Mainstem Trinity River Chinook Salmon Spawning Survey, 2018

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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 2018 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 2018 was 2,375. 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 1,563 redds were constructed by natural-origin Chinook Salmon, 812 by hatchery-origin Chinook Salmon, and none 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 97% were within 10 km of the dam). Pre-spawn mortality of female Chinook Salmon was 2.1% for carcasses in all reaches and 1.6% 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 2018 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 the mid-river reaches from 2002 to 2018, while the proportion of hatchery-origin Chinook Salmon redds remained almost completely within the two reaches nearest to Lewiston Dam.

Introduction

The Trinity River 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 the mid-river sections of the river.

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 of the Central Valley Project. Downstream of the North Fork Trinity River, valley narrowing 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 2018 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 [182.2 river kilometer (rkm)] 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 2018 began August 26 and concluded December 14. This period was intended to encompass the majority of Chinook Salmon spawning activity.
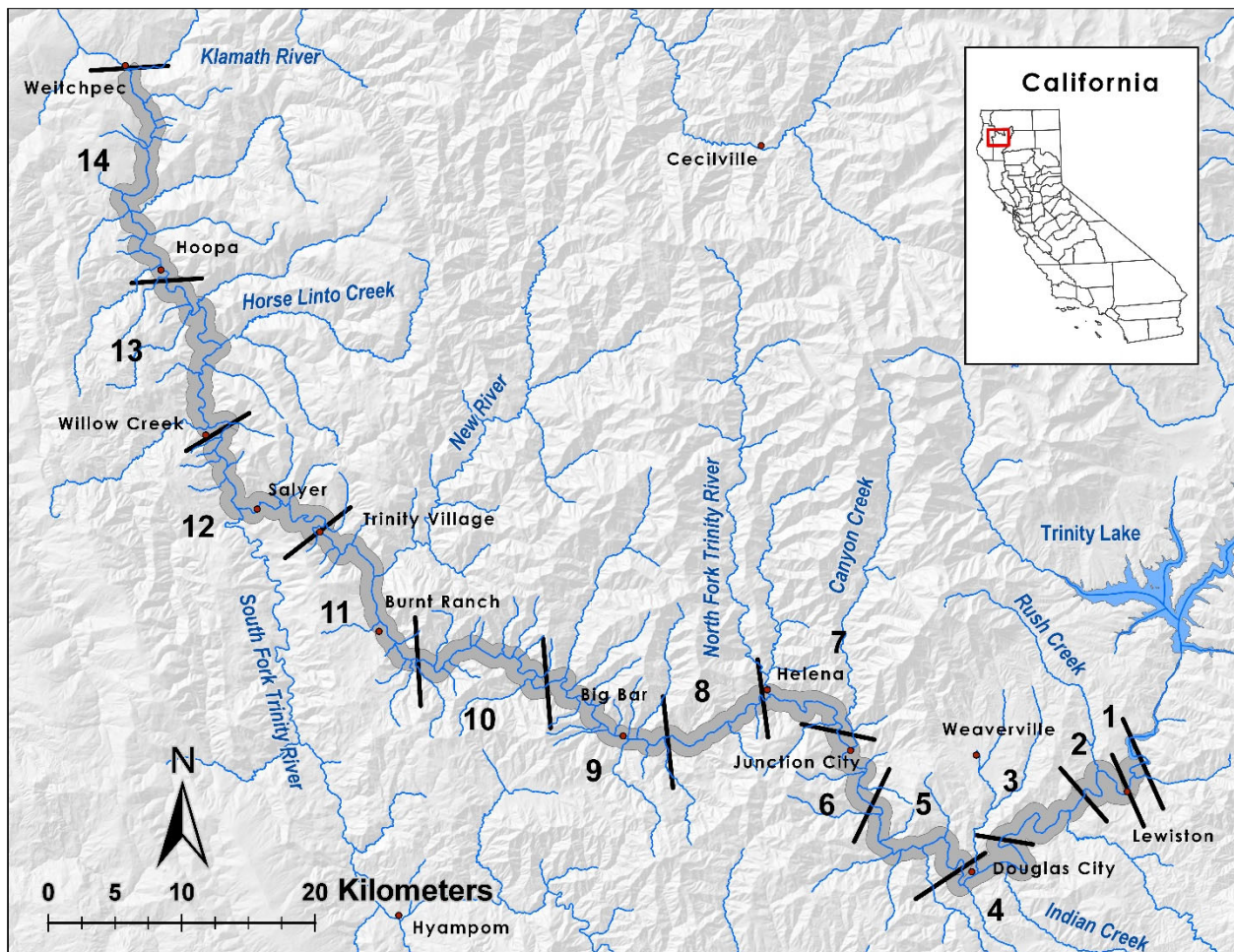
Figure 1. Survey Reaches 1–14 (Lewiston Dam to Weitchpec) on the mainstem Trinity River. Dangerous whitewater conditions precluded surveys in Reaches 8 and 11.

Table 1. Reach boundaries [and river kilometer (rkm)] for the mainstem Trinity River 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). In 2018, the USFS crew substituted for the primary surveying agency on various reaches throughout the season.

| Reach | Boundaries | | Primary surveying agency |
	Upstream	Downstream (rkm)	
1	Lewiston Dam (rkm 182.2) [a]	Old Lewiston Bridge (178.7)	CDFW, YTFP
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 was 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 are in Reaches 1–7.

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 these estimates should be considered maximum values of natural-origin spawning when not accounting for the hatchery–natural interaction. 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 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.

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, 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 2018 were combined with the preceding sixteen years (2002–2017) of mainstem Trinity River redd data from Chamberlain et al. (2012), Rupert et al. (2017a, 2017b), and Gough et al. (2019) 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.

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.

Ten reach-scale sections were used to evaluate long-term trends in natural- and hatchery-origin Chinook Salmon redd abundance (Figure 2, Table 2). 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.

For finer resolution spatial analyses, the river was partitioned into individual segments based on morphology 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 2002–2018 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 3). These site designations were generally based on the TRRP site designations of the SAB units (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.
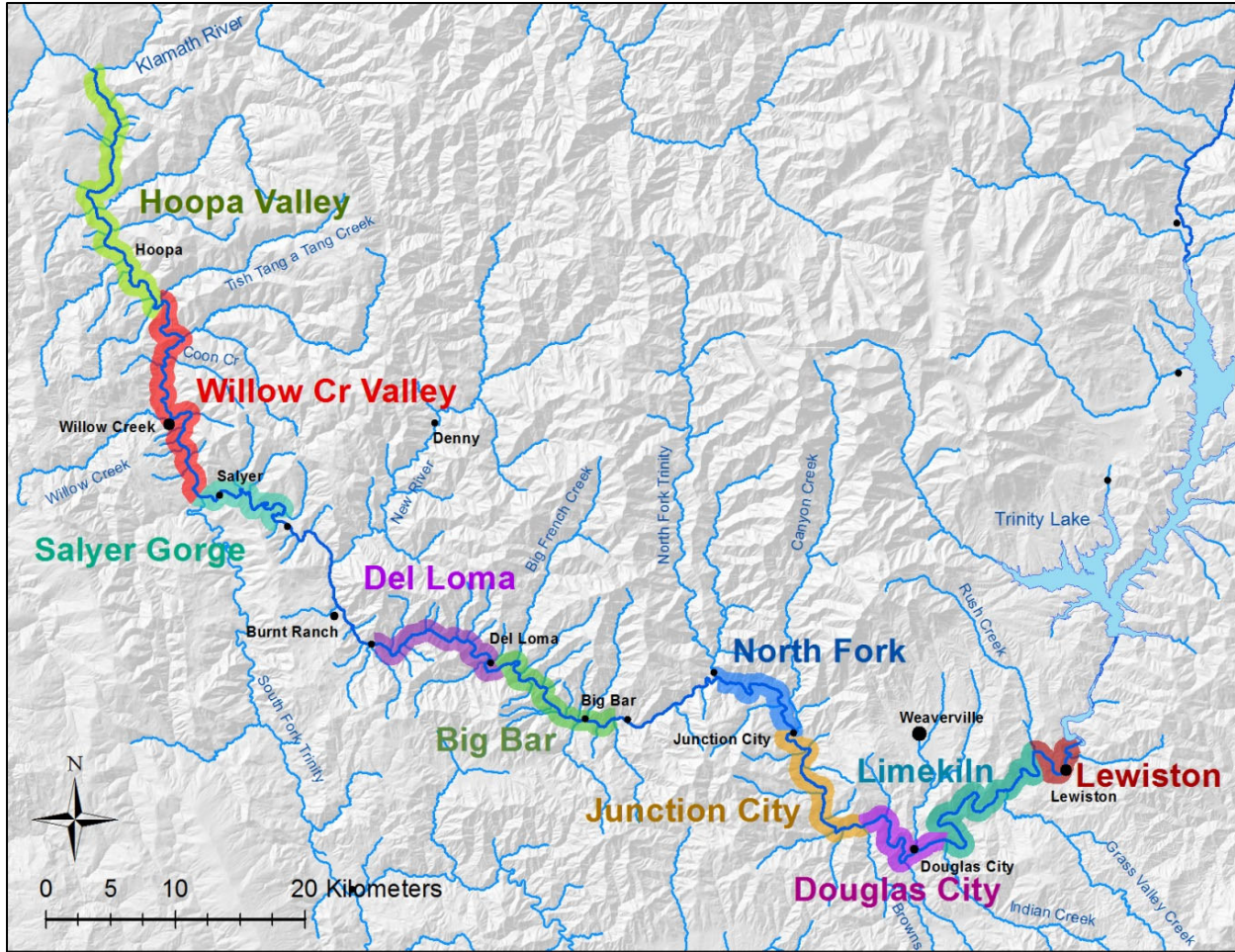
Figure 2. The ten sections of the mainstem Trinity River used for reach-scale analyses of Chinook Salmon redd distribution.

Table 2. 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

Table 3. 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

Results

Survey Success and Conditions

Crews were able to complete 90% of the originally scheduled surveys in 2018 (Appendix A). Most missed surveys, which typically occurred between mid-November and early December, were cancelled due to rain events causing increased turbidity and inhibited visibility.

Discharge in the mainstem Trinity River at Lewiston flowed at three main stages throughout the spawning surveys in 2018: 1) about 20.0 m^3/s from the beginning of the survey season to September 20, 2) about 13.5 m^3/s from then until mid-October, and 3) around 8.5 m^3/s from then until the remainder of season (Appendix B). At Hoopa, California, mean daily discharge ranged between 14.1 and 25.3 m^3/s from the start of the survey season to November 22, after which rain events caused flows to increase in mid-November. Mean daily flow then peaked at 68.5 m^3/s on November 30 and again at 140.2 m^3/s on December 19.

Crews reported water visibility between 1.5 and 3.0 m during most of the surveys in 2018 (Appendix A). Visibility was occasionally higher (>3.0), particularly during the early weeks. Visibility was lower (0.9–1.5 m) during a few scattered surveys and was less than 0.9 m once in Reach 5 in late November.

Salmon Carcasses

During the 2018 surveys, 874 fresh (Conditions 1 and 2 as described in Rupert at al. 2017a) Chinook Salmon carcasses were examined (Table 4). Of these fresh carcasses, 97 (11.1%) were adipose fin-clipped ('ad-clipped') and 49 (5.6%) 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 ad-clipped for an external mark at a constant fractional mark rate of 25%. The sex of the fish was identified in 867 of the fresh Chinook Salmon carcasses, and of these 582 (67.1%) were females.

From the 97 ad-clipped fresh Chinook Salmon carcasses observed, 90 heads were sampled, and 74 CWTs were read (Table 5). Data from CWT recoveries yielded an average annual marking rate of 0.236.

Of the 582 fresh female Chinook Salmon carcasses recovered, 75 (12.9%) were ad-clipped, and of these, 71 heads were collected. CWTs were recovered and read from 59 of these heads. Of the spawned female hatchery-origin Chinook Salmon carcasses (spring and fall broods combined) with associated CWT data, 96.6% (57 of 59) were recovered within 10 km of Lewiston Dam (Figure 3).

Relatively few (five) Coho Salmon carcasses were recovered during the 2018 surveys (Table 6). Of these, three were fresh and of these, two were right maxillary-clipped, which indicates hatchery origin. None of the fresh Coho Salmon carcasses were female. The absence of spawned female Coho Salmon carcasses recovered inhibited the ability to differentiate Coho Salmon redds by origin in 2018.

Table 4. Summary of fresh (conditions 1 and 2) Chinook Salmon carcass data by survey reach, 2018 Trinity River surveys.

Reach	Total [a]	Males	Females	Female proportion	Ad-clipped	Weir-tagged
1	332	82	249	75.2%	54	22
2	254	91	163	64.2%	36	15
3	67	30	35	53.8%	2	4
4	79	27	51	65.4%	3	3
5	39	13	26	66.7%	0	5
6	36	13	22	62.9%	0	0
7	18	12	6	33.3%	0	0
9	20	7	12	63.2%	0	0
10	7	1	6	85.7%	0	0
12	11	3	8	72.7%	0	0
13	9	5	3	37.5%	1	0
14	2	1	1	50.0%	1	0
Total	874	285	582	67.1%	97 [b]	49

[a] may includes carcass(es) of unknown sex

[b] head samples were collected from 90 of the 97 fresh ad-clipped Chinook Salmon carcasses

Table 5. Coded-wire tag (CWT) information retrieved from fresh adipose fin-clipped Chinook Salmon carcasses, 2018 Trinity River surveys.

