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Distribution and Abundance of Chinook Salmon Redds in the Mainstem Trinity River 2002 to 2011

Charles D. Chamberlain[1]; Shane Quinn[2]; and Billy Matilton[3]

U.S. Fish and Wildlife Service [1]
Arcata Fish and Wildlife Office
1655 Heindon Road, Arcata, CA 95521
(707) 882-7201

Yurok Tribal Fisheries Program[2]
Weitchpec, CA 95546
(530) 625-4130

Hoopa Valley Tribal Fisheries Department[3]
Hoopa, CA 95546
(530) 625-4267

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Charles D. Chamberlain[1]; Shane Quinn[2]; and Billy Matilton[3]

[1]*U. S. Fish and Wildlife Service, Arcata Fish and Wildlife Office*
1655 Heindon *Road; Arcata, California 95521; charles_chamberlain@fws.gov*

[2]*Yurok Tribal Fisheries Program - Highway 96 Box 196 Weitchpec Route*
Hoopa, California 95546; squinn@yuroktribe.nsn.us

[3]*Hoopa Valley Tribal Fisheries Department - P.O. Box 417*
Hoopa, CA 95546; bmatilton@hoopa-nsn.gov

Abstract.— Salmon redds were mapped and carcasses collected in the mainstem Trinity River each fall 2002 through 2011 to quantify and spatially characterize Chinook salmon spawning in the mainstem Trinity River. We applied generalized additive models to the spatiotemporal distribution of hatchery marked or unmarked spawned female salmon carcasses to apportion redd numbers for natural origin and hatchery origin Chinook salmon. These data serve as baseline for the Trinity River Restoration Program to evaluate response of spawning distributions to river rehabilitation and other management actions. Eighteen river rehabilitation sites between Lewiston Dam and the North Fork Trinity River have been implemented over the course of this study. Though spawning distribution responded to physical alterations on a local feature scale (salmon constructed redds in newly created side channels for example), the proportion of redds constructed within the up and downstream boundaries of these rehabilitation sites had not yet significantly changed at broader reach scales. High density spawning area locations remained consistent year to year with little exception. We observed an increase in the mean distance from Lewiston Dam for construction of natural origin Chinook salmon redds over the course of this study. The distribution of hatchery origin Chinook salmon redds remained highly skewed toward Lewiston Dam and Trinity River Hatchery. The number of redds estimated to be constructed by natural origin Chinook salmon females ranged from as low as 2,249 in 2005 to as high as 5,312 in 2011. Estimates of those constructed by hatchery origin Chinook salmon females ranged from as low as 350 in 2009 to as high as 2,269 in 2003. There was no relationship observed in distance downstream of Lewiston Dam that Chinook salmon constructed redds and the yearly total number of Chinook salmon redds. There apreared to be a weak relationship between the distribution of natural origin Chinook salmon redds and the number of hatchery origin Chinook salmon spawning in-river (closer to Lewiston Dam in years with many hatchery strays).

INTRODUCTION

The Trinity River drains a watershed of approximately 7,679 km^2 (2,965 mi^2) in Trinity and Humboldt Counties of northwestern California. Dramatic degradation of rearing habitat and decline of Trinity River salmonid populations occurred following construction and operation of the Trinity River Division (TRD) of the Central Valley Project (CVP). Lewiston Dam blocks upstream salmon migration 182.2 river kilometers (rkm) from the Klamath/Trinity confluence at Weitchpec. Trinity River Hatchery (TRH), located near the base of Lewiston Dam, is intended to mitigate for the loss of salmon production upstream of the dam. Approximately 4.3 million juvenile Chinook salmon (*Oncorhynchus tshawytscha*) are released to the Trinity River from TRH annually. For the first few decades after construction, as much as 90% of the annual runoff of the Trinity River at Lewiston was diverted to the Sacramento Valley. Responding to population declines, the Secretary of the Interior signed the Trinity River Mainstem Restoration Record of Decision (ROD) in the year 2000 (DOI 2000).

The rehabilitation approach of the ROD is to restore habitat forming alluvial processes that were detrimentally influenced by the diversion of water and loss of coarse sediment sources upstream of Lewiston Dam. The Trinity River Restoration Program's (TRRP) toolbox for reinitiating these alluvial processes includes 1) retaining a larger portion of the water from the watershed above Lewiston for use in the Trinity River through implementation of five annual flow volumes variable by water year type; 2) mechanically reshaping the river channel to function under the new hydrologic regime; and 3) reintroducing an appropriate supply of coarse sediment. These collective actions are intended to dramatically increase the availability of salmonid rearing habitat and production of fish in the Trinity River. The primary portion of river targeted by the TRRP for these actions is the 64 km of mainstem from Lewiston Dam to the North Fork Trinity where impacts from construction and operation of the TRD are most acute. For the river downstream of North Fork, valley narrowing and tributary accretions of flow and sediment largely attenuate many of the morphological impacts that have been observed in the Lewiston to North Fork reach (USFWS and Hoopa Valley Tribe 1999).

Trinity River fall Chinook salmon typically enter the Klamath Estuary in early fall and migrate upstream to spawn mid-October to late December. Spring Chinook salmon enter in spring and early summer, hold for several months in deep pools, and begin spawning in early September. Spring and fall Chinook salmon spawning in the mainstem Trinity exhibit considerable spatial and temporal overlap. We make no attempt to quantify by these races with this report. Since brood year 2000, Chinook salmon produced at the Trinity River Hatchery have been marked with adipose fin-clips and coded wire tags at a rate of approximately 25%.

Our survey period (September through December) partially overlaps with spawning activity of coho salmon (*O. kisutch*) which begin to construct redds about half way through our typical survey season. A large portion of Trinity River Chinook salmon return as three year olds (annual KRTAT 2003 to 2012), and the redds they construct are largely undifferentiable based on size to those of coho salmon. This report makes no attempt to draw inferences regarding quantification or distribution of coho salmon spawning as a significant portion of their spawning period occurs after our survey season. We use coho salmon data in this effort solely for the purposes of accounting for their presence among mainstem Trinity River salmon redds in order to describe distribution and estimate numbers of Chinook salmon redds.

Spawning habitat is not believed to be limiting Trinity River natural Chinook salmon populations (USFWS and Hoopa Valley Tribe 1999), but spawning habitats will be locally influenced by TRRP actions intended to increase rearing habitat. The TRRP aims to increase the Trinity River's ability to naturally produce Chinook salmon by increasing the availability of juvenile rearing habitat through actions that alter the river's morphology. River morphology plays a key role in the suitability of habitat for spawning salmon (Beschta and Platts 1986, Geist and Dauble 1998, Hanrahan 2007). Changes at the rehabilitation site scale (e.g. the scale of constructed bar or side channels, 100 to 1,000 meters plus) can occur rapidly through construction or through channel response to significant flow events. The localized use of spawning habitats should likewise respond quickly to these morphological changes.

The spatial distribution of spawning salmon is influenced not only by the spatial distribution of spawning habitat, but the distribution of rearing habitat. A lack of rearing habitat can result in underutilization of prime spawning habitat (Beschta and Platts 1986). Newly emerged salmon fry experience higher survival if they emerge from redds that are proximate to rearing areas of sufficient quantity and quality. Those fish are more likely to contribute to the distribution of fish returning to construct redds in natal spawning areas than are newly emerged fry that experience unfavorable rearing conditions. If TRRP management actions successfully improve rearing conditions in the Trinity River, the influence that rearing habitat exerts on salmon spawning distribution will increase in relation to the influence exerted by straying hatchery fish. At the system scale (64 km of river from Lewiston Dam to North Fork Trinity River) the distribution of spawners should respond to broad scale changes in the distribution of rearing habitat over a period that spans multiple salmon generations.

The purpose and objectives of this study are summarized in the below excerpt from our 2010 proposal.

The project objectives are:

- *i. Assess the spatial distribution of Chinook salmon redds, particularly in relation to TRRP management actions.*
- *ii. Quantify Chinook salmon spawning in the mainstem Trinity River.*
- *iii. Quantify pre-spawn mortality for female Chinook salmon.*
- *iv. Quantify and describe temporal and spatial distribution of natural and hatchery origin Chinook salmon spawning.*
- v. *Collect biological data ancillary to escapement (fork lengths for estimating size distribution and jack proportion, scales for age composition, sex ratio, etc.).*

Not included within this report are analysis specific to the carcass data (items *iii* and *v* above) that are analyzed and reported separately by California Department of Fish and Game (CDFG).

Included as a deliverable from the co-investigators of this effort to the TRRP is a GIS database of redd locations. Those data include estimated probability of construction by natural origin Chinook salmon and hatchery origin Chinook salmon. This database will facilitate a multitude of analysis by other uses (e.g. spawning response to individual features at rehabilitation sites, response to infrastructure, response to hatchery management, etc.).

METHODS

For this study, the Trinity River from Lewiston Dam to its confluence with the Klamath River (Figure 1) was delineated into 14 reaches. Individual reaches were based on logistical practicality (what could be surveyed in a day) and range in length from 3.3 to 21.3 km (Figure 2, Table 1). The only mainstem anadromous portion omitted in this survey is the 15.6 km reach that includes the Burnt Ranch Gorge (Reach 11), a whitewater reach that supports little salmon spawning. Reaches 1 through 7 were surveyed once every week as conditions permitted. Reaches 8 through 14 (excluding Reach 11 for safety) were surveyed about every two weeks. Surveys for all years began in early to mid-September and extended into mid-December.

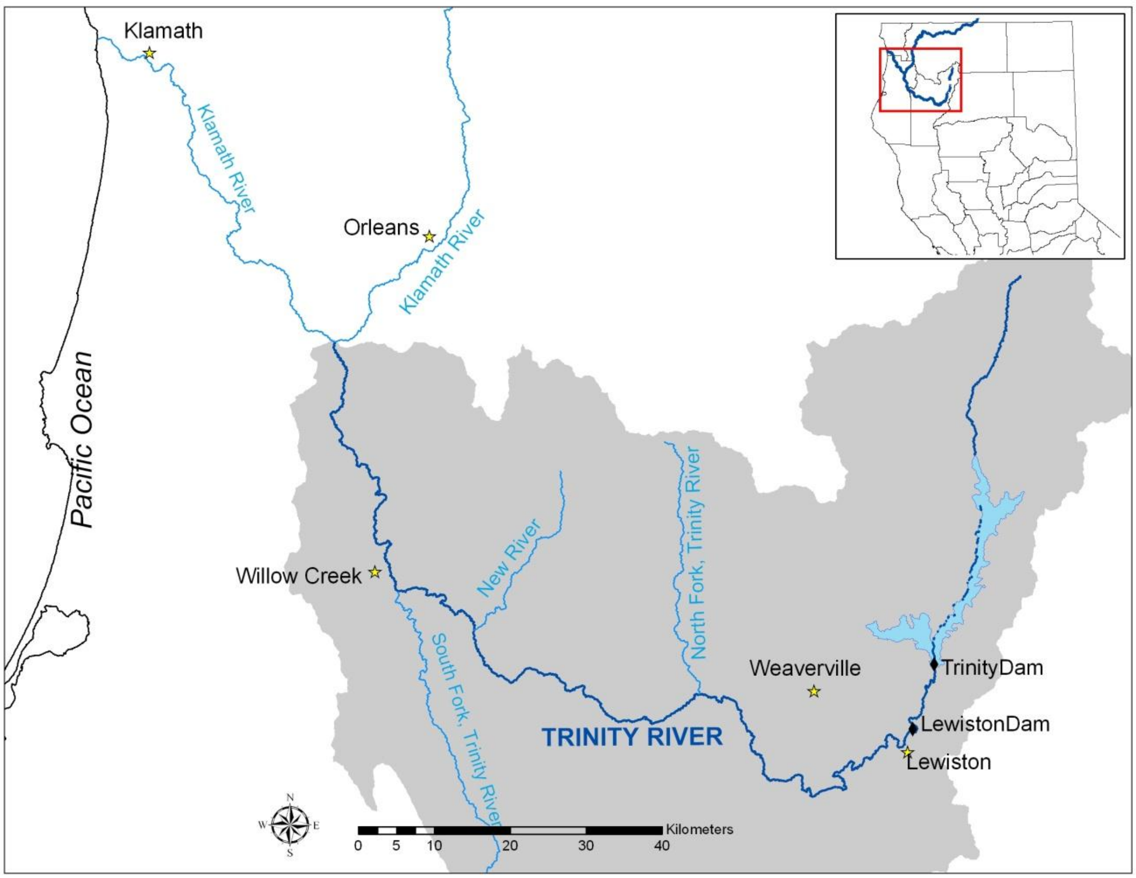

Figure 1. Trinity River area. Survey area extends from Lewiston Dam to the mouth of the Trinity River at its confluence with the Klamath River.

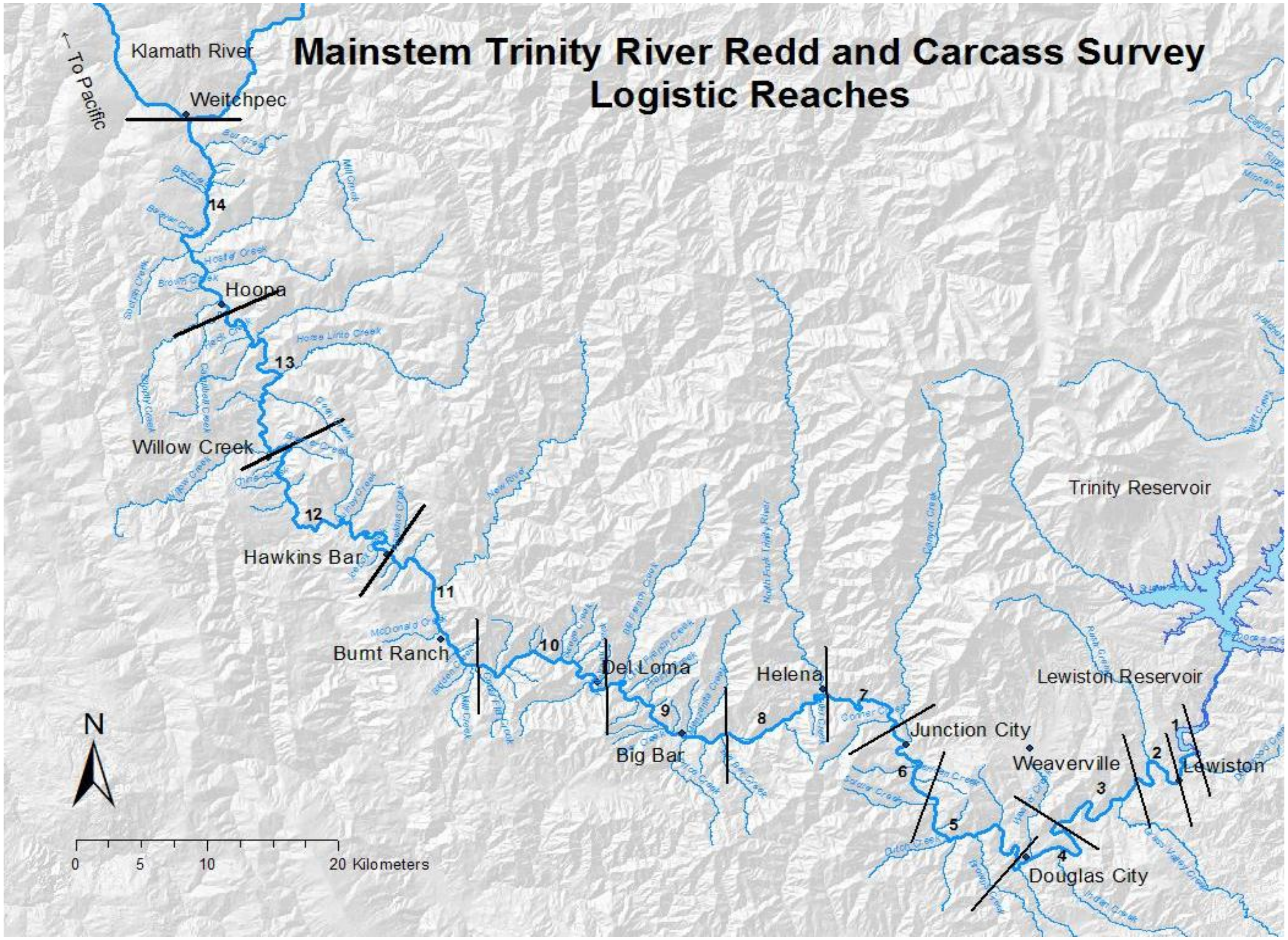

Figure 2. Survey reaches 1 through 14 of the mainstem Trinity River Redd Survey from Lewiston Dam to Weitchpec. Reach 11 through the Burnt Ranch Gorge not surveyed due to extreme whitewater.

Table 1. Logistic reaches 1 through 14 of the mainstem Trinity River survey. Agencies involved in data collection include California Department of Fish and Game (CDFG), Shasta Trinity National Forest (USFS), United States Fish and Wildlife Service (FWS), Yurok Tribal Fisheries Program (YTF), and Hoopa Valley Tribal Fisheries Department (HVT).

Reach	Top	Bottom	Agency
1	Lewiston Dam	Old Lewiston Bridge	USFS, YTFP, CDFG
2	Old Lewiston Bridge	Bucktail River Access	CDFG, YTFP
3	Bucktail River Access	Steel Bridge River Access	CDFG, YTFP
4	Steel Bridge River Access	Douglas City Campground	CDFG, YTFP
5	Douglas City Campground	Round House	CDFG, YTFP
6	Round House	Junction City Campground	USFWS, HVT
7	Junction City Campground	Pigeon Point Campground[1]	USFWS, HVT
8	Pigeon Point Campground[1]	Big Flat River Access	USFWS, HVT
9	Big Flat River Access	Del Loma River Access	USFWS, HVT
10	Del Loma River Access	Cedar Flat River Access	USFWS, HVT
11	Cedar Flat River Access	Hawkins Bar	NO SURVEY
12	Hawkins Bar	Camp Kimtu in Willow Creek	USFWS, HVT
13	Camp Kimtu in Willow Creek	Roland’s Bar in Hoopa Valley	USFWS, HVT
14	Roland’s Bar in Hoopa Valley	Weitchpec (Trinity mouth)	USFWS, HVT

[1] Pigeon Point Campground access is 0.8 km downstream of the North Fork Trinity River.

Data collection

Each reach was navigated with a pair of inflatable rafts, one assigned to each bank. The crew on board each raft consisted of an observer and an oars person. Base flow channel widths averaged less than 30 meters (Hoopa Valley Tribe et al 2011). With the Trinity River's typically high water clarity and shallow spawning areas used by spawning Trinity River Chinook salmon (Hampton 1997), the entire river bottom in spawning areas was usually visible by two crews operating side by side. In cases where local width exceeded limits of visibility, the oars persons maneuvered back and forth to get entire coverage of the river bottom. Non navigable side channels were walked by an observer.

Observers searched for the scoured oval pit and distinctive mound typical of a complete redd (Burner 1951). Newly constructed redds were typically distinguishable from surrounding river bed by the lighter color of freshly overturned gravel (Figure 3). Eventually (3 to 4 weeks or more) color of the redd would return to that of the ambient river rock as periphyton colonized the overturned gravel. All located redds were enumerated and locations determined by aerial photo interpretation or GPS (discussed below).

From 2002 to 2007, crews carried laminated 3,125:1 scale aerial photos of the river. Drawn on each photo was a river centerline marked in river kilometer (rkm) designations. Over this period, numerous aerial photo sets were acquired by TRRP and made available to this study. Each photo set was taken at summer base flow of approximately 12.7 cms (450 cfs) from Lewiston Dam. The path of the river centerline printed on the photos was derived from United States Geological Survey (USGS) 1:24,000 Digital Raster Graphics (DRG) topographic maps. The rkm designations began with 0.0 at the mouth of the Trinity and extended to 182.2 at Lewiston Dam. Redd or redd cluster locations were estimated from field interpretation of the photos using visible landmarks (trees, river features, etc.), and the estimated rkm was recorded on datasheets.

