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Mainstem Trinity River Chinook Salmon Spawning Survey, 2019

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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 2019 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 2019 was 1,549. 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 1,164 redds were constructed by natural-origin Chinook Salmon, 358 by hatchery-origin Chinook Salmon, and 27 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 (82.7% were within 10 km of the dam). Pre-spawn mortality of female Chinook Salmon was 3.5% for carcasses in all reaches and 3.6% 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 2019 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 reach immediately downstream of Lewiston Dam and increased in some mid-river reaches from 2002 to 2019, 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 (TRD) 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 2019 on the mainstem Trinity River. Surveying salmon carcasses provides pre-spawn mortality data and carcass estimates and reflects 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 2019 began August 26 and concluded December 17. This period was intended to encompass the majority of Chinook Salmon spawning activity.

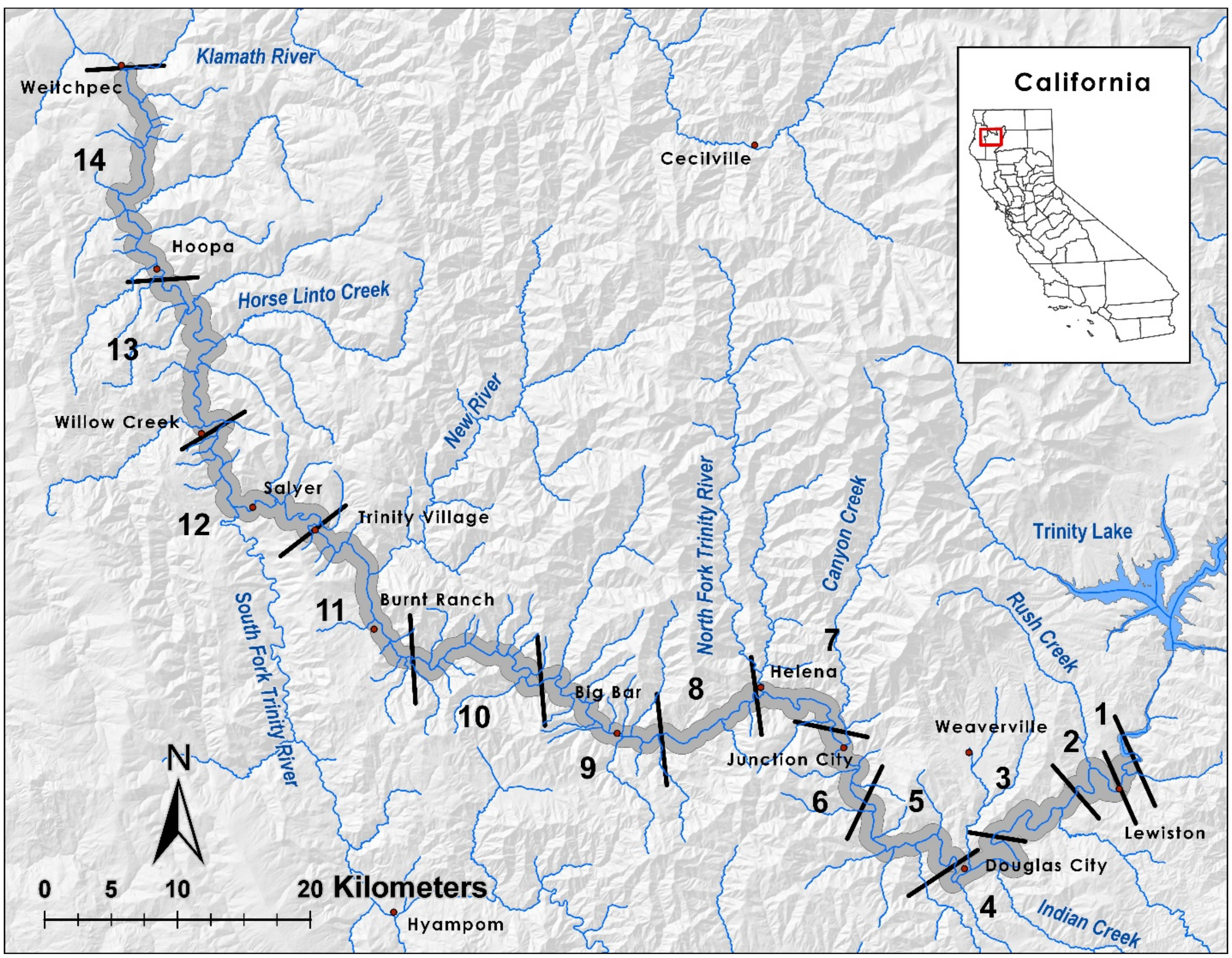

Figure 1. Survey Reaches 1–14 (Lewiston Dam to Weitchpec) on the mainstem Trinity River. Dangerous whitewater conditions precluded surveys in Reaches 8 and 11.

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).

	Boundaries		
Reach	Upstream	Downstream (rkm)	Surveying agency
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, 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 2019 were combined with the preceding seventeen years (2002–2018) of mainstem Trinity River redd data from Chamberlain et al. (2012), Rupert et al. (2017a, 2017b), Gough et al. (2019, 2021) 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.

Contiguous groups of riffle units were combined to create the sections used for the site-scale analysis (Table 3). Site designations in this report are 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.

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 2002–2019 data set was analyzed using the newer riffle unit-based divisions at each spatial scale.

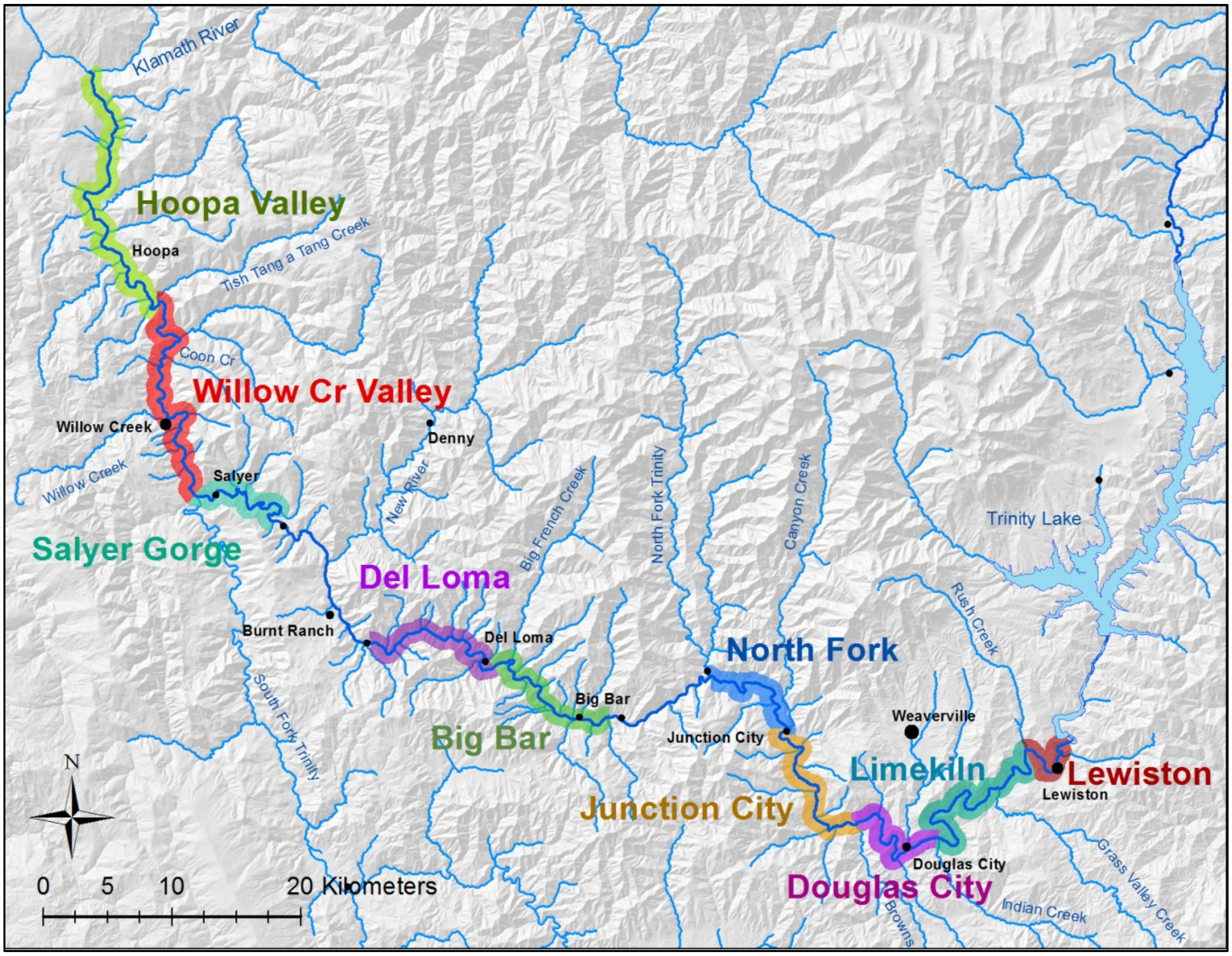

Figure 2. The ten sections of the mainstem Trinity River used for reach-scale analyses of Chinook Salmon redd distribution.

Table 2. River sections [with river kilometer (rkm)] used for the reach-scale analysis of redd abundance.

Section	Boundaries: Upstream (rkm)	Boundaries: 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 89% of the originally scheduled surveys in 2019 (Appendix A). Most surveys during the first week of September were cancelled when discharge in the mainstem Trinity River at Lewiston was increased to 76.5 m^3/s (66.5 m^3/s daily mean) on September 2 for the Hoopa Valley Tribe's ceremonial Boat Dance (Appendix B). Following this flow event, discharge remained steady around 13.3 m^3/s until mid-October when discharge dropped to around 8.5 m^3/s for the remainder of the survey season. At Hoopa, California, mean daily discharge reached 65.4 m^3/s during the flow event in early September, after which discharge ranged between 18.1 and 31.1 m^3/s into the first week of December. During the last two survey weeks, rain events caused discharge to spike twice when mean daily flows reached 154.3 m^3/s on December 8 and 157.2 m^3/s on December 14.

Crews reported water visibility greater than 3.0 m during most of the surveys in 2019 (Appendix A). Visibility was often lower in Reach 6 and downstream due to sediment washing into the river during a concurrent restoration project near Chapman Ranch.

Salmon Carcasses

During the 2019 surveys, 541 fresh (Conditions 1 and 2 as described in Rupert at al. 2017a) Chinook Salmon carcasses were examined (Table 4). Of these fresh carcasses, 70 (12.9%) were adipose fin-clipped ('ad-clipped') and 49 (9.1%) 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 ad-clipped for an external mark at a constant fractional mark rate of 25%. The sex of the fish was identified in 538 of the fresh Chinook Salmon carcasses, and of these 318 (59.1%) were females.

From the 70 ad-clipped fresh Chinook Salmon carcasses heads that were sampled, 61 CWTs were read (Table 5). Data from CWT recoveries yielded an average annual marking rate of 0.283.

Of the 318 fresh female Chinook Salmon carcasses recovered, 45 (14.2%) were ad-clipped and their heads were collected. CWTs were recovered and read from 39 of these heads. Of the spawned female hatchery-origin Chinook Salmon carcasses (spring and fall broods combined) with associated CWT data, 94.9% (37 of 39) were recovered within 10 km of Lewiston Dam (Figure 3).

Two Coho Salmon carcasses were recovered during the 2019 surveys, one of which was a fresh female carcass that was found Reach 2. The absence of spawned female Coho Salmon carcasses recovered inhibited the ability to differentiate Coho Salmon redds by origin in 2019.

Carcass Estimates

The hierarchical latent variables model estimated 680 (95% CI: 521–881) Chinook Salmon carcasses in Reach 1 and 657 (95% CI: 482–896) in Reach 2 in 2019. Estimates of spawned female Chinook Salmon carcasses were 474 (95% CI: 362–622) in Reach 1 and 371 (95% CI: 269–513) in Reach 2.

Table 4. Summary of fresh (conditions 1 and 2) Chinook Salmon carcass data by survey reach, 2019 Trinity River surveys.

Reach	Total [a]	Females	Males	Female proportion	Ad-clipped	Weir-tagged
1	189	140	49	74.1%	40	15
2	158	92	66	58.2%	25	14
3	44	15	28	34.9%	1	1
4	42	17	24	41.5%	1	6
5	45	26	18	59.1%	3	3
6	30	19	11	63.3%	0	8
7	21	5	16	23.8%	0	1
9	7	1	6	14.3%	0	1
10	3	3	0	100.0%	0	0
12	1	0	1	0.0%	0	0
13	1	0	1	0.0%	0	0
14	0	0	0	-	0	0
Total	541	318	220	59.1%	70 [b]	49

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

[b] head samples were collected from 61 of the 70 fresh ad-clipped Chinook Salmon carcasses

Table 5. Coded-wire tag (CWT) information retrieved from fresh adipose fin-clipped Chinook Salmon carcasses, 2019 Trinity River surveys.

