1997 Final Report

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Salmon Redd Composition, Escapement and Migration Studies in Prairie Creek, Humboldt County, California, 1996-1997

Prepared for:
California Department of Transportation

Prepared by:

Bernard Klatte
and
Dr. Terry Roelofs

Humboldt State University
Arcata, California
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Abstract

Humboldt State University and Pacific Coast Fish, Wildlife and Wetlands Restoration Association, under a Memorandum of Agreement with the California Department of Transportation Compliance Plan under Regional Water Quality Control Board Order 90-8, monitored the migration of adult and juvenile salmonids and spawning substrate composition in Prairie Creek, an old-growth coastal stream, located in northern California. Anadromous salmonids entering and spawning in Prairie Creek were examined over a 5-month period starting in November of 1996 and ending in March of 1997. A total of 237 live fish were captured using a weir and fish trap placed 9.5 km above the creek mouth. Species composition, numbers, size of fish, run timing, and sex ratios were recorded. Spawning and carcass surveys were conducted over the study period. A total of 160 individual chinook and coho salmon redds and 221 carcasses were measured within the Redwood National Park 10.5 km index reach (Streelow Creek to Good Creek) plus an additional 4 km upstream. Sixteen coho redds were used for a spawning gravel composition study and of these redds, 6 were used for an emergent fry trapping study. A negative linear relationship was demonstrated between intragravel flow and the percentage of fines less than 2 mm of the spawning substrate for all 16 coho redds. A significant difference in inflow rates and percent fines was determined between coho redds above Brown Ck. and below Brown Ck. Juvenile migrating salmonids were captured using an EG Solution rotary screw trap, a fyke net, and six pipe traps. The screw trap was operated upstream from the confluence of Streelow Ck. from 20 February 1997 to 19 June 1997. Total captures included 25,994 chinook young of the year (YOY); 3,113 coho YOY; 2,302 coho yearlings; 247 trout YOY; 710 trout yearlings; 94 steelhead smolts, and 430 coastal cutthroat trout. Weekly trapping efficiencies were conducted when possible with juvenile chinook. The rotary screw trap total mortality rate calculated over the trapping period was less than 1 %. The fyke net trap was operated above the confluence of Boyes Ck. from 3 March 1997 to 19 June 1997. Total captures included 34,987 chinook YOY, 6,368 coho YOY, 633 coho yearlings; 1,797 trout YOY; 177 trout yearlings; 31 steelhead smolts and 210 coastal cutthroat trout. Pipe traps were located at the confluence of S.F. and N.F. Brown Ck., Boyes Ck., Godwood Ck., May Ck., and above HWY 101 in Little Lost Man Ck. Total captures for pipe traps combined included 6,681 chinook YOY, 19,909 coho YOY, 596 coho yearlings; 820 trout YOY; 801 trout yearlings; 68 steelhead smolts and 274 coastal cutthroat trout. A summer coho population estimate produced 24,558 juvenile coho between Streelow Creek and below Ten Tapo Creek (14.5 km)(1,694 coho/km).

Acknowledgments

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Introduction

Prairie Creek is a tributary to Redwood Creek in Humboldt County, California. It is an important spawning and rearing area for anadromous salmonids, specifically chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and coastal cutthroat trout (*O. clarki clarki*). The recent decline in numbers of anadromous species has increased the potential for these species to become listed in California under both federal and state endangered species laws. In October 1989, a storm event generated numerous mud flows from a highway construction alignment project within the Prairie Creek Basin (Welsh and Olliver 1992). Several hundred tons of sediment eroded from the project and were deposited into the Prairie Creek Basin. In anticipation of damage to fish and other aquatic resources, the California Department of Transportation (Caltrans) proposed monitoring to study the impacts and persistence of this fine sediment (Myers et al. 1994). Caltrans also contracted the Pacific Coast Fish, Wildlife and Wetlands Restoration Association (PCFWWRA) to rear and release salmonids in Prairie Creek in 1990. Efforts to supplement the salmon populations using streamside incubation and rearing ended in 1995 (PCFWWRA 1995). Currently, natural spawning success and rearing within the Prairie Creek Basin is being evaluated. Here we present the results of the 1996-1997 field study of the anadromous salmonids in Prairie Creek.

Objectives

In this study we proposed to quantify the impacts of a human-caused sedimentation event on salmonids in a coastal old-growth redwood forest. Our objectives were as follows:

- Determine the species composition of the anadromous fish runs,
- estimate the anadromous salmon escapement,
- determine run-timing for salmon,
- determine the age and size of salmon,
- describe sex ratios,
- document locations and success of spawning activities,
- measure intragravel characteristics of coho redds,
- determine gravel composition of coho redds, and
- determine the survival to emergence of coho salmon.

Study Area

The Prairie Creek Basin lies within the Coast Redwood Belt of the Humid Transition Life Zone near the town of Orick, Humboldt County, California (Figure 1). Prairie Creek, tributary to Redwood Creek, is 22.5 km long and drains an area of 77.5 km^2. The altitude ranges from sea level to 305 m and the rainfall of the area averages about 127 cm annually (Briggs 1953). The Prairie Creek channel originates at USGS Fern Canyon, CA quadrangle T12N R1E section 10, and flows south along U.S. Highway 101 through private agriculture and old-growth forests in Prairie Creek Redwoods State Park and Redwood National Park (RNP). The stream enters Redwood Creek 5.5 km from the Pacific Ocean at USGS Orick, CA quadrangle T11N R1E section 34. The study was conducted between the confluence of Streelow Creek and below Ten Tapo Creek , within the RNP 10.5 km index reach and extended an additional 4 km (Figure 2).

Methods and Materials

Upstream Migration

A weir and fish trap were placed in Prairie Creek at Elk Prairie Campground, campsite 65, and operated between 21 November 1996 and 3 February 1997 (Figure 2). The weir spanned the entire width of the creek with the trap located in the thalwag. The trap was 1.1 m. wide by 1.4 m long by 1.1 m high, constructed of marine plywood flooring with sides and top formed by a combination of chicken wire and wood. Steel weir panels used were 1.1 m high by 1.8 m long and placed end to end in a 'V' configuration leading upstream, directing fish into the trap (CDFG 1992). The trap was operated and monitored 24 hours per day, 7 days per week except when flows prevented safe operation or were too low for adult migration. Each salmon captured was identified to species, sexed, and measured to the nearest cm fork length (FL). A scale sample was taken from the left side slightly above the lateral line and posterior to the insertion of the dorsal fin. All fish were released upstream in a side eddy as soon as possible.

Spawning and Carcass Surveys

Spawning Survey

Spawning and salmon carcass surveys were conducted within the RNP 10.5 km index reach and extended above an additional 4 km in order to identify and measure salmonid redds and recover tagged and untagged fish. Two person crews surveyed the creek on a weekly basis throughout the period of salmon spawning and dying, unless poor visibility or high stream discharge prevented surveying. All new redds were measured (width and length), recorded, and marked with pink surveyors flagging. All live fish sighted were identified by sex and species if possible.

Carcass Survey

The carcass survey was conducted with the spawning surveys. A long handle gaff was used to retrieve carcasses from the deeper pools. All new recoveries were identified to species, sex, and condition. Carcasses were classified as fresh + (firm flesh), fresh - (eyes milky), decayed + (flesh

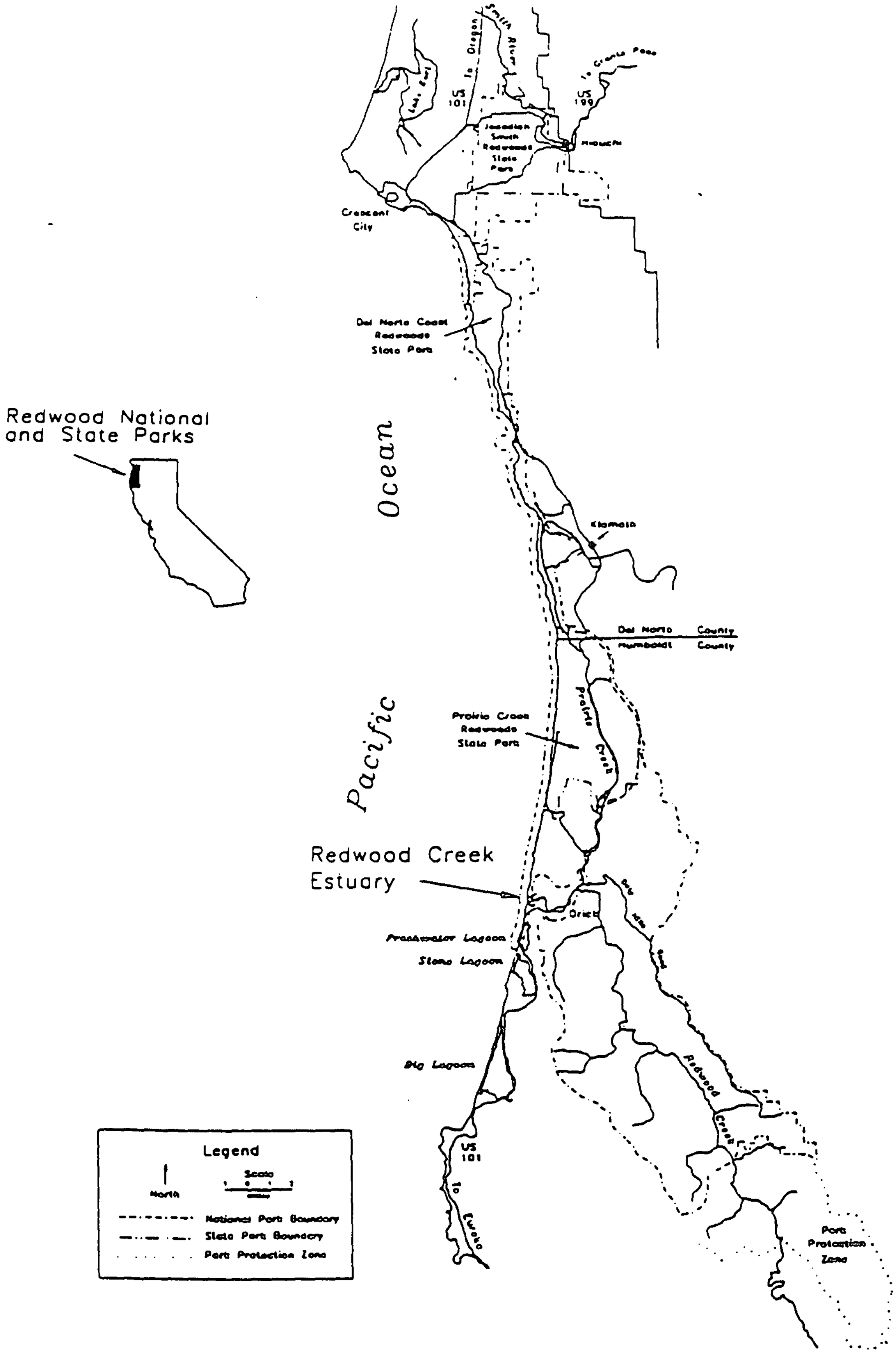


Figure 1. Location map of Prairie Creek, Redwood National and State Park, Humboldt County, California.

