DRAFT
Stanislaus River Chinook Fry Habitat Assessment

2007- 2011 Summary Report

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KEY FINDINGS

- **Shallow margins with vegetative cover consistently supported highest relative index densities of Chinook salmon fry.**
  The highest densities of Chinook salmon fry were observed in shallow margins with vegetation cover and slow current velocities (shallow/slow/vegetation, SSV) consistent with other studies, resulting in highest estimated suitability of said habitat category, followed closely by shallow/fast/vegetation (SFV) margins; however, the latter margin type was rare in the river at all flows.

- **The availability of SSV margins decreased with discharge, while the availability of deep/slow/vegetation (DSV) margins increased greatly at higher flows.**
  Increase in DSV margins at high flows is likely a result of the entrenched nature of the Stanislaus River channel and the associated absence of readily inundated floodplain habitat at intermediate flows. DSV margins supported intermediate to high relative densities of Chinook fry during elevated flows.

- **At higher flows (above 1000 cfs) margin habitat becomes more homogenous.**
  While a wide variety of margin habitat types are available in the Stanislaus River at low flows, the distribution of margin types in the lower Stanislaus River becomes more homogeneous at higher flows. During these higher flows, river margins are dominated by deep, vegetated habitats with slow current, which appear to provide suitable fry habitat (based on high relative index densities of Chinook fry).

- **Overall habitat suitability remains relatively constant over the range of flows analyzed in this study (less than 10% fluctuation between 200 cfs and 3,000 cfs).**
  The increase in proportion of both deep, vegetated margins (with both, slow and fast current) at higher flows offsets the loss of shallow/slow/vegetation margins, and results in nearly constant habitat suitability scores over the range of flows examined. At higher discharge levels (up to 3,000 cfs), the elevated water level inundates the steep, densely vegetated banks, yet remains within the entrenched channel and does not create floodplain habitat.

- **Entrenched channel morphology may be limiting to the Chinook fry rearing capacity of the Stanislaus River, a factor that cannot be addressed by modified discharge patterns (other than very high channel-forming flows).**
  Shallow, vegetated margins appear to be the most suitable habitat for Chinook fry, yet become increasingly rare as flows increase from 200 cfs to 3,000 cfs. High gradient banks do not allow for inundation of extensive shallow water rearing habitat under the range of flows examined in this study, suggesting that discharge is not a limiting factor to Chinook fry rearing capacity of the Stanislaus River.

INTRODUCTION

FISHBIO and Normandeau Associates (formerly Thomas R. Payne & Associates) initiated a study during the winter of 2007 to assess the relationship between Chinook fry abundance, instream habitat characteristics (emphasizing margin habitat where most fry reside), and stream flow. Although salmonid fry are well known to prefer shallow and slow microhabitats (Everest and Chapman 1972, Moore and Gregory 1988, Bozek and Rahel 1991, Hampton et al. 1997), conventional analyses sometimes fail to associate fry habitat requirements with margin characteristics, such as distance to bank and availability of vegetative cover. This study was intended to offer an alternative to conventional instream flow analyses, which often suggest that habitat for small salmonids is maximized at the low stream flows (e.g. Hatfield and Bruce 2000, Rosenfeld et al. 2007). However, this stands in contrast to findings from a study conducted in the Klamath River, which suggests that inundation of riparian vegetation during elevated flows was requisite for promoting high production of anadromous fry, and that instream habitat devoid of vegetative cover was essentially unsuitable (Hardy and Addley 2001). That conclusion was inconsistent with the common occurrence of high fry densities along non-vegetated margins in other productive streams (e.g., Beechie et al. 2005, Everest and Chapman 1972, Moore and Gregory 1988, Bozek and Rahel 1991), but had profound implications in the assessment of flow needs in the Klamath River.

Clearly, instream flow requirements for optimizing habitat for juvenile salmonids vary greatly between river systems (depending on their respective biological and physical characteristics), necessitating a case-by-case evaluation of fish population response to riparian flooding.
The physical habitat characteristics of the Stanislaus River, along with its vital adjacent agricultural resources, present a somewhat unique environment to which results derived from other watersheds with different channel characteristics (e.g., Klamath River) may not be applicable. Extensive mining, dam construction, agricultural development and implementation of flood control measures have resulted in drastic alterations to the natural hydrologic regime, including the elimination of most channel-forming flows. Today the Stanislaus River features a highly entrenched channel with a dense and stable riparian zone that is only partially inundated under typical base flows (approx. 500 - 1500 cfs, monthly mean flows 1975 – 2010, USGS Station 11303000). Substantial increases in riparian flooding are only observed during periods of elevated discharge (>800 cfs) during the winter and spring months (January through early June), which may provide habitat for salmonid fry. However, while high flows inundate riparian vegetation, such increases in flow also result in deeper and swifter margin habitats which may not be beneficial to rearing salmonid fry.

This study was designed to assess how differences in discharge influence the rearing capacity of the Stanislaus River for pre-smolt Chinook salmon. This required assessing the abundance of Chinook fry at various habitat categories (as defined by depths, current velocity and cover) and evaluating the relative availability of these habitats at varying stream flows. For the purposes of this study, fry abundance was considered indicative of habitat suitability. This report summarizes pertinent results from four years of fry abundance surveys and detailed habitat mapping at flows ranging from 200 cfs to 3000 cfs.

STUDY OBJECTIVES

The primary objectives of this study were to:

1. determine the availability of different margin types in the Stanislaus River over a range of flows;
2. determine the relative densities of Chinook salmon fry within different margin types; and
3. synthesize the estimated availability of specific margin types over a range of flows and the suitability of margin types to Chinook salmon fry in order to assess the relationship between river flow and rearing capacity in the Stanislaus River.

METHODS

Study Reach

We evaluated fry rearing areas between rivermile (RM) 54.0 and RM 40.1 (Figure 1), the primary spawning reach for Chinook salmon in the Stanislaus River (Mesick 2001). The canyon reach upstream of RM54 was excluded from this survey due to its high gradient, limited Chinook spawning habitat and poor accessibility. The study area was divided into two reaches, based on overall habitat characteristics (gradient, width, etc.): Oakdale to Orange Blossom Bridge (OAK-OBB; river mile [RM] 40.1-46.9), and Orange Blossom Bridge to Knights Ferry (OBB-KNF; RM 46.9- 54.0). Both of these reaches were further divided into half (0.5) mile segments, from which study sites were randomly selected for measuring margin habitat availability and Chinook fry densities.

Margin Habitat Availability

To estimate the availability of various margin habitat types (see Table 1 for categories), six half (0.5) mile segments were randomly selected for detailed mapping under a variety of flow scenarios, including 200 cfs (mapped in March 2009), 600 cfs (June 2012), 900 cfs (June 2012) 1,300 cfs (April 2009), 2,000 cfs (April 2011), and 3,000 cfs (April 2011).

For the purpose of this study, river margins were defined as the portion of the stream within six feet of the stream bank, which is consistent with other studies showing that most small salmonid fry in larger rivers reside in close proximity to the stream bank (NESCO 1984, Allen 1991, TRPA 2004, Beechie et al. 2005, Hardin et al. 2005). Twelve (12) different margin types were defined based on combinations of three physical variables believed to influence habitat suitability to salmonid fry (Table 1):

Depth: Margin depths were categorized as either shallow (S) or deep (D) based on a 1.5-foot average depth criterion.

Velocity: Margin velocities were visually estimated as either slow (S) or fast (F) using a velocity criterion of 0.5 feet/second.