Carcasses	CWT	Brood Year	Run type	Release type	Production multiplier	Marking rate
2	60772	2015	Spring	Fingerling	4.24	0.236
1	60773	2015	Spring	Fingerling	4.34	0.230
1	60774	2015	Spring	Fingerling	4.17	0.240
1	60775	2015	Fall	Fingerling	4.27	0.234
1	60776	2015	Fall	Fingerling	4.20	0.238
5	60779	2015	Spring	Yearling	4.24	0.236
4	60780	2015	Fall	Yearling	4.25	0.236
9	60954	2016	Spring	Fingerling	4.24	0.236
6	60955	2016	Spring	Fingerling	4.16	0.240
11	60956	2016	Spring	Fingerling	4.12	0.243
2	60961	2016	Spring	Yearling	4.17	0.240
13	60962	2016	Fall	Yearling	4.15	0.241
4	60963	2016	Spring	Fingerling	1.09	0.917
1	61496	2017	Spring	Yearling	4.32	0.232
9		-- Missing CWT/head --			NA	NA
					Mean = 3.99	Mean = 0.283

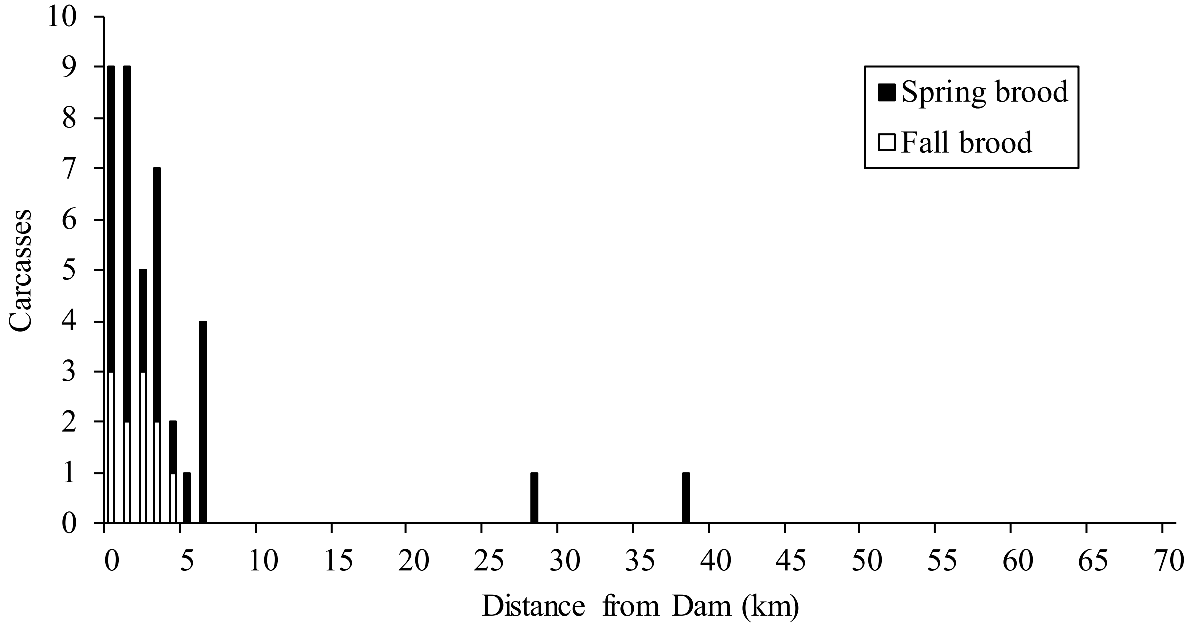

Figure 3. Distribution of coded-wire-tagged (CWT) spawned female Chinook Salmon carcasses by brood type (spring and fall) located in the mainstem Trinity River downstream of Lewiston Dam in 2019.

Pre-spawn Mortality

Eleven fresh unspawned female Chinook Salmon carcasses were found in 2019, two of which had hatchery marks, which yielded a pre-spawn mortality rate among female Chinook Salmon throughout the mainstem Trinity River of 3.5% (Table 6). Weekly pre-spawn mortality rates ranged from 0.0% to 15.4% (the first five survey weeks and the final three 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 3.6%.

One (spawned) fresh female Coho Salmon carcass was encountered in 2019 which precluded any pre-spawn mortality analysis for this species (Table 7). Note that pre-spawn mortality rates were based on data collected through late December, while Coho Salmon are still spawning.

Table 6. 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), 2009–2019 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%
2019	3.5%	3.6%

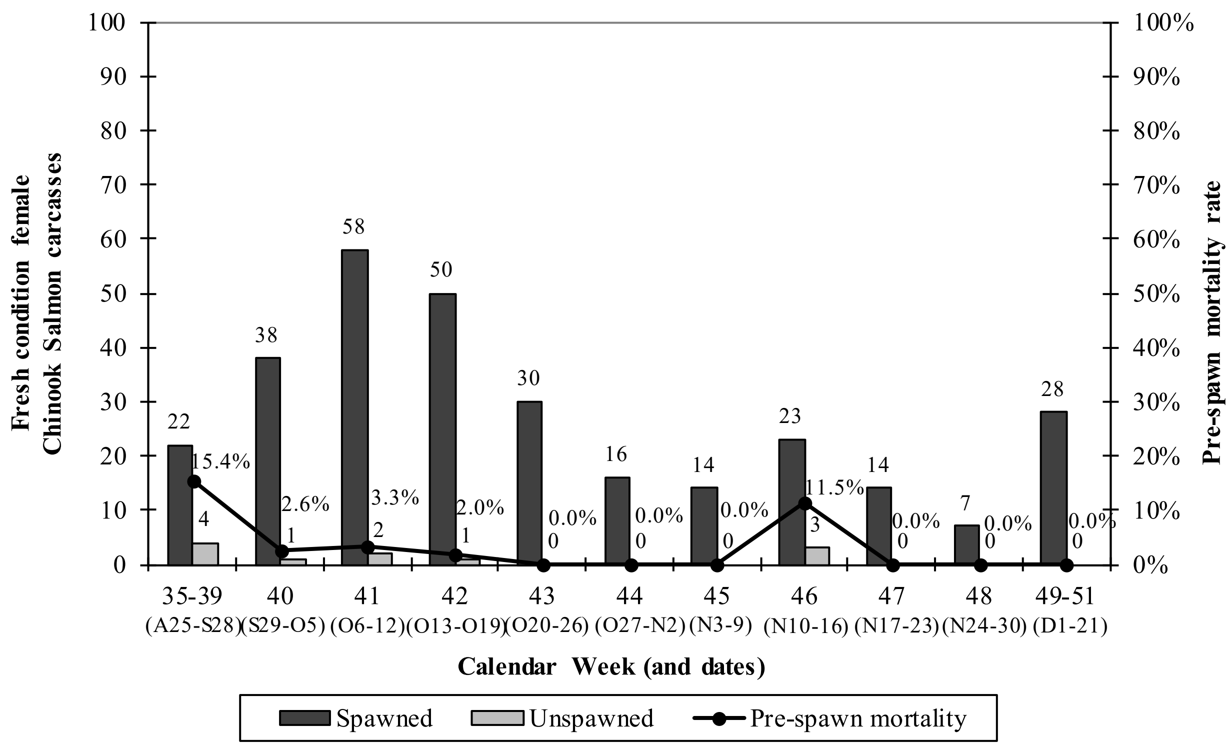

Figure 4. Weekly pre-spawn mortality from fresh (conditions 1 and 2) female Chinook Salmon carcasses, Trinity River surveys 2019. Calendar weeks 35–39 and 49–51 were combined because of low sample sizes in at least one of those weeks.

Table 7. Pre-spawn mortality rates of natural- and hatchery-origin Coho Salmon, Trinity River surveys, 2009–2019. 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	7.4%	19.0%	15.3%
2010	21.9%	15.9%	16.7%
2011	7.1%	12.7%	10.6%
2012	3.6%	9.8%	9.2%
2013	11.1%	5.2%	5.9%
2014	33.3%	26.9%	28.2%
2015	-	-	- [a]
2016	-	-	- [a]
2017	-	-	- [a]
2018	-	-	- [a]
2019	-	-	- [a]

[a] the sample sizes for Coho Salmon from 2015 to 2019 were ≤5 carcasses annually

Salmon Redds

During the 2019 surveys, 1,549 salmon redds were identified (Table 8). A majority of the redds (1,164, 95% CI: 1,036–1,287; 75.1%) were estimated to have been constructed by natural-origin female Chinook Salmon, while hatchery-origin female Chinook Salmon accounted for 358 (95% CI: 235–486; 23.1%) of the total redd count (Table 9). Coho Salmon redds accounted for 27 (1.7%) of the surveyed redds. The low number of spawned female Coho Salmon carcasses collected in 2019 precluded the differentiation of hatchery- and natural-origin Coho Salmon redds. Note that the Coho Salmon spawning season continued beyond our surveys.

Natural-origin Chinook Salmon redds were mostly constructed throughout the restoration reach of 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 with most redds constructed relatively close to Lewiston Dam, the location of the Trinity River Hatchery.

Table 8. Redd counts (before species differentiation) by week and reach, Trinity River surveys 2019. 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 25	0	-	-	-	-	-	-	-	-	-	-	-	-
Sep 1	0	0	NS	NS	NS	NS	NS	-	-	-	-	-	-
Sep 8	5	0	1	4	0	0	0	-	-	-	-	-	10
Sep 15	24	20	3	0	3	0	0	0	0	-	-	-	50
Sep 22	70	25	9	7	6	0	0	-	-	0	NS	NS	117
Sep 29	30	51	8	9	30	0	11	1	2	-	-	-	142
Oct 6	67	36	28	22	41	11	14	-	-	3	0	0	222
Oct 13	16	48	21	16	31	20	37	54	19	-	-	-	262
Oct 20	1	8	9	10	9	9	44	-	-	3	2	0	95
Oct 27	4	2	17	10	19	4	37	78	25	-	-	-	196
Nov 3	16	18	4	11	4	10	4	-	-	9	17	1	94
Nov 10	36	29	18	15	2	7	15	40	20	-	-	-	182
Nov 17	16	14	8	10	5	11	9	-	-	6	13	3	95
Nov 24	7	1	NS	NS	1	4	2	-	-	-	-	-	15
Dec 16	1	13	7	4	1	0	0	6	11	1	-	-	44
Dec 8	2	7	3	1	3	0	0	-	-	-	0	0	16
Dec 15	2	7	-	-	-	-	-	0	0	-	-	-	9
Total	297	279	136	119	155	76	173	179	77	22	32	4	1,549

Table 9. Estimated numbers of salmon redds by species and origin observed in the mainstem Trinity River, 2019. 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	1,522 [b]	-	-
	Natural	1,164	1,036	1,287
	Hatchery	358	235	486
Coho Salmon [a]	All	27 [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 fresh female Coho Salmon carcasses (1) were found in 2019 to calculate a confidence interval.

[c] Not enough fresh female Coho Salmon carcasses (1) were found in 2019 to calculate separate estimates for natural- and hatchery-origin Coho Salmon red

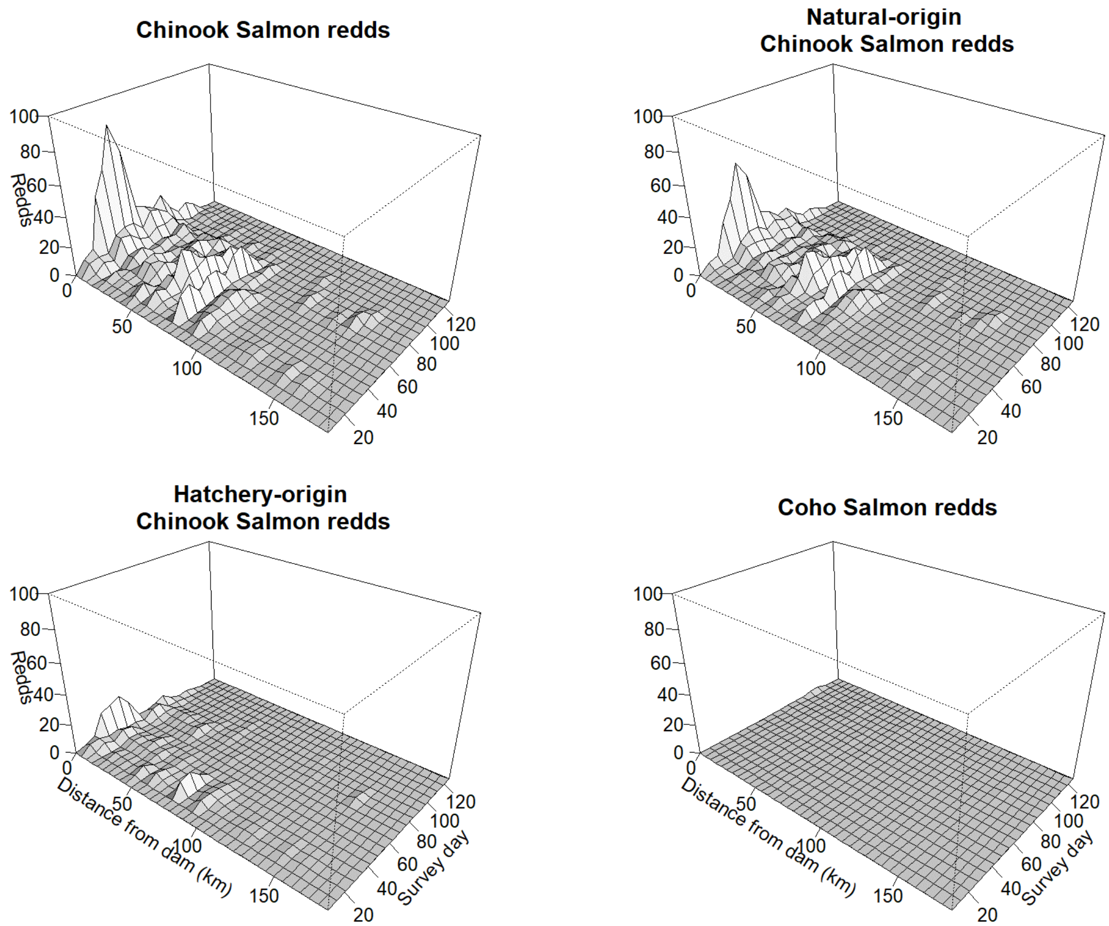

Figure 5. Spatiotemporal distribution of mainstem Trinity River salmon redds from Lewiston Dam to Weitchpec, 2019. Surveys were not conducted in Reaches 8 (rkm 107.6–117.4) and 11 (rkm 63.4–79.1). One fresh female Coho Salmon carcass was observed in 2019 and therefore few redds were predicted to be attributed 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 2019 had a positive linear correlation ($R^2 = 0.84$, $p < 0.001$; 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 = 0.635, 95% CI: 0.490–0.780).

