PHYSICAL PARAMETERS ASSOCIATED WITH COHO SALMON REDDS IN NORTHWEST CALIFORNIA

by

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ABSTRACT

Substrate composition, water depth, water velocity, and water temperature were measured at coho salmon (Oncorhynchus kisutch) redds in six northern California coastal streams of varying sizes. At each redd a gravel sample was taken with a McNeil sampler from inside and outside the redd to determine differences between the two samples in Fredle index and percent fines (<2 mm). Forty six redds were sampled during the 1989-1990 spawning season. Mean Fredle index values ranged from 6.0 to 12.5 outside the redd and 8.7 to 20.3 inside the redd; percent fines ranged from 3.5 to 17.3 outside the redd and 1.5 to 10.1 inside, indicating suitable spawning gravel at all redds. Mean stream velocities at coho salmon redds ranged from 0.11 to 0.51 m/s. Mean spawning depth was from 0.13 to 0.27 m. Water temperature at time of spawning ranged from 3.9 to 8.9 C. Mean water depth and velocity differed significantly between the six streams. The Fredle index and percent fines were significantly different between sample sites.

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INTRODUCTION

Coho salmon (*Oncorhynchus kisutch*) spawn and rear in streams from Monterey Bay, California, to Point Hope, Alaska, and southward along the Asiatic coast to Japan (McMahon 1983). Coho salmon spawn and rear in small coastal streams as well as in the tributaries of larger rivers. In North America coho salmon migrate upstream during the fall and their entry into freshwater often coincides with rises in streamflow, particularly in streams with low summer flows (Shapovalov and Taft 1954). Many small coastal streams in California have a sandbar blocking the entrance to the stream and returning coho salmon cannot enter the stream until rising water from fall rains breech the sandbar (Hassler 1987). Coho salmon usually return to their natal streams to spawn at age 3 or 4 and are 45 to 60 cm. long and weigh from 3.5 to 5.5 kg (Shapovalov and Taft 1954). Some coho salmon will return to spawn after being in the ocean for only 6 to 9 months. These fish are usually precocious males (jacks). The return of precocious fish is more common in the southern portion of their range (Shapovalov and Taft 1954). In California coho salmon enter freshwater from October to March, with spawning peaking from November to January. After coho salmon eggs hatch the young rear in freshwater from one month to two years depending on the area (Scott and Crossman 1973). The majority of the coho salmon in California migrate to the sea after one year of stream residence (Hassler 1987).

Hydrological factors such as water clarity, depth, and velocity, and bottom substrate size are important for successful spawning. Chapman (1943) reported that salmon spawn on riffles where the differences in water head force a flow of water into the gravel (downwelling) which delivers oxygen to the eggs (Figure 1 A). At a redd downwelling occurs in the tailspill which creates a current past the eggs bringing oxygen to them and removing metabolic waste (Figure 1 B and C), (Reiser and Wesche 1977). Coho salmon usually spawn in water velocities from 0.08 to 0.70 m/s and at depths of 0.13 to 0.50 m and in substrate from 13 to 155 mm in diameter (Briggs 1953; Buck 1986).

In the past, coho salmon used any accessible coastal stream in California to spawn. However, they no longer occur in many of these streams and their numbers are greatly reduced in others (Hassler 1988). The sizes of coho salmon runs in California have decreased by 80 percent to 90 percent since the 1940's (Clark 1988). The most recent study of coho salmon redd characteristics in small coastal streams in northern California was done over thirty years ago by Briggs (1953). Since then there has been an increase in urbanization, logging, and water management in the areas that coho salmon use, a new study of coho salmon habitat is needed. The objectives of this study were to: (1) determine water depth and velocity and substrate selected by coho salmon for their redds and compare gravel parameters within the redd to gravel adjacent to the redd; and (2) analyze differences in these factors between watersheds.

