–117.4) and 11 (rkm 63.4–79.1). The Coho Salmon carcass data precluded the differentiation of hatchery- and natural-origin groups. Survey day 1 = September 1.

### *Redd–Carcass Relationship*

Chinook Salmon redds [natural log-(*ln*-) transformed] and fresh spawned female Chinook Salmon carcasses (*ln*-transformed) in Reaches 1 and 2 from 2012 to 2017 had a positive linear correlation ($R^2 = 0.8387$, $p < 0.001$; Figure 6). A significant difference was detected between a slope of '1' and the slope of the linear regression between log-transformed Chinook Salmon redd estimates and Chinook Salmon carcass estimates (slope = 0.637, 95% CI: 0.465–0.809).

### *Redd Abundance and Distribution: System Scale*

From 2002 to 2017, the number of mainstem salmon redds ranged between 1,671 and 7,588 redds and generally decreased over time ($R^2 = 0.2984$, $p = 0.03$; Figure 7). The number of redds constructed by natural-origin Chinook Salmon in the mainstem Trinity River also generally decreased over time, but with no significant trend ($R^2 = 0.0488$, $p = 0.4$), while the number of redds constructed by hatchery-origin Chinook Salmon trended downward ($R^2 = 0.5175$, $p < 0.001$) over this time frame.

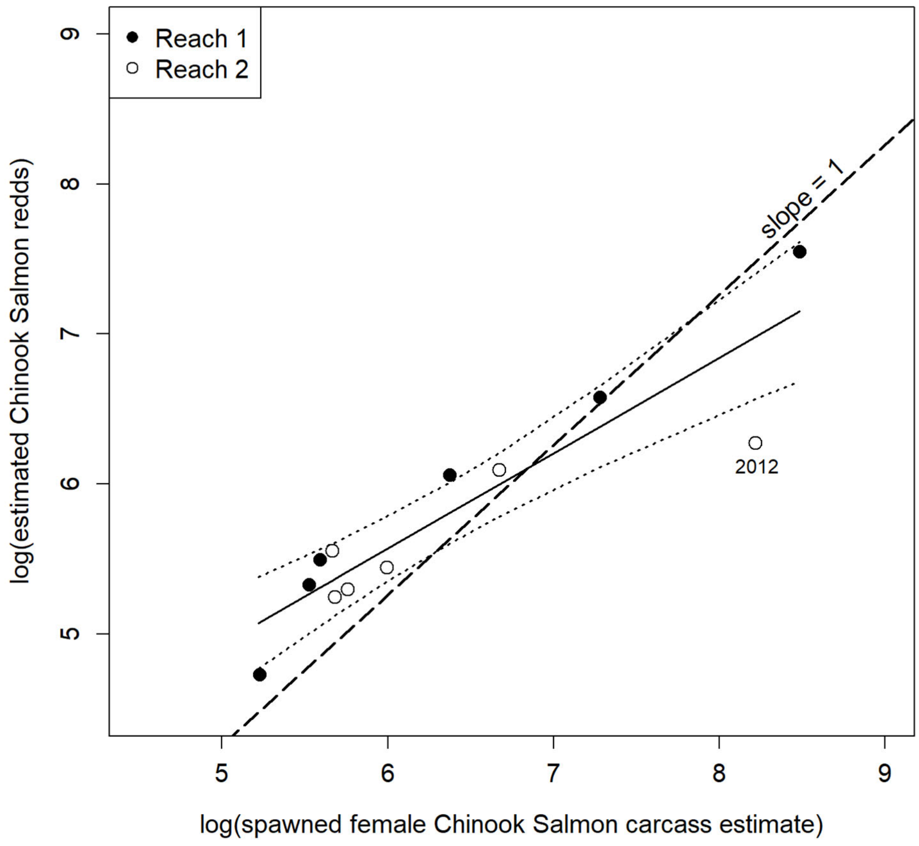

Figure 6. Relationship between counts of *ln*-transformed Chinook Salmon redds and *ln*-transformed estimates of spawned female Chinook Salmon carcasses in Survey Reaches 1 and 2 (solid line), 2012–2017. The dashed line is included to represent a slope of '1', which would be the slope of two perfectly proportional variables. Dotted lines represent 95% confidence limits of the linear model.

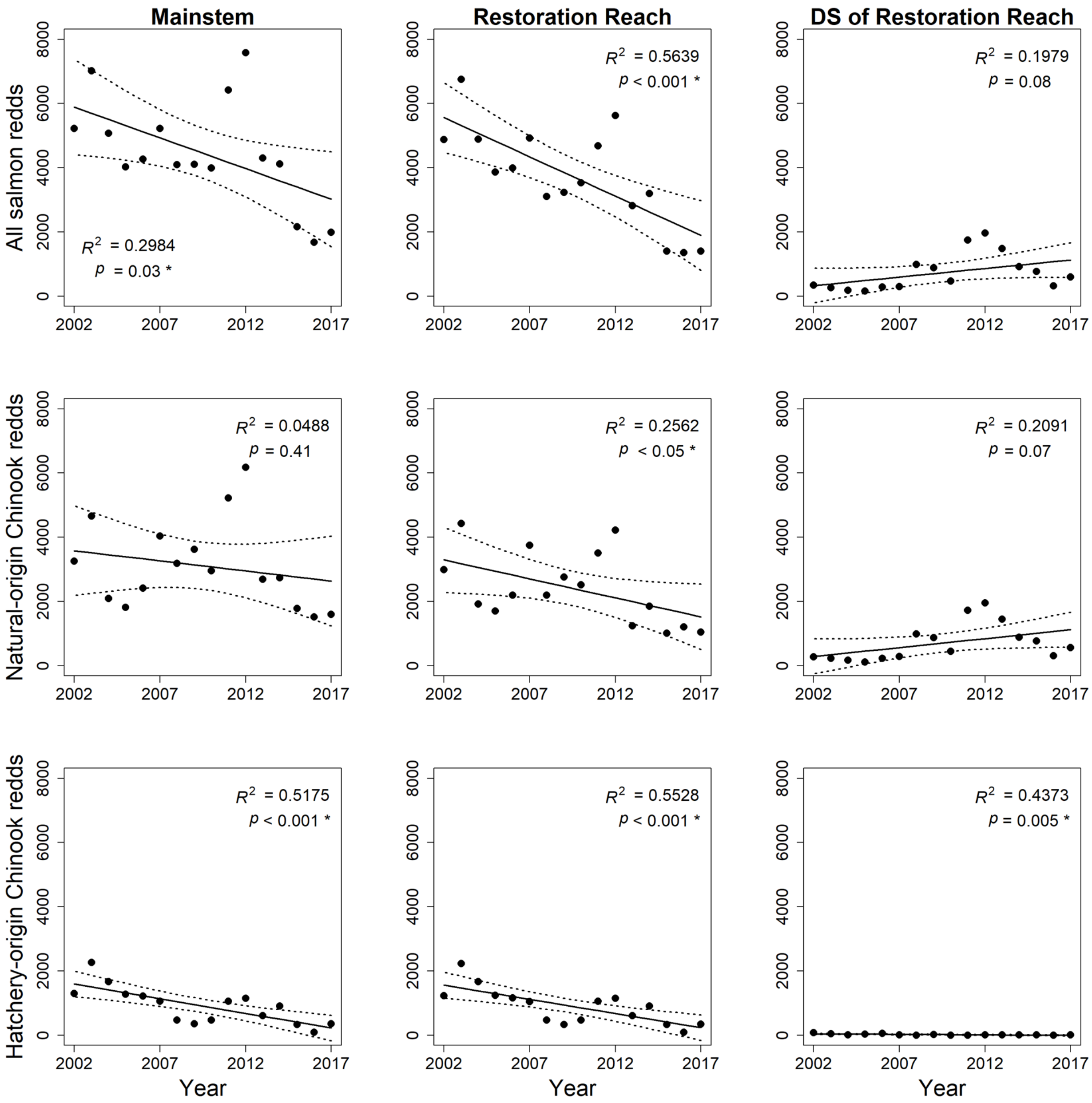

Figure 7. Estimated number of redds constructed in the entire mainstem Trinity River (left), within the restoration reach (center), and downstream (DS) of the restoration reach (right) by all Chinook Salmon (top), natural-origin Chinook Salmon (middle), and hatchery-origin Chinook Salmon (bottom) from 2002 to 2017. Each plot includes a linear model with the $R^2$ value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).

The trends in redd abundance within the restoration reach were similar to the mainstem-wide data (Figure 7). From 2002 to 2017, the number of redds constructed annually by natural- and hatchery-origin Chinook Salmon in the restoration reach were variable but trended downward ($R^2$ = 0.2562, $p < 0.05$ and $R^2$ = 0.5528, $p < 0.001$, respectively).

Downstream of the restoration reach the number of natural-origin Chinook Salmon redds constructed from 2002 to 2017 generally increased but with no significant trend ($R^2$ = 0.1979, $p = 0.07$; Figure 7). A significant decrease in hatchery-origin Chinook Salmon redds was detected downstream of the restoration reach ($R^2$ = 0.4773, $p = 0.005$), but relatively few to no redds were constructed by hatchery-origin Chinook Salmon in this section of river. From 2002 to 2006 between 33 and 72 redds per year were estimated to be constructed by hatchery-origin Chinook Salmon downstream of the restoration reach except for 2004 when none were estimated. From 2007 to 2017 between 0 and 14 redds per year were estimated to be constructed by hatchery-origin Chinook Salmon downstream of the restoration reach and only zero or one redd was estimated in 8 of those 11 years.

In the section of river from Lewiston Dam to Cedar Flat (Reaches 1–10), the mean distance from the dam of redds constructed by natural- (49.2 km) and hatchery-origin (14.2 km) Chinook Salmon were both the highest in the 16-year history of this project. From 2002 to 2016, the mean distance of redds from the dam ranged between 15.3 and 48.9 km for natural-origin and between 2.1 and 7.5 km for hatchery-origin Chinook Salmon. In this section of river, the mean distance from Lewiston Dam of natural-origin Chinook Salmon redds shifted downstream from 2002 to 2017 ($R^2$ = 0.7697, $p < 0.001$; Figure 8). This trend, to a lesser degree, was also evident for redds constructed by hatchery-origin Chinook Salmon ($R^2$ = 0.2508, $p < 0.05$), which also consistently spawned near Lewiston Dam.

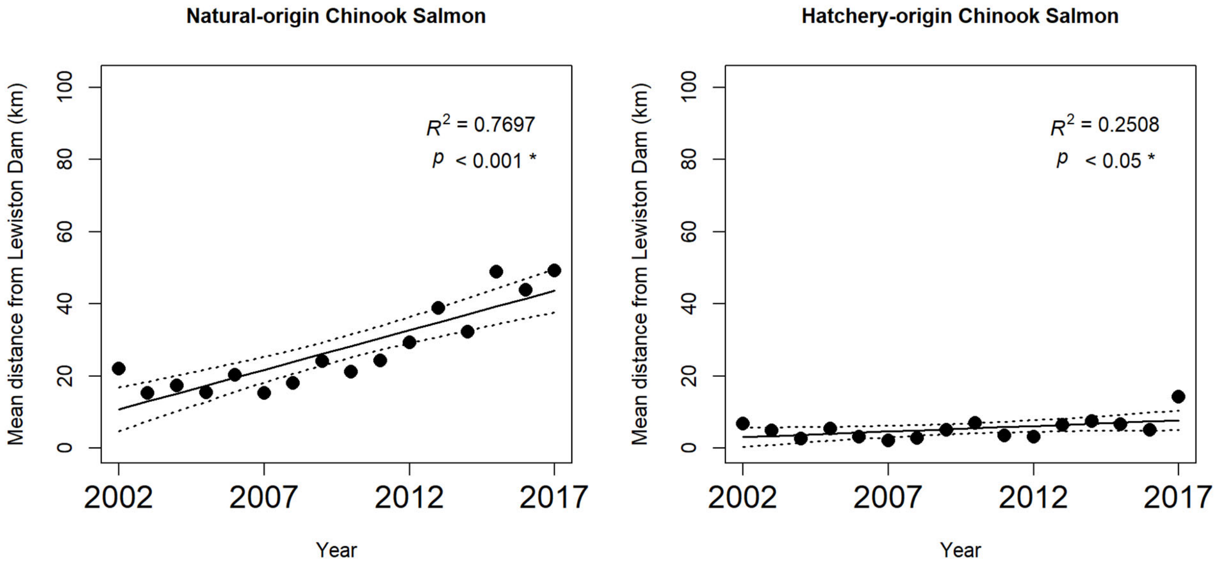

Figure 8. Mean distance from Lewiston Dam of redds constructed by natural- (left) and hatchery-origin (right) Chinook Salmon females between Lewiston Dam and Cedar Flat (0–102.8 km from Lewiston Dam; Reaches 1–10) on the mainstem Trinity River, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines).

### *Redd Abundance and Distribution: Reach Scale*

Long-term changes in natural-origin Chinook Salmon redd distribution were detected at the reach scale (~10–20 km). Redds by natural-origin Chinook Salmon most drastically trended downward in the Lewiston ($R^2 = 0.5252$, $p = 0.002$) and Limekiln ($R^2 = 0.3047$, $p = 0.03$) reaches and generally decreased, although not significantly, in the Douglas City reach from 2002 to 2017 (Figure 9). The number of redds between the Junction City and Del Loma reaches generally increased over this time period and generally decreased, although not significantly, in the Salyer Gorge, Willow Creek Valley, and Hoopa Valley reaches over the shorter time period from 2007 to 2017. To account for annual variation in run size, the proportions of natural-origin Chinook Salmon redds within each of the ten reach-scale segments relative to the annual total in the entire mainstem river were compared (Figure 10). This analysis revealed a shift in spawning distribution, where natural-origin Chinook Salmon redds decreased in the two upstream-most reaches [Lewiston ($R^2 = 0.8034$, $p < 0.001$) and Limekiln ($R^2 = 0.4771$, $p = 0.003$)], did not significantly change in the Douglas City reach, and increased in the mid-river reaches [Junction City ($R^2 = 0.5326$, $p = 0.001$), North Fork ($R^2 = 0.5184$, $p = 0.002$), Big Bar ($R^2 = 0.6798$, $p < 0.001$), and Del Loma ($R^2 = 0.7897$, $p < 0.001$) reaches]. The proportion of redds in the downstream-most reaches (Salyer Gorge, Willow Creek Valley, and Hoopa Valley) have not changed significantly.

Most hatchery-origin Chinook Salmon redds were constructed in the Lewiston rehabilitation reach (range = 72–1,888 redds/year, mean = 770 redds/year) and, to a lesser degree, in the Limekiln rehabilitation reach (range = 19–236 redds/year, mean = 84 redds/year) from 2002 to 2017. Over this time frame, the abundance of hatchery-origin Chinook Salmon redds significantly decreased in the Lewiston reach ($R^2 = 0.5648$, $p < 0.001$) and generally decreased in the Limekiln reach (Figure 11). Fewer hatchery-origin Chinook Salmon redds were found downstream of the Limekiln reach to the Del Loma reach where their redd numbers averaged between 7 and 18 per year in each reach and only changed significantly in the Del Loma reach ($R^2 = 0.2753$, $p = 0.04$). No redds were predicted to be associated with hatchery-origin Chinook Salmon downstream of the Del Loma reach.

To account for annual variation in run size, the proportions of hatchery-origin Chinook Salmon redds within each of the reaches were compared to the annual total in the entire mainstem river (Figure 12). The majority of hatchery-origin Chinook Salmon redds were consistently observed in the Lewiston reach (range = 51.7%–95.4%, mean = 82.3%) and, to a smaller degree, in the Limekiln reach (range = 3.5%–30.2%, mean = 11.5%) from 2002 to 2017. The proportion of hatchery-origin Chinook Salmon redds in the Lewiston reach generally decreased while the proportion of redds in the Limekiln reach significantly increased ($R^2 = 0.4229$, $p = 0.006$) over this time period. The mean proportion of hatchery-origin Chinook Salmon redds in each reach downstream of the Limekiln reach ranged between 0.0% and 2.2% and did not change significantly in any of the reaches (Figure 12).

### *Redd Abundance and Distribution: Site Scale*

The proportional abundance of natural-origin Chinook Salmon within the 44 site-scale river sections show a range of long-term (2002–2017) trends. Most sites (21) did not show a significant change, 17 sites showed an increasing trend, and 6 sites showed a decreasing trend (Appendix D). The three upstream-most sites (Lewiston Hatchery, Sven Olbertson, and Old Bridge sites) underwent significant decreases in the proportion of natural-origin

Chinook Salmon redds, followed by a less drastic general decrease at the Sawmill site and significant decrease at the Upper Rush Creek site. Most sections from the Lower Rush Creek site to the Douglas City site did not significantly change. At each site downstream of the Douglas City site, from the Reading Creek site to the Bagdad site, the proportion of natural-origin Chinook Salmon redds either generally or significantly increased.

Of the 22 mechanical channel rehabilitation sites with at least five years of post-construction data, the proportional abundance of natural-origin Chinook Salmon redds trended upward at 7 sites, trended downward at 2 sites, and displayed no significant change at 13 sites (Appendix E). Similar to the long-term trends, the proportional abundance of natural-origin Chinook Salmon redds generally or significantly decreased in the upstream-most sites (Lewiston Hatchery to Sawmill sites), did not change in the middle sites (Dark Gulch to Upper Douglas City sites), and generally or significantly increased in most of the downstream-most sites (Douglas City to Pear Tree Bar sites).

Hatchery-origin Chinook Salmon redds were not distributed throughout the restoration sites and were too few or absent to merit statistical analysis at the site scale. Like at the reach scale, the proportion of hatchery-origin fish were at or close to zero at most sites below the Limekiln reach from 2002 to 2017.

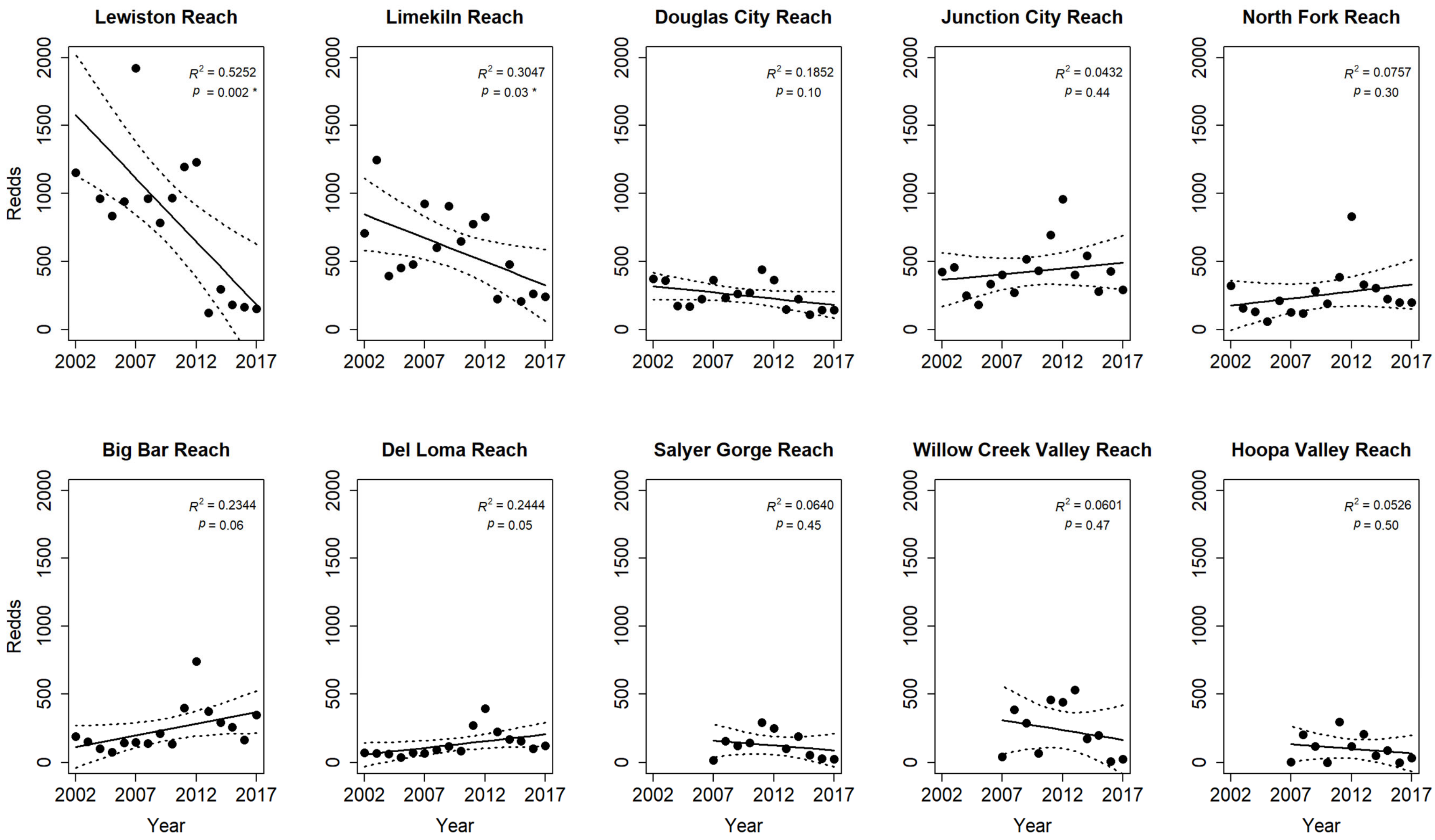

Figure 9. Estimated number of mainstem Trinity River natural-origin Chinook Salmon redds within ten reach-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines).