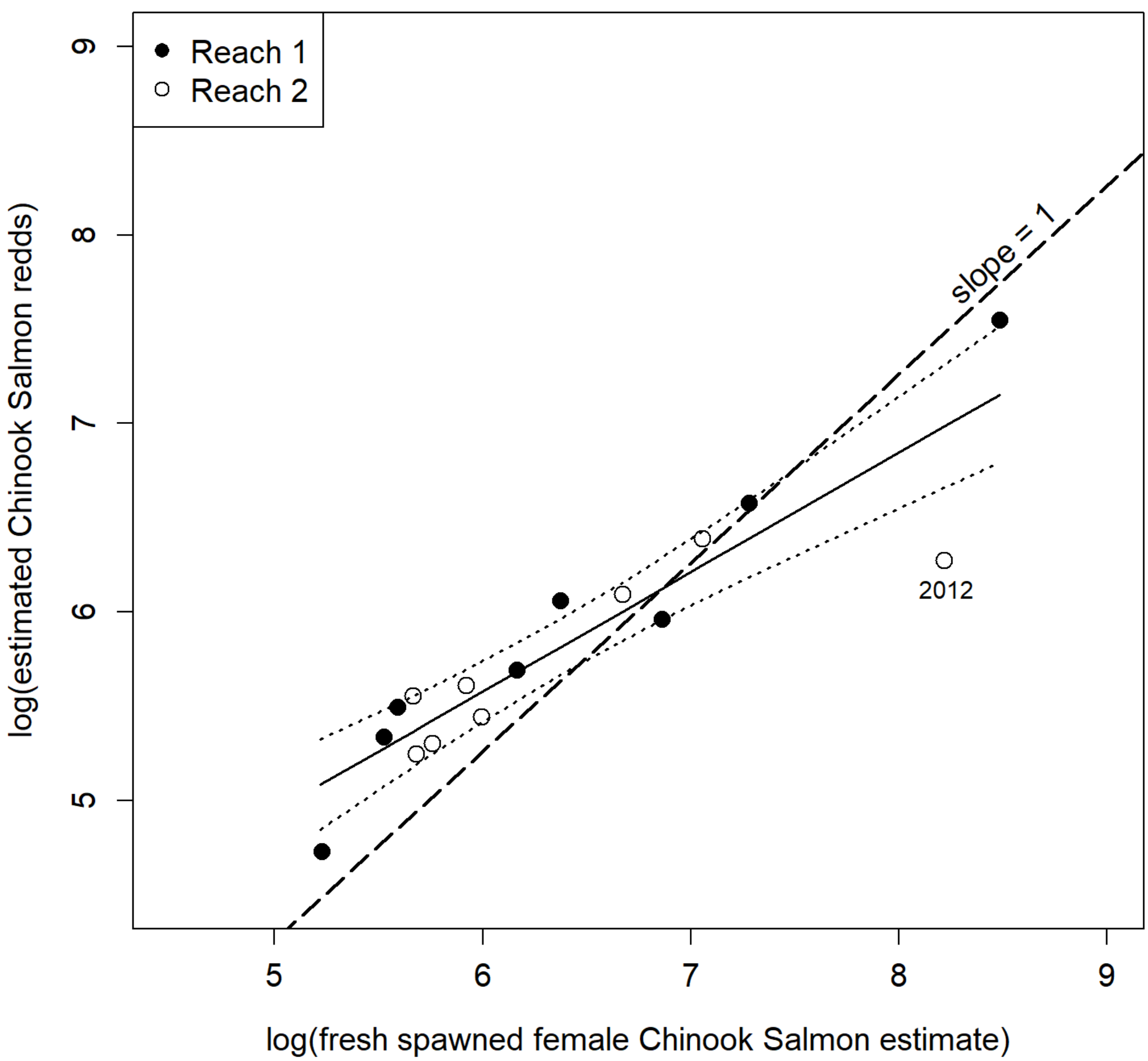

Figure 6. Relationship between counts of *ln*-transformed Chinook Salmon redds and *ln*-transformed estimates of spawned female Chinook Salmon carcasses in Reaches 1 and 2 (solid line), 2012–2019. The dashed line is included to represent a slope of '1', which would be the slope of two perfectly proportional variables. Dotted lines represent 95% confidence limits of the linear model.

Redd Abundance and Distribution: System Scale

From 2002 to 2019, the number of mainstem salmon redds ranged between 1,549 and 7,588 and decreased over time (R^2 = 0.4313, p = 0.003; 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 = 0.1531, p = 0.11), while the number of redds constructed by hatchery-origin Chinook Salmon trended downward (R^2 = 0.5210, p < 0.001) over this time frame.

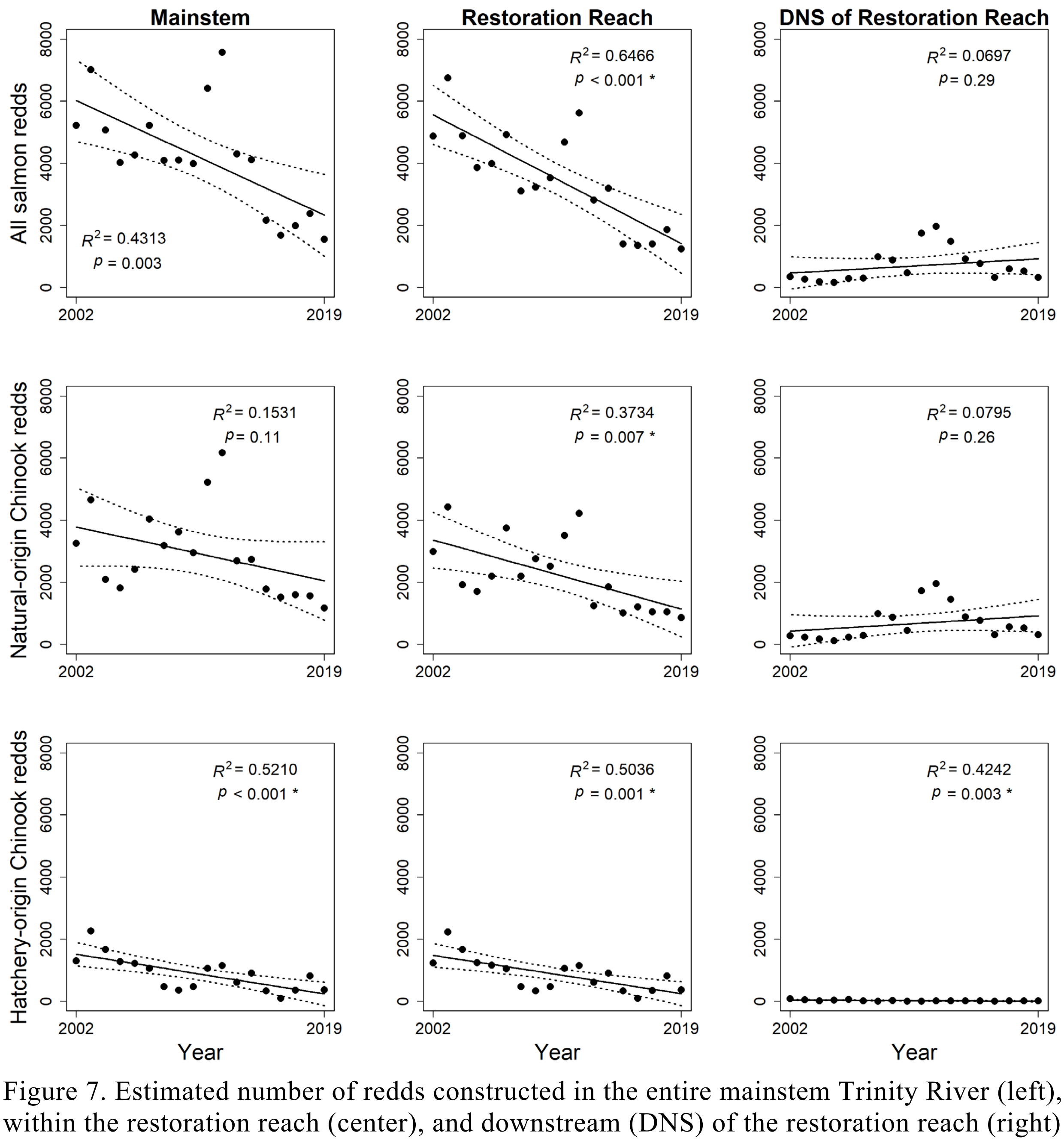

Figure 7. Estimated number of redds constructed in the entire mainstem Trinity River (left), within the restoration reach (center), and downstream (DNS) of the restoration reach (right) by all Chinook Salmon (top), natural-origin Chinook Salmon (middle), and hatchery-origin Chinook Salmon (bottom) from 2002 to 2019. 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 2019, the number of redds constructed annually by natural- and hatchery-origin Chinook Salmon in the restoration reach were variable but trended downward (R^2 = 0.3759, p = 0.01 and R^2 = 0.4967, p = 0.001, respectively).

Downstream of the restoration reach the number of natural-origin Chinook Salmon redds constructed from 2002 to 2019 increased slightly but with no significant trend (R^2 = 0.0795, p = 0.26; Figure 7). A significant decrease in hatchery-origin Chinook Salmon redds was detected downstream of the restoration reach (R^2 = 0.4239, p = 0.003), 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 2019 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 13 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 2019 were 41.2 and 6.3 km, respectively. From 2002 to 2018, 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 2019 (R^2 = 0.7638, p < 0.001; Figure 8). This trend, to a lesser degree (i.e., with a much more gradual slope), was also evident for redds constructed by hatchery-origin Chinook Salmon (R^2 = 0.2421, p = 0.04), which also consistently spawned near Lewiston Dam.

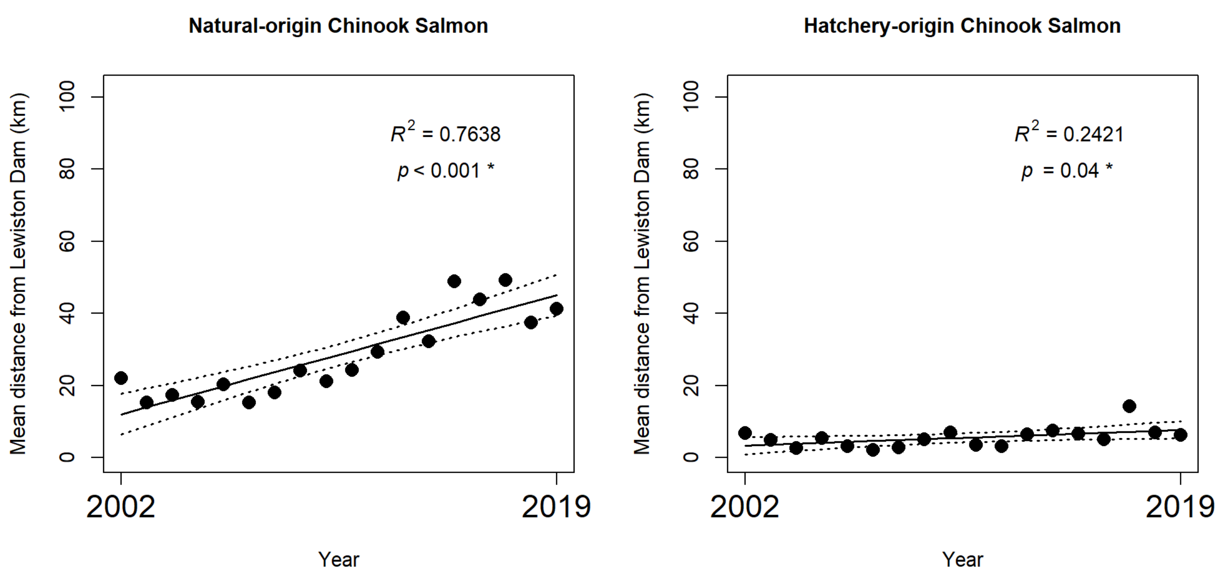

Figure 8. Mean distance from Lewiston Dam of redds constructed by natural- (left) and hatchery-origin (right) Chinook Salmon females between Lewiston Dam and Cedar Flat (0–102.8 km from Lewiston Dam; Reaches 1–10) on the mainstem Trinity River, 2002–2019. Each plot includes a linear model with the R^2 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 ($R^2 = 0.5809$, $p < 0.001$) and Limekiln ($R^2 = 0.3558$, $p = 0.009$) reaches and decreased to a lesser degree in the Douglas City reach from 2002 to 2019 (Figure 9). The number of redds between the Junction City and Del Loma reaches did not significantly change over this time period but generally decreased in the Salyer Gorge, Willow Creek Valley, and Hoopa Valley reaches over the shorter time period from 2007 to 2019.

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 from 2002 to 2019 where natural-origin Chinook Salmon redds decreased in the upstream-most reach (Lewiston; $R^2 = 0.7493$, $p < 0.001$), did not significantly change in the Limekiln, Douglas City, and Junction City reaches, and increased in the mid-river reaches [North Fork ($R^2 = 0.4123$, $p = 0.004$), Big Bar ($R^2 = 0.6784$, $p < 0.001$), and Del Loma ($R^2 = 0.7502$, $p < 0.001$) reaches]. The proportion of redds in the downstream-most reaches (Salyer Gorge, Willow Creek Valley, and Hoopa Valley) did not change significantly from 2007 to 2019.