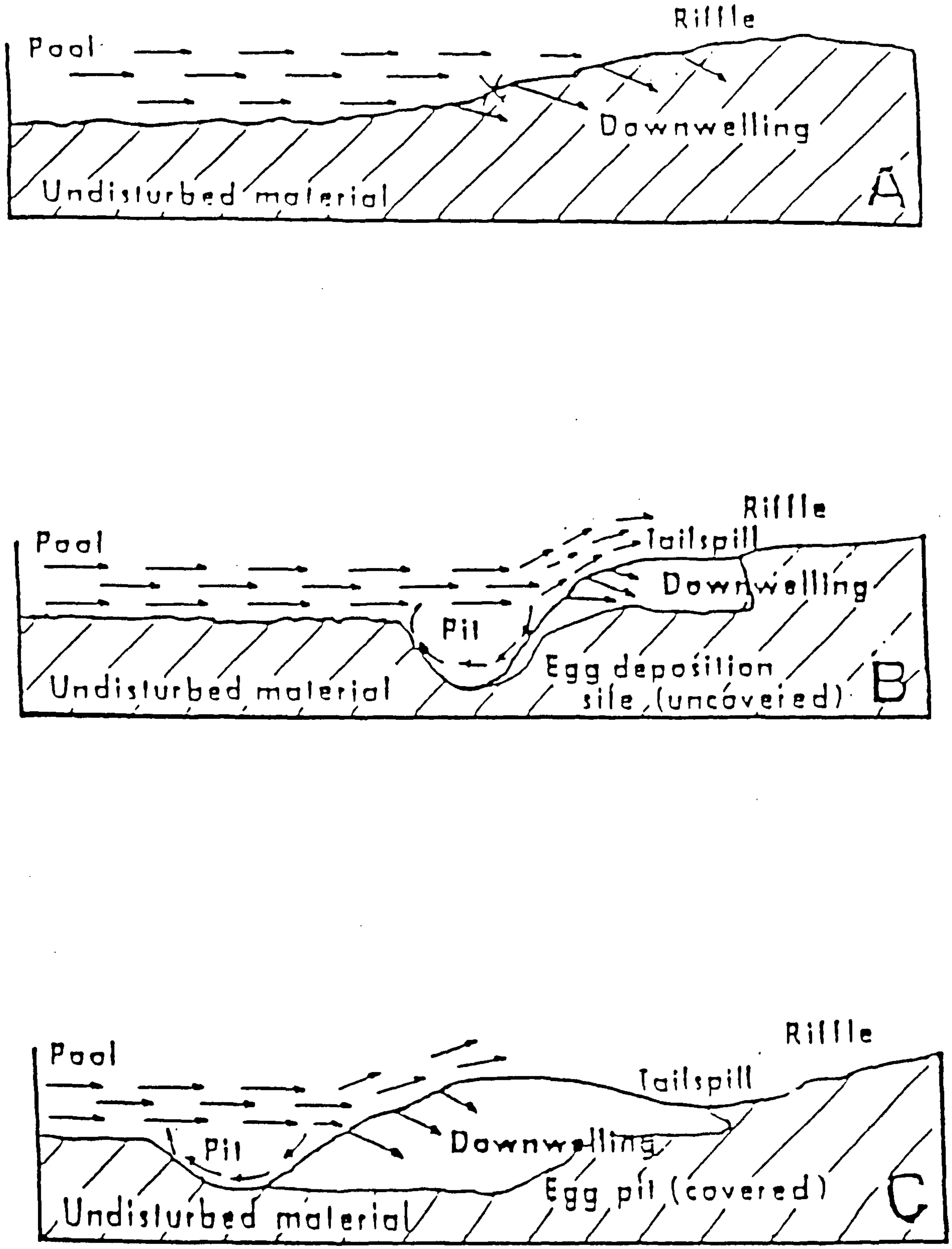

Figure 1. Longitudinal Cross Sections of Spawning Areas (from Reiser and Wesche 1977): A. Downwelling at the Pool-Riffle Exchange. Area Likely to be Used for Spawning Marked With an X, B. Redd Construction Downwelling Over the Tailspill, C. Formation of "Tailspill" Over the Eggs Causing Downwelling.

STUDY SITES

Coho salmon redds were sampled in Trinity River, Rush Creek, Weaver Creek, Freshwater Creek, Lost Man Creek, and Camp Creek (Figure 2). All of the streams support runs of chinook salmon (Oncorhynchus tshawytscha), coho salmon, and steelhead trout (O. mykiss). The Trinity River side channel, where redds were measured, is located upstream from the new Lewiston bridge and about 0.8 km downstream from Lewiston Dam. The side channel is 100 m long and 30 m wide and is a natural channel (Buck 1986). Rush Creek flows into the Trinity River approximately 5 km downstream from Lewiston Dam. The creek is 22 km long with a mean gradient of 2 percent. The redds were all located in the first 4 km upstream of the confluence with the Trinity River. Weaver Creek, a major tributary to the upper Trinity River, flows into the Trinity River at Douglas City, California. The mainstem of Weaver Creek is about 9.5 km long with a mean gradient of 1.0 percent. The redds were all located in the first 2 km upstream from the Trinity River. Freshwater Creek flows through Freshwater and Eureka sloughs and into Humboldt Bay, 1 km. north of Eureka, California. Freshwater Creek is about 20.0 km long with a mean gradient of 0.5 percent. The redds were located in the lower 12 km of the stream. Lost Man Creek, a major tributary to Prairie Creek, flows into Prairie creek 6.5 km north of Orick, California. Lost Man Creek is about 9 km long with a mean gradient in the lower section of 0.64 percent. The redds were located in the first 4 km. of the stream. Camp Creek, a major tributary to the Klamath River flows into the river near Orleans, California. The creek is 23 km long with a mean discharge of 190 cfs and a mean gradient of 5 percent. The redds were located in the lower 4 km of the stream.

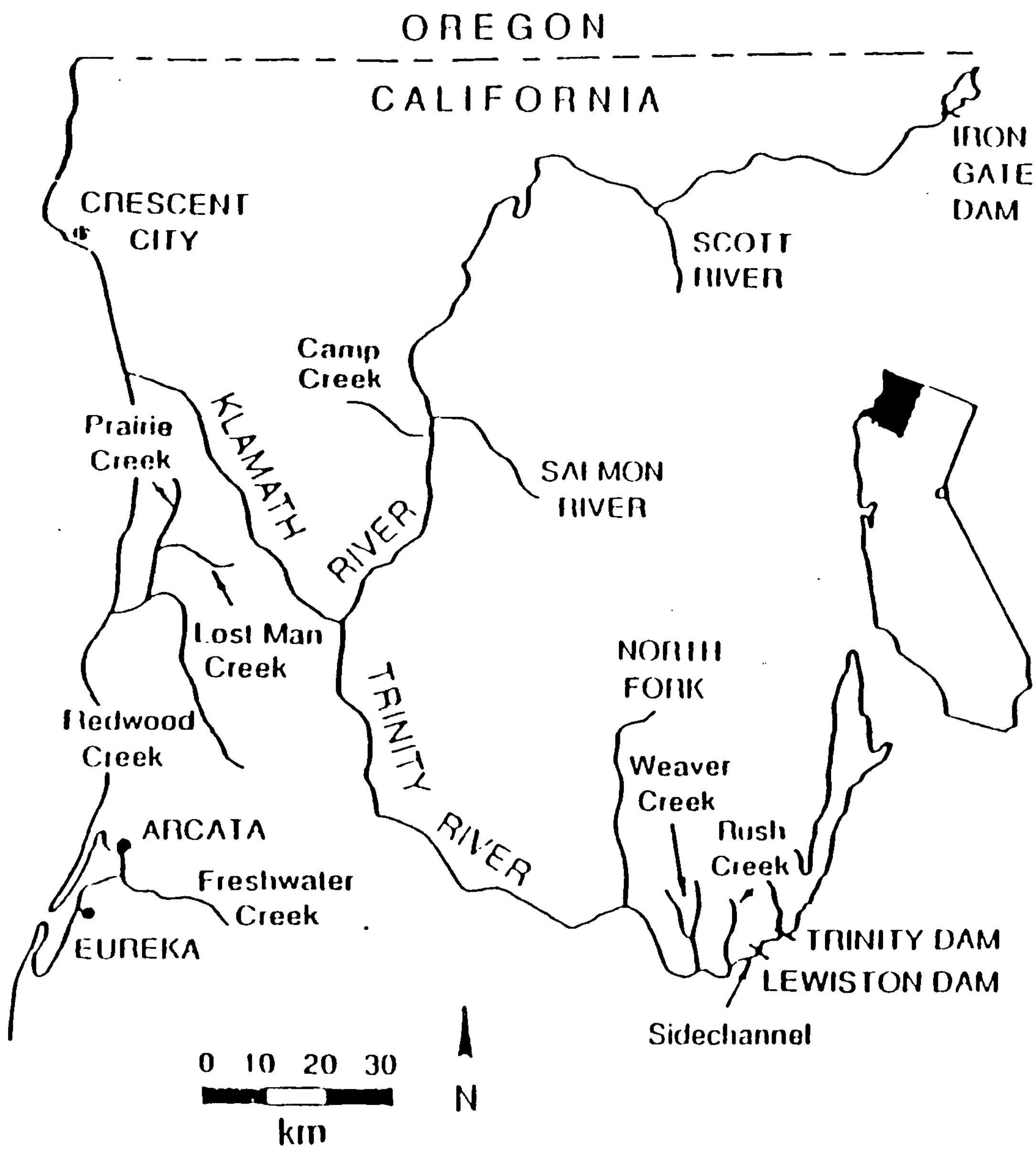

Figure 2. Klamath-Trinity River Basins

METHODS

Coho salmon redds in six streams from four coastal watersheds in northern California were surveyed during November and December 1989 and January 1990. For a redd to be categorized as a coho salmon redd, adult coho had to be actively working the redd or in near proximity to the redd. A transects 1.5 meters long was established immediately above each redd over undisturbed substrate perpendicular to the flow of the stream. Water depth, velocity and temperature were measured at five 0.3 m intervals along the transect. Depth was measured with a 1.2 m top set wading rod. Mean depth of the transect was determined following (Platts et al. 1983) as follows:

$$d = \frac{1}{n} (d1 - d2 \ldots dn)$$

Where d = an individual depth measurement on the transect and n = number of measurements taken on the transect. Water velocity was measured with a USGS pygmy meter attached to the wading rod. Water velocity (v) was measured following Platts et al.(1983) as:

1. If water depth is < 0.3 ft, measure v at 0.5 d.
2. If water depth is > 0.3 ft but < 2.5 ft, measure v at 0.6 d.
3. If water depth is > 2.5 ft, measure v at 0.2d and 0.8d and average.