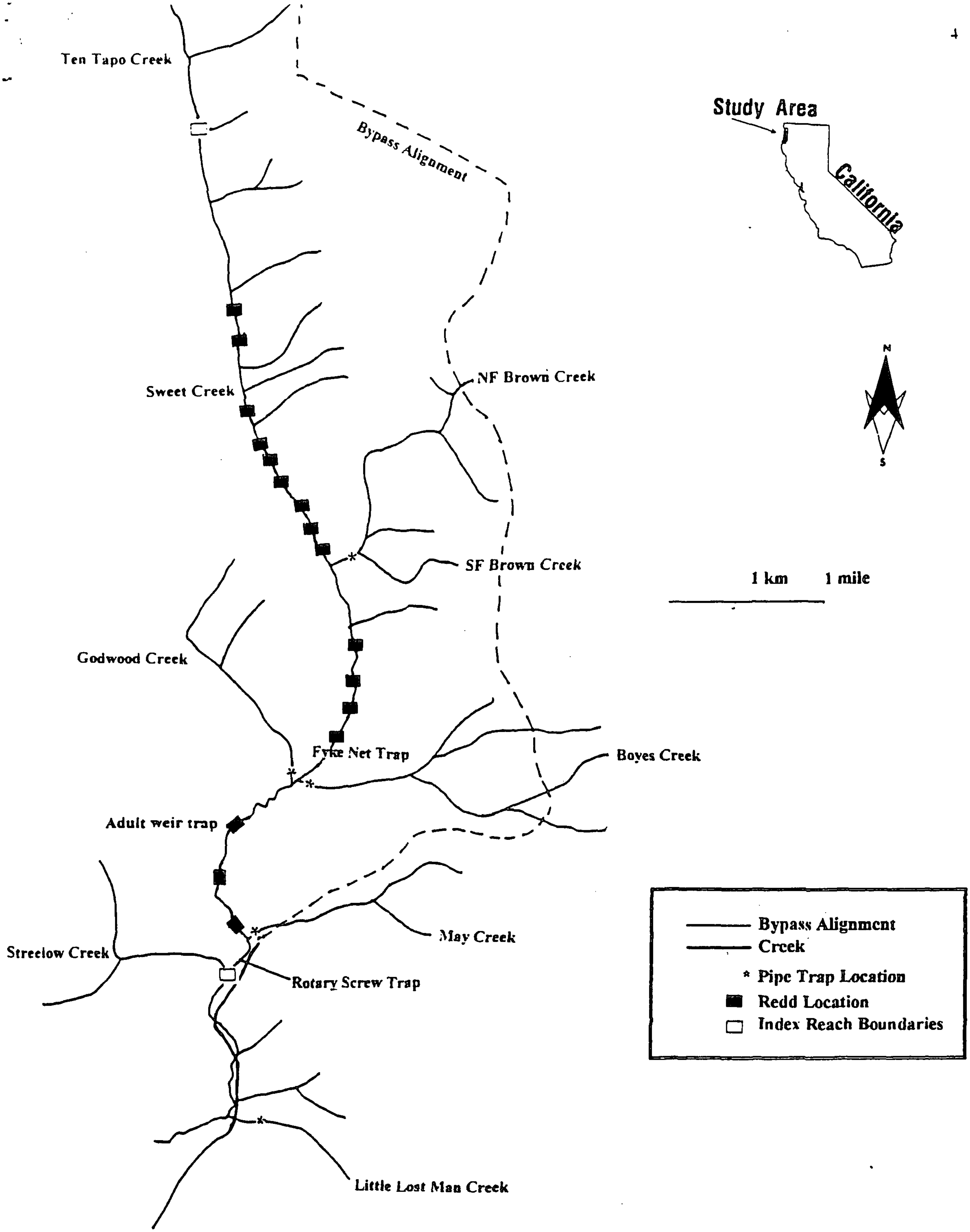


Figure 2. Location map of study site showing trap locations and redd locations in Prairie Creek Basin, Redwood National and State Parks, Humboldt County, California.

soft), and decayed - (flesh falling off). All carcasses received a numbered jaw tag and surveyors flag secured around the maxillary bone of the jaw. Tagged carcass recaptures were identified by tag number, condition classified, and returned back to the location recovered. Heads from adipose fin clipped carcasses were taken to obtain coded-wire tags and sent to the California Department of Fish and Game (CDFG) in Arcata, California for analysis. Tagged carcass information was collected for an escapement estimate using a modified Jolly-Seber mark-recapture estimator.

Coho Redd Measurements

Redd Site Selection

Coho redds selected for this study were identified over the course of the spawning season during weekly surveys. Redd locations were marked with surveyors flagging depicting the date, case number, redd number, and redd dimensions. Redds used for this study were selected only from those redds on which coho salmon were identified as spawning. The number of coho redds available for this permeability study was small because large flow events prevented spawning surveys from occurring during the potential peak migration period. Therefore, all coho redds positively identified after 5 January 1997 (after 15-20 year storm event, R. Klein pers. com. 1997) were used for the coho spawning substrate study (n=16).

Standpipe Site Selection

Three standpipes were placed longitudinally into the egg pocket and tailspill of each coho redd selected. Five redds were randomly selected for adjacent standpipes placed outside of each redd for comparison. Each redd egg pocket and tailspill was measured and divided into four equal lengths. Standpipe placement into each redd was at equal inside intervals (Figure 3). A standard steel CO_2 freeze core probe was pounded 30 cm into each standpipe site with a sledge hammer as a pilot hole for the PVC standpipe. This was necessary in order to create a guide into the redd and reduce any damage to the PVC pipe when inserting it into the redd. When withdrawing the freeze core probe, a rapid transition of freeze core probe to PVC standpipe point would occur in order to use the pilot hole made in the substrate by the probe. The standpipe would then be tamped by hand with a 0.5 inch steel pipe placed inside the PVC standpipe against the wood driving point. As the friction increased while penetrating the substrate, the sledge would be used until the appropriate depth was reached. The depth of the standpipe holes coincided with the depth of egg deposition determined by Briggs (1953) in Prairie Creek to be 25 cm. Once the standpipe was inserted to the appropriate depth it remained in place over the study period with a PVC cap placed over the top.

Inflow Rate Measurements

The method used for inflow rates and dissolved oxygen follows Barnard and McBain's (1994) with a few modifications. A polyvinyl chloride (PVC) freeze core standpipe allows liquid nitrogen to serve as the cryogenic medium. The 4.2 cm diameter (inner) standpipe measuring 40 cm long is sealed at one end by a wooden driving point. It is modeled after the Mill

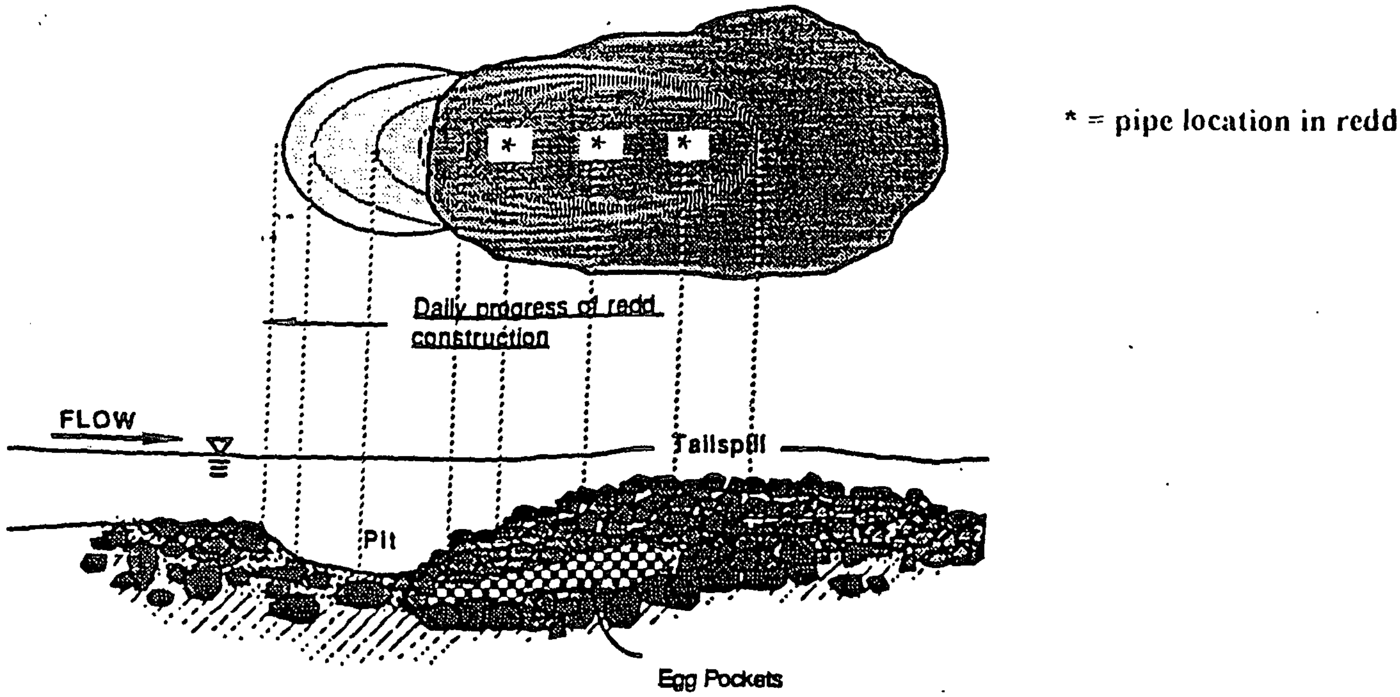


Figure 3. Salmon redd construction with modified pipe locations (Barnard 1992).