Data collected at each spawning location included the number of redds newly constructed since the previous survey and the cumulative number of redds to date. To aid the observers in differentiation of new redds from those counted on previous visits, a flag was hung in nearby vegetation and descriptors of redd location in relation to the flag were recorded (distance from bank; distance up or downstream from flag location).

In 2007, the California Department of Water Resources (DWR) developed a new river centerline for the portion of river from Lewiston Dam to the North Fork Trinity River based on thalweg location of a 141.6 cms (5,000 cfs) modeled flow. This line matched the contemporary channel much better than the previous version and we adopted it for the river upstream of North Fork, merging it with the old line at the confluence with North Fork Trinity River. To avoid ambiguity with multiple versions of rkm designation that all used the mouth at Weitchpec as their origin (rkm 0.0 = the mouth), we redesignated the origin of the merged line as the base of Lewiston Dam. For our analysis, all pre-2008 data were transposed to this merged version of the river centerline, and 2009 and later data were 'snapped' to the merged line (discussed below).

From 2009 forward, each individual redd was marked at the upstream edge of its pit using a Trimble ProXH GPS receiver connected to a tablet PC running ArcPad (years 2009 and 2010) or Trimble TerraSync (year 2011). Distance from Lewiston Dam for each record was determined by "snapping" its *xy* location to the river centerline and creating a route event in ArcGIS (ESRI 2008).

Figure 3. Trinity River salmon redds. Redds distinguishable from surrounding substrate by the lack of periphyton and brighter appearance of freshly overturned gravel.

Carcass and redd surveys were conducted concurrently in all years. Carcass data were used by CDFG to comprehensively report incidence of female pre-spawning mortality, size distribution, sex ratios, and incidence of marked and tagged individuals among the naturally spawning mainstem populations. Further information on methods and CDFG analysis specific to mainstem Trinity River carcass surveys are available from CDFG annual reports (Sinnen 2004, Knechtle and Sinnen 2006, Hill 2009, Hill 2010).

For our purposes, we define a 'hatchery origin' fish as one that was born in the hatchery, and a 'natural origin' fish as one that was born from a redd constructed in stream gravels. We used encounters with spawned female salmon carcasses to model spatiotemporal distribution of Chinook salmon (hatchery and natural origin) proportions and applied those to observed redds. The behavioral differences of spawning male and female salmon result in highly disparate utility of the carcasses of each sex for inferring spatial distribution of redd construction by species or origin. Typical spawning behavior of a female salmon is to dig a pit in the gravel, deposit eggs as they're fertilized by one or more males, bury the eggs, and continue to deposit 'pockets' of eggs until spent (Burner 1951). Once she has completed her redd, the female typically guards the nest until her body deteriorates to the point she can no longer maintain position in the river and she dies. The carcass of a female salmon is typically recovered fairly close (within a km) of the redd she constructed due to this behavior (Glock et al 1980, Cederholm et al 1989, Riggers et al 1999, Murdoch et al 2009b, this report). Male salmon on the other hand can spawn with multiple females, sometimes on redds several kilometers apart. Males do not exhibit nest guarding behavior and their carcasses are frequently recovered several kilometers away from their original spawning location(s) (Murdoch et al 2009b).

The spatial and temporal expression of spawned female salmon carcass data is a function of redd location, time from redd construction to subsequent death, and distance of drift. Therefore, the composition of recovered carcasses (by species and origin) informs estimates of the construction of redds by species and origin some distance upstream (spatial offset), and some number of days previous (temporal offset). Observations of long distance drift (several kilometers) and/or time between redd construction and death (several days) would compel adjustments to model output in terms of spatial and/or temporal offset to effectively use the model for informing the composition of redds by species or origin.

To examine the need to spatially offset our carcass data to inform redd composition, we evaluated drift from 163 carcass mark and recovery records from 2009 and 76 records from 2010. Carcass movement between 2009 mark and recapture events ranged from 15 m in an upstream direction (eddy), to a maximum of 5,444 m downstream. The mean and median total drift between mark and recovery of carcasses in 2009 were 391 and 134 m downstream respectively (standard deviation 688.8). Carcass movement between 2010 mark and recapture events ranged from 23 m in an upstream direction (eddy), to a maximum of 30,169 m downstream. The second largest drift observation in 2010 was 3,765 m downstream. With the extreme outlier removed, the mean and median total drift between mark and recovery of carcasses were 433 and 134 m downstream respectively (standard deviation 764.5). For 2009 and 2010 respectively, 79% and 75% of the recaptured carcasses were recovered less than 0.5 km from their release point. Based on these observations, we decided not to incorporate a spatial offset into our proportion estimates for redd numbers by carcass species or mark class.

A review of survey life estimates (length of time from occupancy of redd location to death) conducted by Perrin and Irvine (1990) revealed averages of 11.4 days for coho salmon and 12.1 days for Chinook salmon. Our survey intervals were weekly rather than daily and we decided to apply a two week temporal lag to our carcass data for informing redd composition by species or origin which appears to be a reasonable approximation.

To standardize temporally across years, we designated September 1 of each year as 'survey day 1'. The date of collection (survey day) and location (distance from dam) were used as independent variables in generalized additive models (GAM's) to estimate proportion of each species and mark class of interest (Equation 1). Spline smooths with 3 degrees of freedom were used for both independent variables in program R (Wood 2004, R Development Core Team 2009) and the 'response' was predicted at regular spatial and temporal intervals that enveloped the study area and season.

For years 2002 to 2008, the maximum spatial resolution recorded for carcass data was at the logistic reach level. For those years, distance from Lewiston Dam to the midpoint of each reach was used as spatial input to the GAM for generating proportion estimates. For the years 2009 and later, GIS coordinates of each carcass recovery location were recorded with a GPS unit. Those records were "snapped" to the river centerline and distance from Lewiston Dam was determined by creating route events in ArcMap (ESRI 2008).

Chinook salmon females each typically construct a single redd while wild coho salmon females may each construct many redds (Laufle et al 1986, Gallagher and Gallagher 2005, Murdoch et al 2009a, Gallagher et al 2010). Based on previous work of Gallagher (2003) in unregulated northern California coastal streams, Duffy (2005) recommends the assumption of 1.0 redd per female Chinook salmon, and 1.25 redds per female coho salmon for the purposes of estimating escapement from redd counts in California waters. We employed a multiplier to account for these differential rates of redd construction between the Chinook and coho salmon carcasses recovered in our survey (Equation 2).

Equation 1. Binomial model construction for generalized additive model (GAM) estimation of carcass proportion by species or mark condition (hatchery marked or unmarked) among all spawned female salmon.

$$\hat{p} \sim s(DFD, 3) + s(Survey\ Day, 3)$$

Where $\hat{p}$ =	Estimated proportion of species/mark condition of interest
$s(DFD, 3)$ =	distance from Lewiston Dam in kilometers (spline smoothed with 3 df)
$s(Survey\ Day, 3)$ =	Day of survey (spline smoothed with 3 df)

Equation 2. Chinook salmon redd multiplier to account for differential rates of redd construction between Chinook and coho salmon females.

$$\text{Chinook redd multiplier} = \frac{\hat{p}_{\,Chinook\ female}}{\hat{p}_{\,Chinook\ female} + \left(\hat{p}_{\,coho\ female} \times 1.25\ {coho\ redds}/{female}\right)}$$

Where $\hat{p}$ = Proportions estimated from GAM model output (Equation 1).

The composition of 3 to 5 year old fall Chinook salmon observed at Trinity River Hatchery (gleaned from Klamath River Technical Advisory Team [KRTAT] reports 2003 through 2012) was assumed to approximate the age composition of female hatchery Chinook salmon straying to and spawning in the river. A weighted hatchery mark rate was calculated for each spawning year utilizing the adipose clipped rates of Trinity River Hatchery fish released in the brood years represented in each year's return to the Hatchery (mark rates from Eric Logan, Hoopa Valley Tribe, personal communication). These weighted hatchery mark rates were utilized to expand for estimated hatchery component using the proportion of hatchery marks among Chinook salmon females recovered in our concurrent carcass survey.

Spatiotemporal distribution

Redd data were binned into segments and arranged cumulatively. Segment boundaries were placed at the start and end of each logistic reach, at regular 5 km intervals, and at the up and downstream ends of all rehabilitation sites constructed through the period of this survey. 'Zero' redd counts were added to the beginning and end of the season at bins where zero counts were not encountered on the first or last survey to 'bound' the data for interpolation purposes. The cumulative number of redds for each survey day was then estimated using monotonic cubic Hermite spline interpolation in program R (R Development Core Team 2009). The number of redds constructed daily was in turn estimated from these interpolated data by subtracting the cumulative redd total of survey day *i* from survey day *i*+1.

To estimate the number of redds attributable to Chinook or coho salmon, and the number attributable to hatchery or natural origin Chinook salmon, generalized additive model results of the carcass data estimating spatiotemporal proportions of each (discussed earlier) were applied to the interpolated redd estimates. A 14 day offset was applied such that the predicted ratios expressed by carcasses on day *i* was used to apportion the redds on day *i - 14*. Season totals were calculated by summing the predictions across all bins and days. A bootstrap routine in program R was applied with 1,000 replications of the prediction for total redd numbers by natural origin Chinook salmon females, and the 2.5 and 97.5 percentiles were returned as 95% confidence intervals (Davison and Hinkley 1997, Canty and Ripley 2009, R Development Core Team 2009). We tested for trend in redd abundance for natural origin Chinook salmon and hatchery origin Chinook salmon across 2002 to 2011 using simple linear regression.

We employed linear models to look for evidence of two social interactions that might influence longitudinal distribution of spawning Chinook salmon. First, if salmon 'fill' available spawning habitats near Lewiston Dam and discourage new arrivals through territorial behavior or defense of redds, new arrivals might be pushed downstream, especially in years with relatively high abundance. We looked for a relationship between mean distance from Lewiston Dam and total number of Chinook salmon redds (hatchery and natural origin pooled) from Lewiston Dam to North Fork Trinity River.

Second, if spawning activity and/or high densities of spawning salmon exert attraction to incoming fish preparing to spawn, disproportionate to the influence of habitat suitability or fidelity to natal birth place, then years with especially high occurrence of hatchery strays might 'draw' more natural origin fish upriver where hatchery strays tend to concentrate. We tested for a relationship between mean distance of natural origin Chinook salmon redds from Lewiston Dam and total estimated number of hatchery origin Chinook salmon redds from Lewiston Dam to North Fork Trinity River. Each redd observation was weighted by its associated probability of construction by a natural origin Chinook salmon female (as estimated from GAM of the carcass data).

We looked for a trend in the distance that natural origin Chinook salmon constructed redds from Lewiston Dam by employing a linear model to test for change in mean distance across years within the TRRP rehabilitation reach (Lewiston Dam to North Fork Trinity). We used a linear model to test for trend in the mean distance from Lewiston Dam expressed across years 2002 to 2010. We repeated this analysis to look for trend in mean distance from Lewiston Dam of redds constructed by hatchery origin fish.

Stream power, hydrology, sediment input and alluvial potential of the mainstem varies longitudinally from Lewiston Dam to the North Fork Trinity River with tributary input, variable valley confinement etc. (Hoopa Valley Tribe et al 2011). The rate with which the river morphology responds to TRRP mechanical rehabilitation actions and the ultimate magnitude of those responses should likewise vary longitudinally. Hoopa Valley Tribe et al (2011) delineates five channel rehabilitation reaches for the TRRP within the mainstem upstream of North Fork Trinity River (Table 2). We calculated abundances and compare relative densities of natural origin Chinook salmon redds within each channel rehabilitation reach.

We determined the upstream and downstream boundaries of each rehabilitation site (Table 3), and queried our data for redds occurring within each to assess the response of spawning distribution to mechanical rehabilitation over the course of this study (2002 to 2011). Using the calculated abundance of natural origin Chinook salmon redds within each rehabilitation reach, we determined the proportion of those redds occurring in each rehabilitation site and plotted those against year for an initial visual indicator of construction's long term influence on longitudinal distribution within a rehabilitation reach.

Table 2. Rehabilitation reaches of the Trinity River Restoration Program (from Hoopa Valley Tribe et al 2011).

Rehabilitation reach	Extent
Lewiston	Lewiston Dam to Rush Creek (rkm 0.0 to 6.89)
Limekiln	Rush Creek to Indian Creek (rkm 6.89 to 26.65)
Douglas City	Indian Creek to Browns Creek (rkm 26.65 to 38.95)
Junction City	Browns Creek to Canyon Creek (rkm 38.95 to 59.91)
North Fork	Canyon Creek to North Fork Trinity River (rkm 59.91 to 63.80)

For each year, we determined linear density by calculating the number of natural origin Chinook salmon redds within 150 meters up or downstream at 10 meter intervals from Lewiston Dam to North Fork Trinity River. Plots of these were generated for all years to look for consistency in high density spawning locations.

RESULTS

Over the survey years 2002 through 2011, we documented the locations of 52,200 mainstem Trinity River salmon redds and collected 31,549 spawned female salmon carcass records to inform redd composition by species or origin (Appendix A). The highest number of redds (7,441) over this period was observed in 2003, though a large portion of those (31%) were estimated to be constructed by hatchery origin Chinook salmon females. Hatchery origin Chinook salmon females accounted for as much as 36% of all yearly Chinook salmon redds (2004) and as little as 9% (2009; Table 4, Table 5). The focus of this report is on Chinook salmon but coho salmon accounted for anywhere from 1% (2003) to 22% (2004) of salmon redds observed during the Chinook salmon spawning season.

Table 3. List of rehabilitation sites constructed in the Trinity River over the period covered by this report (2002 to 2011).

Rehabilitation reach (from Hoopa Valley Tribe et al 2011)	Site name	Distance (km) from Lewiston Dam to midpoint	Site length (km)	Year constructed
Lewiston	Lewiston Hatchery	0.43	0.55	2006
	Sven Olbertson	1.30	0.60	2008
	Deadwood Creek	2.35	0.20	2008
	Cableway	2.88	0.65	2008
	Hoadley Gulch	3.45	0.30	2008
	Sawmill	4.53	1.05	2009
Limekiln	Dark Gulch	9.58	2.35	2008
	Lowden Ranch	11.93	1.22	2010
	Trinity House Gulch	12.85	0.40	2010
	Vitzthum Gulch	25.30	1.20	2007
Douglas City	Indian Creek	28.00	2.60	2007
	Reading Creek	31.27	1.57	2010
North Fork	Hocker Flat	53.80	1.60	2005
	Conner Creek	56.20	0.70	2006
	Wheelhouse Gulch	57.86	0.43	2011
	Valdor Gulch	59.43	1.45	2006
	Elkhorn	61.38	0.95	2006
	Pear Tree Gulch	62.85	0.30	2006

Note: At the time of this report, no sites had yet been constructed in the Junction City rehabilitation reach.

Table 4. Redd numbers from Lewiston Dam to Cedar Flat (Reaches 1 to 10). Total redds observed, those constructed by Chinook salmon, by hatchery origin Chinook salmon females, and by natural origin Chinook salmon females with bootstrap generated confidence bounds for natural origin estimates.

Year	All salmon redds	Chinook salmon redds (any origin)	Hatchery origin Chinook salmon redds	Natural origin Chinook salmon redds (and 95% confidence bounds)	
2002	5,232	4,569.6	1,226.5	3,343.1	(3,128 to 3,570)
2003	7,085	6,979.1	2,269.4	4,709.5	(4,534 to 4,888)
2004	5,128	3,808.0	1,668.6	2,139.3	(1,902 to 2,310)
2005	4,046	3,110.6	1,275.9	1,834.7	(1,608 to 2,039)
2006	4,326	3,686.8	1,220.6	2,466.2	(2,258 to 2,707)
2007	5,199	5,058.2	1,053.2	4,004.9	(3,806 to 4,191)
2008	3,371	2,927.1	467.1	2,459.9	(2,286 to 2,570)
2009	3,629	3,496.1	350.0	3,146.1	(3,046 to 3,248)
2010	3,784	3,238.9	469.0	2,769.8	(2,627 to 2,917)
2011	5,447	5,321.4	1,059.0	4,262.3	(4,140 to 4,393)

Table 5. Redd numbers from Hawkins Bar to Weitchpec (Reaches 12 to 14). Total redds observed, those constructed by Chinook salmon, by hatchery origin Chinook salmon females, and by natural origin Chinook salmon females with bootstrap generated confidence bounds for natural origin estimates.

Year	All salmon redds	Chinook salmon redds (all)	Hatchery origin Chinook salmon redds	Natural origin Chinook salmon redds (and 95% confidence bounds)	
2002 [a]	270	270	0	270	[c]
2003 [a]	356	356	0	356	[c]
2004 [a]	892	892	0	892	[c]
2005 [a]	414	414	0	414	[c]
2006 [a]	374	374	0	374	[c]
2007 [b]	68	68	0	68	[c]
2008	745	745	0	745	[c]
2009 [b]	533	533	0	533	[c]
2010 [b]	238	212.4	0	212.4	(115 to 238)
2011 [b]	1,063	1,049.6	0	1,049.6	(627 to 1,063)

[a] Reach 12 – 14 data prior to 2007 maintained and reported by Hoopa Valley Tribe
[b] Survey season cut short by winter storms and turbidity
[c] Bootstrapping not performed when no female coho salmon or hatchery marked female Chinook salmon were among carcasses recovered

Within the mainstem Trinity TRRP restoration area (Lewiston Dam to North Fork Trinity) over the years 2002 through 2011, the number of redds constructed by natural origin Chinook salmon was highly variable and we did not observe a detectable trend (adjusted $r^2 = -0.12$, df = 8, p = 0.929). In contrast, there was a significant negative trend in number of redds constructed by hatchery origin females over the same period (adjusted $r^2 = 0.47$, df = 8, p = 0.018: Figure 4). Estimates of redds constructed by hatchery origin females were especially low over the years 2008 to 2010.

The mean distance from Lewiston Dam that Chinook salmon constructed redds each year exhibited no apparent relationship to the total number of Chinook salmon redds from Lewiston Dam to the North Fork Trinity River (adjusted $r^2 = -0.05$, df = 8, p = 0.461; Figure 5). There appeared to be a slight negative relationship between the number of hatchery origin Chinook salmon redds and the distance that natural origin Chinook salmon constructed redds from Lewiston Dam (adjusted $r^2 = 0.19$, df = 8, p = 0.116). This may be confounded by a downstream trend in the distribution of natural origin redds over time (discussed below) and a relatively low incidence of hatchery strays on natural spawning grounds over three years clustered near the end of the period covered by this report (2008, 2009, and 2010; Figure 4, Figure 6).

We observed a moderately positive trend in the mean distance from Lewiston Dam of redds estimated to be constructed by natural origin Chinook salmon females in the portion of river from Lewiston Dam to North Fork Trinity River over the period 2002 to 2011 (adjusted $r^2 = 0.17$, df = 8, p = 0.133). There was not a corresponding downstream trend in redds constructed by hatchery origin Chinook salmon females (adjusted $r^2 = -0.05$, df = 8, p = 0.461) (Figure 7).

There was a strong gradient in the reach-level density of redds, dominated by the especially high densities observed in the Lewiston Rehabilitation Reach (Figure 8 and Figure 9). Hatchery origin Chinook salmon contributed most to the redds constructed in the Lewiston Reach (Figure 10). There was no apparent trend in the proportion of redds observed within the up and downstream boundaries of rehabilitation sites (Figure 11 to Figure 14). While magnitudes of longitudinal density varied greatly, high density hotspots remained consistent year to year with rare exception (Figure 15 to Figure 23).