All measurements were in reference to the water surface. Velocity was determined as V=R/T where R=revolutions and T=time in seconds. Water temperature was measured with a hand held thermometer. Water depth and velocity were measured after the redd was completed. Water temperature was measured during and after redd construction.

The Rosgen (1985) stream classification system was used to describe the stream channel at the locations of the redds (Table 1).

Table 1. Stream Channel Type Descriptions (Rosgen 1985).

Stream type	Description
B1	General Description: Moderate gradient, stable small boulder/Large cobble channel. Landform/Soils: Stable, course grained. Gradient: 2.5 - 4.0 Sinuosity: 1.1 - 1.3 Width/Depth ratio: 5 - 15 (x:10) Channel materials: Small boulder, Lrg. cobble, coarse gravel Entrenchment/Confinement: Mod. entrenchment/Well confined.
B2	General description: Moderate gradient, stable large cobble/course gravel channel. Landform/Soils:Moderate steep, course depositional soils. Gradient: 1.5 - 2.5 Sinuosity: 1.3 - 1.5 Width/Depth ratio: 8 - 20 (x:14) Channel materials: Large cobble, coarse gravel and sand. Entrenchment/Confinement: Moderate entrenched/well confined.
C1	General description: Gentle gradient, cobble bed meandering channel. Landform/Soils: Relatively stable course river terraces. Gradient: 1.0 - 1.5 Sinuosity: 1.2 - 1.5 Width/Depth ratio: >10 (x:18) Channel materials: Cobble bed, cobble, gravel, sand banks. Entrenchment/Confinement: Moderate to shallow entrenchment, moderate confinement.

Table 1. Stream Channel Type Descriptions (Rosgen 1985). (continued)

Stream type	Description
C2	General description: Gentle gradient overfit cobble bed channel. Landform/Soils: Coarse river terraces, active channel oversized by historical geomorphic event. Gradient: 0.3 - 1.0 Sinuosity: 1.3 - 1.5 Width/Depth ratio: >10 (x:20) Channel materials: Cobble, very coarse gravel. Entrenchment/Confinement: Moderate entrenchment/well confined.
C3	General description: Gravel bed channel. Landform/Soils: Low river terraces, fine textured banks, gravel bed, banks unstable. Gradient: 0.5 - 1.0 Sinuosity: 1.8 - 2.4 Width/Depth ratio: >10 (x:20) Channel materials: Gravel bed, sands and silts in bank. Entrenchment/Confinement: Moderate entrenched/poorly confined.

One gravel sample was collected from the "pit" of the redd and one from the undisturbed gravel directly upstream from the redd at the transect with a McNeil sampler (McNeil and Ahnell 1964). Each gravel sample was taken to the laboratory, dried in an oven at 105 C for twenty-four hours, passed through nine sieves of 32, 16, 8, 4, 2, 1, 0.5, 0.25 and 0.125 mm and weighed to the nearest tenth of a gram. The suitability of the gravel for spawning was determined by using the Fredle index (Lotspeich and Everest 1981). The index (f) was calculated as: f=dg/So where dg=(d1"w1"x d2"w2"x..........dn"wn"), and dn=midpoint diameter of particles retained in the nth sieve, wn=decimal fraction by weight of particles retained in the nth sieve, and sorting coefficient (So)=(d75/d25)0.5, where d75 and d25 = particle size diameters at which 75 and 25 percent of the sample is finer on a weight basis. The percent fines in each gravel sample was calculated using 2 mm as the cutoff point for the size of the fines (Barnard 1990). The percent fines was calculated by plotting particle size against percentage cumulative weight of the sample and picking a maximum size (2 mm) to be considered a fine and calculating the percentage of the sample that lay below that size. Spawning habitat use curves were developed according to Bovee and Cochnauer (1977). The probability of use curves are based on the assumption that individuals of a species will tend to select areas within a stream having the most favorable combinations of hydraulic conditions. The curves were rated as "excellent" if they were generated from 200 measurements or more and had a Chi-square value of $p < 0.10$ of significant difference of frequencies within the optimum. A "good" rating was given if the frequency analysis contained less than 200 measurements and the Chi-square test of the optimum showed $0.10<p<0.25$ of significant difference of the frequencies within the optimum. A "fair" rating was obtained if there were less than 50 measurements used to develop the curves and the Chi-square showed significant variance within the optimum.

Water depths and velocities used by coho salmon for spawning in the six streams were analyzed by analysis of variance (ANOVA) and Tukeys multiple comparison test to determine if differences in selected depths and velocities occurred among streams (Zar 1984). The Fredle index and percent fines of gravel samples collected inside and outside the redd by stream were also analyzed by ANOVA and Tukeys test. The percent fines were transformed with an arcsine transformation before being analyzed by ANOVA (Zar 1984).

RESULTS

I sampled 46 coho salmon redds; twelve from the side channel on the Trinity River, five from Rush Creek, five from Weaver Creek, seven from Freshwater Creek, four from Camp Creek, and thirteen from Lost Man Creek. Water temperature at the sites varied from 5.6 C at the Trinity River, Rush and Weaver creeks, 3.9-4.7 C at Camp Creek, 4.2-5.0 C at Freshwater Creek to 5-8.9 C at Lost Man Creek. Mean water depth at the redds in the six streams was from 0.13 to 0.27 m and ranged from 0.03 to 0.45 m (Table 2). Mean water velocity over redds in the six streams was from 0.11 to 0.51 m/s and ranged from 0.01 to 0.90 m/s (Table 2). Mean water depth and velocity measured at the redds was significantly different ($P<0.05$) between streams (Table 3). The Tukey test showed that coho salmon spawned in significantly deeper water ($P<0.05$) in Lost Man Creek than in Freshwater, Weaver, and Rush creeks (Table 4). Coho salmon spawned in significantly higher water velocity ($P<0.05$) in Lost Man Creek than in Freshwater, Rush, Weaver, Trinity River and Camp creeks (Table 5). There was a significant interaction between depth and velocity in the six streams (Table 3). This indicates that the effect of one of the factors (depth or velocity) is not independent of the presence of a particular level of the other factor (Zar 1984). At least two of Rosgen (1985) stream channel types were used in each stream for spawning (Table 6). Channel type C2 was the most frequently used, occurring in four of the six streams.