Carcasses	CWT	Brood Year	Run type	Release type	Production multiplier	Marking rate
1	60696	2014	Spring	Yearling	4.27	0.234
2	60697	2014	Fall	Yearling	4.18	0.239
7	60772	2015	Spring	Fingerling	4.24	0.236
4	60773	2015	Spring	Fingerling	4.34	0.230
4	60774	2015	Spring	Fingerling	4.17	0.240
6	60775	2015	Fall	Fingerling	4.27	0.234
5	60776	2015	Fall	Fingerling	4.20	0.238
2	60777	2015	Fall	Fingerling	4.32	0.231
4	60778	2015	Fall	Fingerling	4.30	0.232
9	60779	2015	Spring	Yearling	4.24	0.236
25	60780	2015	Fall	Yearling	4.25	0.236
1	60781	2015	Spring	Fingerling	4.36	0.229
1	60961	2016	Spring	Yearling	4.17	0.240
3	60962	2016	Fall	Yearling	4.15	0.241
16		-- Missing CWT/head --			NA	NA
					Mean = 4.24	Mean = 0.236
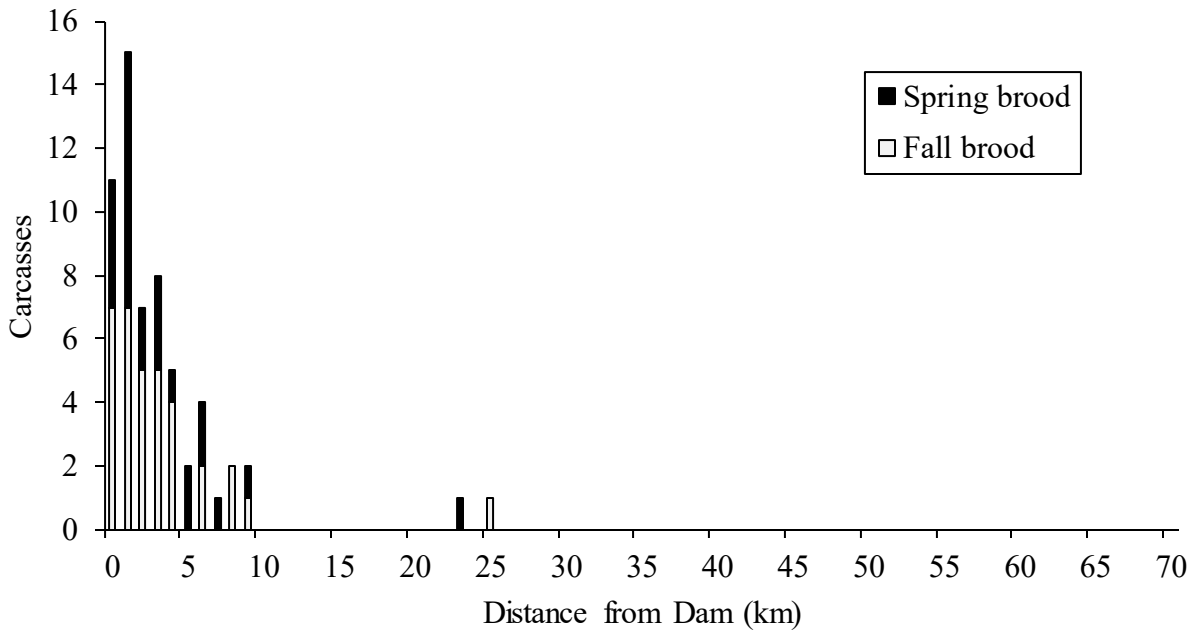
Figure 3. Distribution of coded-wire-tagged (CWT) spawned female Chinook Salmon carcasses by brood type (spring and fall) located in the mainstem Trinity River downstream of Lewiston Dam in 2018.

Table 6. Summary of fresh (conditions 1 and 2) Coho Salmon carcass data by survey reach, 2018 Trinity River surveys.

Reach	Total	Males	Females	Female proportion	Maxillary-clipped	Weir-tagged
1	1	1	0	0.0%	1	0
2	2	2	0	0.0%	1	0
3	0	0	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	3	0	0.0%	2	0

Carcass Estimates

The hierarchical latent variables model estimated 1,288 (95% CI: 1,042–1,587) Chinook Salmon carcasses in Reach 1 and 1,890 (95% CI: 1,321–2,702) in Reach 2 in 2018. Estimates of spawned female Chinook Salmon carcasses were 953 (95% CI: 771–1,182) in Reach 1 and 1,160 (95% CI: 815–1,645) in Reach 2.

Pre-spawn Mortality

Twelve fresh unspawned female Chinook Salmon carcasses were found in 2018, one of which had a hatchery mark that yielded a pre-spawn mortality rate among female Chinook Salmon throughout the mainstem Trinity River of 2.1% (Table 7). Weekly pre-spawn mortality rates ranged from 0.0% to 12.9% (the first six survey weeks were combined due to small sample sizes; Figure 4). The overall pre-spawn mortality rate of female Chinook Salmon in the Trinity River restoration reach was 1.6% in 2018.

No fresh female Coho Salmon carcasses were encountered in 2018 which precluded any pre-spawn mortality analysis for this species (Table 8). Note that pre-spawn mortality rates were based on data collected through late December, while Coho Salmon were 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), 2009–2018 surveys. Pre-spawn mortalities by week and reach for unmarked and ad-clipped Chinook Salmon are presented in Appendix C.

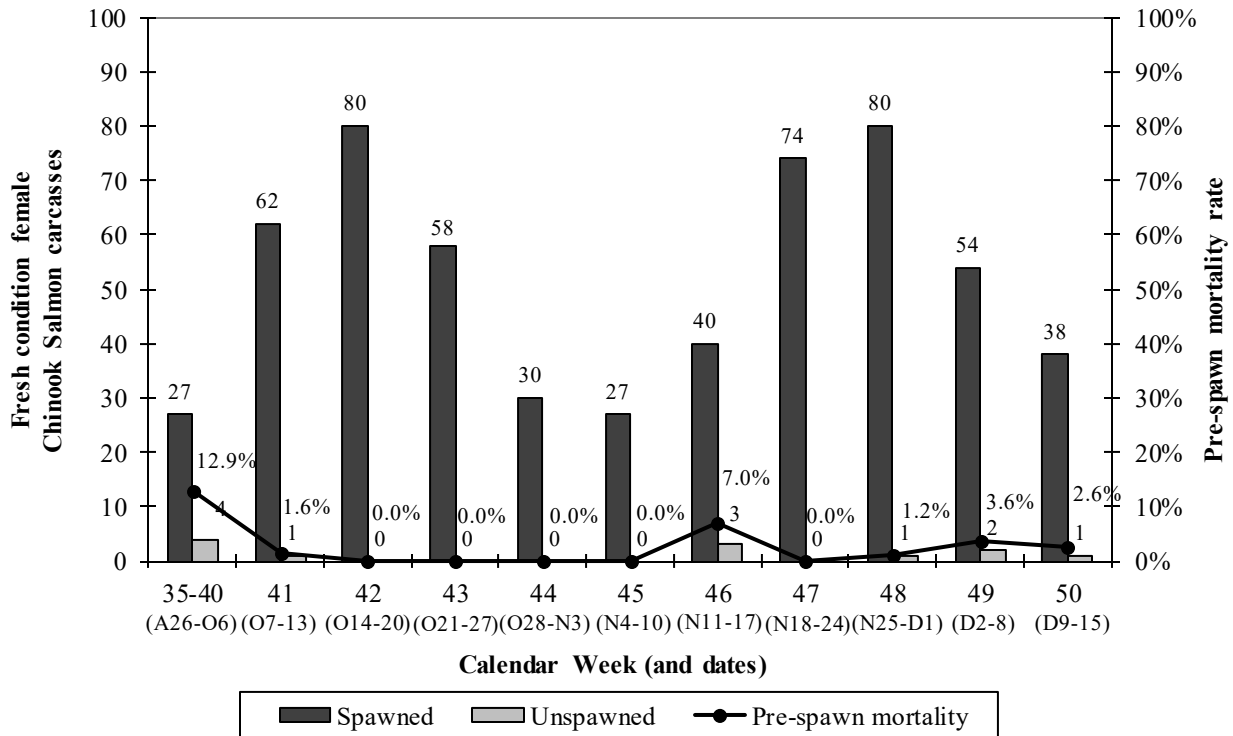|	Chinook Salmon pre-spawn mortality rate	
	Reaches 1-14	Reaches 1-7
Year	(Lewiston Dam to Klamath River)	(Lewiston Dam to North Fork)
2009	7.9%	6.8%
2010	10.2%	9.5%
2011	4.6%	4.6%
2012	2.4%	2.4%
2013	5.1%	6.1%
2014	11.5%	9.1%
2015	0.8%	0.0%
2016	0.7%	0.8%
2017	1.8%	2.0%
2018	2.1%	1.6%

Figure 4. Weekly pre-spawn mortality from fresh (conditions 1 and 2) female Chinook Salmon carcasses, Trinity River surveys 2018. Calendar weeks 36–40 were combined because of low sample sizes in at least one of those weeks.

Table 8. Pre-spawn mortality rates of natural- and hatchery-origin Coho Salmon, Trinity River surveys, 2009–2018. 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.

	Coho Salmon pre-spawn mortality rate		
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]
2018	- [d]	- [d]	- [d]

[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

[d] no female Coho Salmon carcasses were observed in 2018

Salmon Redds

During the 2018 surveys, 2,375 salmon redds were identified (Table 9). A majority of the redds (1,559, 95% c.i.: 1,309–1,741; 65.8%) were estimated to have been constructed by natural-origin female Chinook Salmon, while hatchery-origin female Chinook Salmon accounted for 812 (95% c.i.: 634–1,066; 34.2%) of the total redd count (Table 10). The annual natural-origin Chinook Salmon redd count from 2002 to 2018 ranged between 1,516 (in 2016) and 6,170 (in 2012). The absence of spawned female Coho Salmon carcasses observed in 2018 precluded attributing any of the redds to Coho Salmon. Note that the Coho Salmon spawning season continued beyond our surveys.

Natural-origin Chinook Salmon redds were constructed throughout most of the mainstem Trinity River with the highest numbers skewed toward Lewiston Dam (Figure 5). Hatchery-origin Chinook Salmon redds were also mainly in the upstream-most reaches but with little to no spawning detected downstream of Reach 7.

Table 9. Redd counts (before species differentiation) by week and reach, Trinity River surveys 2018. NS = 'No Survey' for scheduled surveys that were missed. Dashes (-) represent days when surveys were not scheduled.

Week start	Reach													
	1	2	3	4	5	6	7	9	10	12	13	14	Total
Aug 26	0	-	-	-	-	-	-	-	-	-	-	-	-
Sep 2	0	0	0	0	0	0	0	-	-	-	-	-	-
Sep 9	0	0	0	1	1	0	0	0	0	-	-	-	2
Sep 16	3	9	6	7	4	0	0	-	-	-	-	-	29
Sep 23	36	64	52	34	NS	0	0	1	0	-	-	-	187
Sep 30	23	65	58	NS	43	0	2	-	-	0	0	0	191
Oct 7	39	47	30	53	31	3	8	63	22	-	-	-	296
Oct 14	43	62	15	36	41	19	19	-	-	12	16	2	265
Oct 21	21	42	16	23	49	4	29	99	51	-	-	-	334
Oct 28	11	19	28	11	18	11	7	-	-	33	60	13	211
Nov 4	44	51	28	9	16	3	7	4	15	-	-	-	177
Nov 11	55	139	40	18	NS	0	0	-	-	11	30	8	301
Nov 18	59	35	NS	NS	1	3	7	NS	NS	-	-	-	105
Nov 25	32	10	NS	NS	4	0	1	-	-	NS	NS	NS	47
Dec 2	15	40	15	9	18	2	6	13	25	-	-	-	143
Dec 9	6	12	9	16	1	NS	NS	-	-	36	3	4	87
Total	387	595	297	217	227	45	86	180	113	92	109	27	2,375

Table 10. Estimated numbers of salmon redds by species and origin observed in the mainstem Trinity River, 2018. Hatchery- and natural-origin estimates are for the maternal first generation only. Bootstrap-generated 95% confidence intervals are in parentheses.

Species	Origin	Redd estimate	95% confidence limits	
			Lower	Upper
Chinook Salmon	All	2,375 [b]	-	-
	Natural	1,559	1,309	1,741
	Hatchery	816	634	1,066
Coho Salmon [a]	All	0 [c]	-	-
	Natural	0 [c]	-	-
	Hatchery	0 [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. A confidence limit could not be calculated here because no fresh female Coho Salmon carcasses were found in 2018.