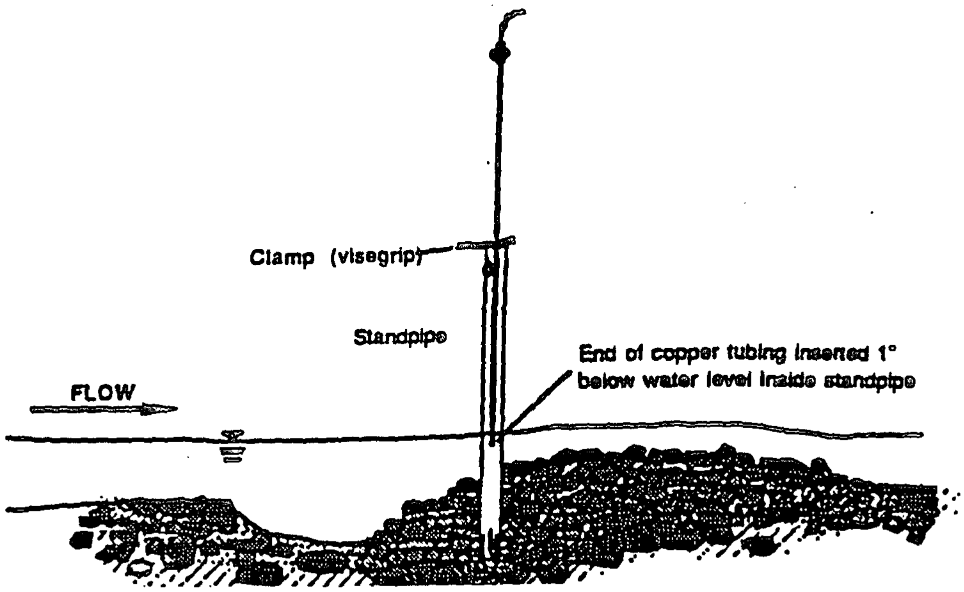
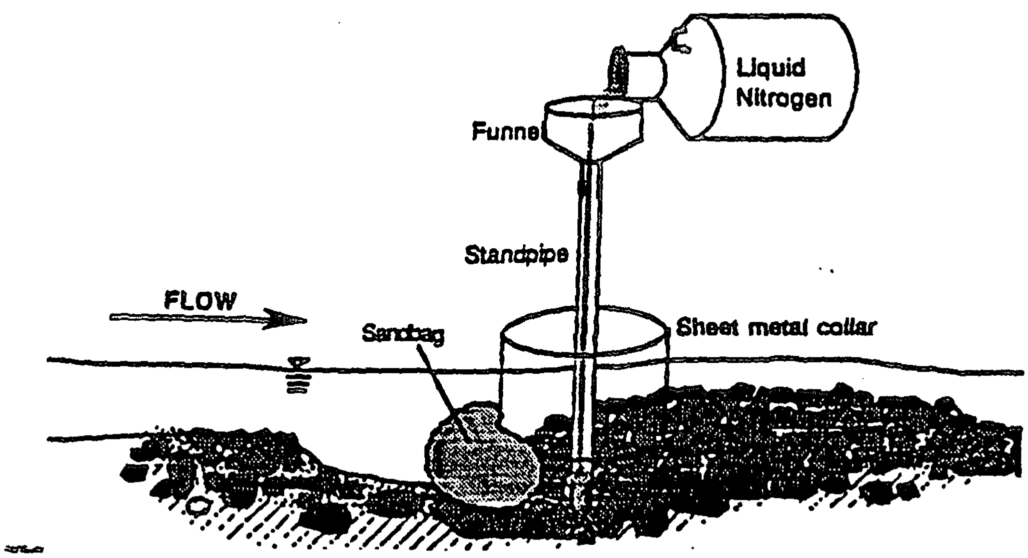


Figure 4. Modified permeability/freeze core standpipe in redd used by Barnard (1992) to study coho redds in the Freshwater Creek basin, Humboldt County.



Creek (Gangmark and Bakkala 1958) standpipe and Barnard and McBain's (1994) modified Terhune Mark VI standpipe (Figure 4). This standpipe was designed to be driven into the gravel streambed only one time. Once the standpipe is driven, it is left in place to monitor the intragravel flow, temperature, and dissolved oxygen (DO) over the egg incubation and fry emergence period. The standpipe consists of a schedule 40 PVC pipe, 40 cm in length, beveled at one end with a driving point. The driving point consists of a 4.2 cm (outer diameter) fir closet rod inserted 10 cm into the PVC pipe. This point is secured with 3 #12 SS tapered head wood screws and 5-minute epoxy. The transition space between the tapered PVC pipe and the wooden driving point was filled and smoothed with Plumber's® epoxy. The beveled end above the driving point is perforated with sixteen 4.0 mm diameter holes divided into 4 evenly spaced rows (3.5 cm x 3.81 cm). The holes imitate a spherical sink allowing water to freely flow into the standpipe from the adjacent gravel column (Terhune 1958). Each hole has a horizontal groove 1 mm wide and 10 mm to each side to minimize blockage of the hole by small particles (Barnard and McBain 1994). When the standpipe is driven into the gravel, intragravel water enters the pipe through the holes and rises to the level equal to the outside water surface. To sample the inflow rate a vacuum pump maintains a 2.54 cm pressure head causing water to flow through the gravel and into the standpipe. In maintaining this pressure head, the vacuum pump evacuates the water from the standpipe at a rate equal to inflow. This water is stored in a manometer so volume per unit time (i.e., inflow rate) can be measured (Barnard and McBain 1994). While Terhune (1958), Barnard (1994) and others using this technique reported actual values of permeability derived from a calibration curve relating permeability to inflow rate, the field values (inflow rate) are reported here because the pipes used in this study have not been calibrated to convert to values of permeability. In this sense, inflow rates are used as indices of permeability.

Two people are required to measure the inflow rate. One person (pumper) operates the pump system which is an electric, battery powered vacuum pump connected to a 500 ml manometer, a 90 cm flexible vacuum hose and a 65 cm straight copper tube. The second person (timer) lowers the copper tube into the standpipe and listens for a characteristic slurp indicating that the end of the tube has just made contact with the water surface inside the standpipe. A 2.54 cm wooden spacer is place on top of the standpipe and a "visegrip" is attached to the plunger at the top of the spacer. When the spacer is removed, the plunger is lowered until the visegrip rests on top of the standpipe, thereby holding the end of the copper tubing exactly 2.54 cm below the water surface within the standpipe (Figure 4). As the first 2.54 cm of water is removed from the standpipe, a pressure gradient is created driving intragravel water into the standpipe. As the water fills the well and travels up the manometer, the timer starts a stopwatch and records the start distance. Water from inside the standpipe is continuously drawn into the well until the well is almost full or 60 seconds has elapsed. The timer simultaneously raises the copper tubing from the water surface and stops the stopwatch. This procedure is repeated several times to get an average inflow rate. This ratio of the measured water volume per unit time (inflow rate), must be corrected to account for the initial 2.5 cm water column and the time required to remove it (0.25 sec) (Barnard and McBain 1994).

Dissolved Oxygen Sampling and Temperature Measurements

A potentiometric method using an YSI electronic dissolved oxygen (DO) and temperature meter with a probe inserted into the standpipe was used to measure the subsurface and surface DO and temperature for each standpipe over the study period. Subsurface measurements were taken after intragravel water was removed from inside the standpipe for flow measurements. Dissolved. oxygen measurements and temperatures were taken inside and outside the standpipe and were used to calculate the relative DO saturation of intragravel water to surface water (Barnard 1992).

Coho Spawning Substrate Composition Samples

Freeze Core Sampling

The freeze core method was designed to extract a vertical section of relatively undisturbed streambed material and thereby avoid the homogenization of stream bed material that occurs using bulk core samplers (Lisle and Eads, 1991). This method provides direct observation of vertical bed stratification. A successful freeze core demands that water be excluded from the standpipe so that the maximum freezing effect of the liquid nitrogen is directed to the gravel/standpipe interface. To make the permeability standpipe also function as a freeze core standpipe, a steel sleeve is slowly lowered into the standpipe to "seal" the holes and then the entire unit is frozen. The sleeve is a 45 cm long steel electrical conduit, 3.81 cm inner diameter (ID) with a plastic disk and rubber o-ring sealing the inserted end. A steel water key with the "key" removed and a stainless steel size 12 wood screw welded in place is used as a core puller. The plastic washer and o-ring is located immediately above the welded screw. This plunger/puller is inserted into the electrical conduit steel sleeve. The steel sleeve with washer and core puller is slowly lowered into the standpipe and screwed into the wood driving point. A plunger system similar to Barnard and McBain's (1994) was tested but failed, therefore, water was not evacuated from the standpipe but slowly pushed out into the gravel. Once the sleeve was in place a quick check for any water leaking into the sleeve is performed with the vacuum pump. Liquid nitrogen is then poured from a Dewar flask into the standpipe (Figure 5). As the liquid nitrogen boils and vaporizes in the sleeve and standpipe, the gravel column begins to freeze to the sides of the. standpipe. Best results are obtained when the liquid nitrogen level is maintained above the gravel surface. Ten liters of liquid nitrogen (approximately 30 minutes) are sufficient to freeze 20-30 cm diameter core. If redd permeability is high, more nitrogen may be necessary. When the last of the liquid nitrogen in the standpipe is allowed to vaporize, the frozen core is pulled from the streambed using the core puller. The gravel sample is thawed, separated into vertical stratum, and sieved to separate particle size classes.