Most hatchery-origin Chinook Salmon redds were constructed in the Lewiston reach (range = 72–1,888 redds/year, mean = 729 redds/year) and, to a lesser degree, in the Limekiln reach (range = 19–236 redds/year, mean = 93 redds/year) from 2002 to 2019. Over this time frame, the abundance of hatchery-origin Chinook Salmon redds significantly decreased in the Lewiston reach ($R^2 = 0.5510$, $p < 0.001$; 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 16 per year in each reach and only changed significantly in the Big Bar ($R^2 = 0.2266$, $p = 0.05$) and Del Loma reaches ($R^2 = 0.2537$, $p = 0.03$). 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 = 80.9%) and, to a smaller degree, in the Limekiln reach (range = 3.5%–30.9%, mean = 13.2%) from 2002 to 2019. The proportion of hatchery-origin Chinook Salmon redds in the Lewiston reach decreased ($R^2 = 0.3313$, $p = 0.01$) while the proportion of redds in the Limekiln reach increased ($R^2 = 0.5535$, $p < 0.001$). The mean annual proportion of hatchery-origin Chinook Salmon redds in each reach downstream of the Limekiln reach ranged between 0.0% and 2.0% and did not change significantly in any of the reaches except Del Loma (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 showed a range of long-term (2002–2019) trends. Most sites (25) did not show a significant change, 15 sites showed an increasing trend, and 4 sites

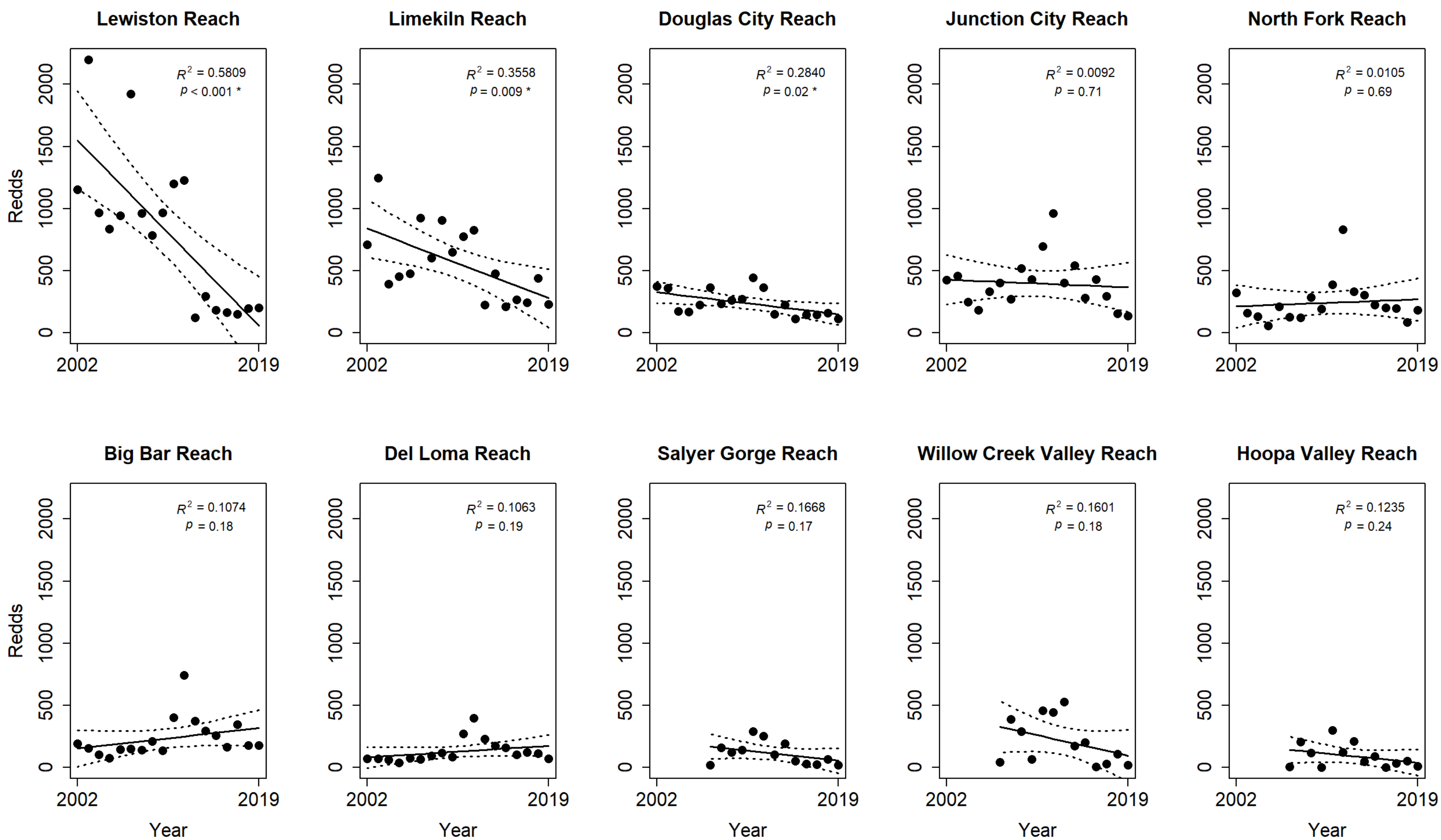

Figure 9. Estimated number of mainstem Trinity River natural-origin Chinook Salmon redds within ten reach-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines).

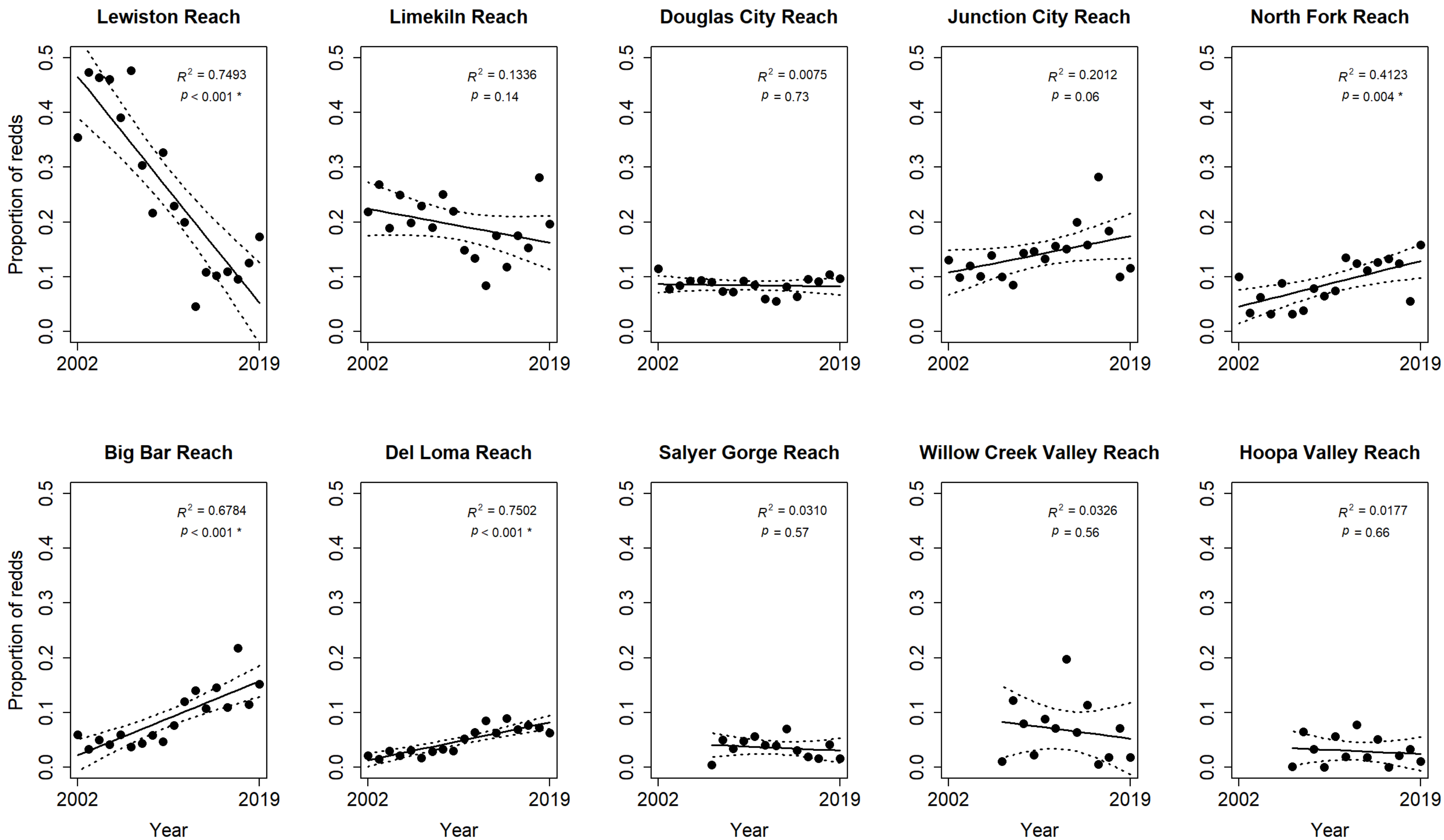

Figure 10. Proportions of mainstem Trinity River natural-origin Chinook Salmon redds relative to the total mainstem count of natural-origin Chinook Salmon redds within ten reach-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).

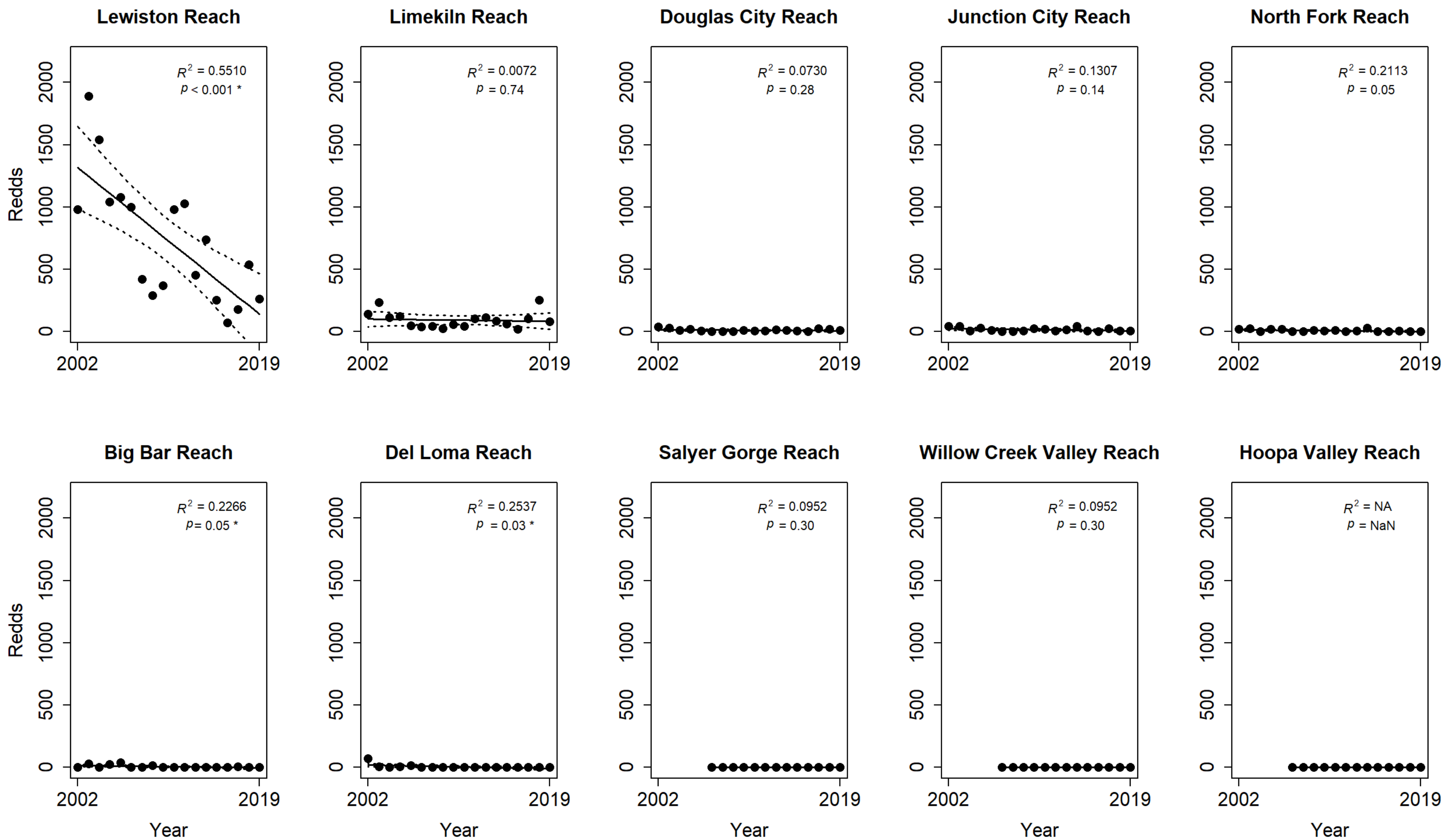

Figure 11. Estimated number of mainstem Trinity River hatchery-origin Chinook Salmon redds within ten reach-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).