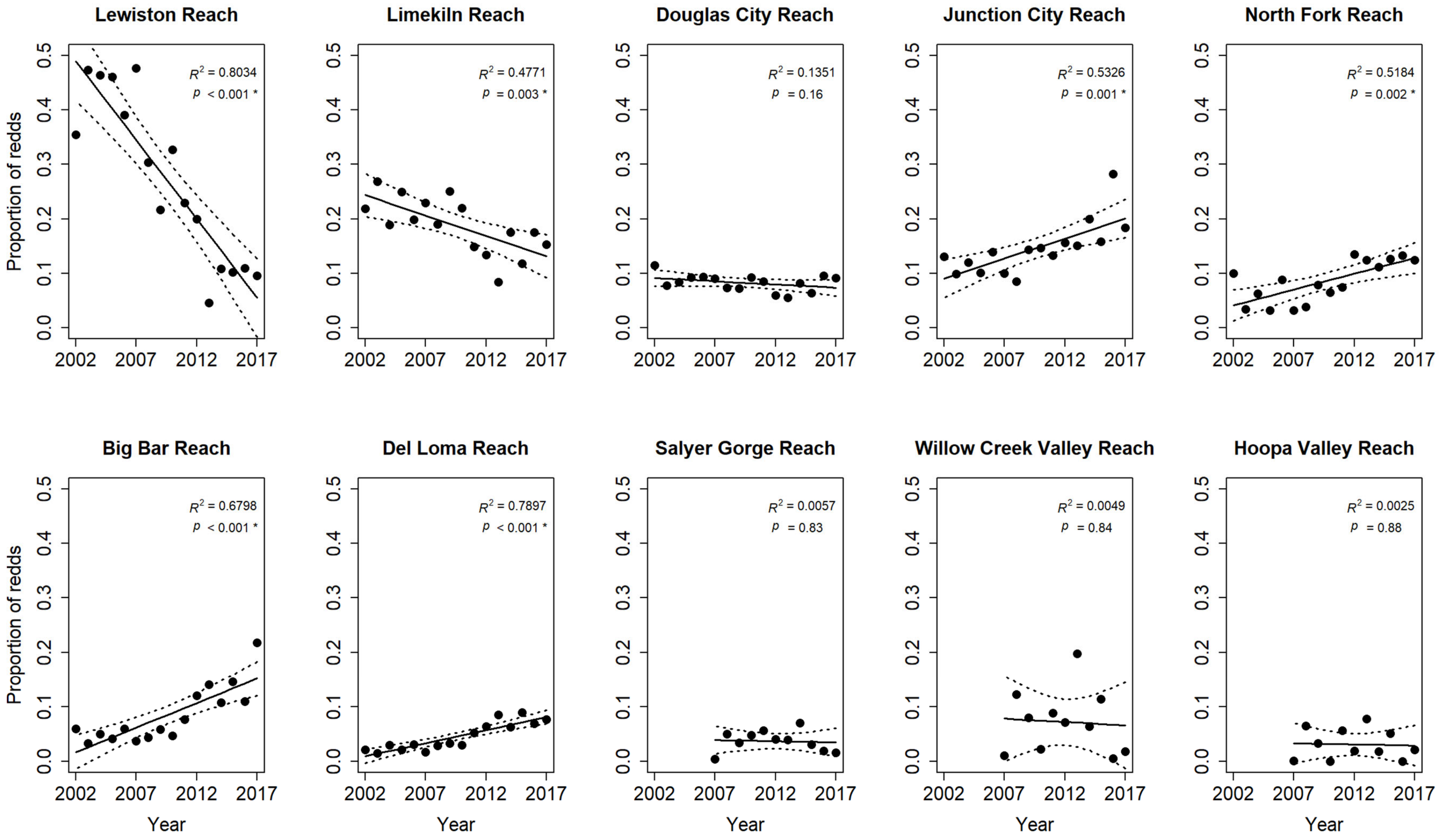

Figure 10. Proportions of mainstem Trinity River natural-origin Chinook Salmon redds relative to the total mainstem count of natural-origin Chinook Salmon redds within ten reach-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, *p*-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines).

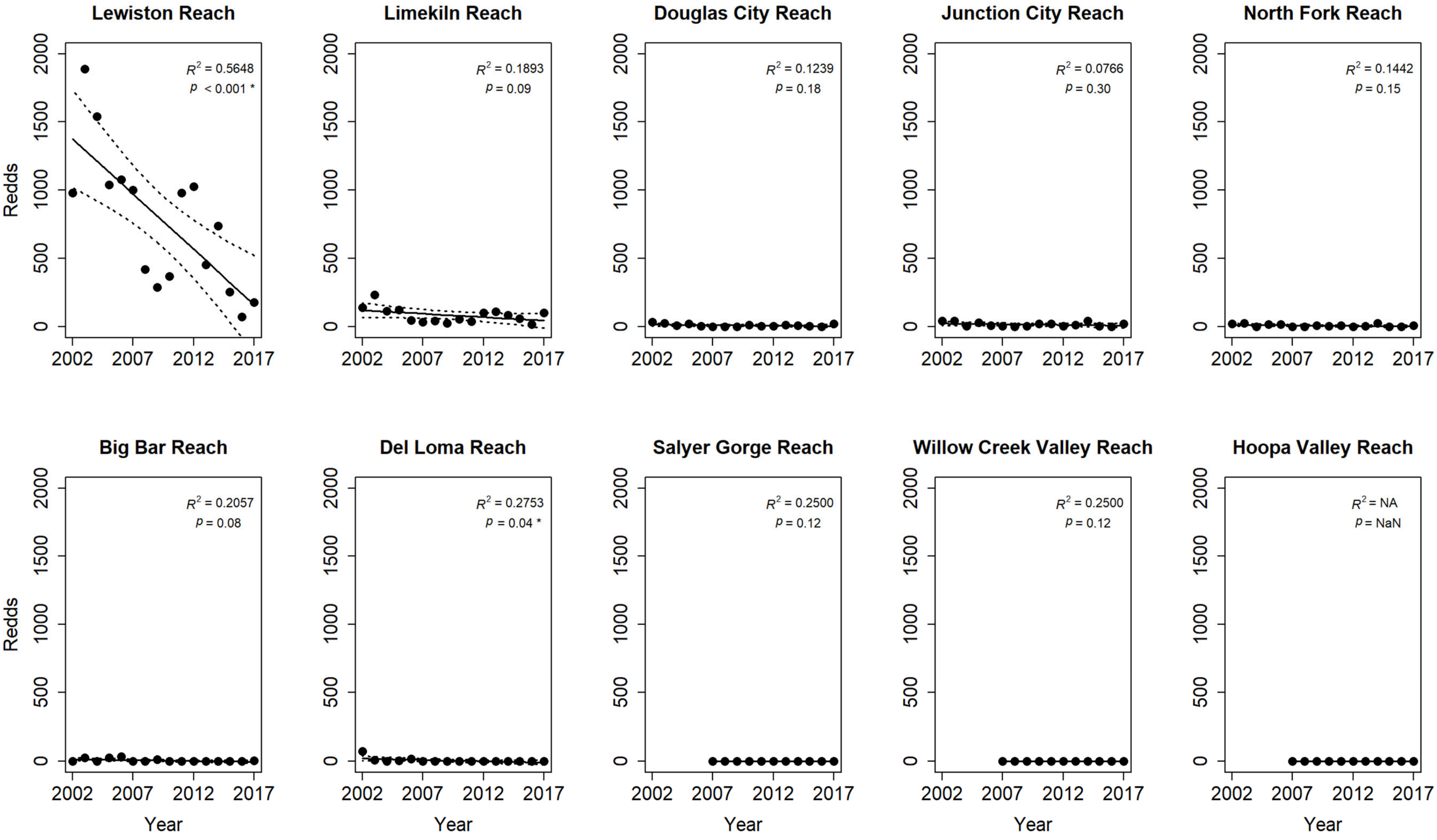

Figure 11. Estimated number of mainstem Trinity River hatchery-origin Chinook Salmon redds within ten reach-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).

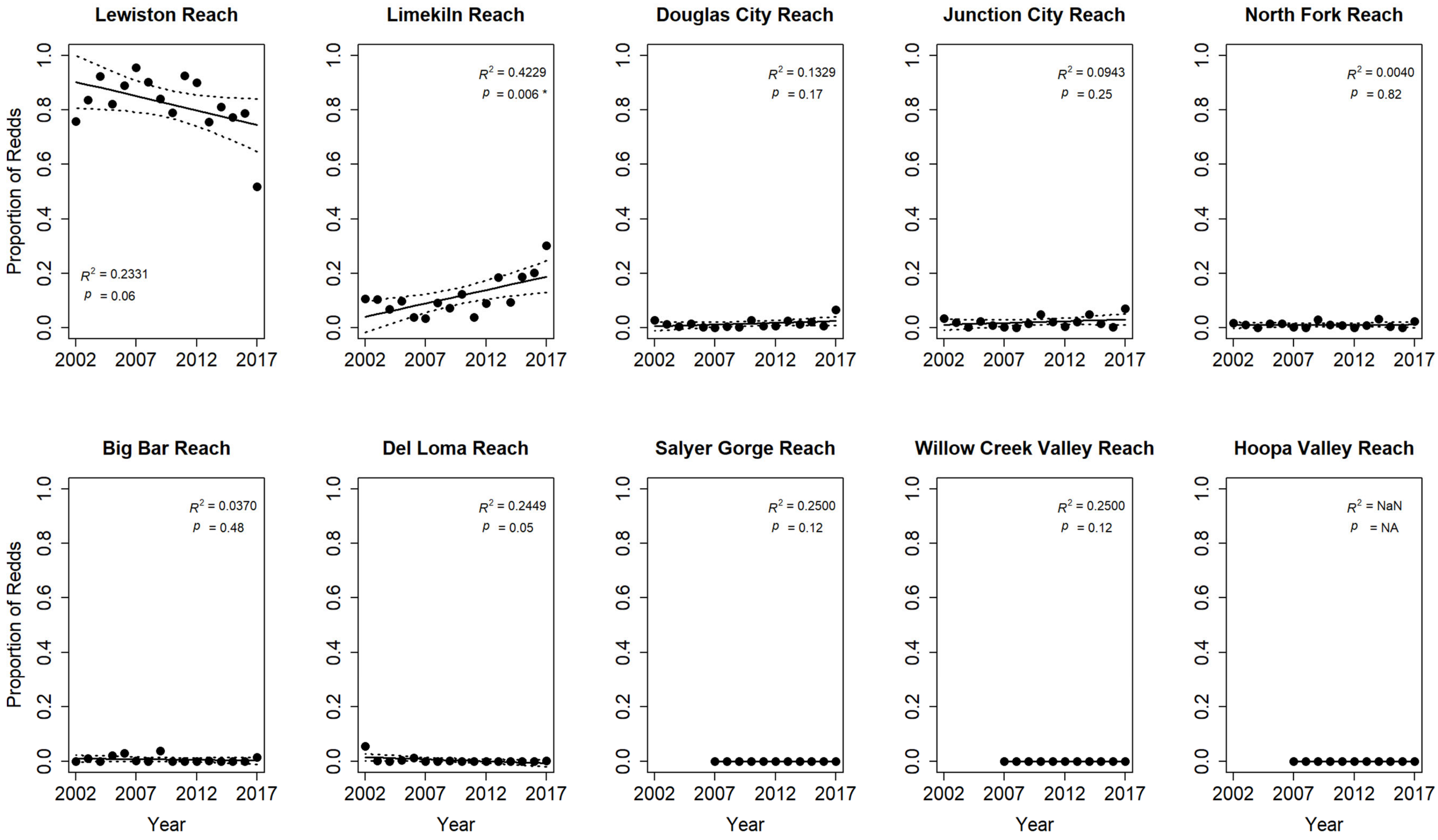

Figure 12. Proportions of mainstem Trinity River hatchery-origin Chinook Salmon redds relative to the total mainstem count of hatchery-origin Chinook Salmon redds within ten reach-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines).

## Discussion

Redd counts from the 2017 spawning season were the second lowest since this survey's inception in 2002 and salmon carcass estimates were the third lowest. Our 2017 results are consistent with the California Department of Fish and Wildlife Chinook Salmon natural spawner escapement estimates for the Trinity River Basin, which estimated the third lowest numbers of both spring- and fall-run Chinook Salmon since 2002 (CDFW 2018a, 2018b).

Flows were generally stable throughout the survey period in the upper reaches and most of the survey period in the lower reaches. Rain events elevated water turbidity and the reduced visibility impaired the ability to detect redds and carcasses in the lower reaches from mid- to late November. Though scheduled lower river (Reaches 12–14) surveys in mid- to late November were cancelled due to high flow and poor visibility, spawning is typically sparse in these reaches and any missed redds from this section would likely have only been a minor contribution to the total redd count.

The analyses of long-term data from our spawning surveys provide insight into the dynamics of Chinook Salmon spawning activity on the Trinity River. The main themes that emerge are 1) the overall abundance of natural-origin Chinook Salmon redds did not change significantly from 2002 to 2017, 2) straying and spawning of hatchery-origin salmon is generally confined to areas near the hatchery below Lewiston Dam, 3) the spatial distribution of natural-origin Chinook Salmon spawning continues to change, and 4) pre-spawn mortality has been relatively low in recent years.

The annual natural-origin Chinook Salmon redd count from 2002 to 2017 ranged between 1,516 (in 2016) and 6,170 (in 2012). Spawner abundance was hypothesized to increase following restoration actions (TRRP and ESSA 2009), but the abundance of natural-origin Chinook Salmon redds in the mainstem Trinity River from 2002 to 2017 did not significantly change (Figure 7). Other factors (e.g., harvest, ocean conditions, in-river conditions, etc.) that influence in-river escapement may have masked any responses in spawning activity to river restoration. Shifts in abundance are common to Chinook Salmon populations (Mantua et al. 1997; Brown 2002) and are evident in the Klamath Basin (CDFW 2018a, 2018b). The estimates of Trinity River natural-spawner adult escapement (2,532 spring-run and 6,072 fall-run; CDFW 2018a, 2018b) in 2017 were notably below the TRRP annual river escapement goal of 68,000 natural-origin Chinook Salmon spawners (6,000 spring-run adults and 62,000 fall-run adults).

Although the abundance of natural-origin Chinook Salmon redds did not show a significant trend from 2002 to 2017, the spatial distribution of redds shifted downstream. The increase in mean distance from Lewiston Dam of natural-origin Chinook Salmon redds was previously documented (Chamberlain et al. 2012; Rupert et al. 2017a, 2017b) and data collected in 2017 continue to follow this trend. This shift is consistent with the IAP's suggestion that changes in longitudinal redd distribution would happen within three to four brood cycles following restoration activities (TRRP and ESSA 2009).

The abundance of hatchery-origin Chinook Salmon redds (redds constructed by hatchery-produced females regardless of male origin) decreased significantly from 2002 to 2017, as evident in the Lewiston Reach where the majority of hatchery-origin Chinook Salmon spawn (Figure 11). Also, even though the distribution of hatchery-origin Chinook Salmon redds has remained skewed towards the TRH (Figure 5), the proportion of hatchery-origin Chinook Salmon redds has generally decreased in the Lewiston Reach and increased in the Limekiln Reach (Figure 12). The number and release timing of hatchery-reared juvenile Chinook Salmon has remained relatively constant over these years, so the reason for the decrease in abundance of hatchery-origin Chinook Salmon redds is unclear. While IAP objectives advocate limiting the genetic interaction of hatchery- and natural-origin Chinook Salmon, and having fewer hatchery-origin Chinook Salmon redds on the spawning grounds does support these objectives, further investigations are suggested to examine the causes for this decrease in hatchery-origin Chinook Salmon redds.

Reach-scale analyses revealed the clearest resolution for analyzing spawning distribution shifts of natural-origin Chinook Salmon. The proportion of natural-origin Chinook Salmon that spawned near TRH and Lewiston Dam (Lewiston and Limekiln reaches) decreased from 2002 to 2017 and more spawned in the mid-river sections (Junction City–Del Loma reaches; Figure 10). This shift is contrary to the IAP hypothesis that redd abundance in the reaches below the North Fork Trinity River would not increase until escapement began to approach restoration goals (TRRP and ESSA 2009). TRRP restoration actions may therefore be influencing a larger portion of the Trinity River than expected. Presumably, flow management is the primary factor for the spawning distribution shift of natural-origin Chinook Salmon since the effects of flow extend downstream much further than the generally localized effects of mechanical channel rehabilitation, course sediment augmentation, and watershed (tributaries) restoration.

Changes in redd abundance at the site scale was specifically used to evaluate the effect of TRRP channel rehabilitation activities. Our analysis revealed no clear post-construction response at rehabilitation sites. As reported in Rupert et al. (2017a), despite being the smallest scale used in our analyses, the site scale may still be too spatially broad and too few years have passed since construction to detect responses to restoration. A positive response in the abundance of Chinook Salmon redds to channel rehabilitation may take many generations that encompass several years of geomorphic change and restoration site maturation. TRRP channel rehabilitation sites only secondarily affect spawning habitat since many constructed features are intended to increase and diversify juvenile rearing habitats and/or change the geomorphology of the site. The long-term effects of flow management, however, are intended to increase spawning habitat, though this would presumably affect all sites regardless of channel rehabilitation treatments (TRRP and ESSA 2009).

The relationship between redd counts and the estimated number of spawned female Chinook Salmon in Reaches 1 and 2 using the 2012–2017 data set indicate a density-dependent redd observation bias (Figure 6). This is contrary to the result that Rupert et al. (2017a) found with just the 2012–2014 data set. The Reach 2 data point from 2012, the largest run year, appears to have a negative influence on the slope of the regression line. Large spawning runs in the future may help validate or refute the density-dependent observation bias within this section of the river.

The importance of describing pre-spawn mortality has increased in recent years with ongoing drought conditions and associated higher risks of epizootic events. Aguilar et al. (1996) reported that pre-spawn mortality for Chinook Salmon ranged between 1.1% and 44.9% in the mainstem Trinity River above the North Fork confluence from 1978 to 1982 and 1987 to 1995. In comparison, pre-spawn mortality rates that we measured were relatively low (between 0.0% and 9.5% from 2009 to 2016 and 2.0% in 2017) in this section of the river. Salmon pre-spawn mortality rates are typically highest at the beginning of the spawning season and decrease as the season advances (Aguilar et al. 1996; Gough and Williamson 2012). Too few pre-spawn mortality Chinook Salmon carcasses (six) were observed in 2017 to conduct a temporal analysis. Aguilar et al. (1996) also reported a positive correlation between pre-spawn mortality and run size for Trinity River Chinook Salmon from 1978 to 1995. After adding the data from 2017, which had the second lowest redd count and third lowest pre-spawn mortality rate since 2009, to the data from 2009 to 2016, no correlation was detected between these two parameters in the restoration reach (Appendix F). The lack of correlation suggests that other factors beyond run size (i.e., river conditions, run timing, etc.) may be influencing pre-spawn mortality rates. The 2017 Coho Salmon run size was notably small and the carcasses sample size (n = 1 fresh female) was inadequate to assess pre-spawn mortality for this species. Interpretation of results pertaining to spawning success should take into account that pre-spawn mortality occurs outside of the temporal and spatial extend of the surveys. Pre-spawn mortality fish are available to our carcass survey because they expired prior to spawning. The spatiotemporal location of carcass recovery is unlikely to be an accurate depiction of when and where fish were destined to spawn had they survived. For instance, pre-spawn mortality occurring in the Lower Klamath River for Trinity River-bound fish were not detectable during our Trinity River spawn surveys. Likewise, spring-run Chinook Salmon that expired well before the first surveys in September were also undetectable.

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# Appendices

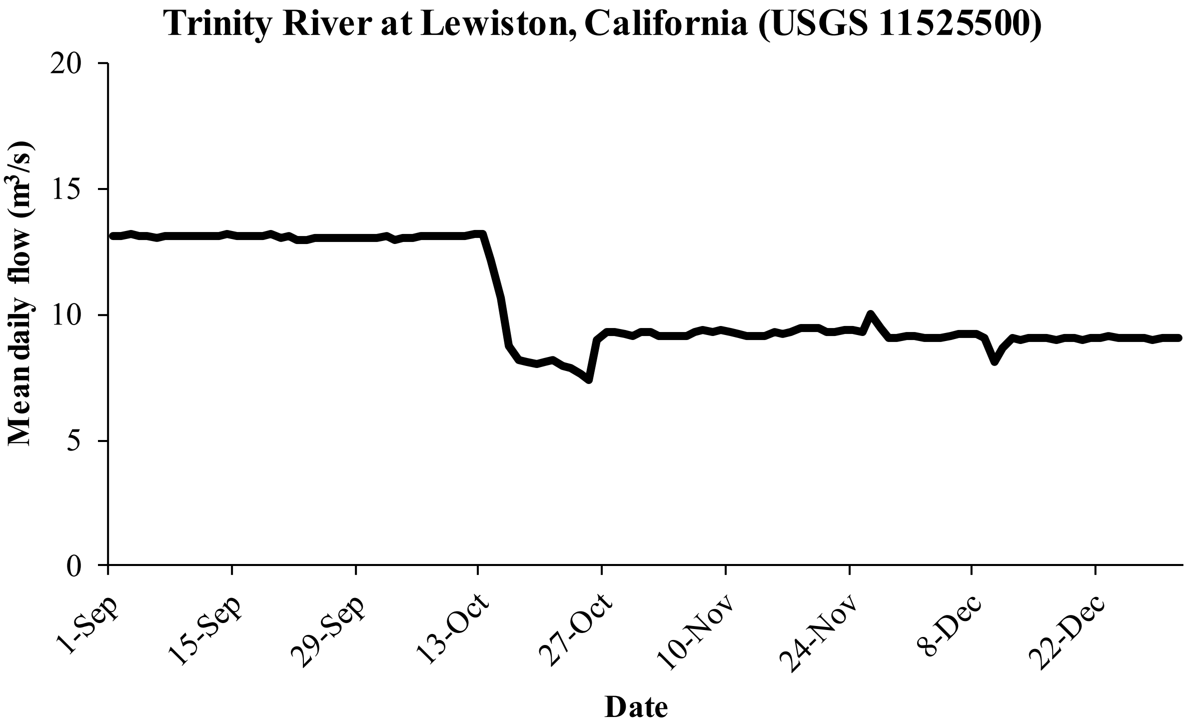
Appendix A. Trinity River water visibility by week and reach throughout the 2017 survey period. Grey boxes represent surveys with sub-optimal visibility. NS = No Survey for scheduled surveys that were missed. Dashes (-) represent days when surveys were not scheduled or performed.