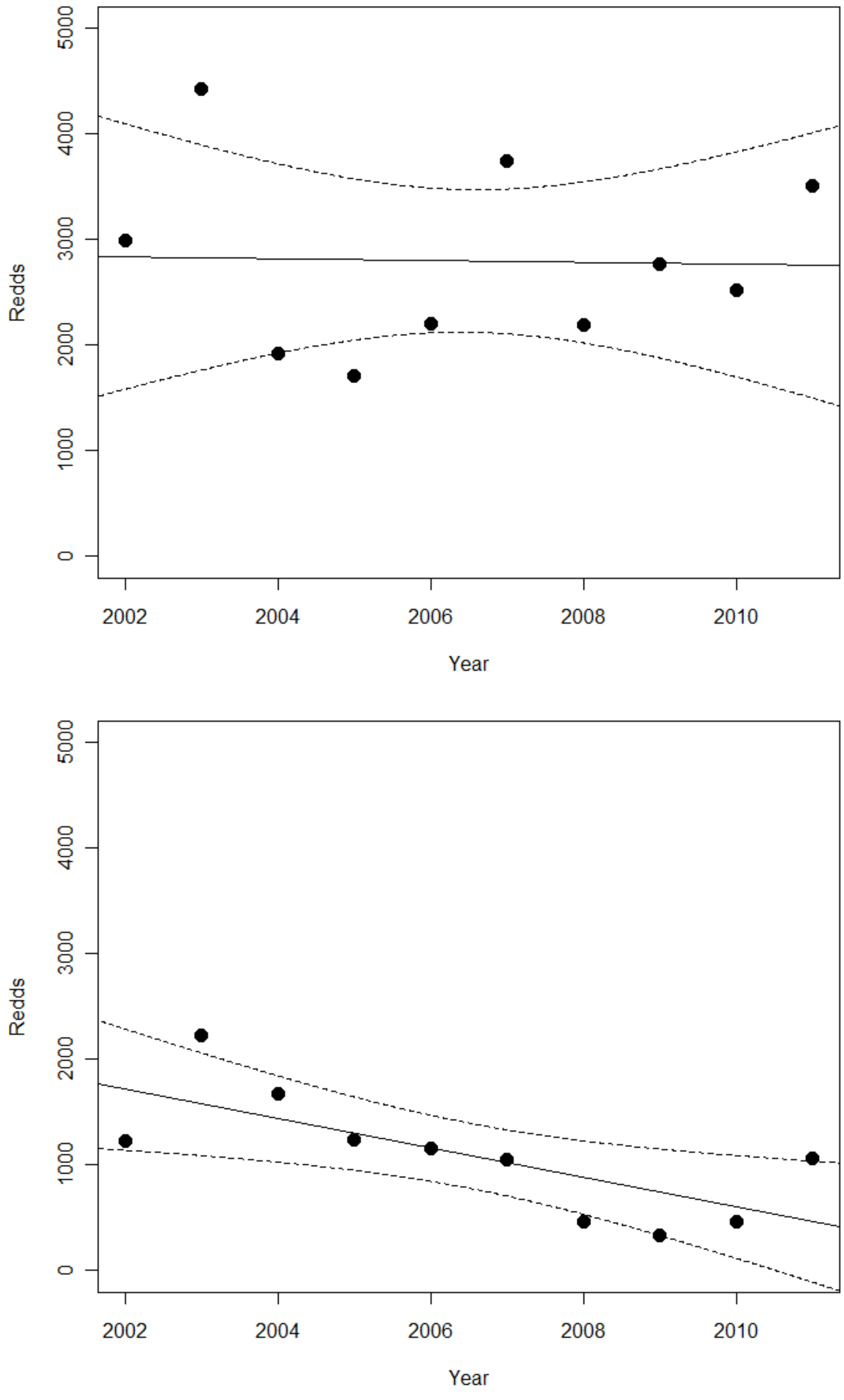

Figure 4. Estimated number of redds constructed by natural origin Chinook salmon females (top) and hatchery origin Chinook salmon females (bottom) Lewiston Dam to North Fork Trinity River. Solid and dashed lines equal regression and 95% confidence limits.

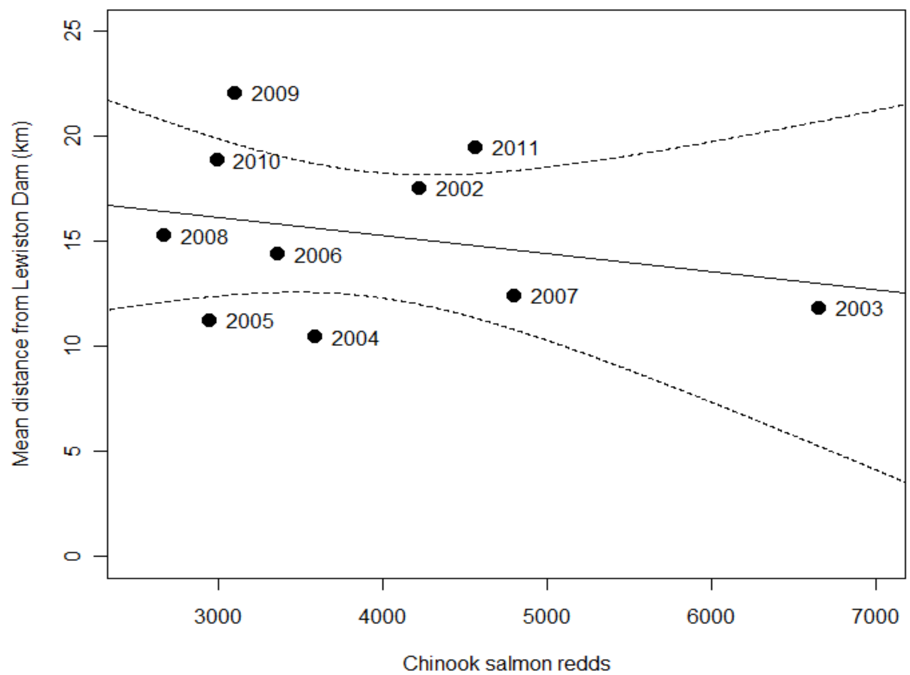

Figure 5. Mean distance from Lewiston Dam of Chinook salmon redds in relation to total number of Chinook salmon redds. Solid and dashed lines equal regression and 95% confidence limits.

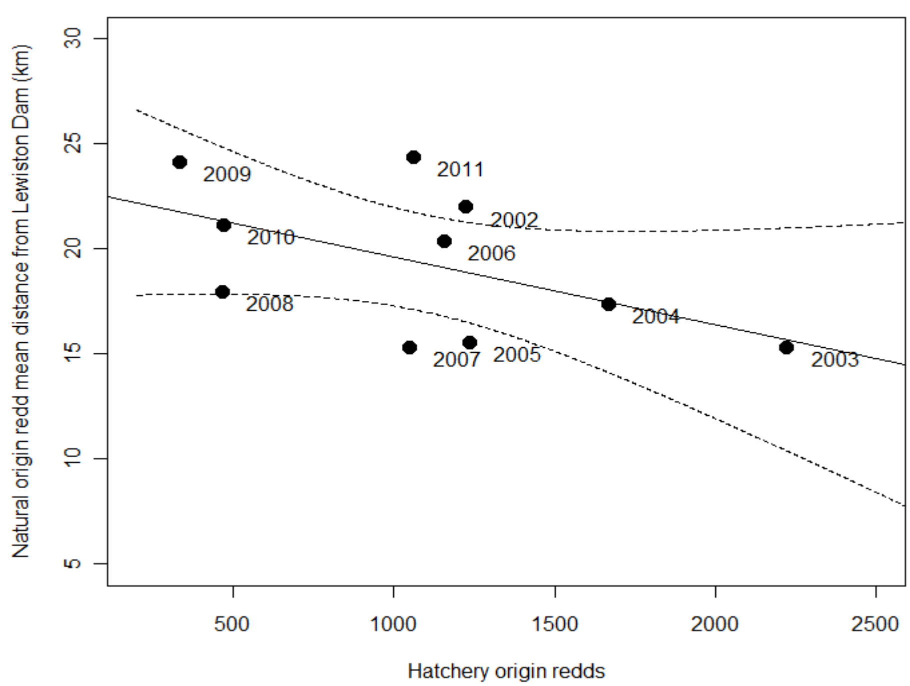

Figure 6. Mean distance from Lewiston Dam of redds constructed by natural origin Chinook salmon females in relation to total number of redds constructed by hatchery origin Chinook salmon females. Solid and dashed lines equal regression and 95% confidence limits.

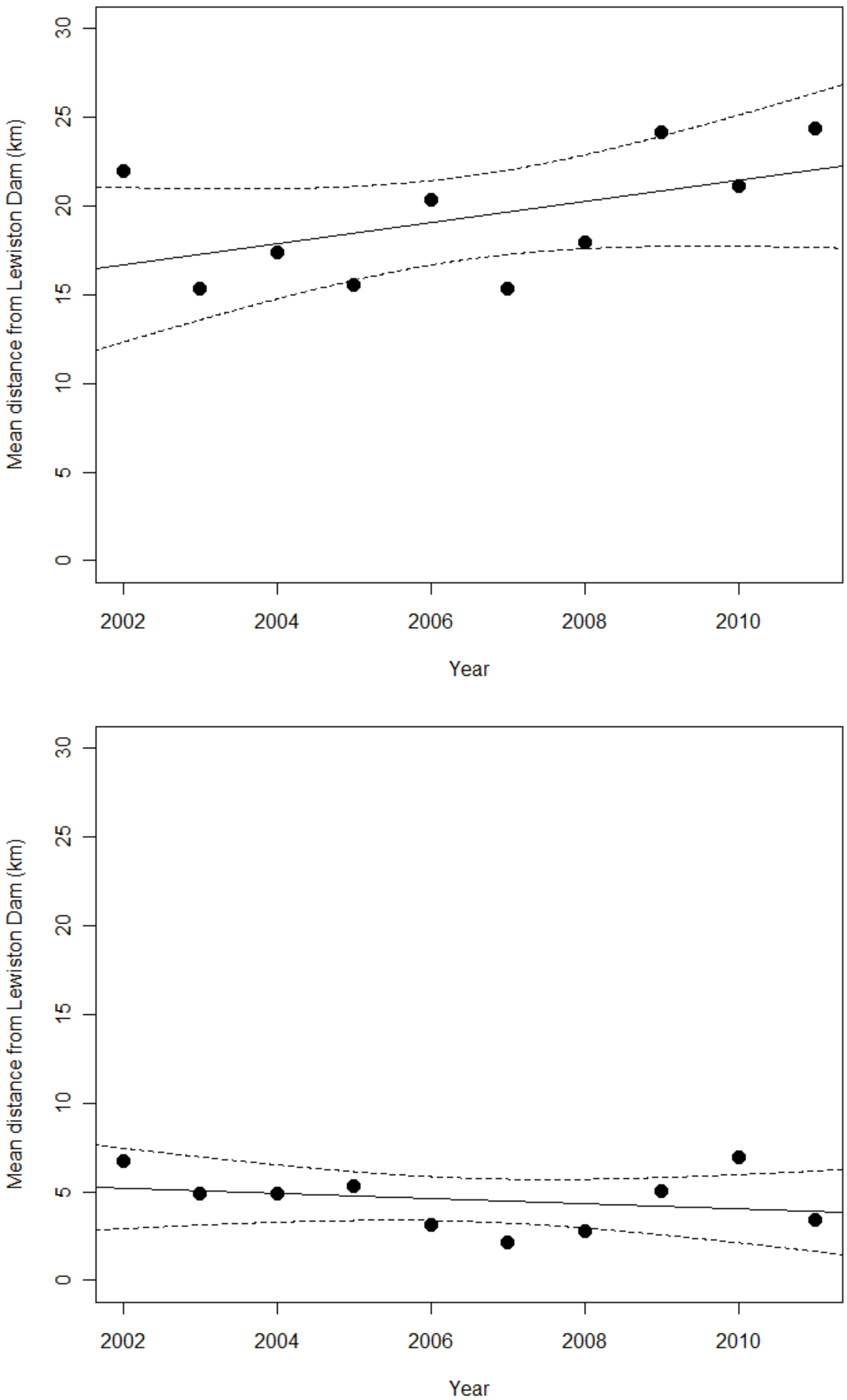

Figure 7. Mean distance from Lewiston Dam of redds constructed by natural origin Chinook salmon females (top) and hatchery origin Chinook salmon females (bottom) Solid and dashed lines equal regression and 95% confidence limits.

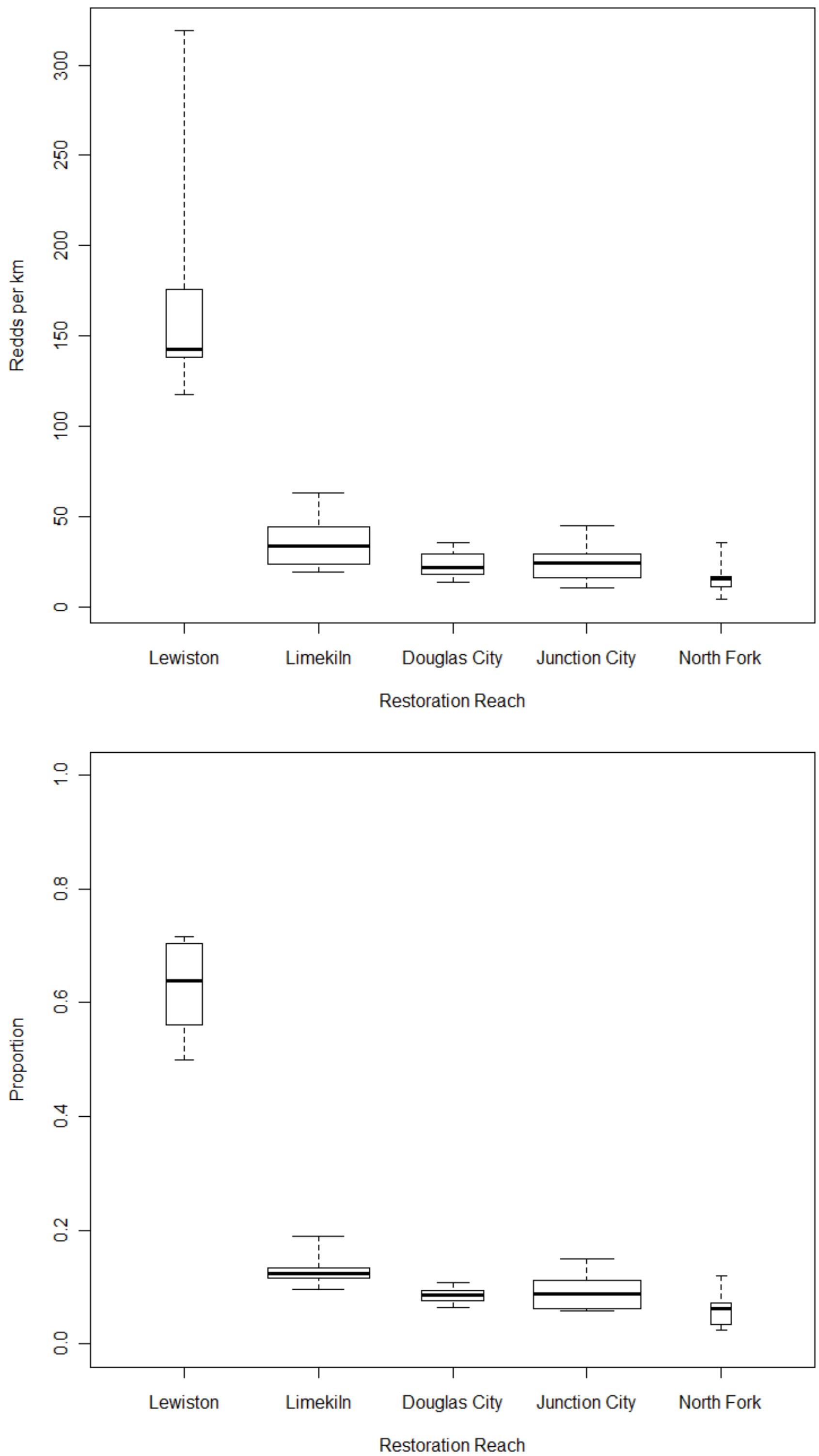

Figure 8. Linear density of redds (redds/km) constructed by natural origin Chinook salmon females (top) and the proportion of the 'natural origin' redds occurring within each Trinity River Restoration Program restoration reach (bottom) 2002 to 2011. Thick line = median, box = interquartile range, whiskers = total range of observation. Width of box proportional to reach length.

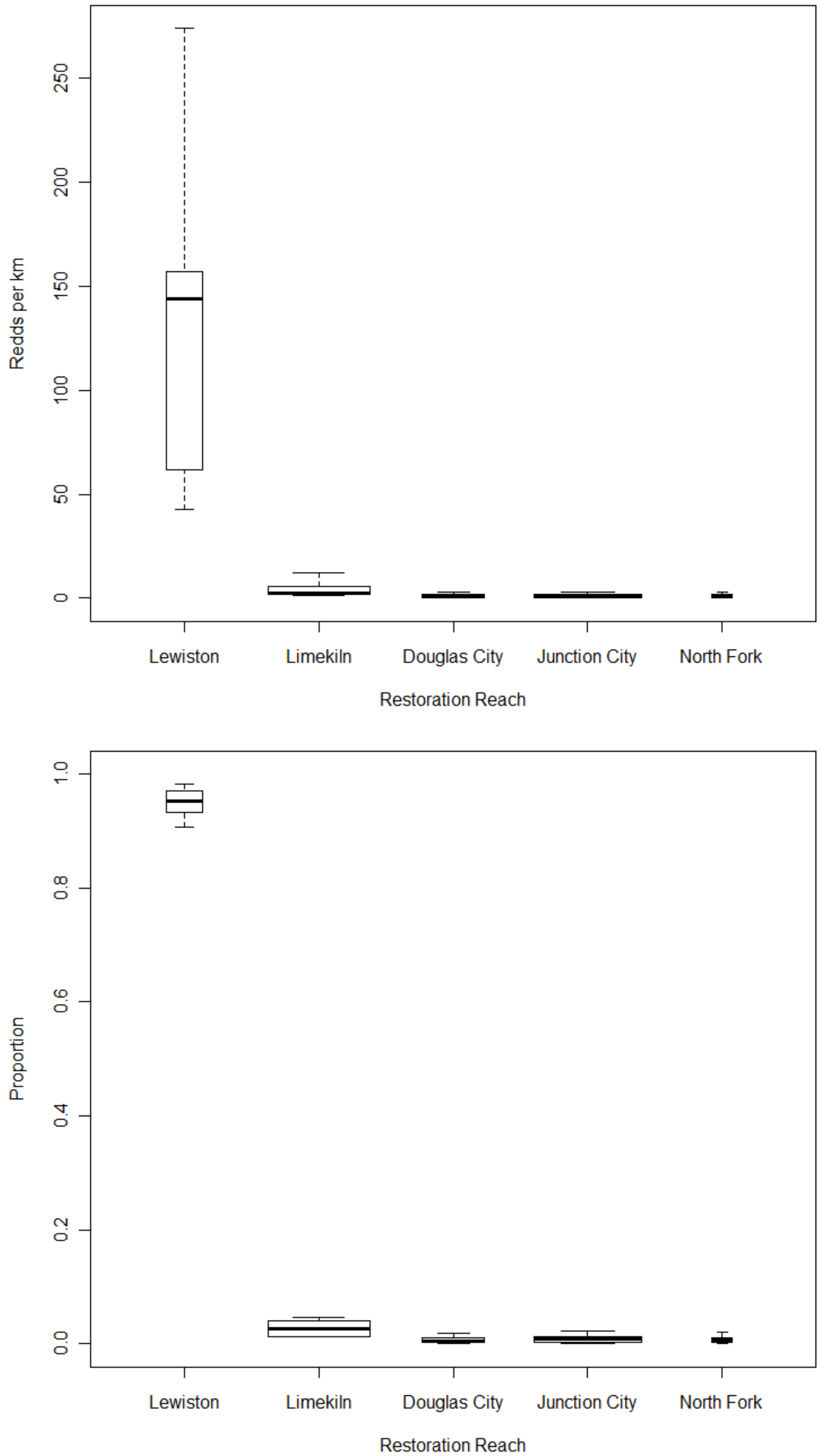

Figure 9. Linear density of redds (redds/km) constructed by hatchery origin Chinook salmon females (top) and the proportion of the 'hatchery origin' redds occurring within each restoration reach (bottom) 2002 to 2011. Thick line = median, box = interquartile range, whiskers = total range of observation. Width of box proportional to reach length.