McNeil Sampling

Field Procedure

The McNeil sampler was constructed from PVC sewer pipe 30.5 cm diameter by 91.4 cm long with two handles on top and a beveled edge on the bottom. Samples were collected around each standpipe by placing the sampler on the streambed with the standpipe as close to the center as possible. Material was lifted out of the sampler by hand and placed into plastic buckets. As material was removed, the McNeil sampler was lowered into the streambed. If a piece of gravel was on the border of the sampler , it would be "pinched" and pulled into the sampler. If the rock was more than half in it would be included in the sample, if not it would be thrown out. Substrate material would be removed until the sampler was 25 cm below the streambed surface. The . remaining depth of the turbid water in the McNeil sampler would be measured for total volume and subsampled prior to extracting the sampler from the streambed. The sample would be wet sieved using the Wentworth scale from 128 mm and less down to 4 mm (64, 32, 16, 8, 4). The remainder less than 4 mm is placed into 5-gallon buckets and carried back to the RNP sediment lab for future analysis. Wet weights and volumes of all fractions (including > 128 mm) were recorded and the b-axis diameter of the largest rock in the sample was measured. All sieved gravel is placed back into the stream after volumes and weights are recorded.

Laboratory Procedure

The remaining sample uses the dry sieve technique based on the Wentworth scale with a geometric progression of size-classes ranging from 0.062 to 2 mm. Material from each sieve size is spread out in a standard cake pan (25.4 cm X 35.6 cm) and remaining water is removed with a siphon. The pan is placed into a 60° C oven for 24 hours to dry. The dry sample is weighed and split down to a workable size (2-cups) using a splitter. The subsample is placed on top of a series of sieves (2, 1, 0.85, 0.5, 0.25, 0.125, 0.062 mm) and covered. This stack is placed into a shaker for 5 minutes. Each fraction is weighed and placed into bags for future volumetric measurements. This material is suspended in a graduated cylinder and the volume measured. This is repeated for each sieve size until entire sample has been added. The cylinder is agitated for 1 minute and then poured into an Imhoff cone for final volumetric measurement. Volumes are recorded 30 and 60 minutes after pouring.

McNeil Water Sample

The subsample of turbid water taken from inside the McNeil sampler in the field is filtered and weighted in the lab. The subsample volume is recorded and then filtered using a vacuum filter apparatus with 1.5 micron filter paper. The filtrate is dried and weighed to determine the suspended weight by volume. This ratio is extrapolated to the entire McNeil volume sampled.

Coho Fry Emergence

Spawning and carcass surveys helped identify redds with actively spawning coho salmon. From these redds, 6 were randomly selected for an emergent fry trap to be placed over the egg pocket. These emergent fry traps, used in Prairie Creek by Coey (1990, 1991), were placed over the selected redds 10-30 days before expected emergence. Each trap frame is 2.5 m long by 2 m wide, constructed from 1.6 cm diameter steel rod and covered with 3 mm polyethylene netting (Figure 6). Each trap netting has a zipper sewn into it running the length of the trap in order to access the standpipes under the trap. Each trap was anchored to the streambed using hooked rebar stakes. Streambed material was removed around the margin of the trap frame to a depth of approximately 20-35 cm for the net apron. The apron was secured with gravel/cobbles to prevent lateral migration of fry beyond the trap perimeter. The placement, maintenance, and operation of the traps was in accordance with the methods of Olson (1996), and Coey (1994). Traps were inspected and maintained every two days until emergence occurred, then monitored daily. All captured fry were anesthetized with Tricaine methanesulfonate (MS-222) to facilitate handling. Each fish was measured to the nearest millimeter and released downstream upon recovery. Each trap was fished until 10 'zero catch' days were recorded after the last fry captured or 20 'zero catch' days after the expected emergence date.

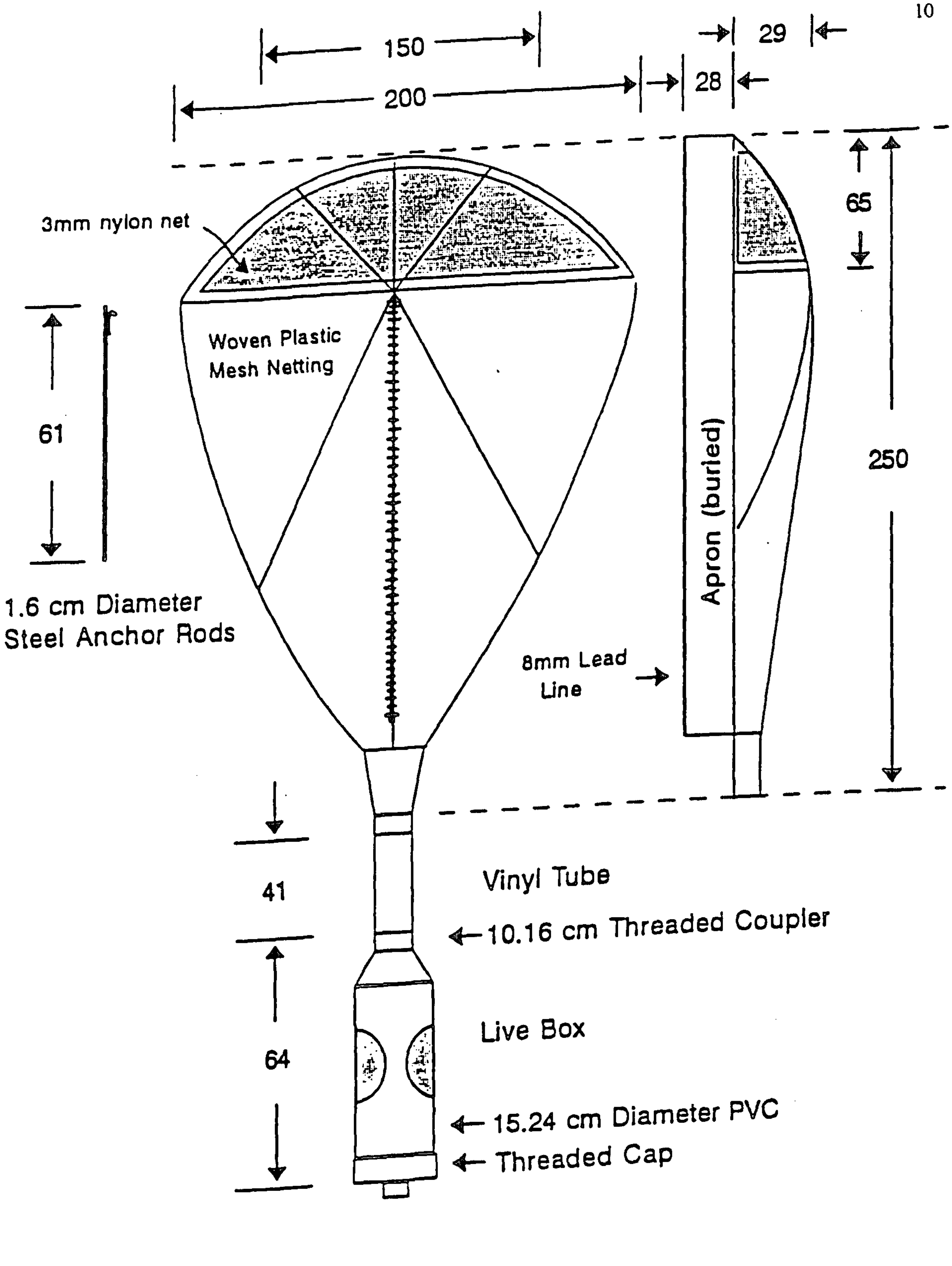


Figure 6. Specifications of the emergent trap for capturing fry from coho redds in Prairie Creek (Olson 1994).

Downstream Migration

Rotary Screw Trap

A United States Fish and Wildlife Service (USFWS) EG Solution rotary screw trap was used for the assessment of emigrating juvenile salmonids and other species of Prairie Creek. The rotary screw trap was comprised of a 1.5 m (5 ft.) diameter cone with a spiral vein supported by foam filled aluminum pontoons. The trap was placed 50 m above the confluence of Streelow Creek (Figure 2) and fished at a depth of 0.75 m throughout the trapping period. As water pushes the spiral vein the cone spins, entrapping emigrating fish and forcing them into the live holding box located at the rear of the trap (Shaw and Jackson 1994). The trap was operated 24 hours per day, 7 days per week, from 18 February to 19 June 1997. The live holding box was checked daily and a random sample of size n=30 fish was taken for chinook young-of-the-year (YOY) salmon. Fork length and weight were recorded for each individual. Also, samples of size n=30 were taken for all other age and species of fish present. All remaining fish were identified and counted. The separation of age was based on fork length and appearance. Fish were anesthetized with Tricaine methanesulfonate (MS-222) to facilitate handling. Each fish was measured to the nearest millimeter and weighed to the nearest 0.10 gram.

Trap efficiencies were conducted weekly, when possible, to estimate the numbers of fish emigrating from above the trapping site in Prairie Creek. This estimate does not take into account the level of production downstream from the trap or those fish remaining in the basin beyond the trapping season. Juvenile chinook salmon were marked weekly with alternating caudal fin clips. The numbers marked varied due to the fluctuations in downstream migration. At least 50-100 or more fish were used for the efficiency tests. Marked fish were transported upstream from the rotary screw trap 0.5 km and released in a deep pool containing large woody debris for refuge. A control group of 25 marked and 25 unmarked fish was held instream in a 0.75 m by 1.22 m. by 0.92 m live pen to determine marking mortality. Recaptures were recorded and weekly estimates of outmigrant chinook were calculated using the equations of Shaw and Jackson (1994) in Table 1.

Table 1. Equations used to estimate the number of emigrating juvenile salmonids each week in Prairie Creek during 1997 (Shaw and Jackson 1994).