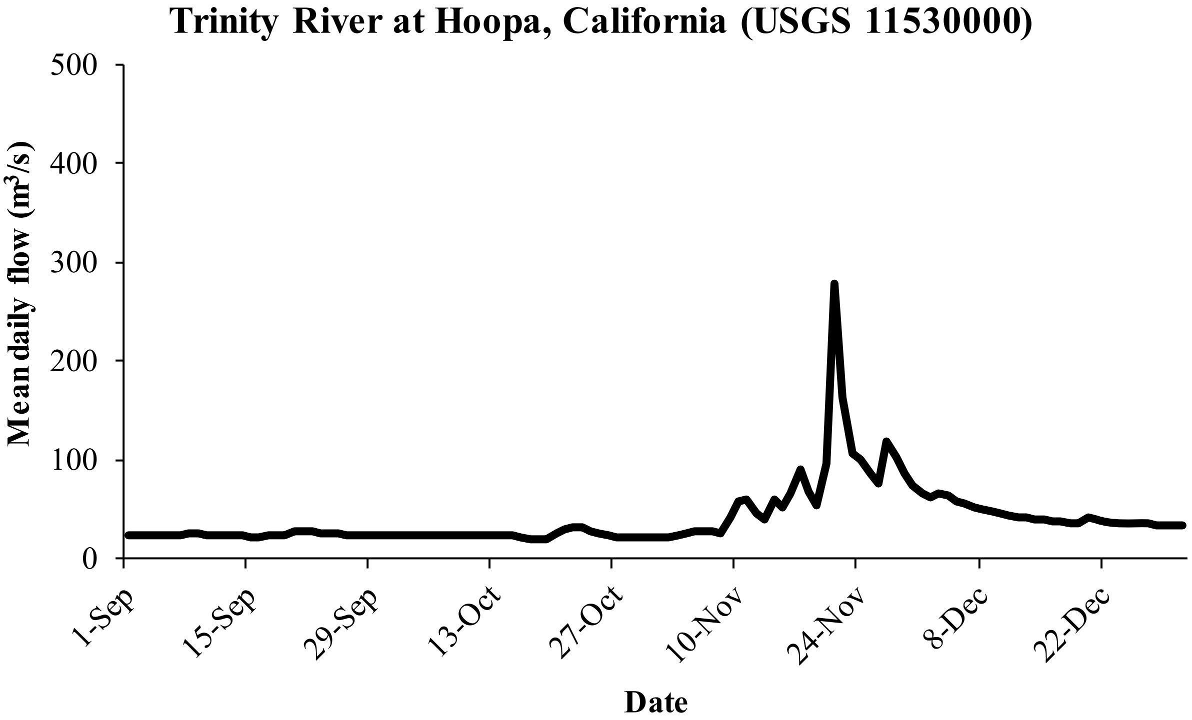
| Week | Reach | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| start | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 10 | 12 | 13 | 14 |
| Aug. 27 | 1.5-3.0 | - | - | - | - | - | - | - | - | - | - | - |
| Sep. 3 | 0.9-1.5 | 0.9-1.5 | 0.9-1.5 | NS | NS | NS | NS | - | - | - | - | - |
| Sep. 10 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 0.9-1.5 | 0.9-1.5 | <0.9 | 0.9-1.5 | - | - | - |
| Sep. 17 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 0.9-1.5[b] | 0.9-1.5[b] | - | - | - | - | - |
| Sep. 24 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 0.9-1.5 | NS | 0.9-1.5 | 0.9-1.5 | - | - | - |
| Oct. 1 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[a] | NS | - | - | 1.5-3.0 | >3.0 | >3.0 |
| Oct. 8 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | >3.0 | >3.0 | 1.5-3.0[b] | 0.9-1.5 | - | - | - |
| Oct. 15 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[a] | 0.9-1.5 | 1.5-3.0[a] | >3.0 | >3.0 | - | - | >3.0 | >3.0 | NS |
| Oct. 22 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[b] | 1.5-3.0[b] | 1.5-3.0[b] | NS | - | - | - |
| Oct. 29 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[b] | 1.5-3.0[b] | - | - | >3.0 | >3.0 | >3.0 |
| Nov. 5 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | >3.0 | >3.0 | >3.0 | >3.0 | - | - | - |
| Nov. 12 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[a] | 1.5-3.0 | 0.9-1.5 | 0.9-1.5 | - | - | NS | NS | NS |
| Nov. 19 | 1.5-3.0 | 1.5-3.0 | 0.9-1.5 | NS | NS | 0.9-1.5 | NS | NS[c] | NS[c] | - | - | - |
| Nov. 26 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[b] | 1.5-3.0[b] | 1.5-3.0[b] | 1.5-3.0 | 1.5-3.0 | 1.5-3.0 | >3.0 | NS[c] | NS | NS |
| Dec. 3 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[b] | 1.5-3.0[b] | 1.5-3.0[b] | >3.0 | >3.0 | NS[c] | NS[c] | 1.5-3.0 | - | - |
| Dec. 10 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[b] | 1.5-3.0[b] | 1.5-3.0 | NS | NS | 1.5-3.0[b] | >3.0 | NS[c] | >3.0 | 1.5-3.0 |
| Dec. 17 | 1.5-3.0 | 1.5-3.0 | 1.5-3.0[b] | >3.0 | - | - | - | - | - | >3.0 | >3.0 | - |

[a] this is the higher visibilty reported by the two crews. The other crew reported visibilty 0.9-1.5 m

[b] this is the lesser visibilty reported by the two crews. The other crew reported visibilty >3.0 m

[c] missed survey rescheduled for following week





Appendix B. Trinity River mean daily discharge at Lewiston (USGS Gage 11525500) and Hoopa, California (USGS Gage 11530000) during the 2017 survey season.

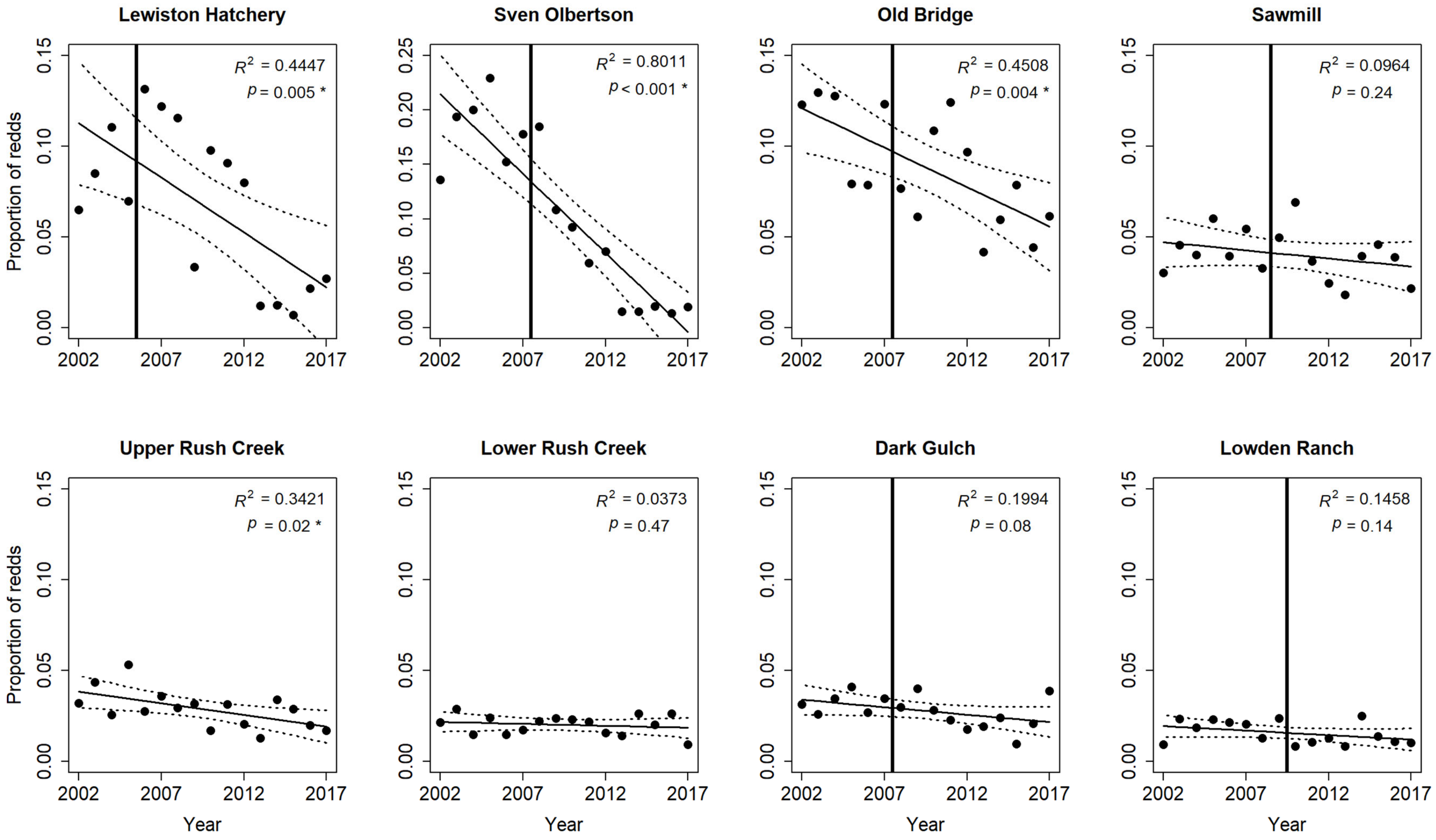
Appendix C. Pre-spawn mortality numbers by week and reach of unmarked and ad-clipped fresh (conditions 1 and 2) female Chinook Salmon carcasses, mainstem Trinity River surveys 2017. Also included are weekly pre-spawn mortality proportions among like mark-type carcasses. Ad-clipped carcass numbers were not expanded by CWT-specific production multipliers and are therefore about 25% of hatchery-origin carcass numbers. Likewise, unmarked carcass numbers include hatchery-origin carcasses that were not ad-clipped. ‘NS’ = no survey and dashes (-) represent a sample size of zero.

Unmarked

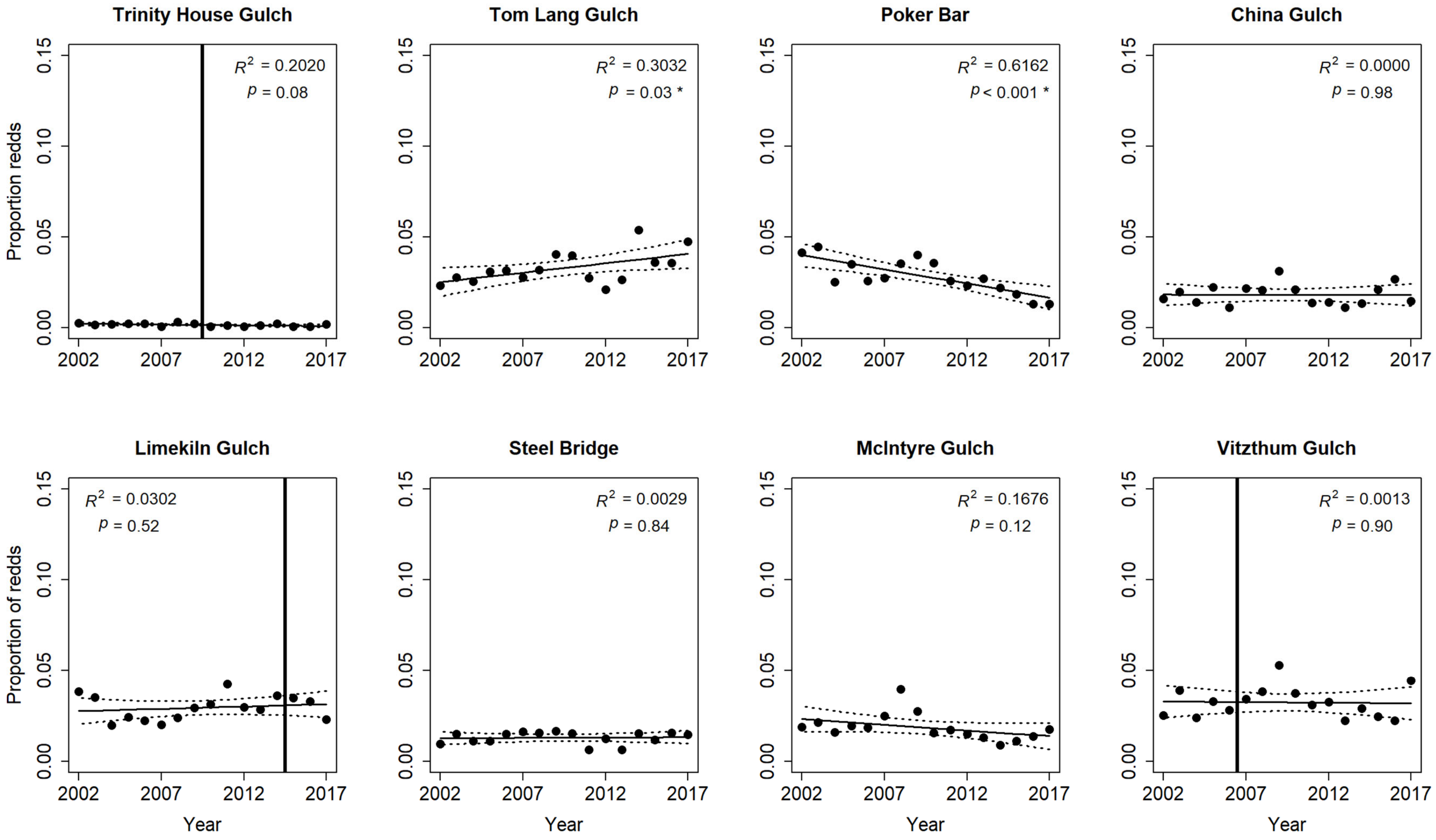
| **Calendar** | | **Reach** | | | | | | | | | | | | **All reaches** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **week** | **Dates** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **9** | **10** | **12** | **13** | **14** | **n** | **Pct.** |
| 35 | Aug. 27 - Sep. 2 | - | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | **-** | **-** |
| 36 | Sep. 3 - 9 | - | - | - | - | - | - | NS | NS | NS | NS | NS | NS | **-** | **-** |
| 37 | Sep. 10 - 16 | - | - | - | - | - | - | - | - | - | NS | NS | NS | **-** | **-** |
| 38 | Sep. 17 - 23 | 1 | 0 | - | - | 1 | - | - | NS | NS | NS | NS | NS | **2** | **40.0%** |
| 39 | Sep. 24 - 30 | - | 0 | - | - | - | - | NS | - | - | NS | NS | NS | **0** | **0.0%** |
| 40 | Oct. 1 - 7 | 0 | 0 | 0 | 0 | - | 0 | NS | NS | NS | - | - | - | **0** | **0.0%** |
| 41 | Oct. 8 - 14 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | - | 0 | NS | NS | NS | **1** | **4.2%** |
| 42 | Oct. 15 - 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NS | NS | - | - | NS | **0** | **0.0%** |
| 43 | Oct. 22 - 28 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | NS | NS | NS | **1** | **1.9%** |
| 44 | Oct. 29 - Nov. 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NS | NS | - | 0 | - | **0** | **0.0%** |
| 45 | Nov. 5 - 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NS | NS | NS | **0** | **0.0%** |
| 46 | Nov. 12 - 18 | 0 | 0 | 0 | 0 | - | - | - | NS | NS | NS | NS | NS | **0** | **0.0%** |
| 47 | Nov. 19 - 25 | 1 | 0 | 0 | NS | NS | 0 | NS | NS | NS | NS | NS | NS | **1** | **3.7%** |
| 48 | Nov. 26 - Dec. 2 | 1 | 0 | 0 | 0 | - | 0 | - | - | 0 | NS | NS | NS | **1** | **3.2%** |
| 49 | Dec. 3 - 9 | 0 | 0 | 0 | - | - | - | - | NS | NS | - | NS | NS | **0** | **0.0%** |
| 50 | Dec. 10 - 16 | 0 | 0 | - | - | - | - | NS | - | - | NS | - | - | **0** | **0.0%** |
| 51 | Dec. 17 - 23 | - | 0 | - | - | - | NS | NS | - | - | - | - | - | **0** | **0.0%** |
| | **All weeks** | **3** | **0** | **0** | **0** | **1** | **2** | **0** | **0** | **0** | **-** | **-** | **-** | ***6*** | ***2.0%*** |

Ad-clipped

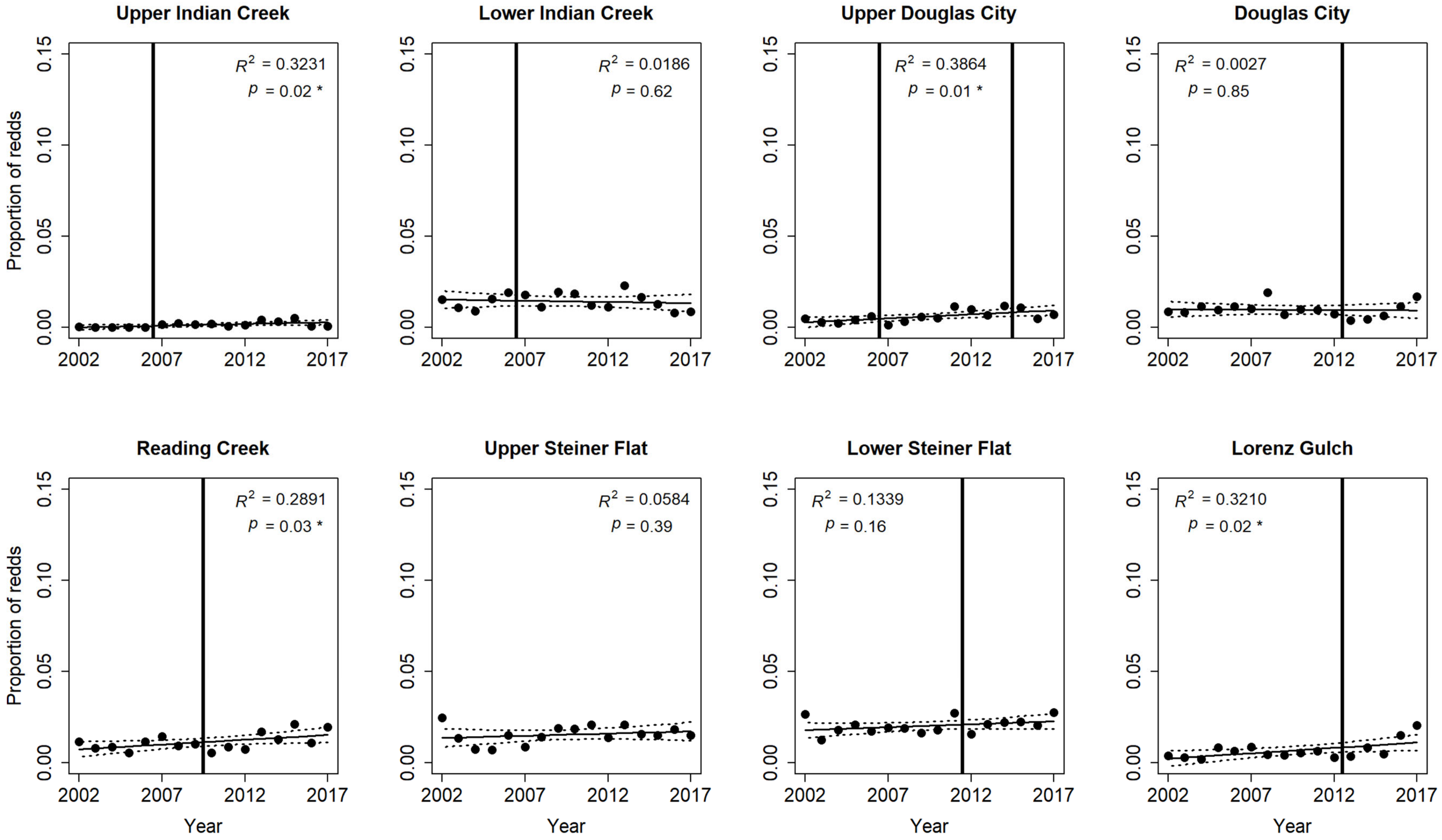
| **Calendar** | | **Reach** | | | | | | | | | | | | **All reaches** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **week** | **Dates** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **9** | **10** | **12** | **13** | **14** | **n** | **Pct.** |
| 35 | Aug. 27 - Sep. 2 | - | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | **-** | **-** |
| 36 | Sep. 3 - 9 | - | - | - | - | - | - | NS | NS | NS | NS | NS | NS | **-** | **-** |
| 37 | Sep. 10 - 16 | - | - | - | - | - | - | - | - | - | NS | NS | NS | **-** | **-** |
| 38 | Sep. 17 - 23 | - | - | - | - | - | - | - | NS | NS | NS | NS | NS | **-** | **-** |
| 39 | Sep. 24 - 30 | - | - | - | - | - | 0 | NS | - | - | NS | NS | NS | **0** | **0.0%** |
| 40 | Oct. 1 - 7 | - | 0 | 0 | - | - | - | NS | NS | NS | - | - | - | **0** | **0.0%** |
| 41 | Oct. 8 - 14 | 0 | - | - | - | 0 | - | - | - | - | NS | NS | NS | **0** | **0.0%** |
| 42 | Oct. 15 - 21 | - | 0 | - | - | - | - | - | NS | NS | - | - | NS | **0** | **0.0%** |
| 43 | Oct. 22 - 28 | 0 | - | - | - | - | - | - | - | - | NS | NS | NS | **0** | **0.0%** |
| 44 | Oct. 29 - Nov. 4 | 0 | 0 | - | - | 0 | - | - | NS | NS | - | - | - | **0** | **0.0%** |
| 45 | Nov. 5 - 11 | - | - | - | - | - | - | - | - | - | NS | NS | NS | **-** | **-** |
| 46 | Nov. 12 - 18 | 0 | - | - | - | - | - | - | NS | NS | NS | NS | NS | **0** | **0.0%** |
| 47 | Nov. 19 - 25 | 0 | 0 | - | NS | NS | - | NS | NS | NS | NS | NS | NS | **0** | **0.0%** |
| 48 | Nov. 26 - Dec. 2 | 0 | 0 | - | - | - | - | - | - | - | NS | NS | NS | **0** | **0.0%** |
| 49 | Dec. 3 - 9 | 0 | - | - | - | - | - | - | NS | NS | - | NS | NS | **0** | **0.0%** |
| 50 | Dec. 10 - 16 | - | - | - | - | - | - | NS | - | - | NS | - | - | **-** | **-** |
| 51 | Dec. 17 - 23 | - | - | - | - | - | NS | NS | - | - | - | - | - | **-** | **-** |
| | **All weeks** | **0** | **0** | **0** | **-** | **0** | **0** | **-** | **-** | **-** | **-** | **-** | **-** | ***0*** | ***0.0%*** |



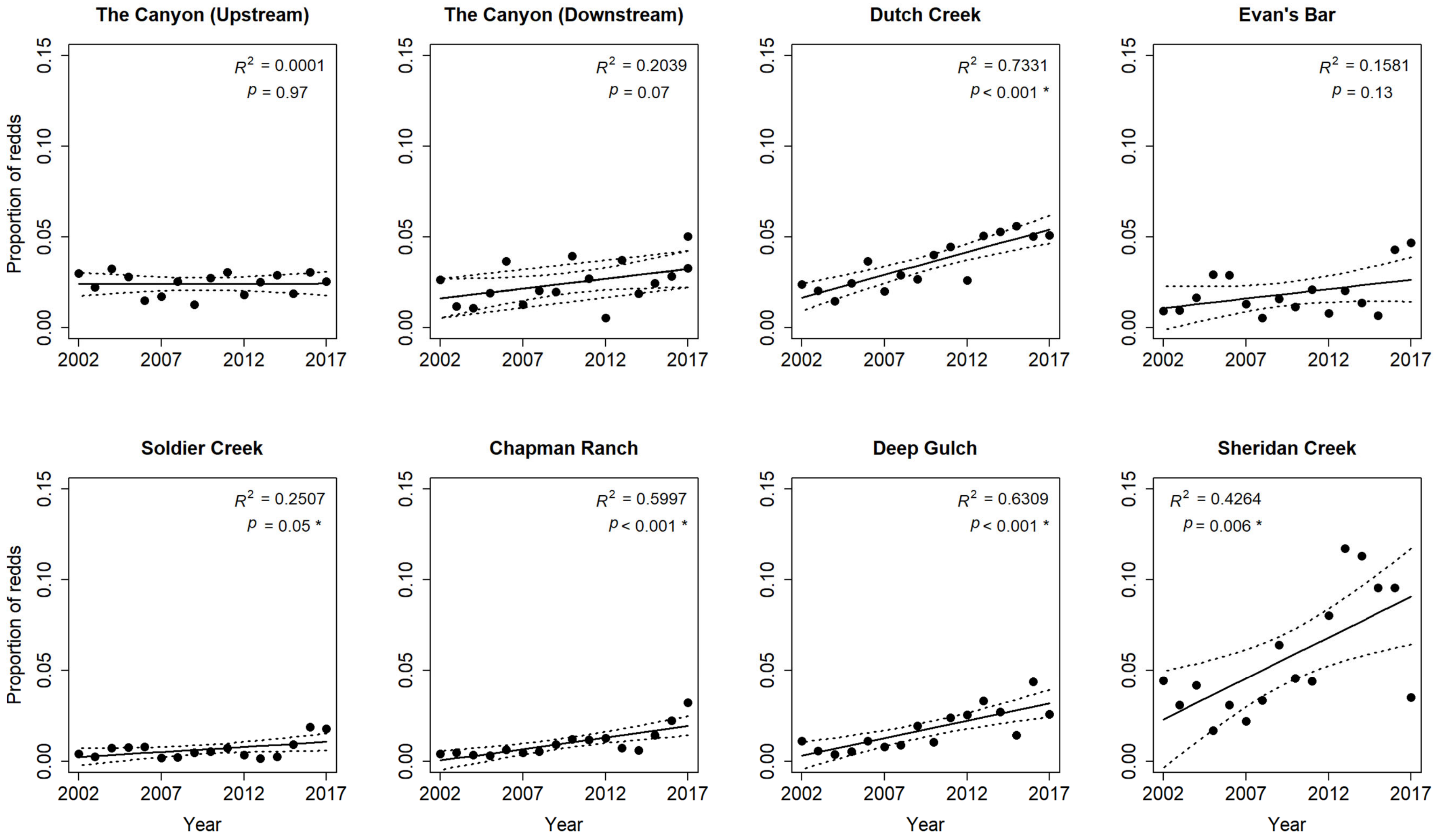
Appendix D. Proportion of TRRP restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars. Note the change in $y$-axis scale in the Sven Olbertson site.