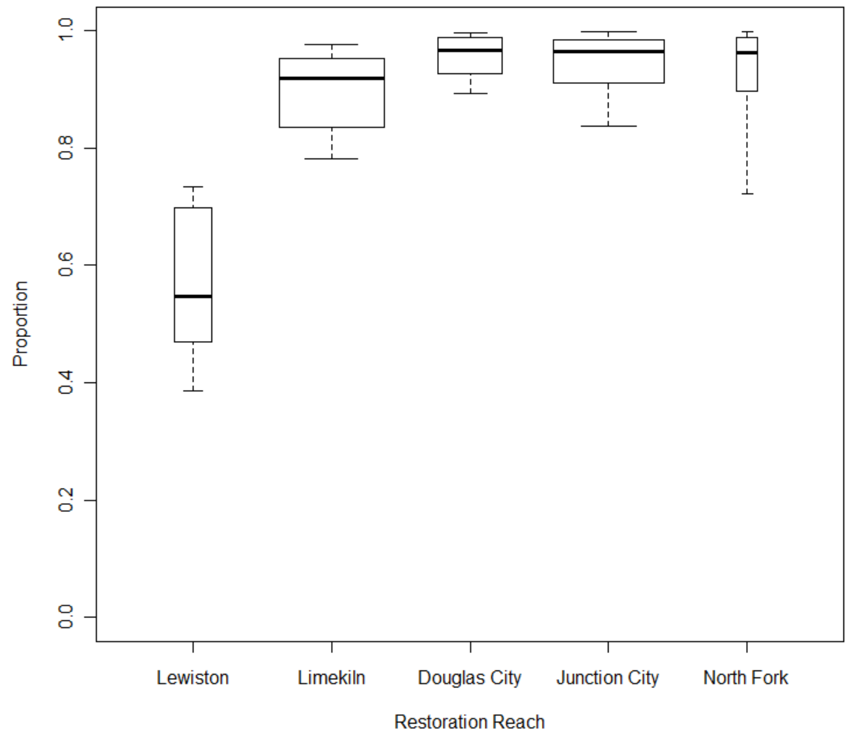

Figure 10. Proportion of the Chinook salmon redds within each restoration reach estimated to be constructed by natural origin females 2002 to 2011. Thick line = median, box = interquartile range, whiskers = total range of observation. Width of box proportional to reach length.

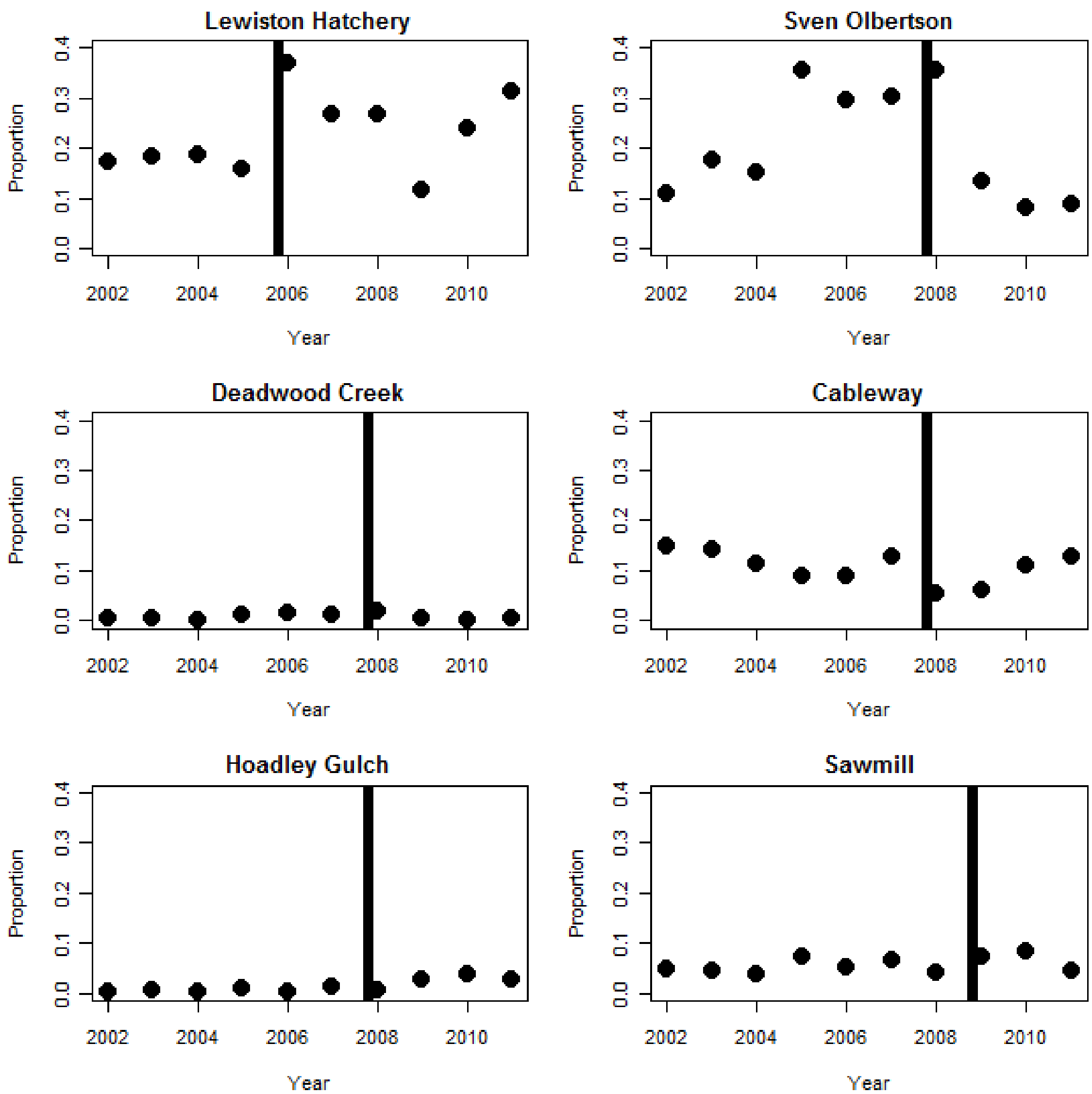

Figure 11. Proportion of Lewiston Channel Rehabilitation Reach (Lewiston Dam to Rush Creek) Chinook salmon redds occurring within each Rehabilitation site. Vertical bar indicates construction year.

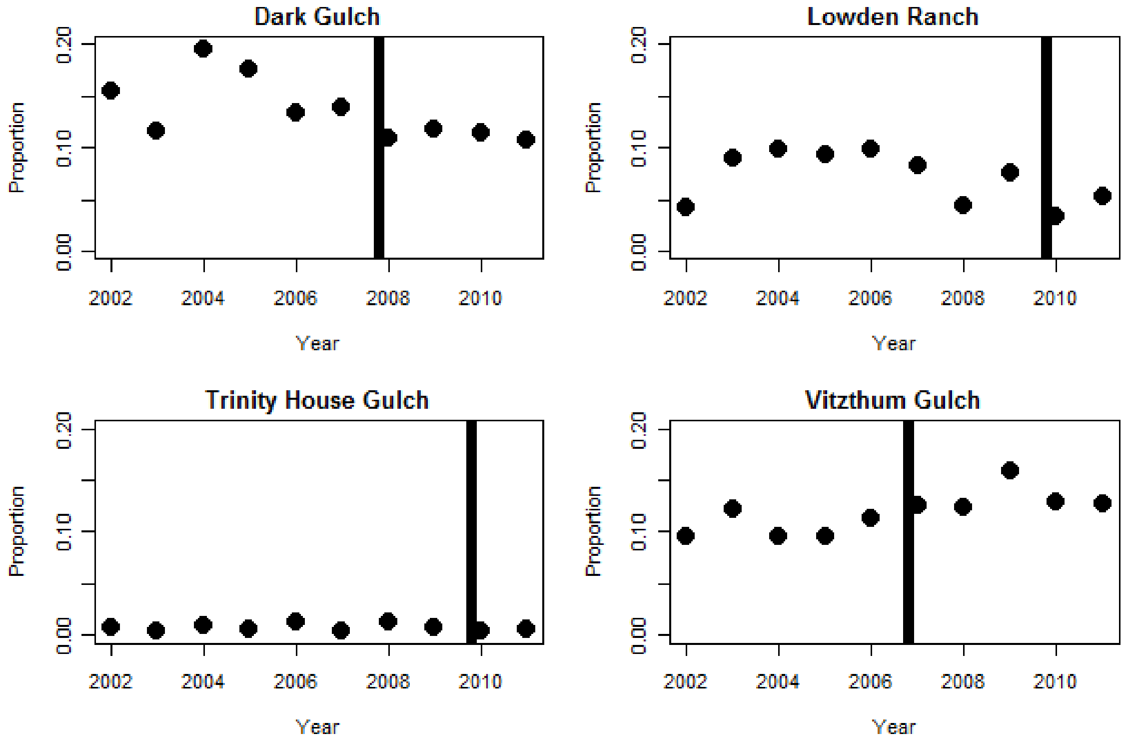

Figure 12. Proportion of Limekiln Gulch Channel Rehabilitation Reach (Rush Creek to Indian Creek) Chinook salmon redds occurring within each Rehabilitation site. Vertical bar indicates construction year.

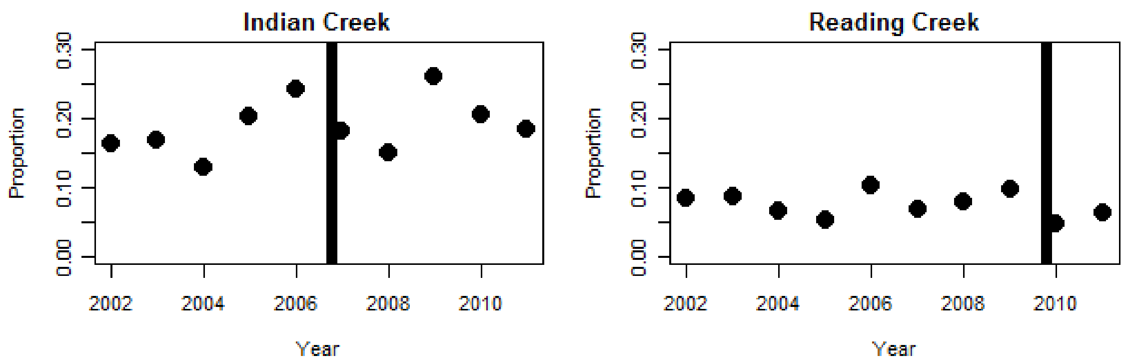

Figure 13. Proportion of Douglas City Channel Rehabilitation Reach (Indian Creek to Browns Creek) Chinook salmon redds occurring within each Rehabilitation site. Vertical bar indicates construction year.

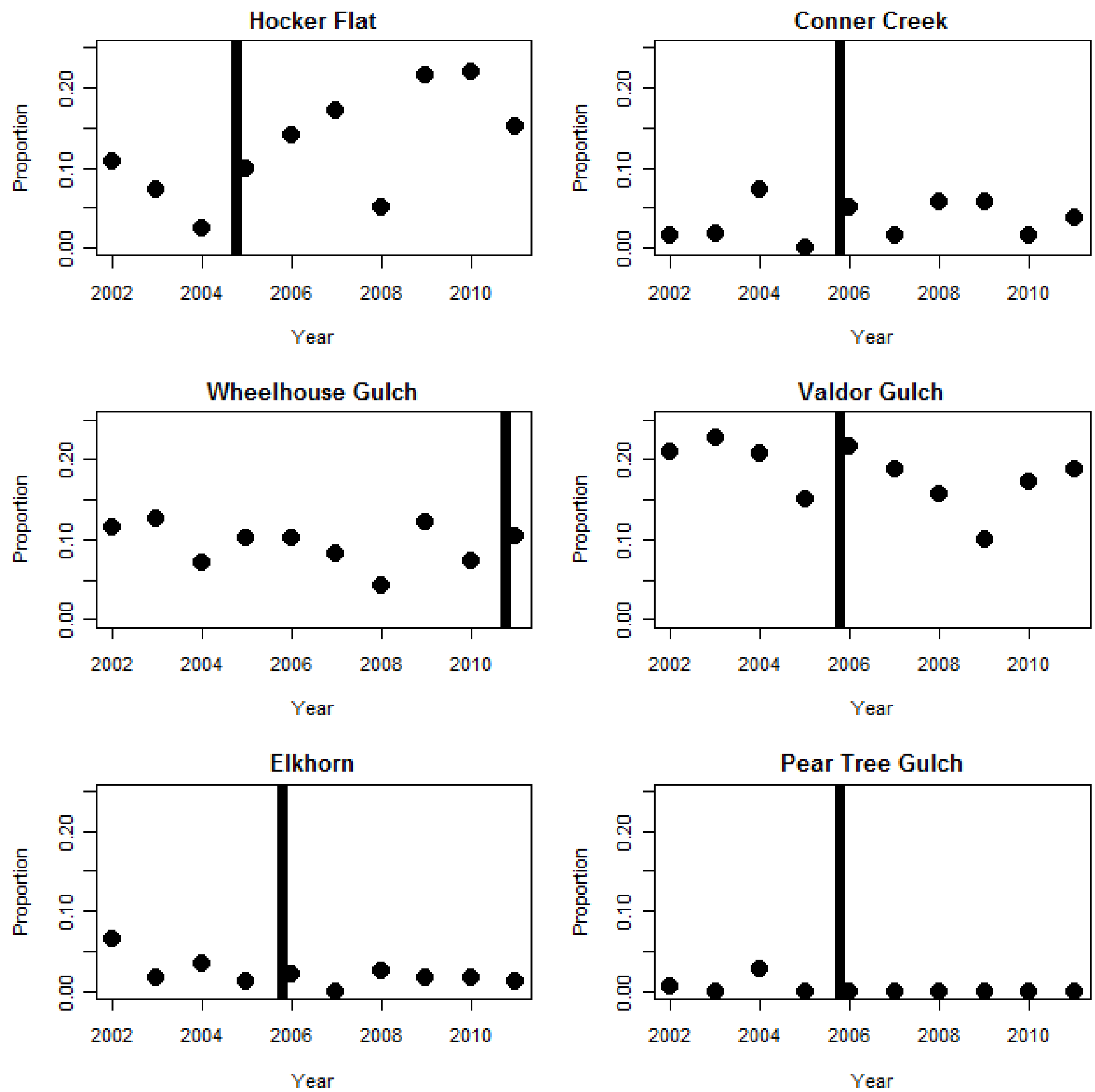

Figure 14. Proportion of North Fork Channel Rehabilitation Reach (Canyon Creek to North Fork Trinity River) Chinook salmon redds occurring within each Rehabilitation site. Vertical bar indicates construction year.

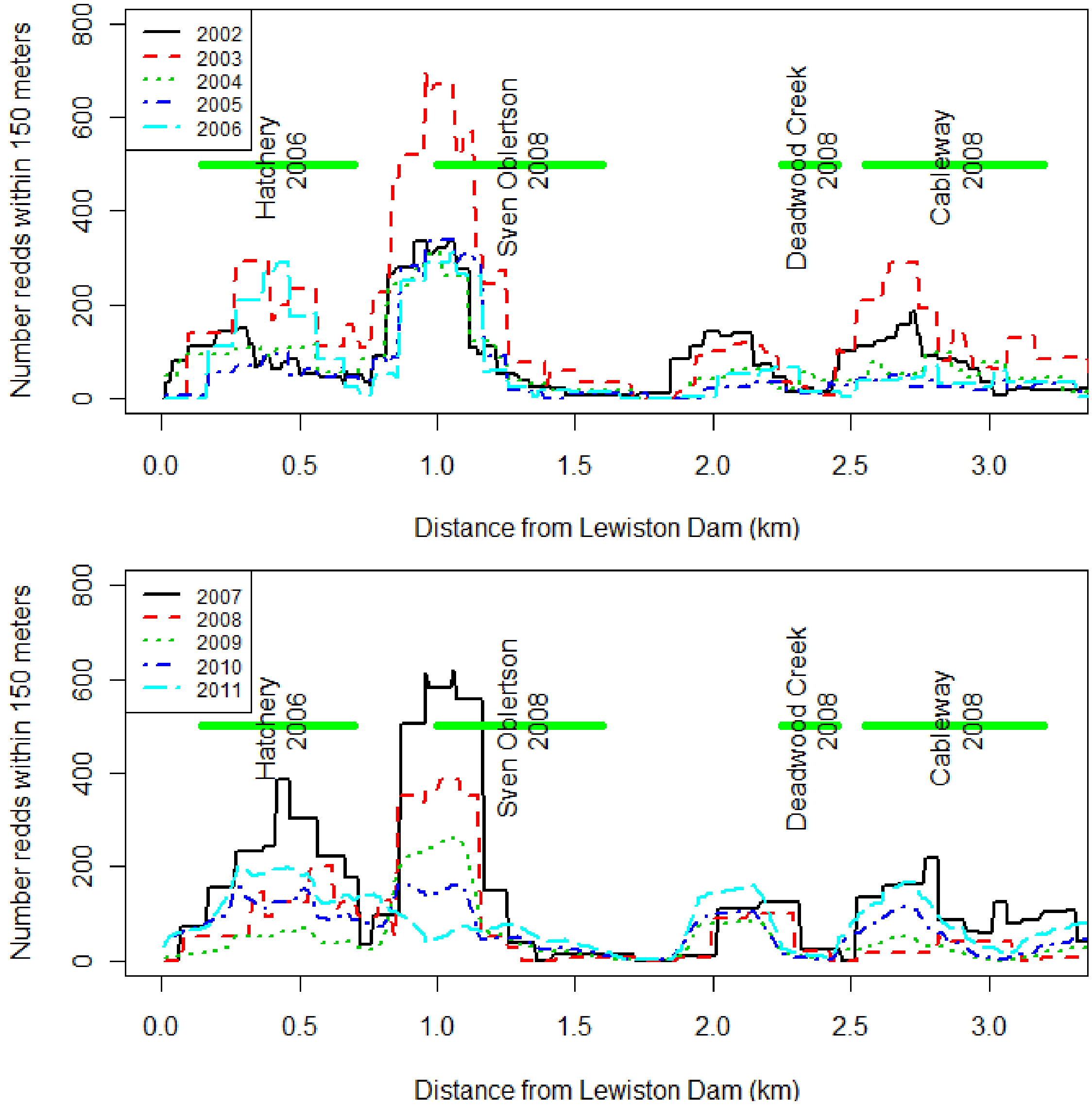

Figure 15. Density (redds/300m) of natural origin Chinook salmon redds Lewiston Dam to Old Bridge. Horizontal bars show location of channel rehabilitation sites.