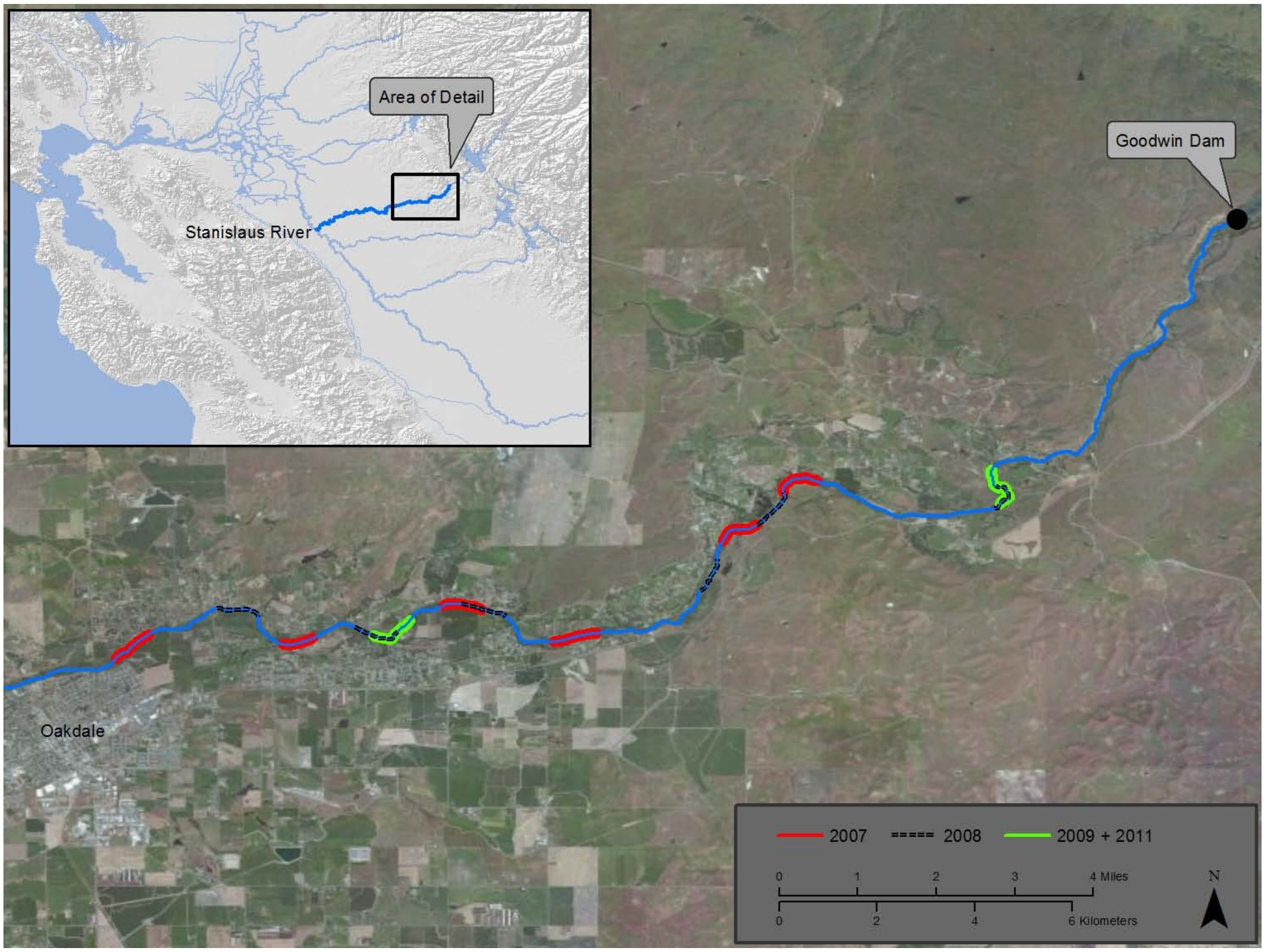


Figure 1. Locations of margin habitat mapping (red lines) and Chinook fry suitability assessment reaches in 2007- 2009 and 2011/2012.

Table 1. Definitions of margin categories, including abbreviation, depth category, current speed and predominant cover type.

Unit Type	Definition		
	Depth	Velocity	Cover
DSN	Deep	Slow	No cover
DSR	Deep	Slow	Rock cover
DSV	Deep	Slow	Veg. Cover
SSN	Shallow	Slow	No cover
SSR	Shallow	Slow	Rock cover
SSV	Shallow	Slow	Veg. Cover
DFN	Deep	Fast	No cover
DFR	Deep	Fast	Rock cover
DFV	Deep	Fast	Veg. Cover
SFN	Shallow	Fast	No cover
SFR	Shallow	Fast	Rock cover
SFV	Shallow	Fast	Veg. Cover

Instream Cover: Instream cover was categorized as one of three categories: no cover (N), vegetation cover (V), or rock cover (R). Units providing less than 10% cover (by area) were considered to have no cover, area coverage of greater than 10% was categorized as vegetative or rock cover, depending upon which type was dominant.

Cutoff criteria for depth and velocity were selected based upon habitat suitability curves for Chinook salmon fry from various river systems (Normandeau HSC metadata files, Figure 2), and represent approximate thresholds between high- and low suitability conditions. The instream cover category was aimed at representing structures that may provide protective cover (refuge from current and /or predators) to Chinook fry.

Depending upon flow conditions, selected study segments were accessed and mapped (both banks) in a downstream direction from kayaks (high flows) or wading (low flows). For visual reference during mapping and subsequent fry surveys, the boundaries of study reaches were marked with surveyor's flagging tape. Unit depth (deeper or shallower than 1.5 ft) was determined in short intervals by using a stadia rod, while current velocities (greater or slower than 0.5 fps) were visually estimated based on the speed of debris floating past a fixed point.
Each study segment contained between 80 and 116 margin units, from which units were selected for detailed mapping and fry abundance surveys. Lengths of specific habitat units (classified according to categories listed in Table 1) were measured with a handheld laser range finder, using a minimum margin length of 30 ft (except for rare margin types). Long habitat units were mapped along their full length, however, stream segments greater than 100 ft in length selected for fry abundance estimation (see below) were split into units <100 ft in length. Margin unit number, type, length, and associated notes were recorded in a field notebook.

Margin Habitat Suitability to Chinook Fry

Slight differences existed in unit selection for assessing margin habitat suitability between years, as outlined in more detail below. During the first year (2007), the assessment was conducted in the same six study segments that were mapped for margin availability. However, as some margin types (in particular margins containing rock cover) were very rare in the study segments, fry counts in subsequent years were conducted in half (0.5) mile segments selected according to the known presence of these rare margin types. Thus, in 2008, six new (0.5 mile long) segments were selected (three per reach) for conducting fry counts (Figure 1). In 2009 and 2011, fry sampling effort was re-allocated to produce larger sample sizes within individual study segments; consequently, all fry sampling in those years was conducted in two study segments (one per reach, Figure 1).

2007

Most of the six study segments (Figure 1) contained 80 to 100 margin units, from which a total of 146 units were selected for mapping and conducting fry counts. Overall, 15-17 units were randomly sampled per margin type, with the exception of those with dominant rock cover, which were rare at the high flows experienced during our surveys (i.e., margin habitat, defined as extending 6ft from the water's edge consisted mainly of steep, vegetated banks).