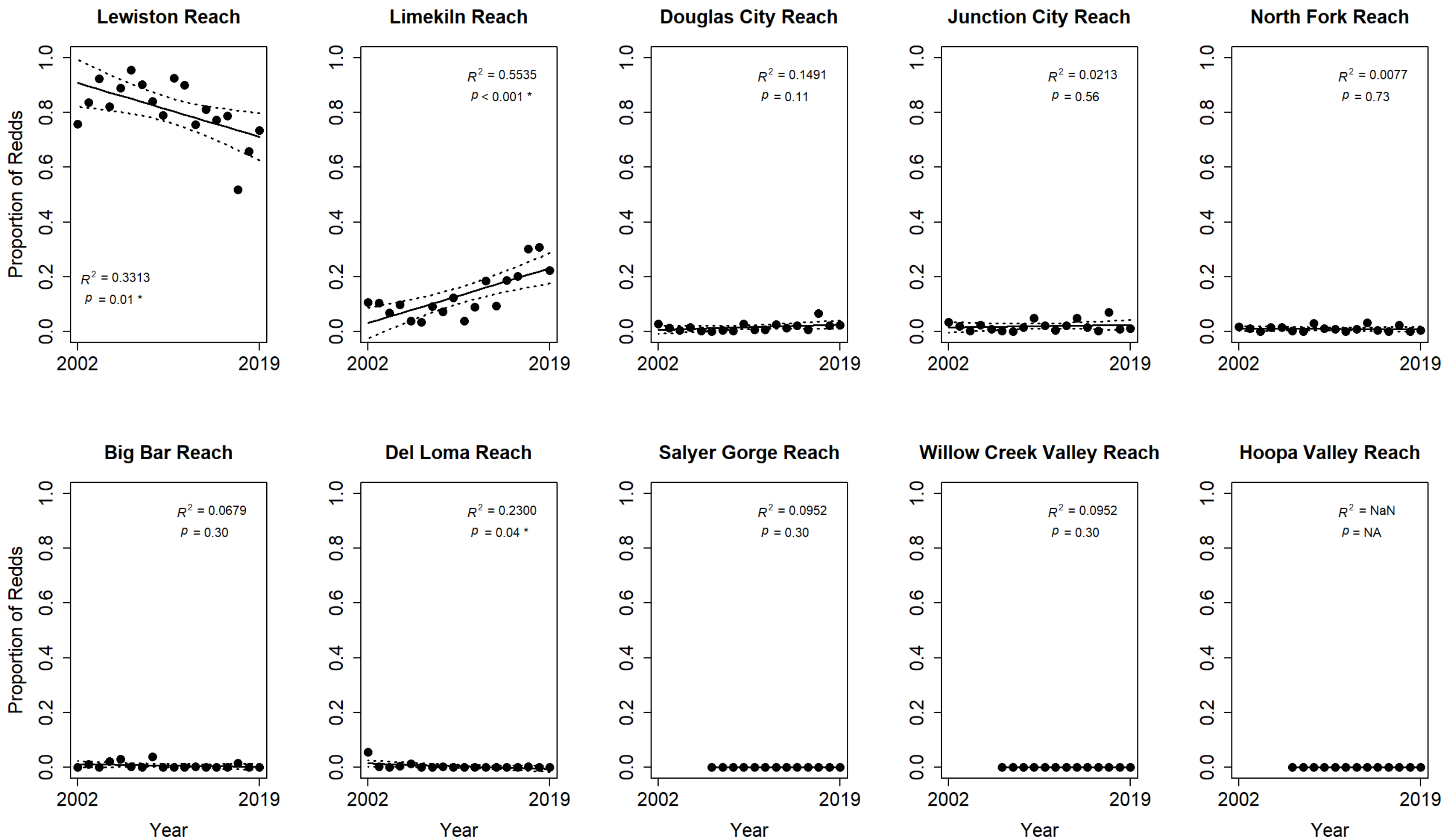

Figure 12. Proportions of mainstem Trinity River hatchery-origin Chinook Salmon redds relative to the total mainstem count of hatchery-origin Chinook Salmon redds within ten reach-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an ‘*’ if <0.05), and 95% confidence limits (dotted lines).

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. The sections from the Sawmill site to the Lower Indian Creek site did not significantly change except for an upward trend at the Tom Lang Gulch site and downward trend at the Poker Bar site. At each site from the Upper Douglas City site and downstream, the proportion of natural-origin Chinook Salmon redds either increased or showed no trend.

Of the 24 mechanical channel rehabilitation sites, the proportional abundance of natural-origin Chinook Salmon redds post-construction trended upward at 7 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 and Sven Olbertson sites), did not change in the middle sites (Old Bridge to Lower Indian Creek sites), and either increased or showed no trend in the downstream-most sites (Upper 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 2019.

Discussion

Redd counts from the 2019 spawning season were the lowest since this survey's inception in 2002 and salmon carcass estimates from Reaches 1 and 2 were the fourth lowest. Our 2019 results are consistent with the California Department of Fish and Wildlife Chinook Salmon natural spawner escapement estimates for the Trinity River Basin, which estimated below-average numbers of spring- and fall-run Chinook Salmon (CDFW 2020a, 2020b). The 2019 Trinity River fall-run natural-spawner adult Chinook Salmon escapement estimate (6,693) was notably below the TRRP annual river escapement goal of 62,000 naturally produced fall-run adults (2020a). The escapement goal of 6,000 spring-run adults was met (7,635) in 2019 for the first time in since 2013 (2020b).

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 2019, 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 2019 ranged between 1,117 (in 2019) 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 2019 did not significantly change (Figure 7). We acknowledge that other factors (e.g., harvest, ocean conditions, in-river conditions, etc.) 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 2020a, 2020b).

Although the abundance of natural-origin Chinook Salmon redds did not show a significant trend from 2002 to 2019, 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, 2021) and data collected in 2019 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 2019, 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.

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 2019 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 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 2012–2019 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 2018 and 3.6% in 2019) 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 2019 data, the lowest redd count and median pre-spawn mortality rate since 2009, to the data from 2009 to 2018, 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. The 2019 Coho Salmon run size was notably small and the carcasses sample size (n = 1 fresh female) was insufficient to evaluate pre-spawn mortality for this species. Interpretation of results pertaining to spawning success should consider 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

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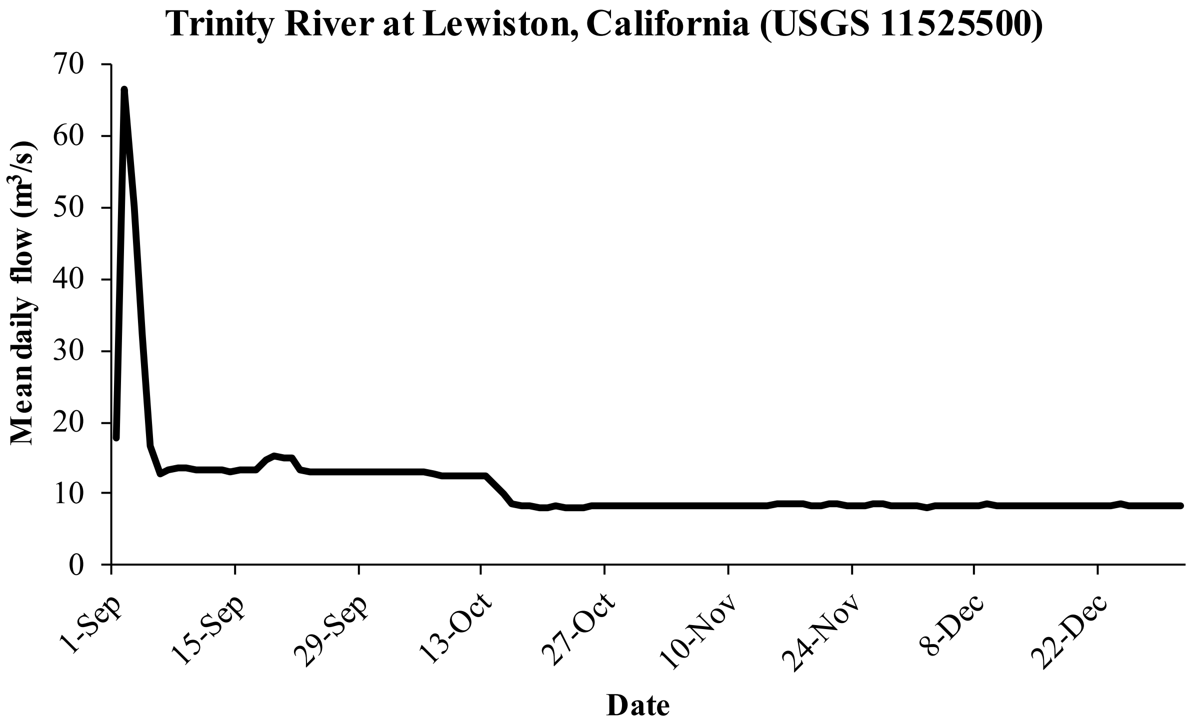
Appendices

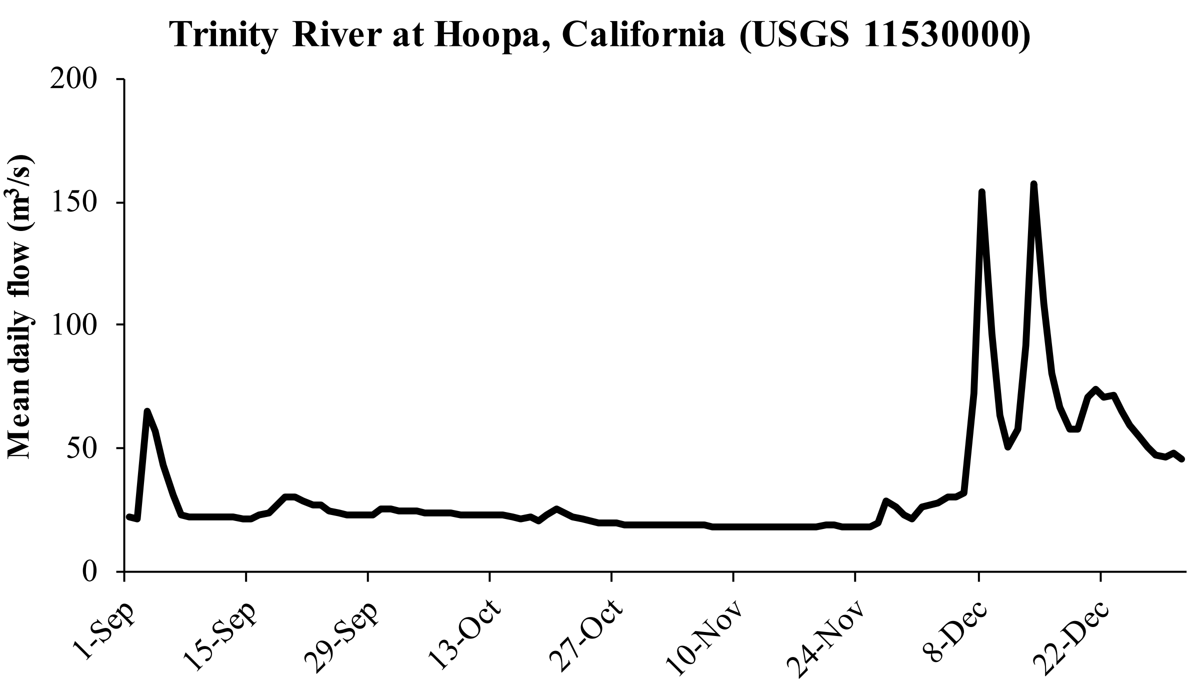
Appendix A. Trinity River water visibility by week and reach throughout the 2019 survey period. Grey boxes represent surveys with sub-optimal visibility. NS = No Survey for scheduled surveys that were missed. NA = This data was not recorded. Dashes (-) represent days when surveys were not scheduled or performed.

Week	Reach											
start	1	2	3	4	5	6	7	9	10	12	13	14
Aug 25	NA	-	-	-	-	-	-	-	-	-	-	-
Sep 1	>3.0	>3.0	NS	NS	NS	NS	NS	-	-	-	-	-
Sep 8	>3.0	>3.0	>3.0	>3.0	>3.0 [a]	1.5-3.0	1.5-3.0	-	-	-	-	-
Sep 15	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	0.9-1.5	0.9-1.5	-	-	-
Sep 22	1.5-3.0	1.5-3.0	>3.0	>3.0	>3.0 [a]	0.9-1.5	0.9-1.5	-	-	NA	NS	NS
Sep 29	>3.0 [a]	>3.0 [a]	1.5-3.0	>3.0	>3.0	NA	NA	NA	>3.0	-	-	-
Oct 6	>3.0	>3.0	>3.0	>3.0	>3.0	>3.0	>3.0	-	-	NA	NA	>3.0
Oct 13	>3.0	>3.0	>3.0	>3.0	>3.0 [a]	1.5-3.0	1.5-3.0	1.5-3.0	NA	-	-	-
Oct 20	>3.0	>3.0	>3.0	>3.0	>3.0	1.5-3.0	1.5-3.0	-	-	1.5-3.0	>3.0	1.5-3.0
Oct 27	>3.0	>3.0	>3.0	>3.0	>3.0	>3.0	1.5-3.0	1.5-3.0	1.5-3.0	-	-	-
Nov 3	>3.0	>3.0 [a]	>3.0 [a]	>3.0	>3.0 [a]	NA	NA	-	-	NA	1.5-3.0	>3.0
Nov 10	>3.0	>3.0 [a]	>3.0	>3.0 [a]	NA	0.9-1.5	>3.0	1.5-3.0	NA	-	-	-
Nov 17	>3.0	>3.0	>3.0	>3.0	>3.0	>3.0	>3.0	-	-	1.5-3.0	1.5-3.0	NA
Nov 24	>3.0	>3.0	NS	NS	NA	>3.0	>3.0	NS [b]	NS [b]	-	-	-
Dec 1	>3.0	>3.0	>3.0	>3.0	>3.0	NA	NA	1.5-3.0	1.5-3.0	>3.0	NS [b]	NS [b]
Dec 8	>3.0	>3.0	>3.0	>3.0	>3.0	1.5-3.0	1.5-3.0	NS [b]	NS [b]	-	0.9-1.5	0.9-1.5
Dec 15	1.5-3.0	1.5-3.0	NS	NS	NS	NS	NS	>3.0	>3.0	NS	NS	NS

[a] This is the higher visibilty reported by the two crews. The other crew reported visibilty 1.5-3.0 m.