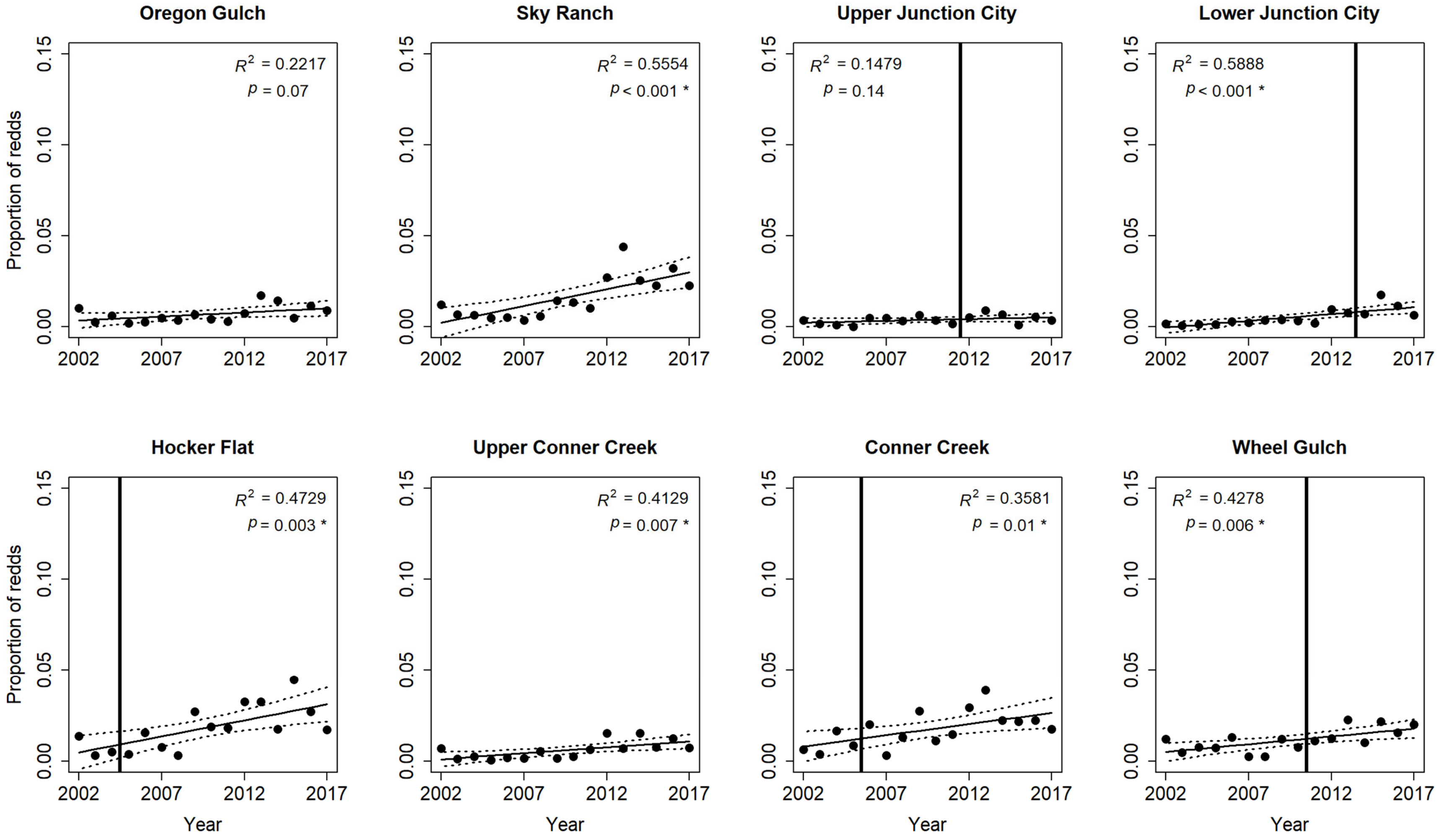
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



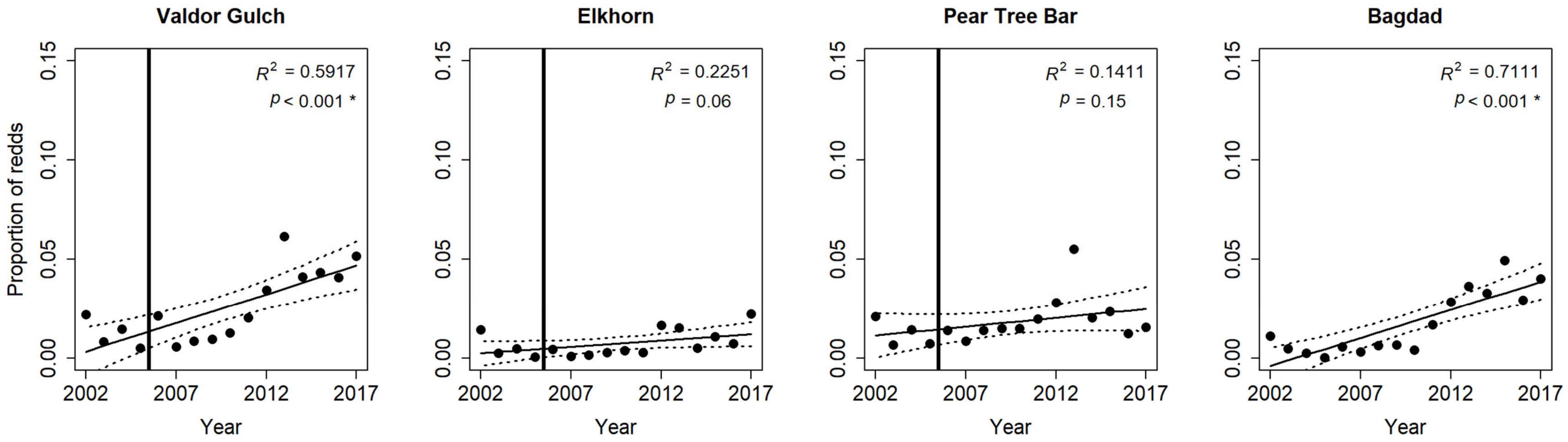
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



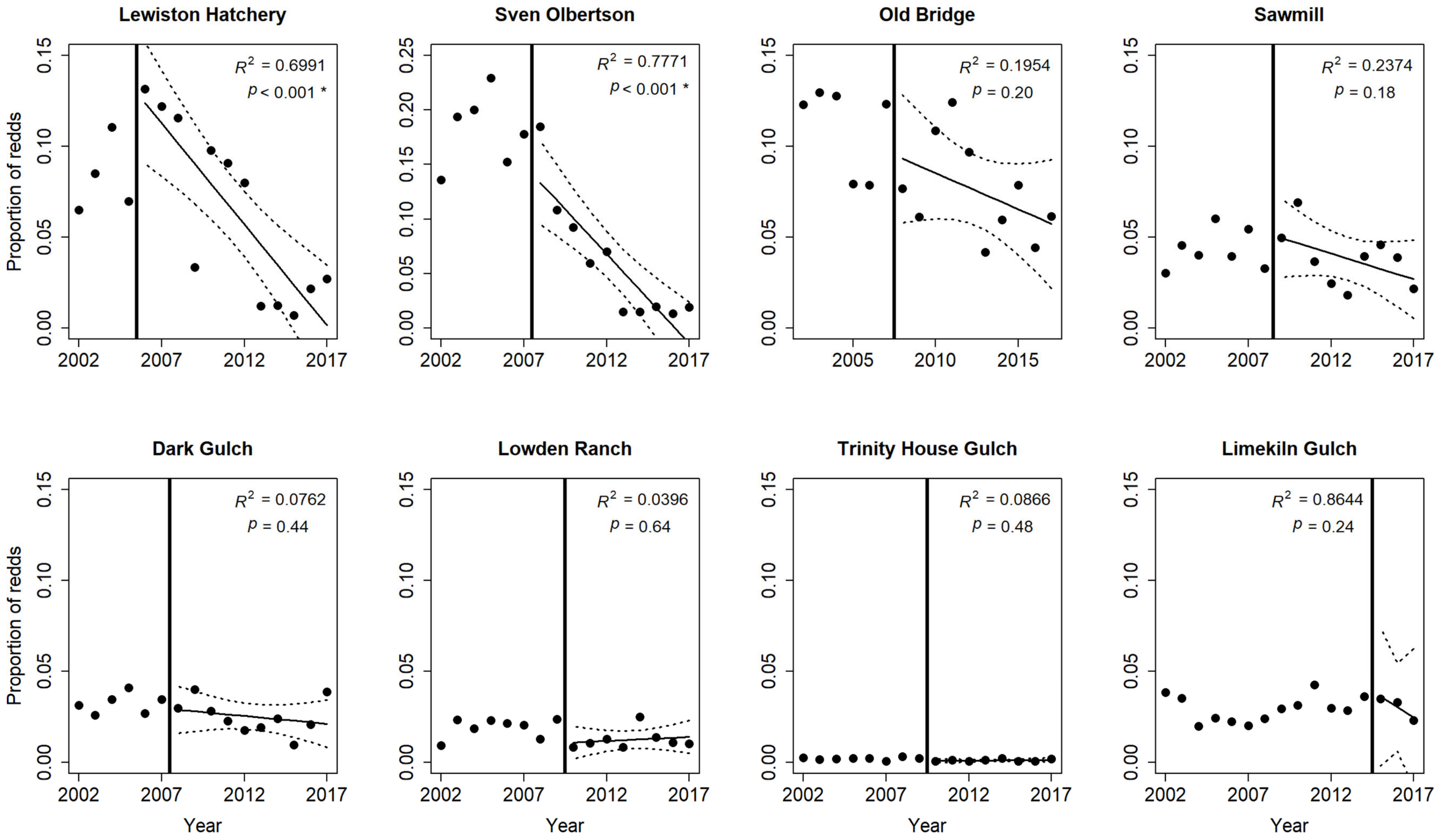
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, *p*-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines).



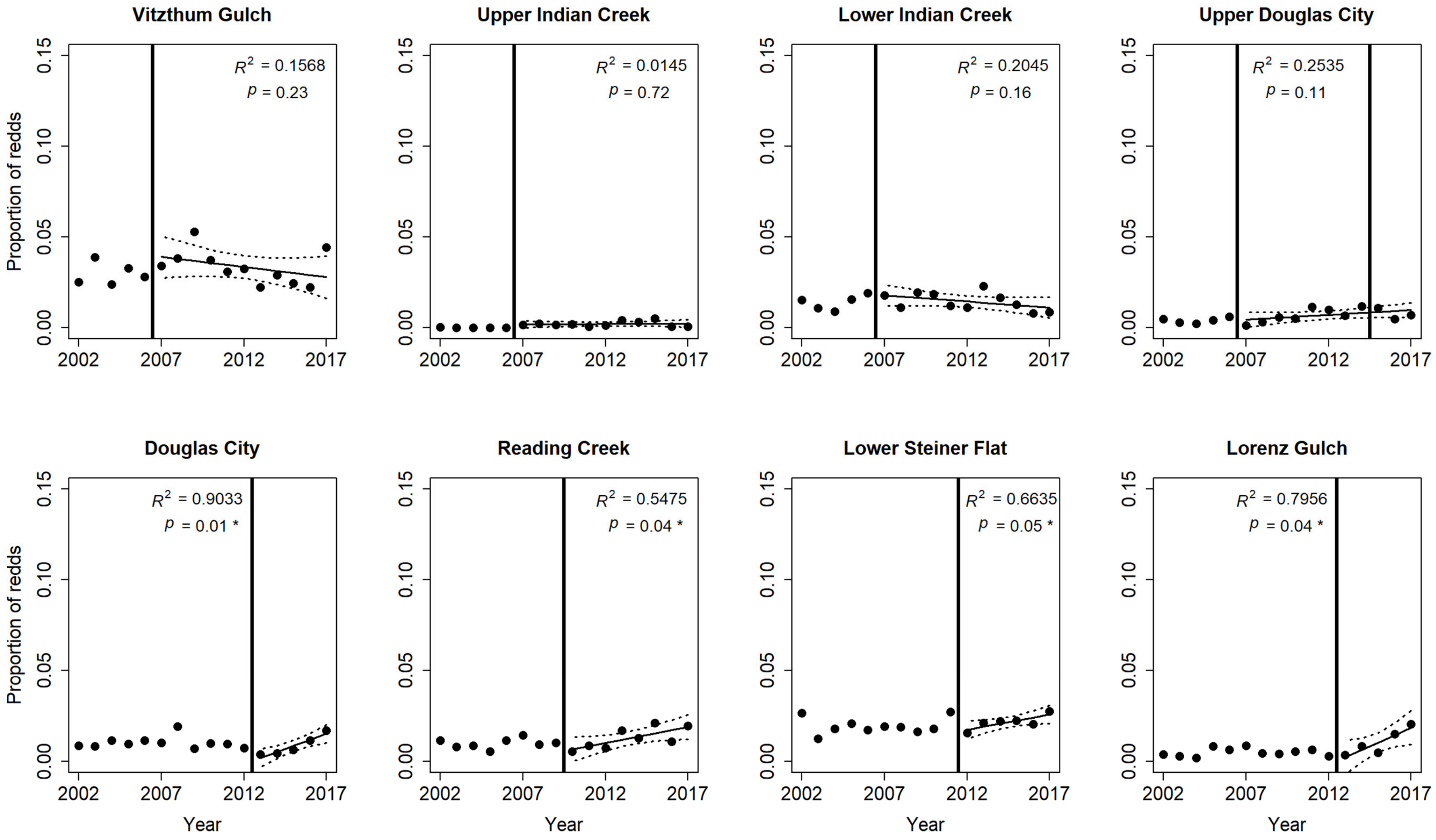
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, $p$-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



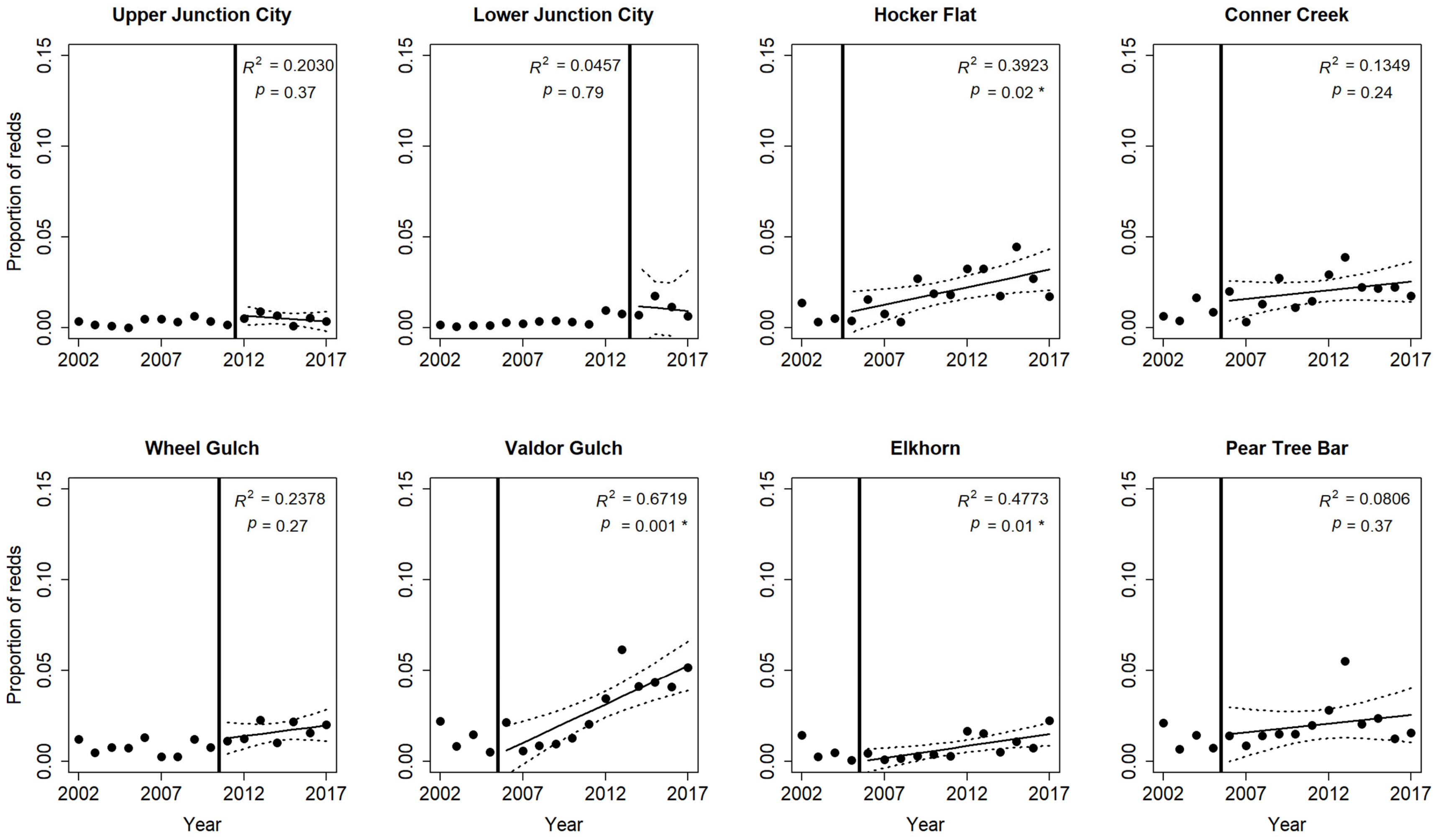
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2017. Each plot includes a linear model with the $R^2$ value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



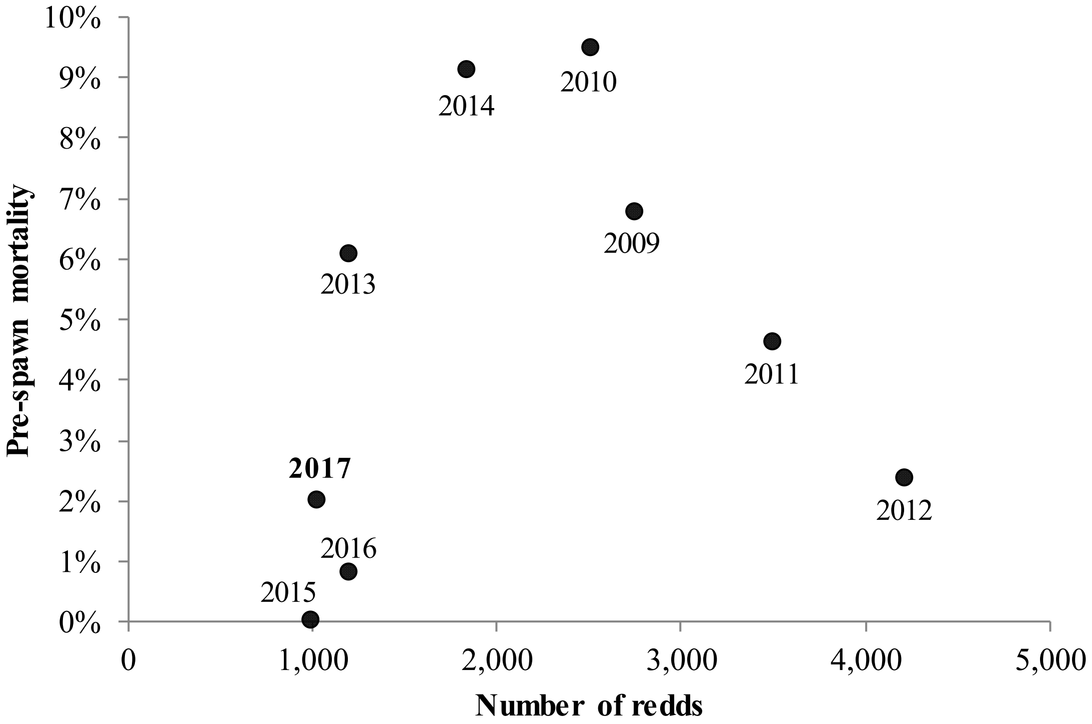
Appendix E. Proportion of natural-origin Chinook Salmon redds within site-scale sections in the TRRP restoration reach that encompass mechanical channel rehabilitation locations, 2002–2017. Each plot includes a post-construction linear model with the $R^2$ value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



Appendix E (continued). Proportion of natural-origin Chinook Salmon redds within site-scale sections in the TRRP restoration reach that encompass mechanical channel rehabilitation locations, 2002–2017. Each plot includes a post-construction linear model with the $R^2$ value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



Appendix E (continued). Proportion of natural-origin Chinook Salmon redds within site-scale sections in the TRRP restoration reach that encompass mechanical channel rehabilitation locations, 2002–2017. Each plot includes a post-construction linear model with the $R^2$ value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



Appendix F. Natural-origin Chinook Salmon redd counts versus estimates of pre-spawn mortality from Lewiston Dam to the North Fork confluence, Trinity River surveys, 2009–2017.