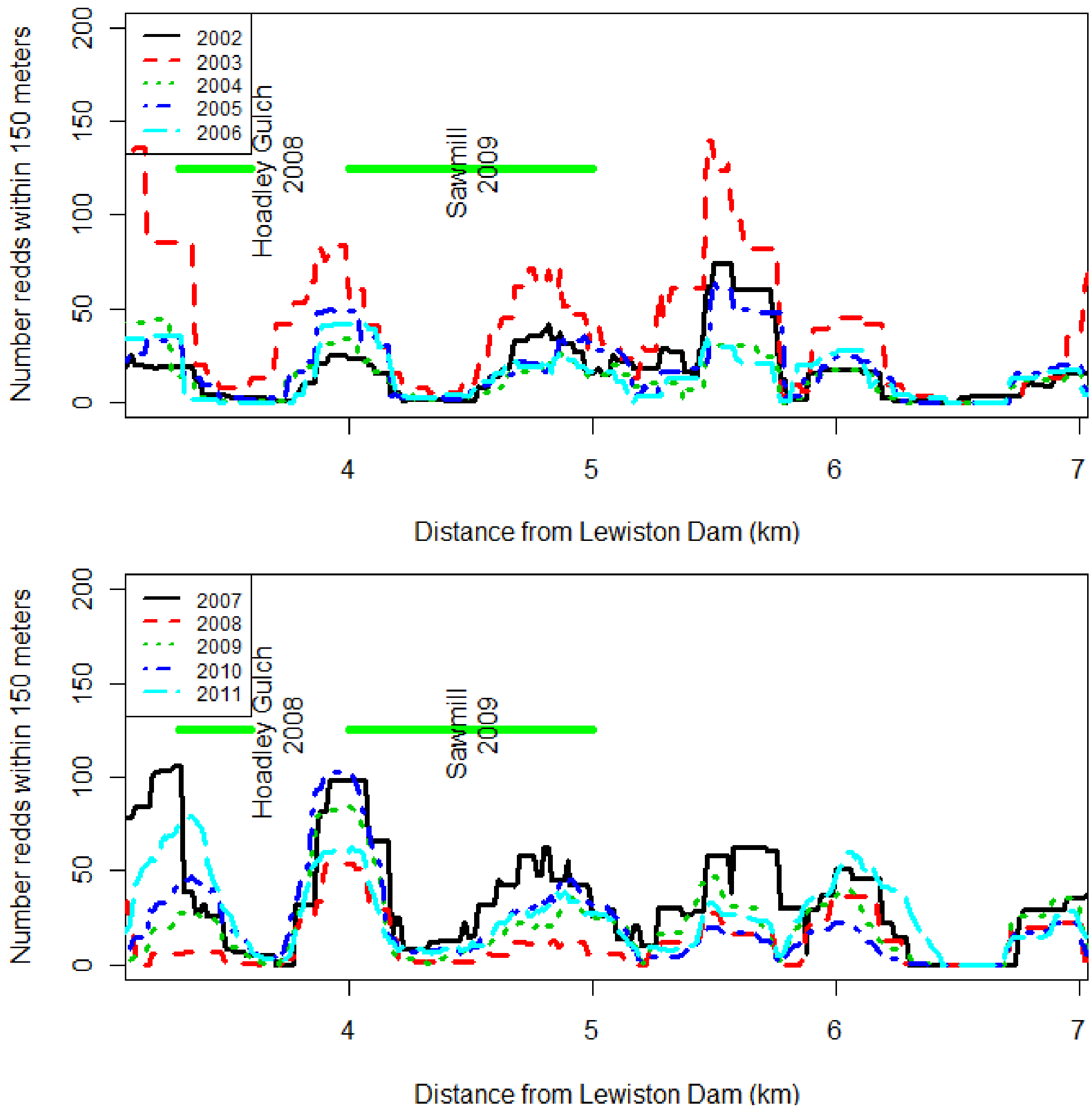

Figure 16. Density (redds/300m) of natural origin Chinook salmon redds Old Bridge to Rush Creek. Horizontal bars show location of channel rehabilitation sites.

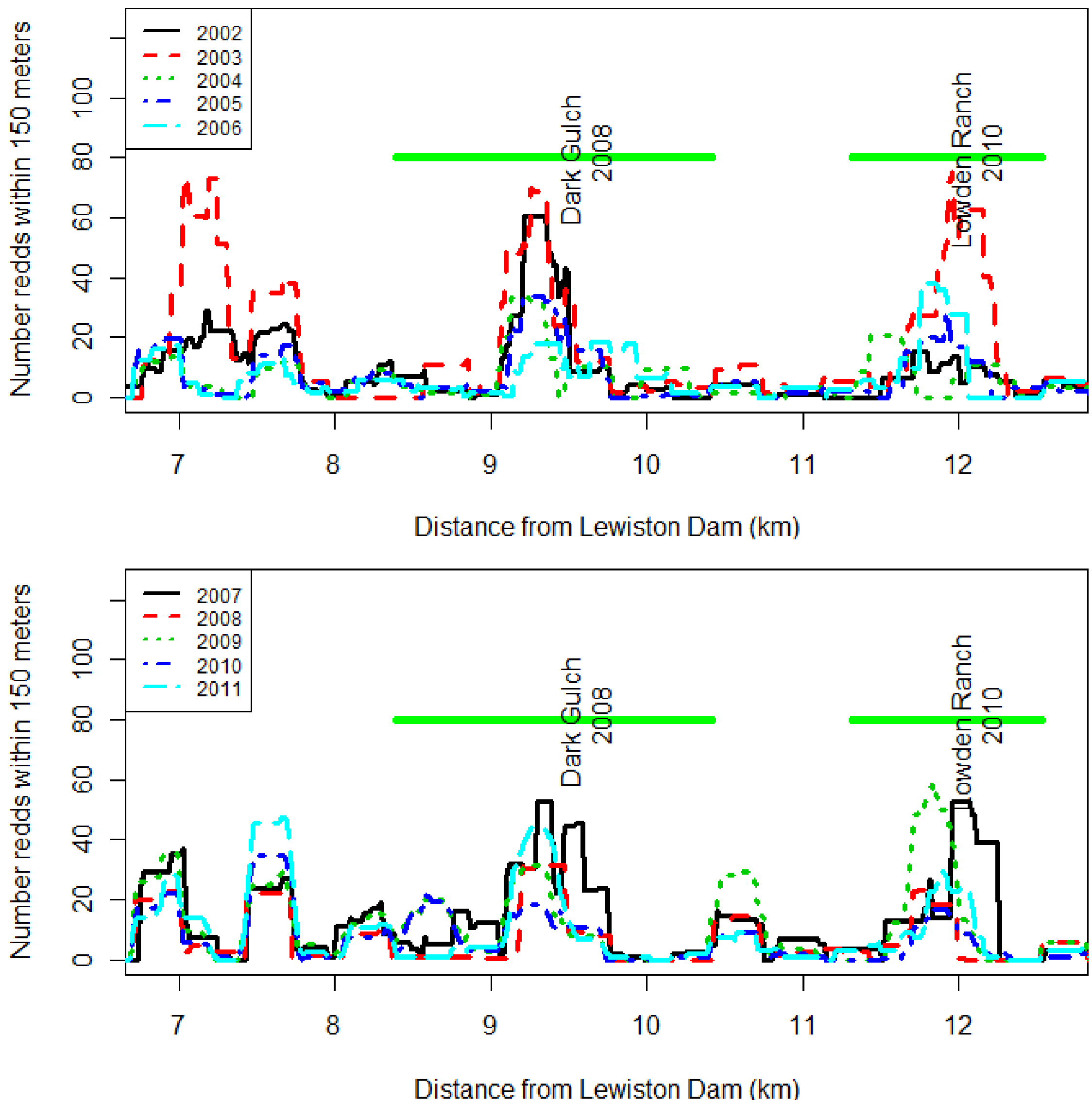

Figure 17. Density (redds/300m) of natural origin Chinook salmon redds Rush Creek to Grass Valley Creek. Horizontal bars show location of channel rehabilitation sites.

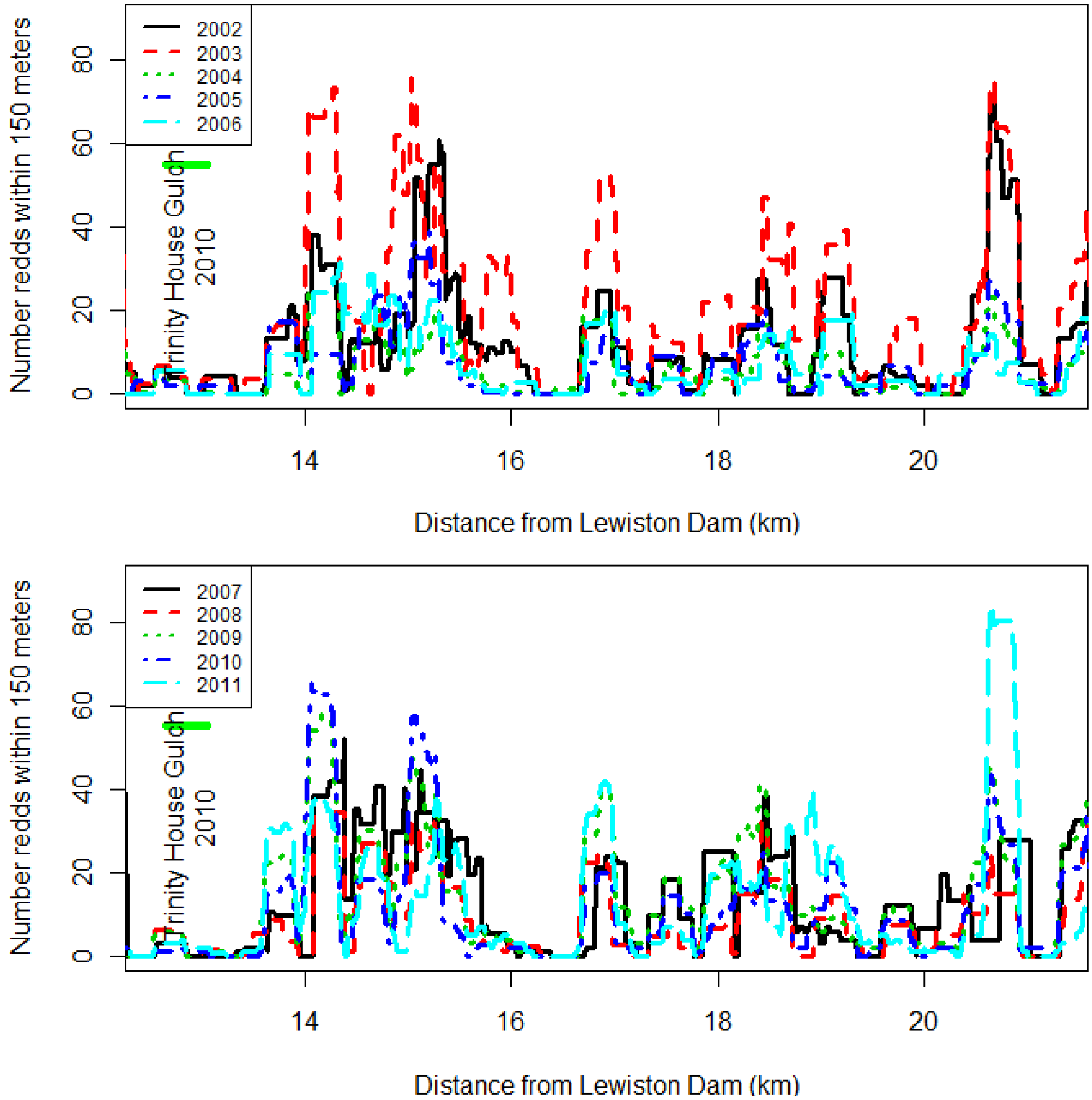

Figure 18. Density (redds/300m) of natural origin Chinook salmon redds Grass Valley Creek to Steelbridge. Horizontal bars show location of channel rehabilitation sites.

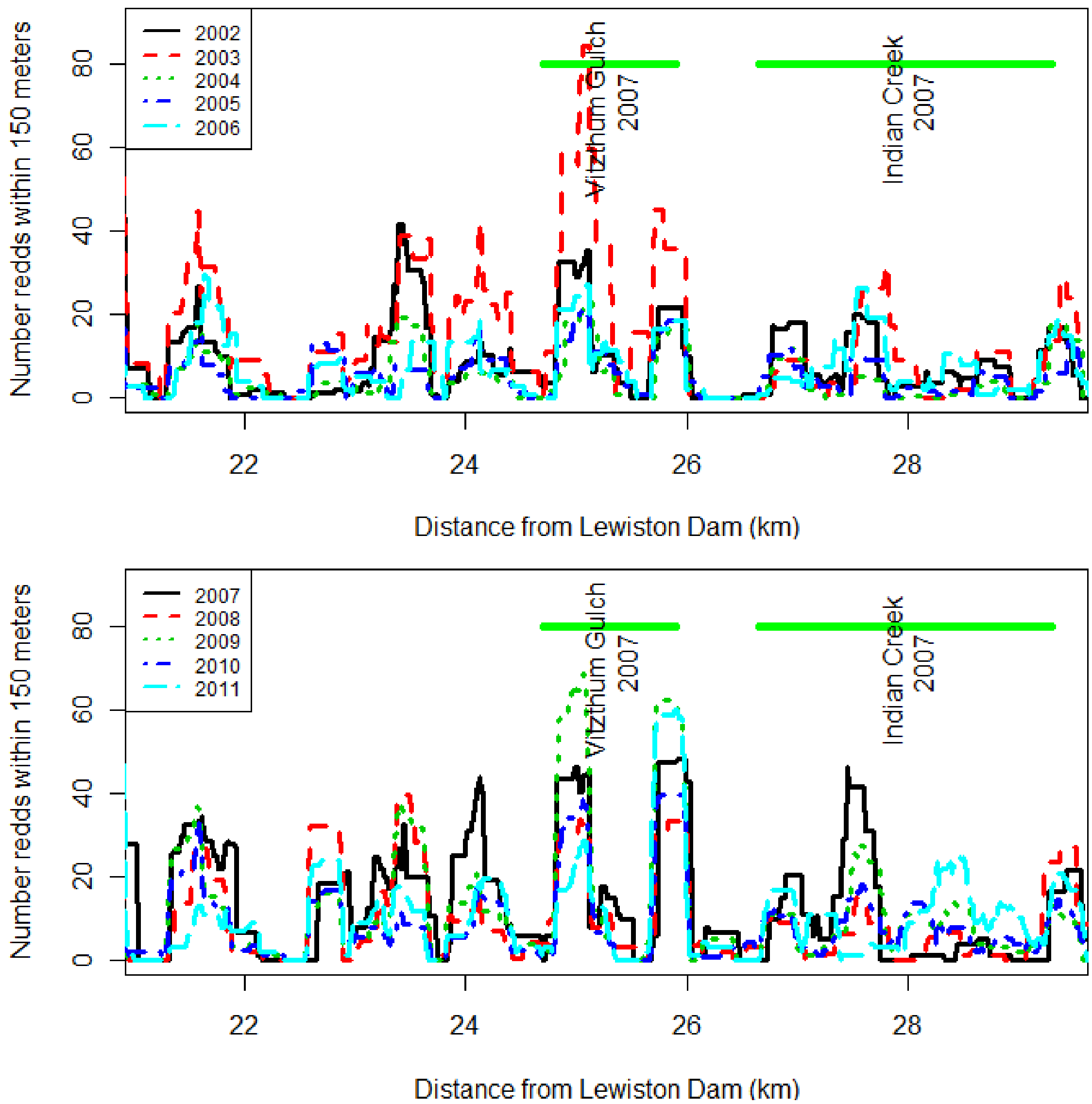

Figure 19. Density (redds/300m) of natural origin Chinook salmon redds Steelbridge to Weaver Creek. Horizontal bars show location of channel rehabilitation sites.

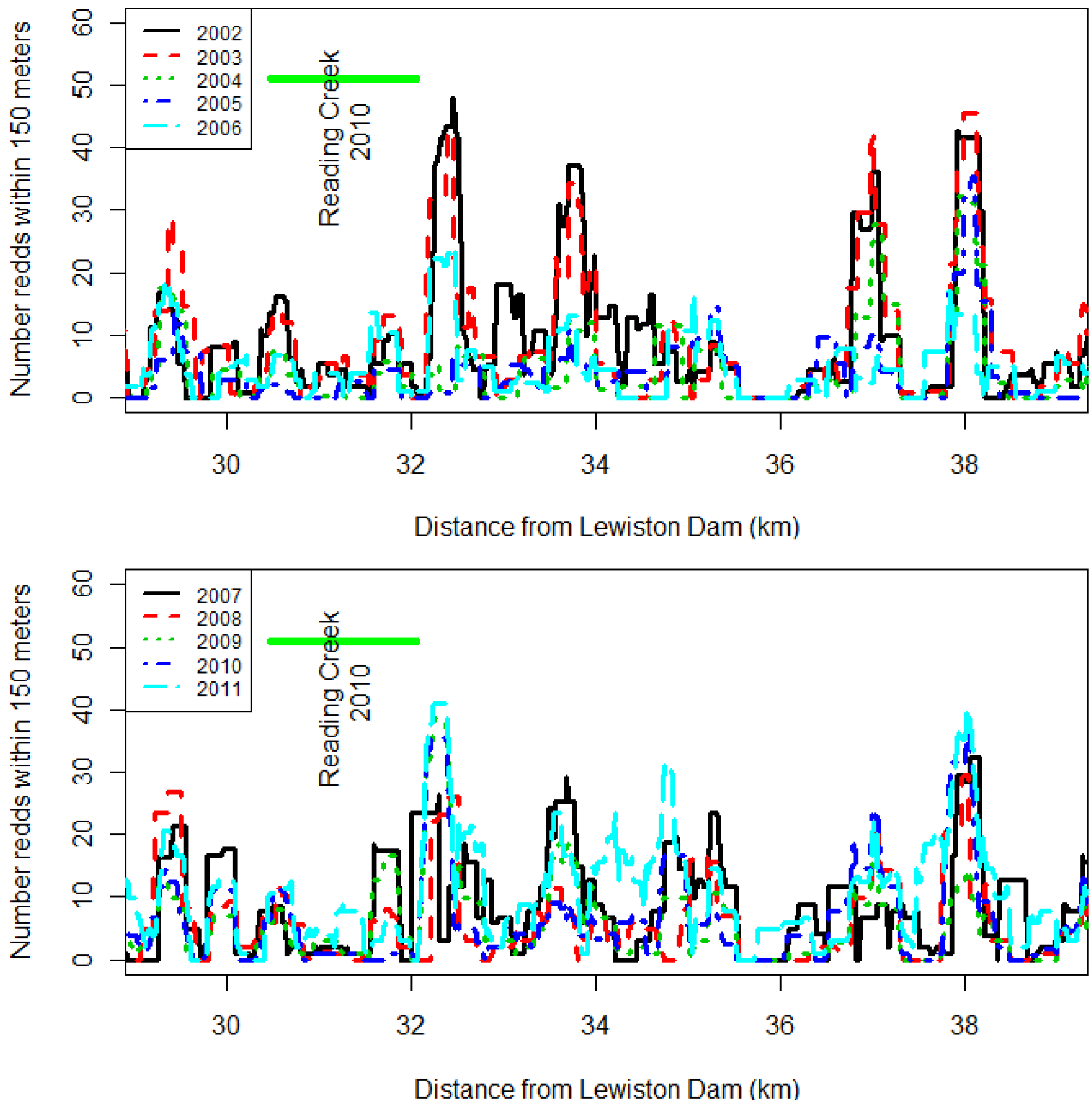

Figure 20. Density (redds/300m) of natural origin Chinook salmon redds Weaver Creek to Browns Creek. Horizontal bars show location of channel rehabilitation sites.