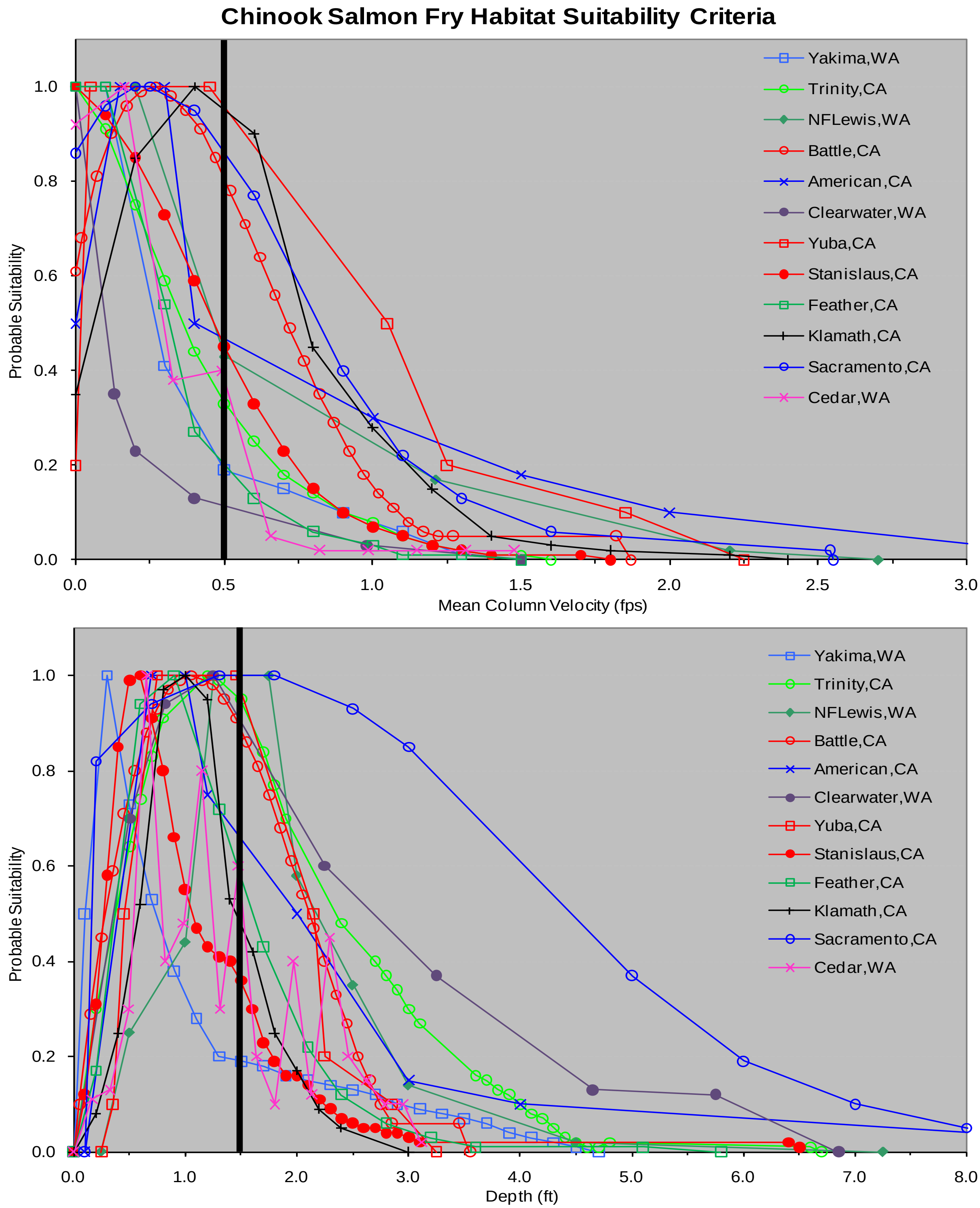


Figure 2. Habitat suitability criteria curves for Chinook salmon fry from various river systems (Normandeau HSC metadata files). Heavy vertical line shows margin depth and velocity cutoff used to distinguish between shallow/deep and slow/fast habitat categories, respectively.

2008

Most of the six study segments (Figure 1) contained 80 to 100 margin units, from which a total of 155 units were selected for mapping and conducting fry counts. Overall, 13-23 units were sampled of each margin type, with the exception of those with dominant rock cover or no cover which were, similar to 2007, rare at the high flows experienced during our surveys.

2009

Sampling was limited to two 0.5-mile long segments (Figure 1), containing 109 and 116 margin units each, from which a total of 127 units were selected for mapping and conducting fry counts. Overall, 7-13 units of each margin type were sampled.

2011

Sampling occurred in the same two segments that were sampled in 2009 (Figure 1), to maximize the number of the rare rock units. The two segments were mapped again in 2011 and contained 105 and 118 margin units each; from which a total of 149 units were selected for detailed mapping and conducting fry counts (Table 2).

Snorkel Surveys

Mapping

Study segments selected for fry snorkel counts were mapped according to the procedures outlined above for assessing the relative availability of different margin types; however, long units (greater than 100 ft in length) were divided into shorter units (≤100 ft) prior to unit selection. Margin units were selected by stratified random sampling from each of the 12 margin types for snorkel counts and detailed habitat typing. Up to 10 units of each margin type were sampled in each study segment every year, depending upon unit type availability and time allotted for sampling each segment. When three or fewer of a particular margin type were available for sampling in a particular segment, all units of that type were sampled. If a particular habitat type was absent from the mapped segment (e.g. some of the rock cover margin types), we deliberately selected the nearest representative units upstream or downstream of the mapped area (if available). Margin units containing flooded vegetation too dense to sample were excluded from sample selection.

Fry Counts

Each margin unit selected for fry counts was snorkeled in an upstream direction by a single diver who counted all fish observed within six feet of the water's edge (approximately corresponding to the diver's arm span). Visibility was estimated by measuring the distance at which the diver could identify a weighted fishing lure comparable in size to Chinook fry. The diver also estimated the maximum distance from the bank (i.e., offshore) where fish were observed in the unit. To assess the variability in fry counts one or two margin units (per margin type) were randomly selected for replicate counts from 2007 – 2009, and three additional snorkel counts were obtained immediately following the initial count.

Habitat Variables

After snorkeling, detailed physical measurements were taken throughout the sampled margin unit. Measurements were taken at six (four in very short units) transect locations within each unit. At each transect, several parameters (depth, mean column velocity, and substrate type) were measured at three distances from the bank (1, 3 and 5 ft), for a total of 18 measurements in each unit. Depths were measured using a graduated depth rod and velocities were measured using mini velocity meters (Marsh-McBirney). Depth and velocity measurements were averaged to estimate mean depth and velocity for each sampled margin unit. Substrate type (percent coverage), embeddedness, instream vegetation (percent coverage and type) and overhead cover were visually estimated for the entire margin unit. In some years, mean stem diameter and mean stem density (# stems/ft^2) of vegetation were also assessed.

Data Analysis

Fry densities and habitat suitability

Fry counts within individual margin units were converted to index densities (# fish/ft^2), by dividing the total fry count by the margin unit surface area (unit length x 6 ft width). Comparison of fish densities between margin types, but within segments, utilized *actual estimated* index densities.

However, comparisons between margin types from pooled segment estimates utilized *relative*, or normalized, index densities (i.e. the maximum index density in each segment was set to 1, and all other densities were rescaled according to that maximum) to ensure that the potential influence of variable recruitment within each segment (e.g., proximal spawning) or differences in annual escapement would not confound comparisons between margin unit types. These densities were then used as a representative habitat suitability index score (HSI) for each of the 12 margin types.

To investigate how varying discharge levels affect the availability of particular habitats (and subsequently the overall habitat suitability to Chinook salmon fry), the estimated availability of each margin type was multiplied by its respective HSI, at each flow. The magnitudes of the resulting scores are reflective of the overall habitat value of the different unit types to Chinook fry at varying flows (e.g. a small increase in area of habitat units with high HSI may result in higher overall habitat suitability to Chinook fry than a large area increase in poorly suited fry habitat). Further, summing the habitat scores for each of the 12 margin types allows for comparisons of overall river-wide habitat score at different flows.

Shannon's Diversity and Equitability Indices

To compare the variability of habitat at different flows, Shannon's diversity index (*H*, a measure of the equality or distribution among habitat types) was calculated as

$$H = -\sum_{i=1}^{S} p_i * \ln(p_i)$$

where S is the total number of different habitats observed (12), and p_i is the proportion of habitat comprised of type i (see Table 1 for unit types).

Subsequently, Shannon's Equitability Index (E) is calculated by dividing Shannon's Diversity Index by its maximum value, H_{max} :

$$E = \frac{H}{H_{max}} = \frac{H}{\ln(S)} = \frac{H}{2.485}$$

Equatibility (ranging between 0 and 1) can then be interpreted as a measure of evenness, where a value of 1 would indicate that all habitat types are represented in equal proportions, while values near 0 suggest that the stream is dominated by one (or few) habitat categories (and hence not very "even").

RESULTS

Habitat Type Availability

Habitat mapping of the margin units was conducted in the original six, 0.5 mile segments and repeated over a range of flows (200 cfs-3,000 cfs) to document the changes in availability of the 12 different habitat types. Total availability of each margin type across the range of flows sampled is shown in Figure 3.

The greatest diversity of margin types (all twelve types present) was observed at low flows, and about 69% of the available habitat was comprised of the three most dominant margin types (i.e., SSV, DSV, SSN). In contrast, margin type diversity was lowest at the highest flow (3,000 cfs), when the three dominant types (i.e., SSV, DSV, DFV) comprised 92% of the available habitat, and 6 of the habitat types almost completely disappeared (less than 1% of total habitat area). This is also reflected by a high equitability score of 0.78 and 0.82 at flows of 200 and 600 cfs, respectively, in contrast to scores of 0.59 and 0.50 at 2,000 and 3,000 cfs (Table 2). This illustrates that high flows reduce habitat diversity and evenness in the Stanislaus River, resulting in relatively homogenous river margins dominated by deep, vegetated habitats.