The Fredle Index for the gravel sample from the redd ranged from 8.7 to 20.3 and from above the redd 4.3 to 14.6 (Table 7). There was a significant difference ($\underline{P}<0.05$) in the Fredle index between the redd and undisturbed area for Lost Man and Weaver creeks (Figure 3 and Table 8). There were no differences in the index in the other streams. There were significant differences in the Fredle index between streams for both the redd and undisturbed area (Table 9). Trinity River side channel had significantly higher ($\underline{P}<0.05$) spawning gravel quality than Lost Man Creek both for the redd and above (Table 10 and 11). There were no differences in gravel quality in the other streams.

The percent fines in the redds ranged from 1.5 to 10.1 percent and above redd areas from 3.5 to 17.3 percent (Table 12). There was a significant difference in percent fines between the redd area and above redd at Lost Man, Camp, and Weaver creeks (Figure 4 and Table 13). There was also a significant difference in the percent fines in the redd and above the redd between streams (Table 14). Lost Man Creek had a significantly higher ($\underline{P}>0.05$) percent of fines in the redds than Camp and Weaver creeks and Trinity River side channel (Table 15). Lost Man Creek also had significantly higher ($\underline{P}<0.05$) amount of fines above the redd than the Trinity River side channel and Freshwater and Rush creeks (Table 16).

The habitat use curves developed from the data (Tables 17 and 18) are similar to standard depth and velocity use curves developed by Bovee (1978) for coho salmon spawning (Figures 5 and 6). Most coho spawners used depths from 0.18 to 0.23 m and velocities from 0.15 to 0.30 m/s with an optimum depth of 0.20 m and velocity of 0.23 m/s.

Table 2. Water Depth and Velocity Measured at Coho Salmon Redds During the 1989-1990 Spawning Season in Northern California. Depth and Velocity Were Measured at Five Points Along a Transect at Each Redd.

Stream	No. Redds	Depth (m) Range	Depth (m) Mean	Velocity (m/s) Range	Velocity (m/s) Mean
Freshwater Creek	7	0.06-0.21	0.13	0.01-0.39	0.11
Rush Creek	5	0.03-0.24	0.15	0.15-0.31	0.22
Weaver Creek	5	0.09-0.20	0.14	0.18-0.32	0.24
Trinity River (SC)	12	0.08-0.45	0.20	0.08-0.51	0.24
Camp Creek	4	0.09-0.26	0.19	0.22-0.41	0.31
Lost Man Creek	13	0.09-0.40	0.27	0.19-0.90	0.51

Table 3. Analysis of Variance of Coho Salmon Spawning Depth and Velocity During the 1989-1990 Spawning Season in Northern California. Asterisk Denotes Significant F-Value($\underline{P}<0.05$)

Source of Variation	df	SS	MS	F
Depth	5	0.602	0.120	26.335*
Velocity	5	4.460	0.892	69.824*
Depth x Velocity	25	25	1.225	144.730*
Error	424	3.886	0.009	
Total	459	0.203		

Table 4. Tukey Test of Water Depth at Coho Salmon Redds During the1989-1990 Spawning Season in Northern California.

STREAMS					
Freshwater	Weaver	Rush	Camp	Trinity	Lost Man
Ranked Means Depth (m)					
0.128	0.140	0.148	0.187	0.196	0.267

Table 5. Tukey Test of Water Velocity at Coho Salmon Redds During the 1989-1990 Spawning Season in Northern California.

	STREAMS					
	Freshwater	Rush	Weaver	Trinity	Camp	Lost Man
Ranked means						
Velocity (m/s)						
	0.110	0.222	0.241	0.243	0.307	0.514

Table 6. Stream Channel Types Used by Spawning Coho Salmon in Northern California. (for channel type descriptions see see Table 1)

Stream	Channel Type				
	B1	B2	C1	C2	C3
Trinity River				*	*
Rush creek	*	*			
Weaver creek				*	*
Camp creek	*	*			
Freshwater creek		*		*	*
Lost Man creek				*	*

Table 7. Fredle Index of Substrate Samples from Coho Salmon Redds and Undisturbed Areas Upstream of the Redd During the 1989-1990 Spawning Season in Northern California Streams.

		Fredle Index			
		Redd		Undisturbed	
STREAM	No. Redds	Range	Mean	Range	Mean
Lost Man Creek	13	2.3-20.5	8.7	2.2-8.2	4.3
Camp Creek	4	0.7-32.8	18.9	4.0-10.1	6.7
Weaver Creek	5	9.9-28.8	17.1	6.7-8.8	7.7
Freshwater Creek	7	6.6-17.1	14.5	7.0-14.1	9.8
Rush Creek	5	6.2-15.0	10.3	3.9-35.2	13.6
Trinity R. (SC)	12	9.2-31.4	20.3	4.7-28.7	4.6