# PREDATION BY HATCHERY STEELHEAD ON NATURAL SALMON FRY IN THE UPPER-TRINITY RIVER, CALIFORNIA

by

Seth W. Naman

A Thesis
Presented to
The Faculty of Humboldt State University

In Partial Fullfillment
Of the Requirements for the Degree
Masters of Science
In Natural Resources: Fisheries

December, 2008

# PREDATION BY HATCHERY STEELHEAD ON NATURAL SALMON FRY IN THE UPPER-TRINITY RIVER, CALIFORNIA

by

Seth W. Naman

Approved by Master' Thesis Committee:

Margaret A. Wilzbach, Major Professor

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Bret C. Harvey, Committee Member

Gary L. Hendrickson, Natural Resources Program Coordinator

Natural Resources Program Number

Chris A. Hopper, Interim Dean for Research and Graduate Studies

# ABSTRACT

## Predation by Hatchery Steelhead on Natural Salmonid Fry in the Upper-Trinity River, California

Seth W. Naman

Hatchery fish have been implicated in the decline of stocks of naturally produced anadromous salmonids in the Pacific Northwest. I investigated the extent of predation by hatchery steelhead on naturally produced salmonid fry in the upper-Trinity River, California. During spring of 2007, 315 residualized hatchery steelhead and 1,636 juvenile hatchery steelhead were captured and examined for the presence of salmonid fry in the gut. Residualized steelhead consumed 435 salmonid fry and 2,685 salmonid eggs. Juvenile hatchery steelhead consumed 882 salmonid fry. Predation by juvenile hatchery steelhead was significantly greater near a side channel where a high percentage of adult salmonids were known to spawn. I used mark-recapture techniques to estimate the population of residualized hatchery steelhead and PIT tag recoveries to estimate the population of juvenile hatchery steelhead. Using the population estimates and predation rates, I estimated that 24,194 [95% CI = 21,066-27,323] salmonid fry and 171,018 [95% CI = 155,272-186,764] salmonid eggs were consumed by 2,302 residualized hatchery steelhead in 21 days from 10 February to 2 March 2007. Excluding the results from the side channel, I estimate that 437,697 juvenile hatchery steelhead consumed 61,214 [95% CI = 43,813-78,615] salmonid fry in 30 days from 28 March to 26 April 2007. Assuming a constant population of 1,500 juvenile hatchery steelhead in the side channel during the 30 day period, an additional 49,445 salmonid fry were consumed. Managers should carefully consider all of the risks to naturally produced fish populations from hatchery fish in order to determine if the effects of hatchery releases are consistent with management goals.

# ACKNOWLEDGMENTS

Numerous friends, colleagues, and professors provided much needed help and support in the last three years. Dr. Margaret A. Wilzbach willingly accepted me as a graduate student and provided advice and support. Dr. Walter Duffy and the USGS California Cooperative Fish and Wildlife Research Unit provided financial assistance for coursework. Kay Brisby was always willing to help with problems and administrative questions. Dr. Bret Harvey provided useful insight and advice throughout the planning and development of this research. My friends and colleagues of the Yurok Tribal Fisheries Program supported this research with their help, funding, and advice. Jeremy Alameda and Henry C. Alameda Jr. provided excellent assistance with field work and data collection. Drs. D. G. Hankin, R. W. Van Kirk, and H. B Stauffer were essential for their input regarding mathematics and statistics. I would also like to thank my father, who always had time to take me fishing, and my mother who encouraged me to follow my dreams.

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# INTRODUCTION

Although several researchers have concluded that predation can influence the population dynamics of anadromous salmonids (Mather 1998), little is known about the extent to which hatchery salmonids prey upon naturally produced salmonids. Nonetheless, millions of hatchery salmonids are released into rivers throughout the western United States annually (Levin et al. 2001). Several researchers have studied competition between hatchery and naturally produced salmonids (e.g. Pollard and Bjornn 1973, McMichael et al. 1997, Fleming et al. 2000, Kostow and Zhou 2006), but predation by hatchery salmonids on naturally produced salmonids remains virtually undocumented in the peer-reviewed literature. Several studies have examined predation by naturally produced salmonids on naturally produced salmonids (e.g. Ruggerone and Rogers 1992, Beauchamp 1995), and others have investigated smallmouth bass predation on salmonids (e.g. Fritts and Pearsons 2004, Naughton et al. 2004), but none specifically address predation by hatchery salmonids on naturally produced salmonids. However, there are a variety of contract reports and technical memoranda on the subject (Table 1). Most of these studies documented low rates of predation, and those that have attempted to estimate the total number of fry consumed have reported relatively low numbers (e.g. Cannamela 1993).

Each year, Trinity River Hatchery releases roughly 800,000 steelhead smolts and 500,000 coho salmon smolts at the base of the Lewiston Dam, directly into an important

Table 1.  Review of hatchery steelhead predation studies.

| Citation | River System | State | Methods | Sample size | Fry ingested (n) | Fry/Stomach |
|---|---|---|---|---|---|---|
| Beauchamp 1995 | Cedar | Washington | Electrofishing | 18 | 0 | 0.00 |
| Canamella 1993 | Upper Salmon | Idaho | Hook and line/electrofishing | 6,762 | 10 | 0.00 |
| Hawkins and Tipping 1999 | Lewis | Washington | Seine | 74 | 1 | 0.01 |
| Hawkins and Tipping 1999 | Lewis | Washington | Seine | 110 | 2 | 0.02 |
| Hawkins and Tipping 1999 | Lewis | Washington | Seine | 48 | 52 | 1.08 |
| Jonasson et al. 1994 | Imnaha/Grande Rhonde basins | Oregon | Hook and line/electrofishing | 358 | 1 | 0.00 |
| Jonasson et al. 1995 | Imnaha/Grande Rhonde basins | Oregon | Electrofishing | 175 | 2 | 0.01 |
| Martin et al. 1993 | Lower Snake (Tucannon) | Washington | Hook and line | 1,713 | 3 | 0.00 |
| Whitesel et al. 1993 | Imnaha/Grande Rhonde basins | Oregon | Screw trap/electrofishing | 611 | 8 | 0.01 |

spawning region. The release occurs at a time when many naturally spawned fry and juveniles are emerging from spawning gravels or rearing. Because of the size differential between predator and prey (Pearsons and Fritts 1999) and the spatial and temporal overlap of predator and prey (Mather 1998; Hatchery Scientific Review Group 2004) there is strong potential for predation by hatchery-reared steelhead to significantly impact the abundance of natural salmonid fry.

The upper Trinity River is relatively clear, often averaging less than 2 nephelometric turbidity units (NTU) and sometimes less than 1 NTU during the Chinook salmon and coho salmon fry emergence period. Studies have shown that low turbidity promotes high foraging efficiency by piscivorous fishes (Gregory and Levings 1998; Robertis et al. 2003). However, no estimates of the amount of naturally produced salmonid fry consumed by hatchery salmonids in the Trinity River are available.

There is currently no information available on the extent to which hatchery steelhead residualize in the Trinity River. Hatchery reared steelhead are known to residualize in river systems throughout the western United States (Beauchamp 1995; Viola and Schuck 1995, McMichael and Pearsons 2001). They residualize in greatest numbers near the site of release, decreasing in number as the distance from the point of release increases (Viola and Schuck 1995, McMichael and Pearsons 2001). Negative impacts from predation (Hatchery Scientific Review Group 2004), competition (McMichael et al. 1997), or genetic interactions (Reisenbichler and Rubin 1999), may affect naturally spawned salmonids resulting from the presence of residualized hatchery steelhead. Hatchery reared steelhead have also been shown to be more aggressive than wild steelhead (Berejikian et al. 1996, McMichael et al. 1999, McMichael and Pearsons 2001), which may exacerbate the effects of competition between hatchery and wild fish. In the uppermost 3.2 km of Trinity River, residualized hatchery steelhead cannot be legally removed by fishermen, as fishing regulations specify that the area is “fly only” and “catch and release only.”

The objectives of this study are to 1) estimate the proportion of piscivores in the residualized hatchery steelhead population and juvenile hatchery steelhead population of the upper Trinity River; 2) estimate the rate (fry/piscivore) at which piscivores in the residualized hatchery steelhead population and juvenile hatchery steelhead population prey upon naturally produced salmonid fry; 3) estimate the population sizes of residualized hatchery steelhead and juvenile hatchery steelhead; and 4) estimate the number of naturally produced salmonid fry consumed by residualized hatchery steelhead and juvenile hatchery steelhead on the upper Trinity River, in the study reach, during the period of study. This information could be used to help guide hatchery policies and is critical to understanding one of the impacts that Trinity River Hatchery may have on natural populations of salmonids.

# STUDY SITE

The study area extended from Lewiston Dam, downstream 3.2 km to Old Lewiston Bridge (Figure 1). Trinity River Hatchery is located at the base of the dam, which is the terminus of anadromous fish migration in the Trinity River. This study reach is characterized by a largely confined channel and an alternating series of runs, pools, glides and riffles. Mean channel width is 30.2 m with a mean channel slope of 0.3% (Trinity River Flow Evaluation 1999). Throughout much of fall and winter, discharge from Lewiston Dam is at a base flow of approximately 8.5 $m^3s^{-1}$, and water from Trinity and Lewiston reservoirs keeps daily maximum river temperature, even in the heat of the summer, at approximately 12°C (Trinity River Flow Evaluation 1999). Beginning in the end of April, discharge from Lewiston Dam increases in accordance with the Trinity River Flow Evaluation (Trinity River Flow Evaluation 1999) to serve a variety of fisheries and geomorphological functions. Discharge then decreases, generally in the end of July, to 12.7 $m^3s^{-1}$, and remains at this level through the summer and fall until the beginning of October when it returns to a base flow of 8.5 $m^3s^{-1}$ (Trinity River Flow Evaluation 1999).

Elevation of the study reach is roughly 549 m. Summers are hot and dry followed by a mixture of rain and snow in the winters, typical of northern-California mid-elevation regions that are on the cusp of coastal and arid climates. Average annual precipitation for Weaverville, California, located approximately ten miles northeast of the study area, is 92.8 cm of rain and 45.2 cm of snowfall (National Weather Service 2008).

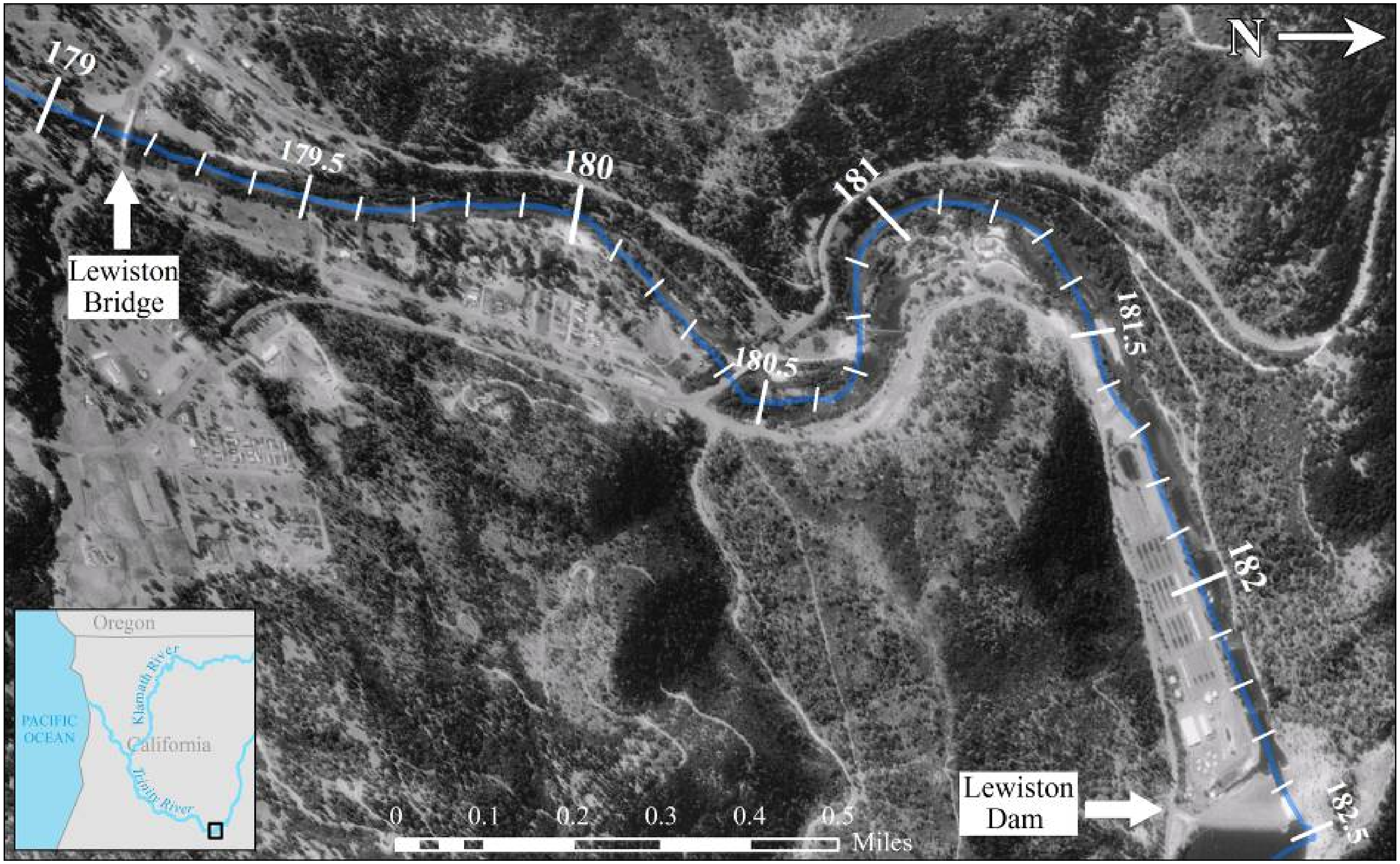

Figure 1. Map of the study location, and river kilometers (in white) on the upper-Trinity River, California. River kilometers increase in an upstream direction and begin at zero at the confluence of the Trinity and Klamath rivers near the town of Weitchpec, California.

The study reach is inhabited by spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead (*O. mykiss*), Pacific lamprey (*Lamptera tridentata*), and brown trout (*Salmo trutta*). Coho salmon are listed under both the federal Endangered Species Act (Good et al. 2005), and the California Endangered Species Act (California Department of Fish and Game 2002).

The upper river provides spawning grounds for anadromous species which are harvested by tribal, recreational and sport fishermen. In the uppermost 3.2 km of the Trinity River, the terminus of anadromous fish migration, estimated redd totals for 2006 were 2,302 redds for Chinook salmon and coho salmon combined. This represents 53% of all redds that were counted from the dam to the North Fork Trinity River, 63.4 km downstream. This high concentration of redds in this section of river is typical for any given year (United States Fish and Wildlife Service 2007). While no data are recorded on the number or distribution of steelhead redds, it appeared to me that a similarly high percentage of the total number of redds were concentrated in the uppermost 3.2 km of river (personal observation).

According to data collected by the California Department of Fish and Game (CDFG) at weirs operated on the Trinity River, the majority of anadromous spawners are of hatchery origin. Returns of hatchery coho salmon have been relatively robust in recent years, but the proportion of natural coho salmon returning to the Trinity River has remained around 10% for many years (Trinity River Flow Evaluation 1999; California Department of Fish and Game 2005). There have been relatively strong runs of hatchery steelhead in the recent past, but the proportion of natural fall-run steelhead returning to the Trinity River has remained around 20% of the total for many years (Trinity River Flow Evaluation 1999; California Department of Fish and Game 2005). The majority of both spring- and fall-run chinook salmon adults are also of hatchery origin, with natural Chinook salmon making up roughly 25% of the total (Trinity River Flow Evaluation 1999; California Department of Fish and Game 2005).

# METHODS

## General Field Methods

Prior to release, all hatchery steelhead are marked by adipose fin excision at Trinity River Hatchery, making the distinction between naturally produced steelhead, few of which were captured, and hatchery steelhead, straightforward. Prior to 15 March, any fin-clipped steelhead present in the study reach, excluding anadromous steelhead, were characterized as a residualized hatchery steelhead. Residualized hatchery steelhead were sampled from 6 February to 28 February 2007 and juvenile hatchery steelhead from 27 March to 26 April 2007. Sampling by the Yurok Tribal Fisheries Program in 2005 indicated that the maximum size of residualized hatchery steelhead was roughly 500 mm (Yurok Tribal Fisheries Program 2008). In addition to this size threshold, behavioral and morphological traits were used to distinguish between residualized and anadromous hatchery steelhead. After 15 March, hatchery steelhead that were 250-500 mm in fork length, excluding anadromous steelhead, were considered to be residualized. I used a cut off of 250 mm because only 3 out of 316 residualized hatchery steelhead captured prior to the release of juveniles on 15 March were less than 250 mm. Scale samples were collected from 99 residualized hatchery steelhead to determine age classes and to verify that none of the steelhead identified as residuals showed signs of ocean entry or ocean growth in scale patterns (Holtby et al. 1990). No attempt was made to determine the age of residualized hatchery steelhead considered to be older than age 3.

Three sites were sampled on a weekly basis throughout the duration of the study: Old Lewiston Bridge (rkm 179), Old Weir Hole (rkm 180.7) and the hatchery area (rkm 182.0, Figure 1). River kilometers begin at zero at the confluence of the Trinity and Klamath rivers near the town of Weitchpec, California and increase in an upstream direction. These sites were roughly located at the downstream end, middle, and upstream end of the study zone. Additionally, one or more of the following sites were sampled on a weekly basis: River Oaks Resort (rkm 180.0), New Lewiston Bridge (rkm 180.4), riffles between Old Weir Hole and New Lewiston Bridge (180.6) and Bear Island Area (rkm 181.5). Within the study reach this regime gave equitable spatial distribution to sampling locations.

Steelhead were captured using hook and line with wet or dry flies. Fish were almost exclusively taken using flies (either dry or wet invertebrate patterns). Using lures might have biased the data because fish that strike lures may have a greater propensity toward piscivory than the population as a whole. It should be noted that great care was taken in selecting small flies (≤ size 16 hooks) so that small fish could be caught as effectively as larger ones. The use of hook and line made it possible to collect fish from a wide range of locations and habitat types that would be inaccessible using other methods such as seining or electrofishing.

On four occasions, the sampling crew captured juvenile hatchery steelhead with hook and line, and then captured juvenile hatchery steelhead with a seine net or backpack electrofishers, generally in the same locale on the same day. This was done in order to compare the rate of predation between fish that were captured using hook and line and other methods, to check for bias resulting from capturing fish with hook and line.

When sampling fish with electrofishers, a single pass was utilized, with personnel moving upstream expeditiously because the electrical current can disable fry and make them easy targets for hatchery steelhead in the area. If temporarily disabled fry float downstream during the electrofishing process and are consumed by hatchery steelhead downstream, and those steelhead are captured and examined within the next 25-30 hours, one might overestimate the number of fry consumed.

In addition to the comparisons of sampling methods, I checked for differences in size between fish that were captured in the river and that of the hatchery population as a whole. Size difference could bias the estimate of total number of fry consumed. On 14 March 2007, one day prior to the release of juvenile hatchery steelhead from Trinity River Hatchery, 50 fish were weighed and measured from each of ten raceways for comparison with the size of individuals captured by hook and line during the first week of study. Testing was constrained to the first week of study because growth, high mortality of small fish, emigration of larger fish, high mortality of sick or weak fish, etc., might change the population characteristics over the course of the study from the original characteristics of the hatchery population.

Captured fish were placed in five gallon buckets before being transferred to a live well that was placed directly in the river. They were examined within 2 hours of being captured. Fish were measured to fork length, visually examined for body morphology, spotting, coloration and skin silvering, then given a smoltification rating of not smolting, transitional, or smolting (Viola and Schuck 1995). Both body morphology (Beeman et al. 1995) and skin reflectance (Haner et al. 1995, Ando et al. 2005) have been successfully used to discriminate between fish that are smolting, and those that are not. I compared condition of juvenile hatchery steelhead among the smolting categories using Fulton's K (Cone 1989). Prior to analysis and testing, each group was tested for isometric growth by regressing the natural log of fork length on the natural log of weight to determine if the slope differed significantly from three (Cone 1989). Additionally, I tested if the regressions of K on fork length were significantly different than zero, in order to check for dependence of condition on fish length (Cone 1989).

A 7.6 L hand pump garden sprayer was used to perform pulsed gastric lavage (Light et al. 1983). Stomach contents were flushed onto a white dish, examined for the presence of fish or fish parts, and recorded as empty, or containing one or more of the following: inorganic or organic material, invertebrates, salmonids, and (or) other fish species. After examination, captured steelhead were revived and released except for approximately 20 samples that were sacrificed to check the effectiveness of the lavage technique. All salmonid fry detected in samples of stomach contents were enumerated.

I did not attempt to identify consumed salmonid fry to species. Both Chinook salmon fry and coho salmon fry were prevalent in the study reach during this study, with steelhead fry beginning to emerge from the spawning gravel towards the end of the study period.

Consumed fry were known to be of natural origin for several reasons. Chinook salmon are not released from the hatchery until June on the Trinity River, whereas this study was conducted from February to May. Hatchery Chinook salmon are also released at a size that is typically larger (roughly 80 mm) than the size of consumed salmonids, which were generally less than 50 mm. Additionally, 100% of coho salmon and steelhead are marked before being released from Trinity River Hatchery, making it easy to distinguish between these hatchery "smolts" and naturally produced eggs, alevin, and fry.

