EGG POCKET DEPTH AND PARTICLE SIZE COMPOSITION WITHIN CHINOOK SALMON REDDS IN THE TRINITY RIVER, CALIFORNIA

by

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ABSTRACT

High discharge events that occur while salmonid embryos are incubating may cause scour-induced mortality. To evaluate this potential for scour-induced mortality, relationships between discharge and bed scour, and bed scour and egg pocket mortality are needed. This study attempts to quantify one important component of this chain of relationships: egg burial depths within chinook salmon redds.

Egg pockets were sampled in twenty-eight redds in the following three reaches of the Trinity River: Salt Flat to Bucktail, Steel Bridge Campground, and Oregon Gulch to Junction City. A liquid nitrogen freeze-core technique was used to sample egg pockets because this methodology preserves the stratigraphy of streambed substrate and allows egg burial depths to be accurately measured. Measurements were made of the depth to the top and bottom of the egg pocket, length and width of the egg pocket, and of the dimensions of each redd. Egg burial depths were referenced both to the original (undisturbed) streambed elevation and to the elevation of the overlying gravel (disturbed substrate).

Egg burial depths referenced to the elevation of the original bed surface ranged from 5.5 cm to 51.5 cm, with a mean of 22.5 cm to the top of the egg pocket and 30 cm to the bottom of the egg. Egg burial depths referenced to an overlying gravel datum ranged from 15 cm to 53 cm, with a mean depth of 26.5 cm to the top of the egg pocket and 34 cm to the bottom of the egg pocket. The mean egg pocket thickness was 7.6 cm, and the mean width was at least 11 cm (measured at the maximum width).

To assess gravel quality surrounding the egg pockets, the particle size distributions of the freeze-core samples were determined. Estimates were made of fine sediment less than 2 mm, geometric mean diameter, the fredle index, and the Tappel and Bjornn (1983) predicted percent survival. The mean concentration of fine sediment less than 2 mm in diameter surrounding the egg pocket was 5.7%. A higher concentration was observed in the Junction City reach (mean = 8.7%) than in the other two reaches. The geometric mean diameter (D_g) was 37.1 mm, with a higher mean value in the Steel Bridge Campground reach (47.1 mm) than in the Bucktail/ Salt Flat reach (33.6 mm) or the Junction City reach (29.0 mm).

The small sample size and the bias of the freeze-core technique towards large cobbles caused samples to be in violation of accepted protocols for sample size, and limits inferences on spawning gravel quality. Although the gravel quality indices suggested that the conditions surrounding the egg pockets were generally favorable to support survival to emergence, a sensitivity analysis revealed that the percentage of fine sediment less than 2 mm contained within sampled egg pockets was underestimated and gravel quality indexes, such as D_g, were overestimated.

While the objectives of this study did not include evaluating bed scour as a function of discharge, existing bed scour data was used along with egg burial depths measured in this study to illustrate future steps needed to evaluate the percentage loss of cohort from discharge. Unfortunately, the variability in the bed scour versus discharge relationship was so large that it masked variability in egg burial depth and egg pocket shape. This simple sensitivity evaluation suggests that site-specific bed scour data for

Trinity River spawning areas is needed to more accurately evaluate bed scour-related egg and embryo mortality.

ACKNOWLEDGMENTS

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INTRODUCTION

River regulation impairs natural flow patterns and sediment transport regimes, thereby altering aquatic habitat downstream. The effects of river regulation, and in particular, accumulation of fine sediment in the channel surface, reduce salmonid spawning and rearing habitat quantity and quality. Deposition of fine sediment in spawning beds reduces the intergravel flow necessary to oxygenate salmon eggs and remove metabolic waste. Many studies have noted that the survival of salmonids from egg to emergence declines as the percentage of fine sediment increases (Shelton 1955, Platts et al. 1983, Tappel and Bjornn 1983, Everest et. al. 1987).

Reservoir releases can be managed to mobilize and scour the streambed, transport fine sediment downstream and improve gravel quality. If a large reservoir release occurs when eggs are incubating in the gravel, bed scour may increase the mortality of incubating salmon eggs deposited in redds within the streambed, which reduces salmonid production (Seegrist and Guard 1972). The increased bed scour can harm incubating salmonid embryos by crushing or washing out egg pockets during episodes of increased bedload transport, or by depositing fine sediment on top of redds which can result in reduced permeability of the area surrounding the egg pocket (DeVries 1997).

The Trinity River, located in Trinity and Humboldt Counties in northwestern California, drains a 7,679-km^2 basin (Figure 1). Originating in the Trinity Alps, the river flows approximately 275 km before draining into the Klamath River at Weitchpec. Lewiston Dam, located at river kilometer (rkm) 180, prohibits further upstream salmon migration and eliminates 175 km of salmonid habitat (USFWS 1998). The upper reach of

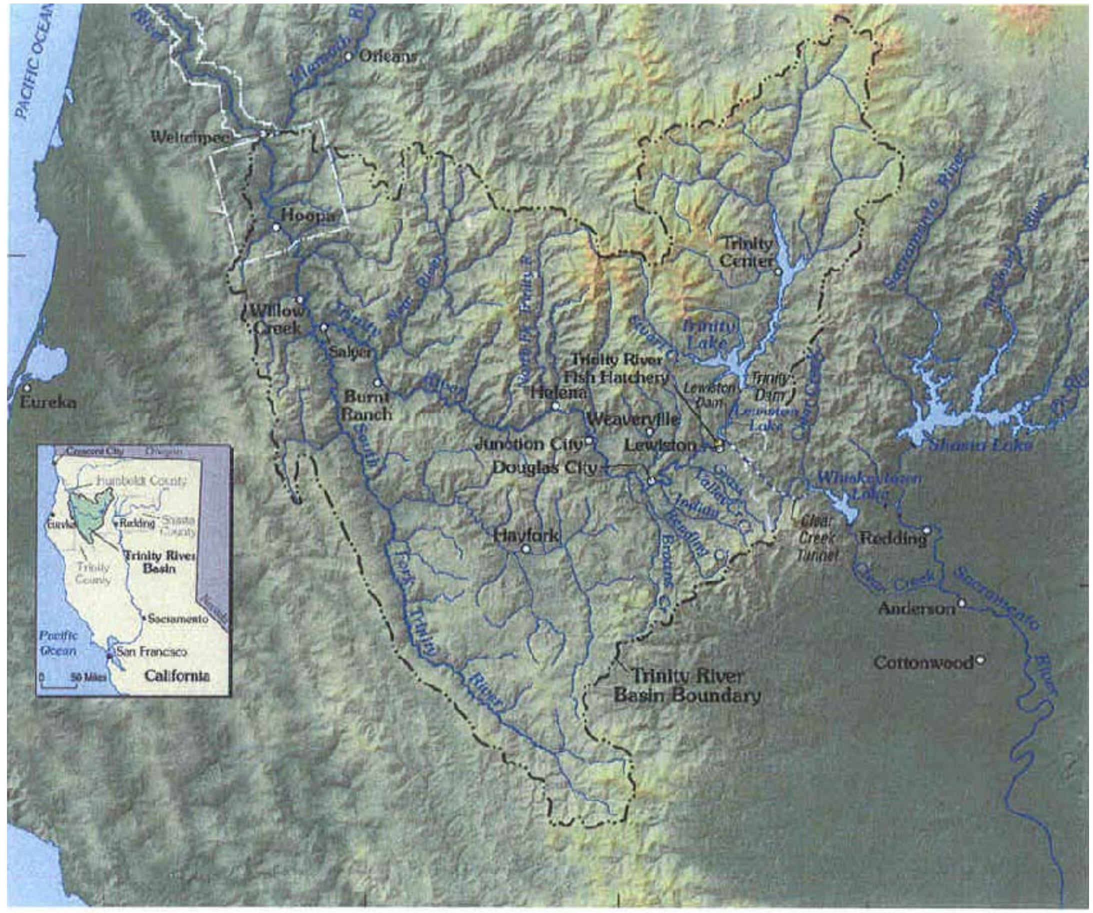


Figure 1. Location map, Trinity River Drainage Basin, California (USFWS 1999).

the river between Lewiston Dam and the confluence of the North Fork with the mainstem (rkm 116.5) is the most heavily used spawning habitat for chinook salmon (USFWS 1988). Historically, the Trinity River was a dynamic alluvial river meandering within a mountainous valley (USFWS 1999). Since completion of the Trinity River Diversion in 1964, which diverted up to 90% of the average annual water yield, riverine habitats below Lewiston Dam have degraded and salmonid populations have declined substantially (USFWS 1998).

Reduced peak flows have contributed to the loss of spawning habitat through the sedimentation of riffles, filling in of pools, loss of alluvial features such as alternate bar sequences, reduction in coarse gravel recruitment, and encroachment of riparian vegetation into the river channel (USFWS 1998). The encroachment of riparian vegetation has allowed fine sediment to accrete along channel margins and form berms. These berms have constricted the river channel and fossilized alternate and point bars, and thereby reduced the complexity of aquatic habitat (Kondolf and Wilcock 1996). The resultant changes in channel geometry have fostered higher stream velocity, and therefore higher shear stress at the streambed surface, for a comparable pre-dam flow.

To address the decline of the Trinity River anadromous fishery, the Secretary of the Interior directed that a multi-agency task force conduct the Trinity River Flow Evaluation in 1981. Management objectives of the evaluation include recommendations for instream flows, channel rehabilitation, and sediment management. Nine “feathered edge” restoration projects were implemented between 1991 and 1993 to remove riparian berms to increase fry rearing habitat for salmonids (Gallagher 1995). In 2000, the Secretary of the

Interior signed the Trinity River Restoration Program Record of Decision, which prescribed high water releases to restore and maintain fluvial geomorphic processes. These flows are intended to prevent the germination and establishment of riparian vegetation along the low flow channel margins, flush the channel of fine sediment, and to form and maintain alternate bar sequences (USFWS 1999).

The synchronization of dam releases and tributary floods maximizes water efficiency to satisfy geomorphic objectives. However, "piggybacking" high flow releases and storm events increases the peak streamflow, thus increasing the magnitude and frequency of streambed scour (USFWS 1999). High flows occurring during periods of egg incubation can cause streambed scour down to the elevation where the eggs are deposited, which can kill incubating embryos and reduce salmonid production (Kondolf et al. 1991, Lisle 1989).

Eggs buried at shallow depths are more at risk of being affected by bed-scour than are eggs buried at deeper depths (Lisle 1989). A study by Montgomery et al. (1996) investigated the relationship between egg burial depths and scour depths in chum salmon (*Oncorynchus keta*); they found that egg burial depths may be adapted to typical scour depths. This suggests that minor increases in scour depths could severely affect egg and embryo mortality.

Before prescribing high flow releases during periods when eggs are incubating (thus susceptible to scour), a better understanding is needed of: 1) the location of spawning activity, 2) the depth at which eggs are deposited, and 3) relationships between discharge and scour depth throughout spawning areas. These functional relationships can be evaluated with a conceptual model (Figure 2). The model first relates bed-scour and discharge in spawning areas (Figure 2a). The distribution of eggs as a function of depth (Figure 2b), the primary focus of this study, is then used to establish a relationship between percentage egg mortality and the bed scour depth at one site (Figure 2c). The ultimate goal is to evaluate potential scour-related impacts of dam releases with a relationship that predicts the percentage loss of cohort directly from discharge (Figure 2d).

The environment surrounding the egg pocket is critical to the survival of salmonid embryos. As female salmon dig their redds, they winnow away fine sediment through bodily undulations that lift sediment into the current. This process cleans the egg pocket of fine sediment (McNeil and Ahnell 1964), which allows greater porosity and permeability, and thus supports the flow of water through the egg pocket. Since particle size composition in gravel-bed streams varies widely, no single index can accurately describe substrate composition surrounding the egg pocket. Several measures are used to characterize the streambed composition and quality of substrate for spawning habitat; these include descriptors of central tendency, porosity, and permeability (Chapman 1988). Measures used in this study included the percentage of fine sediment less than 2 mm, geometric mean diameter (D_g), the fredle index (Lotspeich and Everest 1981), and the predicted percent survival of chinook salmon from egg to emergence (Tappel and Bjornn 1983).

Liquid nitrogen freeze-core sampling allows for accurate measurement of egg burial depths (Crisp and Carling 1989). The freeze-core technique preserves the vertical stratification of particles size composition, whereas bulk-sampling methods, such as the

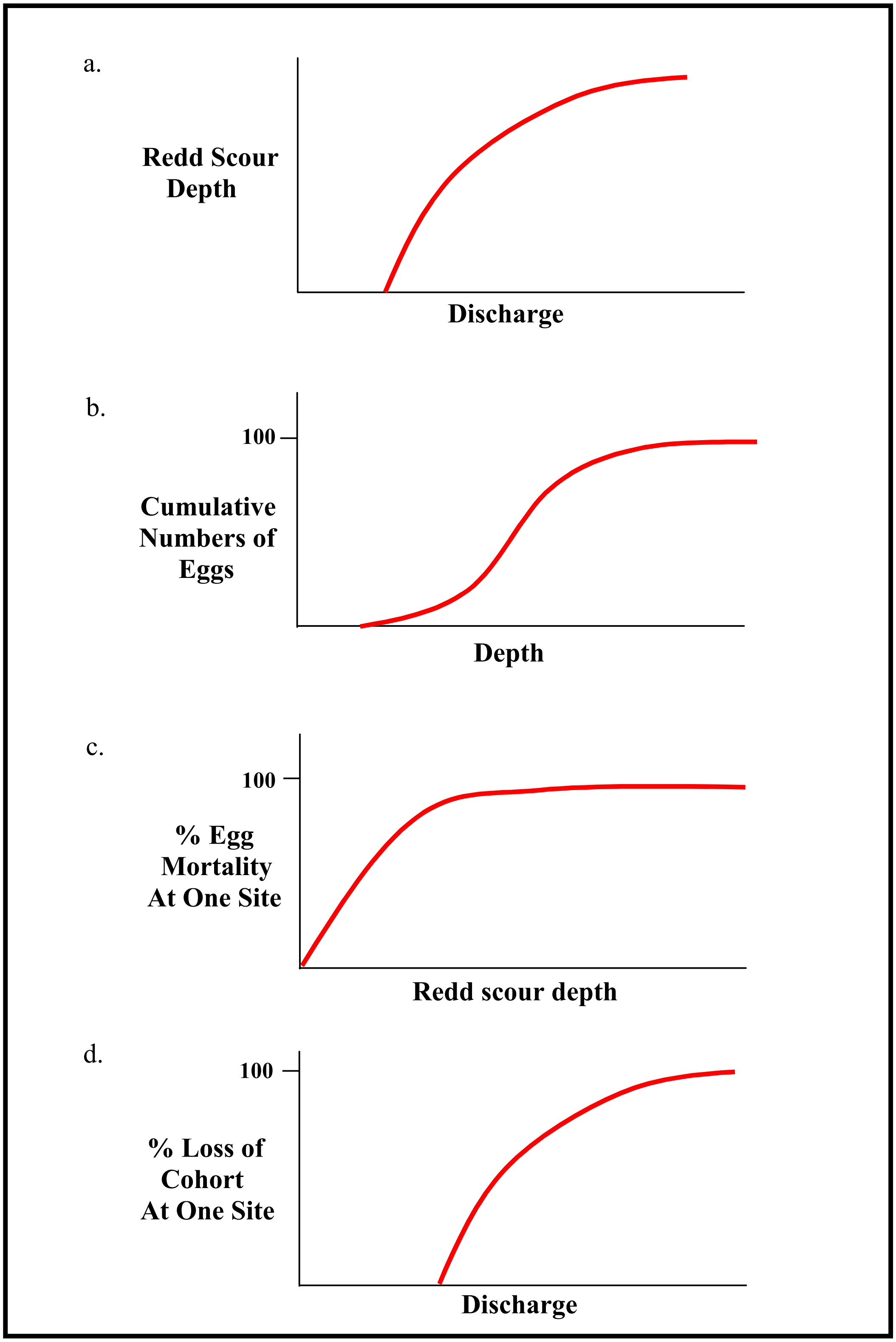


Figure 2. A conceptual model showing relationships between bed-scour depth, discharge, and egg burial depth to predict percentage loss of cohort.