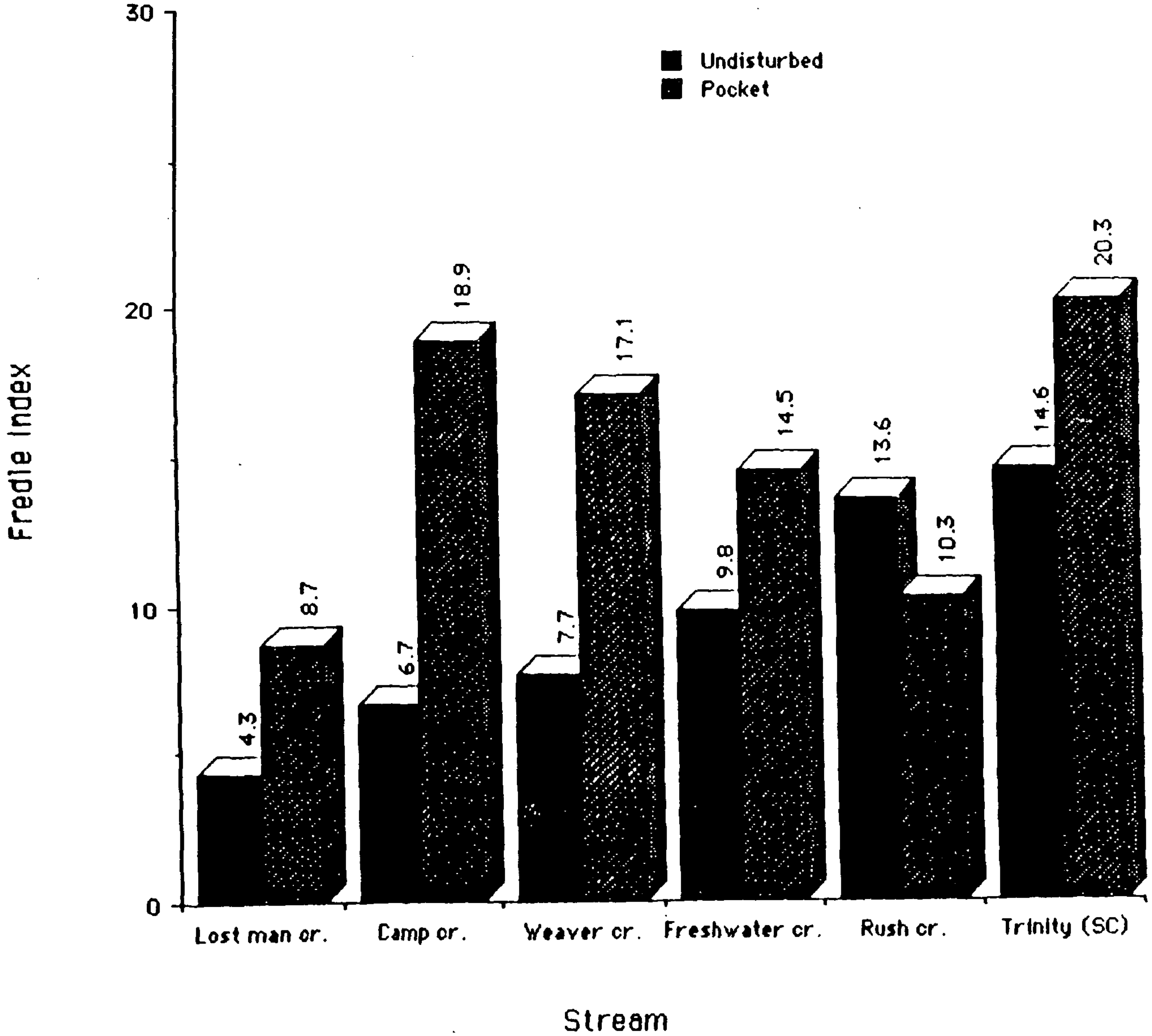

Figure 3. Fredle Index of Substrate Samples From Coho Salmon Redds and Undisturbed Areas Upstream of Redd During the 1989-1990 Spawning Season in Northern California Streams.

Table 8. Analysis of Variance of the Fredle Index from Coho Salmon Redds and Undisturbed Areas by Stream During the 1989-1990 Spawning Season in Northern California. Source of Variation is Between the Redd and Undisturbed Area Samples (R/U). Asterisk Denotes Significant F-Value (*P*<0.05).

STREAM	Source	df	SS	MS	F
Lost Man Creek	R/U	1	116.512	116.512	7.199*
	Error	24	356.064	16.185	
	Total	25	472.576		
Camp Creek	R/U	1	300.125	300.125	0.059
	Error	6	331.540	55.257	
	Total	7	631.665		
Weaver Creek	R/U	1	220.055	220.055	8.880*
	Error	8	198.256	24.782	
	Total	9	418.311		
Freshwater Creek	R/U	1	79.349	1.701	
	Error	12	559.746	46.646	
	Total	13	639.095		
Rush Creek	R/U	1	27.556	27.556	0.297
	Error	8		741.692	92.712
	Total	9	769.248		
Trinity River	R/U	1	212.784	212.784	4.157
	Error	22	1228.591	51.191	
	Total	23	1441.375		

Table 9. Analysis of Variance of the Fredle Index from Coho Salmon Redds and Undisturbed Areas Between Streams During the 1989-1990 Spawning Season in Northern California. Asterisk Denotes Significant F-Values ($P<0.05$).

SAMPLE	Source	df	SS	MS	F
Redd	Between Streams	5	1039.296	207.859	4.108*
	Error	40	2024.033	50.601	
	Total	45	3063.329		
Undisturbed	Between Streams	5	796.228	159.246	4.575*
	Error	40	1392.362	34.809	
	Total	45	2188.590		

Table 10. Tukey Test of Fredle Index Values of Coho Salmon Redds Between Streams During the 1989-1990 Spawning Season in Northern California.

	STREAMS					
	Lost Man	Rush	Freshwater	Weaver	Camp	Trinity
Ranked means Fredle index Pocket	8.7	10.3	14.5	17.1	18.9	20.3

Table 11. Tukey Test of Fredle Index Values of Coho Salmon Redds Between Streams from Undisturbed Samples During the 1989-990 Spawning Season in Northern California.

	STREAMS					
	Lost Man	Camp	Weaver	Freshwater	Rush	Trinity
Ranked means Fredle index Undisturbed	4.3	6.7	7.7	9.8	13.6	14.6

Table 12. Percent Fines (<2 mm) of Substrate Samples from Coho Salmon Redds and Undisturbed Areas Upstream of the Redd During the 1989-1990 Spawning Season in Northern California Streams.

		Percent Fines (≤ 2 mm)			
		Redd		Undisturbed	
STREAM	No. Redd	Range	Mean	Range	Mean
Lost Man Creek	13	2.0-23.8	10.1	6.7-37.2	17.3
Camp Creek	4	0.2-3.3	1.5	6.4-14.7	10.3
Weaver Creek	5	0.03-4.1	1.8	4.6-10.5	8.2
Freshwater Creek	7	0.6-8.4	4.0	2.9-9.0	5.7
Rush Creek	5	2.0-8.0	4.5	0.2-15.9	7.7
Trinity R. (SC)	12	0.06-7.6	2.3	0.13-9.2	3.5