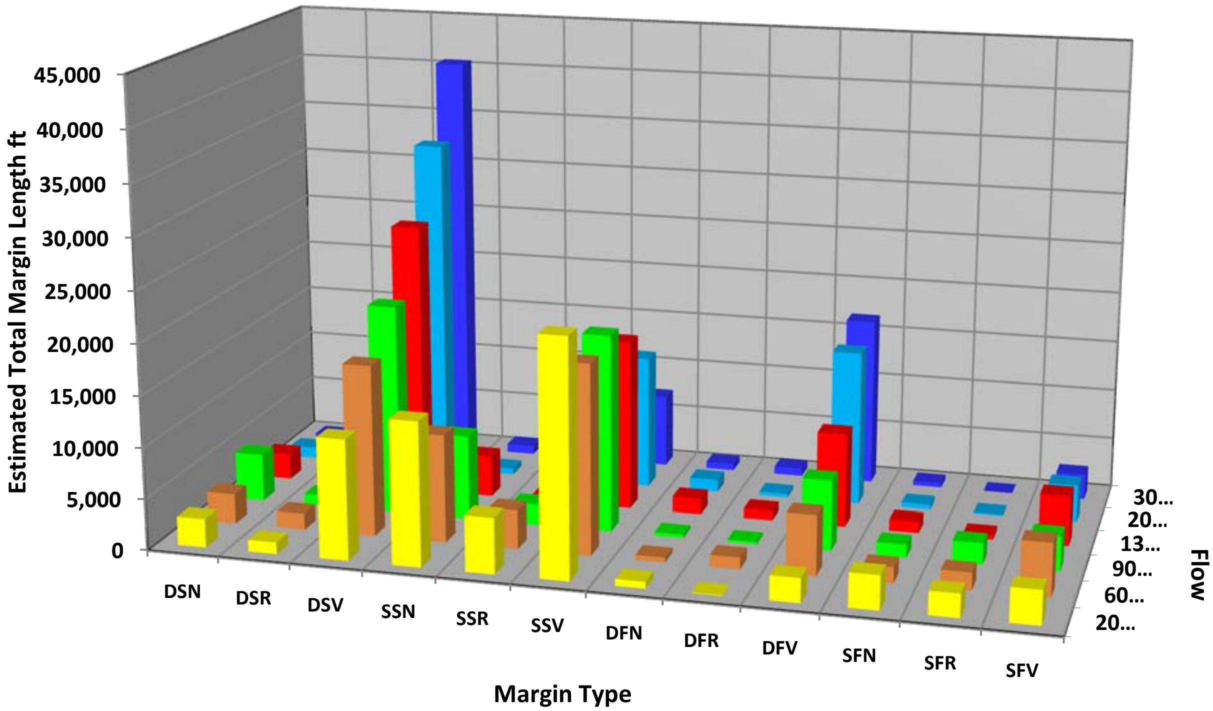


Figure 3. Availability of different habitat categories/margin types in the Stanislaus River at various flows.

Table 2. Shannon's Diversity Index (*H*) and Shannon's Equitability Index (*E*) for margin habitat in the Stanislaus River for flows ranging from 200 cfs to 3,000 cfs.

Flow (cfs)	Shannon's Diversity Index (*H*)	Shannon's Equitability Index (*E*)
200	1.95	0.78
600	2.03	0.82
900	1.91	0.77
1,300	1.80	0.72
2,000	1.46	0.59
3,000	1.24	0.50

Fry Counts

2007

The 2007 Chinook fry survey was conducted between February 1 and February 17 at a flow of 800 cfs (Goodwin Dam gage). Normalized fry densities were greatest in vegetated and shallow habitat units, as well as in the deep/slow/vegetation (DSV) margins (Figure 4). Only the deep margins lacking vegetation had low (<0.2) normalized index densities. Chinook fry were rarely observed more than four (4) feet from the stream bank. Additional collection details, including sample numbers and physical parameters are summarized in Table 3.

2008

The 2008 Chinook fry survey was conducted between February 13 and February 29 at flows ranging from 225 cfs to 375 cfs (Goodwin Dam gage). Again, normalized index densities were highest in vegetated units, with the maximum value in DSV margins (Figure 4). Intermediate densities of fry were observed in rock-dominated, fast margins. Chinook fry were observed up to 8 ft from the bank; however, the average *maximum* distance from the bank of 65 groups of fry was only 2.6 ft.

2009

The 2009 Chinook fry survey was conducted between February 27 and March 13, at a flow of approximately 215 cfs (Goodwin Dam gage). A moderate flow pulse of 800 cfs occurred between sampling in the OBB-KNF reach and the OAK-OBB reach. Normalized index densities indicated high fry abundance only in the shallow, vegetated margins with low current velocity (SSV, Figure 4), though higher densities were always observed in vegetated margins than in those with rock cover or no cover (within a depth/velocity category). Chinook fry were observed over 10 ft from the stream bank; however, the average *maximum* distance to bank of 95 groups of fry was 2.9 ft.

2011

The 2011 Chinook fry survey was conducted between February 7 and March 16, at a flow of approximately 225 cfs (Goodwin Dam gage). Combined data from the two study segments again showed highest normalized index densities within the SSV margins, although all vegetated margin types produced high density estimates (Figure 4). Chinook fry were rarely observed more than 4 ft from the stream bank, with an average *maximum* distance to bank of 3.2 ft.

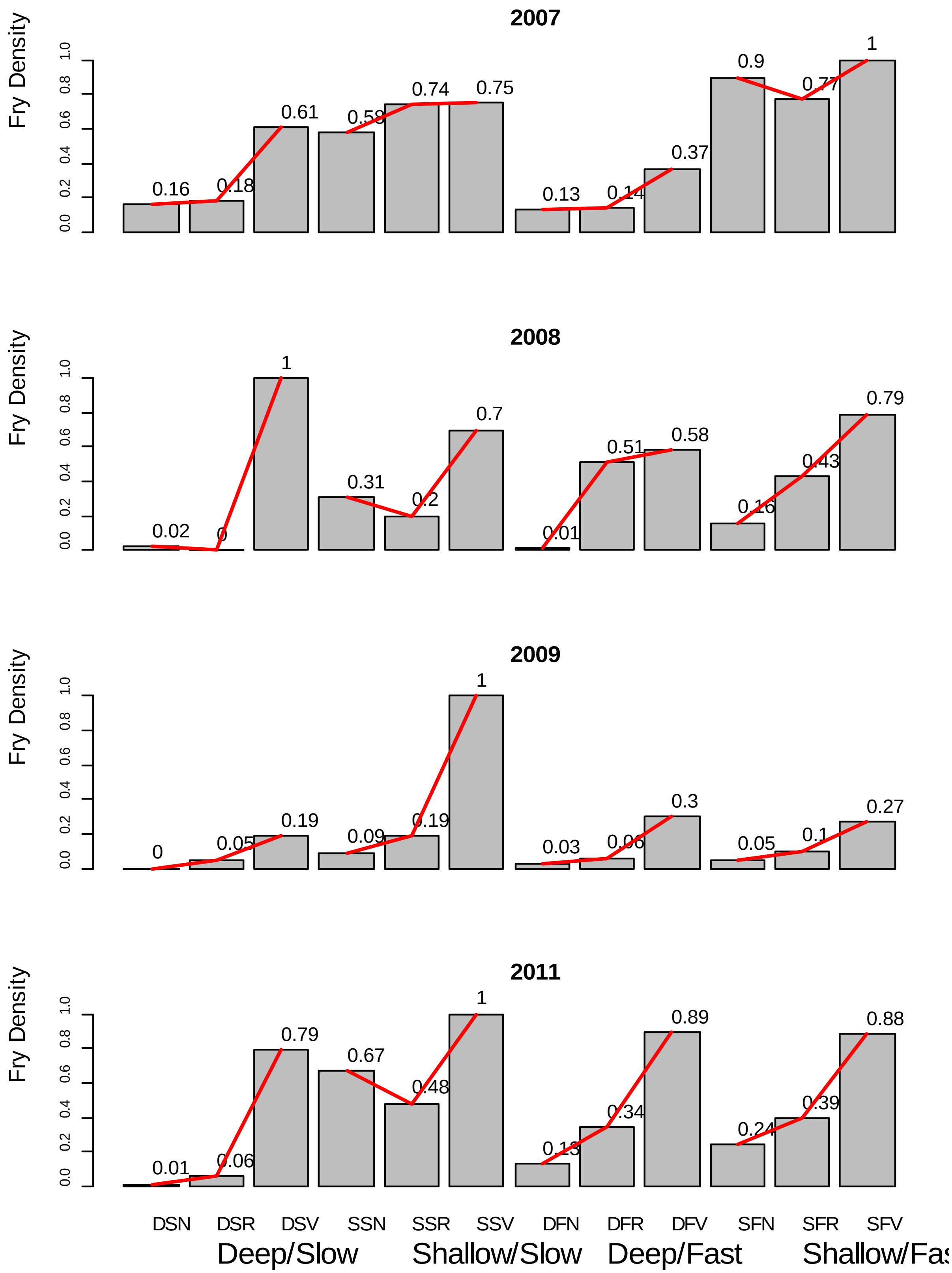


Figure 4. Normalized mean index densities for Chinook fry according to year and margin type (all segments combined).