[c] No fresh female Coho Salmon carcasses were observed in 2018. Therefore none of the redds were attributed to Coho Salmon.
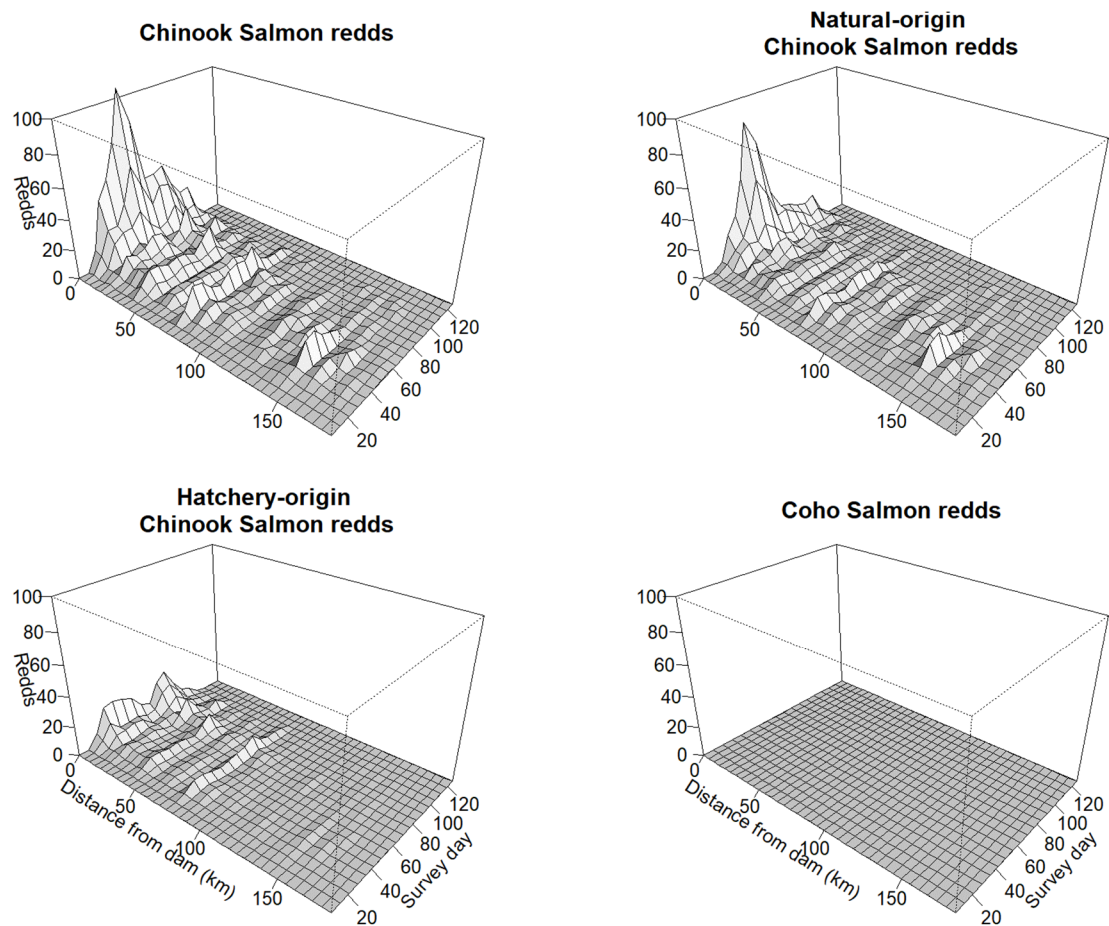
Figure 5. Spatiotemporal distribution of mainstem Trinity River salmon redds from Lewiston Dam to Weitchpec, 2018. Surveys were not conducted in Reaches 8 (rkm 107.6-117.4) and 11 (rkm 63.4–79.1). No fresh female Coho Salmon carcasses were observed in 2018 and therefore no redds were predicted to be attributed to Coho Salmon. 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 2018 had a positive linear correlation ($R^2 = 0.8393$, $p < 0.001$; 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 = 0.638, 95% CI: 0.479–0.797).
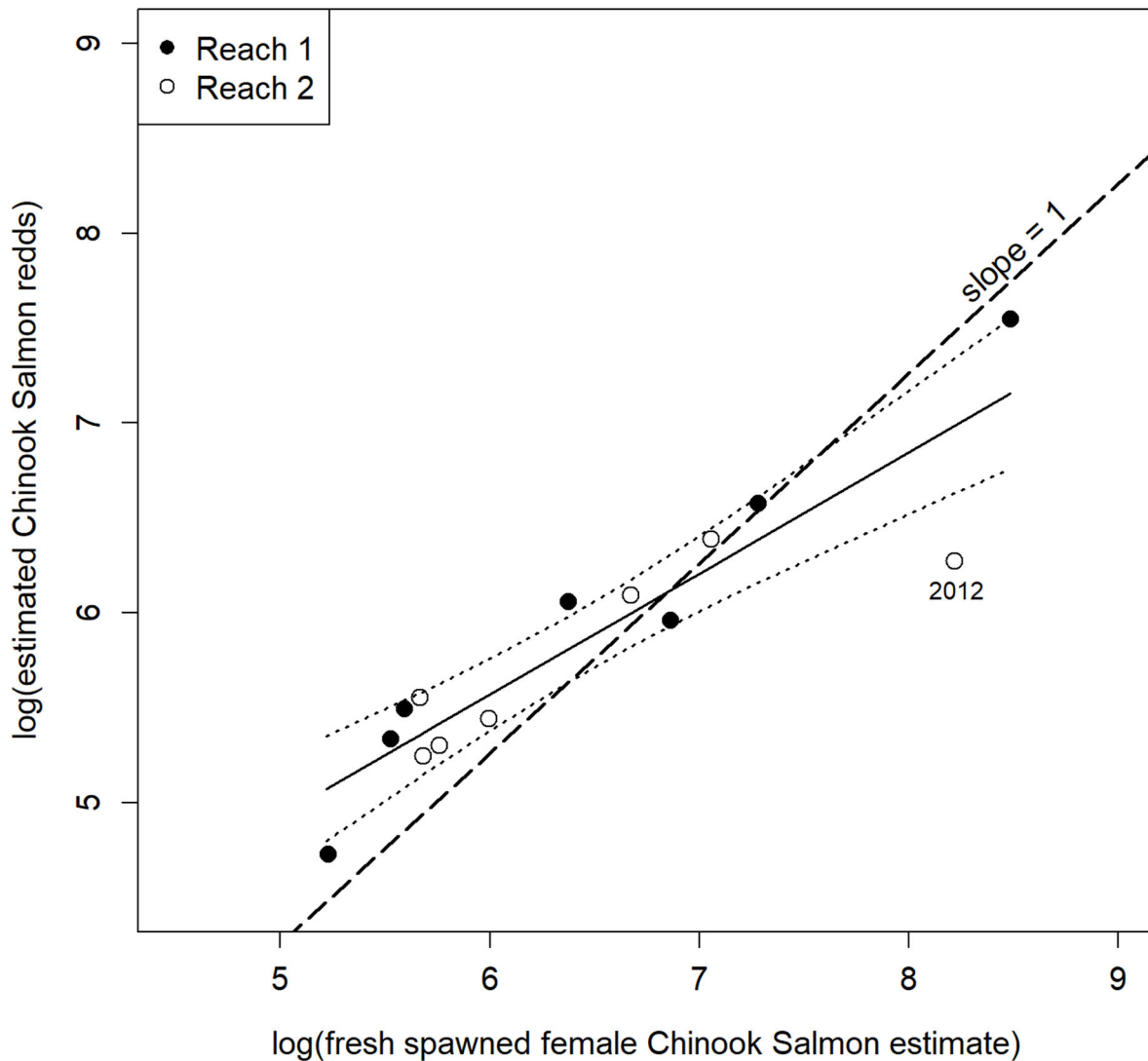

Figure 6. Relationship between counts of *ln*-transformed Chinook Salmon redds and *ln*-transformed estimates of spawned female Chinook Salmon carcasses in Reaches 1 and 2 (solid line), 2012–2018. The dashed line is included to represent a slope of '1', which would be the slope of two perfectly proportional variables. Dotted lines represent 95% confidence limits of the linear model.

Redd Abundance and Distribution: System Scale

From 2002 to 2018, the number of mainstem salmon redds ranged between 1,671 and 7,588 redds and decreased over time ($R^2 = 0.3572$, $p = 0.01$; 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 ($R^2 = 0.0938$, $p = 0.23$), while the number of redds constructed by hatchery-origin Chinook Salmon trended downward ($R^2 = 0.4981$, $p = 0.002$) over this time frame.
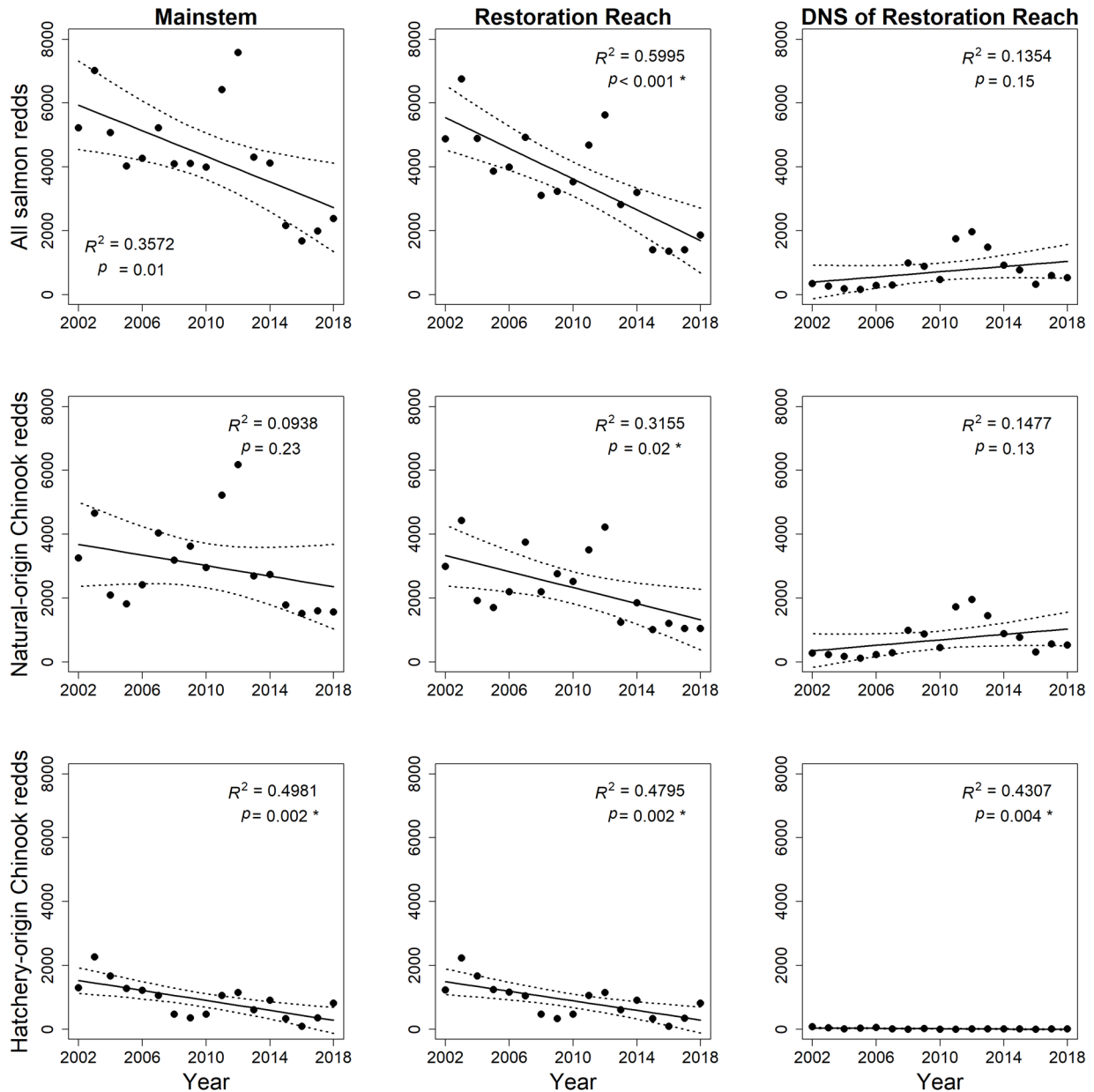
Figure 7. Estimated number of redds constructed in the entire mainstem Trinity River (left), within the restoration reach (center), and downstream (DNS) of the restoration reach (right) by all Chinook Salmon (top), natural-origin Chinook Salmon (middle), and hatchery-origin Chinook Salmon (bottom) from 2002 to 2018. 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 2018, the number of redds constructed annually by natural- and hatchery-origin Chinook Salmon in the restoration reach were variable but trended downward ($R^2 = 0.3155$, $p = 0.02$ and $R^2 = 0.4795$, $p = 0.002$, respectively).

Downstream of the restoration reach the number of natural-origin Chinook Salmon redds constructed from 2002 to 2018 generally increased but with no significant trend ($R^2 = 0.1477$, $p = 0.13$; Figure 7). A significant decrease in hatchery-origin Chinook Salmon redds was detected downstream of the restoration reach ($R^2 = 0.4307$, $p = 0.004$), 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 constructed by hatchery-origin Chinook Salmon downstream of the restoration reach except for 2004 when none were. From 2007 to 2018 between 0 and 14 redds per year were constructed by hatchery-origin Chinook Salmon downstream of the restoration reach and only zero or one in 9 of those 12 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- and hatchery-origin Chinook Salmon in 2018 were 37.4 and 6.9 km, respectively. From 2002 to 2017, the mean distance of redds from the dam ranged between 15.3 and 49.2 km for natural-origin and between 2.1 and 14.2 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 2018 ($R^2 = 0.7544$, $p < 0.001$; Figure 8). This trend, to a lesser degree, was also evident for redds constructed by hatchery-origin Chinook Salmon ($R^2 = 0.2565$, $p = 0.04$), which also consistently spawned near Lewiston Dam.
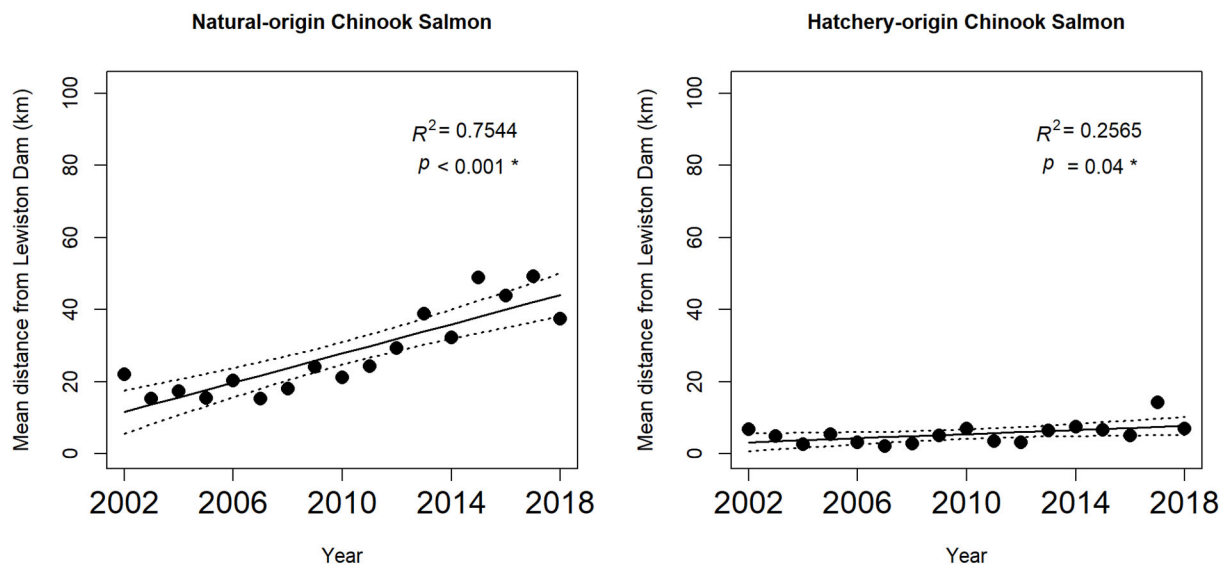

Figure 8. Mean distance from Lewiston Dam of redds constructed by natural- (left) and hatchery-origin (right) Chinook Salmon females between Lewiston Dam and Cedar Flat (0–102.8 km from Lewiston Dam; Reaches 1–10) on the mainstem Trinity River, 2002–2018. Each plot includes a linear model with the R^2 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 ($R^2 = 0.5584$, $p < 0.001$) and Limekiln ($R^2 = 0.3034$, $p = 0.02$) reaches and generally decreased, to a lesser degree, in the Douglas City reach from 2002 to 2018 (Figure 9). The number of redds between the Junction City and Del Loma reaches generally increased over this time period and generally decreased in the Salyer Gorge, Willow Creek Valley, and Hoopa Valley reaches over the shorter time period from 2007 to 2018, though no significant trends were detected downstream of the Douglas City reach.