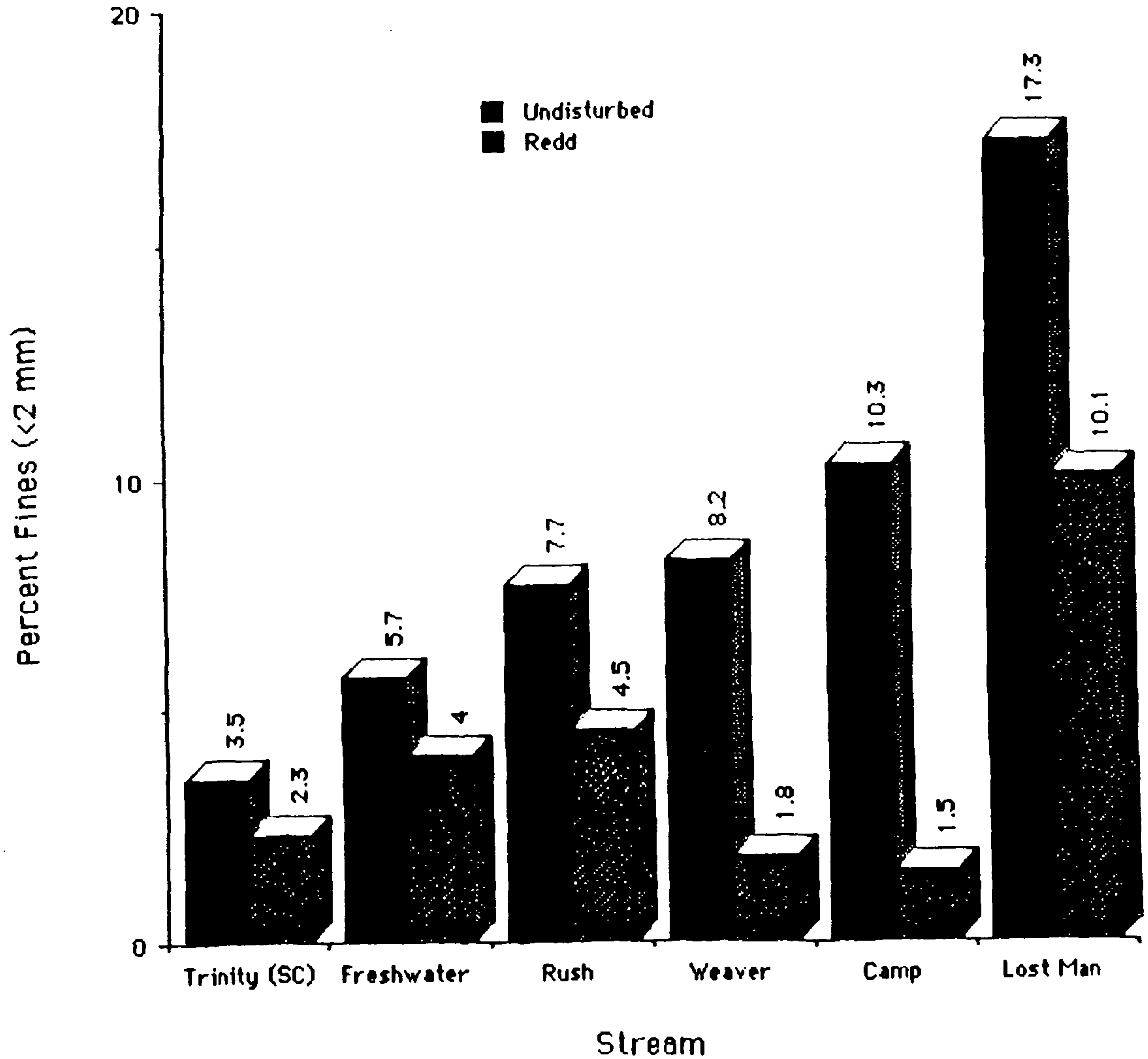

Figure 4. Average Percent Fines of Substrate Samples From Coho Salmon Redds and Undisturbed Areas Upstream of Redd During the 1989-1990 Spawning Season in Northern California Streams.

Table 13. Analysis of Variance of the Arcsine Transformed Percent Fine (< 2 mm) From Coho Salmon Redds and Undisturbed Areas Upstream of the Redd by Stream During the 1989-1990 Spawning Season in Northern California. Source of Variation is Between the Redd and Undisturbed Area Samples (R/U). Asterisk Denotes Significant F-Value (P>0.05).

STREAM	Source	df	SS	MS	F
Lost Man Creek	R/U	1	257.612	257.612	6.903*
	Error	24	821.043	37.320	
	Total	25	1087.655		
Camp Creek	R/U	1	300.860	300.860	27.032*
	Error	6	66.778	11.130	
	Total	7	367.638		
Weaver Creek	R/U	1	219.211	219.211	7.179*
	Error	8	102.086	2.761	
	Total	9	321.297		
Freshwater Creek	R/U	1	6.271	6.271	0.210
	Error	12	358.097	29.841	
	Total	13	364.369		
Rush Creek	R/U	1	16.512	16.512	0.370
	Error	8	741.692	92.712	
	Total	9	769.248		
Trinity River	R/U	1	43.086	43.086	1.432
	Error	22	722.231	30.093	
	Total	23	765.317		

Table 14. Analysis of Variance of the Arcsine Transformed Percent Fines (< 2.00 mm) From Coho Salmon Redds and Undisturbed Areas Above the Redd Between Streams During the 1989-1990 Spawning Season in Northern California. Asterisk Denotes Significant F-Value ($\underline{P}<0.05$).

SAMPLE	Source	df	SS	MS	F
Redd	Between Streams	5	1435.287	287.057	9.966*
	Error	40	1152.114	28.803	
	Total	45	2587.401		
Undisturbed	Between Streams	5	882.942	176.588	6.343*
	Error	40	1113.520	27.838	
	Total	45	1996.462		

Table 15. Tukey Test of Arcsine Transformed Percent Fines (< 2 mm) in Coho Salmon Redds Between Streams During the 1989-1990 Spawning Season in Northern California.

	STREAMS					
	Camp	Weaver	Trinity	Freshwater	Rush	Lost Man
Ranked means Arcsine % Fines Redd	6.3	7.1	7.2	10.6	11.8	17.6

Table 16. Tukey Test of Arcsine Transformed Percent Fines (< 2 mm) Above Coho Salmon Redds Between Streams During the 1989-1990 Spawning Season in Northern California

	STREAMS					
	Trinity	Freshwater	Rush	Weaver	Camp	Lost Man
Ranked means						
Arcsine % Fines	3.5	5.7	7.7	8.2	10.3	17.3
Undisturbed						

Table 17. Frequency Analysis of Water Depths at Coho Salmon Redds During the 1989-1990 Spawning Season in Northern California. The Left Cluster was Chosen for the Curve Construction.

Depth (m)	Tally	Left Cluster	Right Cluster	Probability
0.03	1			
		7		0.12
0.06	6			
			21	
0.09	15			
		54		0.89
0.12	39			
			70	
0.15	31			
		61		1.0
0.18	30			
			62	
0.21	32			
		60		1.0
0.24	28			
			38	
0.27	10			
		26		0.43
0.30	16			
			25	
0.33	9			
		13		0.21
0.36	4			
			8	
0.39	4			
		4		0.07
0.42	0			
			3	
0.45	3			

Table 18. Frequency Analysis of Water Velocities at Coho Salmon Redds During the 1989-1990 Spawning Season in Northern California. The Left Cluster was Chosen for the Curve Construction.