Table 3. Summary of Chinook fry snorkel surveys on the Stanislaus River, including sample numbers, physical habitat characteristics, fry counts, and fry densities.

	2007	2008	2009	2011
Flow (cfs)	800	225-375	215	225
Water temperature (F)	47-50	47-52	50-53	48-54
Margin units sampled	146	155	127	149
Mean unit length in ft (range)	54 (21-108)	54 (24-105)	49 (23-148)	52 (27-114)
Mean unit depth in ft	0.8-8.0	0.3-7.0	0.3-18.6	0.2-17.0
Mean unit velocities (in fps)	0.0-4.5	0.0-2.8	0.0-3.7	0.0-5.1
Mean fry count per unit (range)	15.7 (0-210)	8.9 (0-76)	10.7 (0-142)	10.0 (0-108)
Total fry count	2,287	1,353	1,355	1,487
Mean overall fry density (fish/ft^2)	0.05	0.03	0.04	0.03

Replicate counts

Replicate counts were conducted in 11, 17 and 23 units of various margin types in 2007, 2008 and 2009, respectively. The Coefficient of Variation (CV) was used to assess the consistency of four-pass replicate counts in 53 margin units, which showed moderate to high variability in counts of Chinook fry, particularly in the deep/slow habitats (Figure 5). Although CVs of replicate counts were less than 50% in most of margin types, they ranged from 65% to 158% in deep/slow margins. However, these high CVs- in particular in DSN and DSR units- were largely due to the very low numbers of Chinook fry observed in those units, which can lead to high CVs even with minor changes in counts (e.g., the maximum difference in four repeat counts for those units was only three fry). In general, CVs were lower in vegetated margins than in rock or no cover units, again likely due to the higher numbers of fry observed in those units, which tends to reduce calculated CV estimates.

Overall, there were no significant trends for snorkel counts to either increase or decrease over subsequent passes ($p > 0.05$; linear regression) in any of the 12 habitat categories. Similarly, no significant trends were noted for the different cover types (p = 0.67, 0.20, 0.17 for no cover, vegetation- and rock cover, respectively). The absence of significant trends between multiple passes suggests that the single pass fry counts (which were used to estimate margin densities) are a fair representation of relative densities of Chinook fry.

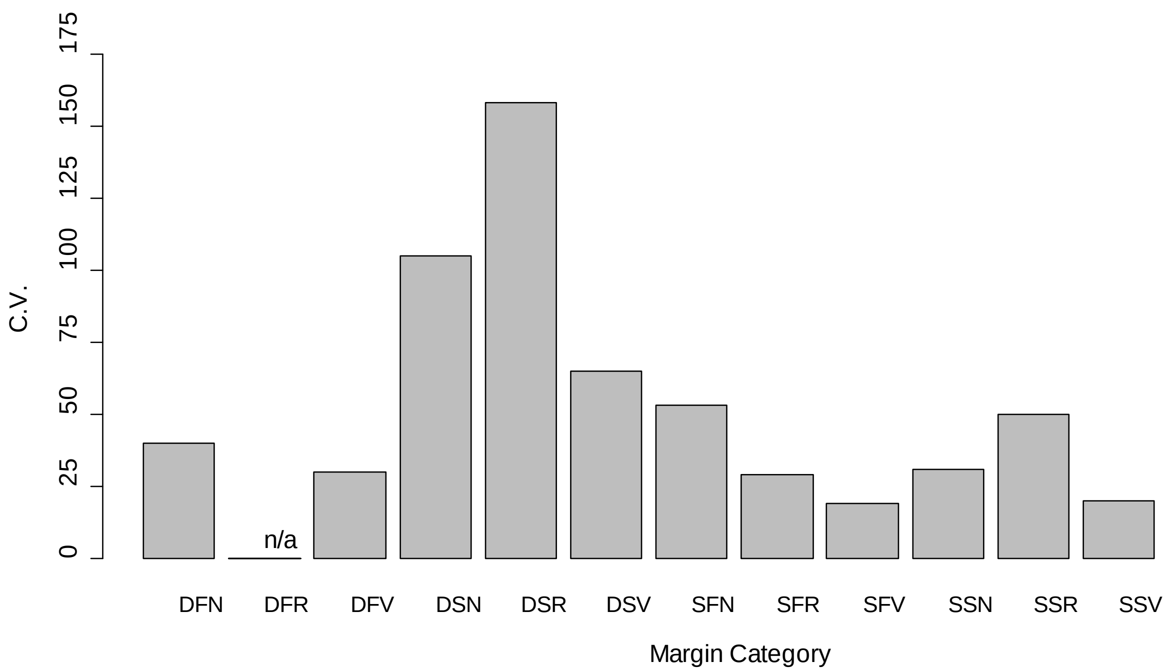


Figure 5. Estimated Coefficients of Variation for replicate dive counts of Chinook fry according to margin type.

Though not statistically significant overall, the observed increases in fry counts between passes in some units may be attributed to fry disturbance by snorkelers, causing them to aggregate into larger, more observable groups, or the divers' increasing familiarity with the fish distribution and cover characteristics of the unit over multiple passes, increasing their efficiency over successive passes. In contrast, decreasing counts may be a result of fry leaving the margin units in order to seek cover in response to snorkelers.

Fry Index Densities – All Years Combined

Overall fry index densities varied from year to year, and are correlated to adult recruitment (Figure 6). Comparison of normalized fry index densities combined across segments and years clearly indicates the highest fry index densities (>0.62) in vegetated margin types, irrespective of depth category or current velocity (Figure 7). Margin units with no cover contained intermediate relative densities of Chinook fry (0.39-0.47) in shallow margins (SSN and SFN), but low densities of fry (0.06-0.09) in deep margins (DSN and DFN). Intermediate fry index densities were also observed in margins dominated by rock cover were generally intermediate (0.30-0.49) except in deep water with slow current velocity (density 0.08). The relative mean fry densities shown in Figure 7 were used to represent the habitat suitability index (HSI) score for each of the 12 margin types.

A comparison of fry index densities by depth and velocity category (without incorporating the influence of cover type) indicates the preference of Chinook fry for shallow water habitat, and shallow/slow margins are estimated to be approximately twice as suitable for fry as either deep/slow or deep/fast margins (Figure 8).