To account for annual variation in run size, we compared 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 (Figure 10). This analysis revealed a shift in spawning distribution, where natural-origin Chinook Salmon redds significantly decreased in the upstream-most reach [Lewiston ($R^2 = 0.7933$, $p < 0.001$)], did not significantly change in the Limekiln and Douglas City reaches, and increased in the mid-river reaches [Junction City ($R^2 = 0.3064$, $p = 0.02$), North Fork ($R^2 = 0.3228$, $p = 0.02$), Big Bar ($R^2 = 0.6474$, $p < 0.001$), 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 reach (range = 72–1,888 redds/year, mean = 756 redds/year) and, to a lesser degree, in the Limekiln reach (range = 19–252 redds/year, mean = 94 redds/year) from 2002 to 2018. Over this time frame, the abundance of hatchery-origin Chinook Salmon redds significantly decreased in the Lewiston reach ($R^2 = 0.5298$, $p < 0.001$) 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 6 and 17 per year in each reach and only changed significantly in the Del Loma reach ($R^2 = 0.2639$, $p = 0.03$). 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 = 81.4%) and, to a smaller degree, in the Limekiln reach (range = 3.5%–30.9%, mean = 12.6%) from 2002 to 2018. The proportion of hatchery-origin Chinook Salmon redds in the Lewiston reach decreased ($R^2 = 0.3143$, $p = 0.02$) while the proportion of redds in the Limekiln reach increased ($R^2 = 0.5190$, $p = 0.001$). The mean proportion of hatchery-origin Chinook Salmon redds in each reach downstream of the Limekiln reach ranged between 0.0% and 7.0% 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 in the restoration reach show a range of long-term (2002–2018) trends (Appendix D). Most sites (23) did not show a significant change, 17 sites showed an increasing trend,

and 4 sites showed a decreasing trend. 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. Most sections from the Sawmill site to the Douglas City site did not significantly change. Downstream of the Douglas City site, from the Reading Creek site to the Bagdad site, the proportion of natural-origin Chinook Salmon redds underwent a range of trends over this time period between no change and a significant increase.

Of the 23 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 6 sites, trended downward at 2 sites, and displayed no significant change at 15 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 Lower Indian Creek 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 0.0% at most sites below the Limekiln reach from 2002 to 2018.
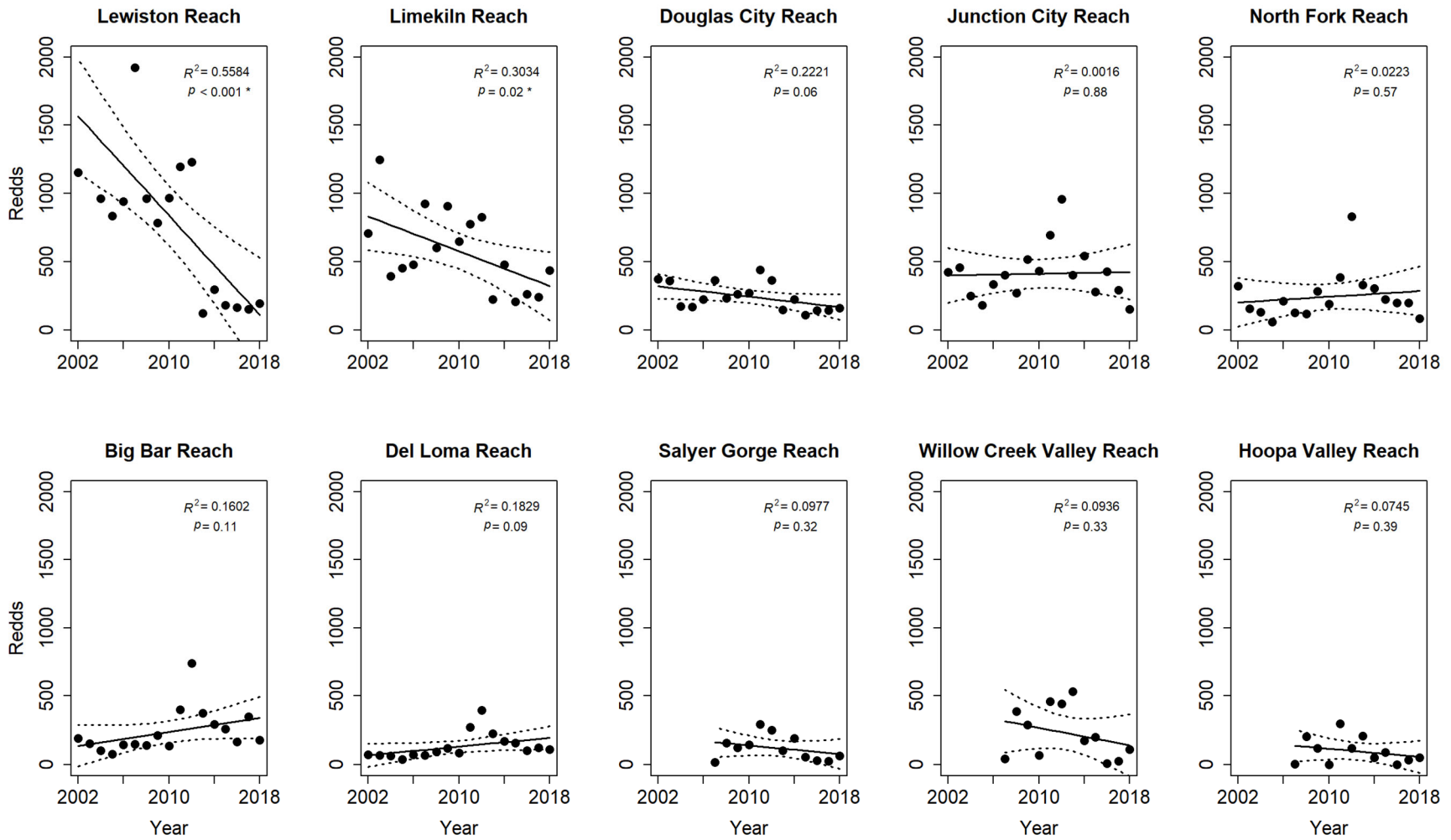
Figure 9. Estimated number of mainstem Trinity River natural-origin Chinook Salmon redds within ten reach-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).
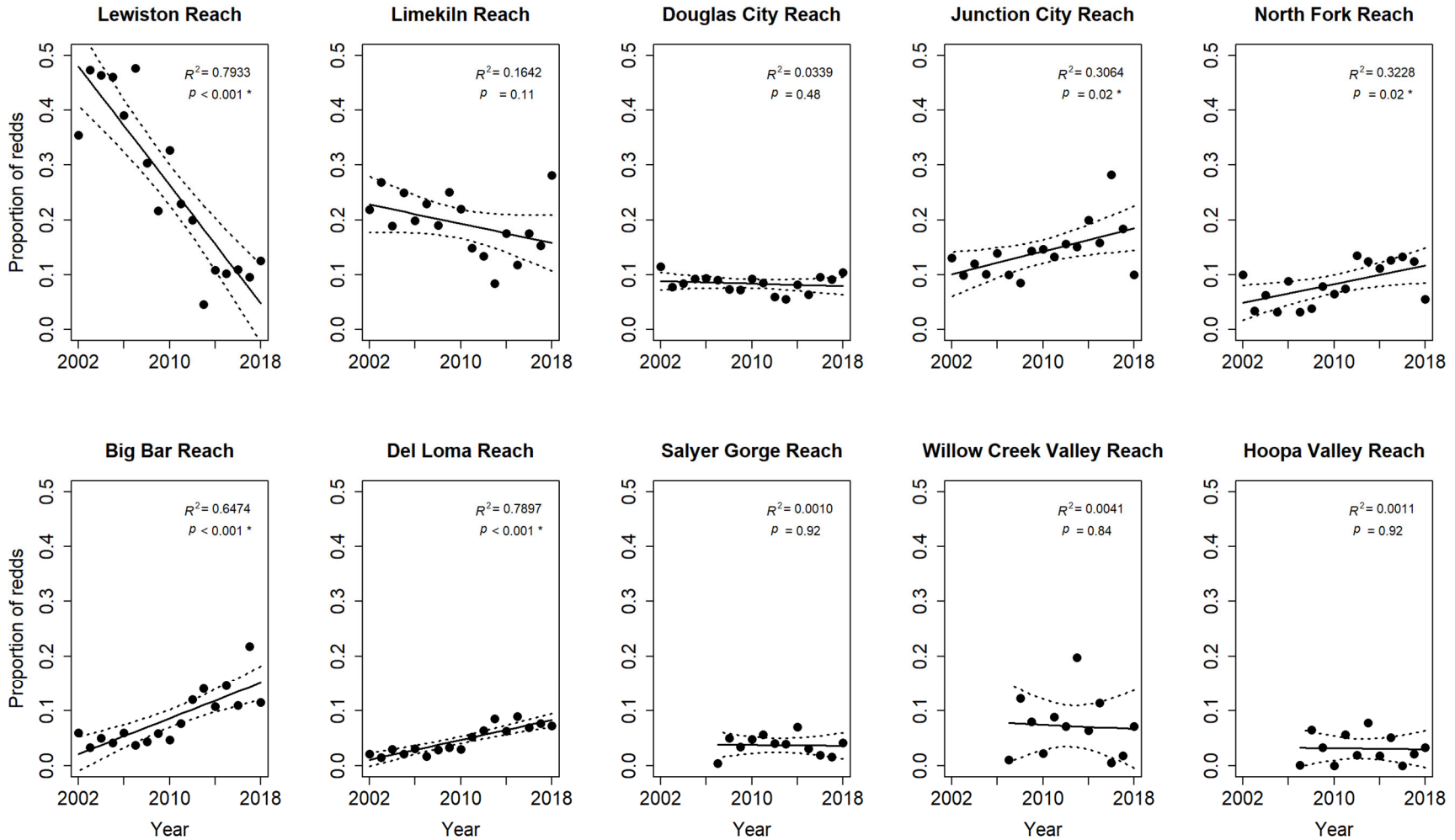
Figure 10. Proportions of mainstem Trinity River natural-origin Chinook Salmon redds relative to the total mainstem count of natural-origin Chinook Salmon redds within ten reach-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).
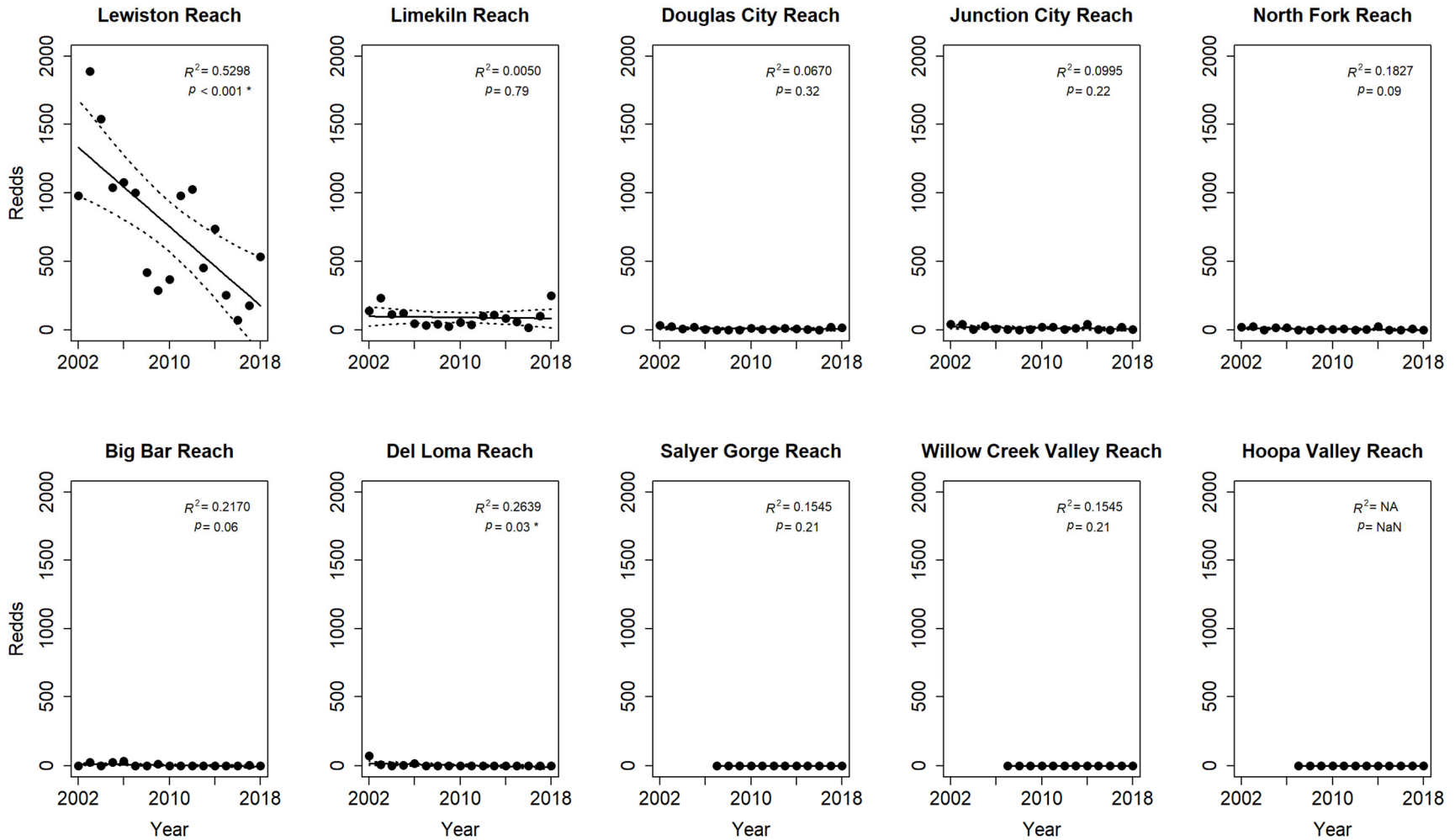
Figure 11. Estimated number of mainstem Trinity River hatchery-origin Chinook Salmon redds within ten reach-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).
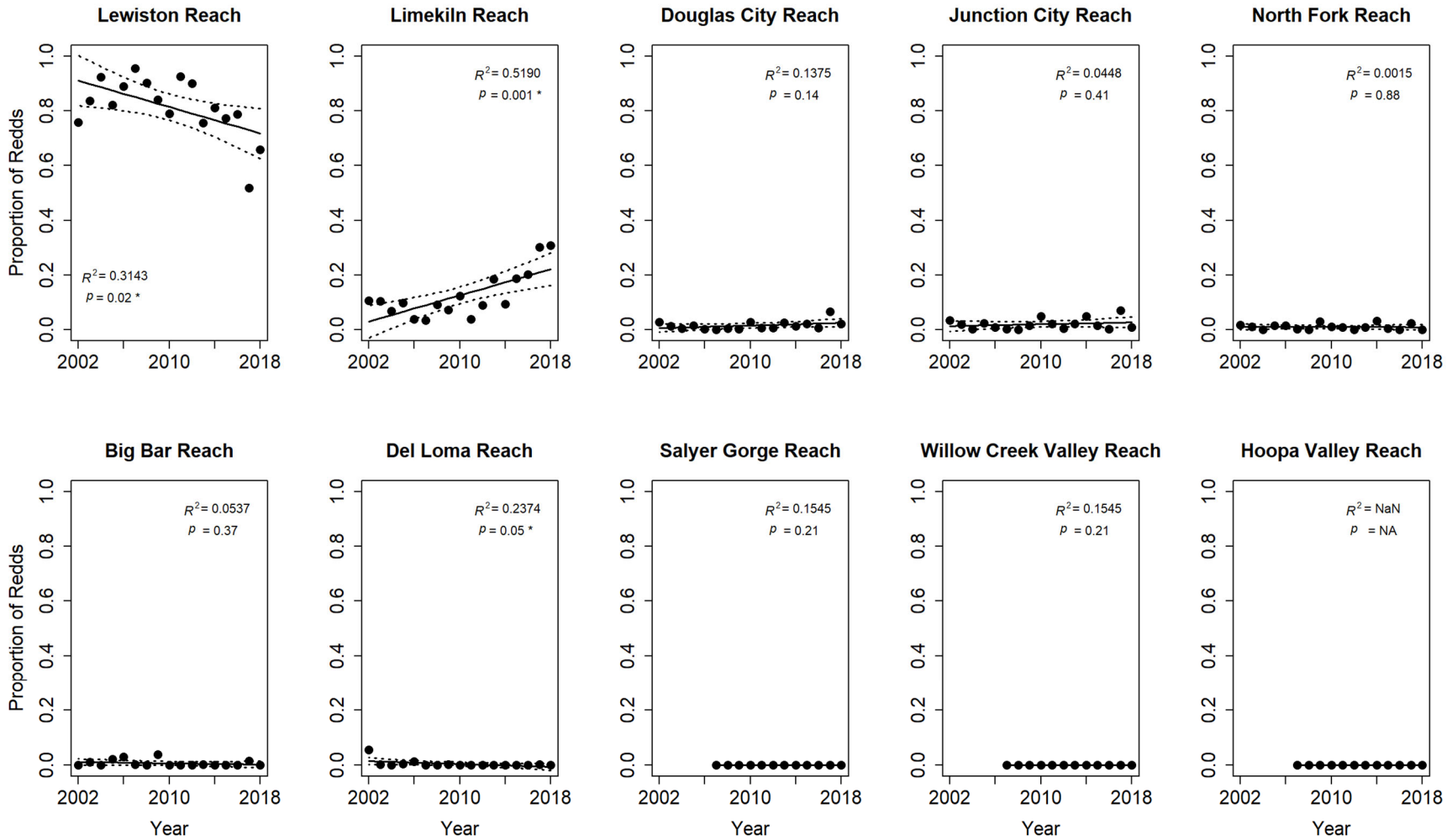
Figure 12. Proportions of mainstem Trinity River hatchery-origin Chinook Salmon redds relative to the total mainstem count of hatchery-origin Chinook Salmon redds within ten reach-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).