McNeil sampler (McNeil and Ahnell 1964) do not. The undisturbed core samples yielded by the freeze-core technique permit the measurement of egg pocket dimensions and allow the internal structure of the egg pocket to be investigated. This technique also has the advantage of potentially recovering all of the particles within freezing range, and therefore preserves the content of fine sediment, unlike bulk sampling methods such as the McNeil sampler (Rood and Church 1994). However, there are inherent biases associated with using a freeze-core technique for this type of analysis: 1) the insertion of the probe may disturb the egg pocket and surrounding substrate; 2) particles may be lost during probe removal; 3) the core size is often too small to accurately depict the particle size distribution of the substrate (Lisle and Eads 1991); and 4) the size of freeze-core samples is highly variable.

The size of core samples is dependent on streambed temperature, stream flow velocity, permeability, the quantity of liquid nitrogen used, and the size and composition of the streambed substrate. High temperature, velocity, and permeability can decrease freezing efficiency, thus sample size (Bunte and Abt 2001). Differential freezing of particles tends to freeze larger particles to the exterior of the core-sample (Adams and Beschta 1980, Lisle and Eads 1991). Larger particles tend to bias the measured particle size distribution, which often leads to the underestimation of fine sediment (NCASI 1986). Church et al. (1987) suggested a methodology in which the largest particle should not exceed 1% of the total sample weight; freeze-core samples are typically in violation of this methodology. To avoid problems with sample size, several studies have suggested truncating particle size distribution data (Lotspeich and Everest 1981, Grost et al. 1991, Rood and Church 1994). However, Chapman (1988) argues that establishing a relationship from truncating a distribution would mask the true conditions within the egg pocket. A sensitivity analysis that compares complete and truncated particle size distributions can illustrate the effect of grain sizes that are heavy relative to the overall sample weight on gravel quality indexes.

The primary objective of this project was to estimate the range of depths in which eggs are deposited in chinook salmon (*Oncorhynchus tshawytscha*) redds within the Trinity River between Lewiston Dam and the North Fork Trinity River. An ancillary objective of this study was to assess spawning gravel quality by examining the particle size composition surrounding the eggs. Information from this project, when combined with studies relating bed scour depth to stream discharge, can help assess the impact of high flows on scour-related mortality of salmon eggs.

METHODS

Study Site

Three study sites were selected from the Trinity River between Lewiston Dam (rkm 180) and Canyon Creek (rkm 128). This reach of river was divided into three equal segments defined as upper, middle, and lower in order to encompass the range of natural variability within the 55 km immediately downstream of Lewiston Dam, and to provide insights on the downstream effects of river regulation. These segments were further subdivided based on accessibility, incidence of spawning, and location of restoration projects. Reaches not accessible from a roadway or on private property were eliminated. Aerial photographs containing the 1999 spawning sites were used to identify areas of suitable spawning habitat. Restoration sites were not included in this study to avoid potential variability caused by the project. Reaches that satisfied these criteria were selected at random. The three reaches selected were Bucktail/ Salt Flat (BT), which contained two sites at Bucktail (rkm 169) and Salt Flat (rkm 174), Steel Bridge Campground (SBC) at rkm 159, and from Oregon Gulch to Dutch Creek Bridge above Junction City (JCY) at rkm 129 (Figure 3).

The wide, homogenous runs that characterize the majority of the Bucktail site appear to provide little of the habitat diversity necessary to encourage spawning of salmonids. Sampling at this site was concentrated above and below the Dirty Bird pool (rkm 105.25). The reach was extended upstream to Salt Flat to obtain a larger sample size because eggs could not be located in several of the redds at the Bucktail site. The Salt Flat site is characterized by a particularly wide, shallow run at dam releases of 8.5

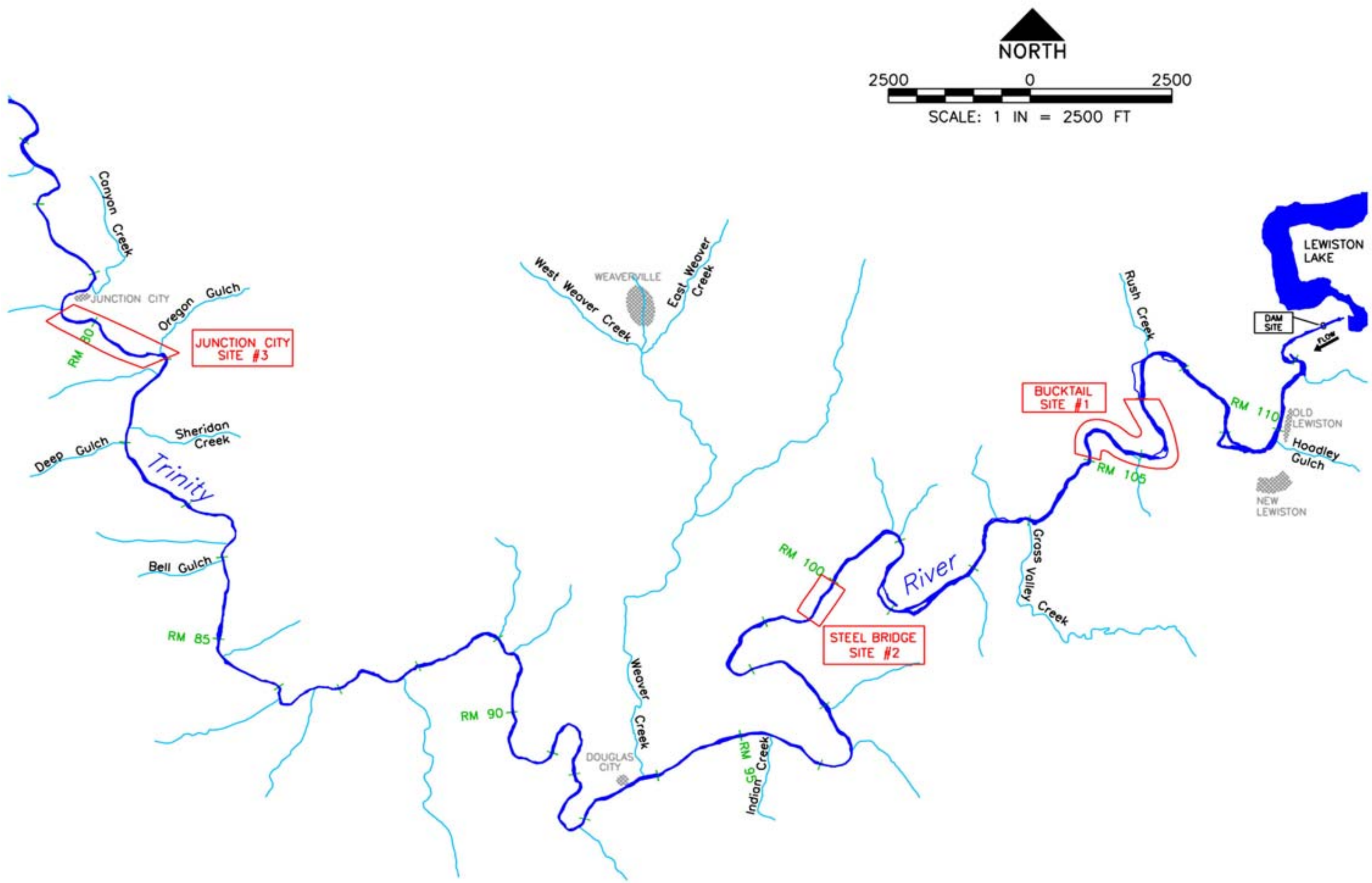


Figure 3. Map of Upper Trinity River from Lewiston Dam to Canyon Creek with study reaches. From McBain and Trush, Inc., Arcata, CA; used with permission.

m^3s^{-1} and contains abundant spawning on the left channel margin (looking downstream). Hoadley Gulch delivers a substantial quantity of decomposed granite into the river 2.75 rkm upstream of Salt Flat, and the decomposed granite is evident at this site.

The Steel Bridge Campground reach is located below Grass Valley Creek, a tributary that has historically supplied a considerable volume of fine sediment to the Trinity River. This site is characterized by a long mid-channel bar that slows river velocity and retains coarse gravel. Spring- and fall-run chinook salmon construct numerous redds at this site; redds are particularly numerous on the right side of the mid-channel bar, despite the large volume of sand that comprises the substrate.

The Junction City reach of the river is highly channelized with steep banks and dense vegetation. This reach contains a swift current even during low flow (dam releases of 8.5 m^3s^{-1}). The rectangular, confined channel morphology provides low habitat diversity. Spawning habitat in this reach is scant.

Sampling

Redds were sampled during low flow periods (dam releases of 8.5 m^3s^{-1}) from mid-October through December 2000. A random sample of discrete redds was selected at Bucktail/ Salt Flat, Steel Bridge Campground, and Junction City. Only discrete redds were sampled to avoid confounding effects from the superimposition of redds. One sample containing eggs was collected at random from each redd. Redds were sampled repeatedly until eggs were located. Core samples were taken along the centerline axis of each redd about 20 cm apart progressing in an upstream direction. A river raft was used to access the reach above Junction City as steep channel banks and dense riparian vegetation limited river access.

A liquid nitrogen freeze-coring technique was used to collect the samples within the salmon redds (Walkotten 1976). Two stainless steel alloy freeze-coring standpipes were constructed similar to the Modified Terhune Mark VI standpipes used by Barnard and McBain (1994). Standpipes were 1.07 m and 1.12 m long with 3.1 cm and 3.05 cm inner diameters, respectively. Each had a stainless steel driving point at its base, and a hole drilled through the top near the open end of the tube (Figure 4). The standpipe was driven 30 to 40 cm into the centerline axis of each redd based on egg depths summarized by DeVries (1997) and field observations. A 4-inch diameter PVC pipe and a 5-gallon bucket with its bottom removed were each placed around the standpipe for insulation.

Liquid nitrogen was poured slowly into the standpipe for an average of 12 to 15 minutes (Figure 5). Liquid nitrogen has a boiling point of –196°C, and it freezes the surrounding substrate to the standpipe as it vaporizes. A 1.25 m steel rod was inserted through the top of the standpipe to facilitate removal of frozen core samples from the streambed. Cores samples were extracted manually.

Extracted core samples were placed on a tray, measured and photographed. Eggs were generally visible from the exterior of the core (Figure 6). Frozen core samples were thawed with a blowtorch. The portion of each core sample that was below the elevation of the egg pocket base, often characterized by large cobbles (Vronskiy 1972), was discarded along with material removed from above the egg pocket centrum. This isolated the contents of the redd from the surrounding substrate so that gravel quality analyses could

Figure 4. Photograph of stainless steel standpipes and extraction rod used in the freeze-coring process.

Figure 5. Photograph of the freeze-coring process; liquid nitrogen is being poured into a standpipe to freeze a sample of the substrate.

Figure 6. Photograph of a freeze-core sample with exposed chinook eggs, Trinity River, CA, Fall 2000.

be conducted on the egg pocket centrum alone. The remainder of the core sample was bagged and labeled for particle size distribution analysis.

Data on redd characteristics were recorded, including the length and width of the pit and tailspill (denoted *A*, *B*, *C* and *D* in Figure 7), the maximum depth of the pit and the minimum depth of the tailspill below the water surface, and the distance from the center of the redd to the closest riverbank (looking downstream) (denoted as *E* in Figure 7). Measurements were also taken from the undisturbed substrate to the free water surface on both the left and right side of each redd along an axis parallel with the location of the standpipe (labeled *a* and *f* in Figure 8).

Egg Burial Depths

The depth to the top of the egg pocket (primary variable of interest) was measured at the elevation at which the first eggs were encountered. Egg burial depths were calibrated to both the elevation of the specific portion of the tailspill or overlying gravel where the sample was taken ($EBD_{disturbed}$) and to the original elevation of the streambed surface ($EBD_{original}$) (Figure 8). The overlying gravel datum has been observed to change over time as considerable streamflow can level out a tailspill (Crisp and Carling 1989). $EBD_{original}$ is defined as the depth the female had to dig to bury the eggs (Steen and Quinn 1999). This datum is more useful for predicting scour depth since it is likely that it will be of uniform thickness (Devries 1997), and more accurate predictions of scour depth relative to the egg pocket can be made.