1.	% MM	= % CM - %CUM, where	3.	TE	= MRC/TMRS, where
	%MM	= percent marked mortalities		TE	= trap efficiency
	%CM	= percent control marked mortalities		TMRS	= total marked released survival
	%CUM	= percent control unmarked mortalities		MRC	= marked released recaptured
2.	TMRS	= %MM x MR, where	4.	EWC	= 1/TE x (TWC), where
	TMRS	= total marked released survival		EWC	= expanded weekly catch
	%MM	= percent marked mortalities		TE	= trap efficiency
	MR	= marked released		TWC	= total weekly catch

Fyke Net

A U.S. Forest Service Redwood Science Laboratory (RSL) fyke net was used for assessment of emigrating juvenile salmonids and other species in Prairie Creek. The fyke was comprised of a 1.5 m X 3.1 m, 0.64 cm mesh nylon net with five internal fykes decreasing incrementally down to 25 cm in diameter and enters a live holding box. The net was placed in the thalwag 90 m above the confluence of Boyes Creek (Figure 2). The fyke was secured with carabiners and line to metal fence posts pounded into the substrate at the upstream opening of the net. A rock weir spanning the width of the creek forced water and migrating individuals into the net and into the live holding box. An additional live holding box was placed directly downstream from the first holding box as a juvenile refugia and secured together with chains. A plastic grate (1.25 cm mesh) was placed in the upstream box to prevent larger fish from passing to the second live box through a flexible tube. All fish were sampled according to the protocol stated above as well as trapping efficiencies when possible.

Tributary Pipe Traps

Six tributaries to Prairie Creek received "pipe traps" to assess the downstream emigration of juvenile salmonids and other species in that tributary (Figure 2). Each trap was comprised of a 25.4 cm (OD) PVC pipe (varied lengths), an inclined ramp and a live holding box. A rock weir spanning the width of the creek forced water and migrating individuals into the pipe, downstream to the adjustable inclined ramp and into the live holding box. South Fork and North Fork Brown Creek pipes were attached directly into a RSL net live box with a PVC frame. All fish were sampled according to the protocol stated above as well as trapping efficiencies. These traps were operated only when flows permitted. The trap locations are (Figure 2):

A. Little Lost Man Creek - 30 m upstream from U.S. Highway 101.
B. May Creek - at the confluence with Prairie Creek.
C. Godwood Creek - at the confluence with Prairie Creek.
D. Boyes Creek - at the confluence with Prairie Creek.
E. S.F. Brown Creek and N.F. Brown Creek - where the forks meet.

Trapping Mortality

Percent trapping mortality was calculated for all salmonids captured over the entire trapping period for each trap used. Artificial refugia was created with plastic milk crates, rocks, vegetation, mop heads, and root wads placed in each live holding box to minimize predation.

Summer Juvenile Coho Salmon Population Estimate

A population estimate for juvenile coho salmon was generated for 14.5 km of Prairie Creek (index reach) between 15 July 1997 and 17 August 1997 using the modified Hankin and Reeves (Moyer 1997) methodology. This index reach was divided into four sections in order to keep the data collection, i.e., habitat typing, snorkeling, and electrofishing, within a two-week period. The sections are: 1) Streelow Ck. to Boyes Ck., 2) Boyes Ck. to Brown Ck., 3) Brown Ck. to Sweet Ck., and 4) Sweet Ck. to 0.8 km below Ten Tapo Ck. (Figure 2). Five habitat types were used for this estimate. These habitat types are defined as: 1) complex pools-those pools difficult to electrofish effectively, 2) deep pools-deeper than 1.1 meters, 3) pools-none of the above, 4) runs-depth at least 0.4 meters to allow diver good field of vision, and 5) riffles-must be longer than wide.

Water Temperature and Stream Discharge

Water temperature data and stream discharge were measured at the United States Geological Survey (USGS) stream gaging station, located at the Wolf Creek Bridge in the Redwood National Park. RNP staff biologists provided this information for the study period. Temperatures were recorded every 1.6 hours by a HOBOTEMP™ temperature monitor placed inside a protective PVC sleeve anchored in Prairie Creek with a cement block. Discharge (Q) was calculated using a calibration curve generated by RNP from water stage heights recorded continuously at three USGS gaging stations located in Prairie Creek above May Creek (R. Klein pers. comm.).

Results and Discussion

Upstream Migration

The weir and trap was operated and monitored 24 hours per day, 7 days per week except when flows prevented safe operation or were too low for adult migration. The trap and weir was in place on 21 November 1996 and was fished until 1 February 1997. The trap was removed from the creek during high flow events and replaced when flows receded.

Chinook Salmon

Fall-run chinook were captured the same day that the weir trap was in place, 21 November 1996 (Figure 7). The peak occurred on 23 November 1996 (n=15) and fluctuated into January 1997. A total of 113 chinook were captured, 33 females (29%) and 80 males (71%, 37 jacks). Average fork length for chinook females was 85 cm and 66 cm for males.

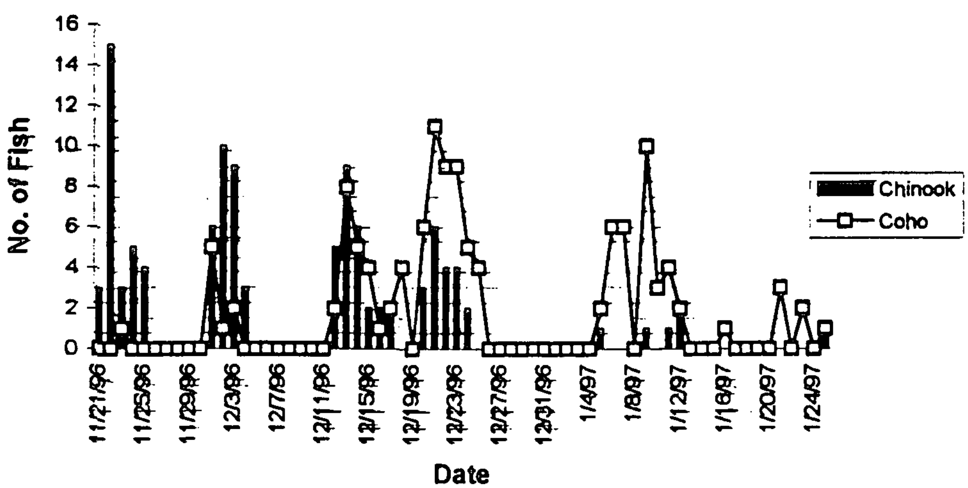


Figure 7. Run timing of chinook and coho adult salmon captured at Prairie Creek weir trap, 1997.

Coho Salmon

A total of 124 coho salmon were trapped, 45 females (36%) and 79 males (64%, 10 grilse). The peak occurred on 21 December 1996 (n=11) (Figure 7). Average fork length for female coho was 65 cm and male coho was 63 cm.

Prior to the 1995-1996 adult trapping season, adult salmonids were trapped in Prairie Creek to supplement the salmon populations using streamside incubation and rearing facilities. The weir trap was operated during permissible flows until an adequate number of adults were captured to artificially spawn. Trapping continued, intermittently, to determine the run size and timing until the goal of 100,000 chinook eggs were acquired (PCFWWRA, 1995). The past two seasons the trap was operated as many days as possible until several zero catch days were recorded. Although the trap was removed several times due to high flow events, we still captured over 200 salmon each year. The sex ratios were similar for chinook, but reversed for coho salmon with less females captured in 1997 than 1996 and more males in 1997 than 1996.

Spawning and Carcass Surveys

Spawning surveys

Measured redds that were greater or equal to 1.5 m long by 1.0 m wide were considered to be excavated by a coho or chinook salmon in Prairie Creek (Briggs, 1953; Bjornn and Reiser, 1991; M. Farro pers. comm. 1996). Surveys were conducted weekly beginning 25 November 1996 to 3 March 1997. A total of 191 salmon redds were measured over the first 10 weeks and 21 steelhead redds recorded in the next 4 weeks. Of these 191 salmon redds, 82 had adult female salmon on them at the time of the survey. Chinook salmon account for 73 % (60 fish) of these fish and coho salmon contributed 27 % (22 fish). Applying the percentage of chinook and coho redds each week to the unknown redds (109) gives a total 111 chinook redds, 54 coho redds, and 26 unknown (Table 2). The average dimensions of all redds measured was 2.7 m long by 1.5 m wide (4.05 m^2). Chinook salmon average redd size was 3.5 m long by 2.1 m wide (7.35 m^2) by 14.3 cm deep. Coho salmon average redd size was 2.5 m long by 1.5 m wide (3.75 m^2) by 14.1 cm deep.

Table 2. Spawning survey results from November 1996 to March 1997 in Prairie Creek.

Survey Date	Chinook	Coho	Unknown	Percentages		Total Redds		
(Week starting)	Redds	Redds	Redds	Chin	Coho	Chin	Coho	Unk.
25 November	0	0	26	0	0	0	0	26
2 December	16	0	11	100	0	27	0	0
9 December	0	0	0	0	0	0	0	0
16 December	23	1	23	96	4	45	2	0
23 December	7	3	9	70	30	13	6	0
30 December	0	0	0	0	0	0	0	0
6 January	12	9	13	57	43	19	15	0
13 January	1	5	16	17	83	4	18	0
20 January	1	3	8	25	75	3	9	0
27 January	0	1	3	0	0	0	4	0
Totals	60	22	109	-	-	111	54	26

Carcass Survey

All salmon carcasses recovered were tagged, identified and released back to the exact place of capture for a spawning escapement estimate (in progress). A total of 164 chinook salmon carcasses were recovered. Of these, 4 were not identifiable by sex, 85 were female, and 71 male. A total of 61 coho salmon carcasses were recovered. Of these 1 was were not identifiable by sex, 26 female, and 34 male. The average lengths and results are listed below in Table 3.

Table 3. Carcass recovery results from surveys conducted in Prairie Creek (November 1996 to March 1997).