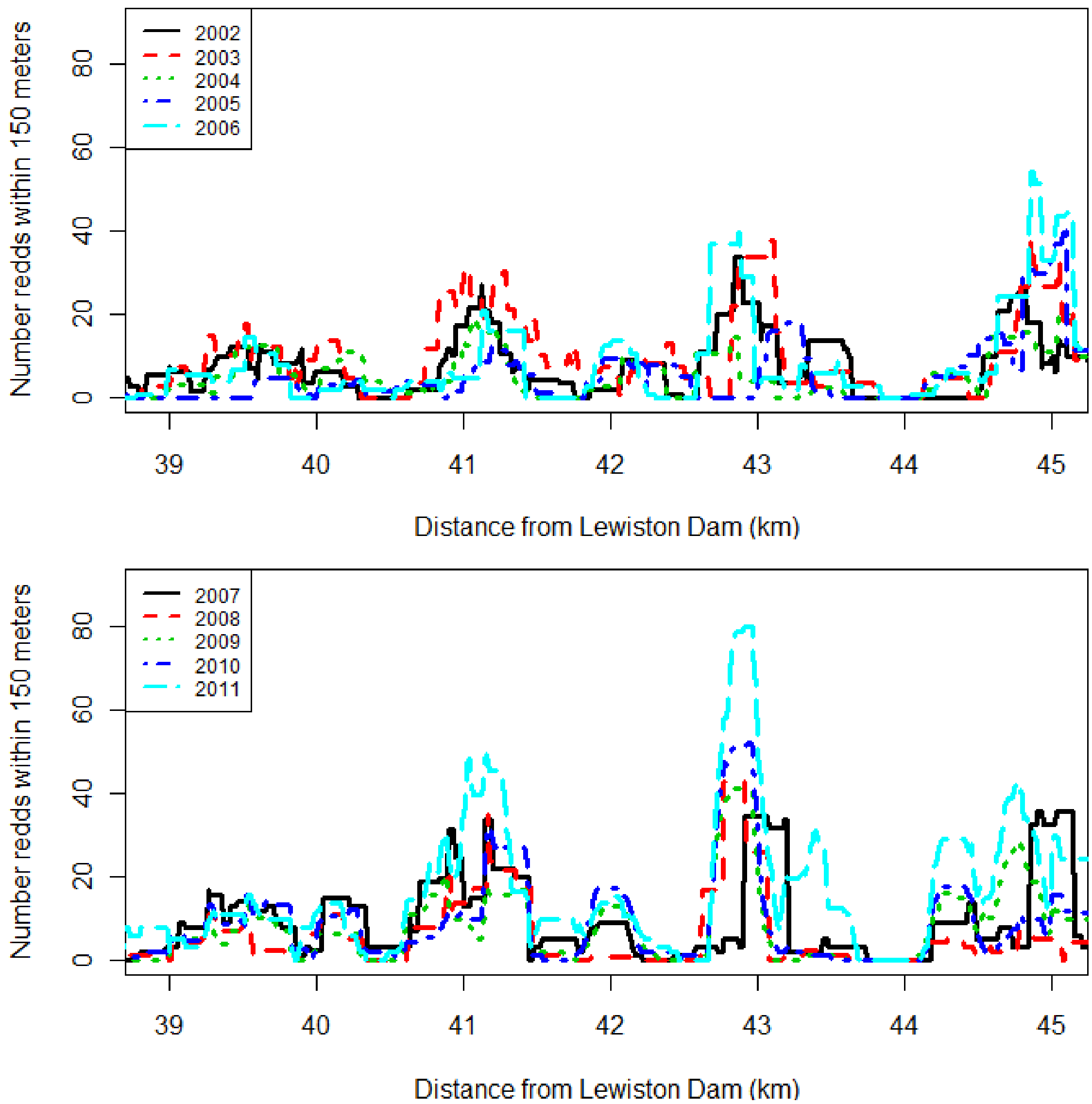

Figure 21. Density (redds/300m) of natural origin Chinook salmon redds Browns Creek to Bell Gulch.

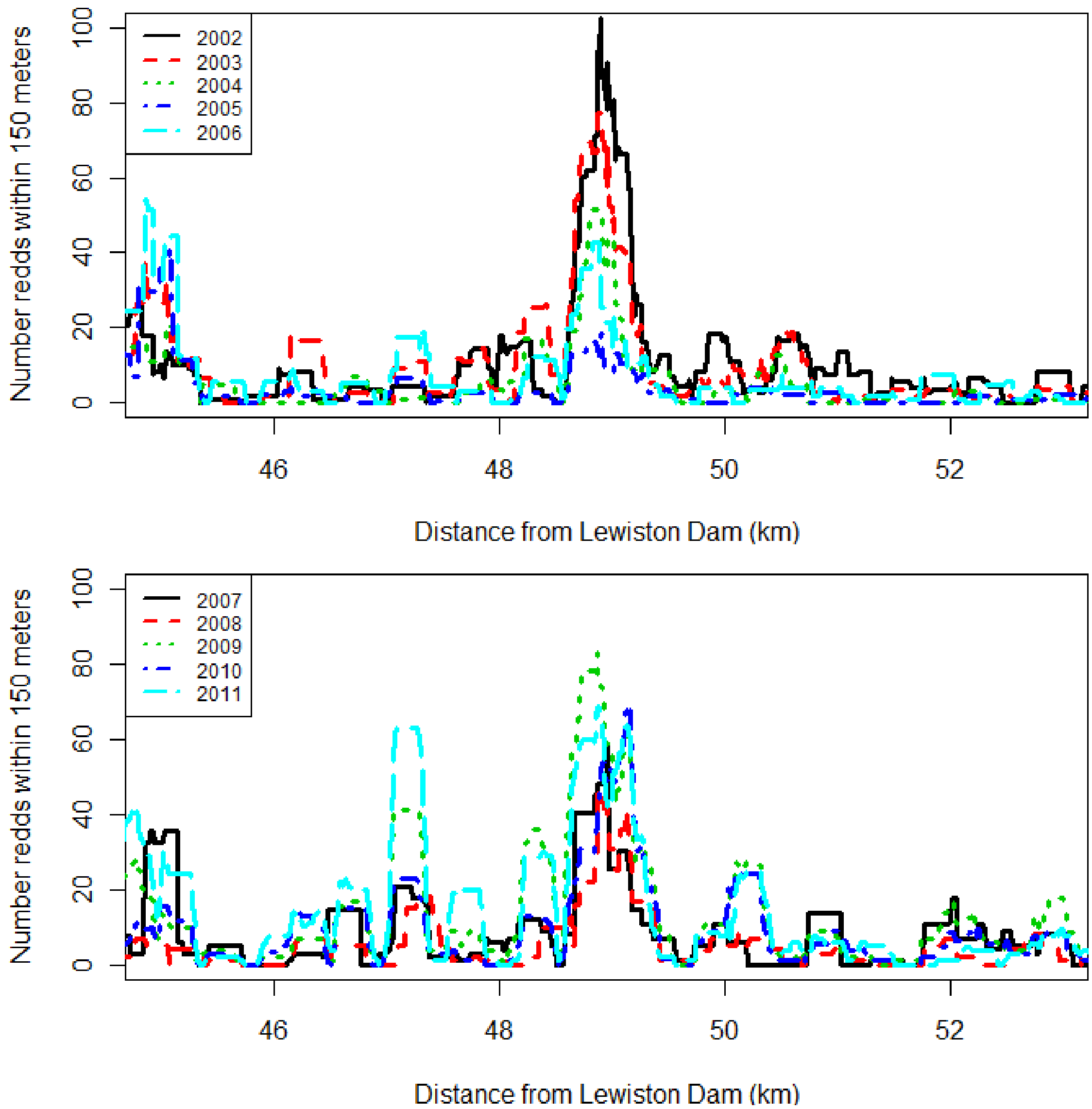

Figure 22. Density (redds/300m) of natural origin Chinook salmon redds Bell Gulch to Canyon Creek.

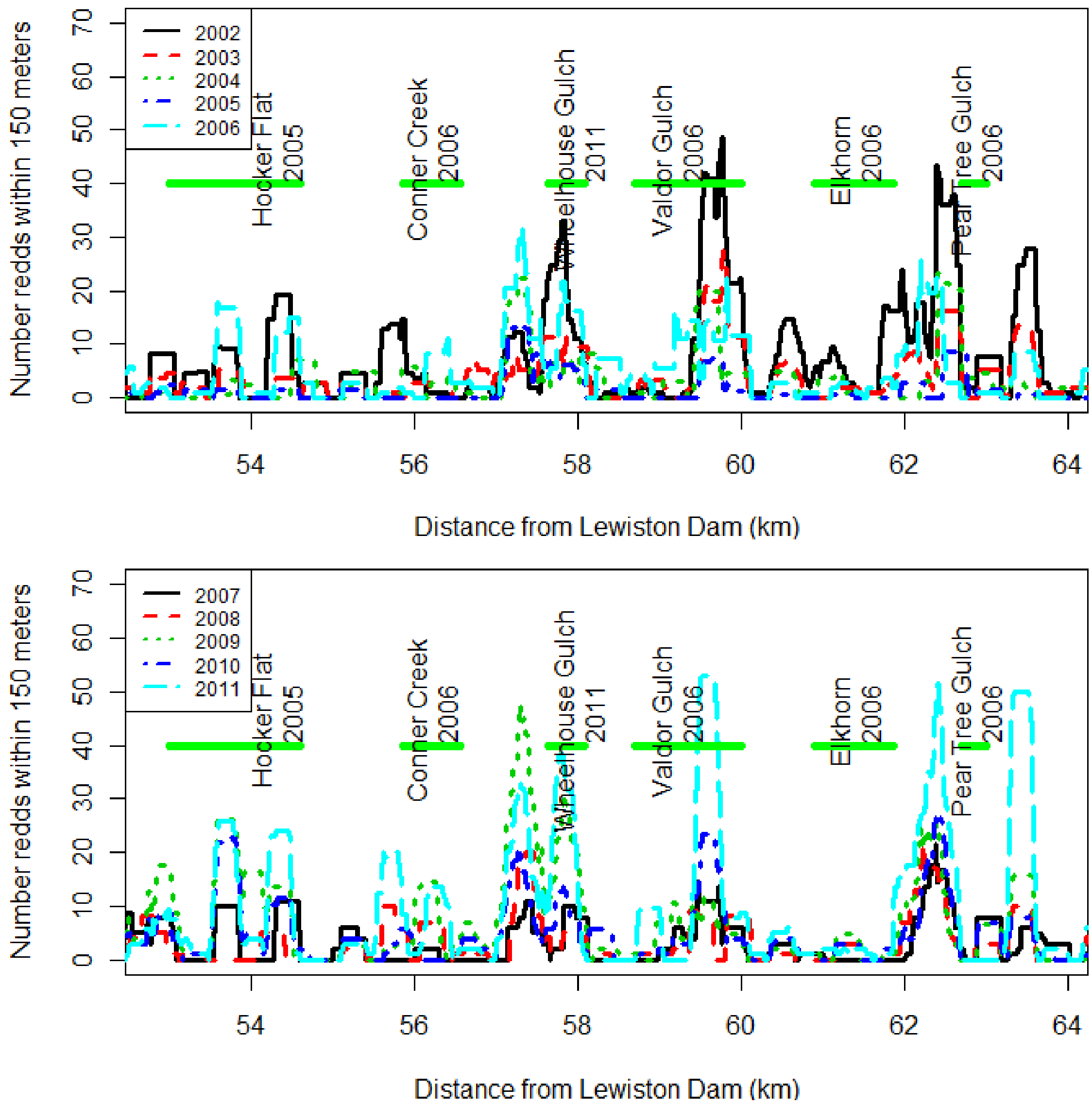

Figure 23. Density (redds/300m) of natural origin Chinook salmon redds Canyon Creek to North Fork Trinity River. Horizontal bars show location of channel rehabilitation sites.

Discussion

Hatchery origin fish that stray and reproduce in the Trinity River influence observed Chinook salmon spawning distributions and skew them toward Lewiston Dam. While the distribution of natural origin Trinity River Chinook salmon spawning in the mainstem is also skewed toward Lewiston Dam, suitable spawning gravels near Lewiston Dam and Trinity River Hatchery experience especially high use from hatchery origin strays (Sinnen 2004, Knechtle and Sinnen 2006, Hill 2009, Hill 2010, this report).

The occurrence of Trinity River hatchery strays on natural spawning grounds was significantly lower in the years 2008 to 2010. While release of Chinook salmon juveniles from TRH remains essentially constant, TRH Chinook salmon contribution to Trinity River escapement can vary widely (CDFG 2012). The Trinity River Restoration Program hopes to realize higher returns of *naturally* produced salmon. Measuring this response in spatiotemporal redd distribution is confounded by the presence of hatchery strays among in-river spawners. We 'correct' for this influence by using the origin of spawned females recovered as carcasses.

The propensity of male salmon to spawn with multiple females, sometimes several kilometers apart (Murdoch et al 2009) limits the utility of recovered male carcasses for informing hatchery influenced redd distribution. For this reason we used the ratios expressed *only* among spawned female carcasses to estimate contribution to the construction of redds by species and origin (wild or hatchery). While we don't have an elegant method to account for the male component of total hatchery influence on natural spawning grounds, it should not go ignored. The true number of redds constructed of entirely 'natural origin' parentage is lower than the number constructed by 'natural origin' females, especially in the upper reaches proximate to Trinity River Hatchery.

The influence that *progeny* of hatchery strays have on distribution of 'natural origin' spawners in the system is unknown. The homing tendency of salmon leads to higher use of the reaches near Trinity River Hatchery by 'naturally born' fish with a hatchery heritage, exerting a persistent pressure that contributes to the lopsided distribution of redds we observe now. Chilcote et al. (2011) demonstrated that salmon populations with mixed natural and hatchery origin fish experienced dramatic reductions in recruitment performance (the ability of spawning adults to produce progeny that successfully rear and return to spawn). While our methods offer reliable results for detecting change in distribution of redds constructed by hatchery born females on in-river spawning grounds, in no way do they fully characterize the influence of Trinity River Hatchery strays on mainstem spawning grounds nor the genetic influence of the Hatchery on natural populations.

Some have speculated that nest defense and/or competition for space might influence spawning distribution of Trinity River Chinook salmon as spawning habitats become saturated in the upper river. These suppositions were not supported by our data. The distance that natural origin Chinook salmon constructed redds from Lewiston Dam exhibited no apparent relationship to the total number of Chinook salmon redds. Redd superimposition is observed in the Trinity River, especially near Lewiston Dam and Trinity River Hatchery (personal observation). High densities of spawning fish in this area does not appear to result in pressure on newly arriving fish to move downstream in response to females defending nests, or males defending females.

We observed a weak inverse relationship between the number of redds constructed by hatchery origin Chinook salmon and the distance from that natural origin Chinook salmon constructed redds from Lewiston Dam. Interpretation of our data are confounded however by a coincident moderately increasing trend in distance by natural origin Chinook salmon, and a cluster of years near the end of the 2002 to 2011 period with relatively low occurrence of hatchery origin strays constructing redds in the mainstem (2008, 2009, 2010). This relationship warrants keeping an eye on in future years to avoid misinterpreting the impact of management actions on longitudinal distribution of natural origin Chinook salmon redds.

The longitudinal distribution of natural origin Chinook salmon spawning 'hotspots' remained largely consistent year to year (Figure 15, to Figure 23). While the magnitudes of use may vary, longitudinal spawning locations remain essentially the same. One major exception to this is the first 1.5 km from Lewiston Dam where gravel movement dramatically changed spawning habitat, especially at what is known as Bear Island between the Lewiston Hatchery and Sven Olbertson rehabilitation sites (Figure 15, Figure 24). High flows during the spring of 2010 redistributed gravels in this area. High spawning use of the Bear Island area appears to have shifted upstream in response.

One of the most valuable deliverables of this project is a GIS database of redd locations. These surveys will append the database each year. Figure 25 is an example of the utility that this spatially explicit data can provide to TRRP rehabilitation site design teams in evaluating feature specific hypothesis regarding spawning use of rehabilitation sites.

Figure 24. Aerial photos and redds at Bear Island 2009 to 2011. Sequence shows movement of bar features and localized response of spawning activity. Downstream end of Lewiston Hatchery rehabilitation site is upper right, upstream end of Sven Olbertson rehabilitation site is lower left.

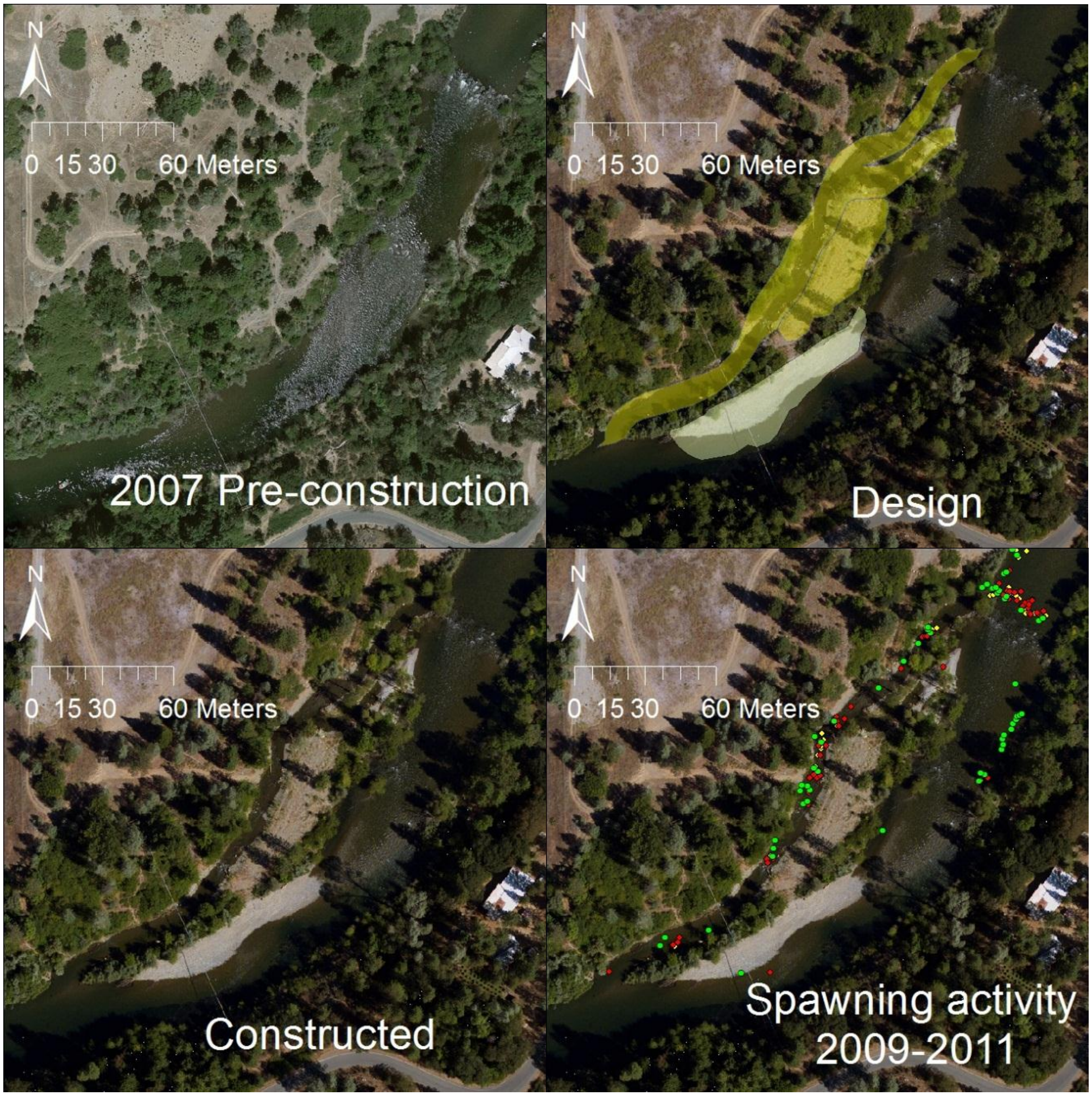

Figure 25. Hoadley Gulch Rehabilitation Site. Constructed 2008.

Mechanical rehabilitation by the TRRP is intended to work in concert with variable flow regimes and volumes by hydrologic year type to exert alluvial processes in the Trinity River that create and maintain quality salmon habitat (USFWS and Hoopa Valley Tribe 1999, DOI 2000, TRRP and ESSA Technologies 2009). The primary habitat targeted for rehabilitation is for fry rearing, but other habitats can be expected to change as well. Redd distribution response to mechanical actions at the rehabilitation site level has been minimal, but these sites are all newly constructed and have had few years to exhibit physical response to morphological processes. The earliest constructed rehabilitation site evaluated in this analysis had only experienced the wet portion of six post-construction water years at the time of this report (fall 2005 through spring 2011). Among those years, we had experienced one "dry" year (2008), three "normal" water years (2006, 2009, 2010), one 'wet' year (2011) and one "extremely wet" year (2007). Channel morphology responds to flow management, riparian community establishment, aging, etc., on decadal scales. Detecting change in salmon use of Trinity River rehabilitation sites will require consideration of temporal scale commensurate with that of morphological evolution (Larson et al 2004).