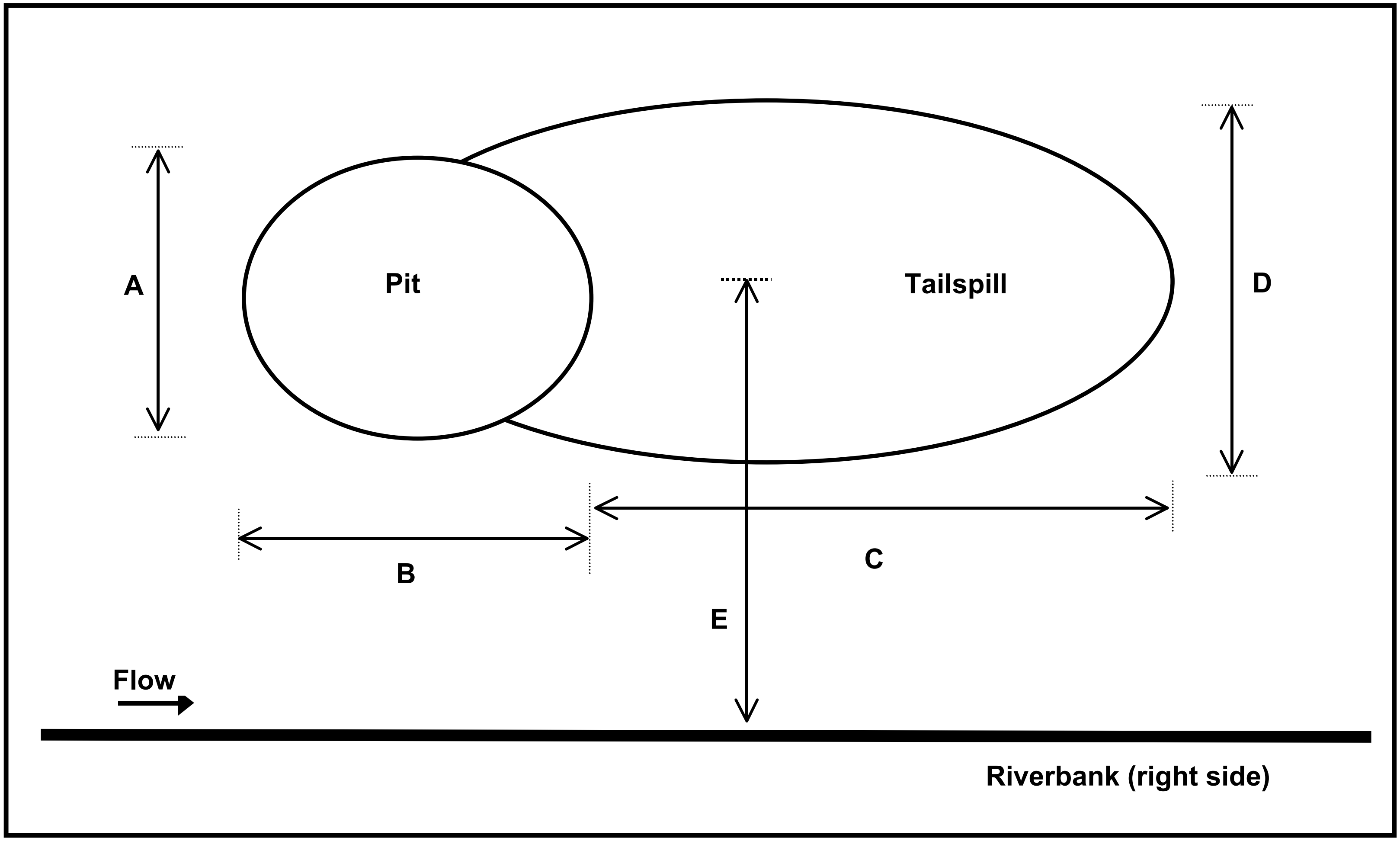


Figure 7. Diagrammatic top view of a chinook salmon redd showing various measurements taken: A) width of the pit; B) length of the pit; C) width of the tailspill; D) length of the tailspill; E) distance to the closest riverbank.

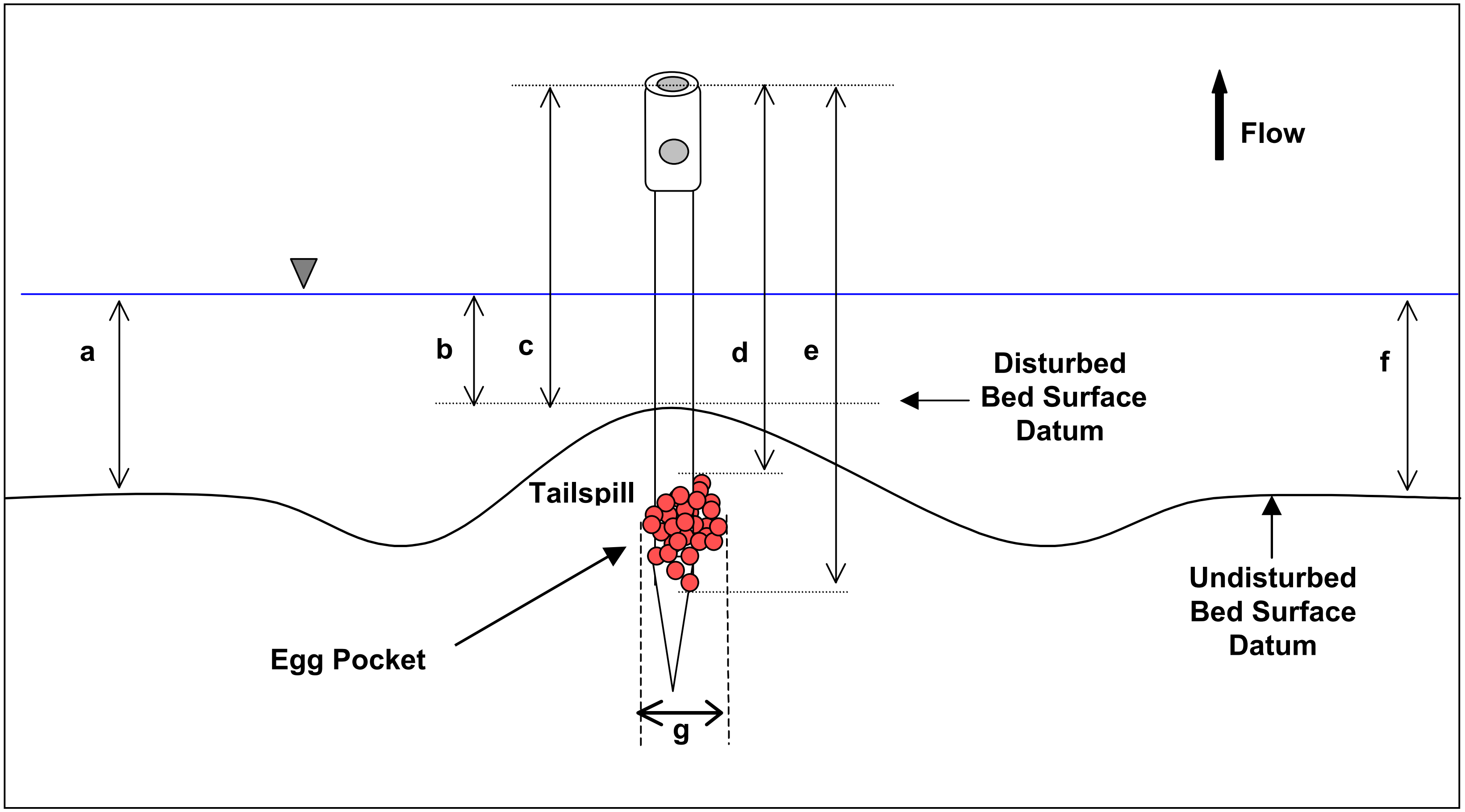


Figure 8. Diagrammatic cross section of a salmon redd, displaying the different measurements taken: a) distance from the water surface to the undisturbed (original) bed surface elevation; b) distance from the water surface to the disturbed bed surface (tailspill); c) distance from the top of the standpipe to the disturbed bed surface; d) distance from the top of the standpipe to the top of the egg pocket; e) distance from the top of the standpipe to the bottom of the egg pocket; f) distance from the water surface to the undisturbed bed surface; g) maximum observed egg pocket width.

Measurements were made of the distance from the top of the standpipe to the top and bottom of the egg pocket (denoted as *d* and *e* in Figure 8), and of the maximum observed egg pocket width (denoted as *g* in Figure 8). Qualitative measurements were taken of egg pocket morphology and median depth of egg deposition. The depths at which eggs were deposited were calculated with a modified version of a formula developed by Steen and Quinn (1999). Egg burial depths referenced to the disturbed substrate ($EBD_{disturbed}$) were calculated as:

$$EBD_{disturbed} = (d - c) \qquad (1)$$

where *d* is distance from the top of the egg pocket to the top of the standpipe and *c* the distance from the top of the tailspill to the top of the standpipe (Figure 8). The egg burial depth below the original streambed elevation ($EBD_{original}$) was calculated by:

$$EBD_{original} = (d - c) - \left(\frac{a + f}{2}\right) - b \qquad (2)$$

where *(d - c)* is the $EBD_{disturbed}$, *a* and *f* are the measurements taken of the distance between the water surface and the original bed surface elevation on the left and right side of the redd (Figure 8), and *b* represents the distance between the water surface and the tailspill.

Data were analyzed with a single-factor ANOVA model at $\alpha = 0.05$ using SAS software (SAS Institute 1999) to determine whether significant differences existed in the depth of egg deposition and the thickness of egg pockets between and within study reaches. The Ryan-Einot-Gabriel-Welsch multiple comparison procedure (Ryan 1960, Einot and Gabriel 1975) was used to compare reaches where the F-tests were significant; it is the most powerful test that controls experimentwise type I error rate (Day and Quinn 1989).

Particle Size Distribution Analysis

The laboratories of Graham Matthews and Associates, Weaverville, CA processed substrate samples. The samples were thoroughly oven-dried and then sieved in a Gilson TS-1 shaker through screens with mesh sizes at half-phi intervals ranging from $\phi = -8$ (256 mm) to $\phi = -1$ (2 mm). Phi (ϕ) denotes the Wentworth streambed particle size classification, given by:

$$\phi = -\log_2 D \qquad (3)$$

where D is the diameter of a given particle size in millimeters.

The remaining sediment finer than 2 mm was sieved through Gilson sieve tester model SS-15 8-inch testing screens at phi intervals down to $\phi = 4$ (0.063 mm). Because sediment finer than 0.83 mm has been shown to have biological significance for survival from egg incubation to emergence in salmonids (McNeil and Ahnell 1964, Tappel and Bjornn 1983), an additional sieve with a 0.85 mm mesh size was used. Tare weights for each screen and the gross weight of the sample portion retained on each screen were measured. The sample category weight was calculated by subtracting of the tare weight in each sieve class from the gross weight of the portion of the sample retained by each sieve. The sediment retained by each sieve size was converted to cumulative percentage dry weight finer than the corresponding sieve size. Percentages of sediment finer than 2 mm and the geometric mean diameter of particle size distributions were each compared among and between the three sites with a single-factor ANOVA model at $\alpha = 0.05$ (SAS Institute 1999).

SEDSIZE, a DOS-based data reduction program (Stevens and Hubbell 1986), was used to calculate statistical measures based on the fluvial particle-size distributions. Diameters were calculated for grain sizes for which the 84th, 75th, 50th, 25th, and 16th percentiles of each sample were finer. The geometric mean particle size (D_g) is a measure of the central tendency of the particle size distribution, calculated as:

$$D_g = D_1^{w_1} * D_2^{w_2} .... * D_n^{w_n} \tag{4}$$

where D is the midpoint diameter of particles retained by a given sieve in mm and w is the weight fraction in percentiles of particles retained by a given sieve (Lotspeich and Everest 1981). The fredle index (f_i) is a descriptor of pore size and permeability, where an increase in f_i is indicative of an increase in porosity (Lotspeich and Everest 1981). The fredle index is given by

$$f_i = \frac{D_g}{s_o} \tag{5}$$

where s_o is computed as:

$$s_o = \sqrt{\frac{D_{75}}{D_{25}}} \tag{6}$$

where D_{75} and D_{25} are the gravel diameters in mm corresponding to the particles sizes which 75% and 25% of the sample is finer.

Tappel and Bjornn (1983) developed an index to predict percentage survival of chinook salmon eggs from a particle size distribution. They documented a relationship between the percentage of particles finer than 9.5 mm, calculated from a non-truncated distribution of substrate finer than 24.5 mm, and survival from egg to emergence in chinook salmon. The equation they developed is given as:

$$Percentage\ survival = 93.4 - 0.171 s_{9.5} s_{0.85} + 3.87 s_{0.85} \qquad (7)$$

where $S_{9.5}$ and $S_{0.85}$ are the percentages of substrate finer than 9.5 and 0.85 mm. Data values for percentages of particles finer than 9.5 mm were interpolated between the 8 mm and 11.5 mm sieves.

RESULTS

Samples were collected from a total of 28 redds from Bucktail/ Salt Flat (n = 10) (Figure 9), Steel Bridge Campground (n = 10) (Figure 10), and Junction City (n = 8) (Figure 11). Coordinates for sample locations are tabulated in Appendix A. Redds were observed to be most abundant at the Steel Bridge Campground reach and least abundant in the Junction City reach. Redds were primarily observed along channel margins (Figure 12), and were an average of 3.6 m away from the riverbank in the Junction City reach, 4.5 m in the Steel Bridge Campground reach, and 7.8 m in the Bucktail reach. The average redd had a pit that was 1.5 m wide, 1.7 m long, had a maximum depth of 0.1 m below the original streambed surface, and contained a tailspill that was 1.5 m wide, 2.4 m long, and 0.13 m above the streambed (Table 1 and Appendix B).

Egg pockets were located in 28 redds, and 1102 eggs were observed. The number of eggs observed per sample ranged from 3 to 223, with a mean of 39 eggs (Table 2 and Appendix C). Most samples contained viable eggs, with the exception of two that contained dead eggs (core sample #15 and #18), and one that contained newly hatched alevins (core sample #29). Egg pockets were located primarily along the centerline axis of each redd parallel with the direction of flow. The majority of successful freeze-cores were extracted from the upstream end of the redd closest to the pit (Figure 13). Most egg pockets were found deposited between large diameter grains (> 90 mm) (Figure 14). Pockets were surrounded by medium size gravel and cobbles, and topped by coarser bed material. Egg pockets appeared to vary in shape depending on the size and