	Chinook salmon		Coho salmon	
	n	ave.ln.	n	ave.ln.
Female	85	78 cm	26	65 cm
Male	71	81 cm	34	66 cm
Unknown	4	75 cm	1	63 cm
Total	**160**	-	**61**	-

Prior to 1995, RNP staff conducted annual spawning and carcass surveys in established index reaches of several streams within the park boundaries, including the 10.5 km in Prairie Creek. RNP's best effort was during the 1992-1993 spawning season when RNP staff measured 167 redds, recovered 87 chinook carcasses, and 18 coho carcasses. No surveys were conducted in Prairie Creek for the 1994-1995 spawning season. The number of carcasses and redds measured during the 1995-1996 season in Prairie Creek is the highest recorded (279 redds, 314 carcasses). The 1996-1997 numbers are not as high as 1995-1996 numbers but a big storm prevented any surveys and trapping from occurring between 25 December 1996 and 5 January 1997. This was a 15-20 year recurrence interval according to RNP staff (R.Klein pers. com.). Most redds and carcasses were lost during this event which was during the 1995-1996 peak salmon run. It is not known if the past two years numbers are due to increased effort, a strong year class, or good quality and quantity of spawnable habitat available due to higher winter flows. An attempt to estimate the spawning escapement is in progress using a Jolly-Seber capture-recapture estimator (Law 1994) above Boyes Creek for 1996-1997. Poor visibility below the confluence of Boyes Creek prevented weekly surveys from occurring between Streelow Creek and Boyes Creek (Reach 1), therefore, 4 surveys were completed over the entire spawning season. This may explain some of the discrepancies in the two years. Weekly spawning and carcass surveys conducted within the RNP 10.5 km index reach plus an additional 4 km upstream is proposed for 1998. All carcasses recovered will be identified, measured, cut in half and returned to the creek. All adipose fin clipped carcass heads will be removed and delivered to CDFG for coded wire tag removal and reading.

Coho Fry Emergence

Preliminary studies on the effect of sediments on salmonid fry emergence in Prairie Creek were conducted by Coey (1994). Results from Coey suggests that fine sediments were responsible for causing 100% mortality in 6 of the 10 redds trapped. Sparkman (1996) found 100% mortality in 3 of the 5 redds trapped in 1996. In 1997 5 of the 6 coho redds trapped produced salmon (Table 4). Also, two redds produced chinook salmon as well as coho salmon, Redds 15 and 8. The lowest trap in the system, Redd 3, did not produce any fish although this redd was the best identification of spawning coho due to the location. This redd was located 10 feet below the adult weir trap. The redd escavation and deposition of eggs/sperm by male and female coho was observed over the entire duration of spawning by the trap operators. This redd did have a high amount of fines with poor intragravel flow (Figure 9). A high spring flow event eroded the

substrate around Redd 7 trap and exposed the apron. The live box did contain a few fish which would indicate a possibility of fish escaping through this opening during this event.
The mean FL of emergent coho fry captured was 37.7 mm, ranging from 33 mm to 41mm. In general, the size of the fish captured increased through the duration of redd trapping. The captured fry were generally in very good condition. Incidental redd trapping mortality was 1.12 %, with nearly all mortality occurring during a high flow event.

Survival to Emergence (STE)
PCFWWRA trapped and spawned an average of 19 female coho from Prairie Creek between 1992-1995 while operating the chinook and coho salmon suplementation program. The average fecundity for coho salmon generated by PCFWWRA is 2503 eggs per female. Running a length-fecundity regression on the coho females spawned yields the equation for estimating fecundity [fecundity = (111.7) * fork length - 4895]. The percent survival to emergence calculated in Table 4 uses the mean fecundity value above (2503) due to visual FL estimates only for each coho spawning in the redds trapped. Egg retention was assumed to be negligible based on a sample of female coho carcasses over the past three years.

Table 4. Results from emergent fry traps placed over six redds in Prairie Creek, Humboldt County, California, 1997.

redd no.	redd survey date	spp.	date of first capture	date of peak capture	date of last capture	FL range (mm)	total	percent STE*
16	1/7/97	coho	4/9/97	4/13 (n=208)	5/2/97	38-41	992	40%
15	-	chinook	3/24/97	3/29 (n= 74)	4/29/97	-	214	
15	1/7/97	coho	3/25/97	4/11 (n=673)	5/5/97	35-40	1902	76%
11	1/7/97	coho	4/6/97	4/12 (n=616)	4/25/97	33-40	2403	96%
8	-	chinook	3/30/97	3/31 (n=648)	4/19/97	-	2105	
8	1/13/97	coho	4/13/97	4/17 (n=411)	5/5/97	35-38	1843	74%
7**	1/13/97	coho	4/7/97	4/8 (n=132)	5/7/97	35-40	371	15%
3**	1/13/97	coho	-	-	-		0	0%

* STE calculated using average fecundity of coho (2503/female)
** Redd located below Brown Creek

To compare the number of emergent coho fry for each redd with the percentage of fines less than 2 mm, I ran a linear regression between the total number of fry captured and the percent fines (Figure 8). The regression plot suggests a negative linear relationship with a R^2 value of 0.524.

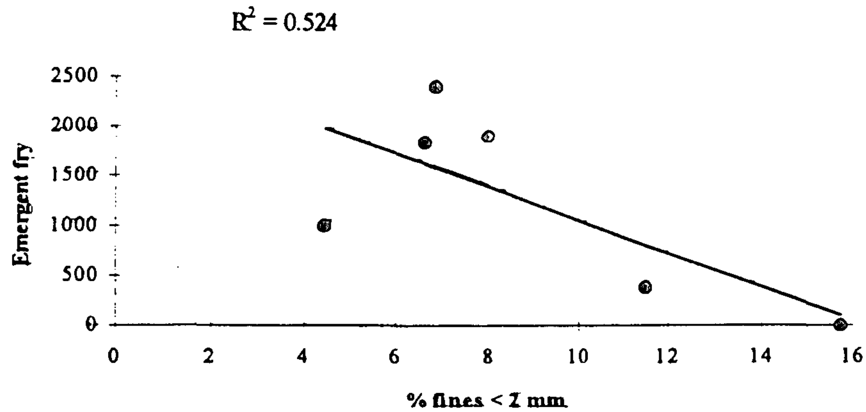


Figure 8. Linear regression between total number of emergent coho fry and percentage of fines less than 2 mm in 6 coho redds in Prairie Creek, Humboldt County, California, 1997.

Coho Redd Inflow Rates

Several intragravel flow measurements were recorded over the egg incubation and emergence period for each standpipe in each redd, these results are reported in Appendix A. Conducting a one-way analysis of variance for these intragravel measurements for pipe A shows that there is a significant difference between these redds (Table 5). The calculated F-value is greater than the F-critical value, therefore you reject the hypothesis of equality and state that there is at least one inequality between redds. Taking this one step further by running a one-way ANOVA between those redds above Brown Creek (control group) against those redds below (treatment group) we find a significant difference between the two groups (Table 6). For this analysis, we threw out two outliers in the redds above Brown Creek. These two redds are redd 9 which was above water over the incubation period and redd 14 which had a bank erode into the creek 10 meters upstream during a spring event.

Coho Spawning Substrate Composition

The six redds used in the emergent fry study were sampled for spawning substrate condition using the freeze core method suggested by Barnard and McBain (1994). The freeze cores taken with the modified standpipes were very small and over sampled the larger substrate which is a drawback to using this technique (Lilse and Eads 1991). Most freeze cores did not sample the upper stratum effectively even when using a collar to block stream flow around the pipes and when pouring extra liquid nitrogen. Therefore, only the egg pocket or bottom stratum was used for comparison between redds. The remaining redds were sampled with the McNeil sampler and the results are shown in Figure 9 below and Appendix B.

Table 5. One-way analysis of variance of intragravel flow for 16 coho redds in Prairie Creek, 1997.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	626164.9	15	41744.33	4.725017	0.000019	1.880174
Within Groups	424067.8	48	8834.746			
Total	1050233	63				

Table 6. One-way analysis of variance of inflow rates for coho salmon redds above and below Brown Creek, 1997.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	88855.29	1	88855.29	5.564922	0.021971	4.019540
Within Groups	862219.7	54	15967.03			
Total	951075	55				

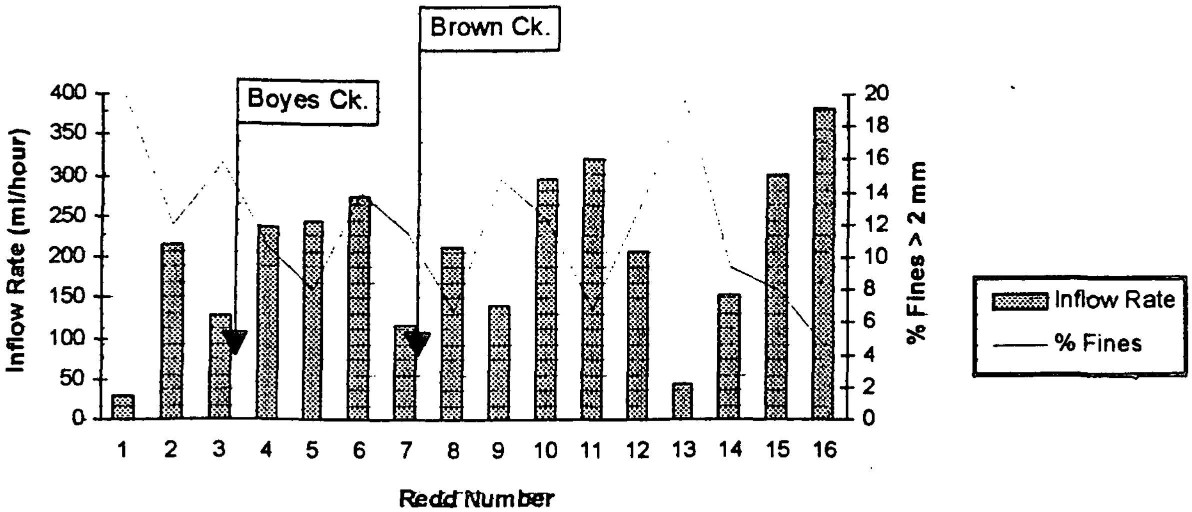


Figure 9. Inflow rates and percentage of fines less than 2 mm for 16 coho redds in Prairie Creek, Humboldt County, California, 1997.

To compare the relationship between the percent of fines less than 2 mm and the inflow rate of each coho redd, I used a simple linear regression (Figure 10). The regression plot suggests a negative linear relationship between the variables with a R^2 value of 0.683.