The Trinity River is not believed to be spawning habitat limited. However, otherwise highly suitable locations for redd construction and egg incubation can experience low density of spawners if the emergent fry produced there don't survive later life stages to one day home to their natal spawning area. We hope the currently lopsided spawning distribution improves through hatchery practices that reduce straying (a management action not under the purview of the Restoration Program) and through increased production of natural fish through actions that increase rearing habitat. If we have no influence on the occurrence or distribution of hatchery strays but significantly increase the production of natural origin fish by providing habitat that increased survival of rearing fish, the hatchery proportion would decrease, lopsidedness in the spawning distribution would reduce , and total return would increase. We expect spawning distribution to be influenced by rearing habitat distribution, and that changes in rearing habitat distribution will be expressed in spawning distribution. Rearing habitat mapping/modeling efforts underway now (Alvarez et al In review, Goodman et al In progress) will one day allow closer scrutiny of this hypothesis.

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PERSONAL COMMUNICATION

Billy Matilton. 2010. Hoopa Valley Tribal Fisheries Department, Hoopa, CA.

Eric Logan. 2011. Hoopa Valley Tribal Fisheries Department, Hoopa, CA.

A. Spatiotemporal distribution of all redds, Chinook salmon redds, hatchery origin and natural origin Chinook salmon redds.

Notes:

- This appendix consists of perspective plots of estimated redd numbers for all surveyed areas.
- Prior to 2007, data for the reaches downstream of Hawkins bar are maintained and reported by Hoopa Valley Tribe. From 2007 forward, these perspective plots include the whole river from Lewiston Dam to Weitchpec.
- For safety reasons, the Burnt Ranch Gorge (river kilometers 102.8 to 118.4) is not surveyed and that portion of the river shows as ‘zero’ estimates in these plots.

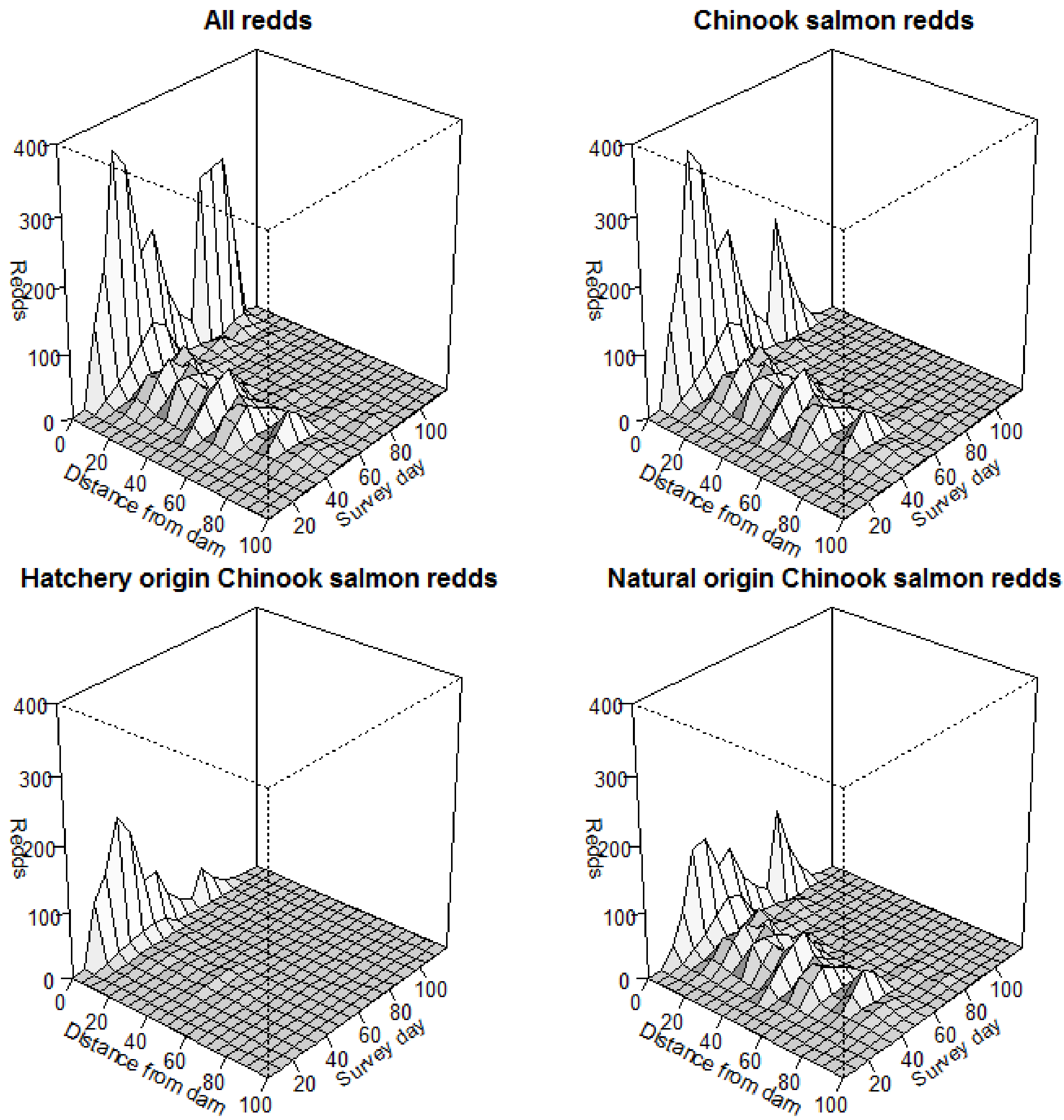

Figure A-1. Distribution of 2002 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

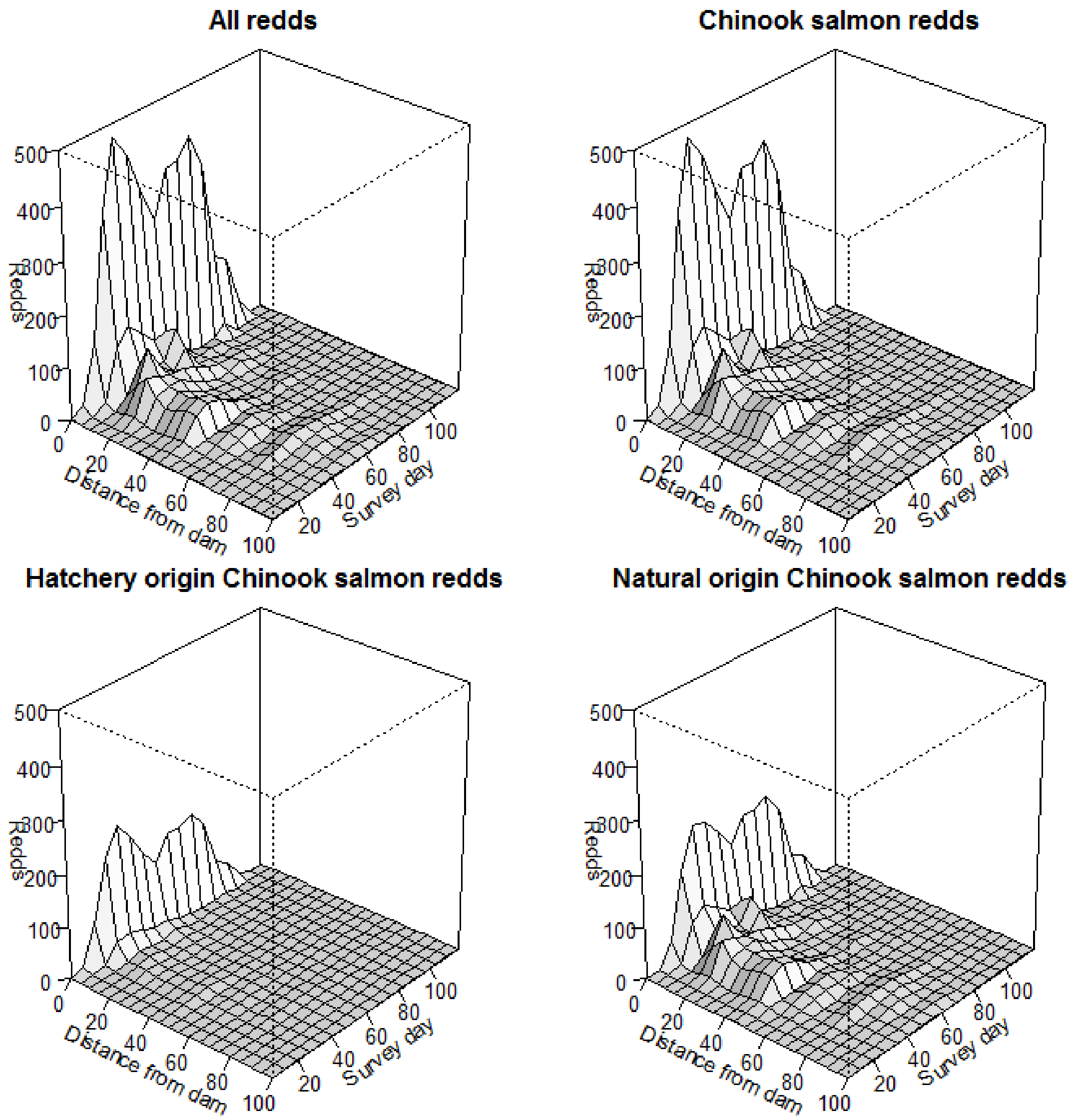

Figure A-2. Distribution of 2003 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

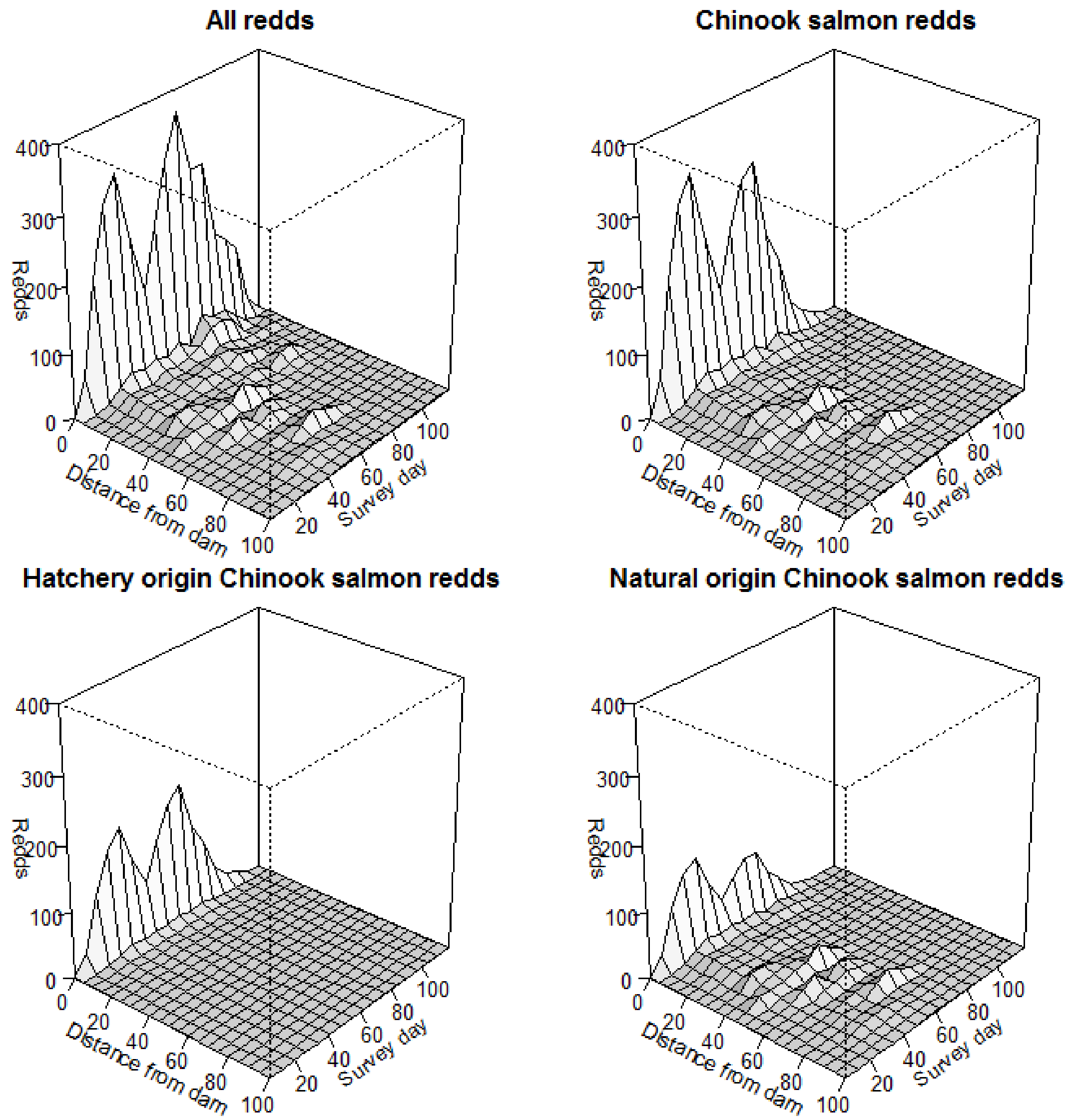

Figure A-3. Distribution of 2004 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

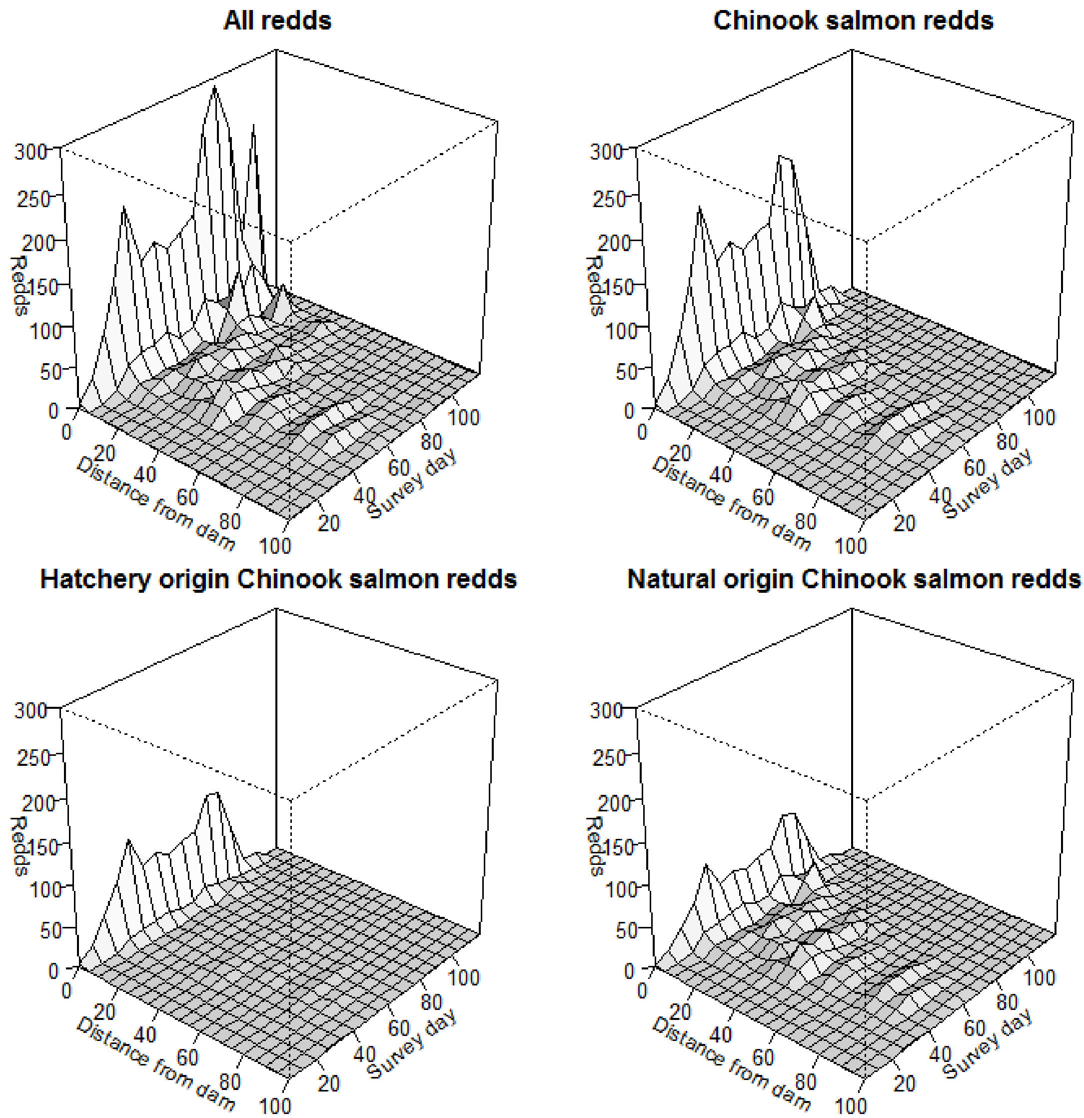

Figure A-4. Distribution of 2005 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

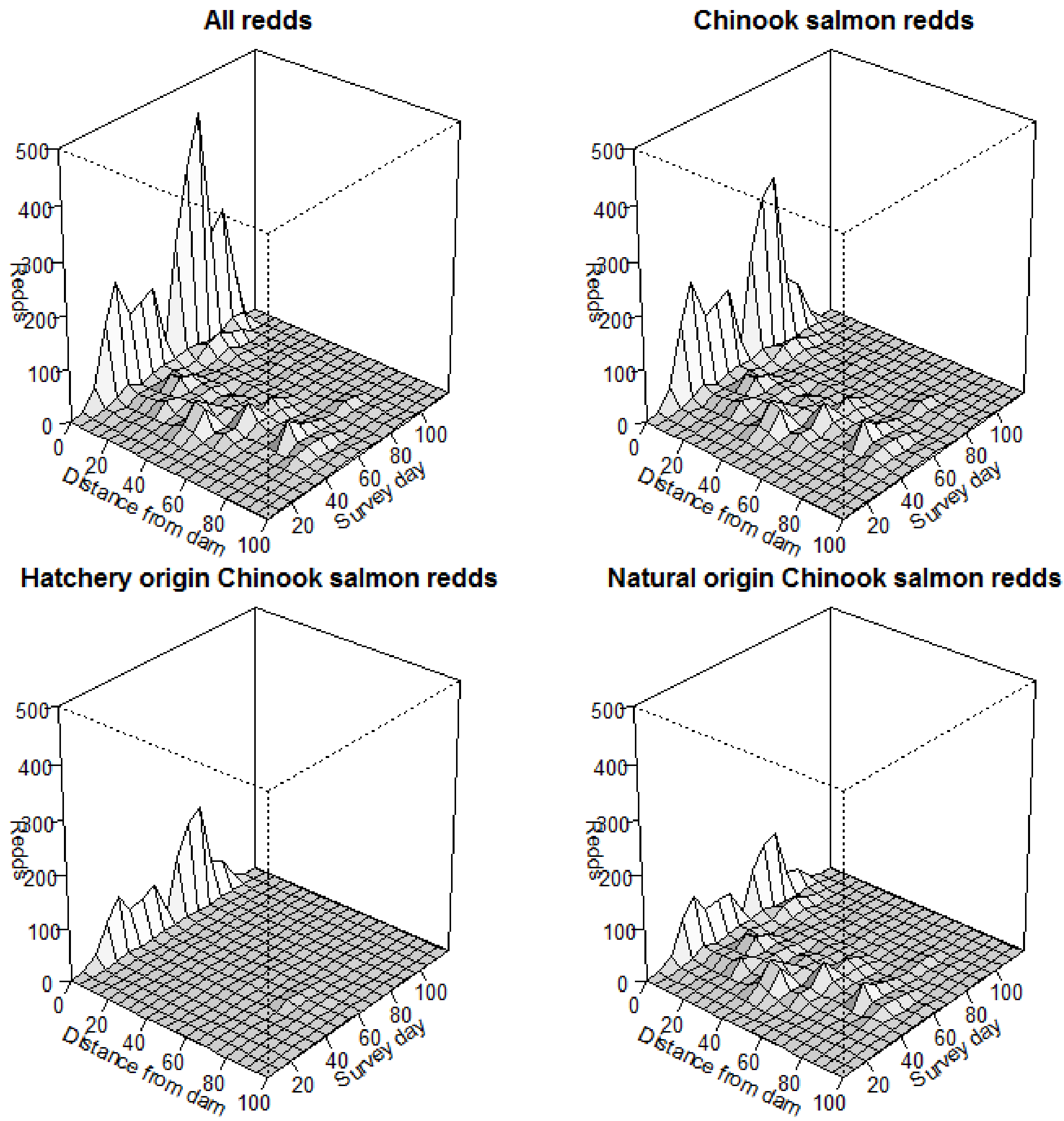

Figure A-5. Distribution of 2006 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