[b] 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 2019 survey season.

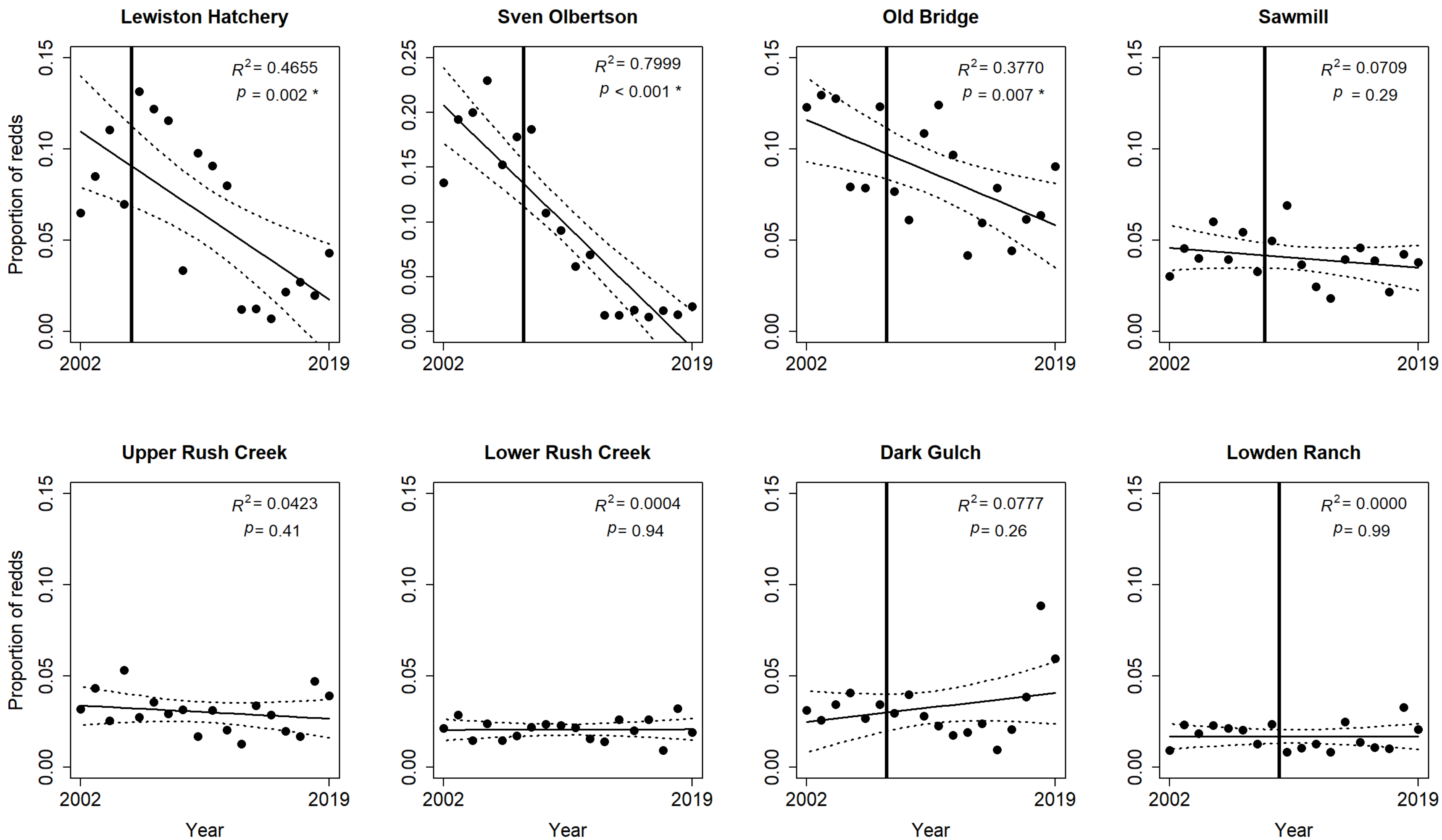
Appendix C. Pre-spawn mortality numbers by week and reach of unmarked and ad-clipped fresh (Conditions 1 and 2) female Chinook Salmon carcasses, mainstem Trinity River surveys 2019. Also included are weekly pre-spawn mortality proportions among like mark-type carcasses. Ad-clipped carcass numbers were 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.

2019 unmarked

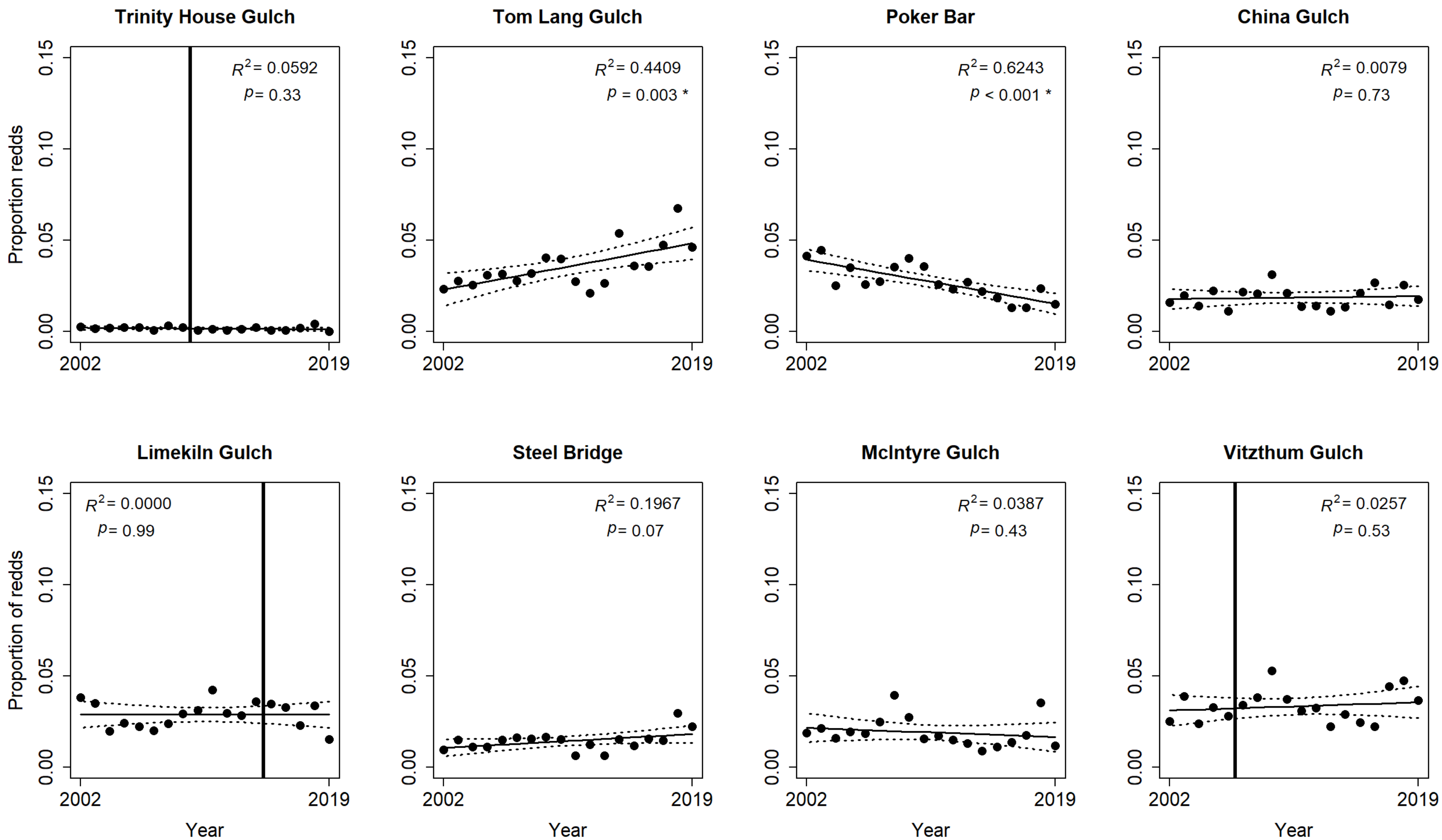
Calendar		Reach												All reaches	
week	Dates	1	2	3	4	5	6	7	9	10	12	13	14	n	Pct.
35	Aug 25-31	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
36	Sep 1-7	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
37	Sep 8-14	2	-	-	-	-	-	-	NS	NS	NS	NS	NS	**2**	**100.0%**
38	Sep 15-21	0	1	-	-	-	-	-	-	-	NS	NS	NS	**1**	**50.0%**
39	Sep 22-28	0	0	0	-	-	-	-	NS	NS	-	NS	NS	**0**	**0.0%**
40	Sep 29-Oct 5	0	0	0	0	0	1	-	-	-	NS	NS	NS	**1**	**3.0%**
41	Oct 6-12	2	0	0	-	0	0	-	NS	NS	-	-	-	**2**	**4.3%**
42	Oct 13-19	0	1	-	0	0	0	0	-	-	NS	NS	NS	**1**	**2.0%**
43	Oct 20-26	0	0	0	0	0	0	0	NS	NS	-	-	-	**0**	**0.0%**
44	Oct 27-Nov 2	0	0	0	0	0	0	-	0	0	NS	NS	NS	**0**	**0.0%**
45	Nov 3-9	0	0	-	0	0	-	-	NS	NS	-	-	-	**0**	**0.0%**
46	Nov 10-16	2	0	-	0	-	0	-	-	0	NS	NS	NS	**2**	**9.1%**
47	Nov 17-23	0	0	0	0	-	0	-	NS	NS	-	-	-	**0**	**0.0%**
48	Nov 24-30	0	0	NS	NS	-	-	-	NS	NS	NS	NS	NS	**0**	**0.0%**
49	Dec 1-7	0	0	0	0	-	-	-	-	-	-	NS	NS	**0**	**0.0%**
50	Dec 8-14	0	0	-	-	-	-	-	NS	NS	NS	-	-	**0**	**0.0%**
51	Dec 15-21	-	-	NS	NS	NS	NS	NS	-	-	NS	NS	NS	-	-
	All weeks	**6**	**2**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**-**	**-**	**-**	***9***	***3.3%***

2019 ad-clipped

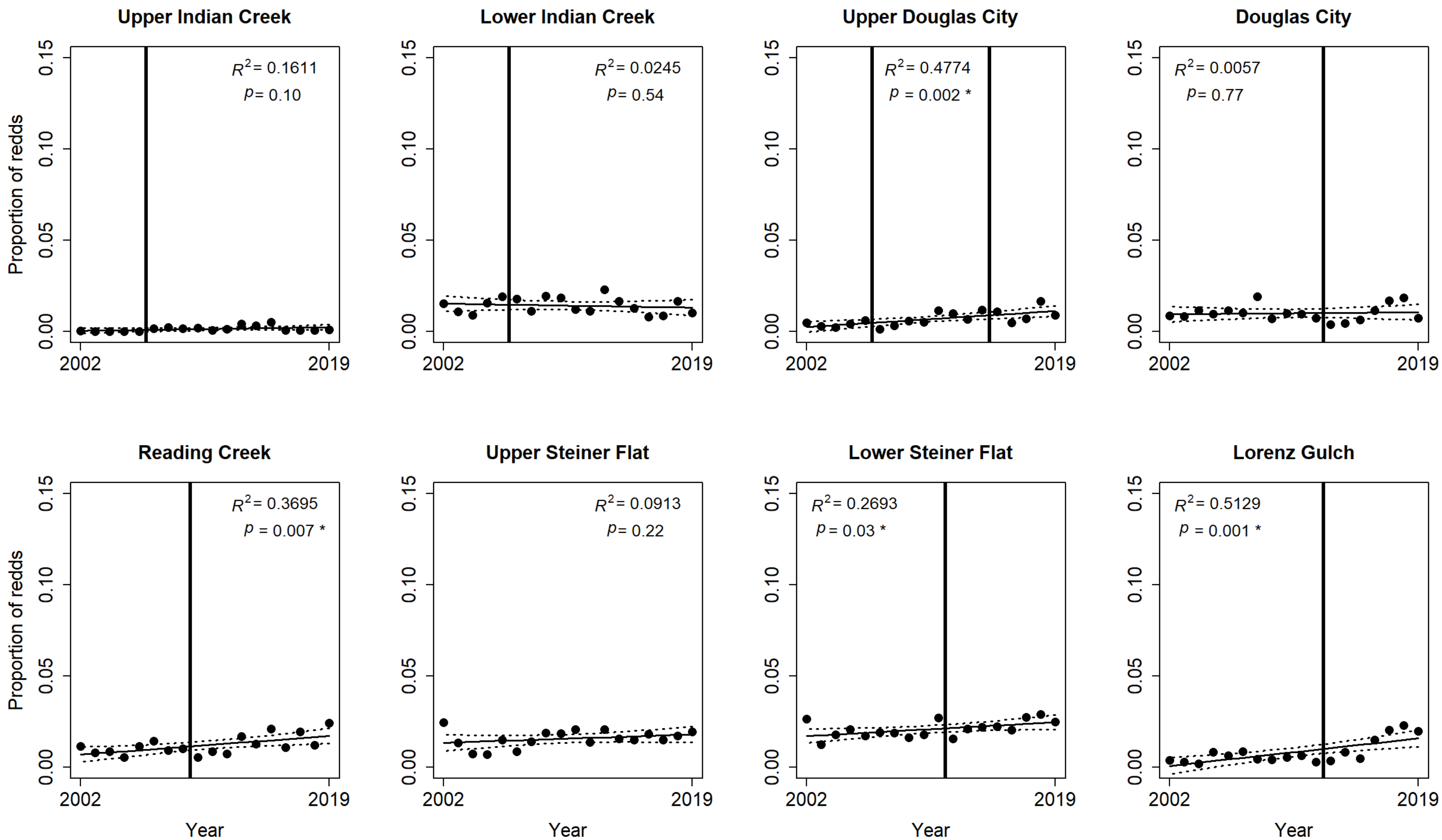
Calendar		Reach												All reaches	
week	Dates	1	2	3	4	5	6	7	9	10	12	13	14	n	Pct.
35	Aug 25-31	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
36	Sep 1-7	-	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
37	Sep 8-14	-	-	-	1	-	-	-	NS	NS	NS	NS	NS	**1**	**100.0%**
38	Sep 15-21	-	-	-	-	-	-	-	-	-	NS	NS	NS	-	-
39	Sep 22-28	0	0	-	-	-	-	-	NS	NS	-	NS	NS	**0**	**0.0%**
40	Sep 29-Oct 5	0	0	-	-	-	-	-	-	-	NS	NS	NS	**0**	**0.0%**
41	Oct 6-12	0	0	-	-	0	-	-	NS	NS	-	-	-	**0**	**0.0%**
42	Oct 13-19	-	-	-	-	-	-	-	-	-	NS	NS	NS	-	-
43	Oct 20-26	0	0	-	-	-	-	-	NS	NS	-	-	-	**0**	**0.0%**
44	Oct 27-Nov 2	0	0	-	-	-	-	-	-	-	NS	NS	NS	**0**	**0.0%**
45	Nov 3-9	-	-	-	-	-	-	-	NS	NS	-	-	-	-	-
46	Nov 10-16	1	0	-	-	-	-	-	-	-	NS	NS	NS	**1**	**25.0%**
47	Nov 17-23	0	0	-	-	-	-	-	NS	NS	-	-	-	**0**	**0.0%**
48	Nov 24-30	-	-	NS	NS	-	-	-	NS	NS	NS	NS	NS	-	-
49	Dec 1-7	0	0	-	-	-	-	-	-	-	-	NS	NS	**0**	**0.0%**
50	Dec 8-14	-	-	-	-	-	-	-	NS	NS	NS	-	-	-	-
51	Dec 15-21	-	-	NS	NS	NS	NS	NS	-	-	NS	NS	NS	-	-
	All weeks	**1**	**0**	**-**	**1**	**0**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	***2***	***5.4%***