Discussion

Redd counts from the 2018 spawning season were the fourth lowest since this survey's inception in 2002, with redd counts only lower in 2015, 2016, and 2017. Salmon carcass estimates in 2018 were the fifth lowest since 2002 and were only lower in 2013, 2015, 2016, and 2017. Our 2018 results ranked lower than the California Department of Fish and Wildlife Chinook Salmon natural spawner escapement estimates for the Trinity River Basin, which estimated the eighth lowest numbers of both spring- and fall-run adults since 2002 (CDFW 2018a, 2018b).

Flows were generally stable in three stages over the survey period in the upper reaches and throughout most of the survey period in the lower reaches. Rain events elevated discharge and turbidity in the lower reaches in late November and scheduled lower river surveys were cancelled due to resultant poor visibility. Surveys resumed in all reaches in December as visibility improved and the redd counts from these surveys likely include those redds that would have been counted during missed surveys.

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 2018, 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.

Contrary to the hypothesis that spawner abundance would increase following restoration actions (TRRP and ESSA 2009), the abundance of natural-origin Chinook Salmon redds in the mainstem Trinity River from 2002 to 2018 did not significantly change (Figure 7). A number of factors (e.g., harvest, ocean conditions, in-river conditions, etc.) can influence in-river escapement and may mask responses of 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 2019a, 2019b). The estimates of Trinity River natural-spawner adult escapement (4,375 spring-run and 14,847 fall-run) in 2018 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 2018, 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; Gough et al. 2019) and data collected in 2018 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).

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 2018 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.

The abundance of hatchery-origin Chinook Salmon redds (redds constructed by hatchery-produced females regardless of male origin) decreased significantly from 2002 to 2018, 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 redds.

Changes in redd abundance at the site scale were 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 2012–2018 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 2017 and 1.6% in 2018) in this section of the river. 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 2018 data to the data from 2009 to 2017, we detected no correlation 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. Pre-spawn mortality could not be assessed for Coho Salmon in 2018 because no fresh female Coho Salmon carcasses were encountered. Interpretation of results pertaining to spawning success should take into account that pre-spawn mortality goes beyond what we observe on the spawning ground surveys. The spatiotemporal locations of pre-spawn mortality carcass recoveries are unlikely to be an accurate depiction of when and where they 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 may also not have been detectable.

Acknowledgements

Literature Cited

Aguilar, B., L. D. Davis, B. W. Collins, L. Hanson, W. Sinnen, M. Zuspan, and M. Dean. 1996. Annual Report: Trinity River Basin salmon and steelhead monitoring project, 1994–1995 season. R. M. Kano, editor. California Department of Fish and Game, Inland Fisheries Division, Sacramento, California. 223 p.

Bradford, M., and D. Hankin. 2012. Trinity River Restoration Program adult salmonid monitoring evaluation. Prepared for TRRP. Weaverville, California. 47 p.

Brown, E. M. 2002. 2000 salmon spawning ground surveys. Pacific Salmon Treaty Program, 538 Award Number NA77FP0445. Idaho Fish Game Report 02-33, Boise, Idaho.

Buffington, J., C. Jordan, M. Merigliano, J. Peterson, and C. Stalnaker. 2014. Review of the Trinity River Restoration Program following Phase 1, with emphasis on the Program's channel rehabilitation strategy. Prepared by the Trinity River Restoration Program's Science Advisory Board for the Trinity River Restoration Program with assistance from Anchor QEA, LLC, Stillwater Sciences, BioAnalysts, Inc., and Hinrichsen Environmental Services.

CDFW (California Department of Fish and Wildlife). 2019a. Klamath River Basin fall Chinook Salmon spawner escapement, in-river harvest and run-size estimates, 1978–2018. California Department of Fish and Wildlife, Arcata, Californian.

CDFW (California Department of Fish and Wildlife). 2019b. Klamath River Basin spring Chinook Salmon spawner escapement, river harvest and run-size estimates, 1980–2017. California Department of Fish and Wildlife, Arcata, Californian.

Chamberlain, C. D., S. Quinn, and W. Matilton. 2012. Distribution and abundance of Chinook Salmon redds in the mainstem Trinity River 2002 to 2011. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report TR 2012-16, Arcata, California.

Gaeuman, D., R. Stewart, and T. Buxton. 2016. First steps towards a river corridor management strategy. Technical report: TR-TRRP-2016-1. Trinity River Restoration Project, Weaverville, California.

Gough, S. A., N. A. Som, N. S. Quinn, W. C. Matilton, A. M. Hill, and W. Brock. 2019. Mainstem Trinity River Chinook Salmon spawning survey, 2017. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Data Series Report Number DS 2019–62, Arcata, California.

HVT (Hoopa Valley Tribe), McBain and Trush, and Northern Hydrology and Engineering. 2011. Channel rehabilitation design guidelines for the mainstem Trinity River. Prepared for the Trinity River Restoration Program, Hoopa, California.

Kery, M., and M. Schaub. 2012. Bayesian population analysis using WinBUGS. Academic Press, Oxford, United Kingdom.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, R. C. Francis. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78(6):1069–1079.

Moffett, J. W., and S. H. Smith. 1950. Biological investigations of the fishery resources of the Trinity River, California. Special Scientific Report No. 12, U.S. Fish and Wildlife Service. 71 p.

Quihillalt, R. R. 1999. Mainstem Trinity River fall Chinook Salmon spawning redd survey, 1996 through 1998. U.S. Fish and Wildlife Service, Arcata, California.

Rogers, D. W. 1972. King Salmon (*Oncorhynchus tshawytscha*) and Silver Salmon (*Oncorhynchus kisutch*) spawning escapement and spawning habitat in the upper Trinity River, 1970. California Fish and Game, Region 1, Anadromous Fisheries Branch Administrative Report Number 73-10.

Rupert, D. L., C. D. Chamberlain, S. A. Gough, N. A. Som, N. J. Davids, W. C. Matilton, A. M. Hill, and E. R. Wiseman. 2017a. Mainstem Trinity River Chinook Salmon Spawning Survey 2012-2014. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2017–52, Arcata, California.

Rupert, D. L., S. A. Gough, N. A. Som, N. J. Davids, W. C. Matilton, A. M. Hill, and J. L. Pabich. 2017b. Mainstem Trinity River Chinook Salmon Spawning Distribution, 2015 and 2016. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2017–56, Arcata, California.

TRRP and ESSA (Trinity River Restoration Program and ESSA Technologies Ltd.). 2009. Integrated Assessment Plan, Version 1.0 – September 2009. Draft report prepared for the Trinity River Restoration Project, Weaverville, California. 285 p.

USDOI (U.S. Department of Interior). 2000. Record of Decision: Trinity River mainstem fishery restoration final Environmental Impact Statement / Environmental Report.

USFWS (U.S. Fish and Wildlife Service). 1986, 1987. Trinity River flow evaluation study, 2 reports. Annual Report, U.S. Fish and Wildlife Service, Sacramento, California.

USFWS (U.S. Fish and Wildlife Service) and HVT (Hoopa Valley Tribe). 1999. Trinity River flow evaluation, Final Report. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata, California and Hoopa Valley Tribe, Hoopa, California.

Appendices

Appendix A. Trinity River water visibility by week and reach throughout the 2018 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 start	Reach											
	1	2	3	4	5	6	7	9	10	12	13	14
Aug 26	>3.0	-	-	-	-	-	-	-	-	-	-	-
Sep 2	1.5-3.0 [a]	>3.0	1.5-3.0	1.5-3.0 [a]	>3.0	>3.0	>3.0	-	-	-	-	-
Sep 9	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0	>3.0	>3.0	1.5-3.0 [a]	1.5-3.0 [a]	-	-	-
Sep 16	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	-	-	-	-	-
Sep 23	1.5-3.0	1.5-3.0 [a]	1.5-3.0	1.5-3.0	NS	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	-	-	-
Sep 30	1.5-3.0	1.5-3.0	1.5-3.0	NS	1.5-3.0	1.5-3.0 [a]	1.5-3.0 [a]	-	-	1.5-3.0	1.5-3.0	1.5-3.0 [a]
Oct 7	1.5-3.0	1.5-3.0	1.5-3.0 [b]	1.5-3.0 [b]	0.9-1.5	1.5-3.0 [b]	1.5-3.0 [b]	0.9-1.5	1.5-3.0 [a]	-	-	-
Oct 14	1.5-3.0	1.5-3.0 [a]	1.5-3.0	1.5-3.0 [a]	1.5-3.0	1.5-3.0 [a]	1.5-3.0 [a]	-	-	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]
Oct 21	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0 [a]	1.5-3.0	-	-	-
Oct 28	1.5-3.0	1.5-3.0	1.5-3.0 [a]	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	1.5-3.0
Nov 4	1.5-3.0	1.5-3.0	1.5-3.0 [a]	1.5-3.0	1.5-3.0 [a]	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	-	-	-
Nov 11	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	NS	1.5-3.0 [a]	1.5-3.0 [a]	-	-	1.5-3.0 [a]	1.5-3.0 [a]	>3.0
Nov 18	1.5-3.0 [a]	1.5-3.0	NS	NS	NA	1.5-3.0 [a]	1.5-3.0 [a]	NS	NS	-	-	-
Nov 25	1.5-3.0	0.9-1.5	NS	NS	<0.9	1.5-3.0 [b]	1.5-3.0 [b]	-	-	NS	NS	NS
Dec 2	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	-	-	-
Dec 9	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	1.5-3.0	NS	NS	-	-	1.5-3.0	0.9-1.5	0.9-1.5