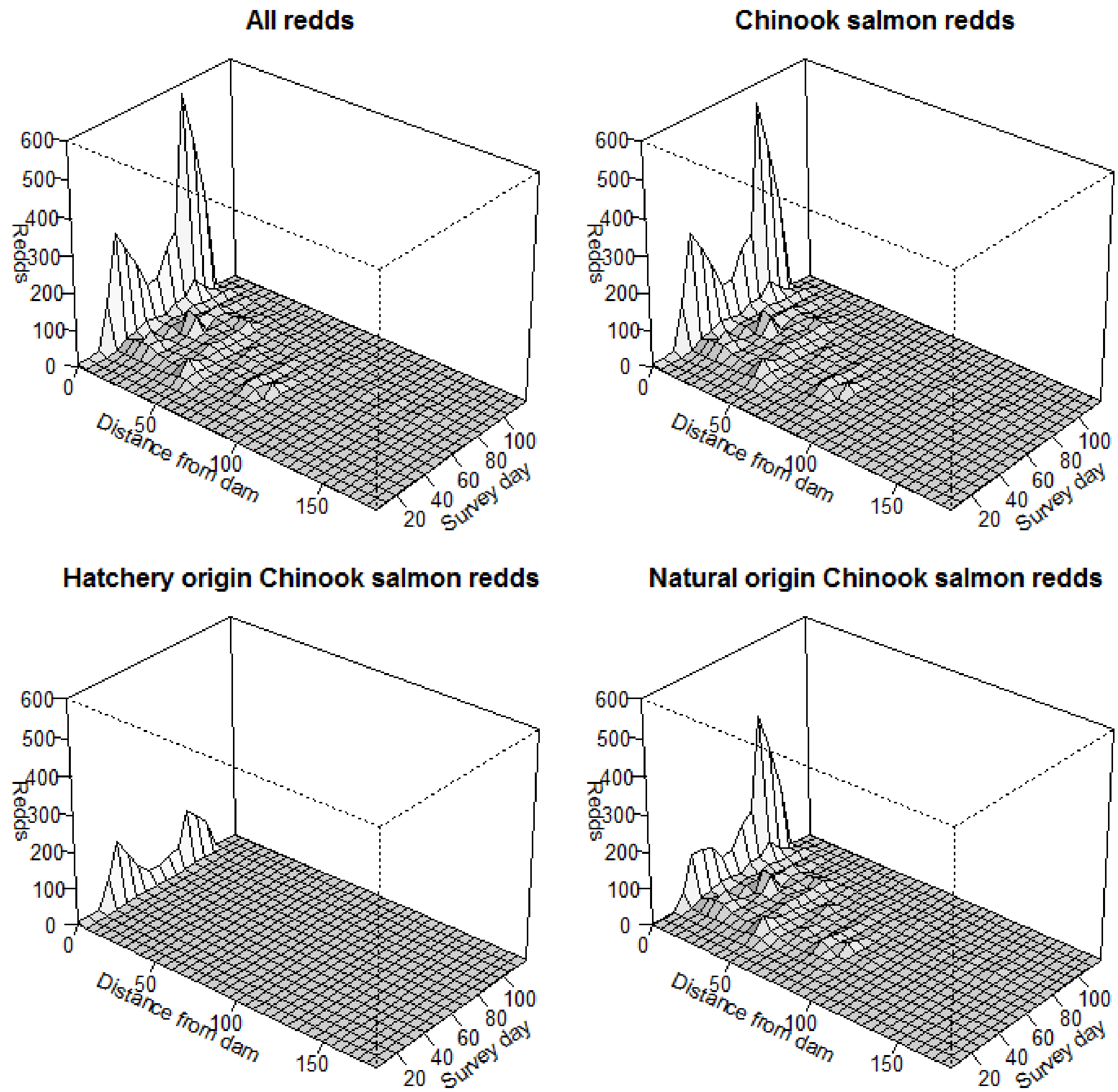

Figure A-6. Distribution of 2007 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

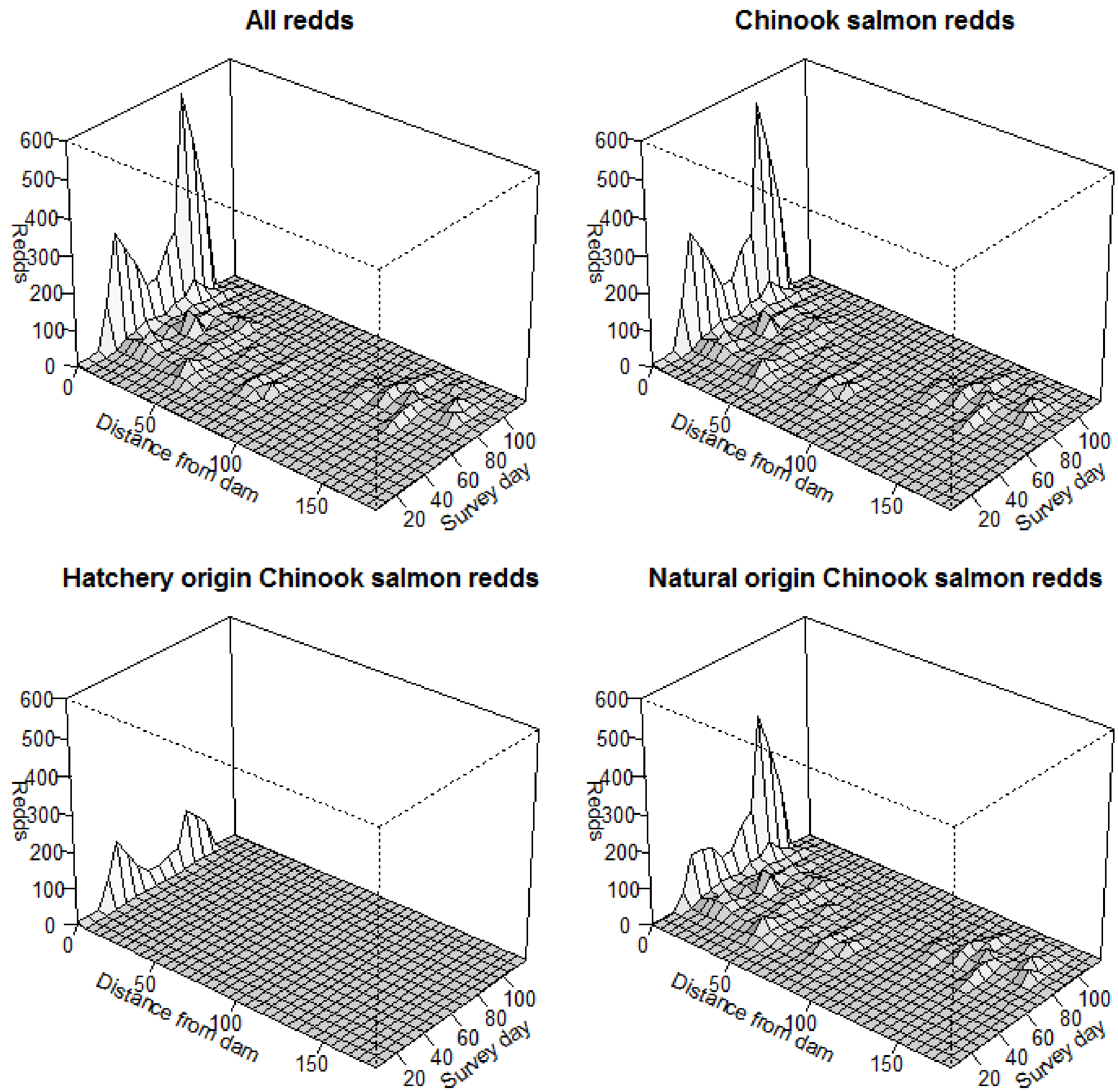

Figure A-7. Distribution of 2008 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

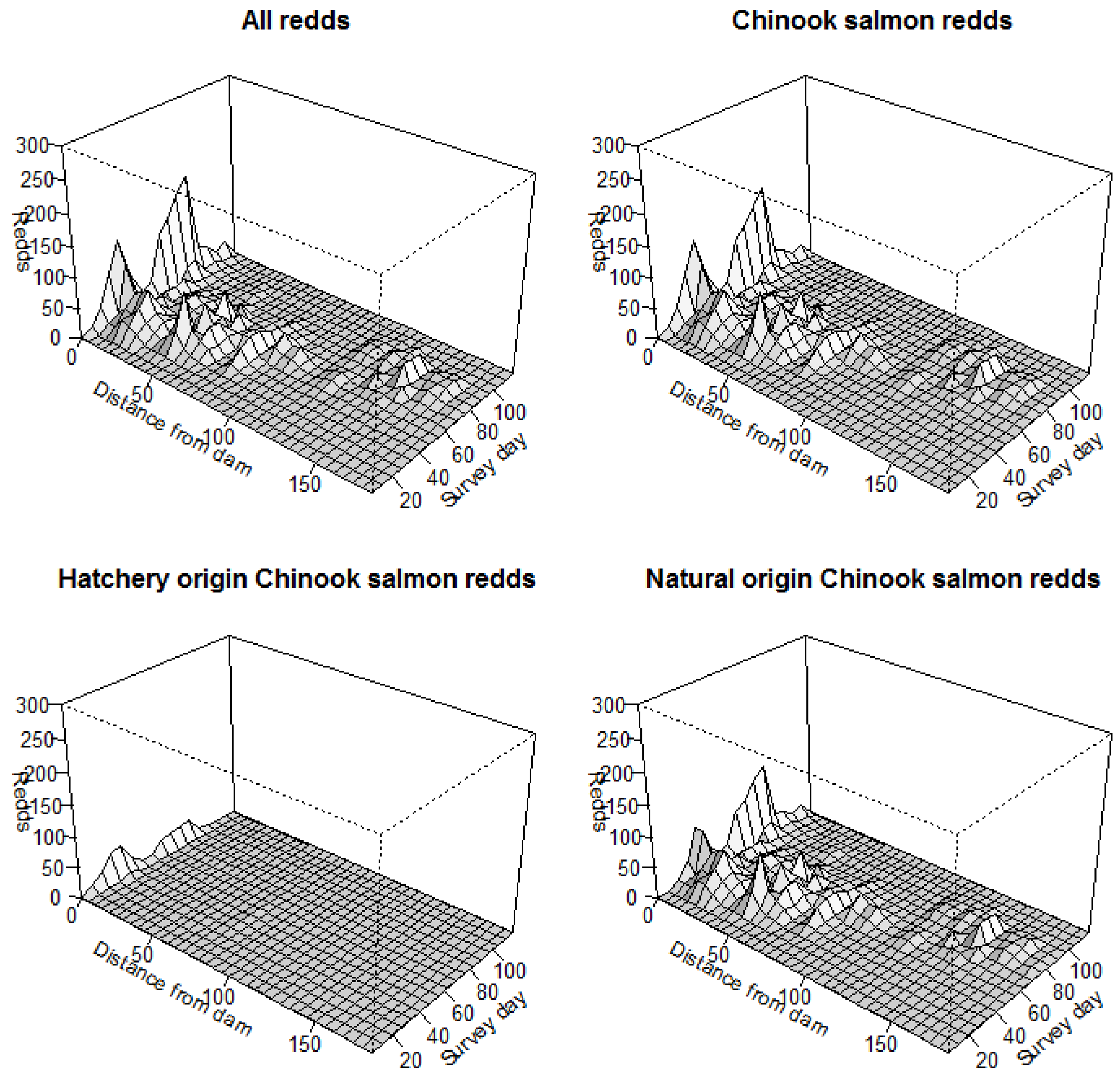

Figure A-8. Distribution of 2009 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

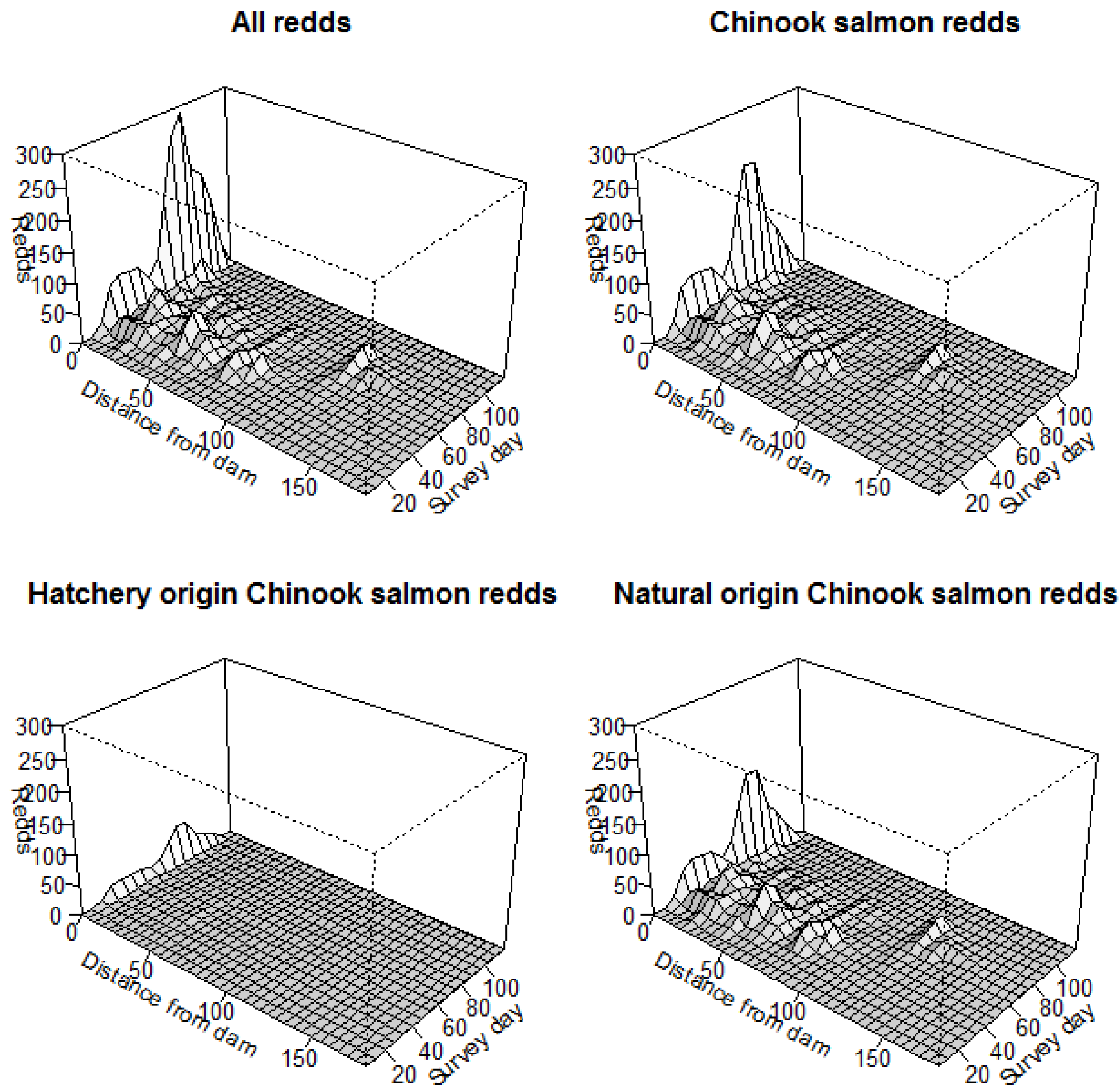

Figure A-9. Distribution of 2010 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.

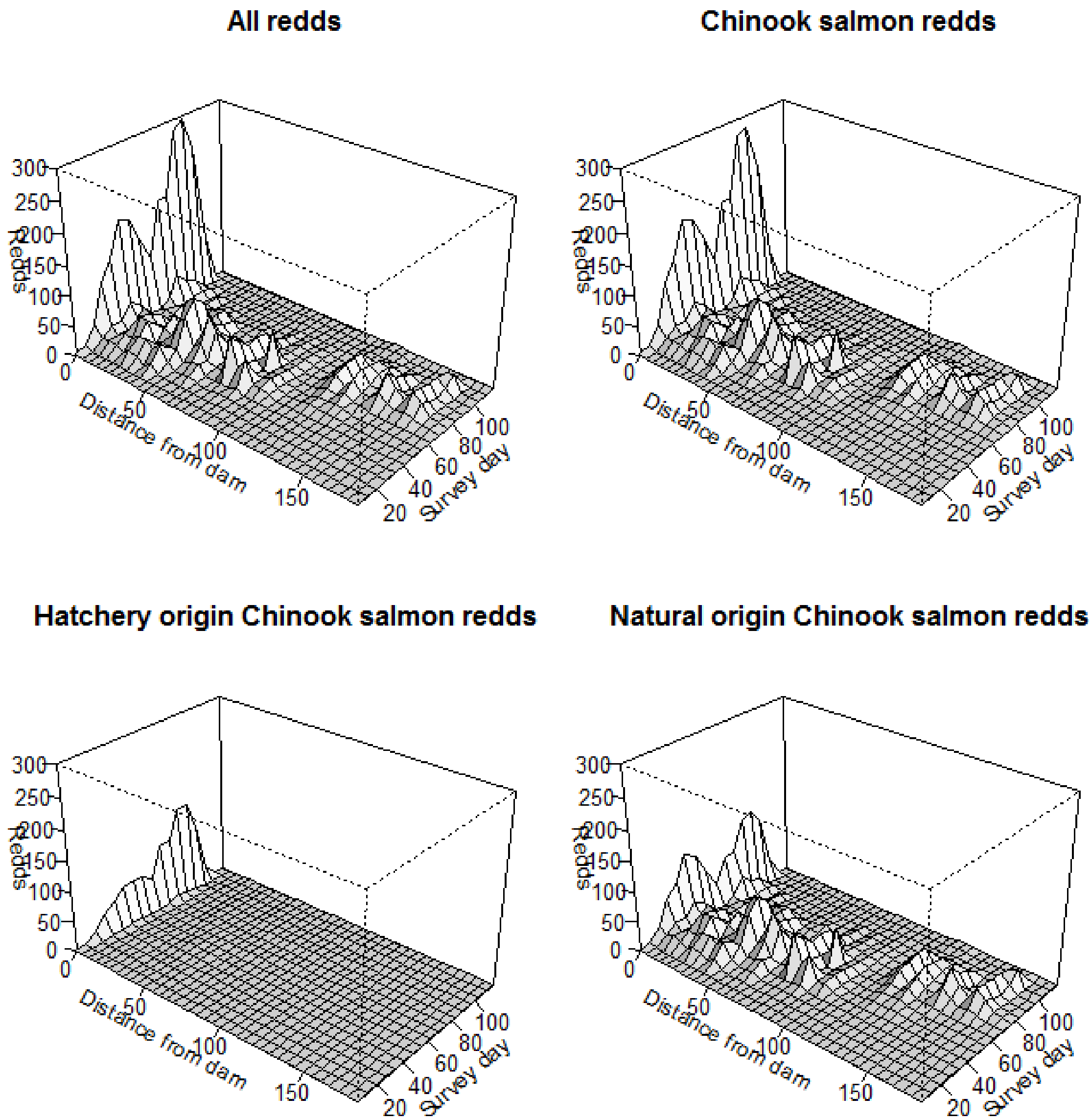

Figure A-10. Distribution of 2011 mainstem Trinity River salmon redds from Lewiston Dam to Cedar Flat.