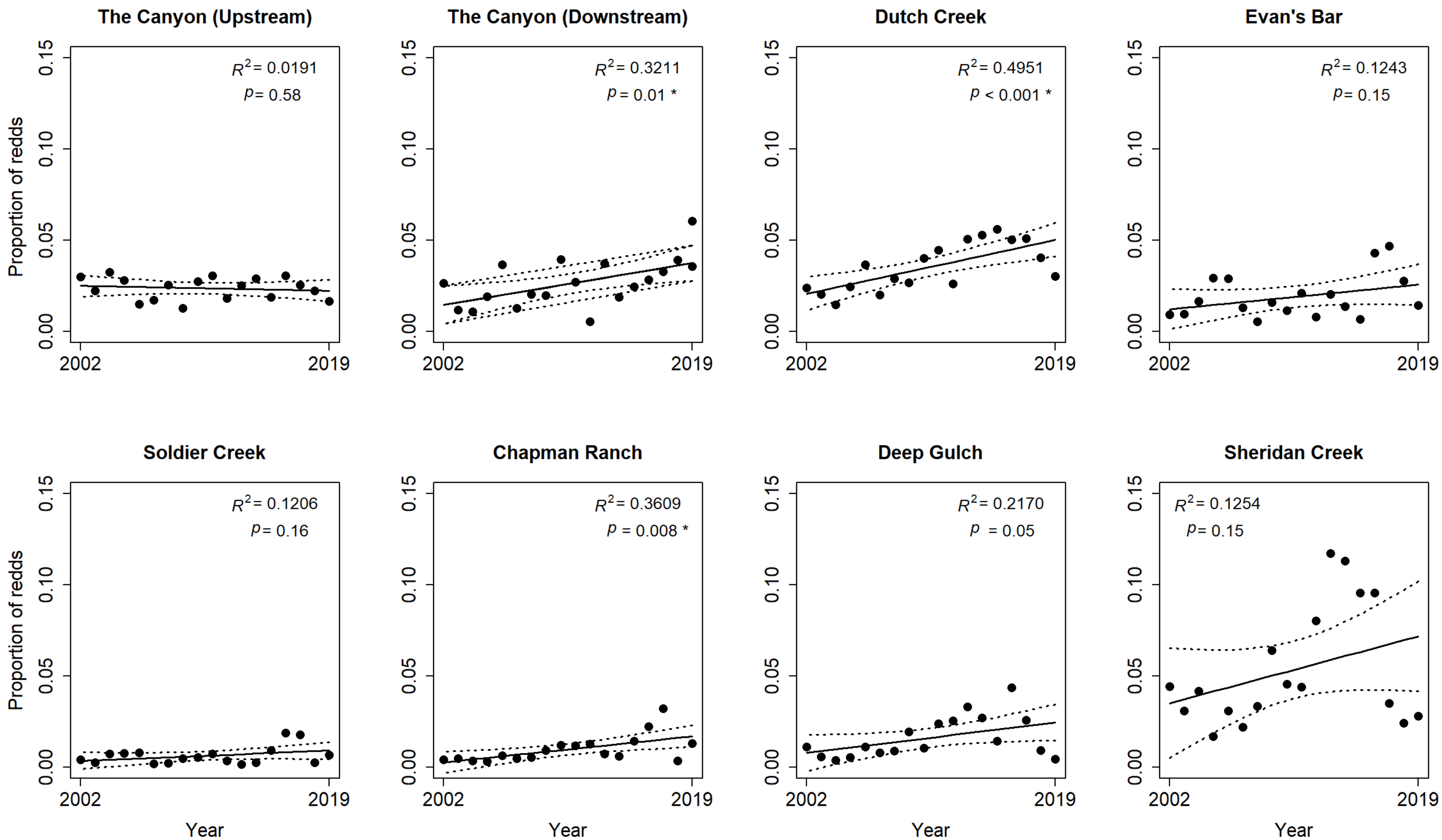
Appendix D. Proportion of TRRP restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars. Note the change in y-axis scale in the Sven Olbertson site.



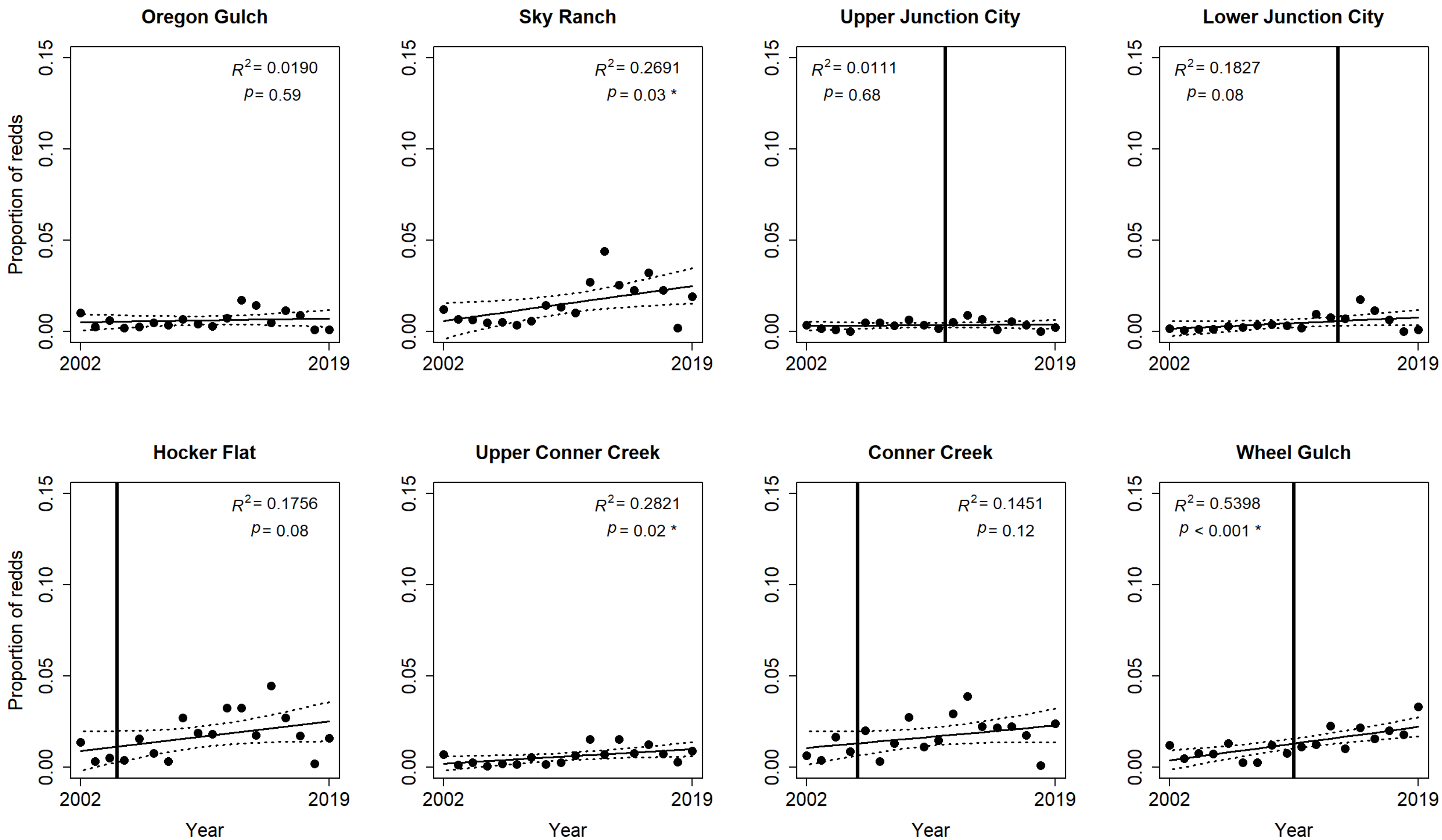
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



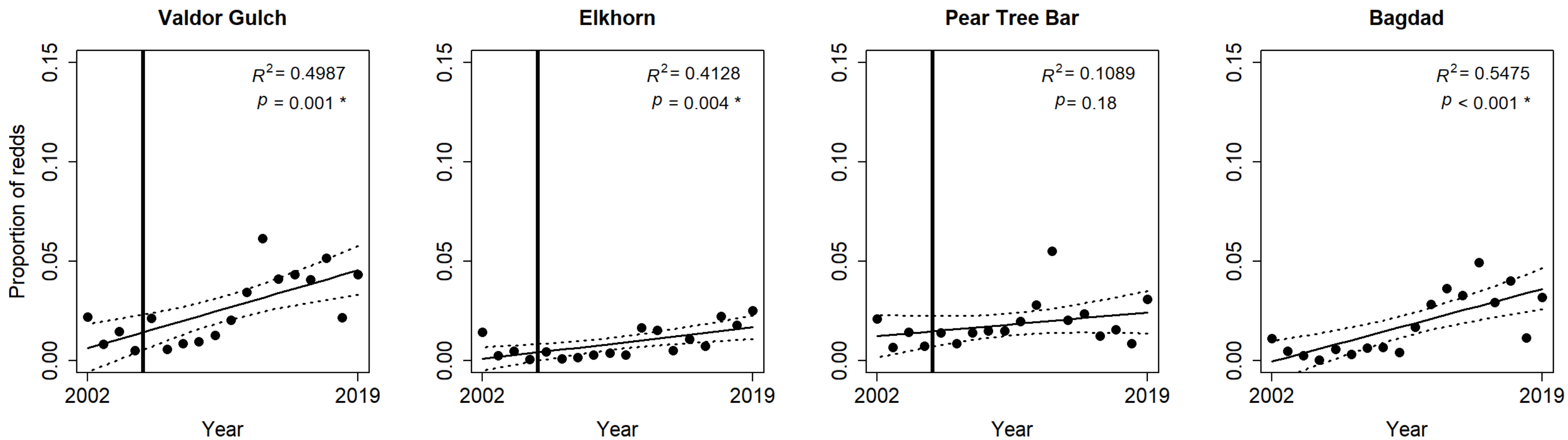
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, *p*-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