Velocity (m/s)	Tally	Left Cluster	Right Cluster	Probability
0.01	3			
			4	
0.03	1			
		5		0.14
0.06	4			
			22	
0.09	18			
		25		0.69
0.12	7			
			20	
0.15	13			
		33		1.0
0.18	20			
			41	
0.21	21			
		41		1.0
0.24	20			
			41	
0.27	21			
		34		1.0
0.30	13			
			24	
0.33	11			
		20		0.55
0.36	9			
			12	
0.39	3			
		13		0.39
0.42	10			
			15	
0.45	5			
		14		0.39

Table 18. Frequency Analysis of Water Velocities at Coho Salmon Redds During the 1989-1990 Spawning Season in Northern California. The Left Cluster was Chosen for the Curve Construction. (continued)

Velocity (m/s)	Tally	Left Cluster	Right Cluster	Probability
0.48	9			
		16		
0.51	7			
		15		0.39
0.54	8			
			1	
0.57	4			
		7		0.19
0.60	3			
			8	
0.63	5			
		8		0.19
0.66	3			
			5	
0.69	2			
		2		0.06
0.72	0			
			3	
0.75	3			
		4		0.03
0.78	1			

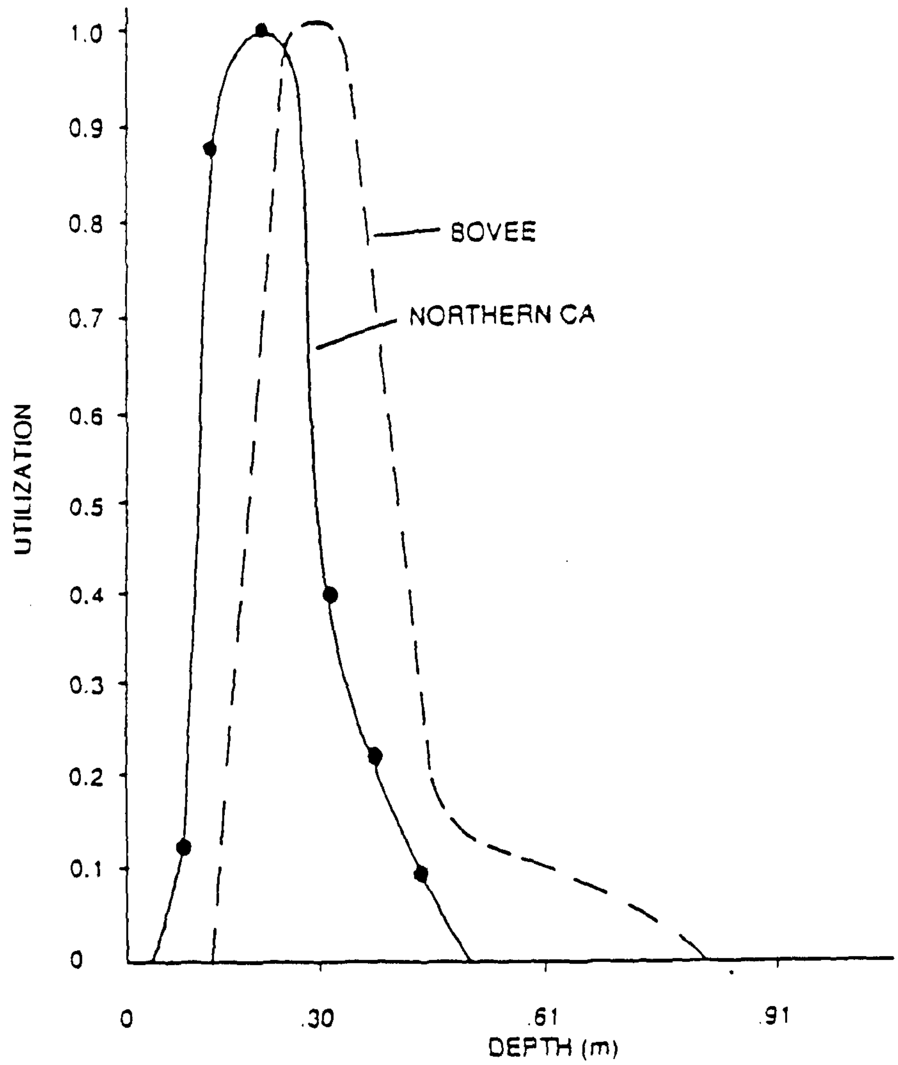

Figure 5. Habitat Use Curve for Coho Salmon Spawning Depths During the 1989-1990 Spawning Season in Northern California Compared to Bovee (1978).

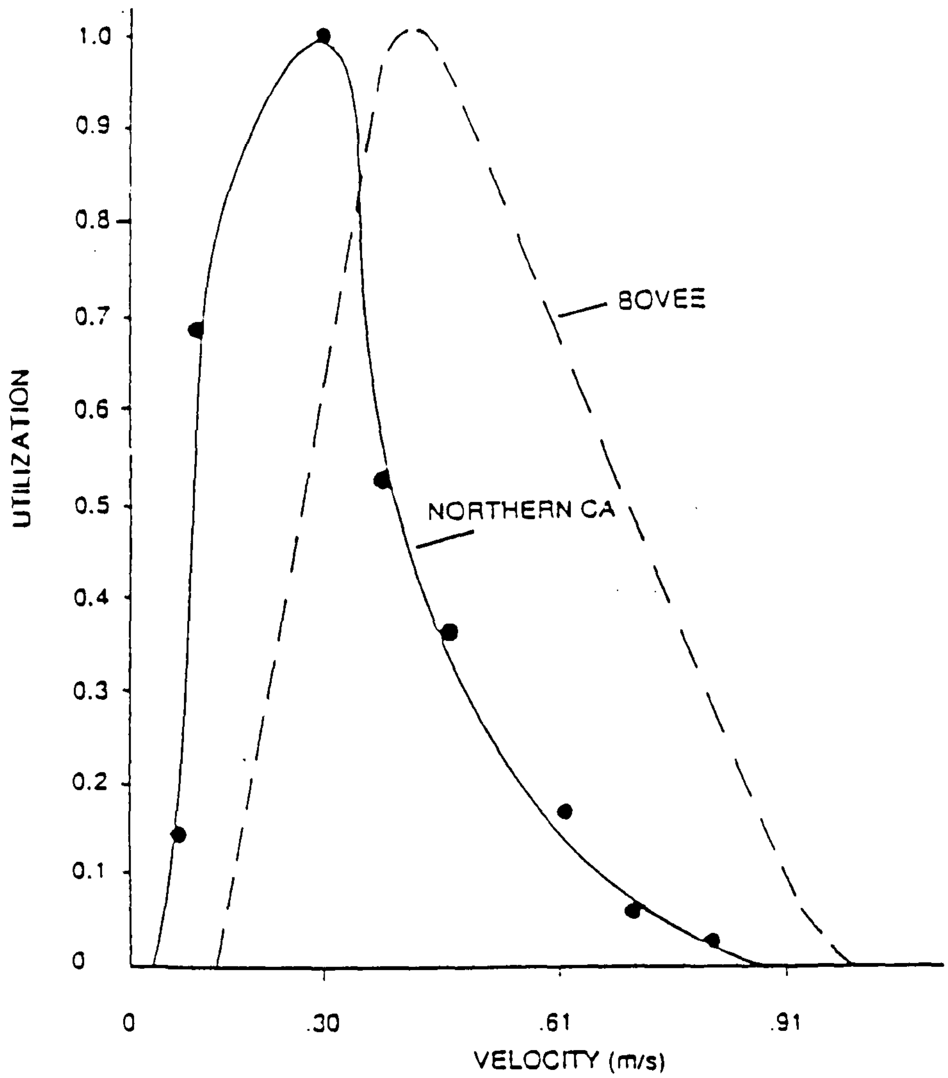

Figure 6. Habitat Use Curves for Coho Salmon Spawning Velocity During the 1989-1990 Spawning Season in Northern California Compared to Bovee (1978).