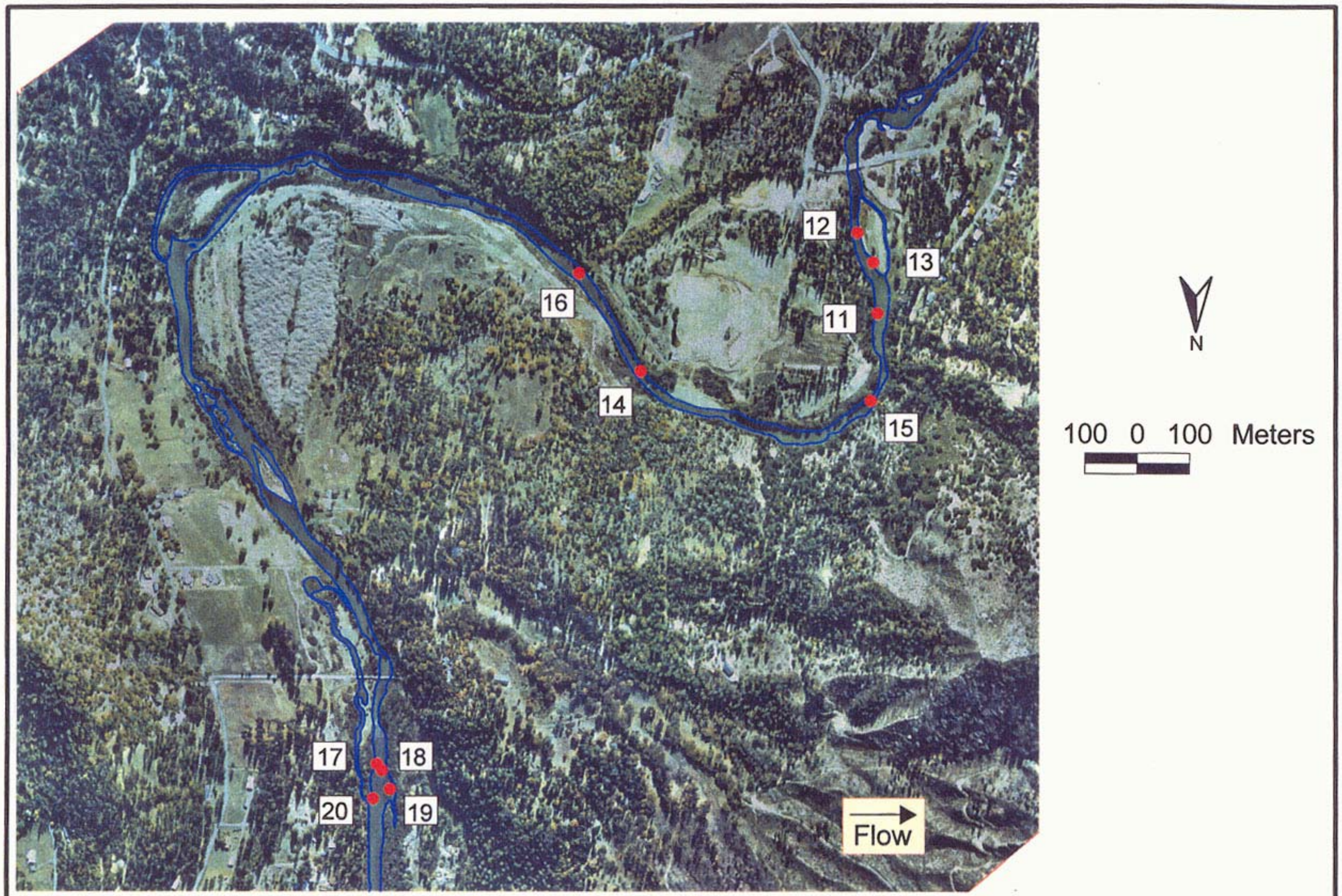


Figure 9. Aerial photograph of reach #1, Salt Flat (rkm 174) to Bucktail (rkm 169), showing individual sample points. 1997 Trinity River aerial photograph courtesy of California Department of Water Resources.

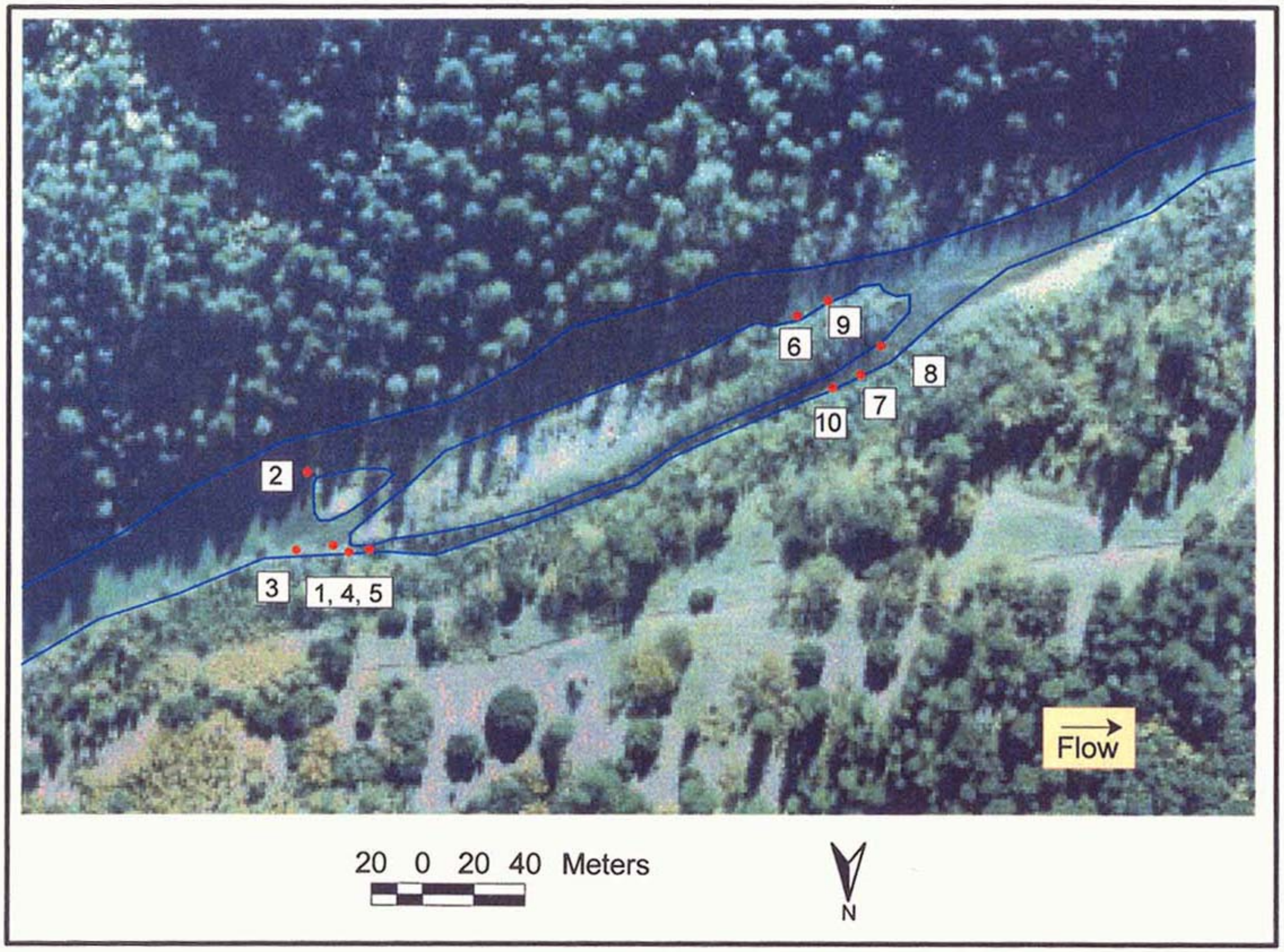


Figure 10. Aerial photograph of reach #2, Steel Bridge Campground (rkm 159) , showing individual sample points. 1997 Trinity River aerial photographs courtesy of California Department of Water Resources.

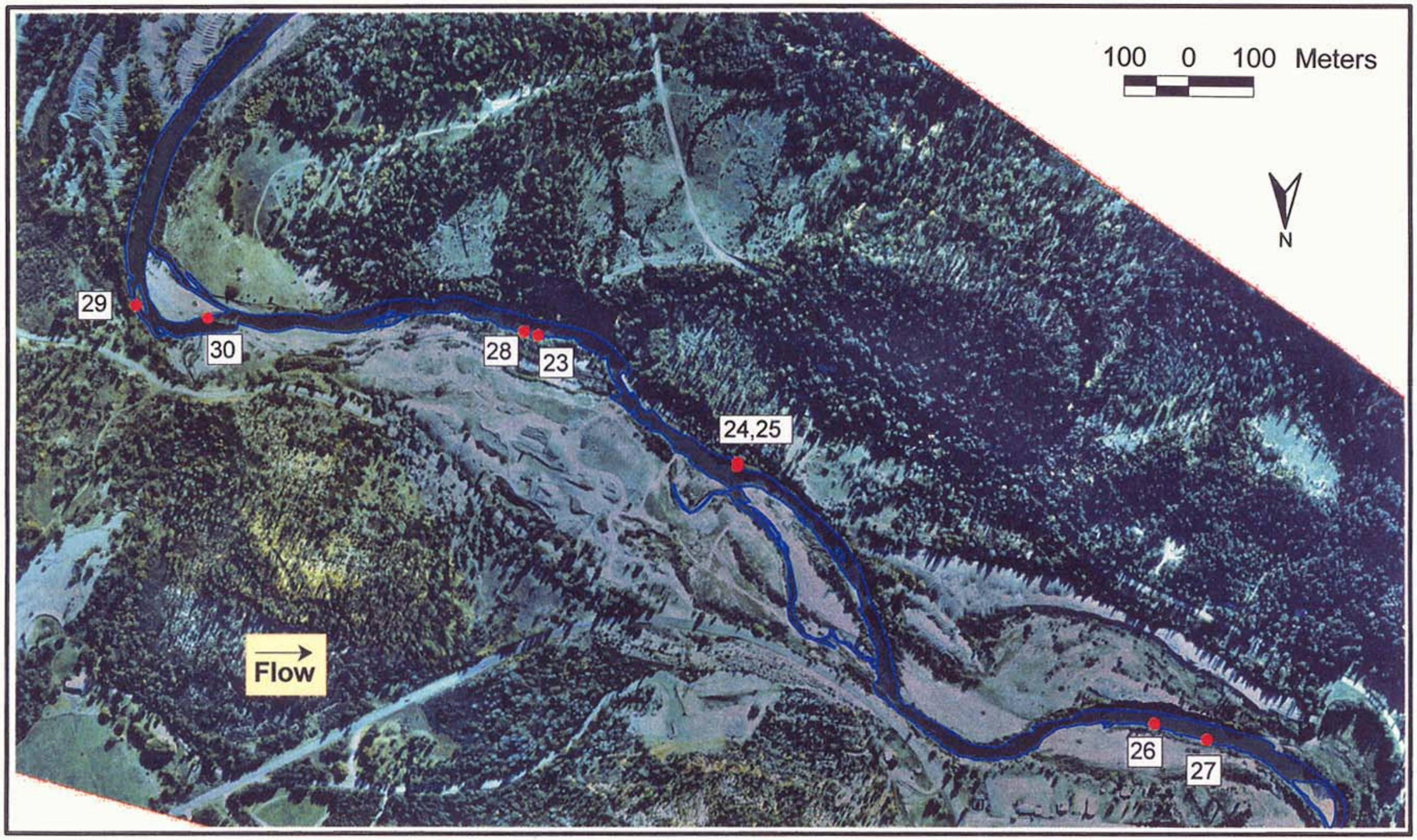


Figure 11. Aerial photograph of reach #3, Oregon Gulch to Dutch Creek Bridge (rkm 129) , showing individual sample points. 1997 Trinity River aerial photograph courtesy of California Department of Water Resources.

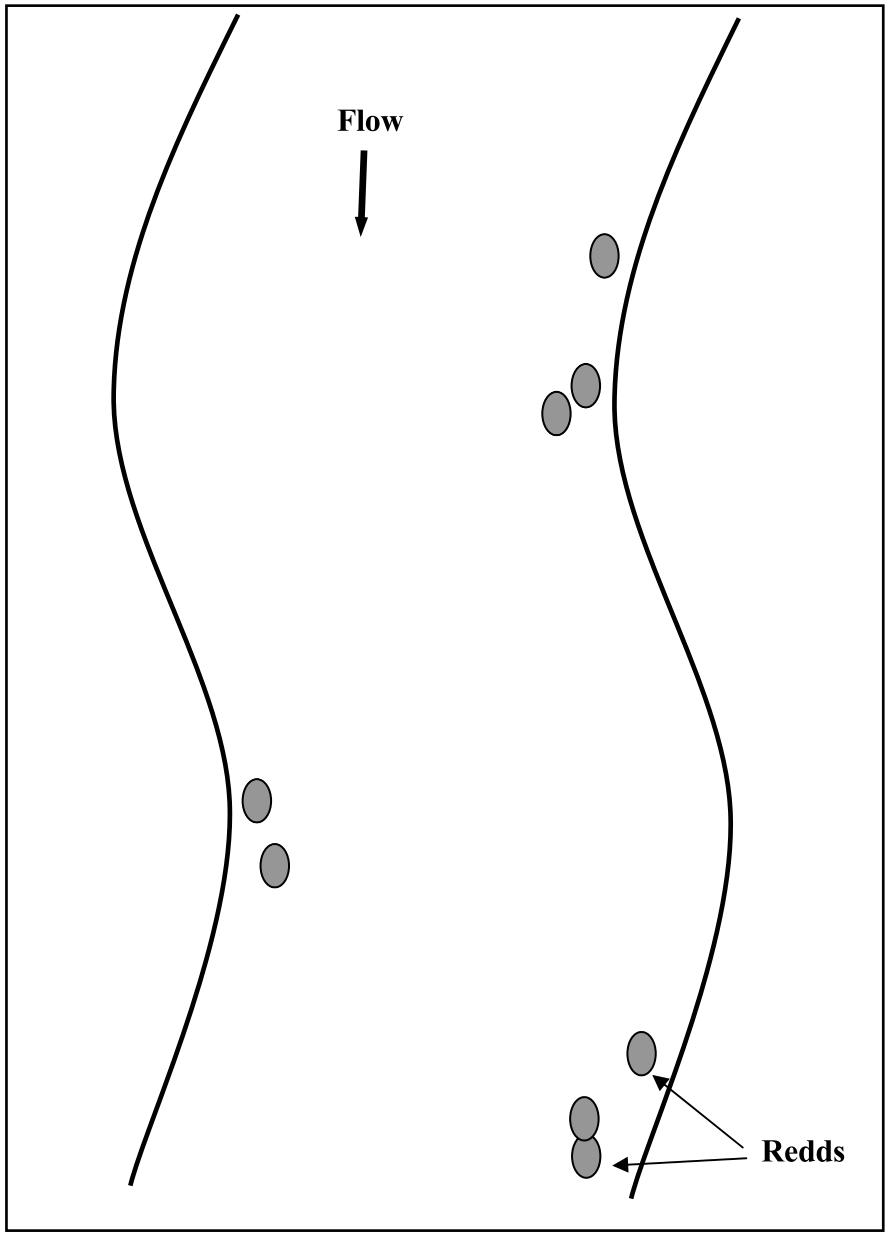


Figure 12. Diagrammatic top view of a stream channel showing relative observed locations of chinook salmon redds, Trinity River, California (Fall 2000).

Table 1. Summary data gathered on chinook salmon redds, Trinity River, California, October 21 through December 7, 2000.

	Pit			Mound			
Site	Width (m)	Length (m)	Maximum depth (m)	Width (m)	Length (m)	Minimum depth (m)	Distance to bank (m)
Bucktail	1.39	1.54	0.09	1.63	2.20	0.10	7.77
Steel Bridge	1.22	1.37	0.10	1.36	2.44	0.14	4.51
Junction City	2.00	2.28	0.13	1.64	3.06	0.16	3.61
Average	1.50	1.69	0.10	1.54	2.44	0.13	5.26

Table 2. Summary data on egg burial depths for the Trinity River, California, October 21 through December 7, 2000.