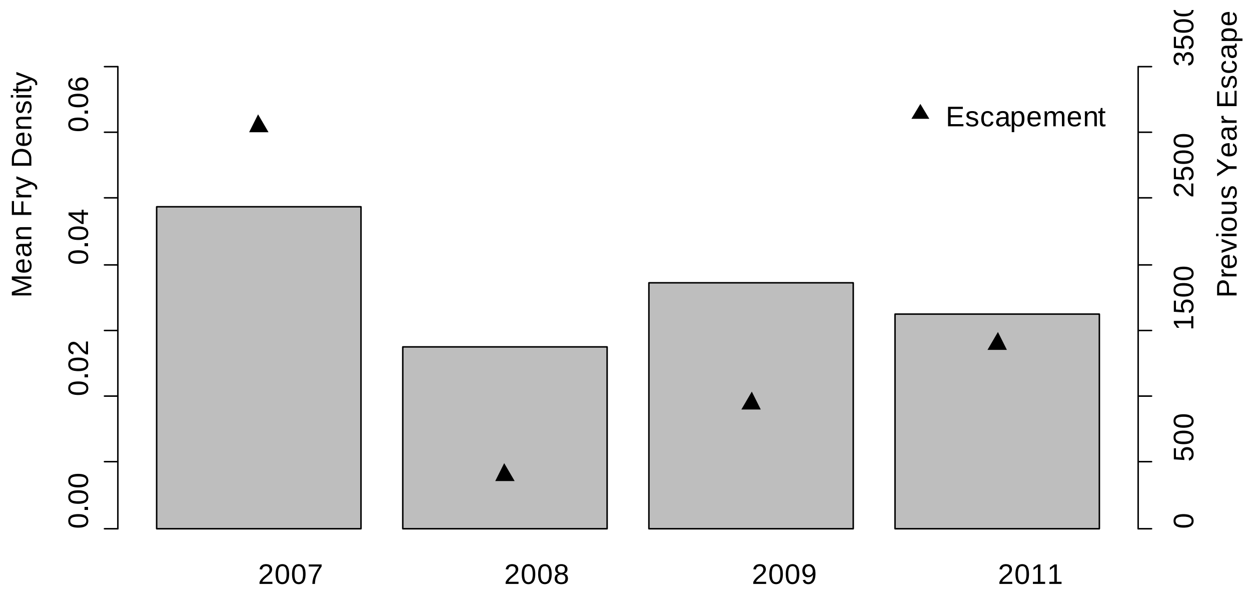


Figure 6. Overall estimated mean densities (fish/ft^2) of Chinook fry in 2007-2011 and escapement estimates from the previous fall.

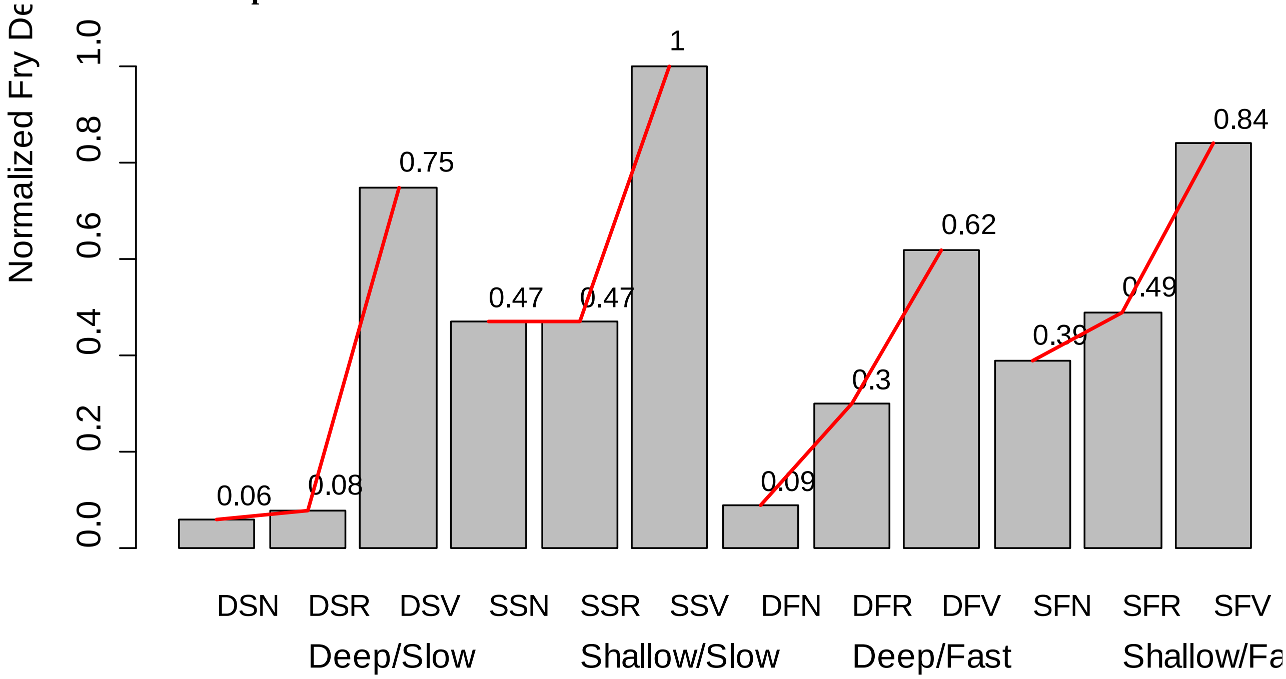


Figure 7. Normalized mean index densities for Chinook fry according to margin type (all data combined). Normalized densities also represent margin type suitability.

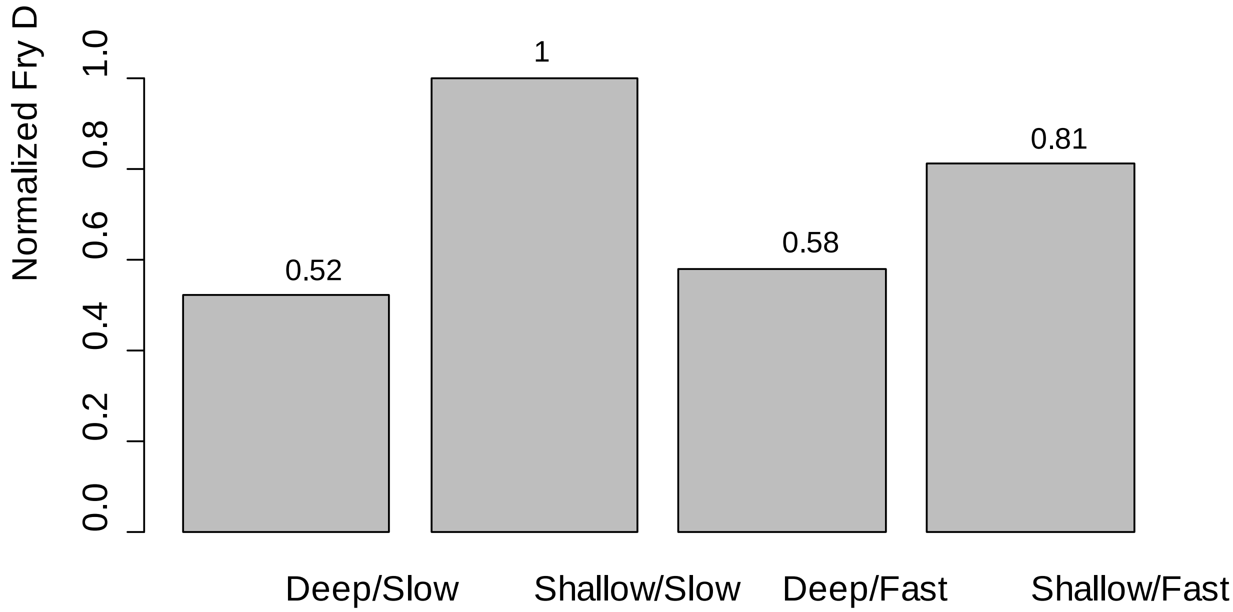


Figure 8. Normalized mean index densities for Chinook fry according to depth- and velocity category (combined over all years).

A comparison of relative fry abundances among cover types (without incorporating the influence of depth and velocity) clearly suggests the preference of Chinook fry for vegetation cover. Observed fry densities in habitat units with rock cover or without a predominant cover type were 60% and 75% less than at margins where vegetation cover was present (Figure 9).

A comparison between observed fry densities and unit depths and velocities reveals that most Chinook fry occur in margins that average 0.5-1.5 ft in depth, and margins with mean velocities of less than 1 fps (Figure 10). Fry were observed in only two of 14 margin units that exceeded 4 ft in mean depth, and only three fry (out of several thousand) were observed in margin units with mean velocities greater than 3.0 fps. This further supports the margin suitability estimates (Figure 7) and other studies (Figure 2) that demonstrate that Chinook fry prefer relatively shallow and slow microhabitats.