DISCUSSION

Water temperature during the sampling period (4.0 C - 9.0 C) was within the reported range of water temperatures (3.0 to 13.0 C) used by spawning coho salmon (Briggs 1953; Chambers et al. 1955; Shepard et al. 1986). Mean water depth and velocity selected by spawning coho in the six streams was similar to reported depth and velocity used by spawning coho (Table 19). However, depth and velocity selected in 1989-1990 was at the lower end of the range except for Lost Man Creek. This was probably the result of lower than normal rainfall in all the watersheds except Lost Man Creek. Coho salmon spawned in deeper water and at higher velocities in Lost Man Creek than in Freshwater, Weaver and Rush creeks and at higher velocities than in Camp Creek. The major factor for this was rainfall in each basin. In Lost Man basin, the rainfall for the month of January when the data was collected was 114 percent of normal but in the other basins rainfall for the month when the data was collected was only 12 percent of normal (National Oceanic and Atmospheric Administration 1989-90). The small number of redds sampled and short spawning season would also affect the results. The spawning habitat use curves constructed from my data are shifted to less depth and lower velocity than the standard depth and velocity curves for coho salmon spawning developed by Bovee (1978). I made over 200 measurements for both spawning depths and velocities and the Chi-square tests was <0.10 for the optimum.

Table 19. Stream Flow and Substrate Characteristics Associated With Coho Salmon Redds. M=Meters and M/S=Meters per Second.

Location	Source	Substrate Diameter (mm) (range)	Mean Water Depth (m) (range)	Mean Water Velocity (m/s) (range)
Northern, CA	This study	-	(0.03-0.45) .19	(0.01-0.90) .24
Lagunitas C CA	Bratovich and Kelley (1988)	-	(0.13-0.24)	(0.21-0.60)
Trinity R CA	Buck (1986)	(75-150)	(0.24-0.39)	(0.27-0.55)
Fraser R., B.C.	Shepard et al (1986)	59	0.50	0.70
Oregon	Smith (1973)	-	0.22	0.44
Oregon	Thompson(1972)	(13-102)	0.18	(0.31-0.91)
Oregon	Sams and Pearson (1963)	-	0.25	0.48
Washington	Chambers et al (1955)	-	(0.31-0.46)	(0.08-0.61)
Prairie Crk CA.	Briggs (1953)		0.16	0.58
Columbia R. Drainage, OR.	Burner (1951)	-	0.20	_

However, since the study took place during only one spawning season I was not able to measure depth and velocity over a wide range of hydraulic conditions. Also, in five out of the six basins sampled rainfall during the spawning season was below normal, indicating that rainfall was the major contributing factor in the differences between my curves and those of Bovee's (1978).

The predominate type of stream channel used by coho salmon for spawning was C2 (see Tables 1 and 6) which was used in four of the six streams. This channel type was typified as having cobble (64-300 mm), coarse gravel (>1-150 mm) and a gradient of 0.3 to 1 percent (Shepard et al. 1986).

Fine sediment is known to influence survival and emergence of salmon embryos. Harrison (1923) was one of the first to report the inverse relation between the quantity of sand and silt in redds and the survival of incubating salmonid eggs. Stuart (1953) found that fine particles of silt were attracted to the chorion and when exposed for a long enough time the embryos died without hatching. He also found that serious inflammation of the gill membrane occurred if yolk-sac fry were exposed to turbid water and that they eventually died. Koski (1966) determined that the single most important factor affecting the emergence of coho salmon fry was the composition of gravel within the redd. I used survivals computed from the Fredle index which was determined in the laboratory by Phillips et al. (1975) to predict the survival from eggs to emergence. The predicted survival to emergence in the streams I sampled was from 25 to 95 percent. The predicted survivals plus the computed Fredle indexes indicated that the quality of the gravel for spawning in the streams I sampled was adequate. Chapman (1988) who reviewed work on fines in salmonid redds concluded that laboratory studies have not completely duplicated the structure and composition of egg pockets of large salmonids, and thus have not accurately modeled survival of embryos in natural egg pockets.

Fredle indexes determined from gravel samples collected by McNeil samples can be higher than indexes determined from freeze cores. Barnard (1990) took freeze core samples from coho salmon redds and outside redds in Freshwater Creek and calculated a mean Fredle index of 12.7 and 8.1 respectively. I calculated a mean index of 14.5 for redds and 9.8 outside the redd in Freshwater Creek from samples collected with a McNeil sampler. Barnard (1990) also measured percent fines (<2 mm) of 8.3% outside redd and 12.4% redd. I measured the same parameters a year later and found that the percent fines were about 50 percent less than Barnard measured. The differences could be that since the two studies were done in different years, the flows could have been different enough to affect the sediment load of the stream The most likely explanation is that Barnard used Freeze-core sampling while I used the McNeil sampler which underestimates fines (Platts et al. 1983).

The digging activity of female salmonid when constructing a redd can remove fines from the substrate (Burner 1951; Semko 1954; Cordone and Kelley 1961). The Trinity River side channel had the least amount of fines <2 mm of the streams sampled. One reason might be the side channels close downstream proximity to the Trinity River Dam which reduces sediment load in the river (Hassler

1990). Another reason could be the high number of spawners using this area which would tend to clean the gravel. Everest et al. (1987) measured the percent fines in a stream with a heavy sediment load which was being used by spawning chinook salmon and found that fines <1 mm in diameter were 30.0 percent before spawning, but had decreased to 7.2 percent after spawning. Allen et al. (unpublished manuscript) noted a reduction of fines <3.2 mm in coho salmon redds from 21.6 percent before spawning to 9.1 percent after in the Toutle River, Washington. The overall quality of spawning habitat can also decline if the spawning populations decrease (Everest et al. 1987).

The data I collected during the 1989-1990 spawning season represent an extreme of the parameters that are associated with coho salmon redds because of low rainfall and small sample size. The data do illustrate that coho salmon alter their habital preferences in relation to streamflow pattern. The study should be repeated in a normal water year to attain measurements over a wider range of hydrological conditions which would provide more accurate data about preferred spawning conditions in small coastal streams.

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