The DO of intragravel water for each redd was lower than the surface water DO for all redds (appendix 3). The mean relative DO saturation was 82 % with a high of 91 % (redd 10) and a low of 65 % (redd 14) (Figure 11).

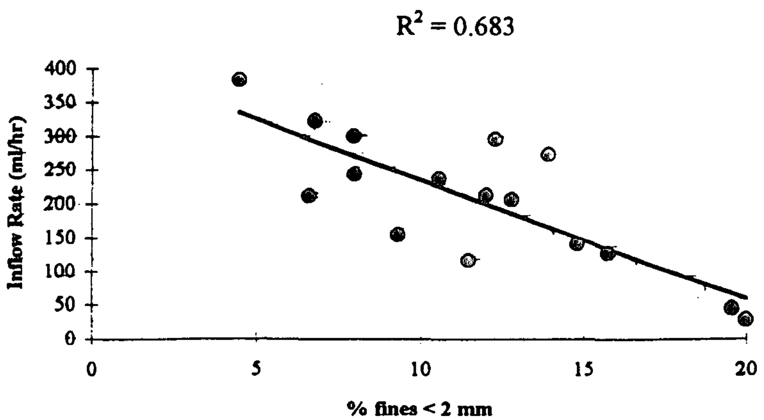


Figure 10. Linear regression between inflow rates and the percentage of fines less than 2 mm for 16 coho redds in Prairie Creek, Humboldt County, California, 1997.

Successful incubation of embryos and emergence of fry depend on many extragravel and intragravel chemical, physical, and hydraulic variables: DO, water temperature, biochemical oxygen demand (BOD) of material carried in the water and deposited in the redd, substrate size, channel gradient, channel gradient, channel configuration, water depth above the redd, surface water discharge and velocity, permeability and porosity of gravel in the redd and surrounding streambed, and velocity of water through the redd (Bjornn and Reiser 1991). Only a few of these variables were addressed in this study. We looked at the DO, substrate size, and porosity of 16 coho redds. The results indicate that DO did not differ between redds but the percentage of fines. and the inflow rates did. The results also indicate that the redds above Brown Creek are significantly different from the redds below.

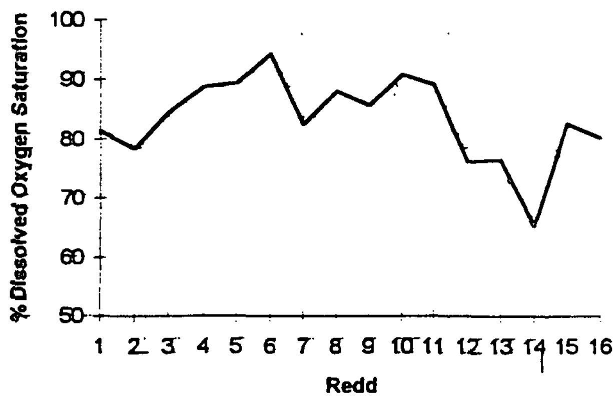


Figure 11. Percent dissolved oxygen saturation for 16 coho redds in Prairie Creek, Humboldt County, California, 1997.

Downstream migration

Rotary Screw Trap

The rotary screw trap was operated 24 hours/day between 20 February 1997 and 19 June 1997. Initially the screw trap was placed approximately 50 m below Streelow Creek but did not function as well as expected as the high spring flows receded. On 25 March 1997 the trap was relocated to the 1996 location (50 m above Streelow Creek) and fished until 19 June 1997 when stream flows dropped to a level which could not spin the cone effectively. The majority of the catch throughout the sampling period consisted of chinook young of the year (YOY). The captures for chinook peaked on 4 April 1997 (n=1251) with a grand total of 25,994 (Table 7). Coho YOY captures peaked on 13 April 1997 (n=388) with a grand total of 3,113. Other salmonids included coho smolts, trout YOY, trout parr, steelhead smolts, and cutthroat trout (Table 7). Other species captured included sculpin (coastrange and prickly), lampreys (sea and brook), salamanders and frogs. Estimates made from weekly trap efficiencies using various fin clips for chinook and coho salmon are listed below in Table 8. The total trapping mortality was less than 1 percent.

The 1996 downstream juvenile salmon migration was monitored using the same rotary screw trap. It was operated from 13 March to 10 July 1996 trapping 26,333 chinook YOY and 25,492 coho YOY. The 1997 coho YOY captures are significantly lower than 1996.

Fyke Net

The fyke net was operated 24 hours/day between 13 March 1997 and 19 June 1997. This trap was removed from the creek due to high stream flows on 21 to 24 April 1997. The majority of the catch throughout the sampling period was similar to the screw trap numbers except for the higher number of coho YOY. The captures for chinook YOY peaked on 31 March 1997 (n=2865) with a grand total of 34,987 (Figure 11). Coho YOY captures peaked on 20 April 1997 (n=636) with a grand total of 6,368. All other species listed above were captured as well (Table 7).

Pipe Traps

The pipe traps were placed into the creeks at different dates listed in the table below and operated 24 hours/day. These traps require low flows to fish effectively, therefore, they were removed several times over the trapping period due to the fluctuating stream flows. The various catches are listed in Table 7 below. Godwood Creek, the most pristine tributary in the basin, produced amazing numbers of juvenile salmon for such a small creek (2.4 km long). No further research has been conducted in this creek but these high numbers for coho salmon justifies further investigation in this system. Of the 32,890 salmonids captured, a total of 201 (0.61%) mortalities were observed. The majority of mortalities observed were regurgitated chinook YOY from predation in the live box.

Juvenile Coho Salmon Summer Population Estimate

The results from the summer habitat and coho salmon population survey for 14.5 km of Prairie Creek are listed in Table 9. These estimates were generated using a S-PLUS program written by C. D. Moyer (1997).

Water Temperature and Stream Discharge

Water temperatures in Prairie Creek follow a relatively constant seasonal pattern (Figure 12). Fluctuations in mean monthly temperatures did not exceed more than 2° to 3° C. The overall mean temperature from December 1996 until June 1997 was 11° C. Stream discharge ranged from ? cfs to ?cfs during the water year WY 97. Pulses in adult migration and juvenile migration occurred predominately during the higher discharges (Appendix 3)

Table 7. Downstream trapping results for all traps fished in Prairie Creek Basin, 1997.

Trap	Dates	0+ chin	0+ coho	1+ coho	0+ trt	1+ trt	stld	cutt	sculp	sucker	t.frog
Rotary	2/20/97-6/19/97	25994	3113	2302	247	710	94	430	303	25	0
Fyke Net	3/13/97-6/19/97	34987	6368	633	1797	177	31	210	89	1	0
L. Lost Man	4/4/97-	129	602	128	195	479	5	10	4	0	0
May	4/1/97-6/4/97	3	1938	167	213	93	3	78	19	1	0
Godwood	3/15/97-6/3/97	6519	13852	176	403	119	35	57	4	0	0
Boyes	3/15/97-6/3/97	30	416	84	0	71	19	44	21	4	0
NF Brown	4/2/97-6/4/97	0	4579	37	3	34	6	63	139	4	0
SF Brown	4/5/97-6/4/97	0	460	4	6	5	0	22	0	0	1

Table 8. Rotary screw trap efficiency results for chinook YOY salmon in Prairie Creek, 1997.

Week starting	Chinook YOY Total Catch	No. Marked and released	No. Captured with marks	Trap Efficiency	Expanded Weekly Estimate
24 February 1997	0	-		-	0
3 March 1997	0	-	-	-	0
10 March 1997	211	-	-	-	211
17 March 1997	103	-	-	-	103
24 March 1997	421	-	-	-	421
31 March 1997	5034	100	49	49 %	10273
7 April 1997	2009	100	24	24 %	8371
14 April 1997	1282	-	-	-	1282
21 April 1997	2129	100	28	28 %	7604
28 April 1997	3673	100	75	75 %	4897
5 May 1997	4529	-	-	-	4529
12 May 1997	2077	-	-	-	2077
19 May 1997	1278	100	65	65 %	1966
26 May 1997	1591	-	-	-	1591
2 June 1997	1052	-	-	-	1052
9 June 1997	490	-	-	-	490
16 June 1997	115	-	-	-	115
totals	25994	-	-	-	**44982**

– efficiency test not conducted

Table 9. Juvenile coho salmon summer population estimate for 14.5 km of Prairie Creek, 1997.

	Reach	Distance	C-Pools	D-Pools	Pools	Runs	Riffles	Totals
Reach 1	Streelow Ck. to Boyes Ck.	4.5 km	1265	3337	2315	NA	4930*	11847
Reach 2	Boyes Ck. to Brown Ck.	4.1 km	1248	1240	2944	468	965	6865
Reach 3	Brown Ck. to Sweet Ck.	3.4 km	681	484	2705	339	27	4236
Reach 4	Sweet Ck. to 0.8 km below Ten Tapo Ck.	2.5 km	162	29	936	NA	483	1610
Totals:		**14.5 km**	**3356**	**5090**	**8900**	**807**	**6405**	**24558**

= 1694 fish/km
= .50 F/ft

* riffle contained undercut bank with scour/depth and should be considered an outlier.

Table 10. Habitat survey results by section for juvenile coho population estimate in Prairie Creek, 1997.