Effects of Flow on Fry Habitat

The HSI scores of different habitat types (based on fry relative densities) and the prevalence of the respective habitat (based on margin lengths at various flow levels) were used to calculate a habitat suitability score (HSIxArea), which is indicative of the relative importance of each habitat type to Chinook fry at various discharge levels (Figure 11). This analysis indicates that deep, vegetated margin habitat becomes the predominant habitat for Chinook fry at flows greater than (approximately) 900 cfs. The importance of deep, vegetated habitat increases with discharge regardless of current velocity (slow or fast), yet is much more pronounced for areas with slow current. This can be attributed mainly to the great increase in area of this habitat type higher flows (also see Figure 3).

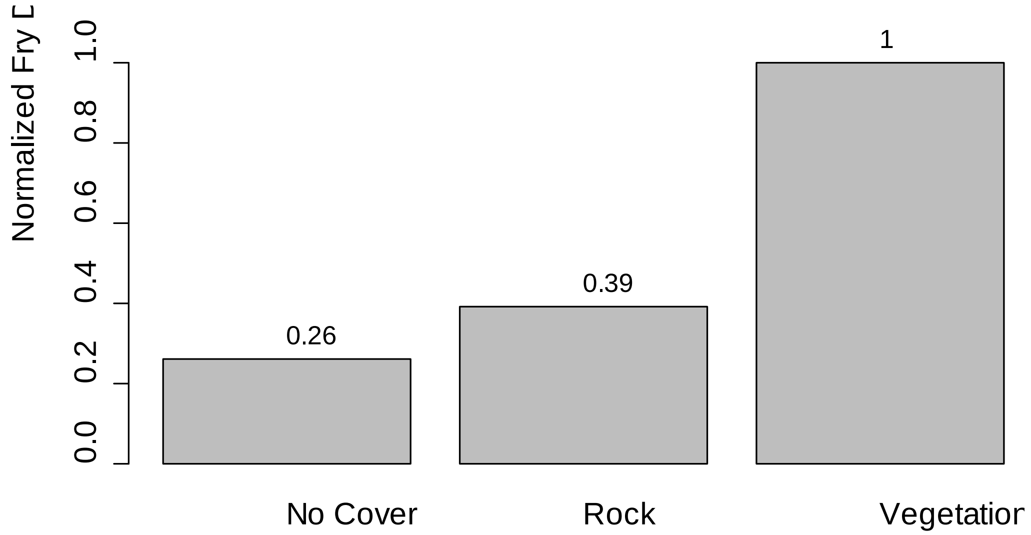
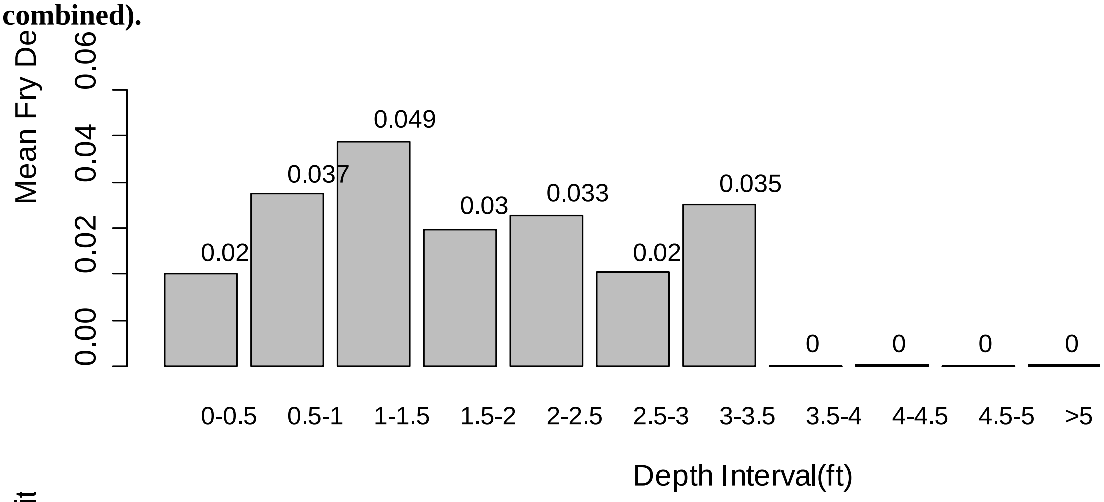


Figure 9. Normalized mean index densities for Chinook fry according to cover type (all years combined).



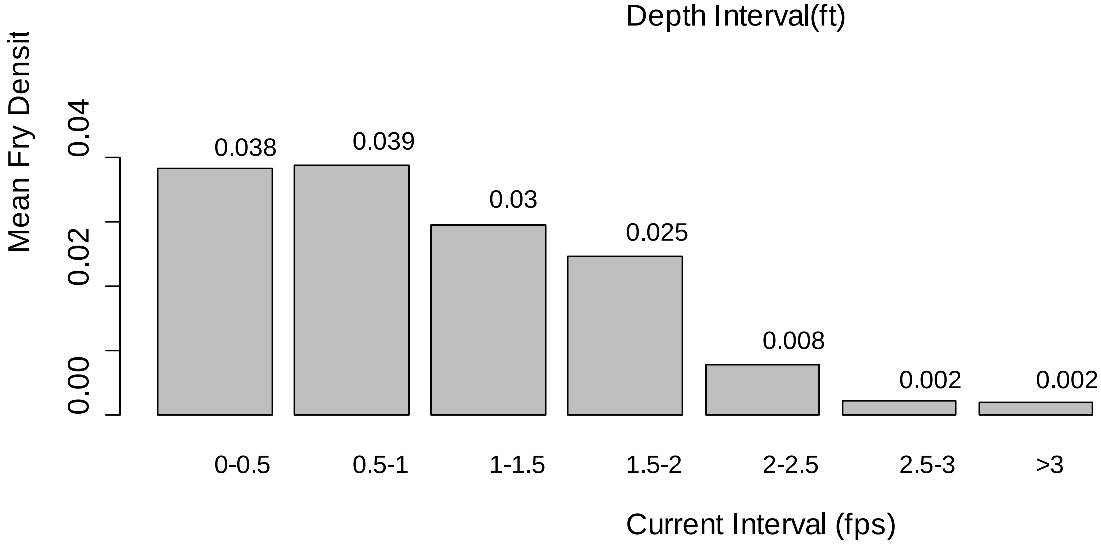


Figure 10. Mean fry density (all years combined) in the Stanislaus River by average unit depth (top, in 0.5 foot intervals) and average unit velocities (bottom, 0.5 fps intervals).