		Disturbed bed surface		Original bed surface			
Site	Mean # of eggs	Depth to top of pocket (cm)	Depth to bottom of pocket (cm)	Depth to top of pocket (cm)	Depth to bottom of pocket (cm)	Egg pocket thickness (cm)	Max. pocket width (cm)
Bucktail	36	22.5	31.5	19.5	28.5	9.0	11.5
Steel Bridge	54	28.0	35.0	25.0	32.0	7.0	11.0
Junction City	24	29.0	36.0	23.0	29.5	6.5	10.0
Average	39	26.5	34.0	22.5	30.0	7.5	11.0

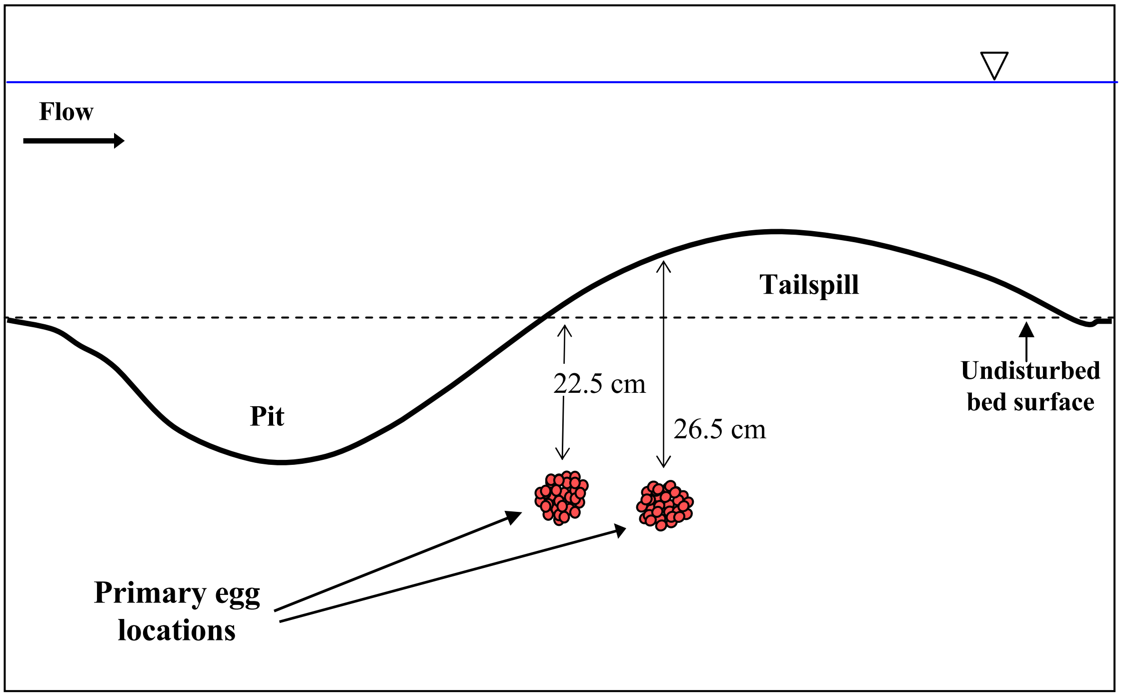


Figure 13. Diagrammatic side view of a chinook salmon redd showing the relative location of egg pockets observed in chinook salmon redds and the mean depth to the top of the egg pocket Trinity River, California (Fall 2000).

Figure 14. Photograph displaying egg pocket structure, Trinity River, California (Fall 2000).

configuration of the substrate they were buried in. Many of the sampled redds contained low percentages of fine sediment (< 2 mm) near the egg pocket (Figure 15). However, in several egg pockets, sand and finer sediment, such as decomposed granite and silt, were observed in high volumes (Figures 16, 17).

Egg Burial Depths

$EBD_{original}$ ranged from 5.25 cm to 51.5 cm, with a mean of 22.5 cm to the top of egg pocket and 28.6 cm to the bottom of egg pocket. The shallowest eggs encountered were located 5.5 cm to 36.5 cm below the original bed surface (Figure 18a). $EBD_{disturbed}$ ranged from 15 cm to 53 cm, with a mean depth of 26.5 cm to the top of the egg pocket and 34.0 cm to bottom of the egg pocket (Figure 18b).

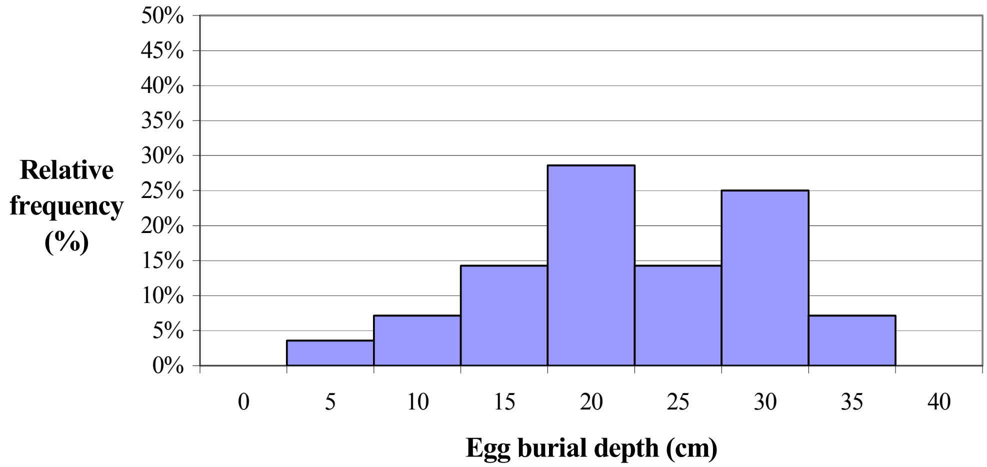
The mean egg pocket thickness was 7.6 cm (Figure 19), and the mean of the maximum observed egg pocket width was 11 cm. Raw data on the depth of egg pocket deposition are summarized in Appendix B. Statistical similarity for the thickness of egg pockets was evaluated and no significant differences were found between the three reaches ($p = 0.666$). The analysis of variance revealed no significant differences between sites for $EBD_{original}$ measured to the top ($p = 0.305$) or bottom ($p = 0.672$) of egg pockets (Table 3). Significant differences between sites were not detected for $EBD_{disturbed}$ depths to the bottom of the egg pocket ($p = 0.135$), but were detected for the depth to the top of the pocket ($p = 0.030$). The Bucktail/ Salt Flat site had a significantly lower $EBD_{disturbed}$ to top of the egg pocket than the other two sites with a mean depth of 22.7 cm.

Figure 15. Photograph of core sample exhibiting a cleaned egg pocket, Trinity River, California (Fall 2000).

Figure 16. Photograph of freeze-core sample from Steel Bridge Campground showing eggs buried in sand, Trinity River, California (Fall 2000).

Figure 17. Photograph showing eggs buried in fine sediment and sand, Trinity River, California (Fall 2000).

a)



b)

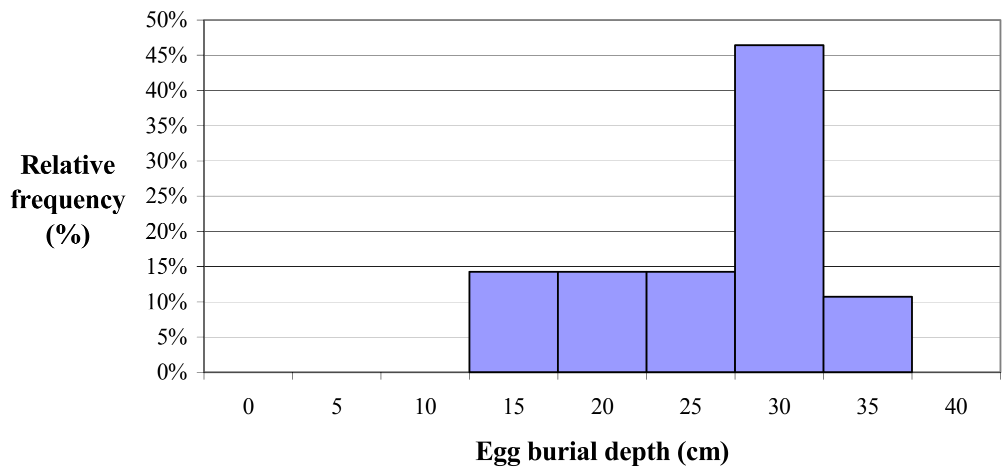


Figure 18. Histogram of depth to the top of the egg pocket referenced to: a) the original bed surface elevation, and b) the disturbed bed surface elevation, Trinity River, California (Fall 2000).

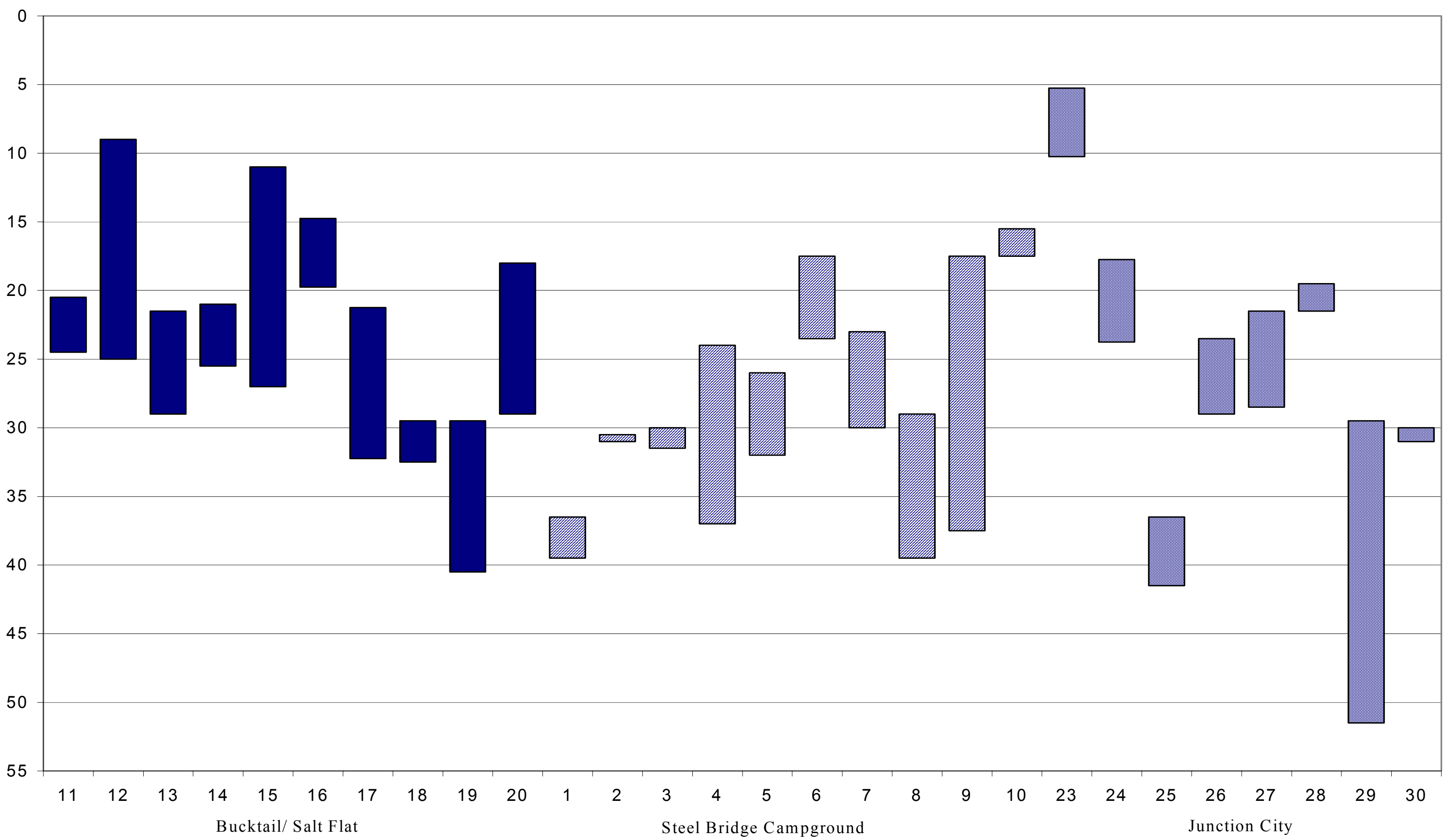


Figure 19. Histogram of egg pocket thickness and depth below the original bed surface, Trinity River, California (Fall 2000).

Table 3. Results of one-way ANOVA for association of chinook egg burial depths and thickness among and between study sites, Trinity River, California (Fall 2000).

Data	Source of variation	df	Original bed surface		Disturbed bed surface	
			F	p	F	p
Top of egg pocket	Site	2	1.25	0.305	4.05	0.030[a]
Bottom of egg pocket	Site	2	0.40	0.672	2.18	0.135
Egg pocket thickness	Site	2	0.41	0.666	-	-

[a] significant for $\alpha = 0.05$.

Particle Size Distribution Analysis

The analysis of conditions within the egg pocket as a function of particle size distribution was intended to be exploratory, especially given the inherent biases associated with the freeze-core technique for this type of analysis. Particle size distribution indexes are summarized in Table 4. Sample weights ranged from 4 to 25 kg. Distributions were skewed by the presence of cobbles that were disproportionately large relative to the overall sample composition (Figure 20, Appendices D, E, F). This prevented the calculation of the D_{75} and D_{84} in several of the samples and inhibited the calculation of the fredle index (f_i).

The cumulative percentage of fine sediment less than 2 mm in diameter was greater in redds from the Junction City site than in redds from the two upstream sites (Figure 21). However, an ANOVA on the percentage of fine sediment less than 2 mm could not be performed because the data did not have a normal distribution and equal variance even when transformed. The geometric mean diameter was greatest in Steel Bridge Campground with a mean of 47.1 mm, and was significantly different from the mean value of 29.0 mm observed in Junction City reach and 33.6 mm in Bucktail/ Salt Flat ($p = 0.014$). The fredle index ranged from 0.8 in the Bucktail/ Salt Flat reach to 24.7 in Steel Bridge Campground, however, it could only be calculated for 7 samples. The Tappel and Bjornn (1983) equation predicted that the survival to emergence of chinook salmon embryos ranged from 62% to 100%, and the majority of samples were greater than 80% (Table 4). The predicted percentage survival decreased with distance downstream, as amount of fine sediment increased. The Bucktail/ Salt Flat reach therefore demonstrated the highest

Table 4. Summary table of particle size distribution indexes calculated for substrate composition surrounding chinook salmon egg pockets, Trinity River, California (Fall 2000).