### Residualized hatchery steelhead population estimation

Upon examination, all residualized hatchery steelhead were marked with a fluorescent yellow 16 mm Petersen Disc™ applied below the dorsal fin, except for those considered to be smolting or injured. This allowed for re-sighting of marked fish, making a mark-recapture population estimate possible. I used a modified Petersen estimator (Seber 1982) to estimate the number of residualized hatchery steelhead that were present in the reach during the study period. The marking of fish began on 12 February. After the completion of gastric sampling on 1 March, fish were re-sighted using four divers swimming abreast of each other. I assumed no mortality or immigration or emigration of residualized hatchery steelhead during this 17 day period. Nominal mortality of residualized hatchery steelhead (naturally caused or otherwise) would have little bearing on results of this study. It is unlikely that there were large scale movements into or out of the study reach during the period of study by these non-migratory fish. For example, river discharge and temperature, which might influence movement of residuals, were generally constant during the period of study.

## Juvenile steelhead population estimation

At Trinity River Hatchery, steelhead eggs are taken in winter and spring. Progeny are raised for approximately one year before being released the following spring. The release strategy is volitional, beginning on 15 March each year and continuing for 10-14 days, at which time hatchery personnel force the remaining fish from the hatchery. This makes the estimation of the number of juvenile steelhead in the study reach at any given time inherently difficult as the proportion that exits the hatchery volitionally, and the proportion that is forced out, are not known.

In order to estimate the population of juvenile hatchery steelhead in the study reach on a daily basis, 991 steelhead were implanted with 23 mm half duplex Passive Integrated Transponder (PIT) tags (Zydlewski et al. 2006). This tagging occurred on 5 February and 6 February 2007, approximately 6 weeks prior to the beginning of volitional release from the hatchery. Juvenile hatchery steelhead in 9 of 10 raceways received approximately 110 PIT tags. The other raceway contained fish that were too small (≤ 100 mm) at the time to implant with the 23 mm PIT tags. The number of hatchery steelhead in each raceway at the time of tagging is known as they are hand counted and marked with an adipose fin clip by hatchery personnel and staff from Hoopa Valley Tribal Fisheries.

To gain an understanding of the proportions and timing of juvenile hatchery steelhead that entered and exited the study reach, two antennas were placed in the hatchery flume (hatchery antennas) and 2 antennas spanning the river were placed near the end of the study reach (river antennas). Sampling of juvenile hatchery steelhead began on 27 March 2007, the day that personnel at Trinity River Hatchery forced steelhead out of the hatchery that remained in raceways after the two week volitional release period.

The two antennas that made up the hatchery array were constructed of wood frames and measured approximately 0.9 m by 1.3 m. Each antenna was wrapped in three loops of eight gauge speaker wire which fit into channels that were routed into the wood frames. Antennas slid neatly into pre-existing slots contained within the walls of the flume, and spanned both the width and depth of the flume.

The first river antenna was installed on 19 March, the second on 21 March. This array consisted of two antennas that were 15 m apart, one measuring 13.6 m and the other 18.2 m wide. The distance between the upper and lower loops of the antennas was approximately 0.45 m. The top portion of the antenna loop remained below the water surface to avoid ensnaring boaters. The antennas were formed from a single loop of 8 gauge speaker wire enclosed in standard garden hose that was attached to steel cable affixed to trees on each stream bank. Rock walls were constructed on the edges of each antenna where they met the stream bank to keep hatchery steelhead from migrating around the side of the antennas. This made the path efficiency (Zydlewski et al. 2006), the probability that a fish swimming downstream will pass through the antenna, approximately 100%. Antenna efficiency at both the hatchery and river arrays was tested weekly, sometimes bi-weekly, with test tags placed in oranges, neutrally buoyant pieces of wood, and on the end of an eight foot pole.

Using data from the hatchery antennas, I determined the proportion of PIT-tagged fish that were forced out of the hatchery. I then multiplied this proportion by the number of hatchery steelhead that were in the 9 raceways which received tags such that

$$\hat{S}_1 = \hat{P}_f \times 729{,}760, \tag{1}$$

where $\hat{P}_f$ is the proportion of PIT-tagged fish that were forced out of the hatchery, $729{,}760$ is the total number of fish in each of the 9 raceways that contained marked fish and $\hat{S}_1$ is the number of steelhead that entered the study reach from the hatchery on the day that sampling of juvenile hatchery steelhead began, 27 March 2007.

I used data from the two river antennas to estimate the proportion of juvenile hatchery steelhead that both emigrated volitionally and exited the study reach prior to the end of the volitional emigration period. I then subtracted this proportion from 1 and multiplied the result by the number of hatchery steelhead that emigrated volitionally- which I obtained by subtracting the number of juvenile hatchery steelhead that emigrated volitionally from the total number released from the 9 raceways as:

$$\hat{S}_2 = \left(1 - \hat{P}_e\right) \times \left(729{,}760 - \hat{S}_1\right), \tag{2}$$

where $\hat{P}_e$ is the proportion of juvenile hatchery steelhead that both emigrated volitionally and exited the study reach prior to the end of the volitional emigration period, and $\hat{S}_2$ is the number of hatchery steelhead that were already present in the study reach on the day sampling of juvenile hatchery steelhead began, 27 March 2007.

I estimated the total number of juvenile hatchery steelhead in the study reach on the day sampling began, defined as:

$$\hat{S}_0 = \hat{S}_1 + \hat{S}_2 , \tag{3}$$

where $\hat{S}_0$ is the total number of juvenile hatchery steelhead in the study reach on the day sampling began, $\hat{S}_1$ is the number of hatchery steelhead that entered the study reach from the hatchery on the day that sampling began and $\hat{S}_2$ is the number of hatchery steelhead that were already present in the study reach on the day sampling of juvenile hatchery steelhead began.

To estimate the number of juvenile hatchery steelhead in the study reach on each day of the study, I regressed the number of unique PIT tag detections (*y*) against the day of study (*x*). Visual inspection of a plot of the data, and trials with various model types, indicated that a power function of the form

$$y = b_0 x^{b_1} \tag{4}$$

best fit the data. I substituted the y-intercept ($b_0$) in this equation with $\hat{S}_0$, the total number of juvenile hatchery steelhead in the study reach on the day sampling began (obtained from equation 3), with $x$ as the day of study. To obtain the variance for this function in the original units, both the x and y values were $\log_{10}$ transformed. I fit a linear regression of $\log_{10}$ x versus $\log_{10}$ y, to obtain the variance of the regression line. The square root of this variance was exponentiated with a base of 10 and squared to get the variance in original units.

## Predation Estimates

I selected an equation developed by He and Wurtsbaugh (1993) that describes the gastric evacuation rate of brown trout that were fed salmonid fry. This equation resulted in a slower rate of gastric evacuation than the equation developed by Elliott (1991), thereby helping to err on the side of underestimating the total number of fry consumed. The equation is given as:

$$\theta_1 \cdot e^{\left(-\theta_2 \cdot T\right)}, \tag{5}$$

where $\theta_1$ is 56.2 hours, $\theta_2$ is -0.073, and $T$ is water temperature in degrees Celsius. The equation had an $R^2$ of 0.98.

To calculate a daily fry consumption rate, the amount of hours in a day (24) must be divided by the gastric evacuation rate. To be conservative in the estimate of the total number of fry consumed, I used the number of daylight hours for each day ($H_j$), which was based on nautical twilight (United States Naval Observatory 2007), instead of 24 hours, because it was not known if piscivorous hatchery steelhead of the Trinity River feed continuously throughout the night. While some salmonids are known to feed continuously throughout the 24 hour period, such as piscivorous coho salmon (Ruggergone 1989), other piscivorous salmonids have been shown to have a diel feeding pattern that is not continuous throughout the 24 hour period (Beauchamp 1990).

Estimates of the proportion of fish that were piscivorous, mean rate of predation by piscivores, and total consumption of salmonid fry were made separately for residualized hatchery steelhead and juvenile hatchery steelhead. The proportion of piscivorous fish in any given week ($\hat{P}_w$) was estimated by dividing the number of hatchery steelhead that consumed one or more fry in week *w* by the total number of steelhead examined in week *w*. To estimate the total proportion of piscivorous fish throughout the study period, the weekly total numbers of hatchery steelhead that consumed one or more fry were divided by the total number of juvenile steelhead examined. A 95% confidence interval of the proportion (Agresti and Coull 1998, Thompson 2002) of piscivorous fish in any given week was approximated with

$$\hat{P}_w \pm t\sqrt{\frac{\hat{P}_w(1-\hat{P}_w)}{m_w - 1}}\,, \tag{6}$$

where $\hat{P}_w$ is the estimated proportion of hatchery steelhead that are piscivores from the hatchery steelhead population as a whole during week *w* of the study period, $m_w$ is the total number of steelhead examined during week *w*, and *t* is the upper $\alpha / 2$ point of the *t*-distribution with $m_w$-1 degrees of freedom.

For steelhead identified as piscivores, the weekly predation rate ($\bar{y}_w$) was given by

$$\bar{y}_w = \frac{\sum_{i=1}^{n_w} y_{iw}}{n_w}, \tag{7}$$

where $y_{iw}$ is the number of fry observed in the stomach of fish *i* in week *w*, and $n_w$ is the number of piscivores observed in week *w*, yielding salmonid prey per piscivore. A 95% confidence interval (Thompson 2002) of the mean predation rate was estimated as

$$\bar{y}_w \pm t\sqrt{\frac{\sum_{i=1}^{n_w}(y_{iw}-\bar{y}_w)^2 \Big/ (n_w-1)}{n_w}}, \tag{8}$$

where $y_{iw}$ is the number of fry observed in the stomach of fish *i* in week *w*, and $n_w$ is the number of piscivores observed in week *w* and *t* is the upper α / 2 point of the *t*-distribution with $n_w$-1 degrees of freedom.

The total number of salmonid fry consumed during the period of study, in the study reach was estimated as:

$$\hat{F} = \sum_{j=1}^{30} \hat{S}_0 \cdot j^{\hat{b}_1} \cdot \frac{H_j}{\theta_1 \cdot e^{(-\theta_2 \cdot T_j)}} \cdot \hat{P}_j \cdot \bar{y}_j, \tag{9}$$

where $\hat{F}$ is the estimated total fry consumption in the study reach during the study period, $\hat{S}_0$ is the total number of juvenile hatchery steelhead in the study reach on the day sampling began, *j* is the day of study, $H_j$ is the number of daylight hours on the *j*th day (based on nautical twilight), $\theta_1$ is 56.2 hours and $\theta_2$ is -0.073 (see equation 5), $T_j$ is water temperature in degrees Celsius on day *j*, $b_1$ is the coefficient for the rate of decay of the power function described in equation 4, $\hat{P}_j$ is the estimated proportion of hatchery steelhead that are piscivores from the hatchery steelhead population on day *j*, and $\bar{y}_j$ is the predation rate for steelhead identified as piscivores on day *j*. For the residualized hatchery steelhead, the same formula was utilized, except the summation was over 21 days.

For $\hat{P}_j$ and $\bar{y}_j$, the weekly values of the piscivore proportion, $\hat{P}_w$, and predation rate, $\bar{y}_w$, were utilized. For example, for any given day in week two of the study, the estimated piscivore proportion and estimated predation rate for week two were used for calculating equation 9. It was assumed that the daily proportion of piscivorous fish and predation rate did not vary within any given week.

Over the five week period during which juvenile hatchery steelhead were studied, 5 days were included in week 1 of the study, 4 days were included in week 5 of study, and 7 days were included in weeks 2-4 yielding 30 days. The timing of the release of hatchery steelhead at the beginning of the study, as well as the timing of water releases from Lewiston Dam at the end of the study, prevented the inclusion of a full 7 days in weeks 1 and 5. Prey consumption of juvenile hatchery steelhead was estimated over a 30 d period and prey consumption of residualized hatchery steelhead was estimated over a 21 d period.

To estimate the number of fry consumed by residualized hatchery steelhead, equation 9 was used, except that $\hat{S}_0 \cdot j^{\hat{b}_1}$ was substituted with the population estimate resulting from the modified Petersen estimator. This population level was held constant for the 21 day residualized hatchery steelhead period of study, assuming no immigration or emigration, and no mortality, natural or otherwise.

To estimate variance of the number of fry consumed by residualized hatchery steelhead and juvenile hatchery steelhead, Gray's (1999) estimator for the variance of a two factor product,

$$\hat{V}(xy) = \bar{x}^2\hat{V}(y) + \hat{V}(x)\bar{y}^2 - \hat{V}(x)\hat{V}(y), \tag{10}$$

was modified to accommodate constants and a three factor product following Gray (1999). Variance of the total number of fry consumed was estimated assuming daylight hours, temperature, gastric evacuation rate, and survival rate were measured without error. Variances in the proportion of piscivorous fish, predation rate (salmonid fry per piscivore), and population were incorporated into the three factor variance estimator to develop a 95% confidence interval for the number of fry consumed by residualized hatchery steelhead and juvenile hatchery steelhead. Separate estimates of the 95% confidence interval of the number of fry consumed were made for residualized hatchery steelhead and juvenile hatchery steelhead as follows:

$$1.96\sqrt{\sum_{j=1}^{30}\left(\frac{H_j}{\theta_1 \cdot e^{(-\theta_2 \cdot T_j)}}\right)^2 \left(\begin{array}{l} [\hat{P}_j\bar{y}_j]^2\hat{V}(\hat{S}_j) + \hat{P}_j^{\,2}\hat{V}(\bar{y}_j)\hat{S}_j^{\,2} \\ +\hat{V}(\hat{P}_j)\bar{y}_j^{\,2}\hat{S}_j^{\,2} - \hat{V}(\hat{P}_j)\hat{V}(\bar{y}_j)\hat{S}_j^{\,2} \\ -\hat{P}_j^{\,2}\hat{V}(\bar{y}_j)\hat{V}(\hat{S}_j) - \hat{V}(\hat{P}_j)\bar{y}_j^{\,2}\hat{V}(\hat{S}_j) \\ +\hat{V}(\hat{P}_j)\hat{V}(\bar{y}_j)\hat{V}(\hat{S}_j) \end{array}\right)} \tag{11}$$

where $H_j$ is the number of daylight hours on the *j*th day, $T_j$ is the temperature on the *j*th day, $\frac{H_j}{\theta_1 \cdot e^{(-\theta_2 \cdot T_j)}}$ is the temperature based gastric evacuation rate described in equation 9, $\hat{P}_j$ is the estimated mean proportion of predators on day *j*, $\hat{V}(\hat{P}_j)$ is the estimated variance of proportion of predators on day *j*, $\bar{y}_j$ is the estimated mean predation rate of piscivores, $\hat{V}(\bar{y}_j)$ is the estimated variance of predation rate of piscivores, $\hat{S}_j$ is the estimated mean of either the residualized hatchery steelhead population or the juvenile hatchery steelhead population, and $\hat{V}(\hat{S}_j)$ is the estimated variance of either the residualized hatchery steelhead population or the juvenile hatchery steelhead population.

As in equation 9, for $\hat{P}_j$ and $\bar{y}_j$, the weekly values of the piscivore proportion, $\hat{P}_w$, and predation rate, $\bar{y}_w$, were utilized. I assumed that the daily piscivore proportion and predation rate did not vary within any given week.

For estimation of the number of eggs consumed by residualized hatchery steelhead, I employed the same process used to estimate the number of salmonid fry. I assumed that salmonid fry and salmonid eggs were evacuated from the stomach of piscivorous salmonids at the same rate, although I am not aware of any study that has evaluated the evacuation rate of salmonid eggs from stomachs of salmonids that consume eggs.

Use of equation 11 to estimate the confidence intervals should be regarded as an approximation of confidence intervals. Because PIT tag recovery data collected over the study period were used to fit a model that was then used to estimate $\hat{S}_0$, $\hat{S}_0$ for the different days are not statistically independent of one another. The expression for estimating variance over time (summations over $j = 1$ to 30) are likely incorrect because they do not account for covariance among successive estimated values of $\hat{S}_0$. The use of literature based gastric evacuation rates, amount of daylight hours, and water temperature, as constants measured without error, also likely introduces some additional estimate error, but the amount is unknown.

# RESULTS

During the course of this study, 315 residualized hatchery steelhead and 1,636 juvenile hatchery steelhead were captured and examined. Of these, 20 (0.95 %) did not have adipose fin clips. One brown trout was also captured during the 3 month duration of study.

## Residualized Hatchery Steelhead

A total of 285 residualized steelhead were marked during the period 12 February to 28 February. Snorkelers counted 313 residuals during the resight event on 1 March, of which 38 were marked. Based on these data, I estimate the population of residualized hatchery steelhead in the study reach to be 2,302 (95% CI = 1,681-2,922).

When snorkelers surveyed the reach on 5 February 2007, prior to capture or examination of individual fish, 280 (86%) residualized hatchery steelhead were counted above the large cascade rapid at the Old Weir (rkm 180.7) that lies half way through the study section (Figure 1), while 46 were counted below. On the same date, snorkelers surveyed 3.0 km of the Trinity River downstream of the end of the study area, and counted seven residualized hatchery steelhead.

The 315 residualized hatchery steelhead examined during this study averaged 331 mm in length (SD = 51 mm; range = 243-494 mm), and 408.4 g in weight (SD = 215.2 g; range = 148.7-1415.8 g) (Table 2). Of the residuals examined, 90 % were smaller than 420 mm, which is the cut-off in fork length below which steelhead are considered to

Table 2. Age composition for 98 residualized hatchery steelhead from the upper-Trinity River, California.

| | Age | | |
|---|---|---|---|
| | 2 | 3 | >3 |
| Sample size | 54 | 33 | 11 |
| Mean fork length (mm) | 310 | 383 | 459 |
| Mean weight (g) | 328.5 | 614.0 | 1001.3 |

exhibit a half-pounder life-history by CDFG (California Department of Fish and Game 2005). There were 29 fish (9%) that were considered to be transitional or smolting. Mean fork length was greater for non-smolting individuals (mean = 333 mm) than for transitional or smolting individuals (mean = 306 mm) (*t*-test, $t = 4.38$; df = 48; $P < 0.001$).

Scale samples of residualized steelhead were collected to evaluate the duration of residualism in the upper Trinity River, and to inspect for evidence of anadromy. Of 99 samples collected, one came from an individual that was 427 mm in length and showed signs of ocean entry and ocean growth. Of the remaining scales, 54 were collected from individuals that were 2 years old, 33 were from individuals aged at 3 years old, and 11 were from fish older than 3 years of age (Table 2). Mean fork length was larger for individuals that were aged (mean = 351 mm) than for individuals that were not aged (mean = 320) (*t*-test, $t = 4.82$; df = 139; $P < 0.001$). This suggests that residualized steelhead that were aged may not be entirely representative of the population as a whole. Ocean growth was clearly evident in the anadromous hatchery steelhead scales. In the residualized hatchery steelhead scales, the spacing of circuli was much tighter and more consistent than that of anadromous hatchery steelhead (Figure 2). Growth in the hatchery was also evident in most residualized steelhead samples, with circuli in the first year of life spaced noticeably greater than in successive years (Figure 2).

Hatchery steelhead residuals were generally smaller than their anadromous counterparts and typically more football shaped than the streamlined anadromous hatchery steelhead. Body morphology, in combination with more colorful fins, a more

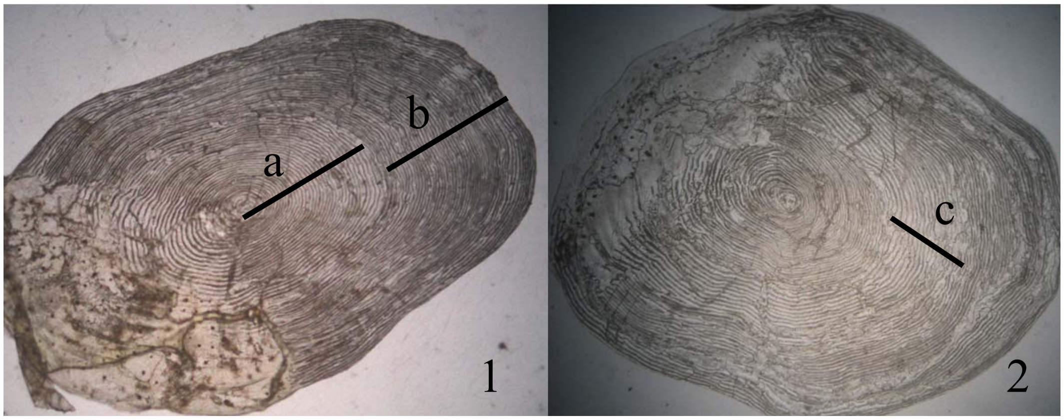

Figure 2. Images of hatchery steelhead scales from the upper-Trinity River, California, 2007. From left to right: 1) a residualized hatchery steelhead >3 years old (468 mm in length) showing wide spacing of first 30-35 circuli from 1 year of robust hatchery growth (a), followed by tightly spaced and uniform circuli from several years of river growth (b) and; 2) an anadromous hatchery steelhead (635 mm in length) showing several signs of anadromy including ocean growth (c) with wider spacing of circuli than that of the first 30-35 circuli of hatchery growth, as well as ocean entry/exit markings.

vibrant pink stripe on the body, and spotting dissimilar to anadromous steelhead, gave the residuals a “troutlike” appearance. Many residuals, including some as small as 285 mm, were observed to be in full spawning colors. Several were ripe males that excreted milt upon examination. I often observed residuals positioned behind spawning anadromous steelhead.