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

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

Trinity River at Lewiston, California (USGS 11525500)
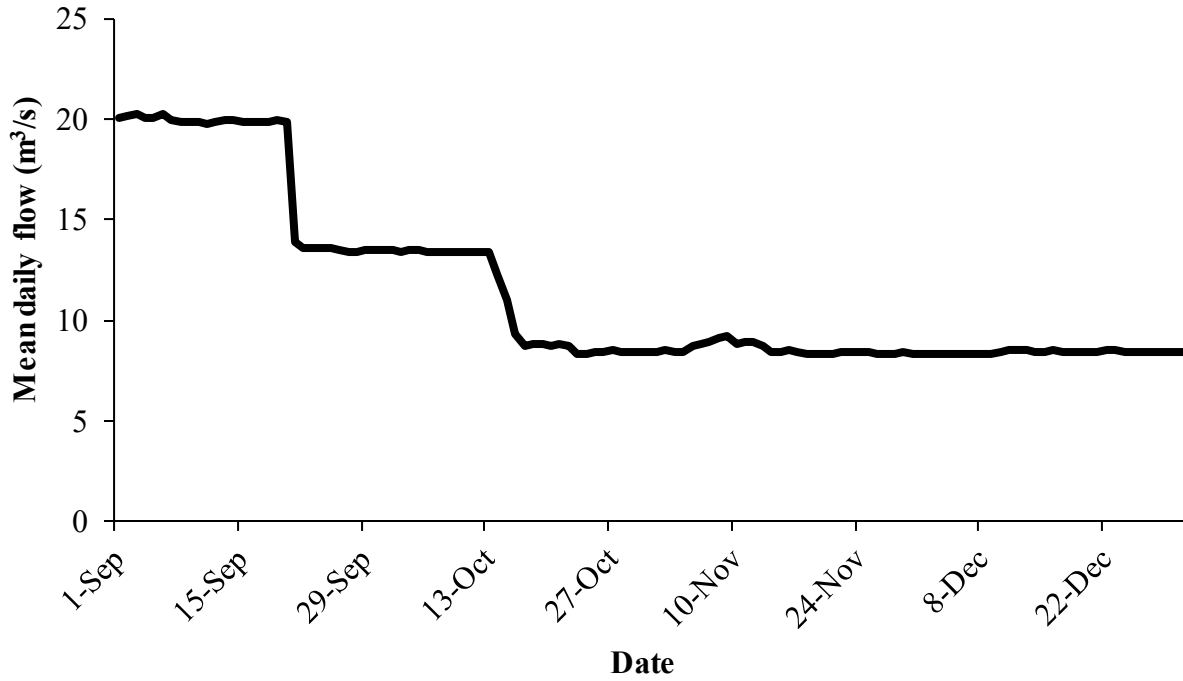
**Trinity River at Hoopa, California (USGS 11530000)**
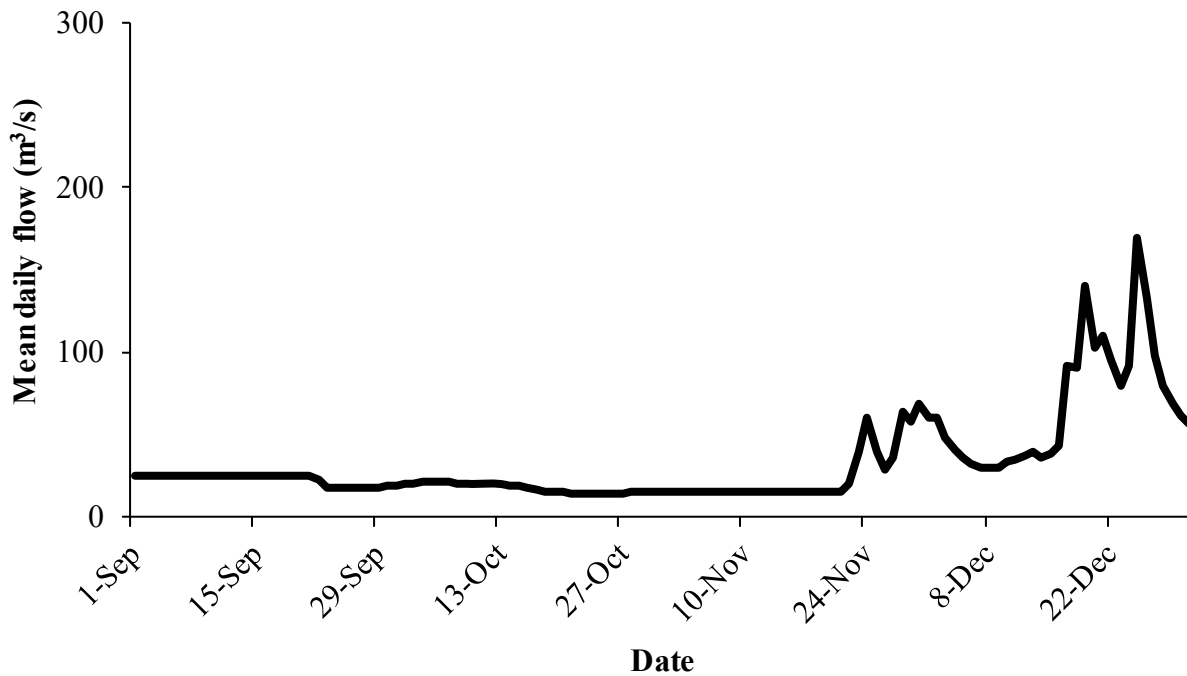
Appendix B. Trinity River mean daily discharge at Lewiston (USGS Gage 11525500) and Hoopa, California (USGS Gage 11530000) during the 2018 survey season.

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 2018. 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.
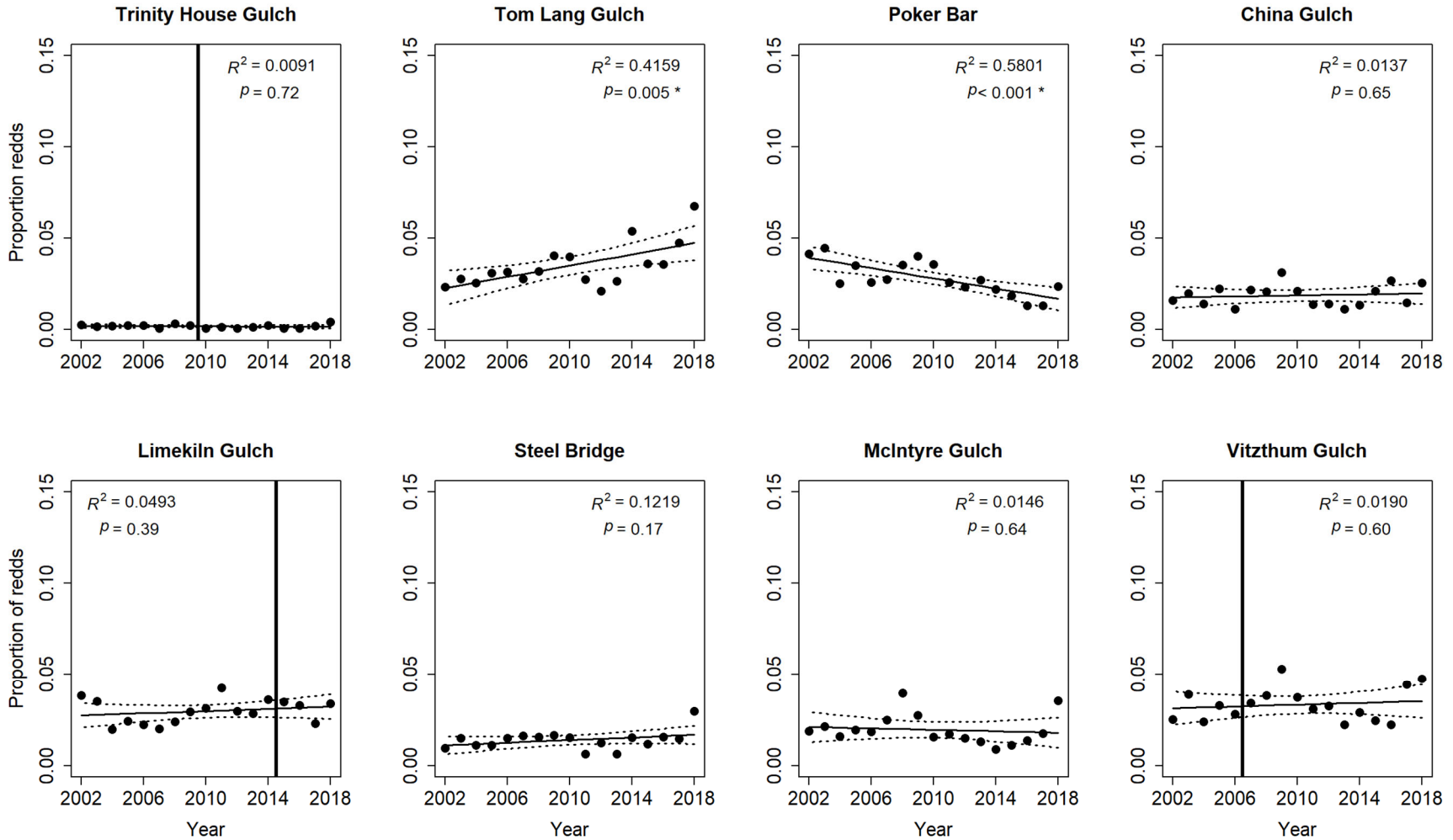
2018 unmarked

Calendar week	Dates	1	2	3	4	5	6	7	9	10	12	13	14	n	Pct.
35	Aug 26-Sep 1	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
36	Sep 2-8	-	-	-	-	-	-	-	NS	NS	NS	NS	NS	-	-
37	Sep 9-15	-	-	-	-	-	-	-	-	-	NS	NS	NS	-	-
38	Sep 16-22	0	-	-	0	-	-	-	NS	NS	NS	NS	NS	0	0.0%
39	Sep 23-29	1	1	-	-	NS	-	-	0	-	NS	NS	NS	2	28.6%
40	Sep 30-Oct 6	0	0	0	NS	0	0	-	NS	NS	-	-	-	0	0.0%
41	Oct 7-13	0	0	0	0	0	0	-	1	-	NS	NS	NS	1	1.9%
42	Oct 14-20	0	0	0	0	0	0	-	NS	NS	-	-	-	0	0.0%
43	Oct 21-27	0	0	0	0	0	0	0	0	0	NS	NS	NS	0	0.0%
44	Oct 28-Nov 3	0	0	-	0	0	0	0	NS	NS	0	-	-	0	0.0%
45	Nov 4-10	0	0	0	-	0	0	0	0	0	NS	NS	NS	0	0.0%
46	Nov 11-17	0	1	1	0	-	0	-	NS	NS	-	0	-	2	5.6%
47	Nov 18-24	0	0	NS	NS	-	0	-	NS	NS	NS	NS	NS	0	0.0%
48	Nov 25-Dec 1	1	0	NS	NS	-	-	-	NS	NS	NS	NS	NS	1	2.8%
49	Dec 2-8	1	0	0	1	0	-	0	-	-	NS	NS	NS	2	4.2%
50	Dec 9-15	0	0	0	0	-	NS	NS	NS	NS	1	-	0	1	2.9%
	All weeks	**3**	**2**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**-**	**0**	*9*	*1.9%*