	% Fine sediment										
Sample #	<2 mm	<1 mm	<0.85 mm	D_{84}	D_{75}	D_{50}	D_{25}	D_{16}	D_g	Fredle index	Tappel & Bjornn
					Steel Bridge Campground						
1	2.8	1.3	1.1	87.6	70.8	44.7	19.8	10.1	31.9	16.9	94.8%
2	2.8	1.0	0.8	n/v	n/v	110.6	41.6	21.1	54.8	n/v	95.3%
3	2.2	1.1	0.9	n/v	n/v	71.7	26.2	13.3	25.0	n/v	94.6%
4	2.8	1.8	1.6	n/v	n/v	71.7	36.0	23.0	48.6	n/v	97.0%
5	1.7	0.9	0.4	n/v	n/v	54.5	44.4	34.6	45.2	n/v	95.0%
6	6.9	3.6	3.0	90.4	78.2	56.4	28.6	12.4	34.9	21.1	97.2%
7	3.8	1.9	1.6	n/v	84.4	71.1	29.0	13.6	42.1	24.7	95.6%
8	3.6	2.2	1.9	n/v	n/v	126.3	48.9	28.6	70.8	n/v	98.4%
9	2.8	1.5	1.3	n/v	n/v	79.6	48.4	34.3	73.0	n/v	97.6%
10	3.8	2.5	2.2	n/v	n/v	75.9	27.4	15.8	44.8	n/v	97.1%
					Bucktail/ Salt Flat						
11	9.6	6.8	6.2	n/v*	n/v	46.8	13.4	5.6	25.4	n/v	90.2%
12	4.0	2.7	2.4	n/v	n/v	47.0	24.6	15.4	33.0	n/v	97.3%
13	4.0	2.5	2.2	n/v	n/v	30.2	35.2	19.0	56.6	n/v	97.8%
14	5.0	2.5	2.1	n/v	n/v	49.3	17.7	9.0	29.2	n/v	94.1%
15	5.9	3.7	3.4	n/v	n/v	52.9	30.5	20.1	35.1	n/v	99.9%
16	3.4	2.5	2.3	n/v	n/v	55.7	33.7	18.1	41.1	n/v	97.6%
17	6.0	2.7	2.0	n/v	n/v	41.6	16.1	8.3	27.1	n/v	93.6%
18	6.6	3.6	3.0	n/v	85.5	47.0	16.7	8.6	29.8	0.8	93.9%
19	8.5	5.7	5.1	n/v	57.3	36.1	14.7	7.1	24.1	0.8	92.3%
20	3.5	1.6	1.3	n/v	n/v	52.2	25.6	13.8	35.0	n/v	95.3%
					Junction City						
23	6.5	3.4	2.7	n/v	n/v	39.6	13.9	7.4	24.6	n/v	92.3%
24	4.7	3.3	2.9	n/v	n/v	48.0	20.2	11.6	30.8	n/v	95.9%
25	7.5	4.8	4.1	n/v	n/v	73.2	23.1	10.1	37.7	n/v	96.8%
26	12.4	8.8	7.6	66.6	51.6	26.6	10.1	4.1	18.2	8.0	81.3%
27	11.8	7.8	6.5	n/v	30.0	28.4	8.4	3.8	19.1	n/v	80.2%
28	17.6	11.1	9.5	63.0	54.4	27.0	4.2	1.7	14.1	3.9	62.1%
29	5.5	3.8	3.5	n/v	n/v	68.4	33.1	16.9	41.8	n/v	98.8%
30	3.4	1.7	1.3	n/v	n/v	108.7	29.9	16.8	46.0	n/v	96.0%

* n/v = no value computed due to small sample size.

Figure 20. Photograph of core sample with large diameter cobble, Trinity River, California (Fall 2000).

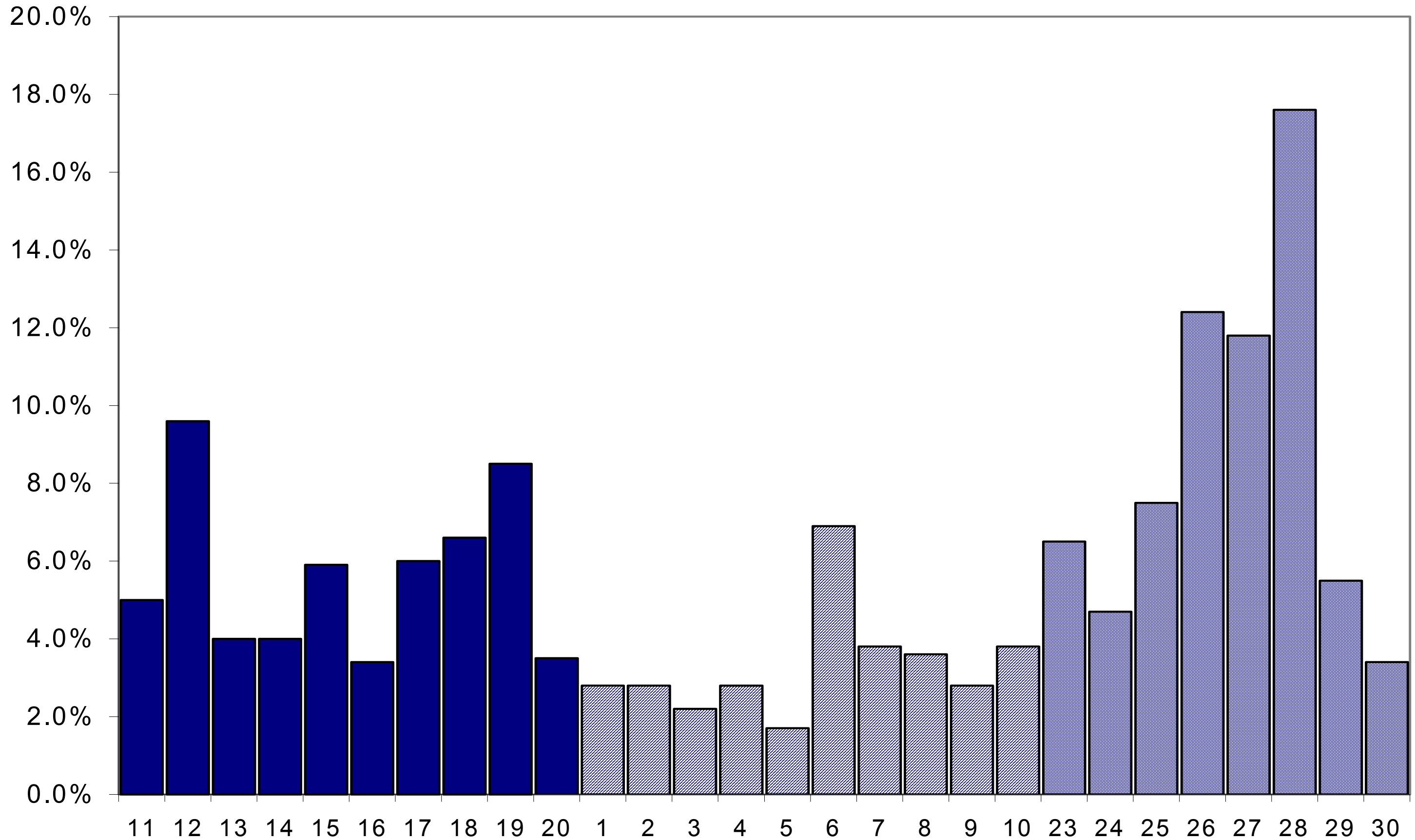


Figure 21. Histogram of cumulative percentage of fine sediment less than 2 mm in diameter by sample number and river reach, Trinity River, California (Fall 2000).

overall survival (90% to 100%), while the Junction City reach displayed a variable range of values (62% to 98%).

DISCUSSION

Location of Redds and Egg Burial Depths

The spawning density was very low in the Junction City reach compared to historical estimates (USFWS 1999). The lack of complex channel features (riffles, pools, alternate bar sequences, etc.) typically associated with quality salmonid spawning habitat may explain the small amount of spawning in this reach. Redds were only observed where woody debris (slash, etc.) had fallen into the active channel. The debris may provide protective cover, retain adequate sized spawning gravels, and provide a break in the elevated shear stress associated with trapezoidal, confined channel morphology. This may explain the proximity of redds to channel banks observed in this reach. The Bucktail reach also had a relatively low density of redds, whereas abundant spawning was observed in the Salt Flat reach. Numerous redds were observed in the alluvial deposits of Steel Bridge Campground despite the presence of large quantities of sand. Data gathered by Barnard (2001) indicates that sand, particularly decomposed granite, has a relatively high permeability. However, the presence of excessive sand can prevent the emergence of alevins (Phillips et al. 1975) and contribute to loss of cohort.

The distance between the disturbed bed surface and the original bed surface elevation was an average of 4.4 cm. These results are consistent with the 0 to 5 cm range reported by DeVries (1997). The mean $EBD_{disturbed}$ values reported in this study for the egg pocket top (22 cm) and bottom (34 cm) are more than 5 cm deeper than the 19 cm and 29 cm mean depths reported by Chapman et al. (1986) for chinook redds on the Columbia River, but they are close to other reported values (Table 5). The egg pocket measured in

Table 5. Summary of reported egg burial depths for chinook salmon. Data are adapted from DeVries (1997).

Datum	Portion of pocket referenced	Authors	Mean depth (cm)	*n*	Range of depths (cm)	Location	Method
Original level	Bottom	Miller (1985)	30			Washington	
		This study (2001)	30	28	10-51	California	Freeze-core
	Bottom						
	Discrete eggs	Hobbs (1937)			30-41	New Zealand	Excavation
	Top	Burner (1951)	22-27		5-51	Washington	Observation
	Top	Briggs (1953)		2	28-36	California	Observation
	Top	This study (2001)	22	28	5-37	California	Freeze-core
Overlying gravel	Bottom	Chapman et al. (1986)	29	54	19-37	Columbia River	Probing
	Bottom	This study (2001)	34	28	18-53	California	Freeze-core
	Top	Chapman et al. (1986)	19	116	10-33	Columbia River	Excavation
	Top	Briggs (1953)	28	8	20-36	California	Excavation
	Top	Vronskiy (1972)	21	10	10-46	USSR	Excavation
	Top	This study (2001)	26	28	15-37	California	Freeze-core

core sample #30 contained the greatest observed range of depths. This may be attributed to the presence of alevins, which can move through pore spaces in the gravel, and it may not be reflective of the original depth of egg deposition. The greatest overall sources of variability may be attributed to measurement technique, microhabitat site selection, substrate size, excavation barriers, and fish size (DeVries 2000).

Spawning Gravel Quality

In the segment of reach #3 immediately upstream of the Dutch Creek Bridge, predicted survival to emergence was affected by elevated concentrations of fine sediment. Samples #25, #26 and #28 all appeared to have reduced quality substrate surrounding the egg pocket, which may be attributed to the microhabitat characteristics associated with the location of the redd in this confined portion of channel. The two egg pockets that contained dead eggs (samples #15 and #19) had no observable differences in substrate composition compared to pockets containing viable eggs; it is likely that the dead eggs were never fertilized.

Although the gravel quality indices examined in this study (percentage of fine sediment less than 2 mm, geometric mean diameter, the fredle index, and the predicted percentage survival) suggest that the conditions surrounding the egg pockets were generally favorable to support survival to emergence, the small sample size precludes strong inferences from being made. Using the criterion that sample size should be 1% of the largest diameter particle (Church et al. 1987), sample sizes would need to be approximately 100 to 1250 kg to be representative of the natural streambed composition. Because sample sizes were small (4 - 25 kg), the particle size distributions were skewed by large particles contained within samples. Most gravel quality indexes are based on the proportion by weight of fine sediment present, therefore, the proportion of particles in any one class, particularly large particles, may bias an entire distribution.

To evaluate the effect of the bias of large grain size on gravel quality indices, a sensitivity analysis was conducted on the percentage of fine sediment less than 2 mm in diameter and the geometric mean diameter (D_g) from four samples. Samples #8, 12, and 14 were selected for this analysis based on a high level of skewness in particle size distributions, and sample #1 was chosen because it contained a distribution less biased toward large grains. The largest particles were removed from each sample at successively smaller half-ϕ intervals, and particle size distributions were re-calculated. The percentage of fine sediment < 2 mm and D_g calculated from the truncated distributions were compared to values from the original distributions (Table 6).

The percentage of fine sediment less than 2 mm in diameter increased by more than 100% in samples #1, 12 and 14 when distributions were truncated at $\phi = -5.5$ (particle diameter = 45 mm), and by more than 300% in sample #8. Values of D_g decreased substantially (14% - 53%) as the largest particles were removed from the distribution (Table 6). The data indicate that the percentage of fine sediment is underestimated by the original distributions, particularly in sample #8. Therefore, gravel quality indicators are overestimated. Furthermore, bulk sampling data collected simultaneously with this study in Trinity River spawning beds indicates a higher concentration of fine sediment than is reported in this study (Barnard 2001) (Table7). The data confirm the findings of Shirazi

Table 6. A comparison of the percentage of fine sediment < 2 mm and geometric mean diameter (D_g) found in four egg pockets sampled with a liquid nitrogen freeze-core technique, Trinity River, California (Fall 2000). Values were calculated from: 1) the complete particle size distribution, and 2) the distribution with largest particles removed at half-ϕ intervals. Percentage difference compares truncated values to the values from the original sample distribution.

	% Fine sediment < 2 mm			D_g		
ϕ	Original distribution	Truncated distribution	% Difference	Original distribution	Truncated distribution	% Difference
			Sample #1			
-7.0	2.8			31.9		
-6.5		3.3	18		25.8	19
-6.0		4.0	43		20.3	36
-5.5		5.6	100		14.0	56
-5.0		8.0	186		9.1	71
-4.5		10.3	268		6.6	79
			Sample #8			
-7.5	3.6			70.8		
-7.0		7.0	94		33.2	53
-6.5		9.9	175		20.3	71
-6.0		12.4	244		14.5	80
-5.5		14.8	311		11.3	84
-5.0		20.4	467		7.1	90
-4.5		27.4	661		4.5	94
			Sample #12			
-7.0	9.6			25.4		
-6.5		14.2	48		12.7	50
-6.0		14.2	48		12.7	50
-5.5		20.0	108		7.0	72
-5.0		20.0	108		7.0	72
-4.5		25.9	170		4.7	81
			Sample #14			
-7.0	4.0			29.2		
-6.5		7.2	80		25.2	14
-6.0		7.2	80		25.2	14
-5.5		9.9	148		16.6	43
-5.0		13.5	238		10.9	63
-4.5		17.1	328		7.8	73

Table 7. A comparison of reported values of percentages of fine sediment less than 2 mm in diameter gathered from bulk-sampling methods (Barnard 2000) and freeze-core sampling (This study 2001) for two locations, Trinity River, California.

Site	Author	Sample size (kg)	% Fines < 2mm
Steel Bridge Campground	Barnard (2000)	707.6	15.6
	This study (2001)	24.7	3.6
Junction City	Barnard (2000)	581.5	16.6
	This study (2001)	13.1	7.5

et al. (1981) and National Council of the Paper Industry for Air and Stream Improvement (1986) that single-probe freeze-coring may not be an appropriate method for sampling particle size distributions in gravel-bed streams, even though it is an effective technique for sampling egg burial depths.