## Juvenile Hatchery Steelhead

Of the 1,636 juvenile hatchery steelhead captured during this study, 771 were captured below the Old Weir Hole, located half way through the study reach, while 865 were captured above it (Table 3). Average fork length and weight for juvenile hatchery steelhead was 167 mm (SD = 29 mm; range = 84-249 mm) and 54.6 g (SD = 30.6 g; range = 6.8-217 g), respectively (Table 4). The fork length of juvenile hatchery steelhead differed among smolting categories (not-smolting, transitional, and smolting) (ANOVA; *F* = 107.12; df = 1,554; *P* < 0.001). Multiple comparisons showed each group was significantly different from the other (Tukey’s 95% Simultaneous Confidence Intervals = 98.06%). Individuals that were not smolting (mean fork length = 159 mm; SD = 31 mm; range = 84-249 mm) were the smallest group, followed by transitional fish (176 mm; SD = 20 mm; range = 125-240 mm), with smolting fish having the largest average fork length (186 mm, SD = 17 mm, range = 154-240 mm). Condition factors also differed among groups (ANOVA; *F* = 113.5; df = 1,554; *P* < 0.001). Multiple comparisons showed each group was significantly different from the other

Table 3. Sampling locations, method of capture, and sample size of juvenile hatchery steelhead captured at each location in the upper Trinity River, California, in March of 2007.

| Location | rkm | Electrofishing | Hook and line | Seine | Total |
|---|---|---|---|---|---|
| Old bridge | 179.2 | 0 | 272 | 163 | 435 |
| Cableway | 179.5 | 0 | 44 | 0 | 44 |
| New bridge | 180.4 | 0 | 169 | 0 | 169 |
| Corner | 180.5 | 0 | 123 | 0 | 123 |
| Weir | 180.7 | 0 | 256 | 0 | 256 |
| Sven Oldertson | 181.1 | 58 | 0 | 0 | 58 |
| Bear Island | 181.4 | 151 | 247 | 0 | 398 |
| Three pipes | 181.9 | 0 | 72 | 0 | 72 |
| First Riffle | 182.2 | 0 | 81 | 0 | 81 |

Table 4. Fork length, weight, and fry consumption of non-smolting, transitional, and smolting juvenile hatchery steelhead captured in the upper-Trinity River, California 2007, using hook and line, seine, and electroshocker.

| | Areas other than Bear Island | | | | Bear Island only[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Juvenile category | | | | Juvenile category | | | | |
| Variable | Non-smolting | Transitional | Smolting | Sub-total or mean | Non-smolting | Transitional | Smolting | Sub-total or mean | Grand total or mean |
| Sample size | 696 | 419 | 123 | 1,238 | 295 | 92 | 11 | 398 | 1,636 |
| Mean fork length (mm) | 156 | 175 | 186 | 166 | 169 | 184 | 199 | 173 | 167 |
| Mean weight (g) | 43.8 | 57.6 | 66.0 | 50.9 | 63.5 | 67.8 | 83.8 | 65.0 | 54.6 |
| Piscivores (*n*) | 45 | 28 | 9 | 82 | 120 | 17 | 2 | 139 | 221 |
| Piscivore proportion | 0.06 | 0.07 | 0.07 | 0.07 | 0.41 | 0.18 | 0.18 | 0.35 | 0.14 |
| Fry consumed | 65 | 32 | 12 | 109 | 715 | 53 | 5 | 773 | 882 |
| Fry per piscivore | 1.4 | 1.1 | 1.3 | 1.3 | 6.0 | 3.1 | 2.5 | 5.6 | 4.0 |

[a] The data are given for one location called Bear Island and the rest of the river separately, due to the high rate of salmonid fry consumption by juvenile hatchery steelhead at the Bear Island site.

(Tukey's 95% Simultaneous Confidence Intervals = 98.06%). Mean condition factor of individuals that were not smolting was the highest (1.11) followed by fish that were transitional (1.05), with smolting individuals having the lowest condition factor (1.01).

Mean fork length and weight for 500 (50 from each of 10 raceways) juvenile hatchery steelhead examined in the hatchery on 14 March 2007, one day prior to the beginning of the volitional release period, were 178 mm (SD = 34 mm; range = 62-246 mm) and 76.2 g (SD = 34.4 g; range = 2.1-188.1 g), respectively. Overall, the difference in fork length between 108 juvenile hatchery steelhead captured by hook and line during the first week of study (mean = 182 mm; SD = 27 mm; range = 121-242 mm) and that of the 500 juvenile hatchery steelhead examined one day prior to the beginning of the volitional release period was not significant (*t*-test; $t = 1.29$, df = 184, $P = 0.198$).

Mean fork length and weight of juvenile hatchery steelhead captured by seining and electrofishing in the river ($n = 371$) were 162 mm (SD = 31 mm, range = 95-248 mm) and 52.2 g (SD = 34.0 g, range = 10.4-217.5 g), respectively. For juvenile hatchery steelhead captured by hook and line on the same dates and locations as those captured by seining and electrofishing ($n = 317$), mean fork length and weight were 166 mm (SD = 27 mm, range = 100-249 mm) and 52.9 g (SD = 29.3 g, range = 13.4-198.0 g), respectively. Fork length of juvenile hatchery steelhead captured within the river differed between capture methods (*t*-test, $t = 2.18$, df = 685, $P = 0.030$). However, it is unknown if these differences, which appear to be small, are biologically meaningful.

## PIT-tag antenna performance and juvenile hatchery steelhead population estimation

The read range and efficiency of PIT-tag antennas was greater in the hatchery than in the river. Hatchery antennas had a read range of approximately 102 cm, and tests indicated an efficiency close to 100% with that read range. Of 991 PIT tags that were implanted in the juvenile hatchery steelhead 6 weeks prior to the beginning of the volitional release period, 877 (88%) were subsequently detected by the hatchery array (Figure 3). Of these, 859 (98%) were detected on both hatchery antennas. Given the high detection efficiency, undetected tags likely reflected either rejection by the fish, or fish mortality prior to release.

Read range of the river antennas was roughly 25 cm, and their efficiency ranged between 65% and 80% throughout the study. Measuring efficiency of the river antennas accurately was difficult with test tags because the orientation of the test tags could not always be controlled, which can greatly affect antenna performance (Zydlewski et al. 2006). Of 877 tagged juvenile steelhead that were detected leaving the hatchery, 663 were detected with the river array, with an overall efficiency of at least 76% (Figure 4). Some of the tagged fish that were detected in the hatchery may have residualized upstream of the river array, or died before reaching it.

The river array was not operational until 19 March, 4 days after the volitional release period began. During this four day period, 33 PIT-tagged steelhead exited the hatchery, 9 of which were eventually detected at the river array.

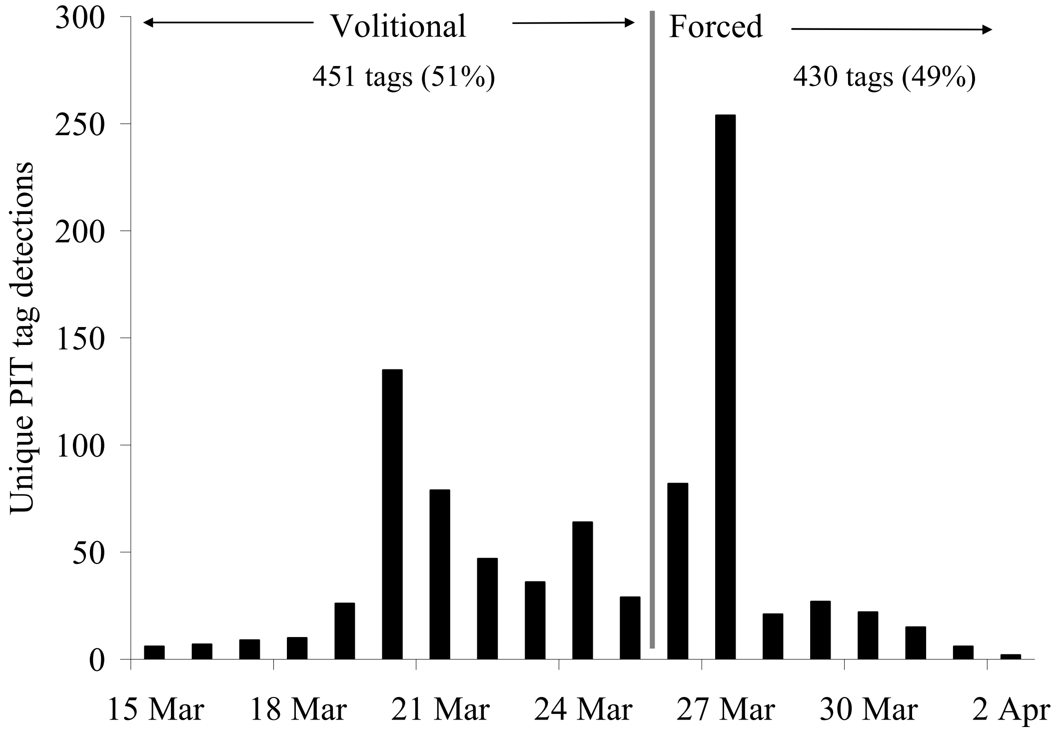

Figure 3. The number of unique detections (first date a tag was detected) of PIT-tagged juvenile steelhead by day, for an array of 2 antennas located in Trinity River Hatchery Juvenile steelhead were forced from the hatchery on 26 and 27 March 2007 following an 11 day volitional emigration period.

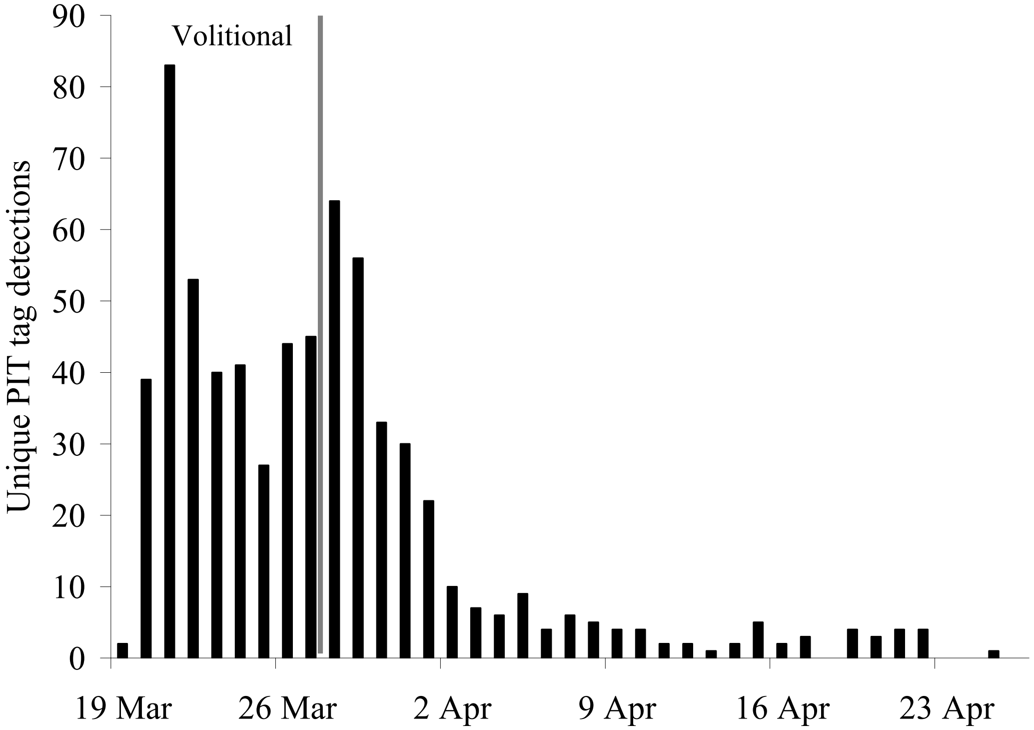

Figure 4. The number of unique detections (first date a tag was detected) of an array of 2 antennas located 3.2 km downstream in the Trinity River (right). Juvenile steelhead were forced from the hatchery on 26 and 27 March 2007 following an 11 day volitional emigration period.

The supporting cable of the downstream river antenna broke on 11 April and was not repaired. During the time that two antennas were in operation, 564 tagged fish were detected. Of these, 276 (49%) were detected at both antennas, while 288 (51%) were detected at only one of the two antennas. Downstream and upstream river antennas appeared to perform similarly. Of the 288 tags detected on one of two antennas, 156 were detected on the upstream antenna and 132 were detected on the downstream antenna.

An estimated 356,975 juvenile hatchery steelhead failed to migrate volitionally from the hatchery. These fish entered the river at the end of the volitional release period, at which time sampling of juvenile steelhead in the river began. A total of 823,210 juvenile hatchery steelhead were released from Trinity River Hathcery between 15 to 27 March 2007. The number of juvenile hatchery steelhead released from 9 raceways that contained PIT-tagged fish was 729,760. Fifty-one percent ($n = 448$) of tagged fish exited the hatchery volitionally (Figure 3). Remaining fish ($P_f = 0.49$) were forced from the hatchery by dewatering of raceways by hatchery personnel.

Prior to 27 March 2007, the end of the volitional release period, 326 of 448 juvenile steelhead that were detected leaving the hatchery were also detected by the river array (Figure 4). This suggests that at least 73 % ($P_e$) of volitional migrants exited the study reach prior to collection of stomach contents of juvenile steelhead. Multiplying the number of juvenile hatchery steelhead that migrated volitionally by 0.27 (1-0.73) yielded a product of 100,488 fish ($\hat{S}_2$). The number of juvenile hatchery steelhead that failed to migrate volitionally and entered the river on the day sampling commenced was estimated to be 357,582 ($\hat{S}_1$). The total number of juvenile hatchery steelhead present in the study reach on 27 March ($\hat{S}_0$) was estimated as the sum of $\hat{S}_1$ and $\hat{S}_2$. An estimated 458,070 ($\hat{S}_0$) juvenile hatchery steelhead were present in the study reach on 27 March 2007.

To estimate the number of juvenile hatchery steelhead present in the study reach during each day of the study, the number of unique tag detections (first date and time a particular tag was detected) from the river array was regressed over time. Examination of a plot of the data, and trials with various model types, indicated that a power function of the form $y = b_0 x^{b_1}$ provided the best fit ($r^2 = 0.89$). The equation was:

$$y = 73.44 j^{-0.92}, \qquad (12)$$

where $j$ is the number of days beyond 27 March 2007. The value for $b_0$ was substituted with 438,304, the number of hatchery steelhead that were estimated to be in the study reach on 27 March. Model results suggest that the hatchery steelhead population decreased sharply in the beginning of the study, losing roughly half of the total population within the first 24 hours (Figure 5).

## Fry consumption

Consumption of salmonid fry varied among juvenile hatchery steelhead. The smallest piscivorous hatchery steelhead had a fork length of 108 mm, and it consumed 2 salmonid fry. A juvenile hatchery steelhead that was 200 mm in length consumed 52 salmonid fry, which was the maximum amount of salmonid fry consumed by any

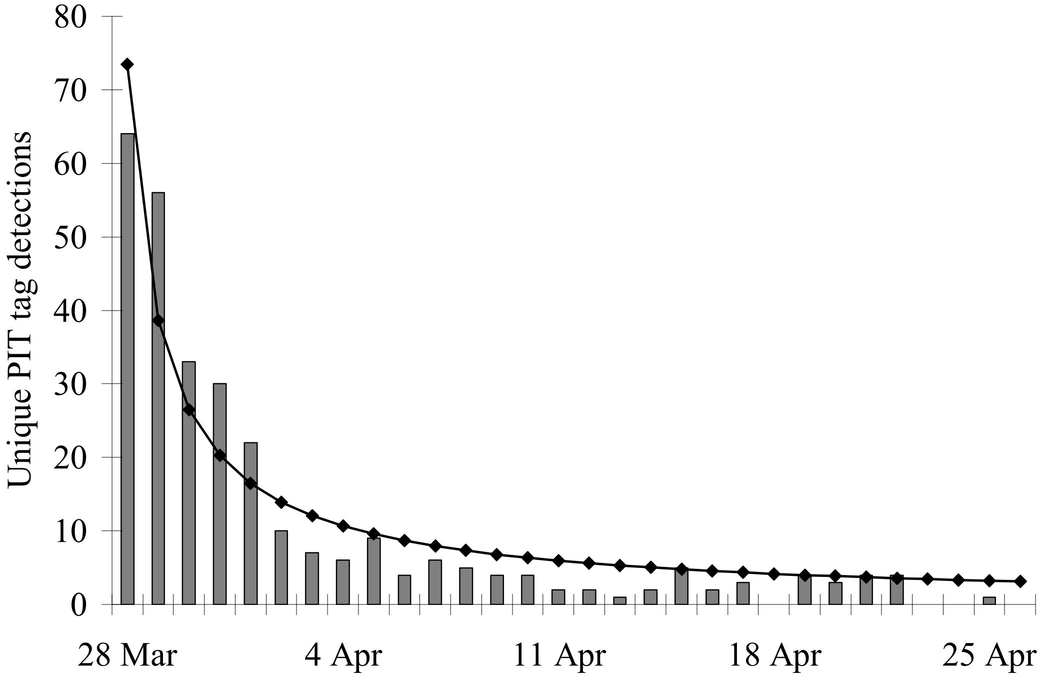

Figure 5. The number of unique detections (first date a tag was detected) of PIT-tagged juvenile steelhead, by day, for an array of 2 antennas located in the Trinity River, California, 2007, 3.2 km downstream from the release site, and a regression of the data with a power function. The data were fit to a power function as $y = 73.44x^{-0.923}$, $R^2 = 0.89$.

hatchery steelhead during this study. Eighty-one of 316 residualized hatchery steelhead (26%) consumed a total of 435 salmonid fry. Additionally, 97 residualized steelhead consumed a total of 2,685 salmonid eggs. The maximum number of salmonid fry consumed by any residualized steelhead was 35, while the maximum number of eggs consumed by any one residualized steelhead was 162. The proportion of piscivores in the residualized steelhead population ranged between 0.20 and just over 0.30 (Figure 6). The number of fry consumed per piscivore decreased from a high of around eight in the first week of study, to roughly 4 in the last week of the study (Figure 6). The average fork length of residualized hatchery steelhead piscivores (363 mm; SD = 61 mm) was greater than that of non-piscivores (319 mm; SD = 41 mm) (*t*-test, $t = 6.08$, df = 104, $P < 0.001$).

Of 1,636 juveniles examined, 221 piscivores (13.5 %) consumed 882 salmonid fry (Table 4). The proportion of piscivores in the juvenile steelhead population increased from about 0.02 in the beginning of the study to about 0.1, before falling back down to around 0.04 by the end of the study (Figure 7). Excluding those hatchery steelhead captured at Bear Island, the amount of fry consumed per piscivore remained consistent between weeks, slightly greater than 1.0 (Figure 7). The average fork length of juvenile hatchery steelhead piscivores (173 mm, SD = 28 mm) was greater than that of non-piscivores (168 mm, SD = 29 mm) (*t*-test, $t = 2.85$, df = 295, $P = 0.005$). The differences between the proportion of piscivores and the number of fry consumed per piscivore for the three smoltification groups were small (Table 4).

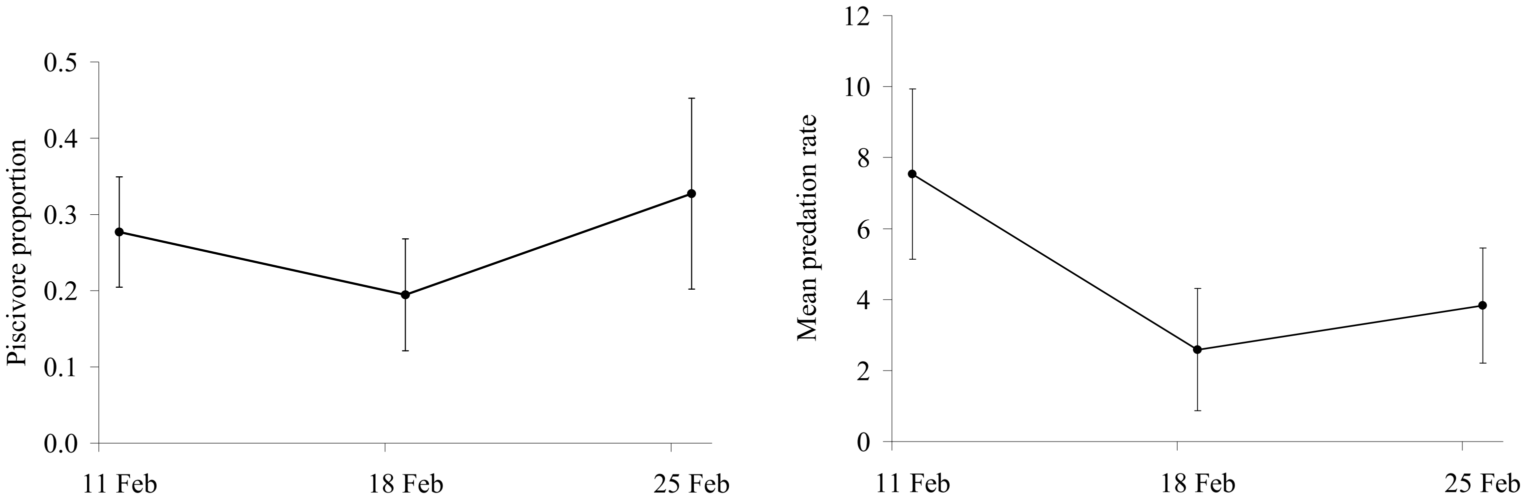

Figure 6. The proportion of piscivores (piscivores/ number of fish examined) ± 95% CI and the mean rate of predation (number of salmonid fry/piscivore) ± 95% CI for residualized hatchery steelhead captured from the upper Trinity River, California, 2007.

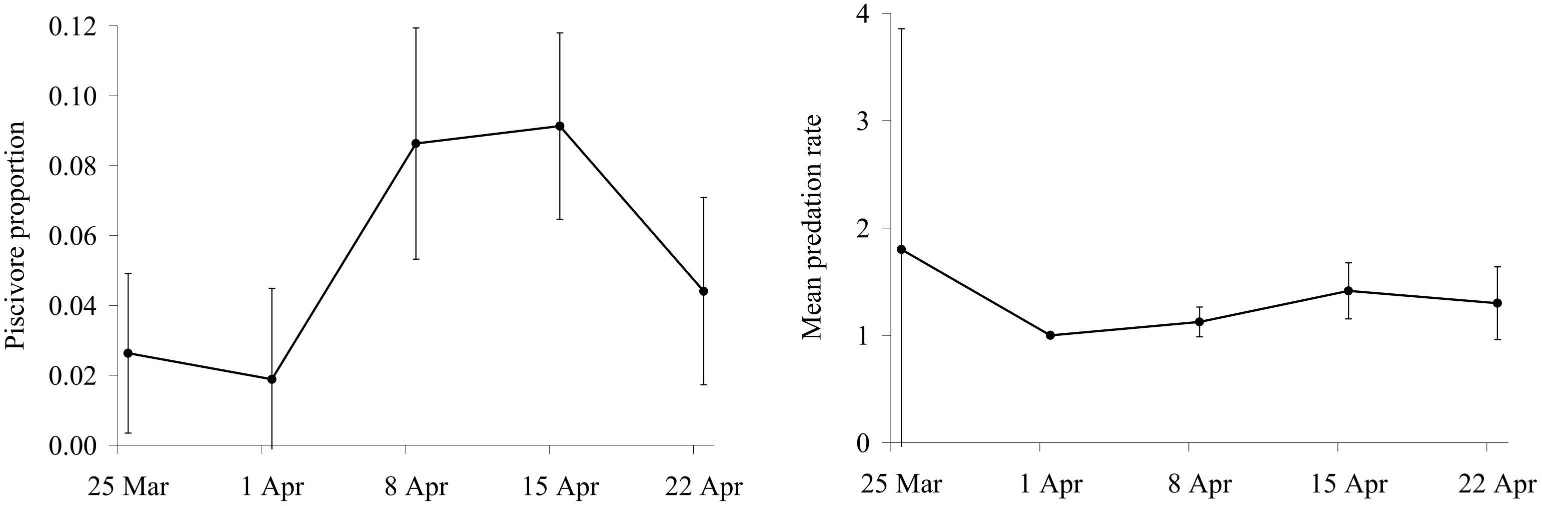

Figure 7. The proportion of piscivores (piscivores/ number of fish examined) ± 95% CI and the mean rate of predation (number of salmonid fry/piscivore) ± 95% CI for juvenile hatchery steelhead captured from the upper-Trinity River, California, 2007. The juvenile data excludes those fish captured at Bear Island.