2018 ad-clipped

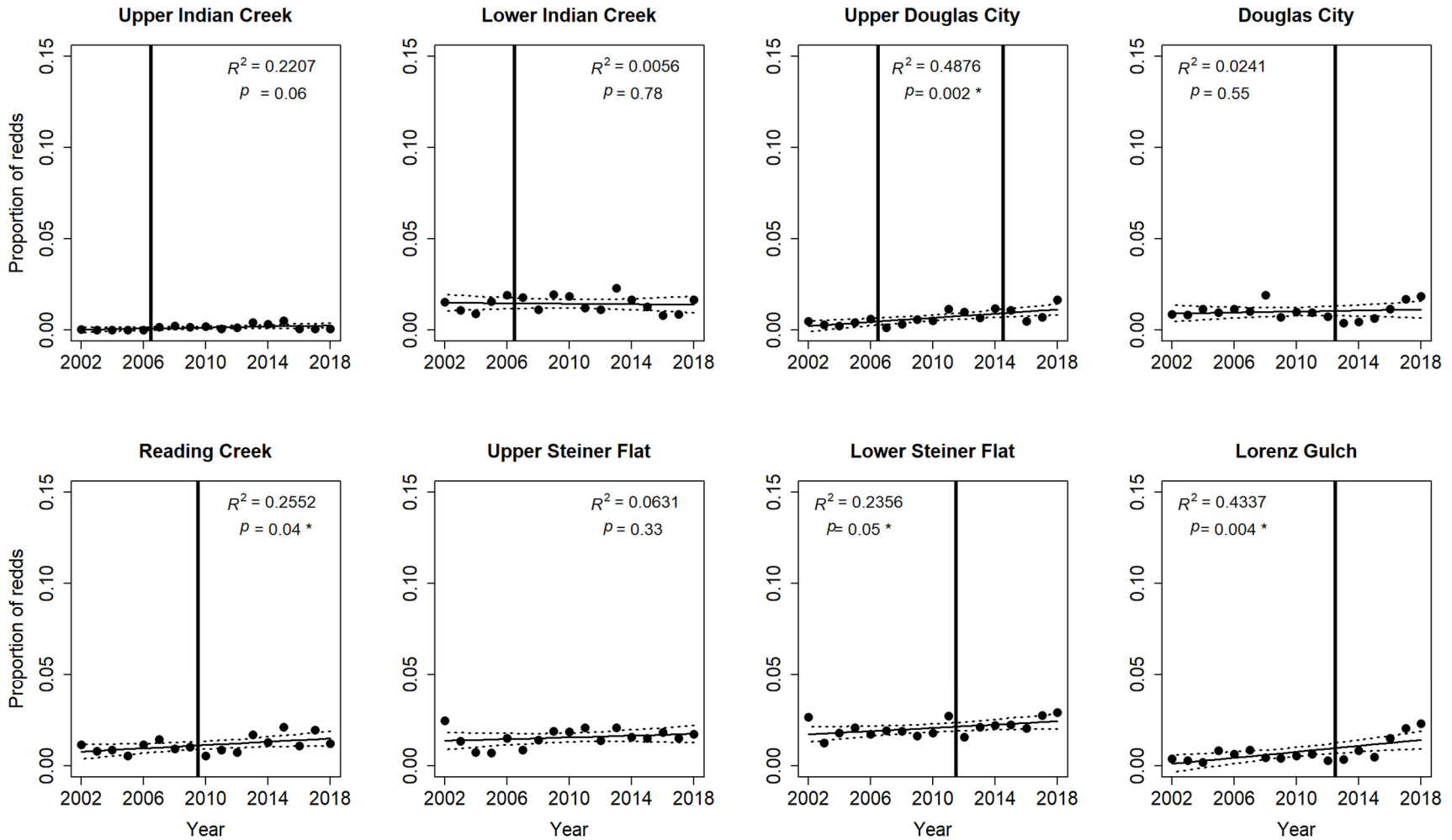| Calendar week	Dates	1	2	3	4	5	6	7	9	10	12	13	14	n	Pct.
35	Aug 26-Sep 1	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
36	Sep 2-8	-	-	-	-	-	-	-	NS	NS	NS	NS	NS	-	-
37	Sep 9-15	-	-	-	-	-	-	-	-	-	NS	NS	NS	-	-
38	Sep 16-22	-	-	-	-	-	-	-	NS	NS	NS	NS	NS	-	-
39	Sep 23-29	-	0	-	-	NS	-	-	-	-	NS	NS	NS	0	0.0%
40	Sep 30-Oct 6	-	-	0	NS	-	-	-	NS	NS	-	-	-	0	0.0%
41	Oct 7-13	0	0	-	0	-	-	-	-	-	NS	NS	NS	0	0.0%
42	Oct 14-20	0	0	-	-	-	-	-	NS	NS	-	-	-	0	0.0%
43	Oct 21-27	0	-	-	-	-	-	-	-	-	NS	NS	NS	0	0.0%
44	Oct 28-Nov 3	0	-	-	-	-	-	-	NS	NS	-	-	-	0	0.0%
45	Nov 4-10	-	0	-	-	-	-	-	-	-	NS	NS	NS	0	0.0%
46	Nov 11-17	1	0	-	-	-	-	-	NS	NS	-	-	-	1	14.3%
47	Nov 18-24	0	0	NS	NS	-	-	-	NS	NS	NS	NS	NS	0	0.0%
48	Nov 25-Dec 1	0	0	NS	NS	-	-	-	NS	NS	NS	NS	NS	0	0.0%
49	Dec 2-8	0	0	-	0	-	-	-	-	-	NS	NS	NS	0	0.0%
50	Dec 9-15	0	0	0	-	-	NS	NS	NS	NS	-	-	-	0	0.0%
	All weeks	**1**	**0**	**0**	**0**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	*1*	*1.4%*
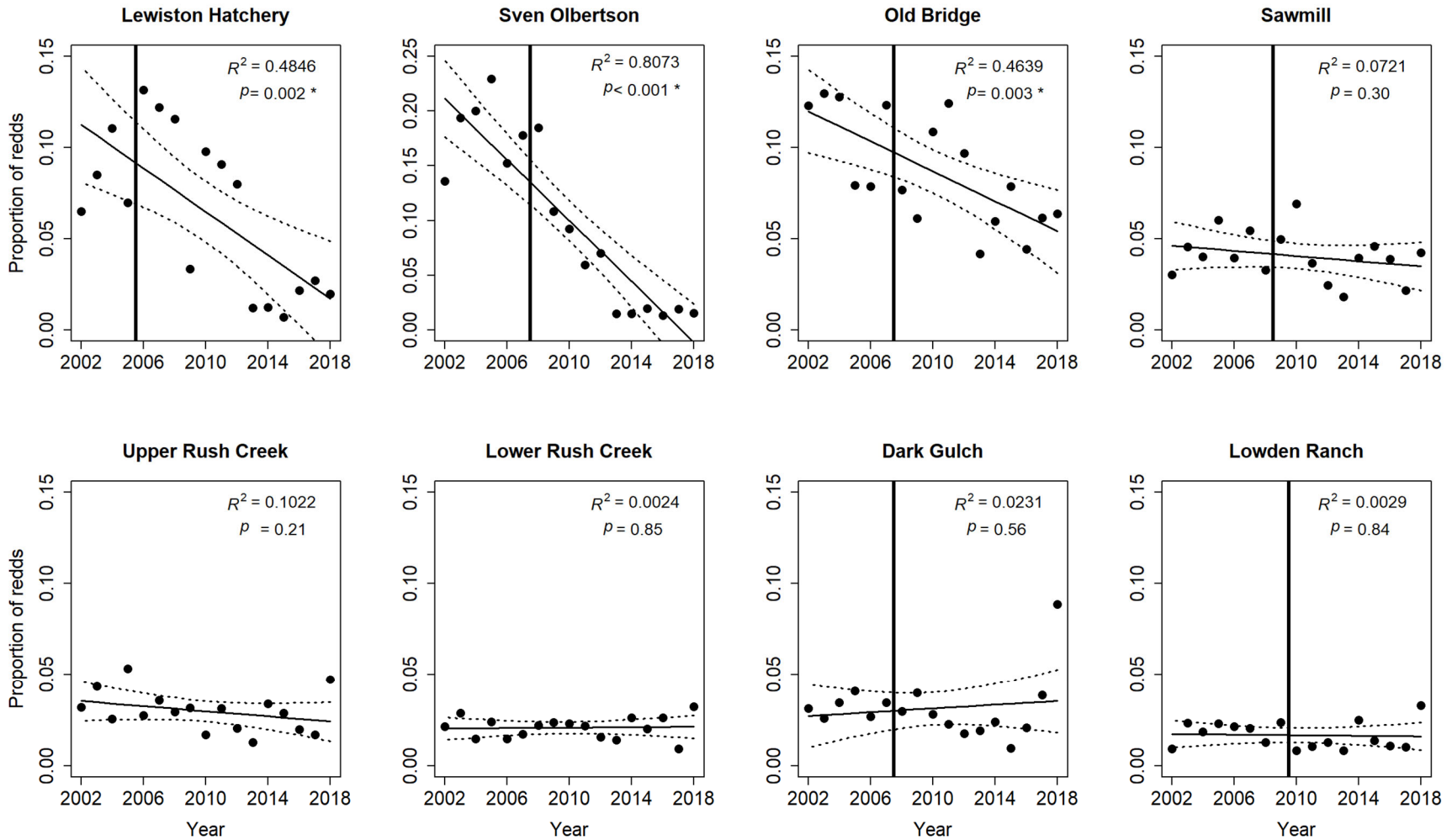
Appendix D. Proportion of TRRP restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars. Note the change in *y*-axis scale in the Sven Olbertson site.
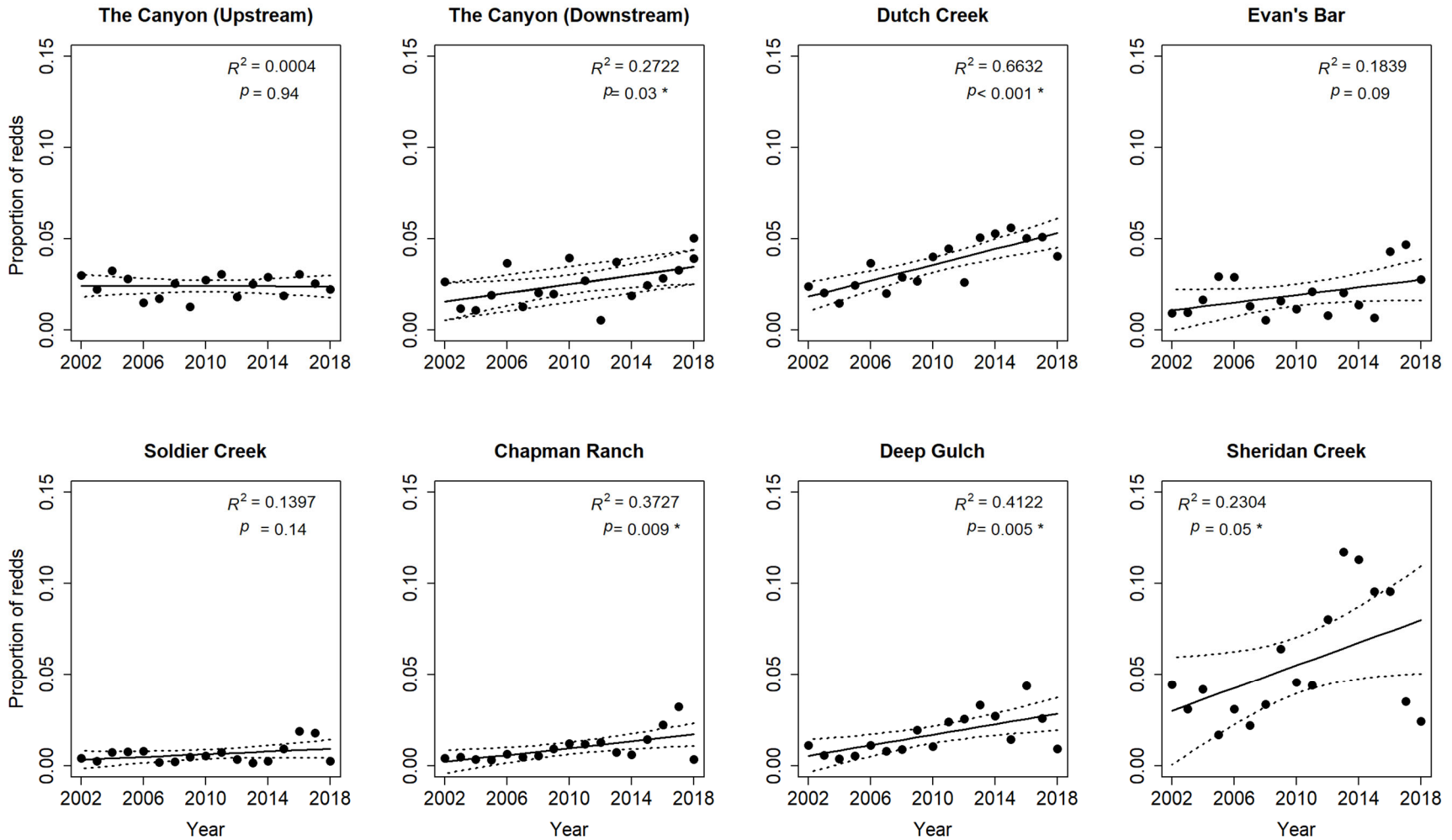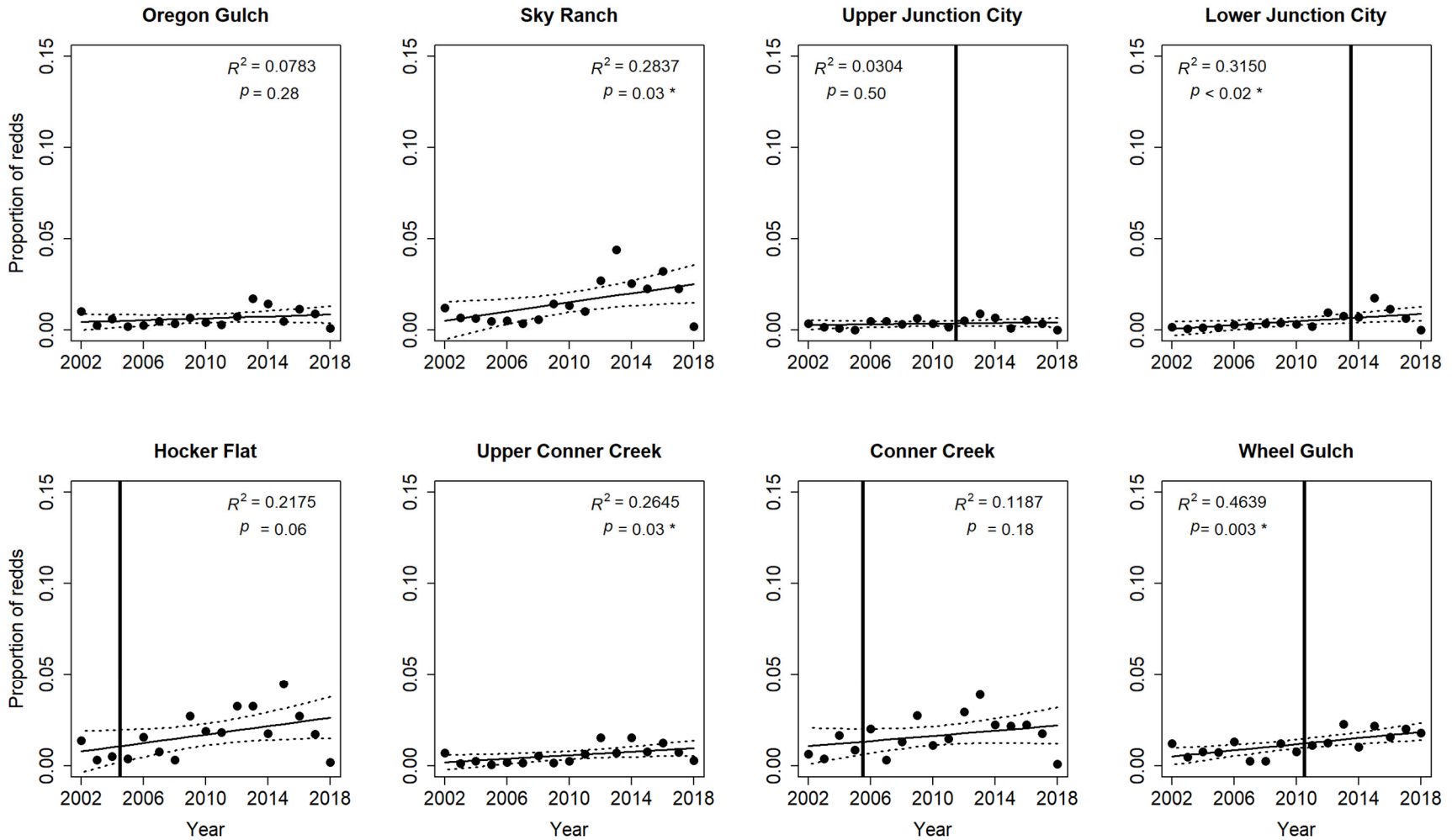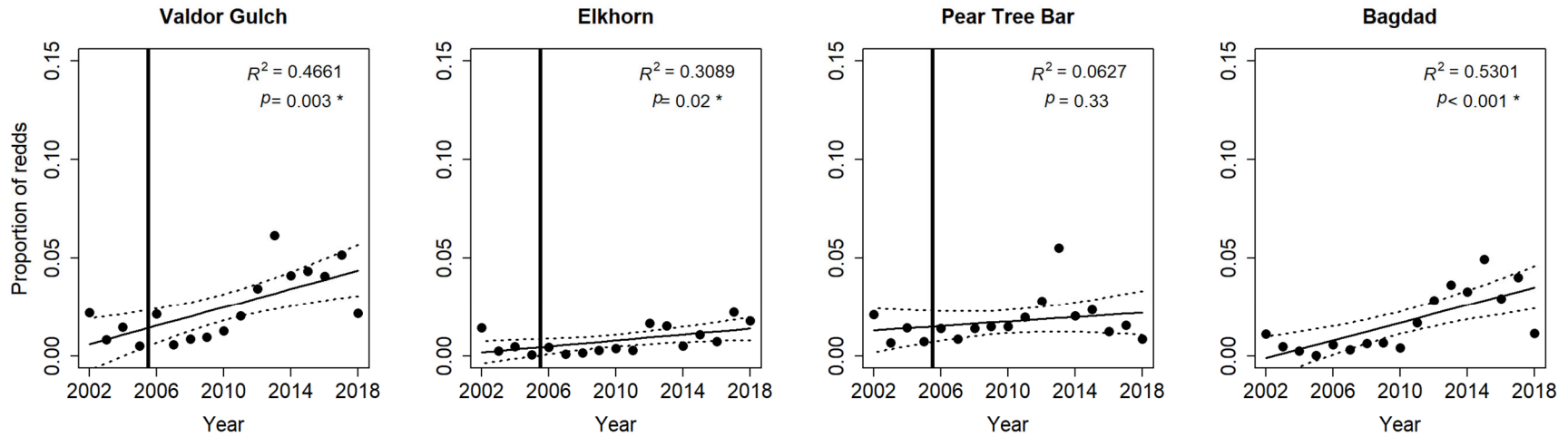
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.
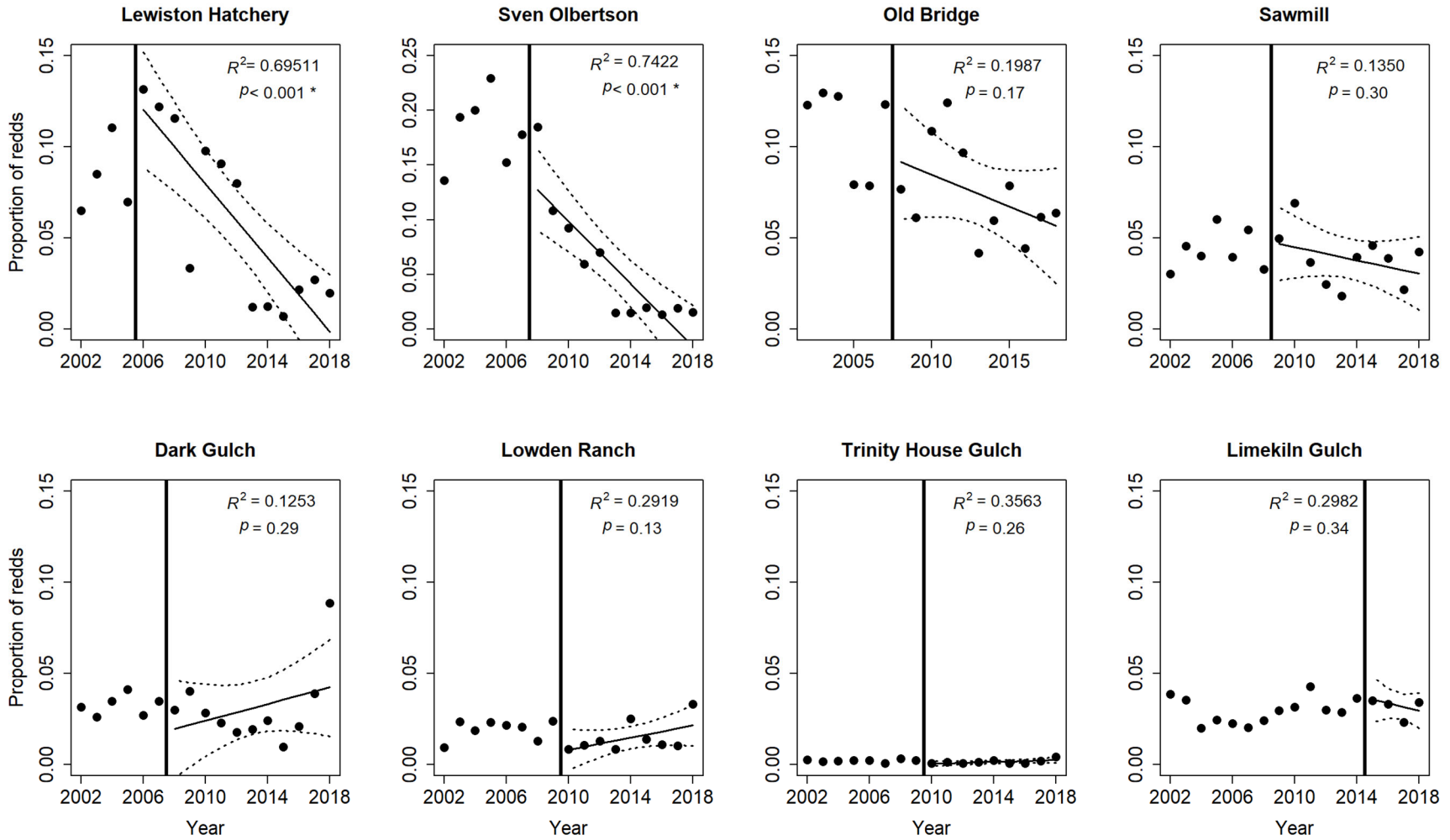
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.

Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2018. 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).
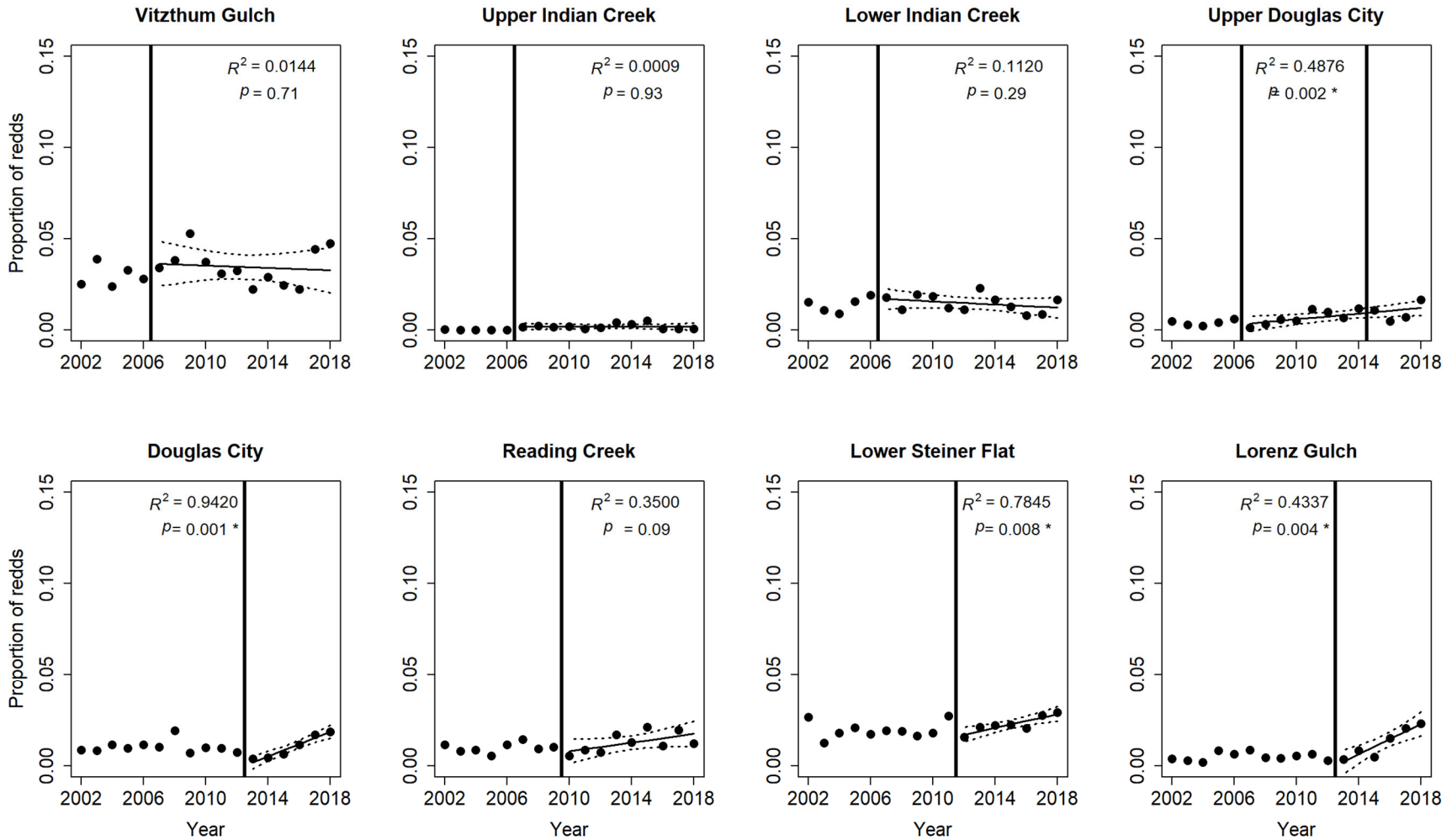
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2018. Each plot includes a linear model with the R^2 value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.

Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2018. 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.
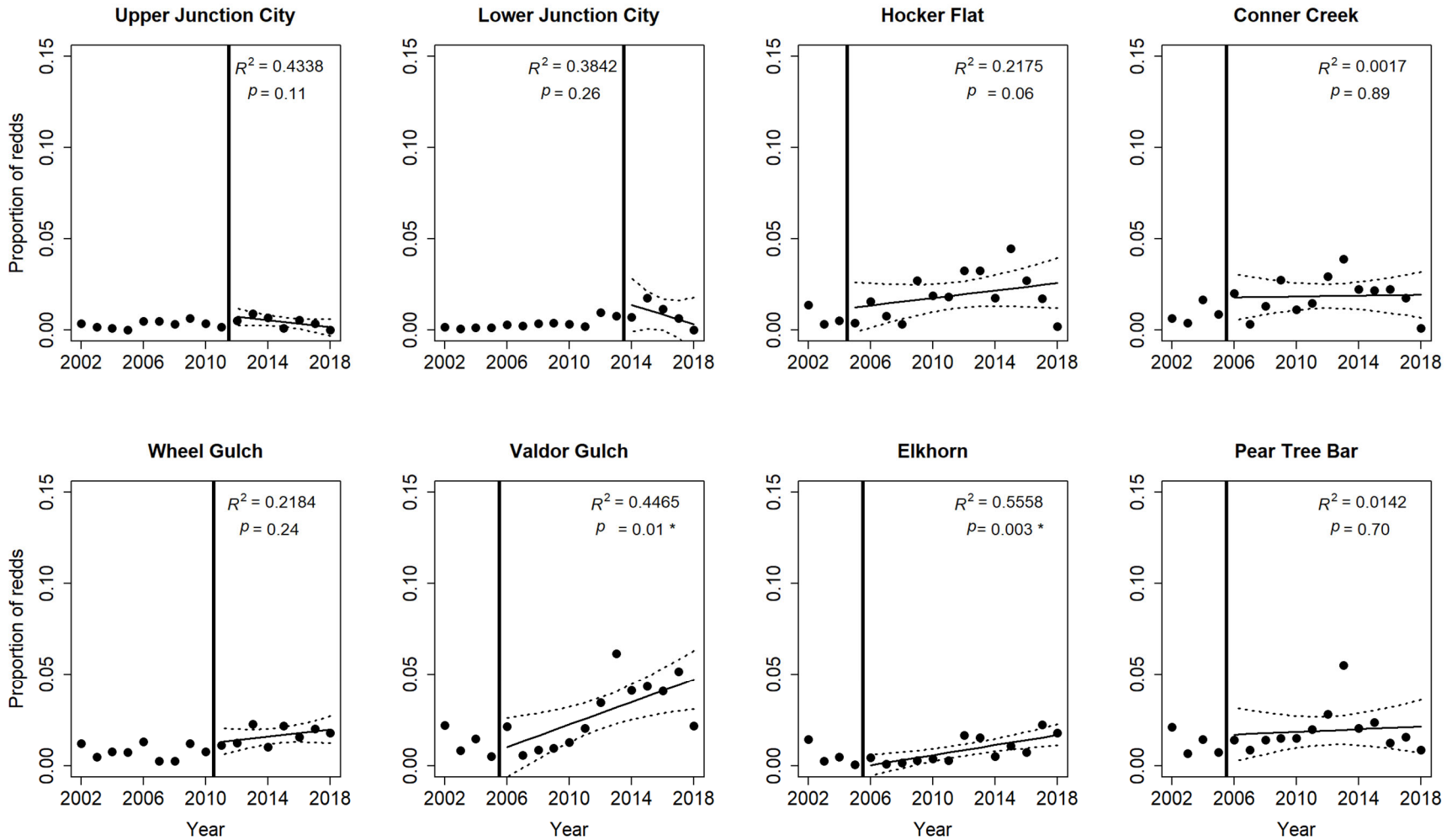
Appendix E. Proportion of natural-origin Chinook Salmon redds within site-scale sections in the TRRP restoration reach that encompass mechanical channel rehabilitation locations, 2002–2018. Each plot includes a post-construction linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.
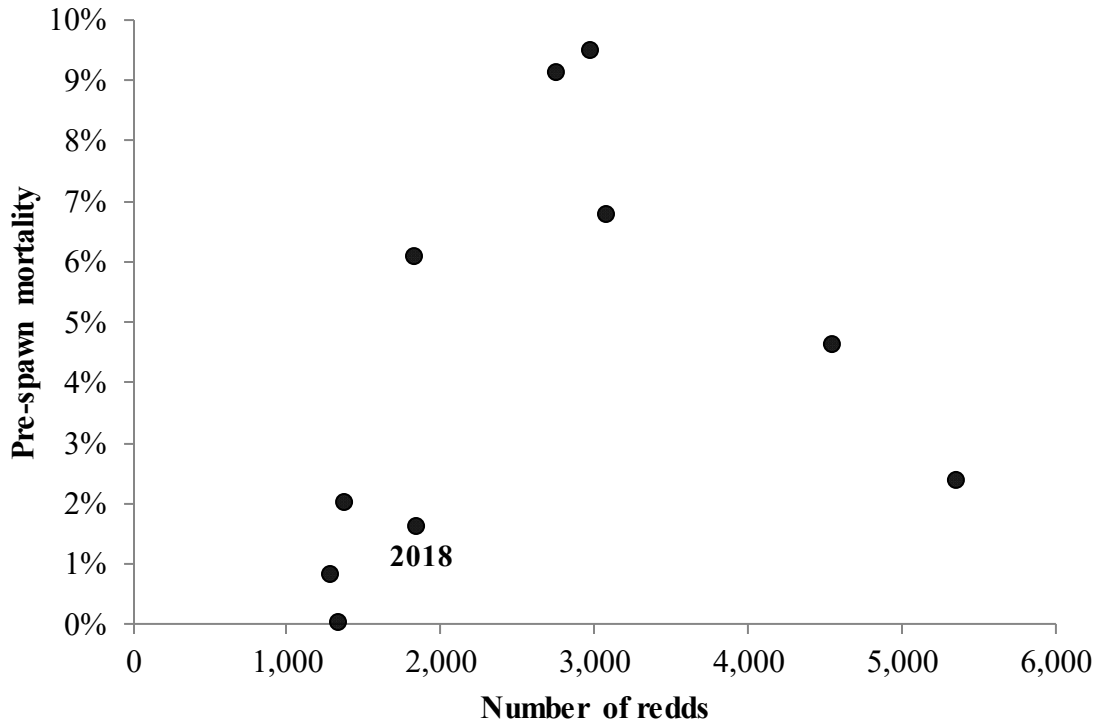
Appendix E (continued). Proportion of natural-origin Chinook Salmon redds within site-scale sections in the TRRP restoration reach that encompass mechanical channel rehabilitation locations, 2002–2018. Each plot includes a post-construction linear model with the R^2 value, p-value (noted with an '*' 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, 2002–2018. 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. Chinook Salmon redd counts versus estimates of pre-spawn mortality from Lewiston Dam to the North Fork confluence, Trinity River surveys, 2009–2018.