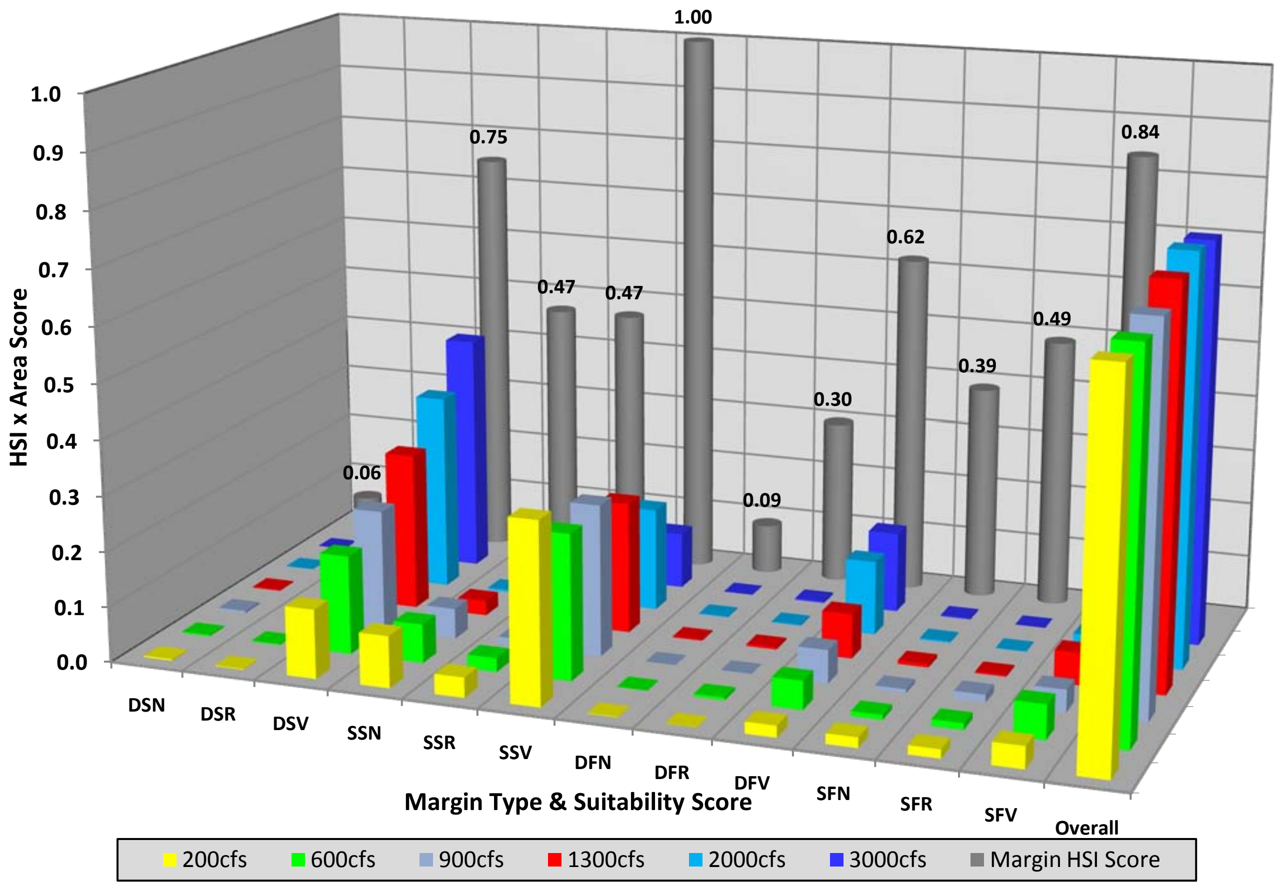


Figure 11. Changes in habitat scores for each margin type according to flow. Cylinders show HSI scores for each type, based on normalized Chinook fry densities.

As flows increase from 200 cfs to 3000 cfs, the importance of shallow water habitat decreases, regardless of current speed or predominant cover type. However, the most notable decrease can be observed in SSV habitat, which comprises the bulk of Chinook fry habitat at low flows (200 cfs) and appears to be the most suitable habitat for that life stage (i.e. highest estimated suitability value).

Little change is observed in the habitat scores of shallow, vegetated margins with fast current, which—although highly suitable for Chinook fry—are relatively rare at all flows.

To investigate how the river-wide suitability of margin habitat for Chinook fry is affected by varying flow, the habitat scores for the 12 margin types were summed across each of the discharge categories (Figure 12). Across the range of flows examined during this study, overall habitat score remain fairly stable (approximately 8% difference), with very minor changes at flows between 1,300 cfs and 3,000 cfs. Higher flows result in a gradual increase in deep,

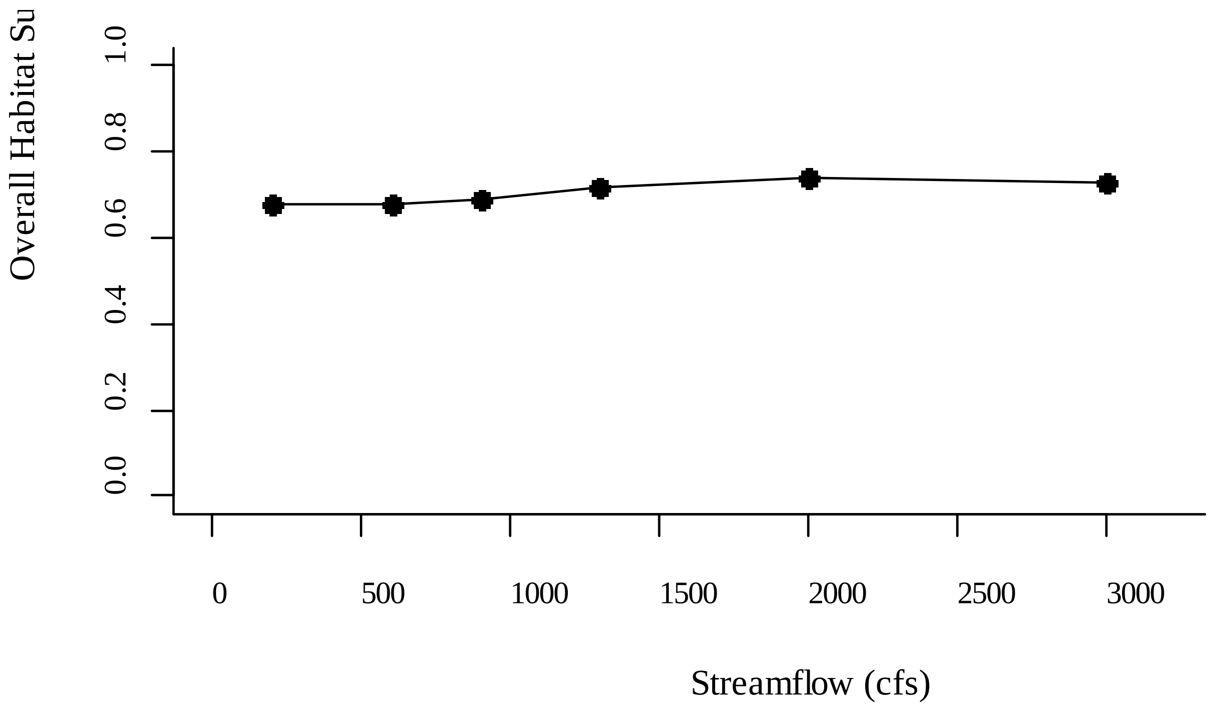


Figure 12. Overall habitat score for Chinook fry in the Stanislaus River at various discharge levels.

vegetated margin (along the steep banks), which - though not quite as suitable to fry rearing - compensates for the loss of shallow, vegetated habitat during periods of elevated flow.

The entrenched channel of the Stanislaus River is the likely responsible for the almost constant suitability index at higher discharge levels (up to 3,000 cfs), since elevated water levels inundate the steep, densely vegetated banks, yet remain within the channel and do not create floodplain habitat. This notion is supported by floodplain inundation analysis conducted by the Department of Fish and Game (DFG, see SWRCB 2012), that found that the Stanislaus River channel does not appear to have a well-defined floodplain within the 100 to 10,000 cfs flow range examined (SWRCB 2012, DFG 2010).

CONCLUSIONS AND RECOMMENDATIONS

During the four years of snorkel surveys, Chinook salmon fry were consistently most abundant along margins with vegetative cover. The highest densities of Chinook salmon fry were observed in shallow margins with vegetation cover and slow current velocities (SSV, consistent with other studies), resulting in highest estimated suitability of said habitat category, followed closely by shallow/fast/vegetation (SFV) margins; however, the latter margin type was rare in the river at all flows.

While a wide variety of margin habitat types is available in the Stanislaus River at low flows, the distribution of margin types in the lower Stanislaus River becomes more homogeneous at higher flows. At higher flows (above 1000 cfs), the highly suitable shallow/slow/vegetation (SSV) margins becomes rare, while deep/slow/vegetation (DSV) margins become the predominant habitat for Chinook fry. An increase in DSV margins at high flows, which supported intermediate to high relative densities of Chinook fry, is likely a result of the entrenched nature of the Stanislaus River channel and the associated absence of readily inundated floodplain habitat at intermediate flows.

The increase in proportion of deep, vegetated margins (with both, slow and fast current) at higher flows offsets the loss of shallow/slow/vegetation margins, resulting in fairly minor changes to the overall habitat suitability score (i.e., only a ~15% difference between the lowest and maximum scores and minimal differences at flows greater than 1,300 cfs). This suggests that the entrenched channel morphology of the Stanislaus River may be limiting to its capacity for Chinook fry rearing, which cannot be addressed by modified discharge patterns (other than very high channel-forming flows). Shallow, vegetated margins appear to be the most suitable habitat for Chinook fry, yet become increasingly rare as flows increase from 200 cfs to 3,000 cfs. High gradient banks do not allow for inundation of extensive shallow water rearing habitat under the range of flows examined in this study (which encompassed and exceeded typical base flows experienced in most years), suggesting that discharge is not a limiting factor to Chinook fry rearing capacity of the Stanislaus River.

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