Prediction of Scour-Related Egg Mortality

This project was designed to investigate egg burial depths to provide a foundation for research on the effects of river regulation on the survival of chinook salmon embryos. One method of predicting egg scour resulting from high discharge events is to establish relationships between bed-scour in redds and discharge. Data on the vertical distribution of eggs can be used to establish a frequency distribution of eggs as a function of depth. Next, a relationship between redd-scour depth and egg mortality at one site is established. The ultimate goal is to develop a relationship that predicts the percentage loss of cohort directly from discharge.

To illustrate this concept, an exploratory experiment was conducted. Existing data on the amount of bed-scour at various discharges were used along with the data gathered in this study on egg burial depths to predict egg and embryo mortality. Bed-scour data were gathered from several sites on the Trinity River (Wilcock et al. 1995; McBain and Trush 1997; Hales 1999). These data were compared to discharge and a logarithmic relationship was plotted with an r^2 value of 0.87 (Figure 22). However, there are several caveats associated with the use of this scour data: 1) the relationship is only based on 8 data points; 2) patterns of scour vary for different geomorphic features and different locations in the

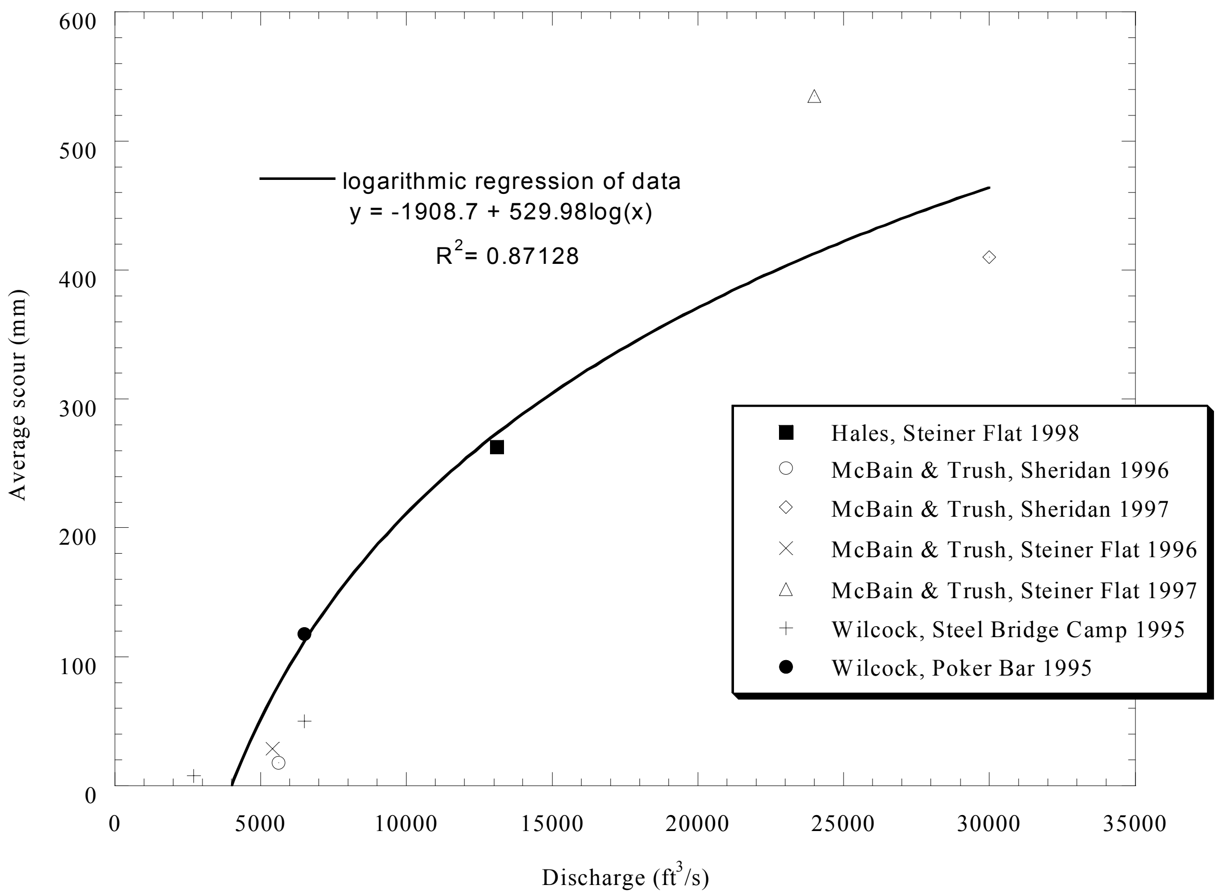


Figure 22. Relationship between average scour depth of the D_{50} particle size and discharge, Trinity River, California. Data are from Hales (1999), McBain and Trush (1996-1997), and Wilcock et al. (1995).

channel (Shuett-Hames et al. 2000); 3) scour mainly occurs on gravel/ cobble bars, and not on redds along channel margins; and 4) the data on scour depth correspond to site specific D_{50} particle sizes, which may not be the same size as D_{50} particle sizes reported in this study, and may result in an inaccurate estimate of bed-scour at a spawning site. Although it is difficult to make site-specific predictions of egg mortality based on bed-scour data gathered throughout a broad reach of the river, the utility in this type of exploratory exercise is to illustrate the predictive model as a management tool.

The depth, shape, and orientation of the egg pocket are also important determinants of the percentage loss of cohort. If an egg pocket is box-shaped and oriented horizontally so that it is wider than it is tall, scour down to the elevation at which eggs are buried will result in a higher percent mortality at that scour depth than an egg pocket with the same mean depth is oriented vertically (Figure 23). In a box-shaped egg pocket, percentage egg mortality will increase incrementally with scour depth, whereas if the egg pocket is conical, percentage egg mortality will initially be very high and increase at a slower rate. Assuming an even vertical distribution of eggs, a frequency distribution of eggs as a function of depth was generated from data on egg burial depths referenced to the original bed surface from this study (Figure 24).

Using the relationship described in Figure 22, a discharge of 297.3 m^3s^{-1} (10,500 ft^3/s) should cause a scour depth of 22 cm. This is the mean depth to the top of the egg pocket, and thus, the threshold discharge where egg mortality begins. Using the hypothetical relationships in Figure 24, a scour depth of 22 cm would cause approximately 42% egg mortality (Table 8). The mean depth observed to the bottom of the egg pocket a)

b)

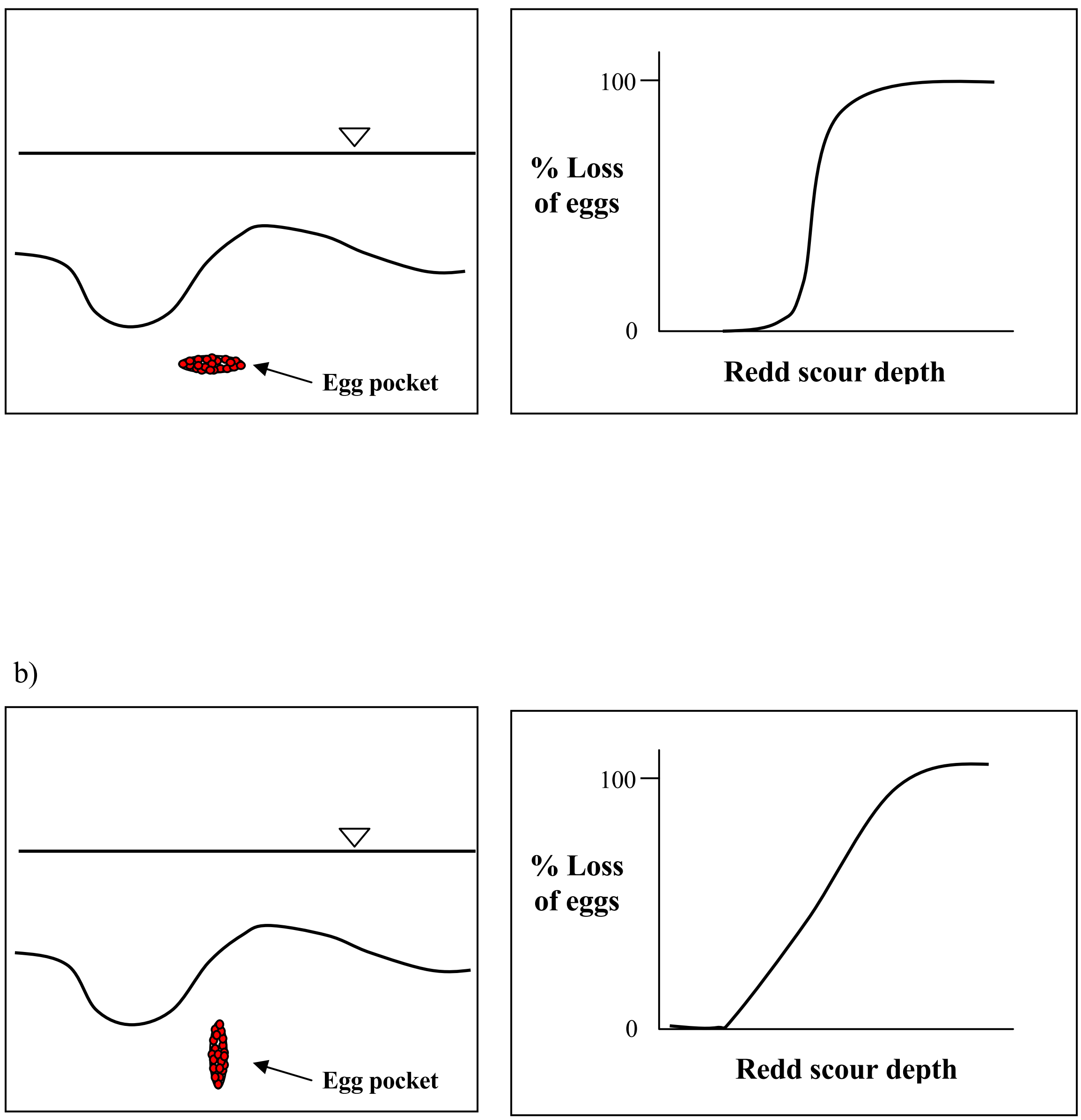


Figure 23. Diagrammatic cross sections of a redd and conceptual graph demonstrating the effect of egg pocket shape and orientation on percentage loss of eggs with the egg pocket oriented a) horizontally and b) vertically.

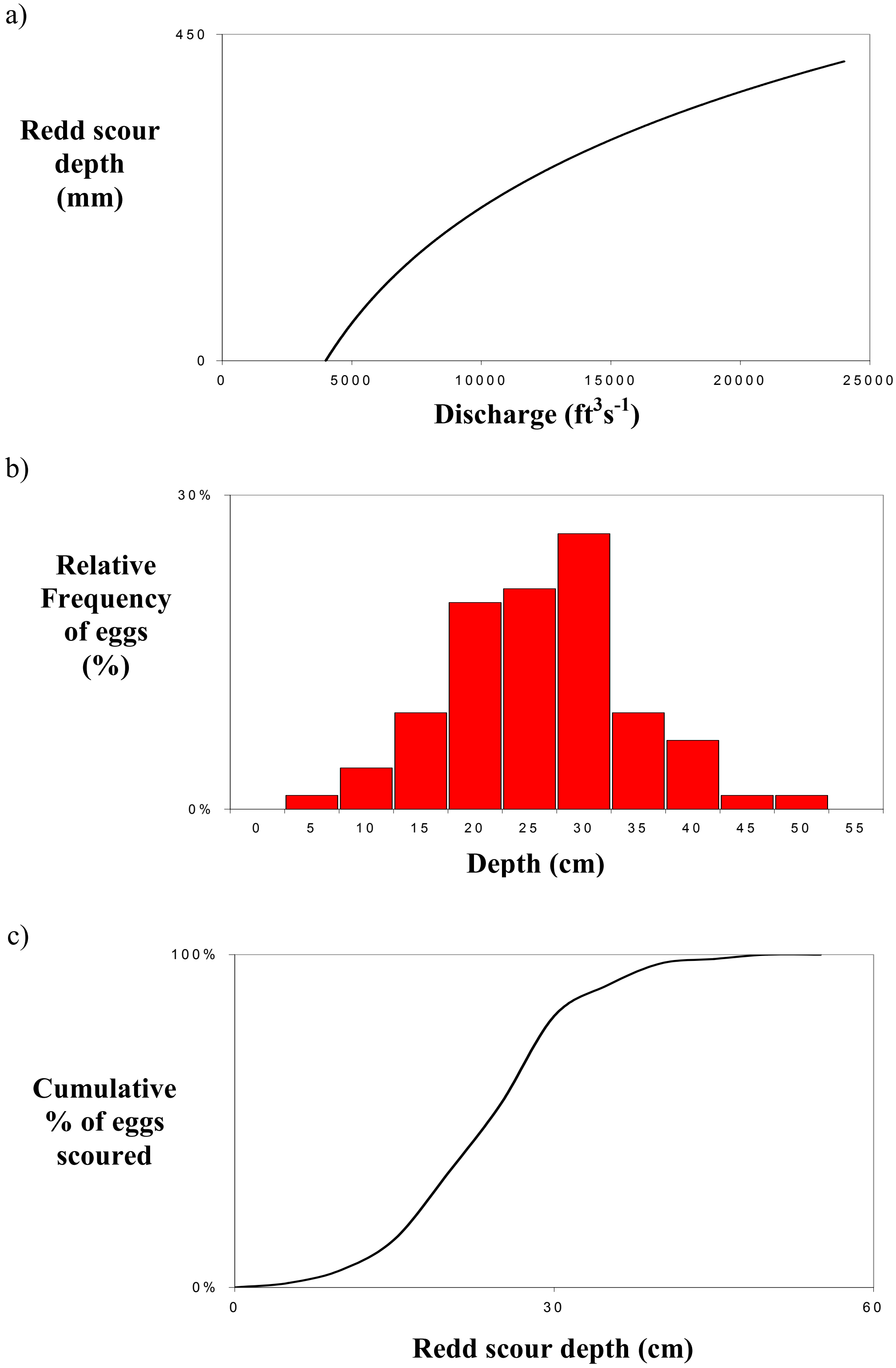


Figure 24. Hypothetical model designed to predict the percent mortality of embryos using relationships between: a) redd scour depth and discharge; b) frequency of eggs and depth; and c) cumulative frequency of eggs and redd scour depth.

Table 8. Results of hypothetical model predicting percent egg mortality from discharge and redd scour depth.