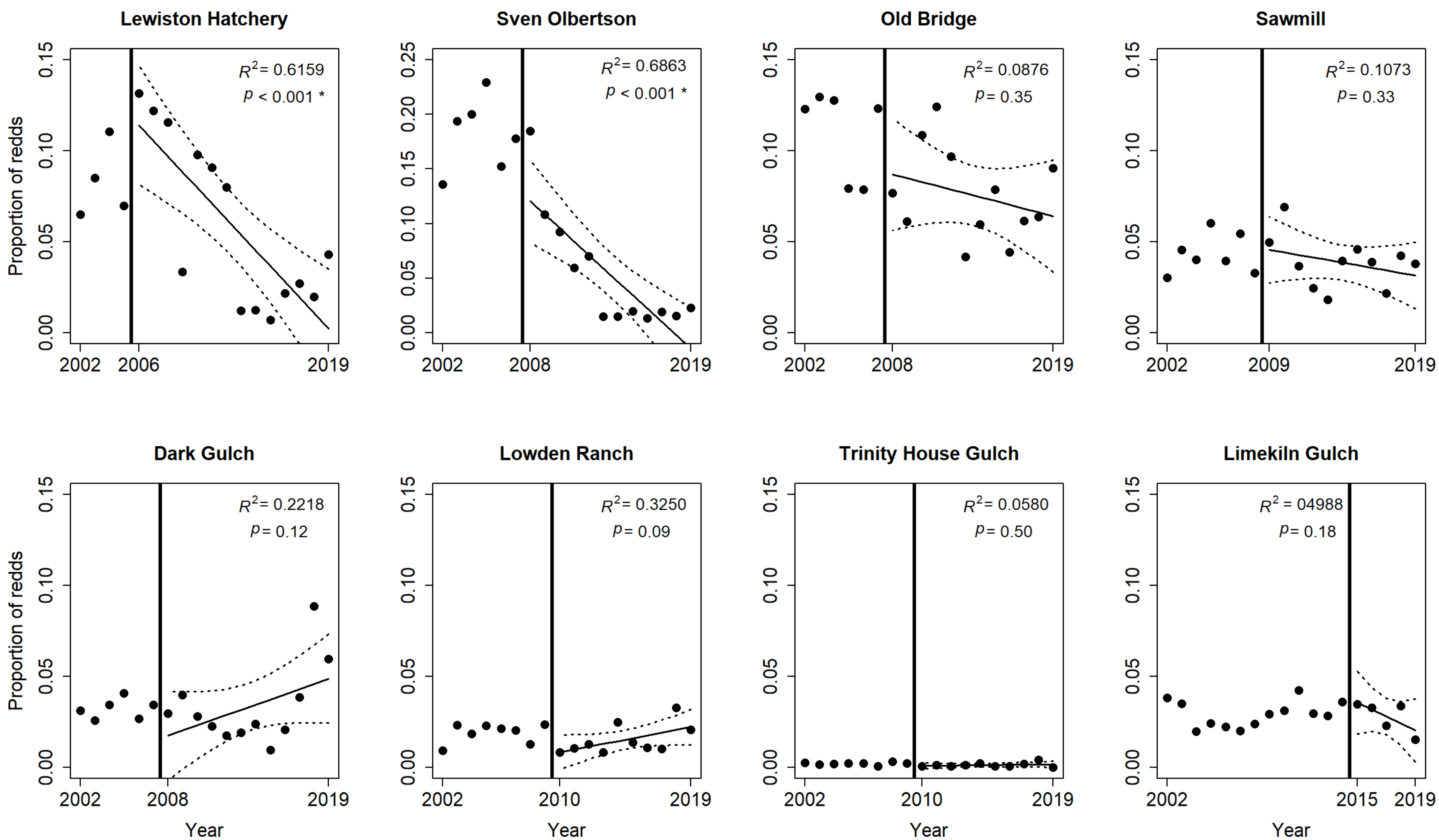
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines).



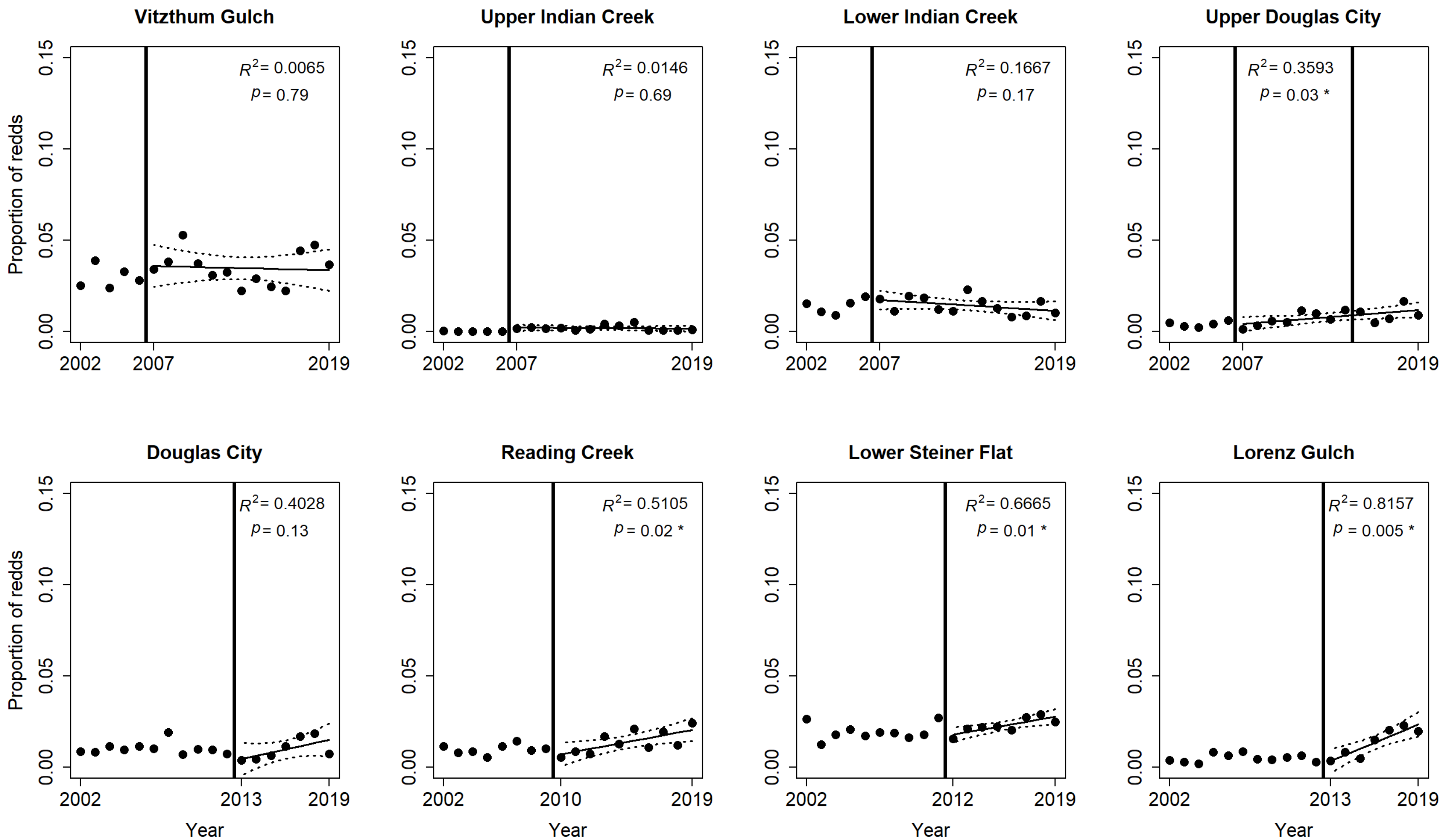
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



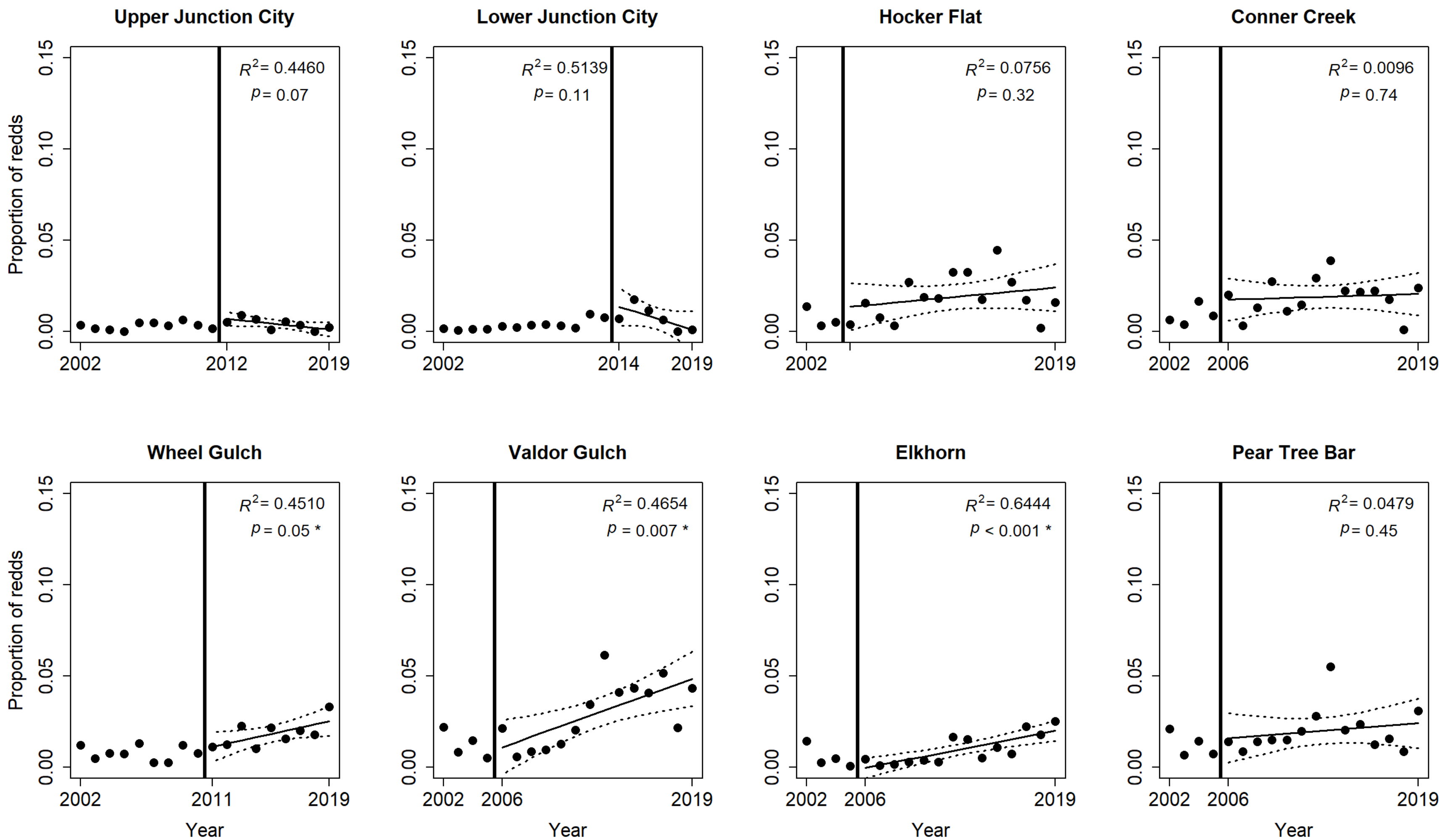
Appendix D (continued). Proportion of restoration reach natural-origin Chinook Salmon redds within site-scale sections, 2002–2019. Each plot includes a linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 95% confidence limits (dotted lines). The time mechanical channel rehabilitation was initiated is shown as black vertical bars.



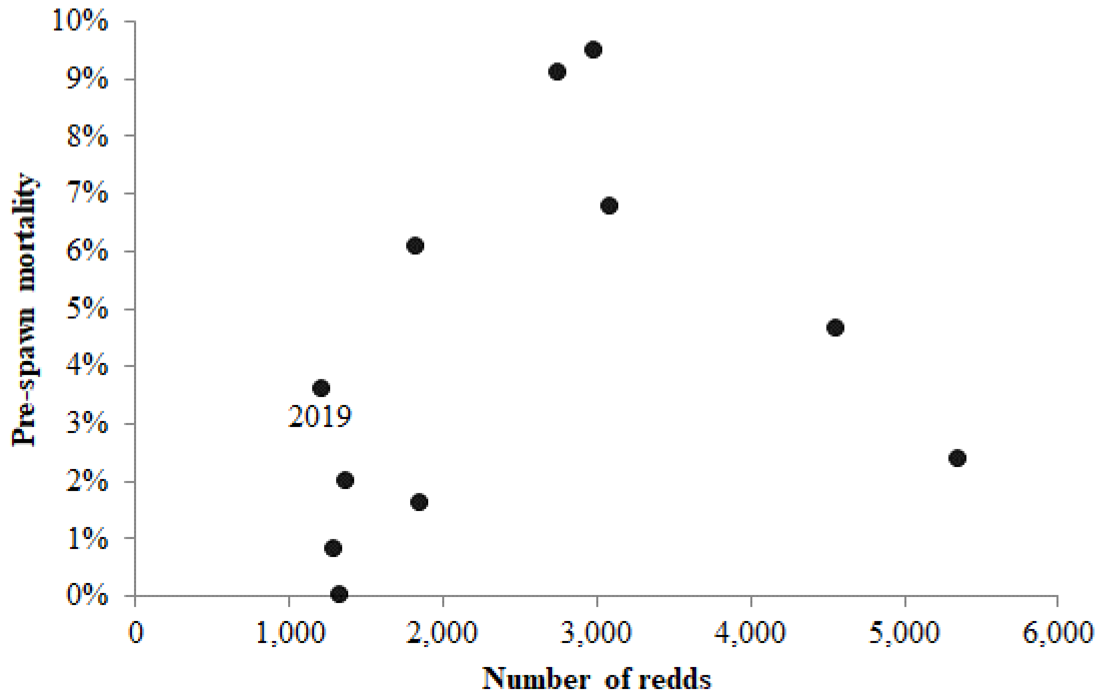
Appendix E. Proportion of natural-origin Chinook Salmon redds within site-scale sections in the TRRP restoration reach that encompass mechanical channel rehabilitation locations, 2002–2019. Each plot includes a post-construction linear model with the R^2 value, p-value (noted with an '*' if <0.05), and 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, 2002–2019. 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, 2002–2019. 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, 2009–2019.