	C-Pools	D-Pools	Pools	Runs	Riffles	Totals
Reach 1						
No. Units	15	34	33	17	52	151
Total Area (m^2)	2511	10065	6134	2700	7215	28634
	(9%)	(35%)	(21%)	(10%)	(25%)	(100%)
Reach 2						
No. Units	22	20	43	36	61	182
Total Area (m^2)	353	3704	5331	4748	4284	18420
	(2%)	(20%)	(29%)	(26%)	(23%)	(100%)
Reach 3						
No. Units	21	11	22	21	68	143
Total Area (m^2)	1508	946	3859	975	1924	9212
	(16%)	(10%)	(42%)	(11%)	(21%)	(100%)
Reach 4						
No. Units	12	1	30	28	67	138
Total Area (m^2)	459	64	623	769	3644	5559
	(8%)	(1%)	(11%)	(14%)	(66%)	(100%)
Total Units	70	66	128	102	248	
Total Area (m^2)	7732	14779	16949	9195	18069	61,835
	.43	.34	.53	.09	.35	= .4 fish/m^2

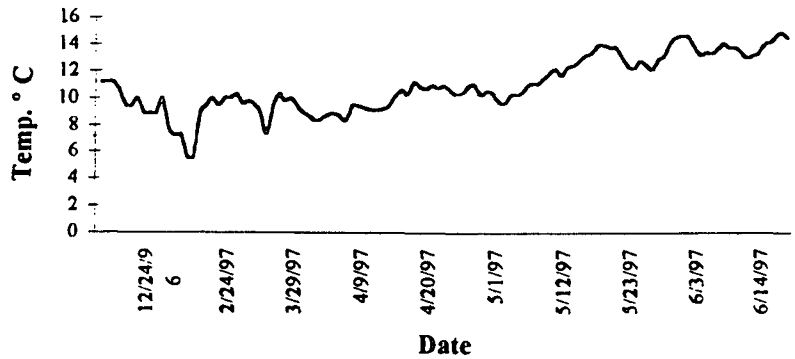


Figure 12. Daily average water temperature of Prairie Creek, Humboldt County, California, December 1996 to June 1997.

Conclusions

The main objective of this study is to quantify the impacts of the 1989 sedimentation event on anadromous salmonids in Prairie Creek. Prior to this event, limited data has been collected on these animals during their freshwater phase in Prairie Creek except for a study by Briggs (1953) on adult salmonid behavior and reproduction. In 1989 a streamside hatchery supplementation program was established by PCFWWRA and continued for 5 consecutive years. Adult chinook and coho salmon were captured and spawned at a streamside facility. The eggs were fertilized, hatched and raised to the parr size then released into Prairie Creek. Periodic stream surveys were conducted to determine the magnitude of natural spawning of salmon during this 5-year period. In 1995, HSU was contracted to assist with the development, implementation, and evaluation of a study design to assess the natural spawning success of salmon in Prairie Creek. We began with a monitoring program to determine the success of spawning and rearing of chinook and coho salmon using various fishery techniques. Using an adult weir trap from the sublementation program, we captured and released 106 adult chinook and 115 adult coho salmon to spawn above the campground. Weekly spawning surveys produced 288 redds, 216 chinook carcasses, 98 coho carcasses, and 54 very decayed salmon carcasses beyond species identification. The rotary screw trap captured 26,333 juvenile chinook and 25,492 juvenile coho migrating past Streelow Creek. An emergent fry trapping project conducted by a HSU senior fisheries student trapped 5 salmon redds below Boyes Creek with low survival to emergence (0%-52%). Also, a summer coho population estimate produced 9,948 juvenile coho between Streelow Creek and Brown Creek (8 km)(1,187 coho/km). These results indicate that successful spawning and survival to emergence of chinook and coho salmon occurred in Prairie Creek for that year. However, poor quality spawning habitat existed below Boyes Creek and could become a limiting factor during low flow or drought years. Prior to 1996, California suffered a 5-year drought which limited the range of anadromous salmonids up Prairie Creek (M. Farro pers. com.). Few redds were observed by PCFWWRA above Boyes Creek during this period. Regardless, in 1996, high winter flows provided access to this spawning habitat above Boyes Creek and Brown Creek and the majority of spawning occurred in this upper area. In 1997, we proposed to continue monitoring the spawning and determine if the spawning quality is a limiting factor to anadromous salmonids. To determine if the 1989 sedimentation event still has a significant effect on the spawning quality of Prairie Creek, we compared spawning gravel quality above Brown Creek, the control which did not received any of the 1989 sediments and spawning gravel quality below Brown Creek, the treatment which did receive 1989 sediments.

Our monitoring results from 1997 are similar to the previous years. Weekly spawning surveys produced 160 redds, 160 chinook carcasses and 61 coho carcasses. The rotary screw trap captured 25,994 juvenile chinook and 3,113 juvenile coho migrating past Streelow Creek. A summer coho population estimate produced 24,558 juvenile coho between Streelow Creek and below Ten Tapo Creek (14.5 km)(1,694 coho/km). Comparing the same reach surveyed in 1996 to 1997, Streelow Creek to Browns Creek (8 km), an estimate of 18,712 (2.339 coho/km) juvenile coho was generated. Our results from spawning gravel analysis for 1997 indicate that the quality of coho spawning gravel in Prairie Creek above Brown Creek is significantly different from spawning gravel below Brown Creek. Both the inflow rates and the survival to emergence showed a strong negative linear relationship with the percent fines less than 2 mm. These results agree with other research supporting the general hypothesis that survival to emergence declines in substrates as quantities of fine sediments increase. The fine sediment reduces gravel permeability and pore space as well as dissolved oxygen in water available to embryos. Due to the small sample size (n=6) of redds used for the survival to emergence study, an increase in the number of coho redds for a survival to emergent study is proposed for the next year to determine the impacts of fine sediments on survival to emergence of coho salmon in Prairie Creek above and below Brown Creek.

Literature Review

Numerous studies have examined the gravel conditions of salmonid spawning habitat and the effects of these conditions have on the survival of incubating salmonid embryos. Several studies are briefly described below, but a thorough assessment of these studies was conducted by Chapman (1988) and since has become the most referenced paper on this subject. A chronological literature review follows with a brief description of each study and results.

Koski (1966) trapped coho redds in Oregon streams and found that coho salmon fry survival was inversely related to the percentage of fines smaller than 3.3 mm and that the size of coho salmon at emergence related directly to the permeability of the substrate.

Phillips and Koski (1969) used a fry trap method to estimate salmonid survival from egg deposition to fry emergence. Field tests showed the efficiency of the trap approached 100%. They concluded that this method provides a more accurate estimate of survival from egg deposition through fry emergence than 4 other methods (1-excavating live redds, 2-using live eggs recovered from a porous container, 3-flushing alevins from gravel, 4-weir counts).

Phillips et al. (1975) tested mixtures of gravel and sand in experimental troughs to simulate hatching conditions in coho salmon and steelhead trout redds. An inverse relationship was found between the quantity of fines and emergent survival. Mean emergent survival for coho salmon ranged from 96% in the control mixture to 8% in the sand mixture (70% fines less than 3.3 mm diameter). Premature emergence of coho fry was related to higher concentrations of fines. These premature fry were smaller and retained more yolk than fry emerging at normal times.

Lotspeich and Everest (1981) developed an index of gravel quality by dividing the geometric mean particle size by the sorting coefficient of a sample. This resulting number, the "fredle index", is proposed as a standard for evaluating the reproductive potential of spawning gravel. They did not experimentally document the relationship between the fredle index and survival to emergence of salmonids but they used the data of Phillips et al. (1975) to establish a preliminary relationship between these parameters. They calculated fredle numbers for the gravel samples collected by Phillips et al. on coho salmon and steelhead trout and plotted them against survival. The relationship indicated that the fredle index is responsive to slight changes in gravel composition, survival, and variations in intragravel habitat requirements of individual species.

Tappel and Bjornn (1983) developed a method of relating size of spawning gravel to salmonid embryo survival based on a cumulative distribution of particle sizes. The two size classes that best reflect the composition of the spawning gravel size were the percentage of the substrate smaller than 9.5 mm and the percentage smaller than 0.85 mm. Salmonid embryo survival was related to these two size classes in laboratory tests and 90-93% of the variability in embryo survival was correlated with the changes in substrate size composition. Gravel mixtures containing high percentages of fine sediment produced slightly smaller steelhead fry than gravels containing low percentages of fine sediment, but no significant difference was found. In gravels containing large amounts of fine sediment, many of the steelhead and chinook salmon fry emerged before yolk sac absorption was complete.

Taggart (1984) trapped 19 redds in Washington streams to determine the effects of forest practices on naturally spawning coho and found that survival to emergence varied directly with intragravel permeability, which varied directly with the proportion of good gravel (>3.35 mm and < 23.9 mm). Intragravel dissolved oxygen and permeability were measured using the MarkVI standpipe and pump as described by Terhune (1958). Gravel samples were obtained with a modified McNeil gravel cylinder 15.24 cm (6 in) internal diameter and gravel composition was determined by sieving the sample through a series of Tyler sieves. This link between permeability and good gravel provides a mechanism to explain the relationship between good gravel and STE.

Chapman (1988) reviewed the variates used to evaluate effects of fines sediments on survival to alevin emergence in redds of large salmonids in streams. He used the data of Koski (1966) and McCuddin (1977) to calculate permeability's of redd and laboratory gravels in relation to embryo survival to emergence for coho and chinook salmon. Survival of both species was positively and significantly related to permeability. Chapman suggests using multiple redds with positive identification of spawning to assess gravel composition in egg pockets the techniques

Young et al (1990) found that survival to emergence of both Colorado River cutthroat trout and brown trout fry was most highly correlated with geometric mean particle size in laboratory studies. The percentage of fine particles and Fredle Index were much less effective predictors of survival to emergence. They recommend that particles <0.85 mm be considered as fine material and that only particles < 50 mm in diameter be included in the computations

Young et al. (1991) compared 15 measures of substrate composition in laboratory tests that evaluated the survival to emergence of Colorado River cutthroat trout in substrates of different composition. Different estimates of geometric mean particle size accounted for the greatest proportion of the variation in survival to emergence in laboratory tests, but the percentage of substrate less than 0.85 mm in diameter was the most sensitive measure of known changes in substrate composition in the field. Their studies indicated that the geometric mean particle size was the best predictor of STE. They concluded that a single measure of substrate composition may be inadequate to both assess the potential survival to emergence in a substrate and detect changes in substrate composition caused by land use.

Young et al. (1991) (biases associated with four stream samplers) compared samples collected from 10 substrates of various compositions with a single-probe freeze-core sampler, triple-probe freeze core sampler, a McNeil sampler (10 in), and a shovel. All four samplers were biased, but the McNeil sampler most frequently produced samples that approximated the true substrate composition.

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Personal Communications

Farro, M. Pacific Coast Fish, Wildlife, and Wetlands Restoration Association, Arcata, California.

Klein, R. Geologist, Redwood National Park, Orick, California