Discharge (ft^3s^{-1})	**Discharge (m^3s^{-1})**	**Scour depth (mm)**	**Egg Mortality (%)**
4500	127.4	2.7	0%
6500	184.0	11.2	7%
10000	283.0	21.1	38%
14000	396.2	28.9	78%
16000	452.8	31.9	86%

is 29.8 cm; using this model, a discharge of 424.7 m^3s^{-1} (15,000 ft^3/s) would cause 30.1 cm of redd scour, which would result in approximately 82% egg and embryo mortality. From a management perspective, this hypothetical exercise would indicate that discharge should not exceed approximately 170 m^3s^{-1} (6000 ft^3s^{-1}) during the period of egg incubation to prevent significant mortality of chinook embryos.

CONCLUSIONS

Depths to the top of egg pocket range from 5.5 cm to 36.5 cm below the original bed surface with a mean of 22.5 cm, while depths to the egg pocket bottom range from 10.5 cm to 51.5 cm with a mean of 30.0 cm. Referenced to the disturbed substrate, egg burial depths ranged from 15 cm to 31 cm with a mean of 26.5 to the top of the egg pocket, and 18 cm to 53 cm with a mean of 34 cm to the bottom of the egg pocket. Mean egg pocket thickness was found to be 7.6 cm.

Although gravel quality estimates suggested that conditions were favorable to support survival to emergence of chinook embryos, the small sample size prevents inferences from being made. All samples were in violation of generally accepted size criteria for particle size distribution analyses. Due to the bias of the freeze-core technique towards large diameter material, the reported particle size data should be used with extreme caution. Particle size distribution data underestimated the percentage of fine sediment, and therefore did not reflect the high percentage of sand observed in many of the samples. The sensitivity analysis suggests that spawning gravel quality indices were overestimated. Although single probe freeze-coring is an effective method for sampling egg burial depth, it may not be an appropriate method for sampling subsurface particle size distributions in gravel-bed streams.

This study provides some of the data necessary to evaluate the potential impacts of synchronizing dam releases on tributary derived high-flow storm events in the Trinity River on survival of incubating chinook salmon. Additional data is still needed on: 1) redd scour versus discharge in different types of spawning features (lateral deposits, pool tails, etc.), and 2) estimated egg to emergence from each redd such that the direct scour impact can be compared to no-scour emergence success.

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APPENDICES

Appendix A. UTM coordinates of individual sample points in NAD 27, Trinity River, California (Fall 2000).

Sample #	Easting	Northing
1	6308450	2131430
2	6308470	2131340
3	6308470	2131470
4	6308440	2131430
5	6308450	2131100
6	6307850	2131200
7	6307570	2131330
8	6307600	2131280
9	6307820	2131160
10	6307810	2131290
11	6326810	2141900
12	6326920	2141390
13	6326800	2141560
14	6328210	2142200
15	6326870	2142400
16	6328620	2141580
17	6329930	2144670
18	6329870	2144700
19	6329850	2144830
20	6329960	2144890
23	6271340	2147570
24	6270300	2148460
25	6270300	2148460
26	6268210	2149780
27	6267960	2149810
28	6271420	2147790
29	6273400	2147650
30	6273060	2147690

Appendix B. Measurements of chinook salmon redds, Trinity River, California, October 21 through December 7, 2000.

	Pit			Mound			
Sample #	Width (m)	Length (m)	Maximum depth (m)	Width (m)	Length (m)	Minimum depth (m)	Distance to bank (m)
Steel Bridge Campground							
1	1.4	2.0	-0.15	1.3	1.5	0.10	4.7
2	1.6	2.6	-0.15	1.2	3.2	0.07	4.3
3	1.3	2.4	-0.23	1.3	2.5	0.20	9.3
4	1.5	2.0	-0.16	1.5	3.0	0.22	3.8
5	1.0	1.0	-0.02	1.5	2.6	0.15	4.5
6	1.0	0.8	-0.04	1.5	2.0	0.26	2.2
7	1.0	0.5	-0.03	1.0	2.0	0.10	4.9
8	1.4	1.7	-0.09	1.3	2.7	0.09	4.1
9	1.0	0.8	0.02	1.5		0.10	
10	1.1	1.0	-0.13	1.5	2.5	0.14	2.8
Bucktail/ Salt Flat							
11	1.0	1.0	-0.04	1.3	1.5	0.18	5.1
12	1.0	0.5	0.04	1.5	1.8	0.20	3.5
13	1.0	1.2	-0.07	1.5	1.8	0.18	3.9
14	1.3	1.3	-0.23	1.3	1.5	0.16	1.5
15	1.0	1.0	-0.02	1.3	1.5	0.08	1.5
16	1.3	1.5	-0.01	1.3	2.0	0.07	9.3
17	1.0	1.7	-0.08	2.5	2.4	0.24	14.2
18	2.6	2.1	-0.19	2.1	2.1	0.01	11.2
19	1.7	3.4	0.00	1.9	5.5	-0.27	14.3
20	2.1	1.7	-0.27	1.8	2.0	0.12	13.2
Junction City							
23	2.0	2.3	-0.06	1.5		0.26	7.3
24	2.0	1.3	-0.03	1.5	2.3	0.21	1.4
25	2.8	2.9	-0.19	1.7	4.3	0.07	2.7
26	1.6	2.3	-0.10	1.7	3.9	0.23	4.6
27	2.5	1.6	-0.17	1.6	1.4	0.08	2.0
28	1.7	3.8	-0.25	1.6	2.2	0.15	3.7
29	1.9	2.1	-0.20	2.1	4.8	0.21	3.4
30	1.5	2.0	-0.09	1.4	5.6	0.12	3.8

Appendix C. Data collected on egg burial depths in chinook salmon redds, Trinity River, California, October 21 through December 7, 2000.

		Disturbed bed surface		Original bed surface			
Sample #	# of eggs	Depth to top of pocket (cm)	Depth to bottom of pocket (cm)	Depth to top of pocket (cm)	Depth to bottom of pocket (cm)	Pocket thickness (cm)	Max. pocket width (cm)
			Steel Bridge Campground				
1	38	28.0	31.0	36.5	39.5	3.0	14
2	3	30.5	31.0	30.5	31.0	0.5	2
3	16	31.0	32.5	30.0	31.5	1.5	10
4	34	28.0	41.0	24.0	37.0	13.0	12
5	19	36.0	42.0	26.0	32.0	6.0	
6	84	24.0	30.0	17.5	23.5	6.0	14
7	11	26.0	33.0	23.0	30.0	7.0	
8	108	33.5	44.0	29.0	39.5	10.5	18
9	223	28.0	48.0	17.5	37.5	20.0	
10	6	16.0	18.0	15.5	17.5	2.0	
			Bucktail/ Salt Flat				
11	8	29.0	33.0	20.5	24.5	4.0	10
12	16	20.5	36.5	9.0	25.0	16.0	
13	23	21.5	29.0	21.5	29.0	7.5	11
14	5	22.0	26.5	21.0	25.5	4.5	
15	112	17.5	33.5	11.0	27.0	16.0	10
16	52	15.0	20.0	15.0	20.0	5.0	15
17	42	29.0	40.0	21.5	32.5	11.0	11
18	40	16.5	19.5	29.5	32.5	3.0	
19	27	25.5	36.5	29.5	40.5	11.0	
20	41	30.0	41.0	18.0	29.0	11.0	9
			Junction City				
23	27	29.5	34.5	5.5	10.5	5.0	14
24	38	29.5	35.5	18.0	24.0	6.0	
25	3	27.0	32.0	36.5	41.5	5.0	
26	10	36.5	42.0	23.5	29.0	5.5	7
27	103	19.0	26.0	21.5	28.5	7.0	16
28	3	31.0	33.0	19.5	21.5	2.0	6
29	7	31.0	53.0	29.5	51.5	22.0	
30	4	30.0	31.0	30.0	31.0	1.0	7

Appendix D. Net dry weight of particles (g) retained by each sieve size class measured at Bucktail/ Salt Flat, Trinity River, California (Fall 2000).

	Sample #									
Sieve size (mm)	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
128.0				4500.0						
90.0		1278.0		0		2106.0		1758.0	1338.0	
63.0	1286.0	0	3656.0	1524.0	3920.0	1226.0	2284.0	428.0	0	4908.0
45.0	1446.0	776.0	3112.0	1066.0	1936.0	2094.0	1748.0	1648.0	1884.0	1634.0
31.5	306.0	0	2024.0	630.0	1474.0	980.0	1704.0	640.0	740.0	1712.0
22.4	286.0	438.0	1072.0	518.0	914.0	362.0	510.0	640.0	922.0	854.0
16.0	300.0	348.0	858.0	448.0	386.0	402.0	428.0	416.0	572.0	568.0
11.2	209.0	229.0	587.5	319.5	270.5	260.5	471.5	353.0	394.0	466.5
8.0	206.0	143.0	335.5	209.5	138.5	191.5	376.0	319.0	297.0	355.5
5.6	163.5	116.5	253.5	153.0	85.0	165.0	302.0	220.0	226.5	288.0
4.0	108.0	94.0	170.5	108.0	70.5	121.5	206.5	142.5	162.5	216.0
2.8	98.0	83.5	130.5	102.5	85.0	101.0	179.5	131.0	133.0	191.0
2.0	79.0	72.0	105.0	95.0	100.0	68.0	153.0	120.0	111.5	152.0
1.4	63.5	57.0	88.0	85.5	113.5	43.0	147.0	118.0	104.5	123.5
1.0	52.5	53.5	84.0	66.5	102.5	35.0	143.0	105.5	103.0	99.0
0.85	21.0	26.0	40.0	26.5	35.5	15.0	59.5	45.0	47.5	40.0
0.50	51.5	87.0	154.0	79.0	121.0	41.5	118.5	107.0	145.5	85.0
0.25	33.5	95.5	117.5	98.0	139.5	74.0	42.5	65.0	148.0	41.0
0.125	8.0	42.5	19.5	31.0	43.0	56.5	9.5	23.0	51.5	11.0
0.063	2.0	11.5	6.0	8.5	17.5	14.5	4.5	11.5	17.5	5.0
pan	2.0	7.5	5.5	7.5	13.0	8.5	5.5	10.5	12.0	5.0
Total weight	**4721.5**	**3958.5**	**12819.0**	**10076.0**	**9965.0**	**8365.5**	**8892.5**	**7301.0**	**7410.0**	**11754.5**

Appendix E. Net dry weight of particles (g) retained by each sieve size class measured at Steel Bridge Campground, Trinity River, California (Fall 2000).

Sieve size (mm)	Sample #									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
128.0								12174.0	5096.0	
90.0	1294.0	7218.0	3496.0	3958.0	3312.0	1570.0	1516.0	3654.0	1480.0	3120.0
63.0	1356.0	2796.0	2968.0	2898.0	0	2512.0	4304.0	1784.0	2834.0	1400.0
45.0	1702.0	310.0	448.0	1184.0	2326.0	2384.0	426.0	1134.0	2468.0	368.0
31.5	1338.0	1040.0	904.0	1158.0	1186.0	768.0	252.0	1622.0	1170.0	638.0
22.4	706.0	404.0	640.0	740.0	380.0	614.0	412.0	1088.0	694.0	478.0
16.0	516.0	544.0	462.0	420.0	370.0	310.0	376.0	646.0	440.0	430.0
11.2	403.5	316.0	495.5	293.5	272.0	258.5	280.0	443.0	202.5	317.0
8.0	270.5	265.0	358.5	202.0	182.0	208.0	216.0	294.5	112.5	180.0
5.6	244.5	205.5	255.0	163.5	169.0	158.0	171.0	256.5	90.5	148.5
4.0	257.0	186.0	254.0	152.0	162.5	137.5	163.0	225.0	72.0	122.0
2.8	286.5	231.5	245.0	161.0	169.0	153.0	203.0	241.0	83.0	101.5
2.0	180.0	211.5	161.0	118.5	98.5	174.5	174.0	214.0	96.0	71.0
1.4	89.0	153.5	83.0	72.5	44.0	172.0	104.0	172.0	98.0	51.0
1.0	47.0	101.5	45.5	48.5	26.5	151.5	60.5	153.0	99.0	47.0
0.85	16.5	32.5	16.5	22.5	10.0	54.5	21.5	79.0	39.0	24.0
0.50	48.0	62.0	50.0	94.0	36.0	120.5	59.5	261.0	91.0	84.0
0.25	35.5	32.5	37.0	73.5	26.0	98.5	60.0	158.0	69.5	55.5
0.125	7.5	8.5	8.0	12.5	4.5	33.5	18.0	32.5	19.5	16.0
0.063	2.5	3.0	2.5	2.5	1.0	20.5	5.0	11.0	7.0	6.0
pan	2.5	3.0	2.5	2.0	0.5	29.5	3.0	9.0	7.5	5.0
Total weight	**8802.5**	**14124.0**	**10932.0**	**11776.5**	**8775.5**	**9928.0**	**8824.5**	**24651.5**	**15269.0**	**7662.5**

Appendix F. Net dry weight of particles (g) retained by each sieve size class measured at Junction City, Trinity River, California (Fall 2000).

	Sample #							
Sieve size (mm)	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
90.0			4816.0	1460.0			5370.0	4176.0
63.0	1012.0	2110.0	2814.0	762.0	2172.0	1504.0	2622.0	0
45.0	862.0	1252.0	566.0	1934.0	770.0	2458.0	1808.0	734.0
31.5	330.0	672.0	866.0	1674.0	322.0	698.0	1564.0	1144.0
22.4	328.0	534.0	772.0	1622.0	494.0	708.0	810.0	468.0
16.0	350.0	420.0	592.0	1310.0	674.0	496.0	488.0	436.0
11.2	274.5	315.5	439.0	1068.5	407.5	470.0	357.0	278.5
8.0	173.0	257.5	376.5	674.0	367.0	442.0	272.0	215.0
5.6	144.0	159.0	248.5	462.0	317.0	415.5	239.0	170.0
4.0	107.5	125.5	219.5	321.0	230.5	383.5	209.5	131.0
2.8	89.5	85.5	199.0	257.5	181.5	359.0	209.0	101.0
2.0	73.0	56.0	178.0	204.0	126.0	323.0	191.5	76.5
1.4	63.5	45.0	170.5	208.5	121.0	319.0	155.5	71.0
1.0	60.0	45.0	181.5	271.0	152.5	325.5	105.5	68.0
0.85	26.0	23.5	91.5	168.0	86.0	164.0	36.5	29.0
0.50	62.0	89.0	296.5	655.5	265.5	514.5	118.0	68.0
0.25	31.5	78.5	187.0	302.0	153.0	359.0	268.0	31.5
0.125	10.0	12.0	35.0	35.5	19.5	58.0	97.5	5.5
0.063	4.0	2.0	10.5	11.0	5.5	11.0	23.0	2.0
pan	2.5	1.5	8.5	8.5	5.0	7.0	19.5	1.5
Total weight	**4003.0**	**6283.5**	**13067.5**	**13409.0**	**6869.5**	**10015.0**	**14963.5**	**8206.5**