Two years earlier, 2,479 juvenile salmonids consumed 135 salmonid fry in the same study reach (Yurok Tribal Fisheries Program 2008). Differences in fry consumption between the two years likely arises from a single sampling location, a side channel at Bear Island (rkm 180.4), which was sampled in 2007, but not 2005.

The observed count of piscivores between the juveniles captured at Bear Island and those not captured at Bear Island (Table 4) differed from the expected count ($\chi^2$ = 140.897, $P < 0.001$). Likewise the amount of fry consumed per piscivore between the two groups differed from the expected count ($\chi^2$ = 75.581, $P < 0.001$). Prior to this study, the initial investigation of predation rates by hatchery steelhead had not uncovered the high rate of predation that was recorded at Bear Island.

Samples obtained by seining and electrofishing were compared with samples obtained by hook and line on the same dates and in the same locations (4 different occasions in total). Of 372 juvenile hatchery steelhead captured by seine and electrofishing, 100 piscivores consumed a total of 635 salmonid fry. Of 317 juvenile hatchery steelhead captured by hook and line, 62 fish consumed 159 salmonid fry. Fish sampled by seining and electrofishing consumed 6.4 salmonid fry per piscivore, while fish sampled by hook and line consumed 2.6 fry per piscivore. The proportion of piscivorous hatchery steelhead did not differ with capture technique (seining/electrofishing versus hook and line) ($\chi^2$ = 3.179, $P = 0.075$), but the number of fry consumed per piscivore did ($\chi^2$ = 25.204, $P < 0.001$).

I estimate that 24,194 [21,066-27,323] salmonid fry were consumed by 2,302 residualized hatchery steelhead in 21 days from 10 February to 2 March 2007.

Additionally, I estimate that the residualized hatchery steelhead consumed 171,018 [155,272-186,764] salmonid eggs during the same period. Assuming an egg-to-fry survival rate of 0.25, the 171,018 eggs consumed by the residualized hatchery steelhead would equate to 42,755 salmonid fry.

Excluding results from the Bear Island side channel, I estimate that 437,697 juvenile hatchery steelhead consumed 61,214 [43,813-78,615] salmonid fry in 30 days from 28 March to 26 April 2007. Assuming a constant population of 1,500 juvenile hatchery steelhead in the Bear Island side channel in the 30 day period, an additional 49,445 salmonid fry were consumed.

# DISCUSSION

This study documents the highest rate of predation by hatchery salmonids on naturally produced salmonids that has been reported (Table 1). Some attributes of the upper Trinity River setting contribute to high predation risk for naturally produced salmonid fry. These include spatial and temporal overlap of predator and prey (Hatchery Scientific Review Group 2004), size differential of predator and prey (Pearsons and Fritts 1999), high concentrations of predators (Mather 1998), as well as abiotic factors including low, regulated flow (8.5 $ms^{-1}$) and high water clarity (< 2 NTU; Gregory and Levings 1998, Robertis et al. 2003). Because salmonids are visual predators, another factor controlling the encounter rate of prey is prey density (Beauchamp et al. 1999). The study area is heavily used by spawning adult salmonids, resulting in high concentrations of prey, relative to other parts of the river with lower redd densities.

The release of large numbers of hatchery steelhead can lead to substantial numbers of fry being consumed, even with relatively low predation rates. For example, if 500,000 hatchery steelhead are released, and 5% of these hatchery steelhead consume 1 fry per day, then 25,000 fry can be consumed in one day. The amount of fry consumed is additive, with hatchery steelhead continuing to consume fry each successive day.

The majority of salmonid spawning in the uppermost 40 km of the Trinity River (California Department of Fish and Game 2005) takes place within 3.2 km of the release location of hatchery juvenile salmonids, so that both predator and prey exist in close proximity to each other. In 2006, there were an estimated 2,302 redds for Chinook salmon and coho salmon combined, although some coho salmon and Chinook salmon may have spawned after redd surveys were terminated on 16 December 2006. Assuming 3,000 eggs per redd and an egg-to-fry survival rate of 0.25, approximately 1,726,500 salmon fry were produced in the study reach. Assuming all fry consumed by hatchery steelhead were Chinook salmon or coho salmon fry, half of the eggs consumed by residualized steelhead were Chinook salmon or coho salmon (the other half being steelhead), and an egg-to-fry survival rate of 0.25, then I estimate that 156,231 Chinook salmon and coho salmon fry were consumed over the 21 d residualized hatchery steelhead study period and the 30 d juvenile hatchery steelhead study period. This represents 9.0 % of Chinook salmon and coho salmon fry that were produced.

For several reasons, the estimate above is not a complete estimate of the number of fry consumed by hatchery steelhead in 2007. The estimate covers only the 21 d and the 30 d periods of study for residualized hatchery steelhead and juvenile hatchery steelhead, respectively. Additionally, almost half of the juvenile hatchery steelhead produced at Trinity River Hatchery in 2007 were not included in this study. The study reach was only a 3.2 km long, the fly only hook and line method utilized may lead to underestimation of fry consumption, and the study only covered a relatively short portion of the entire year. Also, dividing the number of daylight hours by the temperature-based gastric evacuation rate of steelhead resulted in a “correction” of the fry consumption data by approximately one-half throughout the study. Trinity River Hatchery also releases roughly 500,000 coho salmon annually that were not included in this study. Coho salmon have also been documented to consume salmonid fry (Ruggergone and Rogers 1992, McConnaughey 1999).

I found that the average fork length of juvenile hatchery steelhead piscivores was greater than that of non-piscivores. However the difference was five mm, which, while statistically significant, may not be biologically significant. Because the difference between these two groups was relatively small, and the fact that a wide range of juvenile steelhead size classes consumed salmonid fry, it is unlikely that there is a size at which juvenile hatchery steelhead can be released that would reduce the probability that they would consume salmonid fry. The differences between the proportion of piscivores and the number of fry consumed per piscivore for the three smoltification groups were small (Table 4). This indicates that hatchery rearing strategies aimed at increasing the number of steelhead that are ready to smolt upon release may not affect the number of fry consumed by hatchery steelhead. However, because non-smolting hatchery steelhead are more likely to residualize, non-smolting hatchery steelhead may consume more salmonid fry simply because they spend more time in the river than those that are capable of smolting when released.

Both juvenile hatchery steelhead and juvenile coho salmon are released on 15 March of each year. March is a time of year when many fry are either newly emerged, or just emerging from the gravel (Trinity River Flow Evaluation 1999), making the fry susceptible to predation. Residualized hatchery steelhead are present throughout the months that all salmonids spawn and rear. This study has shown that residualized steelhead take advantage of both fry and eggs in the drift, as well as actively pursuing rearing fry. For instance, I saw hundreds of adult steelhead spawning in February in areas where Chinook salmon and coho salmon had already spawned (redd superimposition). Spawning adult hatchery steelhead, upon creating their own nests, would excavate the yolk sac fry and eyed eggs of salmon, sending them into the water column, making for a readily available food resource for residualized hatchery steelhead.

Data from a comparison of fish samples collected by hook and line and those captured by other means suggests that hook and line may underestimate the number of salmonid fry consumed. This indicates that by relying on invertebrate fly patterns to attract juvenile hatchery steelhead, I may have failed to capture those juveniles that specialize in piscivory. For instance, if one casts a floating insect to a group of juvenile hatchery steelhead, an individual that typically focuses on pursuing salmonid fry may be less likely to be the first to look up and strike the dry fly than an individual that focuses on preying upon insects. I often witnessed juvenile hatchery steelhead pursuing salmonid fry in the shallows along the stream banks. It became clear after spending hours watching individual steelhead rush into groups of fry, that some hatchery steelhead tend to specialize in the pursuit of fry, while others do not. This has implication for the results of this research because the majority of the samples (77%) were captured using hook and line with invertebrate fly patterns, possibly underestimating the number of fry consumed.

Undoubtedly, several of the juvenile hatchery steelhead in raceway F, the only raceway that was not included in this study or in the calculations of fry consumption, were larger in size than the smallest piscivore that was recorded during this investigation, and therefore capable of consuming salmonid fry. This means that it is possible that some juvenile hatchery steelhead from raceway F, which on average contained the smallest steelhead released from Trinity River Hatchery, also consumed salmonid fry, thereby underestimating of the total number of fry consumed during the period of study in the study reach. In total, 384,906 juvenile hatchery steelhead were not included in the calculation of the number of fry consumed.

The relatively high rate of predation by juvenile hatchery steelhead on naturally produced fry at the Bear Island side channel was suprising. The number of fry per piscivore at Bear Island was roughly four times that of the rest of the study site (Table 4). Previous sampling by the Yurok Tribal Fisheries Program did not reveal large variation in predation rates at various locations throughout the study reach, but their survey did not sample juvenile hatchery steelhead at the Bear Island site. High predation may reflect a higher concentration of fry per unit of volume than in other areas of the river, and (or) it could reflect learned behavior by hatchery fish. Several juvenile hatchery steelhead had both feed pellets and invertebrates in their stomachs on the first day of our study, indicating that they quickly begin feeding on insects and other food particles in the drift.

Length of juvenile hatchery steelhead in my study was considerably smaller than in the survey conducted by the Yurok Tribal Fisheries Program in 2005 (Yurok Tribal Fisheries Program 2008). Average length differed by 30% (214 mm versus 167 mm) between the two studies. The study by the Yurok Tribal Fisheries Program (2008) found that 78% of juvenile hatchery steelhead examined were transitional or smolting. In this study, only 39% of juvenile hatchery steelhead were transitional or smolting. This is evidence that the average difference of 47 mm in fork length between juvenile steelhead captured in 2005, and those captured in 2007, is not only statistically significant, it is also biologically meaningful. Variability in release size affects inferences regarding survival and adult returns because both survival (Tipping 1997, Miyakoshi et al. 2001, Jokikokko et al. 2006) and smoltification, to a point (Chrisp and Bjornn 1978, Tipping et al. 1995), are positively correlated with juvenile size. Annual variability in release size of juvenile steelhead from Trinity River Hathcery may reflect variability in air temperature, weather, and water temperature, as fish are reared in outdoor raceways.

Chrisp and Bjornn (1978) determined that steelhead parr must reach a minimum total length of 140-160 mm before they have the capability to become smolts and migrate to the sea. Those that were greater than 170 mm in length had more pronounced changes associated with smoltification, and migrated in larger numbers, than smaller juveniles. Rhine et al. (2002) found that steelhead classified as smolts were significantly longer, heavier, and had lower mean condition factor than steelhead classified as transitional or not smolting. This agrees with my findings. Additionally, larger smolt size has been linked with increased rates of survival (Ward and Slaney 1988, Henderson and Cass 1991, Tipping 1997, Miyakoshi et al. 2001, Jokikokko et al. 2006), especially in years with poor ocean conditions (Saloniemia et al. 2004). However, the positive correlation between steelhead smolt size and percentage migrating (Chrisp and Bjornn 1978, Tipping et al. 1995) and survival (Tipping 1997) tends to disappear at roughly 190-210 mm, after which point residualism and precocialism begin to increase (Schmidt and House 1979, Partridge 1986, Viola and Schuck 1995, Newman 2002, Rhine et al. 2002). Tipping et al. (1995) reported that for optimum emigration rates, steelhead smolt lengths should be at least 190 mm and that Fulton's K values should be 0.90-0.99. Excessively large smolts conferred no clear emigration advantage, and were costlier to produce. However, average fork length should exceed 190 mm, in order to account for the normal distribution of a population (Tipping et al. 1995, Tipping 1997).

Because they are not, on average, physiologically capable of smolting, the 175,210 juvenile hatchery steelhead in raceways F (mean fork length = 125 mm) and N (mean fork length = 128 mm) of Trinity River Hatchery were forced into one of two probable pathways which are both undesirable from a management perspective: death or residualism. As mentioned above, mortality tends to be highest for smaller steelhead smolts (Seelbach 1987, Ward and Slaney 1988). Those that do survive compete with naturally produced salmonids for food and habitat (McMichael et al. 1997), exhibit aggression toward other salmonids (Berejikian et al. 1996, McMichael et al. 1999), and consume other salmonids (this study).

Although estimates of the number of residualized steelhead that exist in the upper Trinity River during summer months are not available, tens of thousands may persist throughout the summer (in any given year). Researchers have estimated residualism rates of 10-17% on other river systems (Viola and Schuck 1995, Rhine et al. 2002, Bumgarner et al. 2002). Snorkel surveys in June from previous years have documented tens of thousands of juvenile hatchery steelhead in the upper Trinity River (personal communication, P. Garrison, 2007 California Department of Fish and Game, P.O. Box 1185, Weaverville, CA 96093). For example, Bumgarner (2002) estimated that the number of residualized steelhead present in the Touchet River on 27 May 1999 was

18,411, or 14.7% of the 125,000 released. Assuming a minimum of 10% of steelhead from Trinity River Hatchery fail to migrate by 1 June, roughly 80,000 hatchery steelhead could be present in the Trinity River, most likely in the uppermost reaches.

In two separate years (2005 and 2007) only a few thousand fish were estimated to persist into March from releases of roughly 800,000 the previous year (Yurok Tribal Fisheries Program 2008, this study). The fate of the large number of steelhead that likely remain in the Trinity River between the time of release and the spring of the following year is not known. Most of the fish probably perish, as non-migratory juvenile steelhead tend to have high rates of mortality in freshwater (Chrisp and Bjornn 1978, Seelbach 1987), although some probably continue to smolt throughout the summer months. For example, Chrisp and Bjornn (1978) found that for yearlings planted in the spring, high mortalities (70%) occurred the following summer. It is not advantageous, from a management perspective, for juvenile hatchery steelhead to remain in the river for one year after release, and then migrate to the ocean, because they interact with naturally produced salmonids in the river (McMichael et al. 1997, McMichael et al. 1999, Kostow et al. 2003) and they have low survival rates (Chrisp and Bjornn 1978, Seelbach 1987).

Overall mean fork length for juvenile hatchery steelhead that were captured during the first week of this study was not significantly different from the mean for the 500 juvenile hatchery steelhead that were measured one day prior to release from the hatchery. This indicates that the hook and line method provided a reasonable means to sample fish without bias in relation to fish size. Because longer steelhead, up to roughly 200 mm, smolt at a greater frequency than smaller steelhead (Chrisp and Bjornn 1978, Rhine et al. 2002), it is possible that longer fish continually exited the study reach throughout the course of the investigation, making the mean fork length decrease over time. For instance, the mean length of fish captured during the first week of the study was 182 mm, while the overall mean for the duration of the study was 167 mm.

Even though Trinity River Hatchery serves as one of the large mitigation hatcheries in California, fishing regulations on the uppermost 3.2 km of the Trinity River are “fly only” and “catch and release only”. These regulations have no apparent biological justification. Fish and game agencies in some western states rely on angler harvest to eliminate residualized hatchery steelhead (Partridge 1985). Without this tool, river managers have few available means to eradicate non-anadromous steelhead from the river. Catch and release regulations that are, in this case, closely associated with a large hatchery, may obscure the overall purpose and ethic of catch and release angling from the fishing public, which is meant to preserve wild fish. The California Fish and Game Commission Policy (2004) states that

> “Resident fish will not be planted or resident fisheries developed in drainages of salmon [or steelhead] waters, where, in the opinion of the Department, such planting or development will interfere with salmon [or steelhead] populations. Exceptions to this policy may be authorized by the Commission (a) where the stream is no longer adaptable to anadromous runs, or (b) during the mid-summer period in those individual streams considered on a water-by-water

> basis where there is a high demand for angling recreation and such planting or development has been determined by the Department not to be detrimental to salmon [or steelhead]."

A fishery for non-anadromous hatchery steelhead now exists on the Trinity River. These residualized fish cannot legally be removed by anglers; however, they are targeted by fly fishermen. To date, the California Department of Fish and Game has not examined whether or not this resident fishery is detrimental to salmon or steelhead. Without this information, it is not possible to determine if the fishery is in conflict with the stated policies of the California Fish and Game Commission. Additionally, in some years, tens of thousands of adult hatchery salmonids, in excess of hatchery egg take goals, are returned to the river after entering the hatchery, and they cannot be harvested.

During the course of this study, I learned that virtually 100% of the steelhead broodstock at Trinity River Hatchery is of hatchery origin (personal communication, L. Marshall, 2007, California Department of Fish and Game, 1000 Hatchery Rd., Lewiston, CA 96052). Hatchery-reared, adipose fin clipped anadromous steelhead have been bred at Trinity River Hatchery for decades, with little, if any, genetic input from naturally produced steelhead. In order for the selection regimes in the natural environment to dominate the mean fitness of the hatchery and naturally produced population as a whole, it is recommended that the proportion of hatchery broodstock composed of naturally produced fish must exceed the proportion of hatchery fish spawning in the river (Hatchery Scientific Review Group 2004). For example, if the hatchery uses 10%

naturally produced steelhead for broodstock, then only 10% of steelhead that spawn naturally should be of hatchery origin so that the hatchery does not produce deleterious changes in the hatchery and naturally produced populations. Since Trinity River Hatchery uses virtually 100% hatchery steelhead broodstock, and the percentage of naturally spawning adults in any given year is roughly 75% (Trinity River Flow Evaluation 1999, California Department of Fish and Game 2005), the hatchery, and not the Trinity River, may be driving the natural selection process. This means that steelhead in the upper Trinity River mainstem might be better adapted to reproduction in the hatchery than in the Trinity River. This has bearing on this study and on the restoration of naturally produced fish in the Trinity River. This is because hatchery programs have the potential to significantly alter the genetic composition (Crozier 1998, Lynch and O'Hely 2001, Saisa et al. 2003), phenotypic traits (Einum and Flemming 1997, Hard et al 2000, Kostow 2004, Wessel et al. 2006), behavior (Mesa 1991, Berejikian et al. 1996, Fleming et al. 1996, Jonsson 1997), survival (Jonnnson et al. 2003, McGinnity et al. 2003, Kostow 2004) and ultimately the reproductive success (Reisenbichler and Rubin 1999, Fleming et al. 2000, Mclean et al 2003, Araki et al. 2007) of anadromous salmonids, potentially in a matter of a few generations (Araki et al. 2007). Egg transfers from Iron Gate Hatchery to Trinity River Hatchery were routine until at least 1994, and hatchery steelhead of the Trinity River are more genetically similar to Klamath River steelhead than they are to wild steelhead from Horse Linto Creek, a tributary to the Trinity River (Pearse et al. 2007).

While I did not study the effects of competition between hatchery and naturally produced salmonids in the river, others have reported negative impacts on naturally produced salmonids (Kennedy and Strange 1986, McMichael et al. 1997, McMichael et al. 1999), even to the point of measurably impacting the population of natural salmonids (Kostow et al. 2003, Kostow and Zhou 2006). Competition between hatchery and naturally produced salmonids may be more harmful than predation by hatchery salmonids on naturally produced salmonids, but its effects can be less visible. The end result of the competition may be dead naturally produced fish, which cannot be held in hand and counted as in this study.

Interactions in the freshwater environment between hatchery and naturally produced salmonids are likely to disproportionately affect those species which spend the most rearing time in the river. Naturally produced steelhead, spring Chinook salmon, and coho salmon juveniles typically spend at least one year in freshwater (Healey 1991, Sandercock 1991, Moyle 2002). Fall Chinook salmon, however, are unambiguously ocean-type (Moyle 2002). Fall Chinook salmon juveniles emerge from the gravel in late winter or early spring, and within a matter of months, migrate downstream to the estuary and the ocean (Moyle 2002, Quinn 2005). Therefore, naturally produced steelhead, spring Chinook salmon, and coho salmon juveniles are more likely than fall Chinook salmon to experience competition for food and resources in the river, triggering mechanisms such as density dependent mortality (Kostow et al. 2003, Kostow and Zhou 2006), that may ultimately impact the populations of those species. It then follows that in the upper Trinity River, the stocks which have the lowest proportion of naturally produced individuals returning to the upper Trinity River are coho salmon (~10%) and steelhead (~25%), while fall Chinook salmon have the highest proportion of naturally produced individuals (~40%) (Trinity River Flow Evaluation 1999, California Department of Fish and Game 2005). It should be noted that naturally produced salmonids have also been affected by reductions in available fry rearing habitat of the Trinity River in previous decades resulting from the erection of dams (Trinity River Flow Evaluation 1999, Record of Decision 2000).

Quantifying impacts on naturally produced salmon from predation by hatchery reared fish is one of the steps that can help inform decision makers. For example, one might estimate the number of fry that survive to reach smoltification as a result of a habitat improvement project that would not have survived to smoltification otherwise. This benefit to natural production as a result of a project like habitat enhancement could then be compared with the detriment to natural production caused by predation. This would let managers gauge, with a cost-benefit type analysis, the potential for conflict between the operational regime of a hatchery and river restoration projects. For instance, of 44 different river restoration sites aimed at improving the survival rate of naturally produced fry in the Trinity River, 4 are located in the study reach for this project. Benefits to natural production resulting from these habitat enhancement projects could be compared to the results of this study.

Northern-California Native American Tribes, the State of California, and the U.S. Government have agreed that restoring naturally produced salmonids to “pre-dam levels” is a priority, collectively creating and operating the Trinity Management Council, and the

Trinity River Restoration Program (Trinity River Flow Evaluation 1999, Record of Decision 2000). When ecological and genetic interactions between hatchery and natural salmonids are placed in the greater context of Trinity River restoration, the interactions between these fish has the potential to become problematic, as the goals of Trinity River Restoration Program may be in conflict with the current management regime of hatchery fish. Whether or not the extent of the conflict warrants action by river and hatchery managers is a decision that should be carefully considered.

Other river systems that might be at risk for predation by hatchery salmonids on naturally produced salmonids are those which have similar conditions as that on the Trinity River. Those conditions are relatively low flows, low turbidity, and release location near areas in which spawning adults congregate to build redds.

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